SOLAR DISINFECTION OF DRINKING WATER AND ORAL REHYDRATION SOLUTIONS

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Guidelines for Household Application in Developing Countries

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DEDICATION
to
Dr. Malcolm Hooper Kerr

Late President of the
American University of Beirut

A token of appreciation and gratitude
to the man who sacrificed his own life so

"that they may have life
and have it more abundantly"

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PREFACE AND ACKNOWLEDGEMENTS

This document is a contribution towards the promotion of the *Revolution for Children* recently announced for launching in 1984 by UNICEF in the light of world support for Oral Rehydration Therapy (ORT) as one of the four simple interventions for the control of childhood diarrhoea and the associated condition of malnutrition.

As a practical guide for primary health care workers and those involved in national programmes for the control of diarrhoeal diseases, it provides concise background information on oral rehydration therapy. The text then deals with some practical issues pertaining to the preparation of oral rehydration solutions. However, the main emphasis has been placed on the disinfection of oral rehydration solutions, or the water used in their preparation, as achieved by exposure to sunlight in transparent containers.

The fundamental principles involved in this simple and inexpensive home-based technology are presented for a better understanding of the stepwise instructions which are to be delivered to housewives in rural areas of developing countries for household application.

Readers actively participating in the promotion of oral rehydration therapy in developing countries could make use of the simple technical knowledge needed to intelligently instruct peripheral health workers and mothers on the proper preparation and disinfection of oral rehydration solutions, with possible adaptations dictated by local conditions.

We are particularly thankful to the UNICEF Regional Office for the Middle East and North Africa (MENA) for the publication and distribution of this document. We are also grateful to Dr. May Jurdi and Mr. Bassam Atieh for the graphics, to Dr. Robert Mansour for the illustrations, and to Miss Reem Acra for the cover design.

We take great pride in having accomplished this task within a few weeks under the hardships of the prevailing conditions of war in this country. This is our humble contribution to the children of the world.

Beirut, Lebanon
February, 1984

Aftim Acra
Zeina Raffoul
Yester Karahagopian

A MESSAGE

To meet the pressing health needs of the majority of the world's population, a new health strategy was formulated. This strategy aims at achieving the goal of health for all by the year 2000 through primary health care.

Primary health care strategies are particularly apt for needs in developing countries where resources are scarce and health needs are great. The stress in primary health care on preventive rather than curative services makes a great deal of sense in developing countries where available methods could prevent disease, disability and debilitation. So too does reliance on home self-help and community participation to deliver health care and technology that is appropriate as well as affordable and acceptable by the people. It is a broad-based approach, mobilizing human and material resources ranging from traditional medicine to community education services of schools, agricultural extension agents and the like.

Primary health care strategy relies on the following elements: health education, adequate food supply, nutrition, potable water and basic sanitation, maternal and child care including family planning, immunization, prevention and control of locally endemic disease, appropriate treatment for common diseases and injuries and essential drugs.

This approach can succeed only if it enjoys strong political commitment by government authorities, and if they give real priority to its realization.

The pioneering efforts of UNICEF in promoting low-cost techniques which could save the lives of 25,000 children every day and protect the health of many millions more are gaining world-wide support. The State of the World's Children 1984 shows the drastic gains in child well-being that can be achieved at a low cost, and in a relatively short time despite the economic recession, the challenge of translating the local successes into intensive national campaigns that will be a revolution in child health.

In Lebanon, as well as in other developing countries, infant mortality rates are still four times as high as in developed countries. After nine years of armed conflict, Lebanon's health sector needs to be rebuilt and re-established on a basis which will permit the government to fulfill its commitment to the health and well-being of its citizens. As a result of war, some risk factors such as disrupted sanitation, crowding and population movements as well as unfavourable socio-economic conditions can stress the health situation, especially in relation to communicable disease outbreaks. Although population indices and disease incidence/prevalence data are lacking, it is possible to give some estimates by making cautious inferences from data collected in selected groups and from observations and interviews at hospitals, dispensaries and basic services centres.

Upper respiratory tract infection and diarrhoeal disease head the list of causes of morbidity as in many other countries. These are conditions for which inexpensive effective prevention or treatment is technically possible. The pattern of disease in a particular area is intimately related to levels of fertility, standards of living, cultural habits, poverty, ill-health, high fertility, high mortality, fatalism and short planning horizons constitute a possible low-level social equilibrium. In practice, this equilibrium has already been disturbed in Lebanon.

Government expenditure on health is rather small. The Ministry of Health received 2.3 to 4.1% of the total state budget in the last few years. The Public Health Service covers only a small proportion of the population because the main emphasis is placed on high-cost individual curative services for the victims of the hostilities at the expense of environmental and preventive services. At times of economic hardship, it is unlikely that health will be given a larger share of the budget. Meeting the needs for primary health care will be more difficult unless we adopt or extend simplified systems of health care. These systems should emphasize provision of services and education as near to the home of clients as is practical. Community health workers will be the essential elements of such a system. They will diagnose and treat simple ailments, educate the community in nutrition hygiene and personal health care, and refer patients with problems to more highly trained and equipped workers. Experience suggests that persons with no more than six months of training can safely and effectively provide care for 75% of all patients.

This book, *Solar Disinfection of Drinking Water and Oral Rehydration Solutions,* will serve as a useful guide for primary health care workers and all others involved in the control of diarrhoeal diseases. This technique is an innovative breakthrough that will save human lives and will reduce extensive bills that would have been spent on endless curative interventions in highly strained hospital facilities.

His Excellency Dr. Adnan Mroueh
Minister of Health
Professor of Obstetrics and Gynecology,
Faculty of Medicine,
American University of Beirut.

FOREWORD

Within the framework of the child health revolution to which UNICEF is strongly committed, and in the specific domain of oral rehydration as one of its main supporting techniques, the securing of safe drinking water stands as a foremost priority. Actions toward this end, however, are more often than not impeded by a variety of technical and economic problems.

Over the past few years, a team of Lebanese researchers, headed by Professor Aftim Acra, Chairman of the Department of Environmental Health at the American University of Beirut, worked intensively on the problem of water disinfection, taking into account the environmental conditions prevailing in this part of the world. Their studies led to the discovery of a simple method for the attainment of this goal based on exposing the water to sun rays for a given period of time. This practically costless method has been proven to eliminate all pathogenic organisms from the water, thus rendering it perfectly fit for human consumption.

One remarkable thing about the method in question is that it should be most suitable for adoption in the developing countries where fuel is scarce and sunshine is bountifully available. The matter assumes an evident value where the practical aspects of the oral rehydration technique are involved. It is also in full harmony with UNICEF's eagerness to promote «affordable» approaches aimed at optimal results on the road to a better tomorrow for children. For these reasons, the printing and distribution of the present book is being sponsored by the UNICEF Regional Office for the Middle East and North Africa.

This venture is also a step in the direction of the much-desired technical co-operation among developing countries. Moreover, it is certainly touching to see that Lebanon in this instance is at the giving end and that, in spite of the grave internal disturbances it is suffering from, this country is still able to offer valid contributions to the welfare and progress of humanity.

Victor Soler-Sala
UNICEF Regional Director
for the Middle East
and North Africa

ORAL REHYDRATION THERAPY
THE REVOLUTION FOR CHILDREN

In the past decade there has been an increasing attention to community-based services and primary health care programmes supported by national and international agencies. Similarly, the WHO International Water Supply and Sanitation Decade (1981-1990) has been gaining momentum in the less developed countries. Highly encouraging results obtained from recent field studies and campaigns in twenty different countries around the world have shown significant reductions in child mortality and morbidity. These events and outcomes have made it possible for UNICEF to identify four major public health measures having a combined potential which could save the lives of up to seven million children each year, protect the health and growth of many millions more, and help to slow down world population growth. Having gained worldwide support, the Executive Board of UNICEF was prompted to endorse in May 1983 the four measures that involve simple and cost-effective technologies which could successfully pave the way for revolutionary global action through intensive national campaigns. To translate this into a reality, James P. Grant, UNICEF's Executive Director, has called for the initiation of a *Revolution for Children* through UNICEF's report *The State of the World's Children, 1984.*

The four revolutionary measures, designated for convenience as GOBI, refer to *growth monitoring of young children, oral rehydration therapy, promotion of breast-feeding, and immunization.* UNICEF believes that the revolutionary potential of these four principal strategies, which form a class of their own, resides in their combined impact on children's health in the developing countries. Their other important assets include low implementation costs, simple technology involved, and almost universal relevance. None of these measures is new for they have been integral parts of health and nutrition programmes for many years, except for certain improvements in the technology by which they are applied, and the recently acquired confidence in their effectiveness. Ideally, they should also include the equally vital, but more difficult and costly, approaches designated as FFF that involve family spacing, food supplements, and female education.

UNICEF believes that a new avenue is now available to reach the homes of children in all parts of the world with the aim of saving them from sickness and possible death. It contends that primary health care is the *idea* which makes this revolutionary approach possible. The spread of education, communication, and social organization form the *circumstance* which makes it practicable. The four revolutionary measures are the *techniques* which make it affordable even in the midst of the present world recession.

ORAL REHYDRATION THERAPY
THE FOUR SIMPLE TECHNOLOGIES

GROWTH MONITORING

This technique involves the use of simple, cheap growth charts that would enable mothers to monitor their children's weight on a regular basis. The weight trend is the most important and practical indicator of the normal healthy growth or state of malnutrition of infants and young children. This information is of particular value in breaking the vicious cycle of malnutrition and infection.

Once the mother recognizes that her child is becoming malnourished, she would then seek the advice of health workers as to whether the child needs supplementary foods, more frequent feeding, or medical help. In this manner, it would be possible to prevent up to half of all the cases of malnutrition which underly the death of several million children a year, as well as the poor growth of many millions more occurring in the developing world.

India, Indonesia, Thailand, Colombia, and Jamaica are some of the more than 80 countries where this technique is now going into use.

ORAL REHYDRATION THERAPY (ORT)

Oral rehydration therapy is a simple, cheap, effective, and acceptable treatment that can be prepared and administered by parents at home to counteract dehydration which is the most common cause of death among children with acute diarrhoeal disease. The treatment consists of a solution of sugar and salt given orally to replace both the water and electrolytes lost in diarrhoeal stools.

Diarrhoeal disease is very common in the developing world, where one out of every 20 children born are destined to die from diarrhoeal dehydration before reaching the age of five. Indeed, it is the major single cause of death among children, and accounts for the death of about five million children a year. In addition, repeated diarrhoeal episodes could impair the nutritional status of affected children who become increasingly susceptible to other acute infections.

In contrast to ORT, conventional treatment by intravenous infusions of glucose and salts is an expensive procedure that should be limited to the minority of severe cases of dehydration not amenable to ORT which does not require the skills and facilities available only in well staffed and equipped clinics and hospitals. Thus ORT offers the potential for home-based treatment by mothers throughout the developing world.

Of the numerous countries where ORT programmes have been initiated, the list includes Bangladesh, India, Indonesia, Nepal, Pakistan, Philippines, Haiti, Thailand, Brazil, Costa Rica, El Salvador, Mexico, Nicaragua, Peru, Guatemala, Honduras, Colombia, Venezuela, Jordan, Turkey, Morocco, Syria, Nigeria, Egypt, Sudan, and Tunisia. Recent studies in some of these countries with support from UNICEF, WHO, or other organizations, have indicated that ORT can decrease the number of deaths from diarrhoea by as much as 50 to 60% over a one-year period.

At the *International Conference on Oral Rehydration Therapy (ICORT)*, sponsored by USAID and held in Washington, D.C., in June 1983, almost complete agreement was reached about the efficacy of ORT, and the need to intensify efforts to make it internationally available.

PROMOTION OF BREAST-FEEDING

Recent studies have shown that breast milk, besides being nutritious and hygienic, provides immunity transferred from mothers to breast-fed infants, and thus helps to protect them from malnutrition and infection, including diarrhoeal infections. In contrast, bottle-fed babies are more likely to be malnourished, to contract infections, and to die in the first year of life. Despite the convincing evidence supporting these facts, there are alarming indications that breast-feeding is declining in many parts of the developing world. Breast-feeding should, therefore, be promoted along with growth monitoring and ORT.

EXPANDED IMMUNIZATION

Immunization against the six communicable diseases of childhood (poliomyelitis, diphtheria, measles, whooping cough, tuberculosis, and tetanus) is quite a simple intervention. It presents a great challenge to the developing world where every one of the 100 million children born each year needs to be vaccinated through carefully planned immunization campaigns.

The World Health Organization, in collaboration with UNICEF as the supplier of vaccines and *cold chain* equipment, launched its *Expanded Programme on Immunization (EPI)* in 1977 with the aim of assisting all nations to immunize all children against the six immunizable diseases by 1990. WHO reviewed the EPI in May 1982, and urged its member states to take action to achieve a more rapid improvement of immunization coverage.

GLOBAL DIARRHOEAL DISEASES CONTROL PROGRAMMES

Over 150 nations signed the *Alma Ata Declaration on Primary Health Care* which emerged from the first *International Conference on Primary Health Care* held at Alma Ata in the Soviet Union in 1978. This marked the beginning of a new era for the promotion of health based on community participation and the use of para-professionals and appropriate technologies.

Motivated by the significant recent developments in the treatment and control of diarrhoeal diseases, and as part of its commitment to its global strategy for health for all by the year 2000, based on Primary Health Care (PHC), WHO launched a global *Diarrhoeal Diseases Control (CDD) Programme* in 1978 with the close collaboration of UNICEF, UNDP, and the World Bank. The programme budget for the biennium 1983-1984 is US $20.2 million.

The short-term objective of the WHO global CDD programme involving a concerted attack on diarrhoeal diseases is to endeavour to reduce childhood mortality due to diarrhoeal dehydration and malnutrition through the widespread implementation of ORT and improved feeding practices. An important long-term objective is to substantially reduce childhood morbidity caused by diarrhoeal diseases and their associated ill effects, especially malnutrition, in infants and young children. This objective is to be attained through promotion of improved mother and child care practices, the provision of safe water supply and sanitation facilities, and epidemiological surveillance for the detection and control of epidemics, especially those due to cholera.

The World Health Organization's CDD programme of activities falls into three main categories: first, planning and developing national CDD programmes in developing countries as an integral part of national PHC programmes, with emphasis on ORT; second, providing technical training programmes for national programme managers and field supervisory staff; and third, supporting both field and laboratory research in the development of new methods and approaches for the prevention and treatment of diarrhoeal diseases. Whereas WHO focuses more on the aspects of management, training, and research, UNICEF concentrates on production and supply of oral rehydration salts (ORS).

In the absence of any constraints and setbacks, WHO expects to achieve the following in the developing countries by 1989: (a) development of 80 national CDD programmes; (b) over 30% of all childhood diarrhoea cases will be receiving adequate ORT; and (c) at least 1.5 million childhood deaths due to diarrhoea will be prevented annually. By December 1982, national CDD programmes were already in operation in 38 developing countries.

The WHO global CDD programme is also closely linked with the *International Drinking Water Supply and Sanitation Decade, 1981-1990 (IDWSSD)*. The predominant concern of this international programme is the reduction of such communicable diseases as diarrhoeal infections, polio, typhoid, and amoebiasis, all of which are associated with the widespread lack of safe drinking water and sanitary disposal facilities and practices. The incidence of diarrhoeal diseases transmitted through contaminated food is often indirectly related to inappropriate faecal waste disposal or lack of personal hygiene.

The IDWSSD programme aims at fostering national and international action so that by 1989 the WHO member states will have implemented national programmes for the provision of purer drinking water and better sanitation facilities and practices. This is intended to meet the global target of assuring safe drinking water and adequate excreta disposal for all by 1990. The approach to the decade which WHO has adopted is that water supply and sanitation development must be complementary, and that national decade plans and programmes must be closely integrated with all aspects of PHC programmes. This would require major changes in national policy and management.

