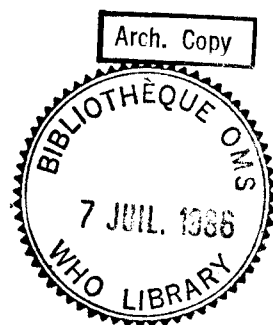# Appropriate use of fluorides for human health

edited by

J. J. Murray

Professor of Child Dental Health, and
Dental Postgraduate Sub-Dean
University of Newcastle upon Tyne
England

World Health Organization
Geneva
1986

Contents

Foreword

IN spite of the overwhelming evidence that the administration of small quantities of fluoride significantly lowers the incidence of dental caries without risk to health, this simple public health measure has not yet been implemented on the scale it deserves. This is due in part to the often misguided opposition to community fluoridation programmes and in part to uncertainty in choosing among the various alternative methods in places where community water fluoridation is not practicable or is unacceptable.

The purpose of this book is to help public health authorities and dental practitioners to decide which methods of ensuring an optimal intake of fluoride are most appropriate to the circumstances of a particular community and to provide advice on the practical aspects of those methods. It is thus complementary to the book published by WHO in 1970 entitled *Fluorides and Human Health*, which dealt mainly with the physiology, distribution, dosage, and safety of fluorides.

The book has been edited by Dr J. J. Murray on the basis of a Conference on Fluorides that was held in Vienna, Austria, from 3 to 5 October 1982 under the joint sponsorship of the Fédération Dentaire Internationale (FDI), the W. K. Kellogg Foundation and the World Health Organization.[a] Dr Murray has drawn both on the papers presented at the Conference and on the daily reports of the Conference discussions, together with other material requested as a result of these discussions. A

---

[a] The majority of the papers presented at the Conference have been collated in document ORH-82 issued by the Pan American Health Organization/WHO Regional Office for the Americas, Washington, DC, USA (1984).

summary of the conclusions and recommendations emanating from the Conference will be found in Annex 1 and a list of the participants in Annex 2.

The World Health Organization is greatly indebted to Dr Murray for his skill in drawing together the various aspects of the use of fluorides in the prevention of dental caries discussed by the Conference, a task to which he brought the benefit of many years of experience in dentistry and of interest in caries prevention. WHO also expresses its gratitude to the FDI for its collaboration and to the W. K. Kellogg Foundation, without which neither the Conference nor this publication would have been possible.

Introduction

DENTAL caries is a major dental disease affecting the lives of a large proportion of the inhabitants of this world. It impairs the quality of life for many people by causing pain and sepsis and lack of treatment can aggravate other systemic diseases. In addition, it places a heavy financial burden on private and public health services.

Dental caries is a disease in which host, agent, and environmental factors interact to produce irreversible destruction of the hard tissues of the teeth—namely, enamel, dentine, and cementum (caries of root surfaces). Despite continuing efforts to develop methods of lowering the number of bacteria on teeth by mechanical means or of reducing their cariogenic activity with chemical agents (42, 46, 59) the proper use of fluorides remains our best defence against dental decay. Until about ten years ago, most dental experts believed that fluorides worked principally by increasing the resistance of enamel to acids produced in dental plaque by bacteria (54). More recent research clearly shows the importance of additional actions of fluoride, such as remineralization of initial or pre-carious lesions and a number of antimicrobial effects (10, 35). Several mechanisms may operate simultaneously, with one or more being pre-eminent at different times because of local conditions at the tooth surface. Which mechanisms are operative also depends upon the agent used, its route of administration, its concentration, its frequency of use, the vehicle used to deliver it, and the age of the person receiving it.

1

The first observations connecting an increased fluoride intake with low caries experience were made at the beginning of this century in populations drinking water containing fluoride at a concentration of 1 mg/litre or more. Many clinical studies during the subsequent seventy years suggested that drinking fluoridated water allowed fluoride to act systemically by being incorporated into the developing dental hard tissues, so making dental enamel more resistant to decay. It was also realized that fluoridated drinking water acts directly on exposed tooth enamel.

A number of investigators have reported beneficial effects comparable with those of fluoridated drinking-water from the use of other vehicles—salt, tablets, and milk—and from school water-fluoridation schemes. Topical application of higher concentrations of fluoride—in toothpastes, mouth rinses, gels, and tooth varnishes—have been employed in order to achieve a cariostatic effect.

This book reviews present knowledge concerning the occurrence of fluorides in the environment, the exposure of human subjects to fluorides, fluoride metabolism, and dental fluorosis. It makes a critical appraisal of the numerous extensive trials that have been conducted using different methods of fluoride administration, provides guidance in choosing a particular method or combination of methods, and sets out practical steps for implementing and monitoring the use of fluorides in caries prevention.

Occurrence and metabolism of fluorides

THE well established inverse relationship between the fluoride concentrations of drinking-water and the prevalence of dental caries has stimulated extensive research aimed at determining the optimum level of fluoride ingestion required to obtain the maximum protection against dental caries with the least risk of producing dental fluorosis in developing teeth.

Fluorides in the environment

Fluorides in soil

Fluorine is the most electronegative of all chemical elements and is therefore never encountered in nature in the elemental form. Combined chemically in the form of fluorides, fluorine is the seventeenth in order of frequency of occurrence of the elements, representing about 0.06–0.09 % of the earth's crust. In rock and soil, fluorine may occur in combined form in a wide variety of minerals, including fluorspar, cryolite, apatite, mica, hornblende, and a number of pegmatites such as topaz and tourmaline. Volcanic and hypabyssal rocks, as well as salt deposits of marine origin, also contain significant amounts of fluoride—up to 2500 mg/kg. Certain minerals of particular commercial importance, such as cryolite used for the production of aluminium and rock phosphates used for the production of fertilizers, can have fluoride contents up to 4.2 % (42 000 mg/kg) (70, 106). There is an obvious abundance of fluoride in the

world, but it should be remembered that most of it is firmly bound to minerals and other chemical compounds and is, therefore, not biologically available in its usual form. The availability of free fluoride ions in the soil is governed by the natural solubility of the fluoride compound in question, the acidity of the soil, the presence of other minerals or chemical compounds, and the amount of water present. Fluoride concentrations in soil increase with depth. In a study of 30 different soils in the USA, 20–500 mg of F^- per kg were found at depths of 0–7.5 cm and levels of 20–1620 mg of F^- per kg at depths of 0–30 cm. Idaho and Tennessee soils had unusually high fluoride concentrations: 3870 mg of F^- per kg and 8300 mg of F^- per kg, respectively (76). In high mountain areas, the fluoride content of the soil is usually relatively low. Owing to the constant erosion of the mountains, the fluoride is removed and, like the other halogens, transferred to a lower plateau or to the sea via streams or rivers. The continents are therefore constantly being deprived of their original fluoride content, which is probably the reason why sea water has a relatively high fluoride content (1.0–1.4 mg/litre).

Fluorides in water

Owing to the universal presence of fluorides in the earth's crust, all water contains fluorides in varying concentrations. The bulk of the water normally available to man is involved in the hydrological cycle, which means that it originates in the seas. Sea water itself contains significant quantities of fluoride at levels of 0.8–1.4 mg/kg. The fluoride content of water obtained from lakes, rivers, or artesian wells is for the most part below 0.5 mg/kg even though concentrations as high as 95 mg/kg have been recorded in the United Republic of Tanzania (91). Water trapped in sediments since their deposition and thermal waters associated with volcanoes and epithermal mineral deposits usually have fluoride levels of 3–6 mg/kg.

Waters with high fluoride content are usually found at the foot of high mountains and in areas with geological deposits of marine origin. Typical examples are the geographical belt from Syria through Jordan, Egypt, the Libyan Arab Jamahiriya, and Algeria to Morocco, and the Rift Valley through Sudan and Kenya. Another belt is the one stretching from Turkey through Iraq, the Islamic Republic of Iran, and Afghanistan to India, northern Thailand, and China. Similar areas can be found in the Americas and in Japan and China. The highest natural fluoride

concentration ever found in water was recorded in Lake Nakuru in the Rift Valley in Kenya, namely 2800 mg/litre. The soil at the lake shore contained up to 5600 mg of F^- per kg, and the dust in the huts of the local inhabitants contained 150 mg/kg (105).

Fluorides in air

Fluorides are also widely distributed in the atmosphere originating from the dusts of fluoride-containing soils, from gaseous industrial waste, from the burning of coal fires, and from gases emitted in areas of volcanic activity.

The fluoride content in the air in some factories can reach levels as high as 1.4 mg of F^- per m^3 and in the neighbourhood of such factories levels of 0.2 mg of F^- per m^3 air may be attained. Ninety per cent of the air samples taken in an industrial city in the Federal Republic of Germany during 1965 and 1966 contained fluoride concentrations of 0.5–3.8 μg of F^- per m^3 (76). The fluoride content in the air in non-industrial areas has been found to be from 0.05 to 1.90 μg of F^- per m^3.

Fluoride ingestion by man

Fluorides in solid food

With a few exceptions there does not appear to be a relationship between the fluoride content of most plants and that of the water or soil in the locality. However, plants grown in acidic soil generally have higher fluoride concentrations (76). Natural concentrations in the foliage of most plants range from 2 to 10 mg of F^- per kg. In the USA, fluoride concentrations in 107 alfalfa samples from areas assumed to be free of industrial pollution were found to range from 0.8 to 36.5 mg/kg, with a mean of 3.6 mg/kg (76). Those parts of the plants (vegetables and fruits) that are consumed by man normally have fluoride contents of the order of 0.1–0.4 mg/kg and are therefore of little concern, unless unusual dietary patterns prevail. However, surprisingly high levels of fluoride have been found in cereals. Singer & Ophaug (87) found fluoride concentrations of 2.0 and 2.1 mg/kg in barley and rice processed in unfluoridated water as compared with 4.3 and 6.4 mg/kg, respectively, if processed in fluoridated water.

Certain plants, such as taro, yams, and cassava, which constitute the staple diet in many tropical areas—particularly in

South America and in the Pacific—have been found to contain relatively high fluoride levels. Tea leaves, also, may contain rather high levels of fluoride.

The fluoride content of meat is low (0.2–1.0 mg/kg) except for chicken meat, which may sometimes contain higher levels, probably when the chickens have been fed on fishmeal or bonemeal.

Fish products—in particular canned fish such as salmon and sardines, the skin and bones of which are also eaten—have a fluoride content of up to 40 mg/kg. The meat of fish is relatively low in fluoride content (2–5 mg/kg) as compared with fish protein concentrates, which may contain up to 370 mg/kg (76). However, even with a relatively high fish consumption in a mixed diet, the fluoride intake from fish alone would seldom exceed 0.2 mg of F^- per day.

On the basis of extensive analyses performed by McClure (65), solid foods have been considered to contribute only slightly to the total daily fluoride intake, at least in Western-style diets. From McClure's analyses it would appear that most foods are low in fluoride, having a content of 0.1–1.0 mg of F^- per kg of dry weight, and would contribute a maximum of 0.27 mg of F^- per day. More recent studies, however, have shown that there are great individual variations in the daily intake of fluorides from solid food (59, 62). Figures ranging from 0.2 up to 3.4 mg per day per person have been reported, depending upon the composition of the diet and the fluoride content of the water in which the food has been prepared (76).

Fluorides in drinks

The fluoride contained in drinking-water is commonly the largest single contributor to the daily fluoride intake. The fluoride intake from water will depend upon (1) the fluoride concentration of the water, (2) the age of the person, (3) climatic conditions, and (4) dietary habits.

The consumption of liquids increases with age, particularly from birth up to 12 years of age. However, it has been shown that during this period drinking-water may represent a maximum of 50% of the total fluid intake. The single most important factor, on a population basis, in determining the amount of water consumed is the maximum daily temperature in the area concerned (45). Roughly, there seems to be an inverse relationship between the amount of water consumed and the distance from the equator. Water consumption is also dependent

upon dietary habits and socioeconomic conditions affecting access.

Human breast milk has a low fluoride content, less than 0.02 mg/litre, and there does not seem to be any diurnal variation. There is little or no difference in the fluoride content of breast milk collected from mothers living in areas where the water contains 0.1 mg of F^- per litre and those living in areas with ten times that concentration. The fluoride concentration in cow's milk is reported to be 0.02–0.05 mg/litre (6, 95).

It is well known that tea leaves are high in fluoride (up to 400 mg/kg dry weight), but the tea infusion itself will have a fluoride concentration of only 0.5–1.5 mg/litre. The amount present in one cup of tea, however, will depend not only on the size of the cup, but also on the brand of tea, the amount used, the duration of the infusion, whether it is a dilution of a previous brew, and whether it was made with fluoridated water. In a study of Duckworth & Duckworth (22), the ingestion of fluoride by tea drinkers of all ages ranged from 0.04 mg to 2.7 mg per day. The fluoride was rapidly released from tea leaves and reached the highest concentration in the tea infusion after approximately 8 minutes. With various brands of tea leaves, there was up to a four-fold variation in the fluoride content of the tea infusions.

Fresh fruit juices have a low fluoride content of from 0.1 to 0.3 mg/litre. Reconstituted fruit juices made with fluoridated water, however, vary in fluoride concentration from 0.3 to 2.5 mg/litre (2).

The fluoride content in soft drinks and mineral water reflects the same level as the water from which it is produced. Beer is normally low in fluorides ranging from 0.3 to 0.8 mg/litre, in contrast to wine, which can have fluoride levels of the order of 6–8 mg/litre.

Fluorides in pharmaceutical products for caries prevention

An increasing number of pharmaceutical products contain fluorides in organic or inorganic form. Products such as sodium fluoride tablets or combined fluoride and vitamin pills are used as a fluoride supplement for use in caries prevention. The tablets usually contain 0.25, 0.50, or 1.00 mg of F^-. The fluoride concentrations in solutions and gels for topical treatment contain from 0.25 to 24.0 g of F^- per litre or per kg. Most dentifrices manufactured today contain 1.0 to 1.5 g of F^- per kg.

The swallowing of fluoride dentifrices is of particular concern

with regard to small children. When ingested on a fasting stomach, fluoride in toothpaste is almost totally absorbed (26). Several reports during the last few years have shown that the amount of toothpaste ingested by children aged 2–5 years may range from 0.1 to 2 g, with a mean of 0.5 g (7, 9, 21, 37). Since most toothpastes contain 1.0 to 1.5 g of F⁻ per kg, the amount of fluoride absorbed may average about 0.50 or 0.75 mg. With young children it is recommended that only small amounts of paste should be dispensed on the toothbrush, and that parents or older siblings should supervise the tooth brushing, or brush the child's teeth themselves.

Certain precautions should also be taken when gels containing 12.3 mg of F⁻ per kg are used in children since there is a risk of overdosing with fluoride and of side effects, such as nausea and gastric discomfort (32).

Fluoride intake from the air

The range of fluoride in air in non-industrial urban areas has been found to be from 0.05 to 1.89 μg/m³. Since an individual inhales about 20 m³ of air per day, the highest level found will yield 0.0378 mg fluoride per day, much of which, however, is exhaled. Under certain extreme environmental conditions, such as heavy dust pollution from special industrial plants, airborne fluorides can be the main contributor to the occurrence of dental fluorosis or even skeletal fluorosis (52, 71, 82).

Total intake of fluorides by man

The available data indicate that total daily fluoride intake by individuals varies from country to country. Although there is no consensus as to the maximum safe daily dosage of fluoride, a total intake of between 0.05 and 0.07 mg of fluoride per kilogram body weight has been suggested as optimum (38).