Through the initiative and support of UNDP, the *Dhaka Cholera Control Laboratory* in Bangladesh was transformed in 1978 into the *International Centre for Diarrhoeal Diseases Research*. Its programme of activities includes conducting research and field trials of new tools and treatment methods. It also serves as an international training ground for health personnel from developing countries.

CAUSES, TRANSMISSION, AND CONTROL OF CHILDHOOD DIARRHOEA

AETIOLOGY

Until about ten years ago, only a fraction of the microbial causes of human diarrhoeal diseases were known as no pathogenic bacteria and viruses could be isolated from the large majority of patients. So far, about 25 pathogenic bacteria, viruses, and parasites have been identified as causes of diarrhoea.

The well known microbial agents of universal importance that invade the intestine and cause acute diarrhoea through a variety of mechanisms are *Shigellae, Salmonellae, V. cholerae,* and certain strains of *E. coli* (ETEC, EIEC, and EPEC). The two other unicellular micro-organisms (protozoa) of world-wide distribution causing both acute and chronic diarrhoea, especially among children, are *Giardia lamblia* and *Entamoeba histolytica.*

Other conditions associated with diarrhoea include infections occurring in organs other than the intestine (e.g. measles, malaria, and pneumonia), as well as malnutrition and food intolerance.

In recent years, five groups of enteric viruses involved in childhood diarrhoea have been recognized through electron microscopy and successful stool cultures. These are *rotaviruses, enteric adenoviruses, asroviruses, coronaviruses,* and *Norwalk viruses.* In addition, a number of other infectious agents of limited or unknown importance in diarrhoeal diseases have been identified in diarrhoeal stools. Among these are *Campilobacter jeujeni* and *Yersinia enterocolitica.*

In 1982, Dr. I. de Zoysa and associates of the Ross Institute in London published a wall chart entitled *A Guide to the Most Common Enteric Pathogens* which provides practical information regarding each of the potential causative agents of diarrhoeal diseases.

Little information is available about the world-wide distribution of some of the newly identified diarrhoeal agents, particularly among children in developing countries, primarily because of the complexity of the diagnostic techniques. Fortunately, diagnosis of rotavirus infection can now be made by means of a simple and rapid procedure recently developed in Sweden based on assaying the antibodies in stools (enzyme-linked immuno-absorbent assay — ELISA).

TRANSMISSION

Practically all of the more common childhood diarrhoeal diseases caused by pathogenic bacteria and viruses are transmitted via the faecal-oral route. The pathogens discharged in the faeces of an infected person may enter the body of another susceptible person through the mouth. This may occur among children ingesting food or water contaminated with human excreta.

Direct transmission among persons in close contact is also possible. Such transmission could occur via unclean hands, or through contaminated objects such as bed linen, kitchen utensils, and tableware. Flies and cockroaches play a role as vectors of the infectious agents of faecal origin.

CONTROL MEASURES

During diarrhoeal episodes, the body rapidly loses fluids together with some electrolytes that are discharged with the stools. The essential electrolytes lost are sodium (Na^+), potassium (K^+), chloride (Cl^-), and bicarbonate (HCO_3^-). At the same time, the intestine may lose its capacity to absorb fluids and electrolytes taken by mouth. In mild cases, where intestinal absorption is not impaired, any fluid given orally might prevent dehydration. About 10 percent of diarrhoea episodes result in dehydration due to the excessive loss of fluids and electrolytes. Infants and young children are much more susceptible to dehydration and its consequences than adults.

It has been demonstrated that ORT involving the oral administration of glucose-electrolyte solutions can effectively restore the intestinal fluid losses, thereby counteracting dehydration in the large majority of cases. This is based on the fact that glucose enhances the intestinal absorption of water and sodium in diarrhoea patients.

Obviously then, ORT constitutes a short-term measure that can and must be adopted on a global scale to enable prompt treatment of childhood diarrhoea.

The four major strategies for controlling the transmission of the common diarrhoeal diseases are: (a) personal and domestic cleanliness; (b) hygienic food preparation and storage; (c) clean and plentiful water supply; and (d) sanitary excreta and refuse disposal.

An essential long-term objective of national diarrhoeal disease control programmes should therefore be based primarily on achieving an improvement in community water supplies and in sanitation facilities and practices. Much can be accomplished through training and health education.

WHO/UNICEF STANDARD FORMULATION

Since 1971, WHO and UNICEF began to promote the use of a standard formulation for the preparation of oral rehydration solutions, widely regarded as the physiologically most appropriate single formulation for world-wide use. It consists of the following active ingredients mixed in dry form for making one litre of solution:

Glucose, anhydrous	20.0 grammes
Sodium chloride	3.5 grammes
Sodium bicarbonate	2.5 grammes
Potassium chloride	1.5 grammes
Total weight	27.5 grammes

Aluminium foil packets containing 27.5 grammes of the mixed ingredients for making one litre of solution are distributed internationally by UNICEF under the non-proprietary name of *Oral Rehydration Salts (ORS)* — formerly *Oralyte*. The use of *Aerosil* (colloidal silicon dioxide) as an excipient in the proportion of 2 grammes per kilogramme of ORS is optional. Aerosil is harmless in this concentration, but renders the ORS solution very slightly turbid. There are a number of alternative preparations that do not comply in composition with the WHO/UNICEF formulation. These have not yet been clinically evaluated.

For reconstitution of the standard formulation when required to be given by mouth, the contents of one ORS packet are to be dissolved in one litre of clean drinking water. UNICEF recommends boiling the water and allowing it to cool before using it for the preparation of the solution as hot water is apt to decompose the sodium bicarbonate.

When the content of one ORS packet is dissolved in one litre of water, the following concentrations of the active ingredients are obtained:

Glucose	111 m mol/litre
Sodium (Na^+)	90 m mol/litre
Chloride (Cl^-)	80 m mol/litre
Bicarbonate (HCO_3^-)	30 m mol/litre
Potassium (K^+)	20 m mol/litre

Solutions complying with the standard formulation, when used correctly, have produced remarkable results in the treatment of dehydration due to a wide variety of diarrhoeal disorders, including cholera, in all age groups. They are also useful to maintain hydration during continuing diarrhoea, provided additional fluids are given to infants to avoid the possible risk of developing hypernatremia. The adoption of such universally applicable solutions simplifies the large-scale production and distribution of premixed ORS.

PRODUCTION AND DISTRIBUTION

Out of an estimated two billion packets of standard ORS believed to be needed annually for dehydration control throughout the world, only about 80 million are being produced for distribution. Since 1981, UNICEF has been distributing about 20 million packets annually at US $0.08 per one-litre packet, including freight, in an attempt to meet the partial national requirements of 87 nations. Together with WHO, it has continued to encourage national and regional production. By December 1982, 30 developing countries were producing ORS with the assistance of WHO and UNICEF. Brazil alone is now producing some 20 million packets a year, and Pakistan has increased its annual production to 5 million packets. On its part, WHO has recently published a very instructive manual (*Guidelines for the Production of Oral Rehydration Salts*) which includes specifications, methodology, and quality control.

Some of the countries producing packets of ORS under different brand names include Costa Rica *(Sueroral)*, Tunisia *(Orasol)*, Egypt *(Rehydran)*, Honduras *(Litrosol)*, and Peru *(Salvadora)*. Packets with amounts of ORS smaller than the standard formula are being produced in some countries for practical reasons. In Costa Rica, for instance, *Sueroral* packets are intended for 240 ml of solution. Such alternative products are more expensive than the UNICEF packets, and can only reach a small minority of users. Besides, the contents may not be uniform in composition or weight. Other shortcomings include the use of packaging materials that are difficult to open, or powders that do not dissolve readily. Some products may have a poor shelf life. These difficulties may discourage some families from using the local products.

The Program for Appropriate Technology in Health (PATH) in Seattle, Washington, USA, has recently developed ORS tablets. These *PATH ORS TABLETS,* 2.5 cm in diameter and weighing 5 grammes, are currently formulated to make 150 ml of rehydration solution. The tablet formula complies with the WHO standard formulation except that sodium citrate is substituted for sodium bicarbonate to provide the tablets with greater stability and a shelf life of at least one year in polyethylene packages, and even more if foil-laminated packaging material is used.

PATH is promoting the local production of these tablets, and is prepared to help in the transfer of the technology for production in developing countries. In fact, by February 1984, PATH was in the process of transferring the production technology to a company in

Indonesia and to another in Thailand. Other technology transfer arrangements in Latin America are presently under consideration.

MODIFIED WHO FORMULATIONS

Some ingredients in the standard ORS formulation may be substituted for in-country packet production, or preparation of home-made solutions, without essentially altering the therapeutic effects on rehydration. Selection of substitutes is determined by such additional factors as availability, relative cost, and prolongation of the shelf life.

Some commercial preparations used for oral rehydration contain sodium citrate in place of sodium bicarbonate to achieve a longer shelf life, although the latter is preferred because of lower cost and greater availability.

WHO is continuing its interest in improving the shelf life of the ORS ingredients by appropriate substitution of ingredients and packaging materials. This has been evoked by evidence from field experience indicating that packaged ORS is subject to deterioration due to the reaction of glucose with sodium bicarbonate leading to the formation of a brownish discolouration and lumping of the ingredients.

Although standard ORS in laminated aluminium foil packets have an estimated shelf life of at least three years, their storage in developing countries with extremely hot and/or damp climates are likely to accelerate deterioration and caking of the ORS mixtures. In an effort to overcome such a problem, WHO has developed three alternative formulations that need to be tested for stability and effectiveness. Sodium bicarbonate is substituted by sodium citrate in two of these alternative formulations, and by potassium citrate in the third.

DETERIORATION ON STORAGE

At the request of WHO, the *Central Laboratory of German Pharmacists* in Frankfurt has carried out accelerated stability tests on the four ORS formulations developed by WHO made from ingredients of pharmacopoeial purity, with and without packaging in polyethylene foil or laminated aluminium foil. The results, reported in June 1983 *(Pharmazeutische Zeitung)*, indicate that both humidity and temperature tend to promote deterioration. The percentage absorption of moisture that leads to lumping of the ingredients may reach as high as 10% for anhydrous glucose, 80% for potassium citrate, and 140% for sodium chloride. Sodium bicarbonate starts to decompose at temperatures above 40°C with evolution of carbon dioxide gas which may cause some packets to burst during storage. Significant changes in colour and consistency were observed at storage temperatures exceeding 40°C. Unlike the formulation with sodium bicarbonate, those with sodium or potassium citrate as substitutes proved to be more chemically stable. The conclusion is that glucose and sodium bicarbonate in standard ORS packets, when stored at high temperatures or humidity, would interact and undergo considerable decomposition. By replacing bicarbonate with citrate, a more stable ORS mixture can be obtained.

Laminated aluminium foil proved to be the best packaging material for long-term storage in extremely damp climates, whereas polyethylene foil is preferable for dry and hot climates as its permeability allows drying and stabilization of the ORS mixture during storage. The choice of packaging material, therefore, depends mainly on a country's climatic conditions. Because polyethylene foil is transparent, however, ORS packets can be checked visually for signs of glucose decomposition accompanied by discolouration and lumping. Therefore, the use of polyethylene packets can be a compromise for world-wide distribution.

It is thus concluded from this study that the formulation prescribed below is recommended for large-scale production because of its much slower rate of deterioration, and therefore potentially longer shelf life, in preference to the other three ORS formulations developed by WHO:

Glucose, anhydrous	20.0 grammes
Sodium citrate ($C_6H_5Na_3O_7.2H_2O$)	2.9 grammes
Sodium chloride	3.5 grammes
Potassium chloride	1.5 grammes
Total weight	27.9 grammes

To help prolong shelf life, an alternative mode of packaging ORS practiced in India essentially involves separation of glucose or sugar from the salt by packaging the latter in a small, sealed packet placed inside a larger packet containing the glucose or sugar, which is then also sealed. These packets, known as *kangaroo packets,* were shown to be effective for storage for as long as nine months in adverse field conditions without detectable changes in the components. They are useful therefore in areas where the usage rates of ORS solutions are low, provided clear instructions are given for their proper preparation.

Because high temperatures and humidity would accelerate the deterioration process, manufacturers must consider these factors when preparing and packing ORS. The packaged product must be properly stored until distributed for use, preferably at temperatures and humidity not exceeding 30°C and 80 percent, respectively. Batches showing signs of deterioration upon inspection (lumping, turning brown, and difficulty in dissolving) should be discarded. If the ORS packets have only turned yellow, and can still be readily dissolved, they are considered to be still effective and safe to use.

SUCROSE AS A SUBSTITUTE

WHO has proposed using 40 grammes of common sugar (sucrose), if justified by availability and cost, in place of the 20 grammes of glucose prescribed in the standard ORS formulation. Altough glucose is preferred if it is available at comparable cost, studies have shown common sugar to be almost as effective as glucose for rehydration. In Bangladesh, for instance, substantial savings in cost were achieved by using a crude, locally produced sugar called *gur* as a substitute for glucose or sucrose. It should be noted, however, that common sugar bought from local markets is sometimes adulterated with water to increase the selling weight, its world prices have fluctuated dramatically in recent years, and shortages are not uncommon in some of the developing countries as is the case in Ghana and Tanzania.

FLAVOURING ADDITIVES

ORS solutions, when properly prepared from UNICEF packets, taste slightly less salty than human tears. Since this is sometimes considered by some to be an unpleasant taste, various flavouring substances have been proposed for addition to ORS to improve the palatability of the solutions. Apart from substantially raising the cost of manufacturing the ORS formulation, solutions with specific artificial flavours do not necessarily appeal to all users.

In a field study carried out in Ankara, Turkey, in 1979, a greater rate of acceptability for the product was observed among children given solutions made from ORS packets supplied by UNICEF compared to those prepared from locally produced packets.

ORAL REHYDRATION SOLUTIONS
DOMESTIC FORMULATIONS

SUGAR AND SALT SOLUTION

In areas with endemic diarrhoeal diseases, it is essential to produce and distribute to the communities at risk sufficient quantities of prepackaged ORS for early home use. Community-based ORT programmes are likely to meet with failure if this is not assured, either through local production, or from supplies distributed by UNICEF. In most of the developing countries where childhood diarrhoea is rampant, and supplies of ORS packets are insufficient for use in every home because of limited resources, the only feasible alternative would be to promote the preparation of sugar and salt solution at the household level. These can serve a useful purpose under such conditions as they have been shown to be quite effective in controlling diarrhoeal dehydration, and are easy to prepare at reasonable costs from locally available materials.

Based on the standard ORS formulation developed by WHO, home-made preparations should actually consist of 40 grammes of sugar and 3.5 grammes of common salt dissolved in one litre of clean, safe water.

IMPROVISED MEASURING AIDS

Measurement of salt and sugar by weight, and of water by volume, using scales and volumetric measures was recognized to be an impractical requirement for household preparation of ORS solutions in village settings throughout the developing world. Where ORS packets are made available to families, the problem arises when the contents are mixed with the correct amount of water specified. These difficulties are not usually encountered in most ORT centres as they are expected to be furnished with the necessary measuring devices. Thus the need for improvised measuring aids led to field testing of a variety of techniques and devices for accuracy and acceptability.

The methods generally used for measuring salt and sugar are essentially based on hand or finger measures (finger pinch) and spoons (household or special plastic spoons). The instructions for the preparation of sugar-salt solutions vary accordingly. The *pinch and scoop* method is based on estimating the amount of salt with a three-finger pinch, and of sugar by a four-finger scoop, the measured amounts being added to a cup of water. With household spoons, a basic recipe uses eight level 5 ml teaspoonfuls of sugar and one level 5 ml teaspoonful of salt for one litre of clean water. Another recipe calls for one heaped 5 ml teaspoonful of sugar and a three-finger pinch of salt for about 250 ml of clean water. The addition of two teaspoonfuls of sugar and a pinch of salt to a glass or mug of boiled and cooled water constitutes yet another variety of formulas. In a field trial, it was required to dissolve one level teaspoon of salt and four heaped teaspoons of sugar in a litre of water.

Field assessments of the methods described have indicated that marked variations exist in the quantities measured by mothers in different parts of the world. A refinement pioneered in Indonesia with encouraging results depends on the use of a special double-ended spoon made of plastic. One end is for measuring one level scoop of sugar, and the other is for measuring one level scoop of salt to be dissolved in one cup (200 ml) or glass (250 ml) of water. Instructions are printed on the spoons in five languages. Because too much salt may be hazardous, mothers are advised to discard any preparations that taste more salty than tears. These spoons can be obtained from TALC (*Teaching Aids at Low Cost,* 30 Guilford Street, London, WC1N 1EH, U.K.).

Different methods for measuring the required volume of water have been tried with varying degrees of success, including locally used cups, mugs, bowls, glasses, bottles, tin cans, coconut shells, and even the dried shells of bottle gourd *(Lagenaria siceraria)*. The difficulty of finding a suitable measuring aid available in the majority of homes was resolved in the Philippines by adopting local beer bottles of uniform size. Subsequently, the glass container for a popular coffee brand was found to be more practical. In Gambia, a novel technique developed by the local health authorities based on the use of a local soft drink *(Julpearl)* bottle and cap as aids for correct measurements. For the preparation of one litre of home-made solution, eight caps of sugar and one cap of salt are to be added to three *Julpearl* bottles of water. A similar technique was recently adopted in Zimbabwe using a local soft drink *(Mazoe)* bottle and cap.

Plastic bags marked at the desired volume deserve consideration by local manufacturers as they are not expected to add substantially to ORT programme costs. These can also serve as *kangaroo packets* to hold the sugar and small packet of salt. Such a double function could significantly reduce the overall costs.

ISSUES TO BE RESOLVED

Each of the previously described techniques for the preparation of sugar-salt solutions at home have advantages and disadvantages. They all serve a useful purpose pending the development of more accurate measuring techniques. In any case, much of the success or failure of any of these techniques depends on proper training of health workers, meticulous instructions given to mothers, and monitoring of the home-made solutions. Mistakes in preparing the solutions may offset some of their beneficial effects.

Some of the major issues arising from the preparation and use of home-made solutions relate to the quality and availability of the ingredients, accuracy in preparing them, and their effectiveness and safety.

In some areas sugar and salt are scarce commodities. Sugar may be adulterated with water to increase its selling weight. Crude salt, with its deliquescent property and impurities, is the kind most likely to be used by virtue of its availability and low cost. It is such factors that could augment the errors committed in measuring the desired quantites of ingredients, and add to the difficulties in promoting and implementing home-based programmes.

The varied composition of the home-made solutions, together with the lack of bicarbonate and potassium, raise the question as to their effectiveness and safety. Field experience has repeatedly validated the effectiveness of these solutions for rehydration purposes even in the absence of bicarbonate. Development of acidosis from lack of bicarbonate does not constitute a significant problem. Because potassium losses in diarrhoea are relatively high, it needs to be replaced during rehydration of undernourished children who have suffered repeated diarrhoeal episodes. There are many locally available sources of potassium that can be added to the sugar-salt solutions. These include coconut water, fresh lemon and orange juices, raw tomato, banana, plantain, and papaya. A home preparation of sugar and salt solution with lemon juice called *Super Limonada* has been successfully tried in Nicaragua.

The addition of slightly more sugar than necessary, which can happen in some cases, would not lead to any serious problem. However, the final concentration of salt is fairly critical. Very low concentrations may render the sugar-salt solutions ineffective. The unintentional addition of too much salt is a much more likely possibility, in which case hypernatraemia could occur. This can be avoided by instructing mothers to measure the salt as carefully as possible, and to check the prepared solutions by tasting their saltiness. Any solution that tastes saltier than tears should be discarded — a somewhat arbitrary decision.

Other areas of concern relate to the inaccuracy in volumetric measurements, quantities to be prepared, storage of solutions, and quality of the water used.

Variations in the composition of oral rehydration solutions, whether prepared from UNICEF packets or from household formulations, are partly dependent on the degree of purity and accuracy in measurement of the ingredients. Volumetric measurement of the fluid is another contributing factor. With the measuring aids available to rural communities, a wide margin of error in the concentration of the ingredients is expected. The issue arising from this is whether the variations in concentration fall within the tolerance limit for the more critical ingredients, like sodium and potassium. It is unfortunate that this issue has not yet been resolved.

It is recommended by WHO that solutions be prepared fresh daily, and that mothers should be instructed to discard any unused portions after 24 hours to avoid the risk of growth and multiplication of microorganisms. This also applies to concentrated stock solutions prepared at dispensaries for distribution to families. This requirement is necessary even when solutions are prepared with boiled water. Solutions containing sugar and water could support the growth, at least for some time, of such microorganisms as bacteria, viruses, molds and yeasts. These contaminants might originate from the ingredients, water, containers and utensils, or through handling. The importance of some of the microbial contaminants relates to the spoilage and storage limitation of the prepared solutions. Contamination with pathogenic organisms, whether from the water or other sources, arouses concern regarding possible detrimental health effects on children undergoing oral rehydration therapy. In any case, mothers should be instructed to prepare solutions with clean water, vessels, and utensils, and to keep them in covered utensils until needed for use.

DISINFECTION BY BOILING

The possibility of obtaining clean, safe water for domestic use is rather remote in village settings throughout the developing world. The availability of treated water would be exceptional. Domestic water supplies are therefore expected to be contaminated with microorganisms in varying degrees. Such situations would have a bearing on the purity and safety of the water to be used for the preparation of oral rehydration solutions, and the risk involved in administering contaminated solutions.

It is logical, therefore, for UNICEF to recommend the use of boiled water for the preparation of standard ORS solutions, as is indicated on the labels of UNICEF packets It is important though to note that the water should be allowed to cool before use. This is necessary to avoid decomposition of the sodium bicarbonate by hot water.

According to the criteria proposed by the WHO Diarrhoeal Diseases Control Programme (document CDD/SER/81.1), a suitable chemical agent to be added to the standard ORS ingredients at the time of packing to ensure decontamination of the reconstituted solution would need to be:

- effective against the organisms concerned,
- non-toxic to man,
- effective in the pH of ORS solution,
- non-reactive with the ORS ingredients,
- non-reactive with ORS packaging material,
- acceptable from the point of view of taste, smell, and colour of the ORS solution,
- non-disruptive of the absorption process in oral rehydration,
- inexpensive.

As none of the chemical agents currently used for the sterilization of water (e.g. chlorine and chlorine compounds) do not meet these criteria, the WHO Diarrhoeal Diseases Control Programme would not recommend their use. In this connection, it should be noted that as a strong oxidizing agent chlorine or its disinfectant compounds (e.g. sodium or calcium hypochlorite) would react with glucose because of its reducing properties.

The WHO Diarrhoeal Diseases Control Programme arrives at the conclusion that boiling is an effective method of decontamination of water to be used for the preparation of ORS solutions, but has the following disadvantages:

- the difficulty of obtaining fuel and its cost,

- the time required for boiling and cooling (and consequently the delay in commencing therapy),
- the risk that, after boiling and cooling, the water or ORS solution prepared with it may become contaminated during measuring, mixing, handling, or storage,
- the risk that the water may be used for preparing the ORS solution before it has been sufficiently cooled,
- the (perhaps minor) risk that the users will mistakenly boil the ORS solution after preparation.

On the basis of available information, the following recommendations have been made regarding the preparation of ORS solutions:

1. ORS solution should be prepared with water made potable by recognized methods (e.g. boiling, chlorination, etc.) in containers washed with such water. This is important because enteric bacteria can grow in ORS solution, and there are as yet insufficient data to show that there is no risk associated with the use of "usual" drinking water;
2. ORS solution, once so prepared, should be protected against subsequent contamination and kept in a cool dark place;
3. If potable water cannot be guaranteed, and ORS solution needs to be administered, the *best* available water should be used;
4. ORS solution, no matter what water is chosen, should ideally be used within 12 hours and never kept for more than 24 hours.

It remains to be pointed out that these recommendations seem to pertain specifically to solutions made from the standard ORS formulation developed by WHO. There is no mention in these directives of the alternative ORS formulations containing sodium citrate as a substitute for sodium bicarbonate, nor of household formulations made from sugar and salt only. It is clear that solutions made from sugar and salt only may be decontaminated by boiling after preparation since they lack the heat sensitive sodium bicarbonate. Disregarding availability and cost of fuel, solutions made at home from sugar and salt only should preferably be boiled after preparation to ensure decontamination of the water, ingredients, and container. However, consideration must be given to the shortcomings of fuel consumption in rural areas of the Third World.

SOLAR ENERGY
FUNDAMENTAL CONSIDERATIONS

ELECTROMAGNETIC ENERGY

The term *electromagnetic energy* comprises all types of energy that travels from its source through space in the form of harmonic waves along straight paths at the uniform speed of light ($3x10^8$ m/sec). *Radiation* is the term that pertains to the emission and propagation of electromagnetic energy in the form of waves.

There are many types of electromagnetic energy, but consideration of the subject is necessarily limited to those of solar origin that provide pertinent background information for the proper utilization of solar radiation for disinfection purposes. It should be recognized that solar radiation constitutes only a portion of the entire electromagnetic energy spectrum. In fact, sunlight as sensed by the human eye essentially represents that part which is visible, although it also includes other invisible radiation components. Strictly speaking, the terms *light* and *sunlight* refer to radiation wavelengths detectable by the human eye (400 to 700 nm).

Electromagnetic radiation, as well as solar radiation, is commonly classified on the basis of radiation wavelength into several regions, or *bands*. The wavelength bands of solar radiation, both visible and invisible, are mentioned in Table 1 along with some useful remarks.

Table 1. Spectral bands of incoming solar energy and atmospheric effects

Band	Wavelength (nm)	Atmospheric Effects
Gamma ray	<0.03	Completely absorbed by the upper atmosphere
X-Ray	0.03 – 3	Completely absorbed by the upper atmosphere
Ultraviolet, UV		
UV (B)	3 – 300	Completely absorbed by oxygen, nitrogen, and ozone in the upper atmosphere
UV (A)	300 – 400	Transmitted through the atmosphere, but atmospheric scattering is severe
Visible	400 – 700	Transmitted through the atmosphere, with moderate scattering of the shorter waves
Infrared, IR		
Reflected IR	700 – 3000	Mostly reflected radiation
Thermal IR	3000 – 14000	Absorption at specific wavelengths by carbon dioxide, ozone, and water vapour, with two major *atmospheric windows*

Similar information is also illustrated diagrammatically in Figure 1 for purposes of visual clarification. Note that the colours shown for the various wavelength bands in the visible region of the solar radiation spectrum are approximate representations of the colours of light within each band.

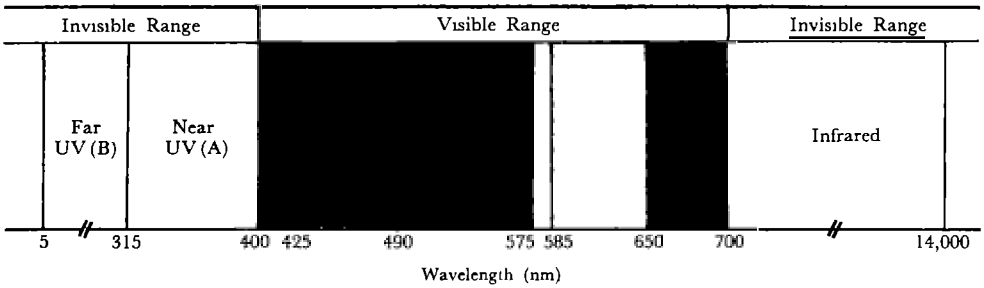


Figure 1. *Solar radiation spectrum showing the different radiation bands and their wavelength ranges*

PROPAGATION OF SOLAR ENERGY

The sun continuously radiates enormous amounts of solar energy at wavelengths that cover the ultraviolet, visible, and infrared bands. The maximum intensity of the emitted solar energy occurs at a wavelength of about 555 nm, which falls within the band of green light (Figure 1).

Solar radiation moves freely in outer space because of the vacuum, unless its path is obstructed by planets, satellites, meteorites, or other space objects. Whatever portion of it reaches the earth and its surrounding atmosphere may encounter a variety of atmospheric or terrestrial objects. When solar radiation strikes any object whether in the form of solid, liquid or gas, changes in its magnitude, direction, and wavelength are expected to occur depending upon the nature and characteristics of the intervening object. These changes may come as a result of any of the following possible phenomena:

- Radiation may be *transmitted* through a transparent object such as air, water, or glass with a change in speed and direction.
- Radiation may be partially or completely *absorbed* by an object, the components thus absorbed being dependent on the wavelength of the specific radiation and the characteristics of the object. Blue tinted glass, for instance, would transmit radiation with wavelengths of 425 to 490 nm and, at the same time, absorb radiation in the other wavelength bands.
- Radiation may be *scattered* by being deflected in all directions, a common example being the scattering of sunlight as it traverses the atmosphere.
- Radiation may be *reflected* by being returned from the surface of an object in an unchanged form except for the deviation whereby the angle of reflection would be equal and opposite to the angle of incidence.

SOLAR ENERGY FROM SUN TO EARTH

OUTER SPACE

The enormous amount of energy continuously emitted by the sun is dispersed into outer space in all directions. Only a small fraction of this energy is intercepted by the earth and other solar planets.

The solar energy reaching the periphery of the earth's atmosphere is considered to be constant for all practical purposes, and is known as the *solar constant.* Because of the difficulty in achieving accurate measurements, the exact value of the solar constant is not known with certainty, but is believed to be between 1,353 and 1,395 W/m^2 (approximately 1.4 kW/m^2, or 2.0 $cal/cm^2/min$). The solar constant value is estimated on the basis of the solar radiation received on a unit area exposed perpendicularly to the rays of the sun at an average distance between the sun and the earth.

In passing through outer space, which is characterized by vacuum, the different types of solar energy remain intact and are not modified until the radiation reaches the top of the earth's atmosphere. In outer space, therefore, one would expect to encounter the types of radiation listed in Table 1, which are: gamma ray, X-ray, ultraviolet, and infrared radiations.

ATMOSPHERIC EFFECTS

Not all of the solar radiation received at the periphery of the atmosphere reaches the surfaces of the earth. This is because the earth's atmosphere plays an important role in selectively controlling the passage towards the earth's surface of the various components of solar radiation.

A considerable portion of solar radiation is reflected back into outer space upon striking the uppermost layers of the atmosphere, and also from the tops of clouds. In the course of penetration through the atmosphere, some of the incoming radiation is either absorbed or scattered in all directions by atmospheric gases, vapours, and dust particles. In fact, there are two processes known to be involved in atmospheric scattering of solar radiation. These are termed *selective scattering* and *non-selective scattering*. These two processes are determined by the different sizes of particles in the atmosphere.

Selective scattering is so named because radiations with shorter wavelengths are selectively scattered much more extensively than those with longer wavelengths. It is caused by atmospheric gases or particles that are smaller in dimension than the wavelength of a particular radiation. Such scattering could be caused by gas molecules, smoke, fumes, and haze. Under clear atmospheric conditions, therefore, selective scattering would be much less severe than when the atmosphere is extensively polluted from anthropogenic sources.

Selective atmospheric scattering is, broadly speaking, inversely proportional to the wavelength of radiation and, therefore, decreases in the following order of magnitude: far UV > near UV> violet > blue > green > yellow > orange > red > infrared. Accordingly, the most severely scattered radiation is that which falls in the ultraviolet, violet, and blue bands of the spectrum. The scattering effect on radiation in these three bands is roughly ten times as great as on the red rays of sunlight.