Singer & Ophaug (87) have shown that the daily fluoride intake of infants 2–6 months of age can be expected to vary from 0.010 mg to 0.127 mg per kilogram body weight, depending upon the fluoride content of the drinking-water and whether or not the child is breast-fed or consumes milk formulas. Assuming a fluid intake of 1 litre/day, a breast-fed child receives approximately 5 to 10μg of fluoride/day, whereas a bottle-fed child living in an area with a water supply containing 1 mg of F⁻ per litre will receive 1000 μg/day, a fluoride dose 100–200 times higher (34).

On the basis of extensive analyses reported by several authors, the total daily fluoride intake may vary from 0.2 mg of fluoride per day in infants to 5.0 mg of fluoride per day in adults. Daily fluoride intakes from food exceeding 3.5 mg per day would usually represent special circumstances, either unusual consumption or unusual dietary habits (74).

Fluoride metabolism

Fluoride absorption in man

The absorption of most water-soluble fluoride compounds after ingestion is rapid and almost complete and occurs mainly in the stomach. It is passive in nature and no active transport mechanism seems to be involved. As shown in Fig. 1, the
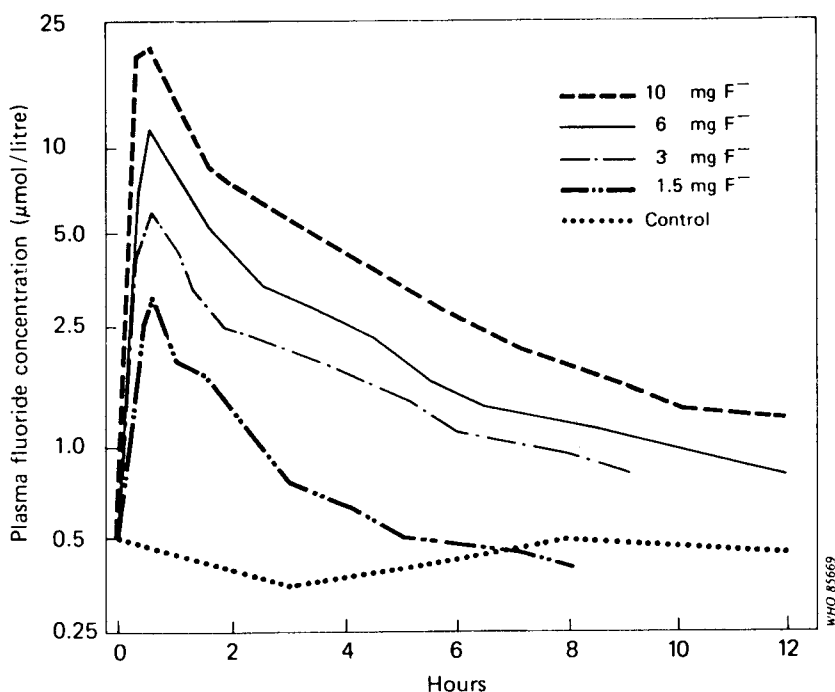
Fig. 1.   Plasma fluoride concentrations in one subject during control conditions and after oral intake of four different doses of fluoride as NaF tablets[a]

[a] Based on data from Ekstrand et al. (29)

maximum plasma fluoride concentration following oral intake of fluoride on a fasting stomach is reached within 30 minutes. When fluoride is taken in conjunction with food, the degree and rate of absorption will decrease. The bioavailability of most dental fluoride preparations is 100%. However, if these preparations are taken together with milk products, the bioavailability decreases to about 60–70% (Fig. 2) (25).
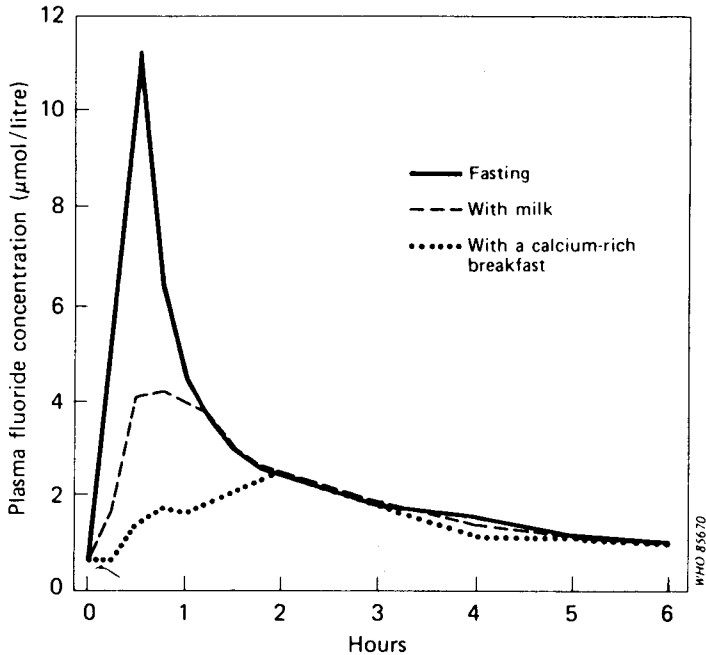
Fig. 2.   Plasma fluoride concentrations in one subject after intake of 3 mg of fluoride as NaF tablets: (a) on an empty stomach, (b) with milk, and (c) with a calcium-rich breakfast[a]

[a] Based on data from Ekstrand & Ehrnebo (25)

Fluoride in blood

Human blood contains fluorine in both organically bound and inorganic forms. It has been suggested that the former originates from the environment and that it does not seem to be related to the inorganic fluoride content (48). Almost all fluoride in plasma is in ionic form and is not bound to any macromolecules (28, 56). The plasma half-life of fluoride is reported to be 4–10 h (29).

The steady state level of fluoride in plasma is determined by dose level and frequency of intake. It is reasonable, therefore, to expect that the plasma levels in subjects living in areas with different fluoride concentrations in the drinking-water will show different steady-state levels. This is illustrated in Fig. 3. The hypothesis that there is some homoeostatic regulation of the plasma fluoride concentration needs further evaluation.
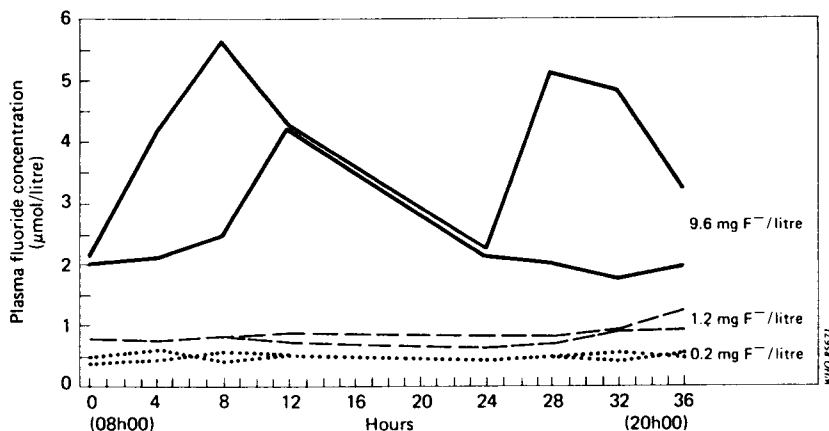
Fig. 3.   Relationship between the plasma fluoride concentration and the fluoride concentration in the drinking-water (six subjects)[a]

[a] Based on data from Ekstrand (24)

Distribution in soft tissues

Once absorbed, fluoride is distributed within minutes through the extracellular fluid to most organs and tissues. The fluoride concentration in most soft tissues is lower than the plasma level except in the healthy kidney where, because of urine production, an occasional fluoride accumulation may result (103). There is no evidence of binding of fluoride to any soft tissues. Fluoride passes the placenta, and studies have shown that the fetal fluoride level in blood is about 75% of that of the maternal blood (5, 85).

Fluorides in bones and teeth

The extent of fluoride uptake in different parts of the skeleton and dentition depends upon the amounts ingested and absorbed, the duration of fluoride exposure, the type, location,

and metabolic activity of the tissue concerned, and the age of the individual.

The affinity that exists between fluoride ions and the bone prototype, hydroxyapatite, is well established. In normal circumstances, fluoride accumulates in the skeleton throughout life and the fluoride content of the bones represents a reliable guide to an individual's lifetime exposure to fluoride (79). Normal values of fluoride in the bones of adults will vary between 1000 and 4000 mg F^- per kg of bone, depending on the fluoride concentration in the drinking-water and the age of the person (99, 109) (Fig. 4).
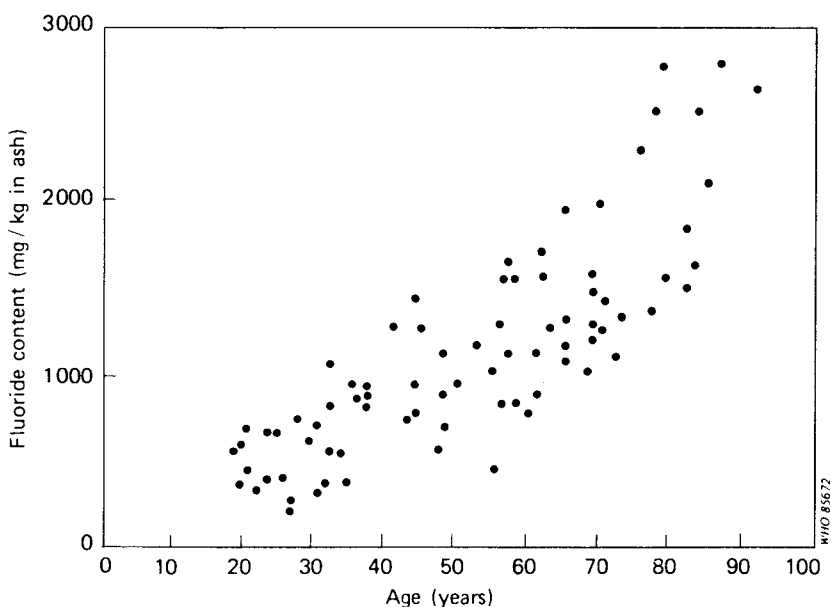
Fig. 4.   Fluoride content of femora compacta from people of different ages living in districts supplied with drinking-water containing < 0.5 mg of F-/litre[a]

[a] Reproduced by permission from Weatherell, J. A. In: *Handbuch der experimentellen Pharmakologie*. Berlin, Springer, vol. 20/1, 1966.

An interesting phenomenon has been recorded in subjects who resided in areas with a relatively high fluoride content in the drinking-water and later moved to a fluoride-deficient area. The urinary excretion of fluoride remained high for a long time, although the daily fluoride intake decreased considerably. This excretion pattern reflects a release of fluoride from the skeleton

that will be maintained until a new fluoride balance has been achieved. This apparent balance or steady-state level can also be monitored in plasma. Following high fluoride intake over a long period, there is a close relationship between the plasma level and the fluoride content of bone (*36*).

Fluoride uptake in dental tissues also increases with age and with increasing fluoride concentration in the water supply. The fluoride content in dentine and enamel is considerably lower than that found in bone from the same individual.

The average fluoride content of enamel in areas with low fluoride concentration in the water increases from about 50 mg/kg at 10 years of age to approximately 100 mg/kg at 30 years of age, whereas the average fluoride content of enamel in areas where the water contains higher fluoride concentrations (1.5–2.0 mg/litre) increases from 170 mg/kg at 10 years of age to a plateau level of 350 mg/kg at 30 years of age.

Dentine has been found to have a fluoride content approximately four times that of enamel. However, results of studies using portions of whole enamel and dentine indicated that the fluoride concentration is not evenly distributed throughout the dental hard tissues (Fig. 5). In areas of high fluoride concentration, the fluoride in the outer layer of enamel can be as high as 2000–3000 mg/kg (*1*). The highest fluoride concentration in dentine is found adjacent to the odontoblastic layer.

Throughout the life of the tooth, fluoride concentrations are relatively high at the enamel surface. Most of the fluoride in the surface region of the enamel in an erupted tooth is acquired prior to eruption, probably during the pre-eruptive maturation period, when the surface of the enamel seems to be quite porous (*12*, *54*).

For some time after eruption, the enamel probably remains porous enough to absorb fluoride relatively easily, and throughout life fluoride seems to be absorbed readily at any site where the enamel is porous, including initial carious lesions. If mature enamel remains intact, it absorbs fluoride with difficulty. In areas of the tooth where enamel is covered with plaque, the concentration of fluoride in the enamel increases with age, while in the more incisal or occlusal areas not covered with plaque but exposed to wear, the fluoride concentration of the outer enamel falls with age. When the mature enamel is treated with relatively high concentrations of fluoride, for example by topical application, the concentration of fluoride in sound enamel will increase, although not permanently.
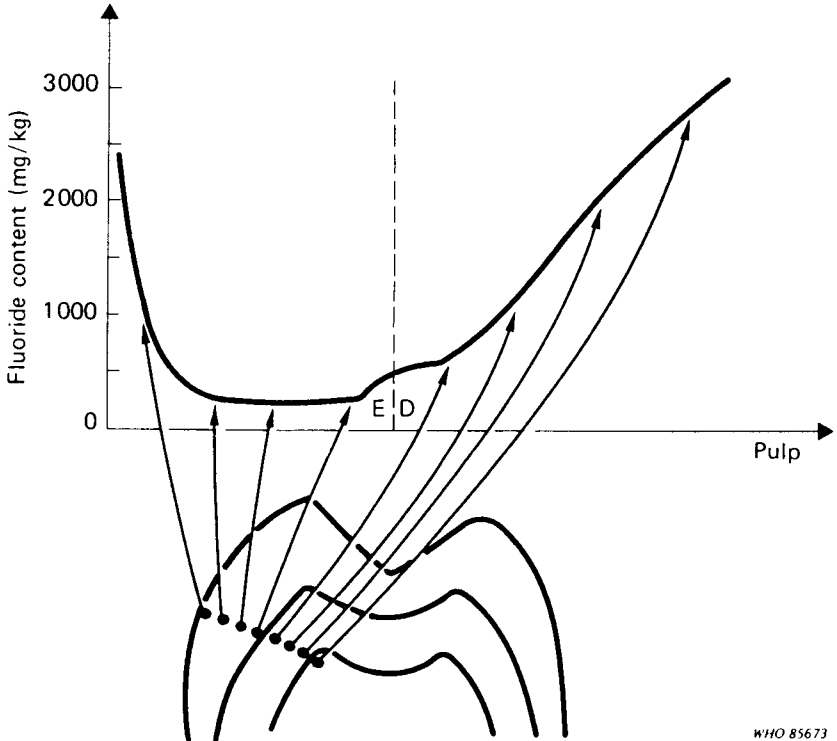
Fig. 5.   Distribution of fluoride in enamel and dentin[a]

[a] Based on data from Weatherell et al. (99)

If the enamel organ is exposed to excessive amounts of fluorides during the formative period, the normal mineralization pattern of the tooth will be disturbed in various degrees of severity. The clinical and microscopical manifestation of this condition, which can vary widely in severity, is known as dental fluorosis (see below).

Excretion of fluoride via the kidney

The main route of fluoride excretion is via the kidney. After glomerular filtration, varying amounts of fluoride are re-absorbed in the proximal and distal tubules. The mechanism involved is simple passive diffusion. Both urinary flow and pH are involved in regulating the renal clearance of fluoride (30, 31, 102). This has several practical implications for the metabolism of fluoride. High urinary flow and an alkaline urine will result in a rapid clearance of fluoride from plasma while a low urinary

flow and an acidic urine will result in a slower renal elimination rate of fluoride. Generally, in an adult 40–60% of an ingested dose is found in the urine. This percentage may vary considerably, however, since it is influenced by the degree of uptake by bone, which in turn is determined by the age of the subject and his or her present and past fluoride intake, so that fluoride retention will, in general, be much higher in a child. It is therefore evident that, on a short-term basis, it is the kidney that regulates the overall metabolism of fluoride in the organism. Bone, on the other hand, is the corresponding "organ" for long-term regulation.