It is interesting to note that the selective scattering of violet and blue light by the atmosphere causes the blue colour of the sky. When the sun is directly overhead at around noon time, little selective scattering occurs and the sun appears white. This is because sunlight at this time passes through the minimum thickness of atmosphere. At sunrise and sunset, however, sunlight passes obliquely through a much thicker layer of atmosphere. This results in maximum atmospheric scattering of violet and blue light, with only a little effect on the red rays of sunlight. Hence, the sun appears to be red in colour at sunrise and sunset.

Non-selective scattering occurring in the lower atmosphere is caused by dust, fog, and clouds with particle sizes more than ten times the wavelength of the components of solar radiation. Since the amount of scattering is equal for all wavelengths, clouds and fog appear white although their water particles are colourless.

Atmospheric gases also absorb solar energy at certain wavelength intervals called *absorption bands,* in contrast to the wavelength regions characterized by high transmittance of solar radiation called *atmospheric transmission bands,* or *atmospheric windows.*

The degree of absorption of solar radiation passing through the outer atmosphere depends upon the component rays of sunlight and their wavelengths. The gamma rays, X-rays, and ultraviolet radiation less than 200 nm in wavelength are absorbed by oxygen and nitrogen. Most of the radiation with a range of wavelengths from 200 to 300 nm is absorbed by the ozone (O_3) layer in the upper atmosphere. These absorption phenomena are essential for living things because prolonged exposure to radiation of wavelengths shorter than 300 nm destroys living tissue.

Solar radiation in the red and infrared regions of the spectrum at wavelengths greater than 700 nm is absorbed to some extent by carbon dioxide, ozone, and water present in the atmosphere in the form of vapour and condensed droplets (Table 1). In fact, the water droplets present in clouds not only absorb rays of long wavelengths, but also scatter some of the solar radiation of short wavelengths.

GROUND LEVEL

As a result of the atmospheric phenomena involving reflection, scattering, and absorption of radiation, the quantity of solar energy that ultimately reaches the earth's surface is much reduced in intensity as it traverses the atmosphere. The amount of reduction varies with the radiation wavelength, and depends on the length of the atmospheric path through which the solar radiation traverses. The intensity of the direct beams of sunlight thus depends on the altitude of the sun, and also varies with such factors as latitude, season, cloud coverage, and atmospheric pollutants.

The total solar radiation received at ground level includes both *direct* radiation and *indirect* (or *diffuse*) radiation. Diffuse radiation is the component of total radiation caused by atmospheric scattering and reflection of the incident radiation on the ground. Reflection from the ground is primarily visible light with a maximum radiation peak at a wavelength of 555 nm (green light). The relatively small amount of energy radiated from the earth at an average ambient temperature of 17°C at its surface consists of infrared radiation with a peak concentration at 970 nm. This invisible radiation is dominant at night.

During daylight hours, the amount of diffuse radiation may be as much as 10% of the total solar radiation at noon time even when the sky is clear. This value may rise to about 20% in the early morning and late afternoon.

In conclusion, therefore, it is evident that in cloudy weather the total radiation received at ground level is greatly reduced, the amount of reduction being dependent on cloud coverage and cloud thickness. Under extreme cloud conditions a significant proportion of the incident radiation would be in the form of scattered or diffuse light. In addition, lesser solar radiation is expected during the early and late hours of the day. These facts are of practical value for the proper utilization of solar radiation for such purposes as destruction of microorganisms.

SOLAR ENERGY
WORLD DISTRIBUTION

REGIONS FOR APPLICATION

It is common knowledge that solar radiation is unevenly distributed, and that it varies in intensity from one geographic location to another depending upon the latitude, season, and time of day. Until recently, valid records for solar radiation have been very scanty in the vast majority of the developing countries. In the absence of such useful information as a guide for the proper exploitation of solar energy, only general hints can be offered regarding the geographic areas with favourable conditions for solar energy applications.

For convenience and simplicity, the geographic distribution of total solar radiation on a global scale is divided in terms of intensity into four broad belts around the earth. These are illustrated in Figure 2, and also described briefly hereunder with respect to the northern hemisphere, with the understanding that the same conditions apply to the corresponding belts in the southern hemisphere:

- *The most favourable belt.* This belt, lying between latitudes 15°N, and 35°N, embraces the regions that are naturally endowed with the most favourable conditions for solar energy applications. These semi-arid regions are characterized by having the greatest amount of solar radiation, more than 90% of which comes as direct radiation because of the limited cloud coverage and rainfall (less than 250 mm per year). Moreover, there is usually over 3,000 hours of sunshine per year.
- *Moderately favourable belt.* This belt lies between the equator and latitude 15°N, and is the next most favourable region for the purpose previously mentioned. Because the humidity is high, and cloud cover is frequent, the proportion of scattered radiation is quite high. There is a total of about 2,500 hours of sunshine per year. The solar intensity is almost uniform throughout the year as the seasonal variations are only slight.
- *Less favourable belt.* This belt lies between latitude 35°N and 45°N. Although the average solar intensity is roughly about the same as for the other two belts, there are marked seasonal variations in both radiation intensity and daylight hours. During the winter months solar radiation is relatively lower than in the rest of the year.
- *Least favourable belt.* The regions in this belt lie beyond latitude 45°N. They include the USSR, and the greater parts of northern Europe and North America. Here, about half of the total radiation is diffuse radiation, with a higher proportion in winter than in summer primarily because of the rather frequent and extensive cloud coverage.

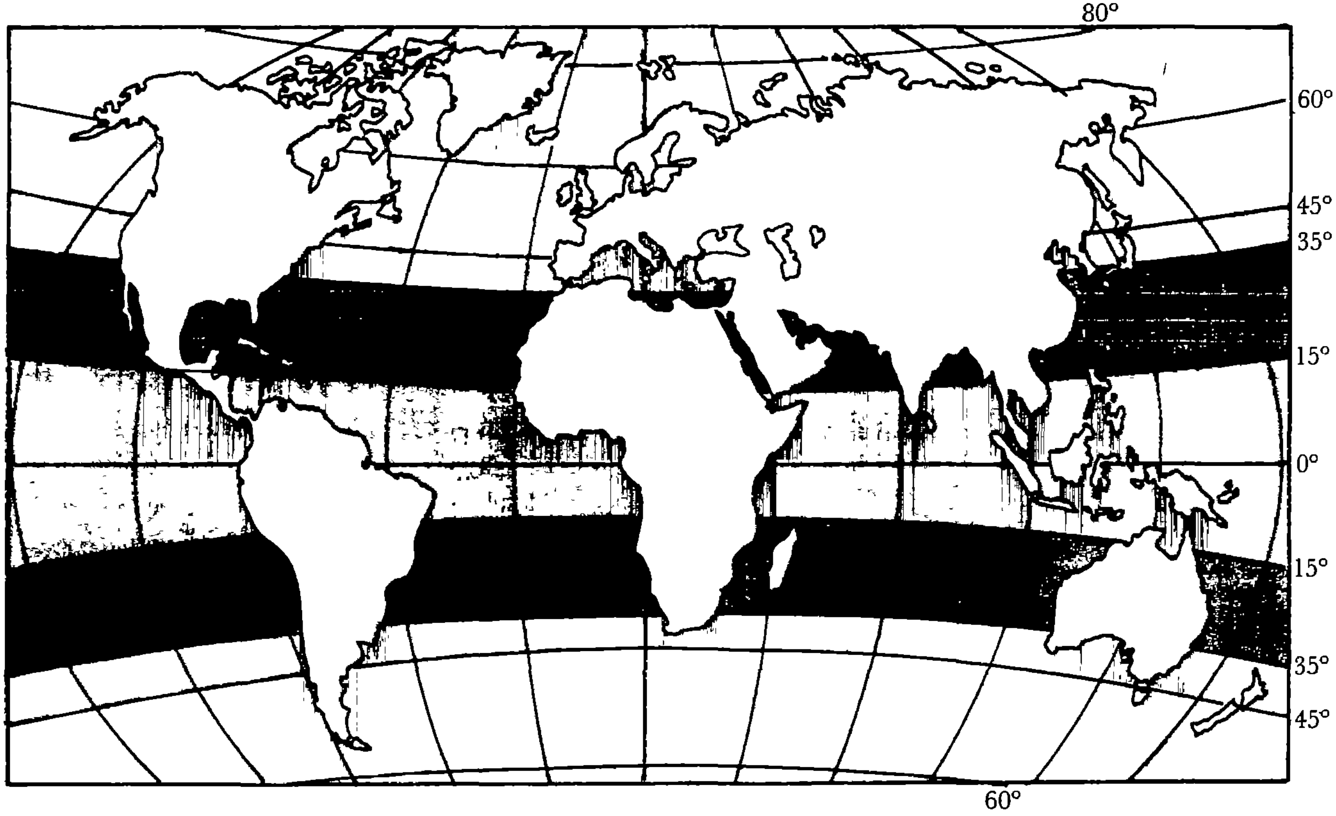


Figure 2. *Worldwide distribution of solar radiation classified into belts indicating feasibility of solar applications*

■ *Most favourable* ■ *Moderately favourable* ▥ *Less favourable* ▯ *Least favourable*

It is important to note that the majority of developing countries fall within the more favourable regions between latitudes 35°N and 35°S. For this reason they can count on solar radiation as a steadfast source of energy that can be readily exploited cheaply by both rural and urban households for a multitude of purposes, including solar disinfection of drinking water and oral rehydration solutions.

SOLAR ENERGY
A COMPETITOR

UTILIZATION

The sun, a source of unlimited energy, can potentially provide the equivalent of about 25,000 times the total amount of energy presently used from all other sources. However, only a very small fraction of this freely available energy is exploited through direct means for human use. At the world's current consumption of fossil fuels (petroleum and natural gas), depletion of the reserves of these energy resources is now a predictable matter of universal concern.

Alternative energy resources other than coal are inadequate to meet the total future needs on a global scale. In order to diminish the dependence on the rapidly depleting oil resources, special consideration is being given to the feasibility of expanding the exploitation of coal reserves in a manner that would ensure the reduction of the associated environmental impacts.

In view of these rapidly growing concerns, it would be reasonable to assume that solar energy is bound to play an important role in the future supply of energy, particularly in the developing world. Although the use of solar energy is still limited at present, the development of appropriate technology is underway to harness solar power, as well as other renewable energy sources, for various industrial and household applications. The areas of solar usage include drying of food and crops, desalination, generation of electricity, heating and cooling of houses, water heating, and cooking and refrigeration.

FUELWOOD, AN ENVIRONMENTAL ISSUE

In many developing countries, particularly in rural and remote population centres, the energy consumed for household use is largely from local resources such as fuelwood, charcoal, cow dung, and agricultural wastes.

According to well informed UN sources (UNEP, *Global Environmental Issues*. Edit., E. El-Hinnawi and M. Hashmi. Tycooly International Publishing Ltd., Dublin, 1982) well over two billion people, mostly in rural areas, use fuelwood as the principal source of energy for cooking and other domestic purposes. This has been a traditional practice for centuries among rural populations in Africa, Asia, and Latin America, where nearly 95% of the households depend upon fuelwood as their major source of energy at an annual consumption rate of 1.3 m^3 to 2.3 m^3 per capita. Kenya, Zambia, Tanzania, Upper Volta, Nigeria, China, India, Bangladesh, Sri Lanka, Thailand, and Nepal are typical examples of the countries involved.

Through over-exploitation of forest trees, shrubberies, and other woody vegetation, partly to make room for new farmlands and partly for use as fuel, situations of acute fuelwood scarcity are currently prevailing in many parts of the developing world. About one billion people are believed to have been faced with such critical situations in 1980. Some of the salient ecological consequences include deforestation, lack of woody vegetation, and destructive soil erosion. In some of the semi-arid regions like the sub-Saharan parts of Africa from Senegal to Ethiopia, there are indications that fuelwood consumption has already contributed to the process of desertification.

THE MERITABLE ASPECTS

Besides its availability in abundance in most parts of the developing world, solar radiation possesses a number of advantages over other energy sources which are now rapidly dwindling. The prominent ones include the following:

- The simple and low-cost technology involved in harnessing solar radiation.
- Solar energy is found at the places where it is needed for use, a convenience that saves transportation costs, time, and effort.
- Unlike other kinds of energy, the utilization of solar energy would not lead to negative environmental impacts.
- Solar energy would help substantially in relieving the critical problem of fuelwood in semi-arid and arid areas.
- The advantages embodied in the practical use of solar energy tend to promote widespread implementation at the household level, as well as personal interest and acceptance.

SOLAR ENERGY
SOME PRACTICAL HINTS

PUBLISHED DATA

The only available data issued by most of the meteorological stations is the total solar radiation (direct and diffuse radiations) received on the surface of an object placed horizontally. Very few stations provide data for the total radiation striking objects placed in a vertical position.

For most solar radiation applications the available data may be sufficiently adequate, but is not quite so for purposes of solar disinfection of drinking water or oral rehydration solutions using bottles or other similar containers. This is on account of two important factors: (a) the effective component of solar radiation involved in microbial destruction is in the near-ultraviolet (A) band (300-400 nm), and to a lesser extent in the visible band of violet and blue lights (400-490 nm); and (b) from a practical standpoint, bottles or similar vessels used in the disinfection process must necessarily be kept upright during exposure to sunlight. In this context, therefore, some care must be taken in the interpretation of certain published data that may not be pertinent to specific local situations or applications. Ideally, each of the developing countries interested in the development of programmes for the exploitation of solar radiation should endeavour to establish solar research centres and monitoring stations. This has been the trend in recent years in some of the Arab states and other developing countries.

SEASONAL VARIATIONS

It is logical to question the feasibility of utilizing solar energy for any particular application in an effective manner throughout the year without serious setbacks or interruptions caused by seasonal variations in solar radiation. There is no doubt that seasonal variations could provoke marked changes in the effectiveness or productivity of solar dependent processes. For this reason it would be useful to consider the possible variations and their potential impacts.

Seasonal variations are primarily due to changes in the solar altitude, and in cloud formation during the rainy season. These two factors determine not only the total amount of solar radiation reaching ground-level at a given location, but also the proportion of the various kinds of radiation. As a general rule, the lower the sun is with reference to the horizon the weaker is the total solar radiation, and the greater is the fraction of scattered light, mainly in the UV (A) and blue light bands. The reverse is also true when the solar altitude increases. Cloud formation may hinder the overall atmospheric transmission of solar radiation to a degree determined by the thickness and density of clouds.

Very dense clouds, about 1000 m in thickness, are said to reflect back into space more than 90% of the incident solar radiation. Such occurrences, however, are generally of short duration in many parts of the world, and so their impact would be transient. In any event, scattered radiation continues to retain its destructive power against microorganisms, although it may be somewhat attenuated.

In the northern hemisphere, for instance, nature decrees that during the winter months the total solar radiation is much reduced, and the length of the day becomes shorter. The lowest values occur in December and January. From then on the values increase gradually, reaching the highest levels in June and July. These facts are illustrated, at least in part, in Figure 3 which is based on hourly measurements of solar radiation at a wavelength peak of 357 nm (an optimal radiation wavelength for microbial destruction). The UV radiation measurements were made in Beirut, Lebanon, on two cloudless days (October 8, 1983, and December 21, 1983), using a Spectroline DM-357X digital radiometer (obtained from Insect-O-Cutor Limited, Stockport, Cheshire, England).

The important inferences drawn from the two graphs in Figure 3 indicate that solar radiation at a wavelength of about 357 nm decreases from October to December, and that the ultraviolet (A) radiation reaches its maximum level at about noontime regardless of the time of the year. In effect, this means that the microbial disinfection process is expected to be much more efficient in summer and autumn than in winter under clear sky conditions in Beirut. In practice, therefore, lengthening the sunlight exposure period for disinfection purposes during the winter months would accomplish the desired results.

ORIENTATION OF RECEIVER

In solar operations using devices designed to collect or concentrate solar radiation, it is generally advised to keep the radiation receiver in a tilted position rather than in a horizontal position in order to be at right angles to the sun's rays. The recommended angle of inclination from the horizontal is equal to the latitude of the location, and the receiver is to face the south. The amount of sunlight collected and utilized is thus substantially increased, for as much as 50% of solar energy could be gained, particularly in winter when the sun is closer to the horizon.

The question that presents itself regarding the solar disinfection process is whether a similar arrangement would be necessary and justifiable. To arrive at a conclusion in this regard, it would be necessary to evaluate the pertinent facts. For the usual solar processes the aim is to collect on the receivers as much direct sunlight as possible to attain an optimum efficiency. While this is partly true for solar decontamination operations, it should be noted that in these cases scattered radiation

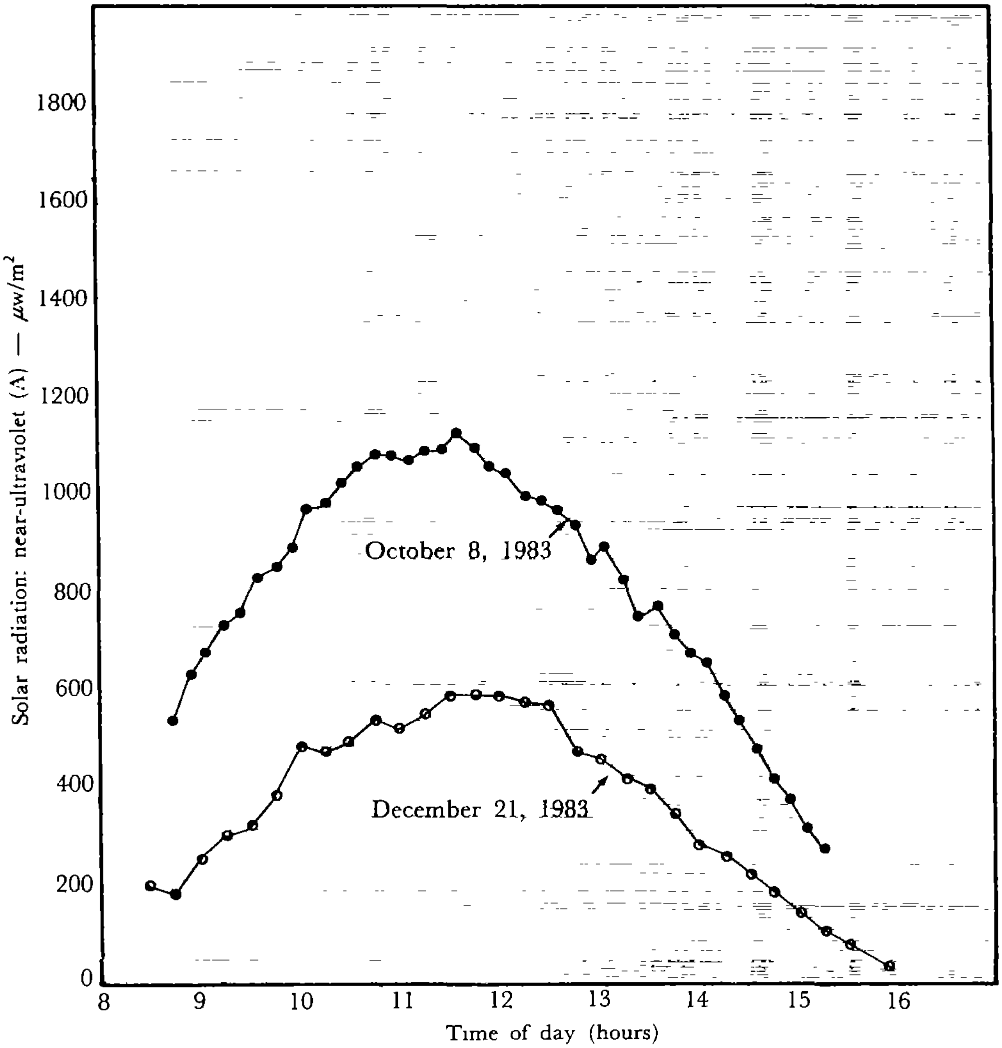


Figure 3. *Solar radiation (near-ultraviolet-A) on a horizontal target as a function of time. Measurements made in Beirut, Lebanon, on October 8, 1983 and December 21, 1983 using a Spectroline digital radiometer at a peak wavelength of 357 nm Clear sky prevailed*

striking from all directions an upright receiving object (e.g. bottle holding water to be disinfected) presents an additional advantage. By tilting such an object, which is a practical problem, more direct sunlight is gained at the expense of scattered radiation.

To help resolve this issue, comparative measurements were made of the UV (A) radiation received on an object kept upright and then lying horizontally. Readings were taken at intervals throughout the day under clear sky conditions using the same radiometer described earlier. The results shown graphically in Figure 4 lead to the principal conclusion that an upright position is much more favourable than a horizontal one. Other experimental data show that, with clear skies, UV (A) radiation intensity values for vertical objects are almost twice as great as those for horizontal objects throughout the greater part of the day, and tend to become equal under conditions of haze or cloudiness.

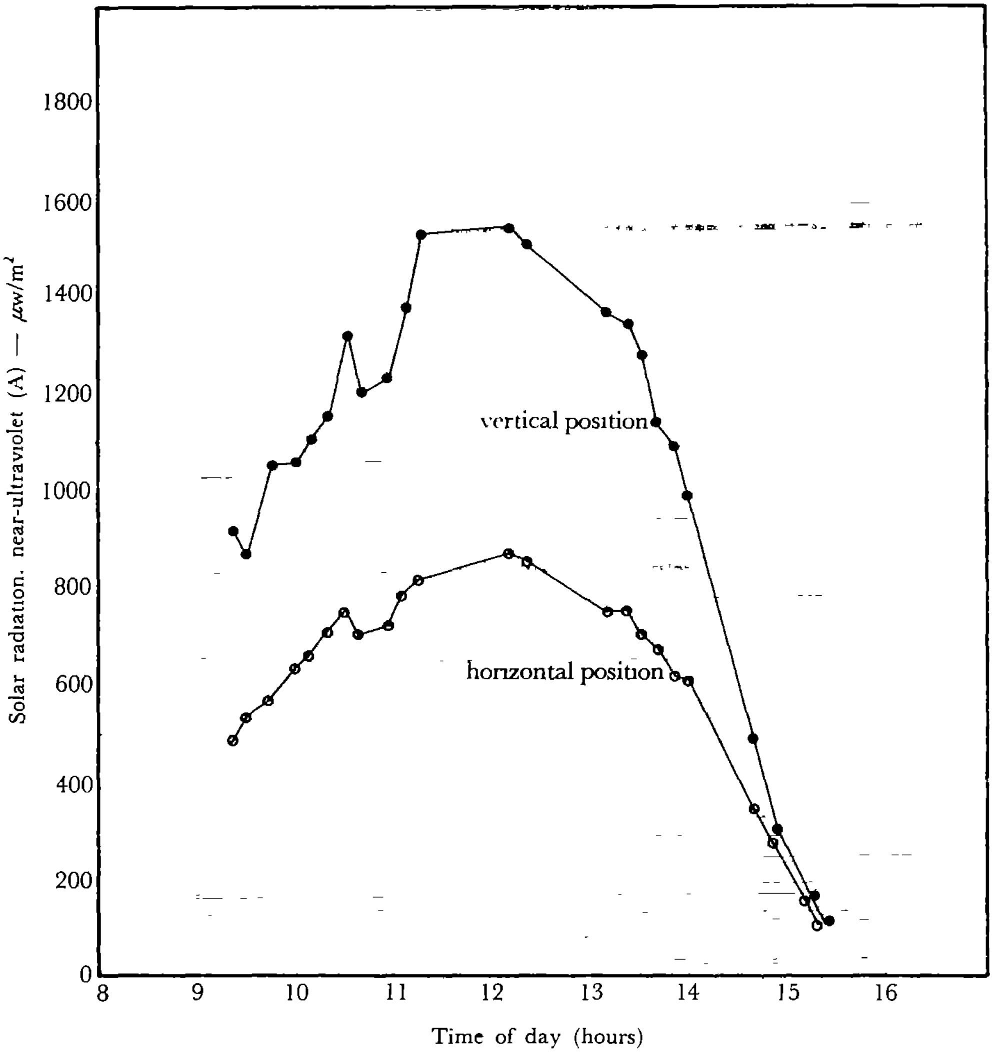


Figure 4. *Effects of orientation of target on solar radiation (near-ultraviolet-A) received throughout the day. Measurements made in Beirut, Lebanon, on January 1, 1984 using a Spectroline radiometer at a peak wavelength of 357 nm Clear sky prevailed*

TRANSMISSION THROUGH GLASS

In selecting containers for solar disinfection of water or oral rehydration solutions, the property of being transparent to sunlight is of utmost importance. Because of their widespread availability, glass containers should be considered with respect to transmission of solar radiation at different wavelength bands, particularly with respect to UV (A) radiation.

Ordinary glass of which most containers such as bottles and jars are made can transmit solar radiation up to about 90%, the remainder being reflected or absorbed by the glass. The amount and kind of radiation that passes through ordinary glass depends on the colour and thickness of the glass, and on the specific wavelength bands of radiation.

Colourless glass transmits solar radiation at wavelengths in the range of 320 to 700 nm. It is therefore opaque to radiation below 320 nm, and to infrared radiation. The maximum amount of radiation transmitted occurs at 400 nm. Pyrex glass, of which most laboratory glassware is made, is opaque to radiation below 280 nm, and attains a maximum transmission at 340 nm. Transparent plastic materials such as *polystyrene* and *methylacrylate* (Lucite and Plexiglass) can have a higher radiation transmittance than glass at wavelengths greater than 290 nm. These materials are therefore better than glass for the transmission of germicidal solar radiation at wavelengths from 300 to 400 nm.

As for coloured glass, the commonest colouring agents are iron, manganese, chromium, copper, and cobalt; but iron is the main colouring material which gives glass a greenish tinge. Each of these colourants imparts to glass a characteristic tint, and causes the absorption of radiation at specific wavelengths. The iron content in ordinary glass determines the transmission of solar radiation at different wavelengths. Glass with a low iron content allows high radiation transmittance at all wavelengths of the spectrum. For wavelengths in the near-ultraviolet region (A) the transmittance is up to about 90%. As the iron content increases and the glass attains a darker green colour, the transmittance in the near-ultraviolet region (A) decreases, but remains at a fairly high level in the visible region (400 to 700 nm).

With coloured glass, the tint perceived by the sight is due to the specific wavelength of visible light transmitted through the glass. For instance, blue glass appears to have a blue tint because visible light in the blue band is transmitted much more than others. Similarly, red glass transmits mostly visible light in the red band of the spectrum. This is of importance in selecting the most appropriate coloured glass containers for solar disinfection purposes. Naturally, colourless glass with a low iron content would be the best choice. Next comes the blue tinted glass.

TRANSMISSION THROUGH WATER

The discussion thus far has traced the fate of solar radiation as it traverses the atmosphere to strike a target at ground-level, which is assumed to be a glass or plastic container holding water or oral rehydration solution. It should be clear by now that the most effective germicidal component of solar radiation (300 to 400 nm) reaching the target container and penetrating its walls remains largely intact in terms of quantity, quality, and microbial destructive action. What remains to be considered is the transmission of the effective component of solar radiation through the water or aqueous solution to reach the ultimate target — the microorganisms to be destroyed.

That sunlight can penetrate water is a well known phenomenon. In fact, it is an essential requirement to sustain the life of aquatic plants like algae that grow in water. An assessment of solar radiation transmission through a colourless aqueous medium such as clear natural water points out the fact that, as the penetration path gradually increases, the radiation intensity decreases accordingly. The loss in intensity varies with wavelength, being particularly low for radiations of short wavelengths. For wavelengths ranging from 300 to 500 nm the reduction in intensity does not exceed 5% per metre of water depth. For the higher wavelengths the value may be as high as 40% per metre. The reduction at all wavelengths is largely due to radiation scattering, for absorption by clear natural water constitutes only a relatively small fraction. These facts show that UV (A) radiation will penetrate clear water to a depth of several metres before it is appreciably diminished in intensity. Obviously, then, UV (A) radiation can be readily transmitted through small volumes of clear water contained in transparent vessels. However, the picture differs in the case of coloured or turbid water.

Substances imparting colour to water are likely to absorb radiation at specific wavelengths that vary with the nature of the substance. Since coloured waters are limited to highly polluted waters not fit for drinking, such cases are of no relevance here. On the other hand, suspended particles in water would cause radiation scattering by deflection from their surfaces in all directions. This phenomenon is known as the *Tyndall effect*. This can be easily demonstrated by viewing a bottle with turbid water against a source of light. The particles become visible, but not in the case of clear water or a clear solution of salt, for instance. In view of this information, water with a high content of suspended particles tends to obstruct the passage of a beam of solar radiation, the penetration depth depending upon the degree of turbidity of the water. In practice, this phenomenon could be neglected if the water is only slightly turbid; otherwise the turbidity needs to be reduced by allowing the larger particles to settle or, better still, by filtration or coagulation of the water.

SOLAR DISINFECTION STUDIES DRINKING WATER

BACKGROUND INFORMATION

There are a few methods commonly advocated for the disinfection of drinking water at the household level. These include boiling of water for about 10 minutes, or the use of certain chlorine compounds available in the form of tablets (Halazone tablets, or calcium hypochlorite tablets) or solutions (sodium hypochlorite solutions). Water purification tablets containing tetraglycine hydroperiodide as the active ingredient (obtainable from Wisconsin Pharmacal, Milwaukee, Wisconsin 53223, USA) are also available for such use. These tablets have an expiration date, and the instructions call for the addition of 1 to 2 tablets per litre of water and waiting for 25 minutes before use.

As each of these procedures has its own drawbacks, their application is extremely limited in the developing regions of the world where water-borne diseases are prevalent, and the safety of drinking water supplies cannot always be assured. Availability and costs are only part of the problem. In the case of boiling, for instance, the need for about one kilogramme of wood to boil one litre of water is totally unjustifiable in fuel-short regions already suffering from aridity and desertification. Besides, the disagreeable taste of boiled water often discourages consumers. The addition of 1 to 2 drops of 5% sodium hypochlorite solution per litre of water requires the use of a dropper and litre measure, both being uncommon devices in most homes. In view of these difficulties and constraints, it was deemed necessary to search for an alternative method for the disinfection of water on an individual basis using simple and inexpensive technology that would be more appropriate for application in the Third World.

THE EXPERIMENTAL WORK

Prompted by an understanding of the prevailing conditions and needs in the developing countries regarding the safety of water supplies in rural communities, and the rampant enteric diseases, a pertinent study was launched by us on June 4, 1979. This study, involving a series of experiments carried out over a period of more than two years, aimed at assessing the feasibility of solar disinfection of small quantities of drinking water that would satisfy the daily needs of individuals or a family. These experiments essentially consisted of subjecting artificially contaminated water in small, transparent containers, 1 to 3 litres in capacity, to direct sunlight for varying periods of exposure.

A variety of containers made of transparent, clear or coloured glass or plastic, and varied in usage and shape (round, conical, and cylindrical), were used for experimental purposes. They ranged from laboratory flasks made of Pyrex glass to an assortment of ordinary bottles. Some experiments also included locally produced glass vessels with a spout commonly used for drinking water, as well as polyethylene bags (*Liquid-Tite* fluid containers; Falcon, Dickinson and Company, Oxnard, California, USA).

The experimental water used was deliberately contaminated with municipal sewage to high levels not normally encountered even with untreated water used for drinking in rural areas. Occasionally some experimental waters were inoculated with cultured pathogenic microorganisms.