Excretion of fluoride via saliva and breast milk

The fluoride concentration in saliva reflects that of plasma and is about two-thirds of the plasma level (29) (Fig. 6). This is true only when saliva is sampled directly from the duct orifices.

There is a limited transfer of fluoride from blood to breast milk. Alteration in the plasma concentration of fluoride influences the fluoride concentration in breast milk only to a minor extent (33).
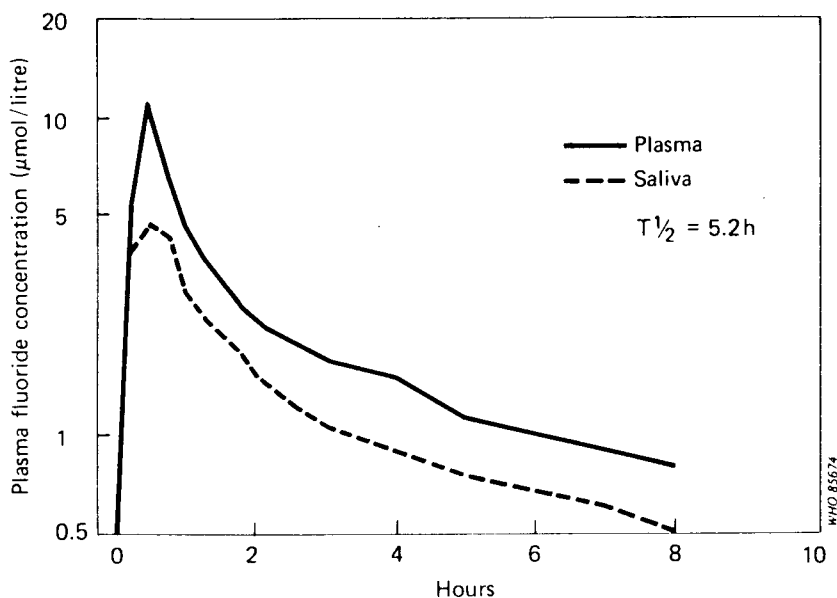
Fig. 6.   Fluoride concentration in plasma and parotid saliva after intake of 3 mg of fluoride as NaF tablets[a]

[a] Based on data from Ekstrand et al. (29)

Dental fluorosis

Endemic dental fluorosis is a specific disturbance of tooth formation caused by excessive intake of fluoride during the formative period of the dentition. Clinical dental fluorosis is characterized by lustreless, opaque white patches in the enamel, which may become striated, mottled, and/or pitted, or may be stained yellow to dark brown. The affected teeth may show a pronounced accentuation of the perikymata and, in more severe cases, discrete pits and larger areas of hypoplasia (confluent pitting) of the enamel appear to such an extent that the normal morphology of the tooth is lost (*17, 70, 72*).

History and classification of dental fluorosis

The earliest report on a condition characterized by opaque, discoloured and disfigured teeth, which appeared to be of endemic origin, dates back to 1888 when Kuhns (*60*) reported such cases in certain areas in Mexico. A similar condition was observed in the USA in immigrants from Naples (*23*). Several reports from other parts of the world and in particular the observations of Colorado Brown Stain by McKay & Black (*68*) led eventually, in 1931, to the discovery that this condition was correlated with the fluoride content of drinking-water (*15, 89*).

Following up McKay & Black's pioneering work, Dean (*17, 18*) continued to elucidate the relationship between the occurrence of dental fluorosis and the concentration of fluorides in the drinking-water. On the basis of statements made in earlier reports to the effect that teeth with dental fluorosis were no more susceptible to dental decay than normal teeth, Dean conducted extensive epidemiological studies that demonstrated the existence of an inverse relationship between the prevalence of dental caries and the fluoride content of the drinking-water (*19, 20*).

The identification of this relationship led eventually to the idea of adjusting the fluoride content in fluoride-deficient drinking-water. Between 1944 and 1947 the first communities to introduce this caries-preventive measure were Grand Rapids, Newburgh, Brantford, Sheboygan, and Evanston, all in the USA (for review see McClure, *66*).

Equations for calculating the optimal fluoride level in drinking-water (i.e., the level at which the caries-reducing effect is the highest and the risk of provoking dental fluorosis the least) have been devised by Hodge (*50*), Galagan & Lamson (*45*), Galagan & Vermillion (*46*), and Richards et al. (*81*).

Classification of dental fluorosis

In order to compare the severity and distribution of dental fluorosis in various communities, Dean (20) developed an epidemiological index according to which each tooth is allotted a score and each score is given a corresponding weighting:

Score			Weight
0	–	normal	0
1	–	questionable	0.5
2	–	very mild	1.0
3	–	mild	2.0
4	–	moderate	3.0
5	–	severe	4.0

For each score a corresponding description of the clinical appearance of the tooth was given:

Normal: The enamel presents the usual translucent, semivitriform type of structure. The surface is smooth, glossy, and usually of a pale creamy white colour.

Questionable: The enamel discloses slight aberrations from the translucency of normal enamel, ranging from a few white flecks to occasional white spots. This classification is used in those instances where a definite diagnosis of the mildest form of fluorosis is not warranted and a classification of "normal" not justified.

Very mild: Small, opaque, paper-white areas scattered irregularly over the tooth, but involving less than approximately 25 % of the tooth surface. Frequently included in this classification are teeth showing no more than about 1 –2 mm of white opacity at the tip of the summit of the cusps of the bicuspids or second molars.

Mild: The white opaque areas in the enamel of the teeth are more extensive but do not involve as much as 50 % of the tooth.

Moderate: All enamel surfaces of the teeth are affected, and surfaces subject to attrition show marked wear. Brown stain is frequently a disfiguring feature.

Severe: Includes teeth formerly classified as "moderately severe" and "severe". All enamel surfaces are affected and hypoplasia is so marked that the general form of the tooth may be altered. The major diagnostic sign of this classification is the discrete or confluent pitting. Brown stains are widespread and teeth often present a corroded-like appearance.

The score assigned to an individual was the one that corresponded to the two most severely affected teeth in the individual's mouth.

On the basis of the number and distribution of the individual scores a community index of dental fluorosis (F_{ci}) could be

calculated (20):

$$F_{ci} = \frac{\text{number of individuals} \times \text{statistical weight}}{\text{total number of individuals examined}}$$

Example:

Number of persons	Score	Sum of statistical weights
50	0	0
25	0.5	12.5
15	1	15
10	2	20
5	3	15
5	4	20
Total 110		82.5

$$F_{ci} = \frac{82.5}{110} = 0.75$$

Dean (20) stated that: "For public health administrative guidance a community index of dental fluorosis of 0.4 or less is of no concern from the standpoint of mottled enamel *per se*; when, however, the index rises above 0.6 it begins to constitute a public health problem warranting increasing consideration."

Several attempts have been made to develop new classifications or indices for the epidemiological recording of dental fluorosis. Some of these have been too complicated to use in the field (58) or have been related to the clinical appearance of dental fluorosis in a particular local area (97).

Smith et al. (88) introduced a classification based on three scores: (1) white opaque patches, (2) dark yellow to brown discoloration, (3) discoloration and "pitting". This classification would seem to be most useful for screening purposes or for rather crude epidemiological surveys.

Møller (70) suggested that three intermediate values should be introduced in order to make Dean's index more sensitive and introduced the relative term "optimal enamel", which is characterized by a clinically homogeneous mineralized enamel with no visual signs of dental fluorosis or other enamel opacities.

A classification system for the diagnosis of dental fluorosis proposed by Thylstrup & Fejerskov (94) included 10 scores designed to characterize the macroscopic degree of dental

fluorosis as it is correlated with histological changes. The macroscopic appearance of increasing degrees of dental fluorosis was shown to be well correlated with the degree of subsurface porosity. This classification system is more sensitive than Dean's classification, particularly in distinguishing variations in the macroscopic appearance of the more severe degrees of dental fluorosis.

Classifications of enamel opacities based solely on the clinical appearance of the lesions have been proposed by Young (107), Al-Alousi et al. (4), Jackson et al. (55), Murray & Shaw (73), and Working Group 5 of the FDI Commission on Oral Health Research and Epidemiology (53), on the principle that the recording of any condition once defined must be made on the basis of that definition and not on the basis of a presumed etiology.

Since dental fluorosis is of developmental origin there is a high degree of bilateral correspondence in the severity of dental fluorosis between homologous teeth (70).

The individual teeth in the dentition are not affected by dental fluorosis to the same degree. The teeth most affected are usually those that mineralize last, namely, premolars, second molars, upper incisors, and canines, whereas first molars and lower incisors are least affected, except in the more severe cases where all teeth are affected to the same degree (70,75). This sequence in the severity of dental fluorosis within the individual dentition might be related to a smaller fluoride exposure in early infanthood because of the smaller intake of water and higher intake of milk, as well as the fact that the available fluoride will be primarily absorbed by the skeleton (74). The difference in severity of fluorosis between upper and lower incisors has been explained on the basis of differences in the thickness of the enamel, i.e., the thicker the enamel the higher the severity of dental fluorosis (94).

Dental fluorosis in the primary dentition is generally reported to be less severe than that in the corresponding permanent dentition. This difference in severity has been attributed to a placental barrier to fluoride and to the shorter duration of enamel formation and maturation of primary teeth; it might also be related to the thinner enamel. The clinical diagnosis of the milder degrees of dental fluorosis in the primary dentition is difficult because the signs of dental fluorosis are blurred by the natural opaque colour of the primary teeth.

Even though the clinical appearance of dental fluorosis normally follows a distinct pattern and distribution within the

dentiton, there are cases where even the experienced examiner will have difficulty in establishing a differential diagnosis between dental fluorosis and initial carious lesions, amelogenesis imperfecta, and enamel opacities of nonfluoride origin.

Several authors (77, 83, 108) have attempted to describe criteria for the differential diagnosis of dental fluorosis. The most characteristic differences are summarized in Table 1:

Table 1.   Characteristic clinical differences between dental fluorosis and enamel opacities

	Mild degree of dental fluorosis	Localized or generalized enamel opacities
Distribution	(1) Symmetrical (2) Most teeth affected	(1) Very seldom symmetrical (2) Only one or just a few teeth affected
Localization	Most visible on the incisal or occlusal two-thirds of the enamel, but following thorough drying visible on the whole tooth surface	Middle or incisal third, mostly localized to buccal surfaces of upper incisors
Configuration	Diffuse horizontal opaque patches following the perichymata	Confined configuration as round or oval spots
Visibility	Visible in tangential reflected light	Directly visible in normal light

Several authors (42, 70, 108) have found an inverse relationship between the occurrence of dental fluorosis and localized enamel opacities. Forrest & James (43) concluded that the prevalence of enamel opacities in a community provided with fluoridated water near the optimal level of approximately 1 mg/litre is smaller than that observed in a community whose drinking-water is not fluoridated. In a further study by Jackson et al. (55) it was concluded that the etiology of the kind of mottling observed in Leeds, Anglesey, Bangor, Caernarvon, and in many other non-fluoride communities was independent of fluoride ingestion. In other words, fluoride may induce enamel opacities, but not all cases of enamel opacities are necessarily caused by fluoride.

A priori one would expect that the prevalence of localized enamel opacities would be the same in fluoride and non-fluoride areas and it has been suggested that the reason why a less frequent occurrence of enamel opacities has been observed in

optimal fluoride areas is because their detection is blurred by the occurrence of the early stages of dental fluorosis (92). Nevertheless—and whatever the reason—it seems to be a fact that from a clinical point of view there is a higher percentage of homogeneously mineralized enamel in optimum fluoridated areas than in areas with fluoride concentrations in the drinking-water that are too high or too low (42, 70, 108).

Histopathology of teeth with dental fluorosis

Since the early work of Black (10), McKay & Black (68), Williams (104), and Ainsworth (3), only a limited number of reports have been published on the histopathological features of enamel affected by fluorosis. Studies on the microscopic features of affected enamel, as viewed with polarized light, have been published by several authors (16, 40, 47, 94), while others have reported on the microradiographic appearance (8, 40, 41, 78, 86) or on the electron microscopical features (39, 41, 86, 90, 93).

In most of these studies, the enamel of affected teeth has been described as hypomineralized with an irregular prism pattern and with the scalloped or arcade pattern of the enamel–dentine junction being more pronounced than in normal teeth. In a study by Fejerskov et al. (40) it was confirmed that dental fluorosis comprises areas of diffuse hypomineralization or porosity, mostly in the outer third of the enamel. In more severe cases, the enamel affected by fluorosis would exhibit a pore volume of 10 % and in extreme cases even up to 25 %. The areas showing the greatest degrees of porosity are in interprismatic positions and along the cross-striations. Even in severe cases of dental fluorosis, the orientation of the prisms seems normal and regular. This would seem to indicate that the ameloblasts are able to lay down a normal enamel matrix, and it is the maturation process that is disturbed by high concentrations of fluoride ions (39).

Because dental fluorosis may be conceived as an insufficient closure of intercrystalline spaces, the processes responsible for the removal of water and inorganic material are of particular interest from a pathogenic point of view. A passive removal of these elements mediated through crystal growth has been suggested, but recent studies indicate that more specific, probably cellular processes, should be considered (92).

The effect of fluoride on enamel formation can follow several possible pathogenic pathways (41):

1. Effect on ameloblasts
    (*a*) Secretory phase
        — diminished matrix production
        — change of matrix composition
        — changes in ion transport mechanisms

    (*b*) Maturation phase
        — diminished withdrawal of protein and water.
2. Effect on nucleation and crystal growth in all stages of enamel formation.
3. Effect on calcium homoeostasis with dental fluorosis as an indirect result.

Treatment and prevention of dental fluorosis

Treatment. Different measures for improving the cosmetic appearance of affected teeth have been suggested:
    — grinding and polishing
    — etching with hydrochloric acid
    — bleaching with hydrogen peroxide
    — remineralization with sodium fluoride and calcium sucrose phosphate solutions
    — acid-etch-resin labial veneer restorations
    — artificial crowns.
The first two methods are not usually recommended. The effectiveness of remineralization needs to be confirmed.

Prevention. The toxic effect of elevated levels of fluorides on the formation of teeth cannot be eliminated by altering already adequate diets. However, in populations with generalized malnutrition the prevalence and severity of dental fluorosis can probably be reduced by improving the diet.

Identification of alternative water supplies with optimal or suboptimal levels of fluoride is the only effective preventive measure in areas where unacceptable cosmetic or disfiguring dental fluorosis is endemic. If this is not possible, the available drinking-water can be defluoridated by inserting filters containing chemical compounds, e.g., activated alumina or bone charcoal, capable of inactivating or absorbing the fluoride ions. Since the defluoridation procedure is normally rather expensive, attempts to develop simple, cheap, and effective defluoridation devices have been made with varying degrees of success (Nair, K.R., personal communication, 1982). Defluoridation of drinking-water is normally recommended if the fluoride ion concen-

tration exceeds twice the optimum concentration for the area in question (see "Partial removal of fluorides", p. 33).

Urinary fluoride excretion and fluoride intake

The monitoring of urinary fluoride concentrations is a convenient method for estimating fluoride intake on a population basis. It can take into account accidental or inadvertent exposures to the ion, as from air pollution or from fluoride preparations for topical use. In addition, determinations of urinary fluoride concentration are easier to perform on a large scale than are the more precise intake studies. They are of doubtful value, however, in estimating fluoride intake by individuals or small groups.

If, in addition to concentration, the urine flow rate is determined, then the urinary fluoride excretion rate can be calculated as the product of the two factors. This procedure has the advantage of reducing the amount of variation among individuals because increases in urine flow rate tend to be associated with lower urinary fluoride concentrations and vice versa. Moreover, the intake of larger amounts of fluoride that result in plasma fluoride levels in excess of 0.6 mg/litre may cause a transient increase in urine flow rate (*69, 101*).

Among adults, the 24-hour urinary excretion of fluoride usually ranges from 40% to 60% of the amount ingested daily. Values outside this range are not uncommon, however, because several variable features of kidney function are involved in the excretory process. Included among these are glomerular filtration rate (*98*), urine flow rate (*14*), and urine pH (*31, 103*). Children excrete relatively less of their ingested fluoride; this has been attributed to increased rates of fluoride uptake by the bones and other calcified tissues in children. There is a paucity of such data for children under six years of age. It is likely that, on average, they excrete less than 30% of their ingested fluoride in the urine. Additonal information on this subject is needed.

The concentrations of fluoride in plasma and urine tend to parallel each other very closely. Among residents of a community with water fluoridated at 1 mg/litre, the fasting plasma fluoride level is approximately 0.02 mg/litre and the urinary concentration is approximately 50 times higher. When fluoride from any source is ingested and absorbed, the plasma concentrations begin to rise almost immediately. They usually reach peak values within the first hour. Thereafter, the

concentrations fall rapidly and, unless unusually large amounts of fluoride were involved, they approach or reach the pre-ingestion levels within three to six hours. During such times, the fluoride levels of the urine entering the bladder change proportionately and almost simultaneously. This relationship has obvious implications for studies aimed at estimating fluoride intake based on urinary fluoride concentrations or excretion rates.

It is known that, among persons living in temperate climates and whose major source of fluoride is the drinking-water, the water and urinary fluoride concentrations are generally similar (61, 68). Accordingly, it is recommended that, in programmes using fluoridated salt, the level of fluoride in salt be adjusted to the level that results in urinary concentrations of approximately 1 mg/litre. It should be noted, however, that when the water fluoride level drops much below 1 mg/litre, urinary concentrations do not fall proportionately (84). The discrepancy appears to be due to the ingestion of foods and/or other substances that also contain fluoride.

In studies involving the analysis of fluoride in urine, four levels of measurement may be distinguished:

— fluoride concentrations in single or "spot" samples;
— the amount of fluoride excreted in 24-hour urine samples;
— the amount of fluoride excreted in shorter periods of time; and
— fluoride/creatinine ratios.

(1) Spot urine samples are easily obtained. The fluoride concentrations of such samples cannot be used to estimate directly the amounts of fluoride ingested or excreted in the long-term. They are influenced by the quantities of fluoride ingested and the resulting plasma levels during the period when the urine sample was formed as well as the urine flow rate and the urine pH. On a population basis, however, urinary fluoride levels generally reflect the levels of intake. It should be kept in mind that children tend to excrete a smaller fraction of their ingested fluoride than adults. Therefore, it would be inappropriate to adjust salt fluoride levels so that the average urinary fluoride concentration of young children is 1 mg/litre.

(2) The best way to estimate fluoride intake is to use 24-hour urinary fluoride measurements. Estimates of fluoride intake based on 24-hour urinary concentrations or excretion rates are more reliable than those based on spot urine samples (51). This

is due to the fact that the impact of transiently high or low values tends to be reduced in the longer term. Even under conditions of apparently similar intake, however, the 24-hour amounts of excreted fluoride as reported by different investigators may differ (64, 80, 100).

If, in addition to concentration, the urine flow rate is determined, then the urinary fluoride excretion rate can be calculated as the product of the two factors. This procedure has the advantage of reducing the amount of variation among individuals because increases in urine flow rate will result in lower urinary fluoride concentrations and vice versa. Urinary excretion rate also mirrors the plasma fluoride level fairly closely (27).

(3) In some types of study, urine collections involving a shorter period of time are desirable. For example, Büttner et al. (13) collected 24-hour urine samples from children during a control period and during a period when a fluoride-containing dentifrice was used. They did not detect any statistically significant difference in the amounts of fluoride excreted in the urine in the two periods. Such a difference would probably have been found if the urine collection had commenced at the time of brushing and had been limited to the following three or four hours. Martin (64) studied the excretion of fluoride during different times of the day. It appeared that one morning sample and one afternoon sample involving a total period of 5–7 hours could be used to estimate the 24-hour excretion with fair reliability.

(4) In attempts to minimize variations in urinary fluoride concentrations due to different urine flow rates, some investigators have determined the creatinine levels in the same samples as used for the fluoride determinations and then calculated the fluoride-to-creatinine ratios (64, 80, 100). This procedure may be of value when studying fluoride excretion by individuals but it does not appear to alter the conclusions based solely on urinary fluoride data when groups are studied (84, 96).

Conclusion

Owing to the universal presence of fluorides in water, soil, and air, it is not surprising that individuals are exposed to various levels of fluoride intake through foods, water, industrial and pharmaceutical products, and other sources. Although

waterborne fluoride has been said to represent the largest single source of daily intake of this element, in some parts of the world, staple diets particularly high in fluoride may be the main contributor. The daily amount of fluoride intake through water varies with climate (maximum daily temperature) and age of the person.

Since fluoride remains pre-eminent among the measures available for prevention of dental caries, continued and renewed research on the cariostatic mechanisms and metabolism of fluorides over a wide range of sociocultural environments still has a high priority as a means of determining standards for the rational use of fluorides by both systemic and topical administration.

References

1. AASENDEN, R. & PEEBLES, T. C. Effects of fluoride supplementation from birth on dental caries and fluorosis in teenaged children. *Archives of oral biology,* **23**: 111 (1978).
2. ADAIR, S. M. & WEI, S. H. Y. Fluoride concentration of fruit juice. *Pediatric dentistry,* **1**: 174 (1979).
3. AINSWORTH, N. J. Mottled teeth. *British dental journal,* **55**: 233 (1933).
4. AL-ALOUSI, W. ET AL. Enamel mottling in a fluoride and in a non-fluoride community. Parts I & II. *British dental journal,* **138**: 9 & 56 (1975).
5. ARMSTRONG, W. C. ET AL. Placental transfer of fluoride and calcium. *American journal of obstetrics and gynecology,* **107**: 432 (1970).
6. BACKER DIRKS, O. ET AL. Total and free ionic fluoride in human and cow's milk as determined by gas-liquid chromatography and the fluoride electrode. *Caries research,* **8**: 181 (1974).
7. BARNHART, W. E. ET AL. Dentifrice usage and ingestion among four age groups, *Journal of dental research,* **53**: 1317 (1974).
8. BAUD, C. A. & ALAMI, A. H. Endemic fluorosis in Morocco. In: Vischer, T. L., ed. *Fluoride in medicine.* Bern, Huber, 1970.
9. BAXTER, P. M. Toothpaste ingestion during toothbrushing by school children. *British dental journal,* **148**: 125 (1980).
10. BLACK, G. V. Mottled teeth. *Dental cosmos,* **58**: 129 (1916).
11. BROWN, W. E. & KÖNIG, K. G. ed. Cariostatic mechanisms of fluorides. *Caries research,* **11**: (suppl. 1): pp. 1–327 (1977).
12. BRUDEVOLD, F. ET AL. The distribution of fluoride in human enamel. *Journal of dental research,* **35**: 420 (1956).
13. BÜTTNER, W. ET AL. Toxicity of fluoride-containing dentifrices in the present status of caries prevention by fluoride-containing dentifrices. In: Mühlemann, H. R. & König, K. G., ed. *Caries*

symposium, Zürich. Bern, Huber, 1961, pp. 92–99.

14. CARLSON, C. H. ET AL. Distribution and excretion of radiofluoride in the human. *Proceedings of the Society for Experimental Biology and Medicine,* **104**: 235–239 (1960).

15. CHURCHILL, H. V. Occurrence of fluorides in some waters of the United States. *Industrial and engineering chemistry* **23**: 996 (1931).

16. DARLING, A. I. & BROOKS, A. W. Some observations on the mottled enamel of fluorosis. *Journal of dental research,* **38**: 1226 (1959).

17. DEAN, H. T. Classification of mottled enamel diagnosis. *Journal of the American Dental Association,* **21**: 1421 (1934).

18. DEAN, H. T. Chronic endemic dental fluorosis (mottled enamel). In: Gordon, S. M., ed. *Dental science and dental art.* London, Kimpton, 1938.

19. DEAN, H. T. Endemic fluorosis and its relation to dental caries. *Public health reports (Washington),* **53**: 1443 (1938).

20. DEAN, H. T. The investigation of physiological effects by the epidemiological method. In: Moulton, R. F., ed. *Fluorine and dental health.* Washington, DC, American Association for the Advancement of Science, 1942.

21. DOWELL, T. B. The use of toothpaste in infancy. *British dental journal,* **150**: 247 (1981).

22. DUCKWORTH, S. C. & DUCKWORTH, R. The ingestion of fluoride in tea. *British dental journal,* **145**: 368 (1978).

23. EAGER, J. M. Denti di Chiaie [Chiaie teeth]. *Public health reports (Washington),* **16**: 2576 (1901).

24. EKSTRAND, J. Relationship between fluoride in the drinking water and the plasma fluoride concentration in man. *Journal of caries research,* **12**: 123 (1978).

25. EKSTRAND, J. & EHRNEBO, M. Influence of milk products of fluoride bioavailability in man. *European journal of clinical pharmacology,* **16**: 211 (1979).

26. EKSTRAND, J. & EHRNEBO, M. Absorption of fluoride from fluoride dentifrices. *Caries research,* **14**: 96 (1980).

27. EKSTRAND, J. & EHRNEBO, M. The relationship between plasma fluoride, urinary excretion rate and urine fluoride concentration in man. *Journal of occupational medicine,* **25**: 10, 745 (1983).

28. EKSTRAND, J. ET AL. Absence of protein-bound fluoride from human blood plasma. *Archives of oral biology,* **22**: 229 (1977).

29. EKSTRAND, J. ET AL. Pharmacokinetics of fluorides in man after single and multiple oral doses. *European journal of clinical pharmacology,* **12**: 311 (1977).

30. EKSTRAND, J. ET AL. Fluoride bioavailability after intravenous and oral administration: Importance of renal clearance and urine flow. *Clinical pharmacology and therapeutics,* **23**: 329 (1978).

31. EKSTRAND, J. ET AL. Fluoride pharmacokinetics during acid-base balance changes in man. *European journal of clinical pharmacology,* **18**: 189–194 (1980).

32. EKSTRAND, J. ET AL. Pharmacokinetics of fluoride gels in children and adults. *Caries research*, **15**: 213 (1981).
33. EKSTRAND, J. ET AL. No evidence of transfer of fluoride from plasma to breast milk. *British medical journal*, **283**: 761 (1981).
34. EKSTRAND, J. ET AL. Fluoride balance studies on infants in a 1 ppm fluoride area. *Caries research*, **18**: 87 (1984).
35. ERICSSON, S. Y. Cariostatic mechanisms of fluorides: Clinical observations. *Caries research*, **11** (suppl. 1): 2 (1977).
36. ERICSSON, Y. ET AL. Blood plasma fluoride: An indicator of skeletal fluoride content. *International Research Communications System*, August 1973.
37. ERICSSON, Y. & FORSMAN, B. Fluoride retained from mouth rinses and dentifrices in preschool children. *Caries research*, **3**: 290 (1969).
38. FARKAS, C. S. & FARKAS, E. J. Potential effects of food processing on the fluoride content of infant foods. *Science of the total environment*, **2**: 399–406 (1974).
39. FEJERSKOV, O. ET AL. The ultrastructure of fluorosed human dental enamel. *Scandinavian journal of dental research*; **82**: 357 (1974).
40. FEJERSKOV, O. ET AL. The histological features of fluorosed human enamel. *Caries research*, **9**: 190 (1975).
41. FEJERSKOV, O. ET AL. Clinical and structural features and possible pathogenic mechanisms of dental fluorosis. *Scandinavian journal of dental research*, **85**: 510 (1977).
42. FORREST, J. R. Caries incidence and enamel defects in areas with different levels of fluorine in the drinking water. *British dental journal*, **100**: 195 (1956).
43. FORREST, J. R. & JAMES, P. M. C. A blind study of enamel opacities and dental caries prevalence after eight years of fluoridation of water. *British dental journal*, **119**: 319 (1965).
44. FROSTELL, G. & ERICSSON, Y. Antiplaque therapeutics in caries prevention. *Caries research*, **12** (suppl. 1): 74 (1978).
45. GALAGAN, D. J. & LAMSON, G. G. Climate and endemic dental fluorosis. *Public health reports (Washington)*, **68**: 497 (1953).
46. GALAGAN, D. J. & VERMILLION, J. R. Determining optimum fluoride concentrations. *Public health reports (Washington)*, **72**: 491 (1957).
47. GUSTAFSON, A.-G. The histology of fluorosed teeth. *Archives of oral biology*, **4**: 67 (1961).
48. GUY, W. S. ET AL. Organic fluoro-compounds in human plasma: Prevalence and characterization. In: Fuller, R., ed. *Biochemistry involving carbon-fluorine bonds*. Washington, DC, American Chemical Society, 1976, pp. 117–134 (Symposium Series 28).
49. HELOE, L. A. & KÖNIG K. G. Oral hygiene and educational programs for caries prevention. *Caries research*, **12** (suppl. 1): 83 (1978).
50. HODGE, H. C. The concentration of fluorides in the drinking water to give the point of minimum caries with maximum safety. *Journal of the American Dental Association*, **40**: 436 (1950).

51. HODGE, H. C. & SMITH, F. A. Biologic properties of inorganic fluorides. In: Simons, J. H., ed. *Fluorine chemistry*, vol. 4, New York, Academic Press, 1965, p. 53.

52. HODGE, H. C. & SMITH, F. A. Occupational fluoride exposure. *Journal of occupational medicine*, 19: 12 (1977).

53. INTERNATIONAL DENTAL FEDERATION (FDI) An epidemiological index of developmental defects of enamel (DDE Index). *International dental journal*, 32: 159–167 (1982).

54. ISAAC, S. ET AL. The relation of fluoride in the drinking water to the distribution of fluoride in enamel. *Journal of dental research*, 37: 318 (1958).

55. JACKSON, D. ET AL. Fluoridation in Anglesey: A clinical study. *British dental journal*, 138: 165 (1975).

56. JARDILLIER, J. C. & DESMET, G. Etude de fluor sérique et de ses combinaisons par une technique utilisant une electrode spécifique. [Study of serum fluoride and its combinations by a technique employing a specific electrode]. *Clinica chimica acta*, 47: 357 (1973).

57. JENKINS, G. N. The mechanism of action of fluoride in reducing caries incidence. *International dental journal*, 17: 552 (1967).

58. KAWAHARA, H. & KAWAHARA, K. The new method of classifying mottled teeth based on fluorine content in drinking water. *Shikoku acta medica*, 5: 120 (1954).

59. KRAMER, L. ET AL. Dietary fluoride in different areas of the United States. *American journal of clinical nutrition*, 27: 590–594 (1974).