In each case, the water was initially examined bacteriologically just before sunlight exposure, and at intervals of 15 to 30 minutes for a few hours during exposure of the containers to direct sunlight. All containers were kept in an upright position, except for the polyethylene bags which were laid flat on the floor, with the screw caps kept tightly in place. The other containers were left open. Removable paper labels on some of the commercial bottles were detached prior to exposure to allow penetration of light. The standard plate count and membrane filter technique were applied routinely for the estimation of total bacterial counts and coliform densities, respectively. Identical batches of water in similar containers kept in the dark, and also under room conditions of lighting, served as controls for comparison and assessment of the effect of sunlight. The experiments were generally run from 9:00 a.m. to 2:00 p.m., when the solar intensity reaches its highest levels. The roof of one of the buildings within the campus of the American University of Beirut served as the site for these experiments.

The highly encouraging results of the numerous experiments demonstrated repeatedly the destructive effect of sunlight on pathogenic and non-pathogenic organisms. Some of these results and the pertinent conclusions derived from the study as a whole are highlighted hereunder for the benefit of those interested in confirming our work, and in adapting the technology to suit local conditions. The conclusions are presented somewhat in the form of constructive instructions of practical value to users of the technology, with explanations being included wherever feasible and necessary.

RESULTS AND CONCLUSIONS

1. *Destruction of bacteria:* The results of each set of experiments have consistently confirmed the fact that the bacteria contaminating water from faecal sources are, as a general rule, susceptible to destruction upon exposure to sunlight for an adequate period of time. The rate of destruction actually depends upon a number of influencing factors. The most important ones that became clear in the course of the study include the following:

- the intensity of sunlight at the time of exposure, which in turn depends upon the geographic location (i.e. latitude), seasonal variations and cloud cover, the effective range of wavelengths of light, and the time of day;
- the kind of bacteria being exposed, the nature and composition of the medium, and the presence of nutritive elements capable of supporting the growth and multiplication of the various microorganisms;
- the characteristics of the containers in which the contaminated water is kept during exposure (e.g. colour, shape, transparency to sunlight, size, and wall thickness);
- clarity of the water (i.e. degree of turbidity), and its depth, both being important factors that determine the extent of penetration of sunlight, as well as the possibility of shielding the microorganisms from its lethal effects.

The progressive decline with exposure time in terms of the percentage of bacteria still surviving followed an exponential decline curve, a pattern typical of bacterial destruction by chemical disinfectants like chlorine and iodine. Figure 5 shows the exponential survival curves for coliform bacteria and for the total bacterial population upon exposure of contaminated water in light blue glass jugs to sunlight, room conditions of lighting (a combination of artificial and natural illumination), and complete darkness. In this case, the time required to kill 99.9% of coliform bacteria by sunlight was 95 minutes, as compared to 630 minutes under room conditions. For the total bacterial population, a 99.9% level of destruction by sunlight was achieved in 300 minutes, and in 850 minutes under room conditions. In complete darkness, the coliform bacteria tend to die naturally at an extremely slow rate, but the total bacterial population tends to increase exponentially in the first 60 minutes followed by an erratic growth pattern.

Similar patterns were obtained when a variety of other containers were used. The time required to destroy 99.9% of the coliform bacteria by exposure to sunlight ranged from 70 minutes for colourless polyethylene bags to 1050 minutes for dark brown bottles. The corresponding mean value for all types of colourless, glass or plastic containers was found to be 85 minutes.

When unchlorinated batches of water inoculated with one type of enteric bacteria obtained from pure cultures were exposed to sunlight in 300 ml round Pyrex flasks, the time required for the complete destruction of each organism was found to be as follows: *P. aerugenosa* 15 minutes; *S. flexneri* 30 minutes; *S. typhi* and *S. enteritidis* 60 minutes; *E. coli* 75 minutes; and *S. paratyphi B* 90 minutes. Under similar conditions, coliform bacteria were destroyed in 80 minutes. These results indicate that, since

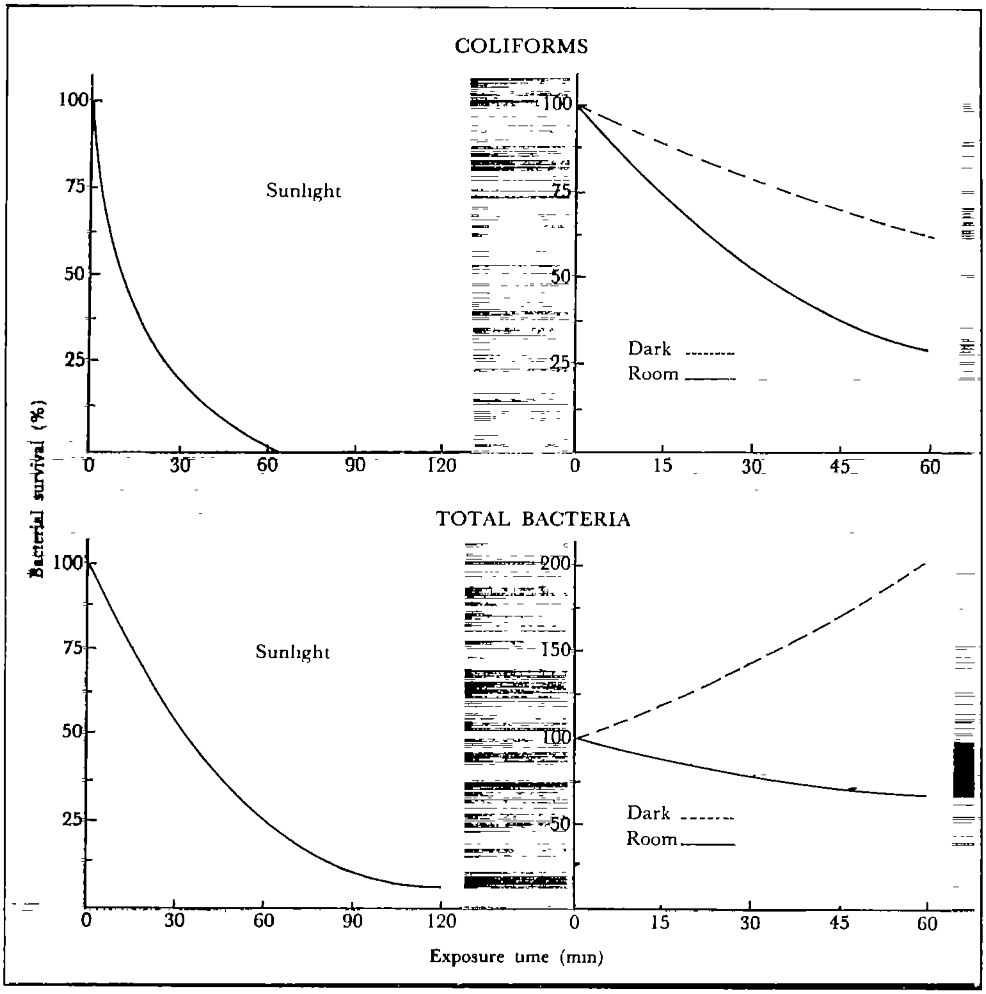


Figure 5. *Germicidal effect of solar radiation on bacteria contaminating water held in blue glass containers. Identical samples of water kept in the dark and in a room served as controls for comparison*

coliform bacteria and *E. coli* are somewhat more resistant to the lethal effects of sunlight, they can serve as useful indicators in assessing the effect of sunlight on enteric bacteria, except for *S. paratyphi B.*

All efforts to run experiments using water inoculated with *V. cholerae* were unsuccessful as judged from the lack of growth in containers subjected to sunlight, room conditions, and darkness. This unfortunate outcome could be due to a number of possibilities, the foremost being, that the available pure culture itself was not viable. Because of the great importance attached to cholera, particularly in endemic areas, it would be extremely useful to repeat these trials elsewhere. Of all the pathogenic intestinal bacteria, *V. cholerae* are among the most sensitive to environmental stresses, and this supports the suspicion that they too are subject to the lethal effect of sunlight.

As it was desirable to check on the possibility of regrowth of the inactivated bacteria, some experiments were designed to investigate this matter. The results obtained by storage for five days of disinfected water showed that inactivated coliform bacteria fail to regrow at ordinary room conditions. It is therefore assumed that already inactivated pathogenic bacteria would also fail to regrow. This would be of importance in relation to the need to store drinking water or ORS solutions without the fear of bacterial regrowth.

2. *Effect on other organisms:* The question often raised is whether exposure of contaminated water to sunlight in accordance with the experimental procedure adopted in our study would also lead to the destruction of microorganisms other than bacteria, e.g. enteric viruses and protozoa. It must be admitted at the outset that no straightforward answer can be offered at present in view of the fact that our study was limited to the possibility of bacterial inactivation.

The lethal effect of ultraviolet light (UV) has been thoroughly investigated, and the use of UV radiation has been applied for the disinfection of water supplies in lieu of chlorination. Although information about the virucidal effect of sunlight is rather scanty, there is some evidence that viruses are inactivated by sunlight in relatively shallow ponds of water or raw sewage. The intensity of sunlight and exposure time are probably important factors.

Since viruses are generally recognized to be more resistant than bacteria to the influence of disinfectants, it would be reasonable to assume that their inactivation by sunlight under our experimental conditions would require prolongation of the period of exposure. However, this matter requires further investigation.

From some of our experiments using pure cultures of a variety of molds and yeasts in aqueous or brine media, it became evident that such organisms are also susceptible to sunlight. Complete destruction of *Aspergillus niger, Aspergillus flavus, Candida* (yeast-like fungus), and *Geotrichum* was achieved within three hours of exposure of suspensions to sunlight. *Penicillium* proved to be the most resistant as it required 6-8 hours of exposure for complete destruction. These experiments constitute part of a study aimed at the control of growth of molds and yeasts by exposure to sunlight in the process of household pickling. The inference to be drawn from these preliminary findings is the possibility of solar preservation of stock ORS solutions prepared for distribution at health care centres and dispensaries.

Spore-forming organisms, not associated with disease transmission, are expected to survive the effect of sunlight until they germinate, since spores are known to be more resistant to the destructive effect of chemical disinfectants commonly used in water purification.

Since the thermal death point of amoebic cysts is about 50°C, contaminated water that attains a temperature of 50°C or more on exposure to sunlight would in itself ensure their destruction by this mechanism. Such temperatures are likely to be attained in regions with hot climates.

3. *Impurities in water:* Inorganic chemicals present in water as natural constituents, or as extraneous contaminants, are generally not expected to be affected by sunlight. Very little is known about photo-decomposition of photo-sensitive organic compounds upon exposure to sunlight. From a practical standpoint, however, the presence in reasonable concentrations of both inorganic and organic impurities would not hinder the disinfection of water by sunlight. In exceptional cases not encountered in drinking water supplies, highly coloured waters may absorb appreciable solar energy in the range of wavelengths effective against microorganisms.

On the other hand, turbidity due to suspended particulate matter would hinder to some extent the penetration of sunlight. This depends on the degree of turbidity, and the depth of water being exposed. Besides, the suspended particles would protect any microorganisms adhering to their surfaces.

Although the problem is not likely to be faced by communities supplied with piped drinking water, villagers deprived of such public utilities should be advised to resort to sources that yield relatively clear water. Wherever this is not feasible, and turbid surface waters from streams, ponds, or irrigation canals have to be utilized, it would be particularly important to somehow clarify the water by a convenient simple method if proper disinfection by sunlight is to be assured. Clarification not only reduces the concentration of suspended matter, but would also concurrently cause a drop in the microbial population. This can be achieved by applying traditional clarification methods often practiced by villagers in some developing countries. It is known, for instance, that in some rural areas of India the seeds of Nirmali trees *(Strychnos potatorum Linn.)* have been used since early times for water clarification by rubbing them against the inside walls of earthenware jars containing the water to be clarified. In fact, exposure of water to sunlight prior to filtration through charcoal for its purification is an ancient art believed to have been praticed about 2000 B.C. in India.

Details about such simple indigenous household methods are presented and discussed by Samia Al Azhari Jahn in a recently published manual entitled *Traditional Water Purification in Developing Countries,* and published by the *German Appropriate Technology Exchange,* Eschborn, West

Germany. Some of these methods depend upon the addition to polluted turbid water of small amounts of certain clays (known in Sudan as *Rauwāq)* that aid clarification. Alternative procedures include the use of a variety of native plant materials for this purpose.

It remains to be pointed out that waters with relatively low microbial populations attained with or without clarification can be more rapidly and effectively decontaminated by sunlight.

4. *Types of containers:* There are a few simple criteria that must be applied in selecting the appropriate type of containers to be used for the proper disinfection of contaminated drinking water by sunlight. The general golden rule that needs to be followed is to base the selection not only on availability and size, but also on the need to use containers that would permit the penetration of those sun rays that would effectively destroy microorganisms. Therefore, the transparency and colour of the materials from which the containers are made constitute two important characteristics as will become clear from the text.

In our study we were able to determine the range of wavelengths of sunlight that are relatively more lethal to microorganisms. This was accomplished by first assessing the percentage of light of different wavelengths transmitted through the glass or plastic material of which each kind of colourless or coloured container used in the experiments is made. This provided the light transmission characteristics (or *spectral transmittance curve)* for each type of colourless or coloured material. In each case, the optimal wavelength for light transmission was determined from the appropriate *spectral transmittance curve.* Then, by relating the optimal wavelength for light transmission for each kind of container with the mean percentage of coliform organisms inactivated by exposure to sunlight under the experimental conditions, an *action spectrum* for coliform inactivation was obtained. This is illustrated graphically in Figure 6.

From the *action spectrum* (Figure 6), it is obvious that the percentage of coliform bacteria destroyed decreases exponentially as the wavelength of light increases from 260 nm to 850 nm. From this it is concluded that the destruction by light of coliforms, and presumably other bacteria too, is most efficient at the lower wavelengths (260 nm to 350 nm), and is least efficient at the higher wavelengths (550 nm to 850 nm). However, we need to disregard the radiation with wavelengths below 290 nm as this component of sunlight does not reach the surface of the earth as was discussed earlier.

It can be concluded, therefore, that sunlight with wavelengths ranging from 315 nm to 400 nm is the most lethal region as it accounts for about 70% of the bacterial destruction potential. This band of wavelengths is known as the *near-ultraviolet region (A)* of the light spectrum. Light with wavelengths falling in this region is not visible as it cannot be perceived by the eye, and is often referred to as *black light.* It should be noted that more of this light comes from diffuse sky light than from direct sunshine.

Visible light is characterized by having wavelengths ranging from 400 nm to about 750 nm, and accounts for about 30% of the bacterial destruction capacity. It ranges in colour from violet at about 400 nm to red at about 700 nm. The sequence of colours in the series is violet, blue, green, yellow, orange, and red — a reminder of the rainbow colours.