60. KUHNS, C. *Deutsche Monatsschrift für Zahnheilkunde*, 6: 446 (1888).

61. LARGENT, E. J. *Fluorosis. The health aspects of fluorine compounds*, Columbus, Ohio State University Press, 1961.

62. LEVERETT, D. H. Fluorides and changing prevalence of dental caries. *Science*, 217: 26–30 (1982).

63. LOESCHE, W. J. Chemotherapy of dental plaque infections. *Oral science review*, 9: 65 (1976).

64. MARTIN, A. *Fluorid im 24-Stunden-Urin: Tagesprofile und Beziehungen zum Kreatinin bei Trinkwasserfluoridierung und Salzfluoridierung* [Fluoride in 24-hour urine samples: daily profiles and relationships to creatinine following fluoridation of drinking-water and salt]. Thesis, Zurich, 1982.

65. McCLURE, F. J. Fluorine in foods–survey of recent data. *Public health reports (Washington)*, 64: 1061 (1949).

66. McCLURE, F. J. *Water fluoridation. The search and victory.* Washington, DC, National Institute of Dental Research, 1970.

67. McCLURE, F. J. & KINSER, C. A. Fluoride domestic waters and systemic effects. II. Fluorine content of urine in relation to fluorine in drinking water. *Public health reports (Washington)*, 59: 1575–1591 (1944).

68. McKAY, F. S. & BLACK, G. V. An investigation of mottled teeth: An endemic developmental imperfection of the enamel of the teeth,

heretofore unknown in the literature of dentistry. *Dental cosmos*, **58**: 477, 627, 781, 894 (1916).

69. MAZZE, R. I. ET AL. Methoxyflurane metabolism and renal dysfunction: clinical correlation in man. *Anesthesiology*, **35**: 247–252 (1971).

70. MØLLER, I. J. *Dental fluorose og caries* [*Dental fluorosis and caries*]. Copenhagen, Rhodos, 1965.

71. MØLLER, I. J. & POULSEN, S. A study of dental mottling in children in Khouribga, Morocco. *Archives of oral biology*, **20**: 601 (1975).

72. MURRAY, J. *Fluorides in caries prevention*. Bristol, Wright, 1976.

73. MURRAY, J. & SHAW, L. Classification and prevalence of enamel opacities in the human deciduous and permanent dentitions. *Archives of oral biology*, **24**: 7 (1979).

74. MYERS, H. M. *Fluorides and dental fluorosis*. Basel, Karger, 1978.

75. NANDA, R. S. ET AL. Factors affecting the prevalence of dental fluorosis in Lucknow, India. *Archives of oral biology*, **19**: 781 (1974).

76. NATIONAL RESEARCH COUNCIL. *Biological effects of atmospheric pollutants: Fluorides*. Washington, DC, National Academy of Sciences, 1971, pp. 369–400, 433–435, 474–487.

77. NEVITT, G. A. ET AL. Occurrence of nonfluoride opacities and nonfluoride hypoplasias of enamel in 588 children after 9 to 14 years. *Journal of the American Dental Association*, **66**: 65 (1963).

78. NEWBRUN, E. & BRUDEVOLD, F. Studies on the physical properties of fluorosed enamel. I. Microradiographic studies. *Archives of oral biology*, **2**: 15 (1960).

79. PARKINS, F. M. ET AL. Relationship of human plasma fluoride and bone fluoride to age. *Calcified tissue research*, **16**: 335 (1974).

80. PETERS, G., ET AL. L'excrétion urinaire de fluorures chez des habitants du canton de Vaud ingérant uniquement du sel fluoré comparée à celle d'habitants de communes limitrophes ingérant du sel non-fluoré. [Urinary excretion of flurides in inhabitants of the canton of Vaud ingesting solely fluoridated salt as compared with inhabitants of neighbouring communes ingesting non-fluoridated salt]. *Médecine sociale et préventive* **20**: 263–271 (1975).

81. RICHARDS, L. F. ET AL. Determining optimum fluoride levels for community water supplies in relation to temperature. *Journal of the American Dental Association*, **74**: 389 (1967).

82. ROHOLM, K. *Fluorine intoxication: a clinical-hygienic study*. Copenhagen, Nyt Nordisk Forlag, and London, Lewis, 1937.

83. RUSSELL, A. L. The differential diagnosis of fluoride and nonfluoride opacities. *Public health dentistry*, **21**: 143 (1961).

84. SHANNON, I. L. & SANDERS, D. M. Urinary fluoride concentration in 6- to 9-year-old children drinking water with a very low fluoride level. *Caries research*, **13**: 18–22 (1979).

85. SHEN, Y. M. & TAVES, D. R. Fluoride concentrations in the human placenta and maternal and cord blood. *American journal of obstetrics and gynecology*, **119**: 205 (1974).

86. SILNESS, J. & GUSTAVSON, F. Some observations on the fine structure of fluorosed dental enamel. *Acta odontologica scandinavica*, **28**: 701 (1970).
87. SINGER, L. & OPHAUG, R. Total fluoride intake in children. *Pediatrics*, **63**: 460 (1979).
88. SMITH, D. A. ET AL. Fluorosis in the Butana, Sudan. *Journal of tropical medicine and hygiene*, **56**: 57 (1953).
89. SMITH, M. C. ET AL. The cause of mottled enamel, a defect of human teeth. *University of Arizona. Agricultural Experiment Station Technical Bulletin* **32**: 253 (1931).
90. SUNDSTROM, B. & MYHRBERG. Light and scanning electron microscopy of fluorosed enamel from human permanent teeth. *Caries research*, **12**: 320 (1978).
91. TANGANYIKA. *Annual report of the Government Chemist of Tanganyika, 1954*. Dar es Salaam, Government Printer, (1955).
92. THYLSTRUP, A. *Fluorids effekt på den humane emaljedannelse med saerlig henblik på det primaere tandsaet. [Effect of fluorides on human dental enamel, with special reference to the primary teeth]* Thesis, Royal Dental College, Aarhus, (1979).
93. THYLSTRUP, A. A scanning electron microscopical study of normal and fluoritic enamel demineralized by EDTA. *Acta odontologica scandinavica*, **37**: 127 (1979).
94. THYLSTRUP, A. & FEJERSKOV, O. Clinical appearance and surface distribution of dental fluorosis in permanent teeth in relation to histological changes. *Community dentistry and oral epidemiology*, **6**: 315 (1978).
95. TINANOFF, N. & MUELLER, B. Fluoride content in milk and formula for infants. *Journal of dentistry for children*, **45**: 53 (1978).
96. VANDEPUTTE, M. ET AL. A contribution to the study of fluoride excretion. *Clinica chimica acta*, **75**: 205–212 (1977).
97. VENKATESWARLU, P. ET AL. Studies in endemic fluorosis: Visakhapatnam and suburban areas. Fluorine, mottled enamel and dental caries. *Indian journal of medical research*, **40**: 535 (1952).
98. WATERHOUSE, C. ET AL. Serum inorganic fluoride: changes related to previous fluoride intake, renal function and bone resorption. *Clinical sciences*, **58**: 145–152 (1980).
99. WEATHERELL, J. A. ET AL. Assimilation of fluoride by enamel throughout the life of the tooth. *Caries research*, **11**: (Suppl. 1): 85 (1977).
100. WESPI, H. J. & BÜRGI, W. Fluoridausscheidung im Urin unter Salz- und Trinkwasserfluoridierung. [Urinary excretion of fluoride following fluoridation of salt and drinking-water]. *Schweizerische medizinische Wochenschrift*, **112**: 1033–1038, (1982).
101. WHITFORD, G. M. & TAVES, D. R. Fluoride-induced diuresis: renal-tissue solute concentrations, functional, hemodynamic, and histologic correlates in the rat. *Anesthesiology*, **39**: 416–427 (1973).
102. WHITFORD, G. M. ET AL. Fluoride renal clearance: A pH dependent event. *American journal of physiology*, **230**: 527–532 (1976).

103. WHITFORD, G. M. ET AL. Fluoride tissue distribution: short-term kinetics. *American journal of physiology*, **236**: 141 (1979).
104. WILLIAMS, J. L. Mottled enamel and other studies of normal and pathological conditions of this tissue. *Journal of dental research*, **5**: 117 (1923).
105. WILLIAMSON, M. M. Endemic dental fluorosis in Kenya. *East African medical journal*, **30**: 217–233 (1953).
106. WORLD HEALTH ORGANIZATION. *Fluorides and human health*, Geneva, World Health Organization, 1970 (WHO Monograph Series No. 59).
107. YOUNG, M. A. *An epidemiological study of enamel opacities and other dental conditions in children in temperate and sub-tropical climates.* Thesis, University of London, London, 1973.
108. ZIMMERMAN, E. T. Fluoride and nonfluoride enamel opacities. *Public health reports (Washington)*, **69**: 1115 (1954).
109. ZIPKIN, I. ET AL. Fluoride deposition in human bones after prolonged ingestion of fluoride in water. *Public health reports (Washington)*, **73**: 732 (1958).

Trends in dental caries

THE creation, in 1969, of the WHO Global Data Bank on Oral Health has enabled health officials to follow and, from 1974, to publicize important trends in relation to the dental caries experience of populations, so that planners can react as early as possible to changed oral health status. The first clear trend affecting large numbers of countries, signalled in 1974, was an increase in caries prevalence in developing countries, particularly in urban centres. Although, by that time, many water fluoridation programmes in highly industrialized countries had demonstrated that reductions in mean DMF (decayed–missing–filled) teeth per person of 50 % or even slightly more could be expected for populations with high to very high prevalence of the disease, the widespread trend of decreasing *national* caries levels in such countries did not become clear from the WHO Global Data Bank until 1978. Since they were first recognized, these two trends have continued in countries where they were first observed and have extended to other countries.

The traditional pattern had been one of high caries experience in industrialized countries and low caries experience in developing countries, but this was clearly changing.

Global situation

What has happened, and is happening, is best displayed in three different forms. First, there are colour-coded global maps for children 12 years of age in 1969 and 1985, and for adults 35–44 years of age in 1983 (Plates 1–3).

The data used in the maps are the latest available. They employ the standard DMF teeth index and related WHO criteria for a sample sufficiently representative of a country or a large population within a country to provide a good working estimate of dental caries prevalence at the national level, i.e., a comprehensive national survey, a national pathfinder survey, a preliminary pathfinder survey, or a survey representing a large sector of a population that is likely to be fairly homogeneous in terms of oral disease experience. It is important to remember that these data have been collected by many different investigators and that some data are quite old (1–10 years for 38 countries and more than 10 years for a further 30 countries) so that they tend to underestimate the increasing or decreasing trend. Despite these unavoidable deficiencies, it is considered that the global maps provide a reliable picture and from them it can be seen that several developed countries have dropped to a lower caries prevalence category, while the situation for developing countries is the opposite. Comparing the data for 12-year-olds in 1969 with those for the 35–44-year age group in 1983 adds a dimension to the cross-sectional picture because these data relate to the status at 12 years of age a generation ago, before the trends had become evident. They therefore provide a "baseline" against which it is possible to judge whether the trends had commenced in 1969 for 12-year-olds in certain countries. Also, they add further evidence of the extent of the change in 12-year-olds by 1985.

For example, in Canada, Finland, Ireland, Norway, Sweden, and the United Kingdom there was a change between the 1969 and 1985 global maps from a very high or high to a high or moderate caries prevalence; in Australia and Switzerland there was a change from very high to moderate. The opposite trend is seen in the changes that took place over the same period in American Samoa, Ethiopia, Jordan, Thailand, Uganda, and Zambia (very low to low or moderate) and in Morocco, Nigeria, and the Philippines (low or moderate to high or very high). Another stark indicator of the increasing trend is that, of 18 developing countries mapped in 1985, only 6 fell in the very low category, while the others ranged from low to high. Almost certainly all of those countries would have been allotted to the very low category in 1969. It is also worth noting that the category "low" for Beijing is an indication that a change towards increased dental caries is occurring in urban areas which would cause massive deterioration in the global oral health status if it extended to the whole of China.

COLOUR PLATES

Plate 1. Global map showing caries prevalence rates (average DMF teeth) in children 12 years of age for the year 1969

DENTAL CARIES PREVALENCE AT 12 YEARS
DATA UP TO AND INCLUDING 1969

D M F T	LEVEL
0.0 – 1.1	VERY LOW
1.2 – 2.6	LOW
2.7 – 4.4	MODERATE
4.5 – 6.5	HIGH
6.6 ⋀	VERY HIGH
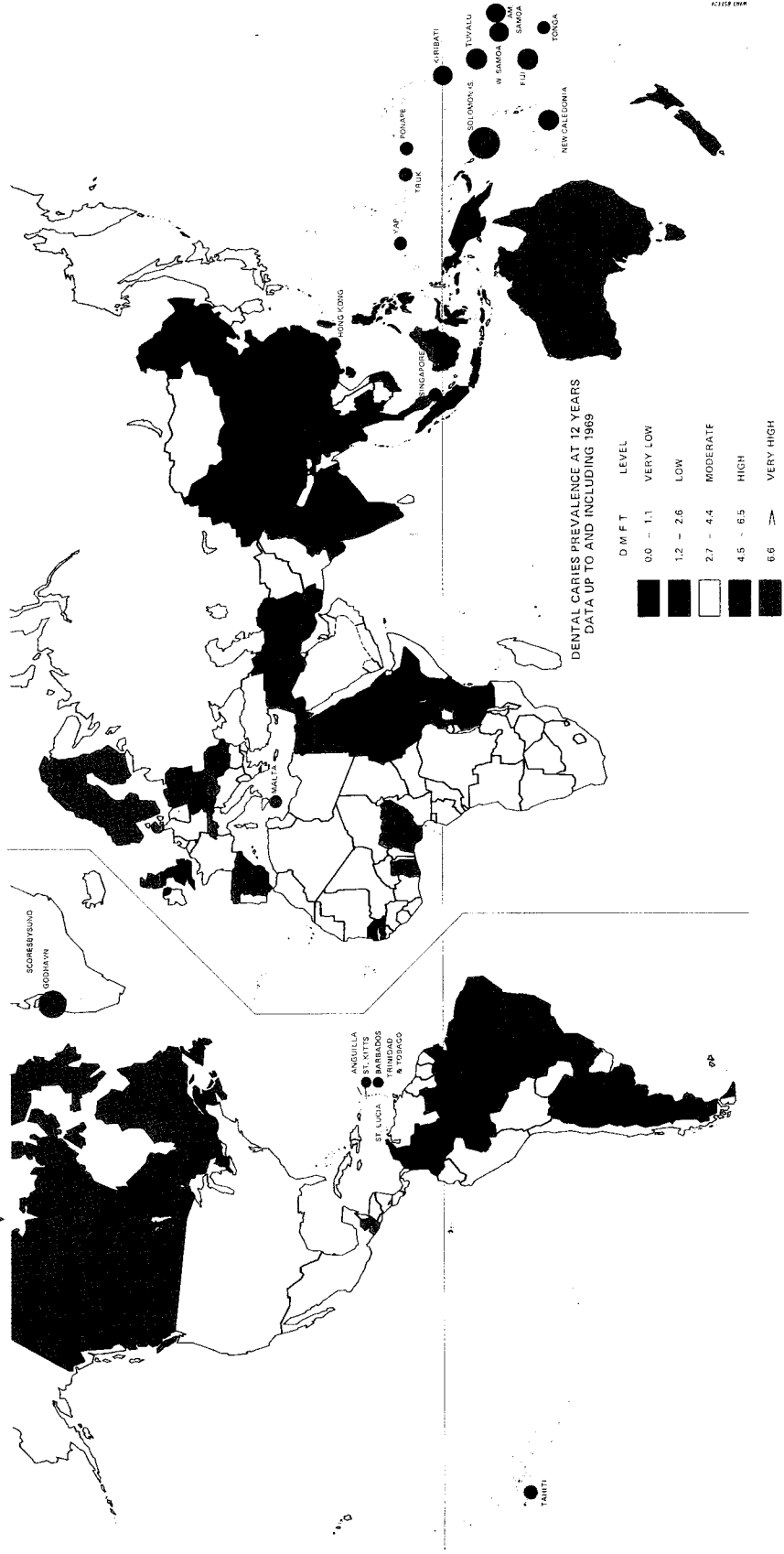
Plate 2. Global map showing caries prevalence rates (average DMF teeth) in children 12 years of age for the year 1985

DENTAL CARIES PREVALENCE AT 12 YEARS
ALL DATA TO 1985

D M F T	LEVEL
0.0 — 1.1	VERY LOW
1.2 — 2.6	LOW
2.7 — 4.4	MODERATE
4.5 — 6.5	HIGH
6.6 ⟶	VERY HIGH
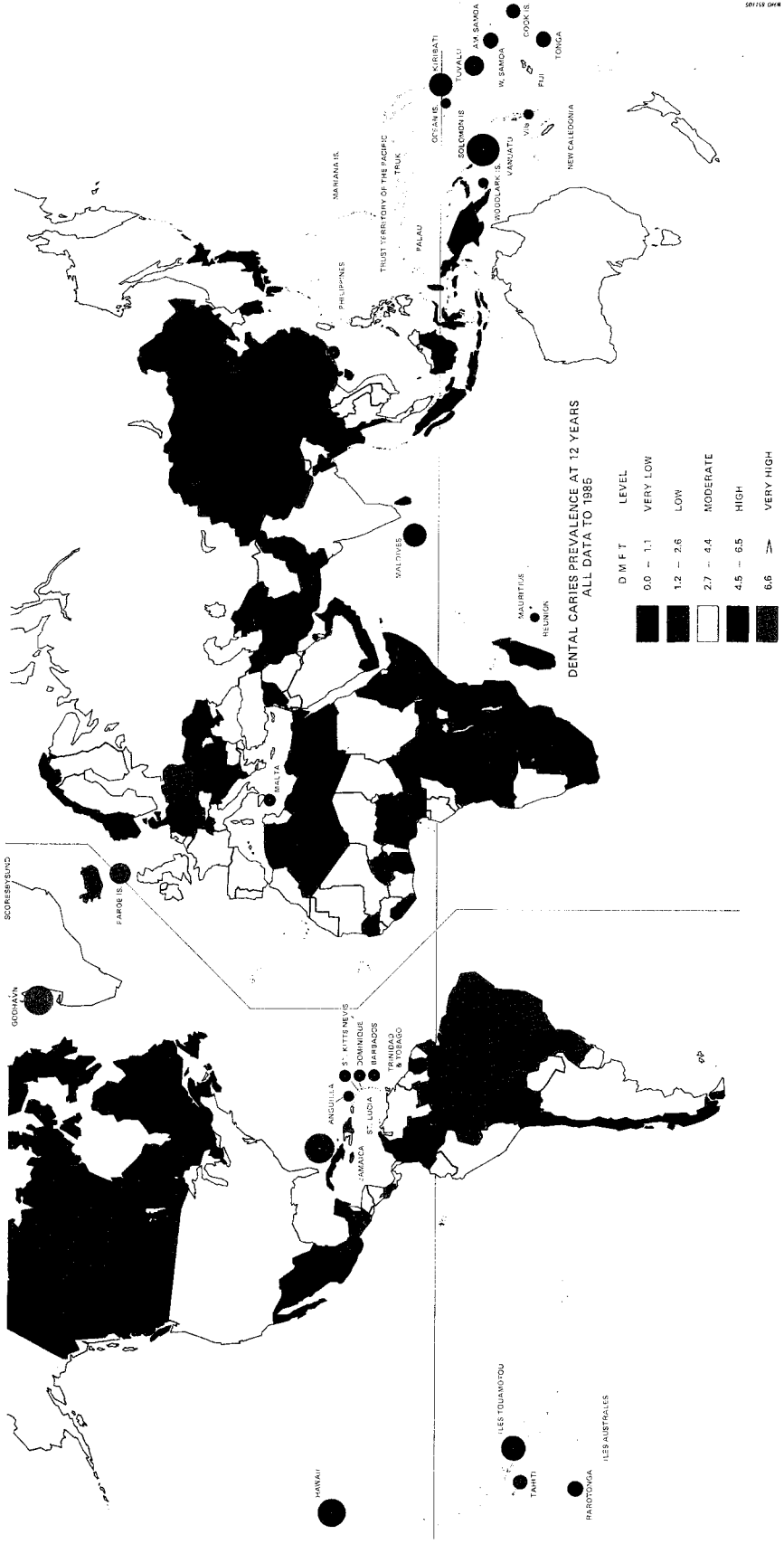
Plate 3. Global map showing caries prevalence rates (average DMF teeth) in adults aged 35-44 years for the year 1983

KIRIBATI

AM.SAMOA

W.SAMOA

COOK IS.

TONGA

TUVALU

FIJI

NEW CALEDONIA

TRUST TERRITORY OF THE PACIFIC

PHILIPPINES

MAURITIUS

ST. KITTS

DOMINICA

ST. LUCIA

TRINIDAD
& TOBAGO

RAROTONGA

MANGAIA

DENTAL CARIES PREVALENCE AT 35 - 44 YEARS

D M F T		LEVEL
0.2	– 1.5	VERY LOW
1.6	– 6.2	LOW
6.3	– 12.7	MODERATE
12.8	– 16.2	HIGH
16.3	>	VERY HIGH

DATA AT 1983
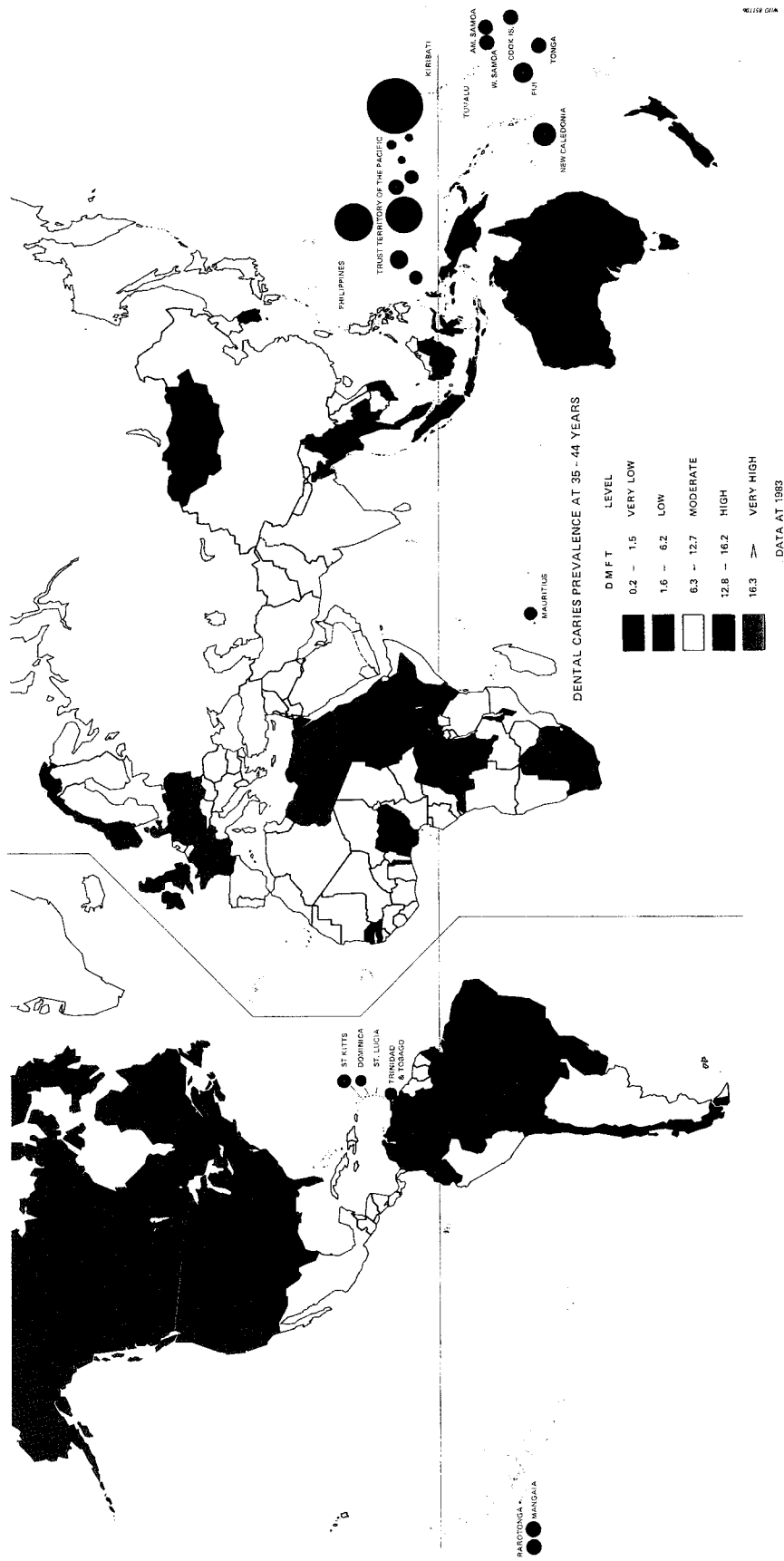
Among the two groups—developing and highly industrialized countries or territories—are some very interesting cases, which on first sight seem to be exceptions. Thus, Hong Kong, Malaysia, and Singapore were classified as developing areas when the Global Oral Data Bank was initiated in 1969. For approximately two decades, fluoridated water has been provided to almost all of the populations of Hong Kong and Singapore and to a large proportion of the population of Malaysia. All three areas have changed from a high caries category in 1969 to a low one in 1985. On the other hand, highly industrialized Italy and Japan have changed from a moderate to a high category, but it should be remembered that, in Japan particularly, industrialization has been a very rapid process attended by dietary changes or, at least, by the introduction of foods of the refined carbohydrate type, so that the caries trend is not surprising. Some of the same pressures may well have applied to population groups in Italy, especially to those that migrated from the rural south to the large urban industrial areas in the north.

The 1983 map for the 35–44-year age group reinforces these comparisons, showing lower caries categories than does the map for 12-year-olds in 1985 for countries experiencing increases in prevalence and the opposite for those where caries is decreasing.

Table 2 shows some actual changes in prevalence as reflected in mean DMF teeth at 12 years of age for selected developing and highly industrialized countries. It is obvious from these data that changes may occur in either direction given similar caries-promoting or caries-inhibiting forces. These data are not necessarily of national validity but indicate highs and lows for large population groups within a given country. The clustering around 3 DMF teeth is especially noteworthy. Also of interest are the data in Table 3 demonstrating the differences between urban and non-urban sections of populations of developing countries. Such differences are a valuable key to trends within a country. These differences, weighted according to statistics for migration to cities and overall population increases, make it possible to estimate the likely impact of the changing levels of caries.

It is a salient feature of the distribution of the main fluoridation measures for caries prevention that they are *all* more readily available and more widely used in industrialized than in developing countries. Since these two groups of countries show opposite trends in caries prevalence, this constitutes strong

Table 2.   Caries prevalence trends in developed and developing countries[a]

A. Highest and lowest mean prevalence of dental caries reported in a group of highly industrialized countries

Country or territory	DMF teeth at 12 years of age			
	Highest	Year	Lowest	Year
Australia	9.3	1956	2.1	1982
Canada	7.4	1958–60	2.9[b]	1979
Finland	7.5	1975	4.0	1982
Japan	5.9	1975	2.0	1979
New Zealand	10.7 (13–14)	1973	3.3	1982
Norway	12.0	1940	4.5	1979
Sweden	7.8	1937	3.4	1979
Switzerland	9.6	1961–63	1.7	1980
USA	7.6	1946	2.0	1980

B. Caries prevalence trends in developing countries

Country or territory	DMF teeth at 12 years of age			
	Level	Year	Level	Year
Chile	2.8	1960	6.3	1978
Ethiopia	0.2	1958	1.5	1975
French Polynesia	6.5	1966	10.7	1977
Islamic Republic of Iran	2.4	1974	4.9	1976
Israel	2.4	1966	3.7	1976
Jordan	0.2	1962	2.7	1981
Kenya	1.7	1973–77	3.7	1982
Lebanon	1.2	1961	3.6	1974
Mexico	2.7	1972	5.3	1976
Morocco	2.6	1970	4.5	1980
Philippines	1.4	1967–68	2.9	1981
Thailand	2.7	1977	4.4	1982
Uganda	0.4	1966	1.5	1982
Zaire	0.1	1971	2.3	1982

[a] Most mean prevalence rates are not national data.
[b] Aged 13–14 years.

circumstantial evidence that fluoridation lowers the prevalence of dental caries. However, there are some very interesting and important features that need to be considered in relation to future strategies aimed at improving oral health on a global scale.

Table 3. Decayed, missing, and filled teeth in 12-year-olds in non-industrialized countries

Date	Country or territory	Rural	Urban
1977	Thailand	1.6	3.0
1982	Morocco	2.5	4.3
1978	Oman	0.7	2.5
1979	Saudi Arabia	1.3	2.2
1979	Somalia	0.3	1.5
1980	Syria	1.3	3.4
1981	United Arab Emirates	1.2	2.6
1982	Cameroon	1.4	1.8
1979	Sudan	0.4	1.4
1981	Jordan	2.2	3.4
1982	Burma	0.8	3.1
1981	China	0.6	1.9

Clearly, from the global viewpoint, WHO's objective is to promote (a) the continuation of the decreasing caries trend in industrialized countries and (b) the arrest and, in many cases, the reversal of the opposite trend in developing countries. The guidance provided in subsequent chapters on the various fluoridation measures for caries prevention and on a strategy for choosing among them is vital to the achievement of that objective. Especially important at the present time is the guidance given on the multiple use of fluoridation methods, as is that given for situations where that natural fluoride content of water supplies is excessive.

Although research is still needed to improve preventive capability, enough is already known to make possible further giant steps in the prevention of dental caries. It is necessary to ensure that present capabilities are exploited to the maximum in all parts of the globe, especially in developing countries where the need is greatest.

3

Community water fluoridation

Areas with different concentrations of fluoride in drinking-water

STUDIES in the USA by Dean et al. (*15*) suggested that, in temperate climates, a high degree of reduction in caries occurred when the fluoride content was approximately 1 mg/litre. This observation was confirmed by results from Denmark and Sweden (*23*) (Fig. 7). Further studies have shown that, in both the deciduous and the permanent dentitions, there was a very strong inverse correlation between decreasing caries and increasing fluoride content of the water supply, up to about 1–1.5 mg of F^-/litre (*1, 9, 25, 27, 43, 52, 60, 73*). Further, the prevalence of dental fluorosis increased markedly when the content of fluoride in the water increased above 1 mg/litre. These two sets of observations led to the process of adjusting the amount of fluoride in a community water supply to an optimal concentration for the prevention of dental caries— community water fluoridation schemes. In temperate climates, the optimal concentration for community fluoridation is 1 mg of F^-/litre.