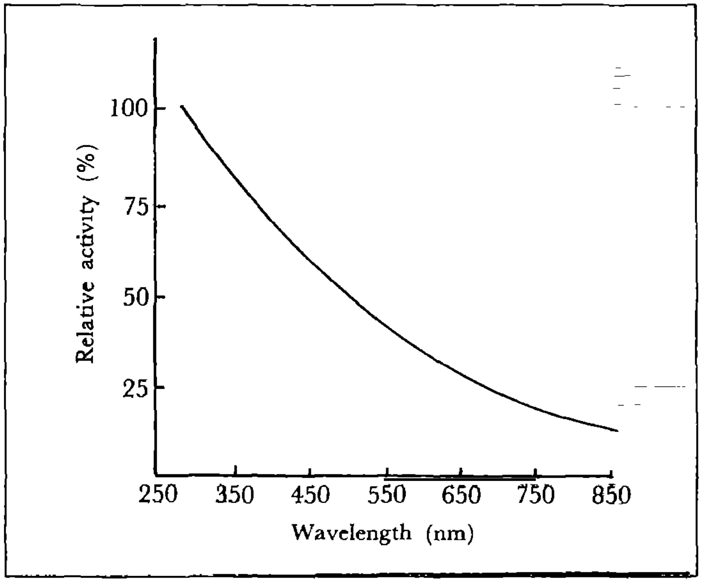


Figure 6. *Action spectrum showing the relative germicidal effect of solar radiation on coliform bacteria as a function of wavelength.*

The foregoing information is of importance in relation to the most appropriate colours of the containers to be selected that would yield optimum results in terms of microbial destruction. It is obvious that colourless plastic or glass containers are the best choice whenever available. This is because they transmit light in the *near-ultraviolet region (A),* which is the most lethal range, as well as in the visible range of the spectrum. Violet and blue tinted containers come next in the order of priority. Since the lethal action continues to decrease thereafter in the descending order of green>yellow>orange>red, containers with these colours should be avoided. Very light green containers may be used provided the period of exposure to sunlight is somewhat extended. Stated differently, containers made of plastic or glass with green, yellow, orange, or red colours obstruct the transmission of the most lethal rays ,of sunlight, unlike those that are colourless or blue. Therefore, preference should be given to containers that are either colourless or blue. Brown bottles, and to a lesser extent red ones, are recommended for the storage of actinic chemicals, i.e. those chemicals subject to chemical changes produced upon exposure to light (including sunlight) in the ultraviolet or visible spectral regions. Naturally, containers made of opaque materials such as pottery should definitely not be used at all.

The wall thickness of the containers is another factor that needs to be considered. Obviously, the thicker the wall of a container the less the transmission of the effective rays of sunlight. This would in turn somewhat retard the disinfection process, thus requiring a longer solar exposure period. Glass jars, for instance, usually have thicker walls than ordinary glass bottles, especially when made in large sizes. For equal sizes, therefore, glass bottles are preferred when both are available. In practice, relatively large-sized glass jars could be used to hold several litres of water to be decontaminated by sunlight without any significant loss in the potential for disinfection provided the exposure period is somewhat prolonged.

The openings of containers need not be closed or stoppered as their closure is not in any way related to the disinfection process. Nevertheless, their closure in an appropriate manner would be a desirable precaution simply to prevent the entry of such extraneous matter as dust or vermin.

Experimentally it was observed that the actual shape of the containers used for solar disinfection has a slight effect on the exposure time required for proper disinfection of water or ORS solutions. Round-shaped containers have proved to be the best in that they yield slightly faster results. Other shapes (cylindrical or conical) are equally satisfactory, although their effect is slightly delayed by several minutes (a matter of no significance in practice). From the practical standpoint, round-shaped, or cylindrical containers are to be preferred to square-shaped ones for the simple reason that a rounded shape conforms better with the motion of the sun from east to west. Nevertheless, square-shaped containers can still be used satisfactorily. Containers with multi-facetted surfaces or ornamental designs that could impede the transmission of sunlight should preferably be avoided.

In some cases, labels on containers may occupy such a large proportion of the exposed surface as to significantly impair the transmission of the incident rays of sunlight. Detachable labels should therefore be removed prior to sunlight exposure. Containers with large, permanent labels are to be disqualified for use; those with small labels on one side may be used provided the unlabelled surface is made to face the sun during exposure.

5. *Availability and cost*· In addition to the previously mentioned requirements pertaining to transparency, colour, shape, and size of containers, availability and cost are also important selection criteria. Wherever possible, preference should be given to locally produced

containers as they are likely to be cheaper and more widely available. Used glass bottles or jars are common in most homes, even in villages. Specially designed jugs with a spout intended for drinking by pouring a stream of water into the mouth are quite popular in the Arab World at reasonable prices. These traditional jugs are made of pottery or glass. The latter come in a variety of colours, and in our experience the clear or light blue ones have proven to be useful containers for disinfection of drinking water. Their availability, low cost, and the fact that the disinfected water does not need to be transferred into another receptacle make them sufficiently attractive for the purpose intended.

6. *Conditions of exposure:* Indeed, it would be quite cumbersome in practice for a housewife to perform the solar disinfection operation on small batches of water a few times a day. It would be much more rational to process the quantity of drinking water estimated to be adequate for one or two days, if the necessary containers are available. For a small family of three to five members it may be feasible to run the operation on two or three occasions per week.

Having secured the necessary containers, and made sure that they are of the right kind and size, they should then be properly cleaned to remove any visible dirt (and detachable labels, if labelled bottles are used). Too much dirt on the inner or outer walls of the containers would surely obstruct some of the rays of sunlight. The containers need not be washed on every occasion as long as they are kept in use and maintained in a satisfactory state of cleanliness. It is of interest to keep in mind that the inner walls of the containers with attached microbial populations will also be decontaminated by sunlight together with the water they contain. In fact, empty containers could also be decontaminated by exposure to sunlight whenever such bottles are needed for any particular purpose. Incidentally, it may be of interest to note that we have also shown experimentally that dishes and similar tableware can be effectively decontaminated by exposure to sunlight for as short a time as 15 to 30 minutes. The idea is not in any way a novel one for in many parts of the Middle East, and perhaps in other regions too, it is a traditional practice for housewives to keep matresses and bed covers of sick family members for a short while in a sunny place.

As a routine practice, the desired number of clean containers (e.g. bottles) are filled with water from a source normally used for domestic purposes. To ensure proper disinfection, they should then be kept in a convenient place (e.g. yard, balcony, terrace, or window) that receives direct sunlight for most of the day, or at least for the duration of the exposure. This should not present any problem in rural areas where open spaces are amply available. The containers should be properly spaced to avoid shadows.

Because the intensity of sunlight is greatest between ten o'clock in the morning and two o'clock in the afternoon, it would be wise to use that period for exposure of the containers. Since it is not practical for a housewife in a rural setting to keep time properly, she could expose the containers as early in the morning as desired, and remove them in the afternoon. Alternatively, she could remove the required number of containers in the afternoon for use, while the rest are kept until needed the next day. Adoption of such regimes would certainly not lead to any undersirable outcome because of over-exposure. They are merely aimed at simplifying matters.

For maximum benefit from the disinfection action of sunlight, the containers should be kept in a slanted manner with their greatest surfaces (if not round or cylindrical) made to face the sun rather than keeping them in an upright or flat position. A special rack designed to hold the containers (e.g. bottles) in a slanted fashion would then be necessary, the optimal angle of inclination from the horizontal being equal to the latitude. Such a stringent requirement is neither practical nor essential, and the benefit derived therefrom is not justifiable. The advantage to be gained can be compensated by simply prolonging the exposure period.

Regions having some 300 or so sunny days with clear skies per year are naturally best suited for the optimal utilization of solar energy for the disinfection of drinking water, as well as other applications. It is there that cloud formation would present no serious problems throughout the greater part of the year. Obviously, clouds tend to reduce the intensity of direct sunlight to some extent, the magnitude of the reduction being dependent on cloud coverage. Under such conditions, however, the scattered rays of sunlight producing diffuse daylight would still exhibit germicidal action, but at a slower rate. We have, in fact, repeatedly demonstrated experimentally that the germicidal action does take place even in indoor areas with reasonable natural light. The germicidal action, however, is roughly about ten times slower than that occuring in direct sunlight. During cloudy days, therefore, all that is necessary would be to prolong the exposure period from a minimum of one hour to several hours. The routine procedure indicated above involving exposure from morning to afternoon would be more than adequate to account for this requirement, even on days with reasonable cloud coverage.

In regions with warm climates and high solar intensities, the water undergoing decontamination could become unpleasantly warm for drinking by the end of the exposure period. The rise in temperature is actually caused by the red and infrared rays of light. Bluish containers would tend to cut off most of this kind of solar energy and, thus, minimize the increase in temperature. However, the issue is somewhat different with containers made of transparent, clear glass or plastic, because such materials do allow the passage of the heat-producing energy. In our experience in Beirut, the temperature of small portions of water in Pyrex glass containers rose by about 5°C from 25°C to 30°C. In hotter places the temperature may rise to 50°C or 60°C. These *pasteurization* temperatures, if attained, would be an additional asset in helping to destroy such organisms as amoebic protozoa. In the event that the water becomes unpleasantly warm for drinking, it would be necessary to keep it in a shady cool place before use. Alternatively, if the exposed containers are routinely kept overnight, the water could then be ready for use in the morning. The problem then arises only in case of emergencies. But, in the case of ORS solutions, warmth may be an advantage in palatability.

SOLAR DISINFEC[illegible] ORAL REHYDRA[illegible]

One of the practical problems in preparing oral rehydration solutions with unclean water in villages not provided with safe drinking water supplies is the potential risk to consumers. Decontamination by an appropriate and simple method that can be performed by a housewife in rural areas in developing countries is therefore indicated.

As previously discussed in the section "Disinfection by Boiling," neither boiling nor the use of chemical agents are suitable for the disinfection of oral rehydration solutions because of the inherent handicaps that preclude their use. One possible way to overcome this problem is to take advantage of the germicidal properties of sunlight. We have found that exposure to sunlight in transparent containers renders these solutions bacteriologically safe, without deterioration of the ingredients.

In the course of our study on the small-scale disinfection of drinking water for home use, we experimented with standard ORS solution prepared with chlorine-free tap water deliberately contaminated with fresh sewage. The contaminated ORS solution was distributed in portions of one litre into sterile polyethylene bags, some of which were placed in direct sunlight, some kept indoors under natural and artificial light, and some in the dark inside a cabinet. The initial coliform counts, typical for heavily contaminated water from village sources, ranged from 7,100 to 16,500 per 100 millilitres.

The results, reported in a letter to *The Lancet* (2:1257, 1980) and reproduced in Table 2, indicate that zero coliform and *Streptococcus faecalis* counts were obtained in one and two hours respectively, in samples kept in direct sunlight. That the action of sunlight is irreversibly lethal was demonstrated by the inability of the coliforms to regrow when the exposed solutions were kept in the dark for 24 hours. Coliform reductions of around 80% took place in two hours at room conditions and in the dark, but heavy regrowth occurred upon further storage for one day.

The temperature of the test ORS solution did not rise much beyond 30°C after two hours of exposure to sunlight, thus supporting the hypothesis that heat was not a factor involved in the destruction of microorganisms. As was shown in the case of solar disinfection of water, the germicidal action seems to be due mostly to solar radiation in the near UV region (A) of the spectrum (315 nm to 400 nm). The fact that the sodium bicarbonate concentration and the pH of 8.33 did not change indicates that there was no detectable decomposition of the constituents.

These experiments clearly demonstrate that ORS solutions in transparent containers will lead to the complete destruction of such enteric bacteria as coliforms and *Streptococcus faecalis*, as well as 90%

Table 2. Destructive effect of sunlight on bacteria in oral rehydration solutions contaminated with sewage

	Experiment A					
Exposure (min)	Dark★	Room★	Sunlight★	Dark★	Room★	Sunlight^{+}
	Coliforms/ml			Total bacteria/ml		
0	71	71	71	1550	1550	1550
30	24	24	1	1075	2070	610
60	16	16	0	1380	1735	165
120	14	15	0	2240	1625	155
	Experiment B					
	Coliforms/ml			Strep. faecalis/ml		
0	165	165	165	75	75	75
30	46	52	6	42	49	24
60	37	51	0	52	42	4
120	26	31	0	27	26	0
24h▲	1290	1620	0	. .	. .	. .

★ Average for 2 bags +Average for 3 bags ▲All the bags were kept at room conditions for 24 hours.

Reproduced from Acra, A., Karahagopian, Y., Raffoul, Z., and Dajani, R "Disinfection of Oral Rehydration Solutions by Sunlight," *The Lancet*, 2.1257 – 1258, 1980

reduction in the total bacterial count, within a period of two hours.

These results are substantially supported by those obtained for plain water as described previously. This is expected because in both cases the procedure and experimental conditions applied were similar in every respect. A salient difference, however, pertains to the additional constituents present in ORS solutions, as well as a slightly higher pH. The differences in composition of the two media have apparently not altered significantly the ultimate lethal action of sunlight, which in both cases was irreversible. It can be concluded, moreover, that even the presence of a carbohydrate, salts, and some nitrogenous substances from the added sewage would not hinder the solar germicidal action. This is in sharp contrast to the legitimate expectation that ORS solutions, being a more appropriate medium for the support of microorganisms, might somehow inhibit the action of sunlight.

The lack of regrowth of the affected bacteria suggests the practicality of storage of both drinking water and ORS solutions for use when needed provided these commodities are protected from recontamination. When storage is desired, it would be wise to keep them in the same containers used in the disinfection process to eliminate the possibility of postcontamination from other vessels, or through handling. Along the same vein, it appears feasible for health care centres and dispensaries involved in oral rehydration therapy to prepare stock, concentrated solutions of ORS, disinfect them by exposure to sunlight, and appropriately dilute them with decontaminated water just before distribution to villagers. Such a system will facilitate matters, reduce efforts and costs, and take the burden off the shoulders of housewives. Wherever such an arrangement is not possible, then housewives need to be instructed on the proper method for the preparation and decontamination of home-made oral rehydration solutions.

Our experimental work was designed merely to demonstrate the feasibility of decontamination of an ORS solution freshly prepared according to the WHO-UNICEF standard formula, using available plastic bags with screw caps. No attempt was made to expand and diversify the work as all the essential experimental information had already been derived from the much more extensive study on decontamination of water. Accordingly, it would be logical to assume that the specific conditions pertaining to containers, fluids, and exposure would be applicable in the two cases. It would be possible, for instance, to use any other type of container which is available and meets the requirements.

In highly endemic rural areas, it would be useful for families to practice routinely solar disinfection of drinking water, in which case the decontaminated water would be available for the preparation at home of ORS solutions when needed. If this procedure is adopted, at least in emergencies, then the time required for disinfection of the ORS solutions after their preparation would be saved in favour of an early start of oral rehydration therapy. In such an event, the only disadvantage is the potential risk of contamination of the ORS solutions from the ingredients or containers.

Indeed, this technology provides a good deal of flexibility which allows for the possibility of adaptation to suit local conditions and needs.

INSTRUCTIONS FOR HOUSEWIVES
SOLAR DISINFECTION OF DRINKING WATER

GENERAL INFORMATION

The following instructions are intended primarily for the benefit of housewives in rural areas in developing countries where safe community water supplies are not available. It is assumed that in these areas water-borne diseases are endemic or sporadic.

These instructions concern the procedure to be adopted on a routine basis for the proper disinfection of drinking water for household use. The procedure involves exposure to sunlight of water from the usual community source for a minimum period of time in available transparent containers such as colourless or blue-tinted glass or plastic bottles.

In order to save time and effort, it is highly desirable for a housewife to make her own arrangements to carry out the routine disinfection operation regularly once a day, or once every other day. For this reason, a housewife should ensure enough containers that would hold the desired quantity of drinking water estimated by her to meet the needs of the family for one or two days.

At the end of the sunlight exposure period, a housewife could then transfer indoors the whole set of containers for use. To avoid recontamination, the already disinfected water should preferably be kept in the same containers used in the solar exposure operation. However, if there is a shortage of small containers, then the disinfected water could be transferred from each exposed container to a clean large container reserved for bulk storage of processed water.

Once a set of emptied containers becomes available after usage, the refilling and exposure procedures are repeated. If the containers are maintained in a good state of cleanliness, then there would be no reason for having to clean them repeatedly each time they are to be re-used.

PROCEDURE

1. *Containers:*

- From among those found at home, or purchased from the local market, select a number of containers made of colourless or blue-tinted glass or transparent plastic estimated to hold an amount of drinking water sufficient for household consumption for one or two days. The selected containers could include ordinary bottles, jars, or any other types of vessels provided they are transparent to light. Coloured containers other than blue, or greenish-blue should not be used as they are not as satisfactory.
- Remove any detachable paper labels from bottles, and wash all the containers with water (and soap, if necessary) to remove dirt and any residue from the previous contents.