Community water fluoridation schemes

The first community water fluoridation scheme began in Grand Rapids, USA, in 1945 and was quickly followed by other large-scale studies in North America. To date, progress reports on caries-preventive effects due to water fluoridation are available
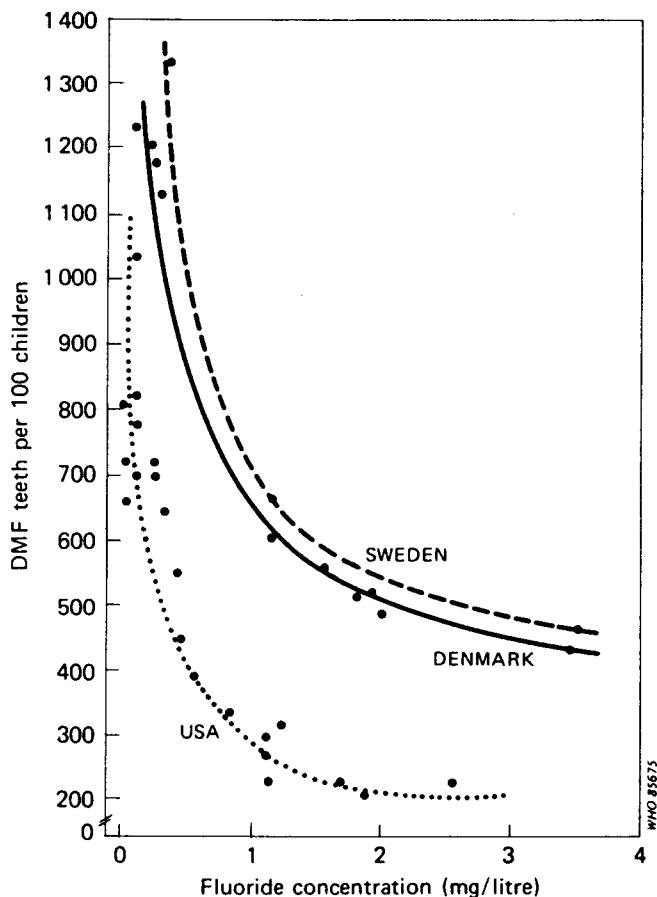
Fig. 7. Caries experience in 12- and 13-year-old children from Denmark, Sweden, and the USA, in relation to the fluoride content of the public water supplies (from MØLLER, I. J. *Dental Fluorose og Caries.* Munksgaard, Copenhagen, 1965.)

from 21 countries (*50*). Owing to the fact that clinical studies had been performed taking the international survey standards of WHO and FDI as a basis, the results compare well with one another (Fig. 8). The findings of 97 studies in these countries show that optimal water fluoridation is highly effective (*50*). As measured in 57 of these studies, the most frequently observed reduction in the prevalence of dental caries in primary teeth ranged from 40 to 50 %. Among the 72 studies that measured protection in permanent teeth, the most frequently observed range of protection was between 50 and 60 %. Indications of the effectiveness of water fluoridation, based upon new studies or

Fig. 8.   Percentage of caries reduction observed in 95 studies into the effectiveness of artificial fluoridation in 20 countries[a]

[a] Reproduced by permission from Murray, J. J. & Rugg-Gunn, A. J. *Fluorides in caries prevention.* 2nd ed., Bristol, John Wright, 1982.

upon longer control periods (*7, 13, 29, 55, 74*), are in keeping with those findings.

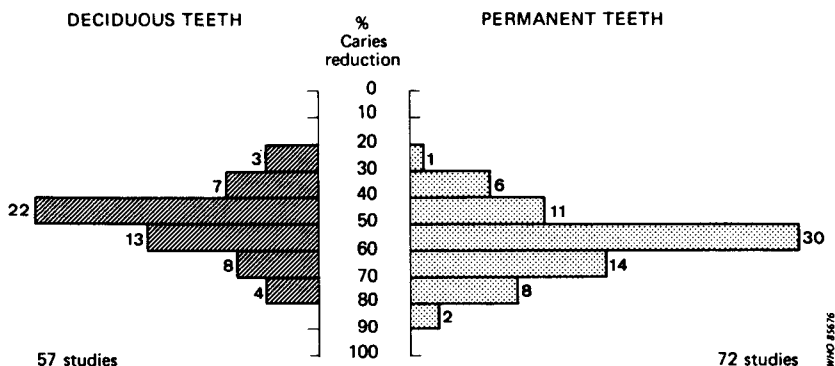Caries reduction in the primary and permanent dentitions has also been associated with a slower rate of progression of carious lesions (*38*) with less frequent involvement of the dental pulp (*20*), and with an increasing number of subjects with caries-free dentitions. These effects of water fluoridation occur in the populations served, irrespective of social differences (*15*).

The provision of drinking-water with adequate amounts of fluoride does not merely delay the development of dental caries in children, but gives substantial life-long protection (*34, 49, 62*).

More than 30 years ago, Russell & Elvove (*62*) found that in Colorado Springs, adults 20–44 years of age who throughout their lives had consumed water that contained 2.5 mg of F^-/ litre, had approximately 60 % fewer DMF teeth for each 5-year age group than did adults of the same ages in Boulder, Colorado, who had consumed water with only trace levels of fluoride. As a result of caries, natives of Boulder had lost 3–4 times as many teeth as natives of Colorado Springs. A more recent study of British adults up to 45 years of age showed similar effects for water supplies containing two contrasting levels of fluoride—0.2 mg/litre and 1.5–2.0 mg/litre (*34*). Moreover, another recent report (*68*) shows that lifelong consumption of fluoridated water also significantly lowers the prevalence of root surface caries in older persons.

For oral health, it is of vital importance that the optimal

supply of fluorides be made available permanently. Long-term studies have revealed that the caries-protective effect may be diminished or wholly eliminated if water fluoridation is interrupted (39, 41). Thus, great importance is attached to continuous water fluoridation.

Table 4 gives estimates of the number of countries and populations having natural or adjusted water fluoridation. With respect to the latter, schemes are in operation or planned in some 46 countries, which vary enormously in climate, geography, and type of political system.

Table 4.   Status of water fluoridation in 1969 and 1981

Description	1969[a]	1981[b]
Number of countries (fluoride added)	32	35
Population served (fluoride added)	110–130 million	210 million
Population served (natural fluoride— unadjusted)	?	103 million[c]

[a] Royal College of Physicians (59).
[b] Fédération Dentaire International. Basic fact sheets, 1981.
[c] Probably underestimated as information was missing for 48 of 116 countries.

Climate and controlled water fluoridation

Drinking habits are affected by ambient temperatures and thus climate influences the quantity of fluoride ingested daily (26). Failure to make adjustment for this factor may result in a higher prevalence of fluorosis (48, 51) in warmer climates, but it may also lead to reduced caries protection if upward adjustment is not made in colder climates.

In 1962, the US Public Health Service established limits for fluoride for the climate zones of North America (45) that had been considered to be the determinants for the gradation of concentrations as a function of the mean annual temperature ($18°C = 1.2$ mg of F^-/litre; $19–26°C = 0.9$ mg/litre; $27°C$ or higher $= 0.7$ mg/litre. These limits are also used in Central and South American regions as a basis for the determination of fluoride concentrations in water. A similar method is used for the different climatic zones in the Soviet Union, according to the epidemiological studies performed (2, 64). The country has been subdivided into three horizontal zones, 0.6 mg/litre being designated as optimal for the south, 1.0 mg/litre for the central zone, and 1.2 mg/litre for the north.

The optimum caries-protective effects of different fluoride concentrations have been demonstrated in hot climatic zones (0.6 mg of F⁻/litre) and in cold zones (1.0–1.2 mg of F⁻/litre). For the former the studies were done in Brazil, Chile (71), Colombia (10, 75), Puerto Rico (28), and Cuba (40) and for the latter in extremely cold zones (including the Arctic) in the north of the Soviet Union (6, 37, 61, 65). In those extremely cold zones, the relations between the frequency and intensity of white spots on the teeth and fluoride concentrations in drinking-water have not been studied very satisfactorily. The lack of sufficient baseline data and diagnostic criteria have been problems in this area. Studies performed in Cuba—after introducing water fluoridation—have revealed that, in spite of exceeding the established limit of 0.6 ± 0.1 mg of F⁻/litre, no signs of white spots on the teeth due to fluorides have become evident (40).

Although it is considered that water is the most important component of the food chain with regard to fluoride uptake in man, other parts of the food chain should also be taken into account, particularly in areas where the diet is known to be high in fluoride. For example, in the fluoridation scheme in Japan, it was decided to adjust the fluoride concentration in the drinking-water to 0.6 mg of F⁻/litre because the Japanese consume large quantities of fish, tea, and seaweed, all of which are rich sources of fluoride.

Systemic and topical effects of water fluoridation

It has been shown that in order to achieve maximum protection for both permanent and primary teeth, the consumption of fluoridated water should begin at birth (46). The systemic effects of fluoride are most apparent in water fluoridation studies. Selected data for children aged 9 and 13 years, as reported by Arnold et al. (3, 4) for Grand Rapids, are shown in Table 5.

Table 5.   Decayed, missing, and filled teeth as a function of exposure to fluoridated water[a]

	Years of exposure prior to examination			
	0	3	8	13
Nine-year olds	3.90	3.12	2.02	—
Thirteen-year olds	9.73	8.47	5.87	3.86

[a] Values are average DMFT per child. Data are compiled from Arnold et al. (3, 4).

In children aged 9 years, the number of DMF teeth had fallen from the initial average of 3.90 in 1944–45 to 3.12 by 1947. The latter figure relates to children who had been exposed to fluoridated water since the age of 6 years. However, in 1952 an average of only 2.02 DMF teeth was found in 9-year-old children who had been exposed to fluoride since the age of 2 years. Pre-eruptive fluoridation had provided the greater part of the benefit. The great majority of teeth becoming carious, i.e., decayed, missing, or filled, prior to age 9 were first molars, which erupt at age 6 years.

Children of age 13 had 9.73 DMF teeth in 1944–45. This mean had fallen to 5.87 in children exposed to fluoride since the age of 5 years (at the 1952 examinations). Children examined in 1957, who were born at about the time of commencement of fluoridation (March 1945) showed only 3.86 DMF teeth. In this age group, two teeth on average (5.87–3.86) were saved from becoming DMF when water fluoridation was started at birth instead of at age 5.

The summarized findings of several water fluoridation studies are given in Fig. 9. For the Grand Rapids study, with
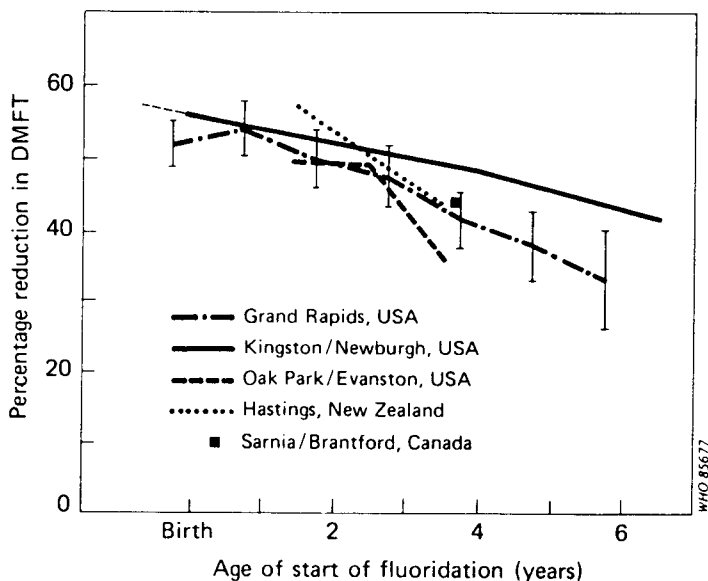

Fig. 9. Percentage inhibition of caries in the permanent dentition (reductions of DMF tooth counts) according to the age at which the children were first exposed to fluoridated water[a]

[a] Reproduced by permission from Marthaler, T. M. (46).

examinations every year, it was possible to compute confidence limits ($P = 0.95$) based on several age groups with fluoride supplementation starting at various ages from 0 to 6 years. The results of all studies indicate that there is little difference in the percentage reduction (50–60%) of caries in the permanent dentition whether fluoride is given from birth or from the age of 1 or 2 years. Moreover, all studies indicate a reduction of less than 50% when water fluoridation is begun at 4 years of age or later.

However, these data also show that fluoridated water not only acts systemically during tooth formation to make dental enamel more resistant to decay, but also acts directly as a topical agent.

The benefits of fluoride are not uniformly conferred on all permanent tooth surfaces; approximal and other smooth surfaces are protected to a far greater extent than are pit-and-fissure surfaces (46, 63). For example, the Culemborg-Tiel study in the Netherlands showed that fluoridated water brought about a caries reduction of 86% in gingival areas of buccal–lingual surfaces and 7.3% in approximal surfaces. In contrast, pit-and-fissure surfaces showed only about 37% fewer carious lesions (5). Although fluoridation benefits smooth surfaces more than pit-and-fissure surfaces, the systemic and pre-eruptive effects are more important for the protection of pit-and-fissure surfaces than for smooth surfaces (46).

Logistics, implementation, technical aspects, and defluoridation

Because of the exceptional health and economic benefits it confers, water fluoridation has been endorsed and recommended by more than 150 scientific, health, and political organizations, including the FDI, the International Association for Dental Research (IADR), the European Organization for Caries Research (ORCA), and WHO. Since 1945, fluoridation has been implemented in numerous countries, to a degree depending on the existing public water supply systems as well as on economic and sociopolitical factors. Some of the most successful programmes include those in Hong Kong and Singapore, where virtually complete fluoridation has been achieved, the Republic of Ireland, where approximately 70% of the population on a piped water supply system has received fluoridated water, Puerto Rico (63%), the USA (51%), Australia (50%), New Zealand (50%), Canada (28%), and Great Britain (12%). Advanced fluoridation pro-

grammes are in operation in the socialist countries of Eastern Europe, e.g., the Soviet Union (20%), the German Democratic Republic (20%), Czechoslovakia (12%), and Poland (8%). There are statutory provisions in the countries for the step-by-step extension of the programmes.

Progress in fluoridation has also been made in Central and South American countries, as well as in Australia, New Zealand, and Malaysia. Initial steps are being taken in many Asian and African countries. One of the advantages of water fluoridation is that the entire community benefits from the caries preventive measure, regardless of age, socioeconomic level, educational achievement, individual motivation, or the availability of dentists. In this context, the clinical advantage of passively obtained benefit should also be weighed against the legislative convenience and political desirability of offering freedom of choice.

Limitations of community water fluoridation

The crucial requirement for community water fluoridation is a well established, centralized piped water distribution system. Unfortunately, in most developing countries, where caries is increasing sharply, centralized water distribution systems are often lacking, even in densely populated urban areas, and they are rarely found in rural regions. To appreciate the global importance of caries prevention and the potential of water fluoridation, it should be remembered that the population of the world is approximately 4500 million and probably more than 50% reside in villages and rural areas. Seen in this perspective, the status of water fluoridation and the time trend (Table 4) are disappointing. Water fluoridation serving 4–5 million people in 5 or 6 countries was discontinued between 1969 and 1981. During this time, it was introduced in 8 or 9 others. Most of the increase in the number of persons served by fluoridated water between 1969 and 1981 was due to population growth in fluoridated areas and to new projects in countries with established traditions of fluoridation—for example, Australia, Brazil, Colombia, Malaysia, the United Kingdom, the USA, and the USSR.

Implementation of fluoridation schemes

To be able to introduce a water fluoridation programme, it is essential for the executing agency to have the support of the top health authorities and of the government. At a national level,

government authorities should express through laws, decrees, regulations, budget allocations, etc., their support for the agency executing the fluoridation programme, whether this be the ministry of health, the national agency responsible for the drinking-water supply, or another official agency or private institution.

Water fluoridation should be considered a multiprofessional type of activity, in which dentists, engineers, chemists, nutritionists, physicians, and other professionals of the health sector should participate. Although the main tasks in fluoridation programmes are usually carried out by dentists and engineers, the participation of other groups is of the utmost importance in all aspects of the programme, including promotion, planning, financing, introduction, operation, maintenance, and monitoring.