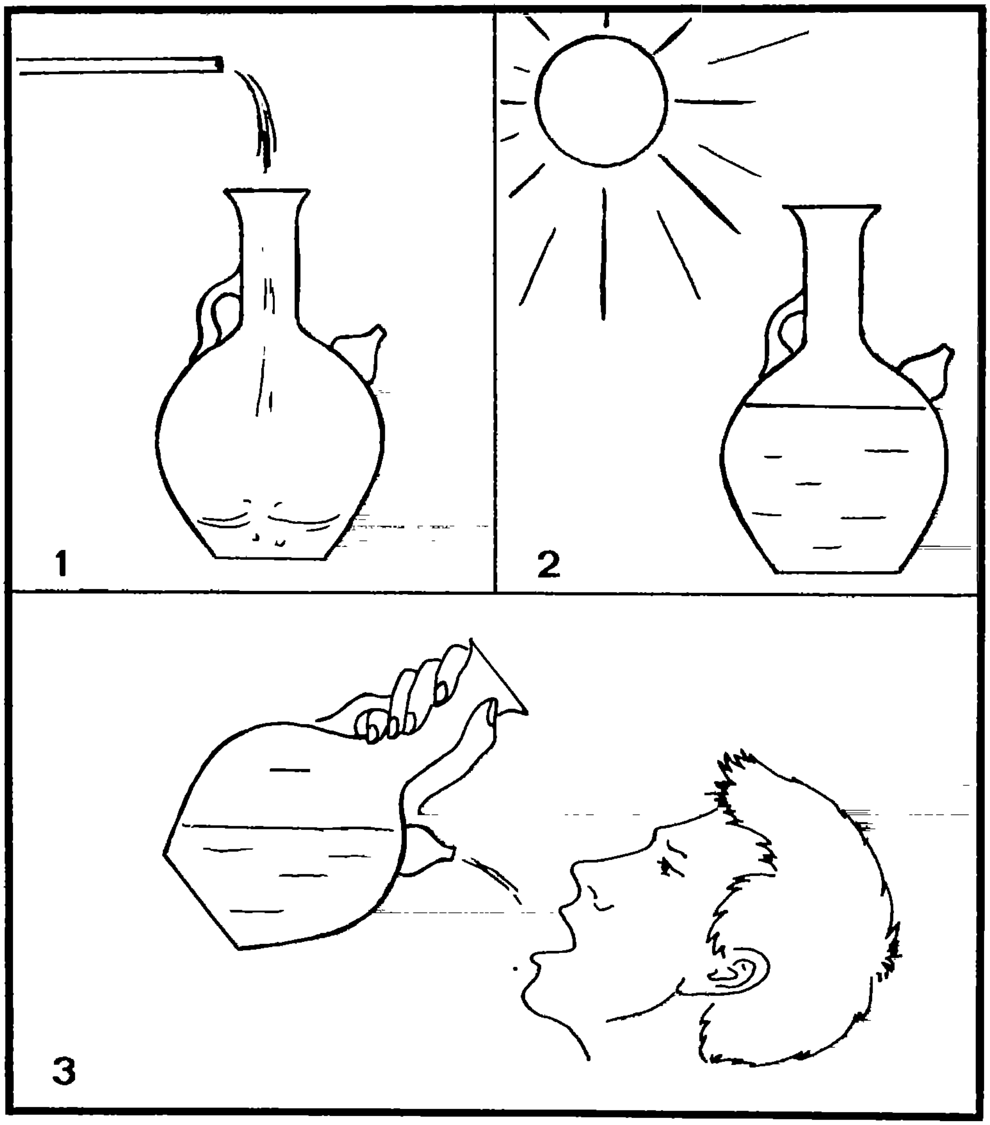
2. *Water.*

- Fetch water in the usual manner from the common village supply (stream, well, pond, reservoir, etc.). If the water is highly turbid, then clarify the water by allowing the suspended particles to settle. Decant the clear water into other vessels.
- Carefully fill each of the containers hereafter reserved for the solar disinfection operation with the clarified water.

3. *Exposure*

- Place the containers outdoors in an open space where sunlight cannot be obstructed by houses, walls, trees, or bushes throughout the day. Porches, balconies, roofs, or window sills would be satisfactory if open land is not available. Select places away from dust, children, domestic animals, and pets to avoid contamination and mischief. Individual containers should be spread out to avoid shadows.
- Keep the containers in their normal upright position. Tilting them at an angle towards the sun (as is commonly advocated for other solar appliances) may diminish the disinfection efficiency. Stoppers for bottles, and original covers for jars may be used to prevent the entry of dust, dirt, or vermin. But, such closures are not essential for the disinfection process. In fact, water exposed to bright sunlight in tightly closed containers could become much warmer than that in open containers. This is because the water vapour escaping from open containers carries with it some of the heat acquired by the water exposed to sunlight.
- Since it is futile to maintain an exact time for sunlight exposure, it would be a wise arrangement on a routine basis to start the sunlight exposure operation at a convenient time in the morning, and to keep the containers exposed until the late afternoon. The exposed containers may then be kept in place overnight to allow the water to cool, or they may be transferred indoors in readiness for use. However, in such emergencies as when a family runs short of disinfected drinking water, an exposure period of about two hours, especially at noontime, should be adequate for proper disinfection. These practical suggestions will ensure satisfactory results even under moderately cloudy conditions. It would not be practical to carry out the operation under conditions of heavy rainfall.
- After use, the empty containers can be re-used without the need for rewashing unless they accidentally become dirty. The cycle can now be repeated from the stage of refilling with water through the stage of sunlight exposure. With time and experience, the whole operation becomes a matter of routine.

It should be noted that these instructions need to be modified or simplified further by health educators and primary health care promoters to suit local conditions, provided the essential requirements are not altered in any way.



INSTRUCTIONS FOR HOUSEWIVES
SOLAR DISINFECTION OF ORAL REHYDRATION SOLUTIONS

GENERAL INFORMATION

As previously emphasized in the text, oral rehydration solutions should ideally be decontaminated by an acceptable method that would not alter the characteristics and composition of the solution.

Boiling of already prepared ORS solutions containing sodium bicarbonate as one of the constituents would lead to the transformation of this substance into sodium carbonate, and thus to the partial loss of its medicinal value. Boiling of water for use in preparing such ORS solutions could be a more acceptable approach, provided the boiled water is allowed to cool prior to use. This procedure would only result in decontamination of the water, but would not ensure the destruction of microorganisms introduced by the potentially contaminated ORS ingredients. In any case, boiling is to be discouraged in fuel-short developing countries, especially in areas where fuelwood is the principal source of energy. It should also be remembered that housewives in these areas have to spend time and effort in fetching firewood from distant places.

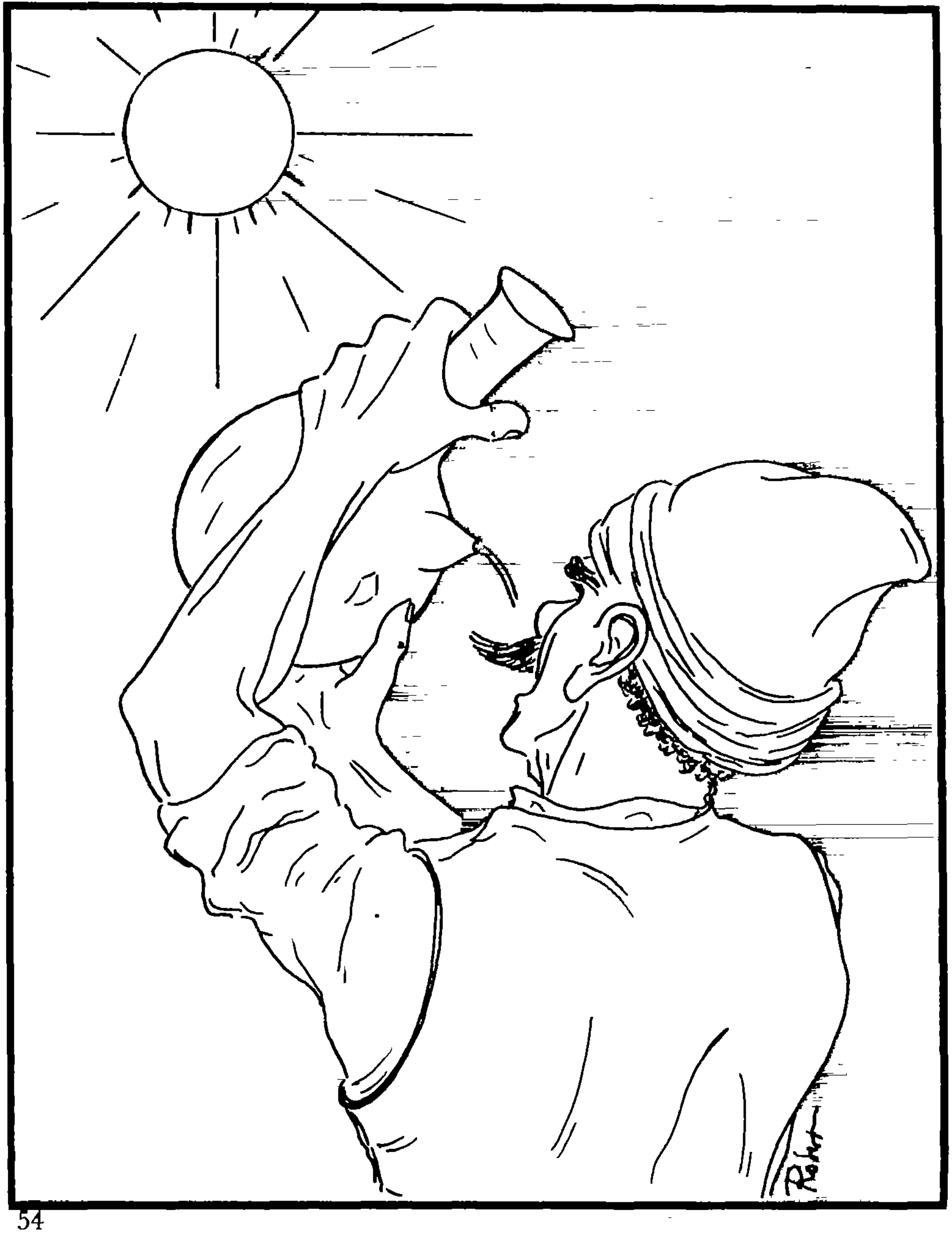
A much more feasible and simple approach is to resort to the utilization of solar energy for the disinfection of oral rehydration solutions. The procedure to be adopted at the household level is similar in all respects to that described previously for drinking water.

A practical problem may arise in emergency situations where one or more members of a family unexpectedly contract a diarrhoeal disease, or when the first symptoms of severe attack appear at night. Naturally, an early administration of ORS solution is highly desirable in such an event. If solar-disinfected water is already available at home, then the proper approach in this case would be to prepare the first batch or two of home-made oral rehydration solution by dissolving the ingredients in the required amount of this water. The same containers holding the disinfected water should preferably be used for the preparation of the solutions since these containers are themselves already decontaminated. Subsequently, arrangements for solar disinfection of oral rehydration solutions in one or more batches need to be made during daylight hours. Incidentally, a decontaminated batch may be stored for intermittent use over a period of several days, provided it is protected from possible recontamination.

In endemic areas where diarrhoeal diseases are rampant, housewives should remain on the alert, and be prepared by stocking at home the necessary ingredients (salt and sugar) or ORS packets, as well as suitable containers for the solar disinfection process.

PROCEDURE

Since the procedure and precautions to be taken are the same as those that apply for drinking water, it would not be necessary to repeat the instructions in this case. Of course, a complete set of instructions should include the essential steps for the actual preparation of the oral rehydration solution by a housewife, as well as those for its proper disinfection by sunlight.



APPENDIX
Sources of Information on Diarrhoeal Diseases

UNICEF

UNICEF Headquarters
United Nations, New York,
New York 10017, U S.A.

UNICEF Geneva Headquarters
Palais des Nations,
CH 1211, Geneva 10, Switzerland.

UNICEF Regional Office for East Africa
P.O.Box 44145, Nairobi, Kenya.

UNICEF Regional Office for West and Central Africa
P.O Box 443,
Abidjan 04, Ivory Coast.

UNICEF Regional Office for the Americas
Calle 76 No. 10-02, Bogotá, Colombia

UNICEF Regional Office for East Asia and Pakistan
P.O.Box 2-154, Bangkok, Thailand

UNICEF Regional Office for the Middle East and North Africa
Amman, Hashemite Kingdom of Jordan

UNICEF Regional Office for South Central Asia
73 Lodi Estate,
New Delhi 110003, India.

UNICEF Office for Australia and New Zealand
G P.O. Box 4045,
Sydney, N S.W 2001, Australia

UNICEF Office for Japan
c/o United Nations Information Centre, 22nd floor,
Shin Aoyama Building Nishikan,
1-1, Minami-Aoyama 1-Chome,
Minato-Ku Tokyo 107, Japan

W.H.O.

Diarrhoeal Diseases Control Programme
Programme Manager,
World Health Organization,
1211 Geneva 27, Switzerland.

Organisation Mondiale de la Santé
Bureau Régional de l'Afrique,
Boîte Postale 6,
Brazzaville, Congo.

World Health Organization
Regional Office for the Americas,
Pan American Sanitary Bureau,
525, 23rd Street, N.W ,
Washington, D C 20037, U.S.A.

World Health Organization
Regional Office for the Eastern Mediterranean,
P O.Box 1517,
Alexandria, Egypt

World Health Organization
Regional Office for Europe,
8, Scherfigsvej,
2100 Copenhagen, Denmark

World Health Organization
Regional Office for South-East Asia,
World Health House,
Indraprastha Estate, Ring Road,
New Delhi 110002, India

World Health Organization
Regional Office for the Western Pacific,
P.O.Box 2932,
12115 Manila, Philippines

Others

Appropriate Health Resources and Technological Action Group, Ltd.
85 Marylebone High Street,
London W1M 3DE, U.K.

International Centre for Diarrhoeal Disease Research
P.O.Box 128,
Dacca 2, Bangladesh.

International Children's Centre
Château de Longchamp,
Carrefour de Longchamp,
Bois de Boulogne,
75016 Paris, France.

International Development Research Centre
P O.Box 8500,
Ottawa, Ontario K1G 3H9, Canada.

Ross Institute of Tropical Hygiene
London School of Hygiene and
Tropical Medicine,
Keppel Street,
London WC1E 7HT, U.K.

Water and Environmental Sanitation Team
Programme Development and
Planning Division,
UNICEF
866 UN Plaza, Room A415,
New York, N.Y. 10017, U.S.A.

Water and Sanitation for Health Project
1611 N. Kent Street, Room 1002
Arlington, Virginia 22209, U.S.A

Program for Appropriate Technology in Health (PATH)
Canal Place,
130 Nickerson Street,
Seattle, Washington 98109, U S A.

Sources of Information on Development of Health Education Materials

British Council Media Group
10 Spring Gardens,
London SW1A 2BN, U.K

British Life Assurance Trust Centre for Health and Medical Education
BMA House, Tavistock Square,
London WC1H 9JP, U.K
London

Bureau d'Etudes et de Recherches pour la Promotion de la Santé
B.P 1977,
Kangu-Mayombe, Zaïre

Hesperian Foundation
Box 1692,
Palo Alto, California 94302, U.S.A.

PIACT de Mexico
Shakespeare No 27,
Mexico 5, DF, Mexico.

Teaching Aids at Low Cost
Tropical Child Health Unit,
Institute of Child Health,
30 Guilford Street,
London WC1N 1EH, U.K.

Voluntary Health Association of India
C-14 Community Centre,
Safdarjung Development Area,
New Delhi 110016, India.

Appropriate Health Resources and Technologies Action Group Ltd. (AHRTAG)
85, Marylebone High Street,
London W1M 3DE, U.K.

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Regional Office for the Middle East and North Africa
P O Box 811721 - Amman, Hashemite Kingdom of Jordan

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