Assuming that the necessary support from the profession and the community has been assured, it is essential to supervise the implementation of a water fluoridation system so that any fault is quickly remedied and any potential controversy avoided.

Choice of equipment and chemicals

The choice of equipment and of fluorides to be used in a water fluoridation programme will depend on circumstances. Various alternatives are listed below. The Dental Health Division of Kentucky, USA, has published a manual for small community fluoridation, which is quite comprehensive (67). Its contents include costs of installation, maintenance, surveillance, etc., and a table listing the costs of spare parts and chemicals. The addresses of suppliers of equipment and materials are available from the Oral Health unit, World Health Organization, 1211 Geneva 27, Switzerland.

When planning a fluoridation system, the selection of the chemical product to be used as the source of the fluoride ion will have an mportant bearing on the final decision as to the type of distribution equipment to be installed. Thus, a saturator is used with granular sodium fluoride, a dry distributor with silico-fluoride or sodium fluoride, and a liquid distributor with hydrofluosilicic acid. The product used should conform to established standards.

The following general characteristics of the system need to be considered:

— The equipment for fluoridation must be adapted to local conditions and needs of the water network.

— The equipment must be efficacious, safe, and precise in all climatic conditions.

— It should be of a standard type, recognized as satisfactory, and for which maintenance is also easily provided.

— The choice of distributor should be based on the quantity and type of fluoride-bearing product used.

— The equipment should have well-defined precision limits, i.e., not more than a 5% error in the whole system whatever the variation in the quantity of water treated. In order to avoid any overdosage, it should be provided with a safety mechanism that automatically stops the addition of fluoride if the flow of water through the treatment plant is suddenly diminished.

— Adjustment of the distributors must be sufficiently easy and rapid.

— The apparatus should operate at between 20% and 80% of its total capacity; this is a security measure that assures a maximum fluoride dosage of 5 times the optimum level in case of serious malfunction. Such a level of fluoride is considered safe for a short period.

— In each fluoridation system an antisiphon mechanism should be installed in the pipes that distribute the fluoride solution into the water, in order to avoid a concentrated solution of fluoride entering the distribution system.

Fluorides used

(*a*) Sodium fluoride

— in granular form when used with the saturator to avoid rapid obstruction of the gravel bed
— usually available in 45-kg bags
— the most expensive source of fluorides.

(*b*) Sodium silicofluoride

— usually available in 45-kg bags
— the cheapest form of fluoride.

(*c*) Hydrofluosilicic acid

— slightly more expensive than silicofluoride on account of the cost of transporting liquids
— can be delivered by tanker lorry with a capacity up to 19 000 litres.

Types of equipment available

The three principal types of fluoridation equipment at present in use in Canada and the USA are (a) the saturator system, (b) the dry-feeder system, and (c) the solution-feeder system. These three types are illustrated in Fig. 10–14 and described briefly below:

(a) *Saturator system* (Fig. 10)

— Principle: a 4% saturated solution of sodium fluoride is produced and injected at the desired concentration at the water distribution source with the aid of a pump.
— Factors limiting utilization: a high hard water level (total hardness of over 75 mg/litre), the need for care in the handling of fluorides, the high cost of sodium fluoride, the need to clean the gravel bed used for water filtration.
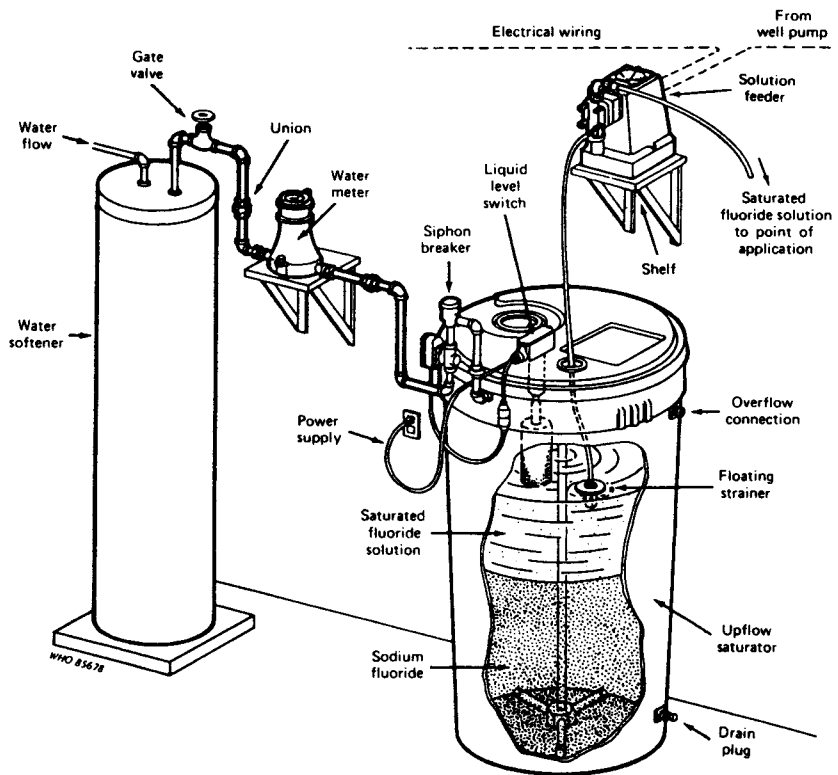
Fig. 10.   Saturator system for water fluoridation

— Recommendation: suitable for small towns with a total requirement of less than 3.8 million litres per day.

(b) *Dry-feeder* (Fig. 11 & 12)

— Principle: sodium fluoride or silicofluoride in the form of powder is introduced into a dissolving basin with the aid of an automatic mechanism to ensure maintenance of the correct supply of fluoride according to the amount of water to be delivered.

— Factors limiting utilization: the need for care in the handling of fluorides, the high cost of sodium fluoride, obstruction of pipes, compacting of fluoride while stocked in a humid atmosphere.

— Recommendation: suitable for medium-sized towns, 3.8 million litres per day, capacity 19 million litres per day.
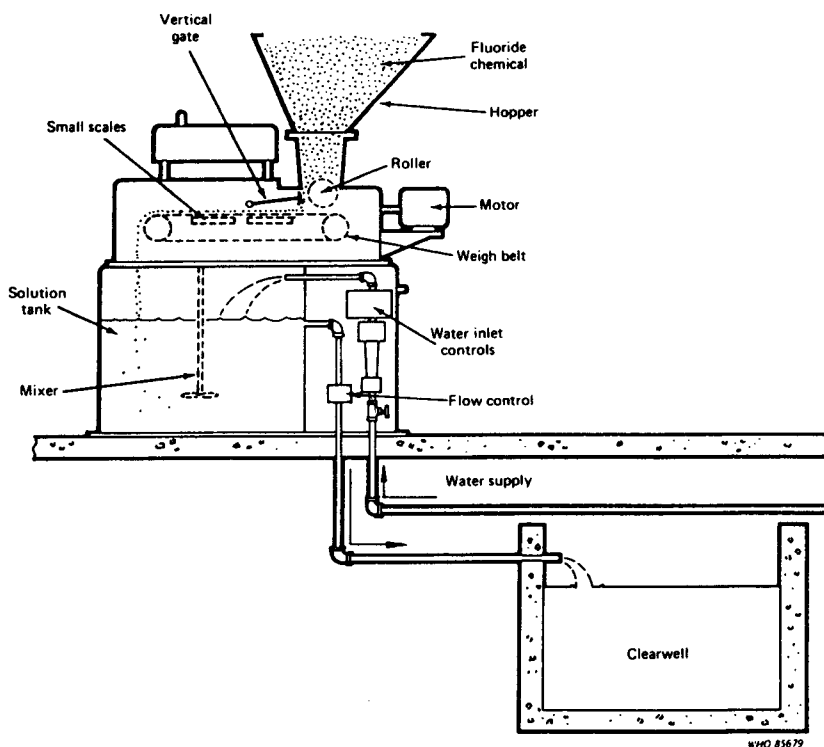
Fig. 11.   Belt type of gravimetric feeder for water fluoridation
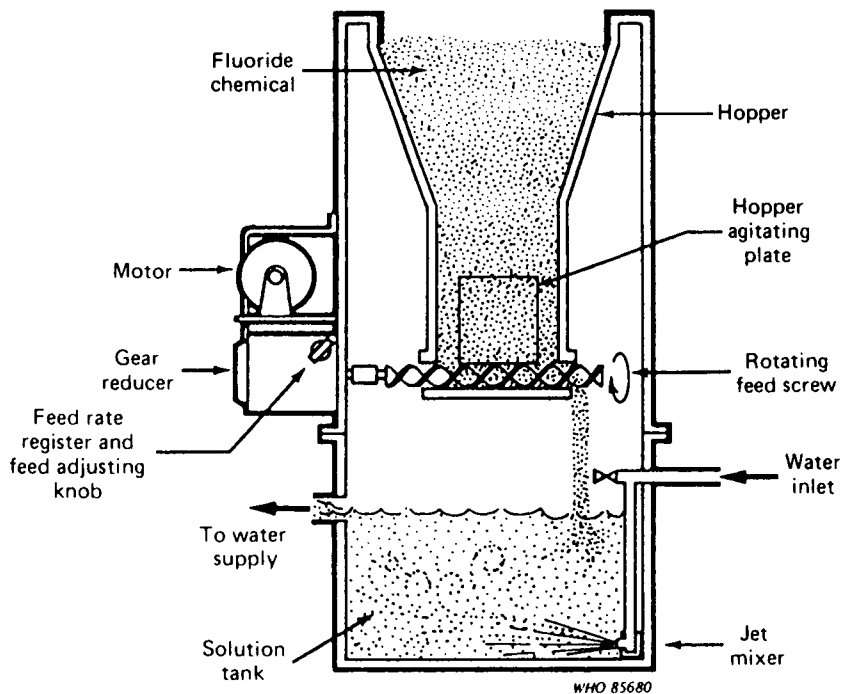
Fig. 12.   Screw type of volumetric feeder for water fluoridation

(c) *Solution-feeder* (Fig. 13 & 14)

— Principle: volumetric pump permitting the addition of a given quantity of hydrofluosilicic acid in proportion to the amount of water treated.
— Factors limiting utilization: all the equipment must be resistant to attack by hydrofluosilicic acid, necessitating construction in (polyvinyl)chloride or another plastic; imprecision in determining the volume used for small quantities.
— Recommendation: suitable for medium-sized and large towns, capacity more than 7.6 million litres per day.

The conventional systems, such as those described above, are either upflow saturators using proportioning pumps that deliver sodium fluoride or sodium silicofluoride or else they employ proportioning pumps to deliver hydrofluosilicic acid, either directly out of a carboy or after appropriate dilution. Although these systems work well, they incorporate electrical and
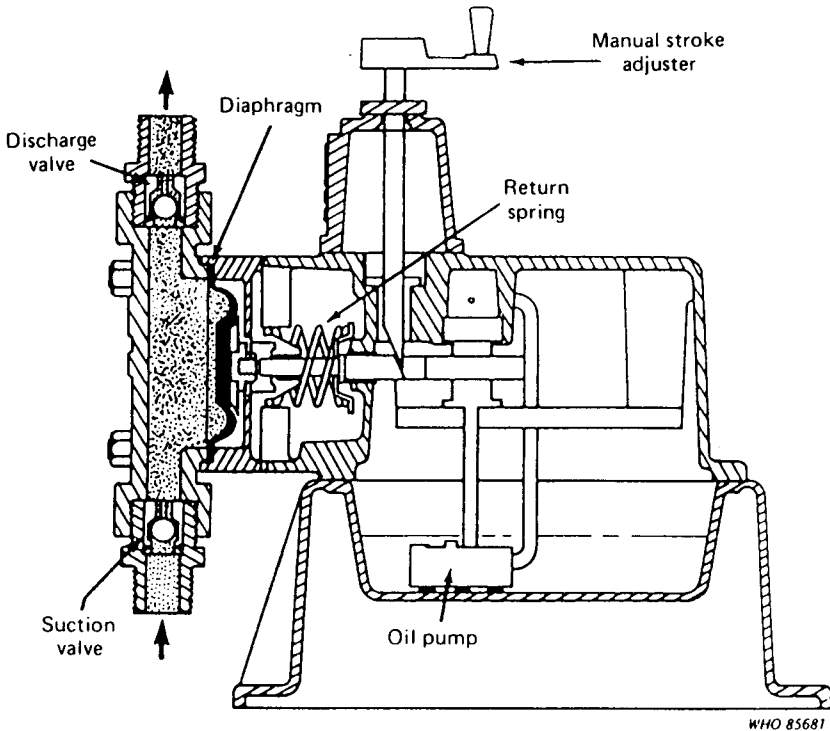
Fig. 13. Typical diaphragm solution feeder for water fluoridation

mechanical devices that require maintenance by capable oper-
ators. Two systems that do not suffer from these drawbacks—the
Venturi fluoridator system and the Saturation–suspension
cone—are described below.

Venturi fluoridator system

In the USA, the Indian Health Service, a branch of the US
Public Health Service, has operated a community water
fluoridation programme in several hundred small rural communi-
ties for many years. These communities do not usually have
conventional repair personnel, parts, etc. It was, therefore,
necessary to develop a system that would function with the
minimum amount of maintenance and operational problems, yet
be able to deliver reliably the correct and optimal fluoride levels.
    The Venturi fluoridator system (Fig. 15), developed by J. N.
Leo, is activated by the flow of water in the main water line and
there is no possibility of accidental overdosing by surges of
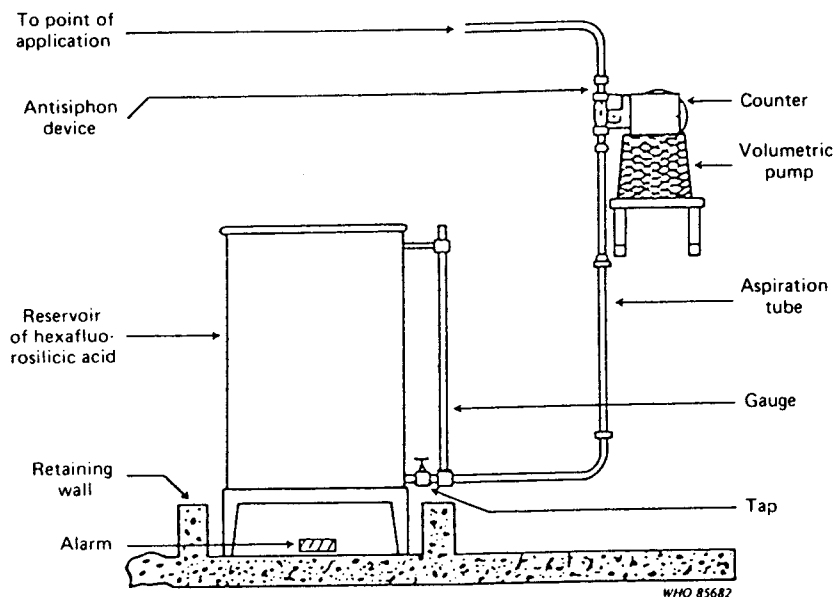
Fig. 14.   Solution-feeder for water fluoridation

fluoride being introduced into the distribution system when the main water pump stops. It is a non-electrical system so it can be installed anywhere. The tank containing the fluoride is made of a clear acrylic thermoplastic (e.g., Plexiglass) that enables the operator to make a visual inspection of the level of chemical at any time in order to replenish it. Because of its simplicity, the Venturi fluoridator can be installed in a single-family dwelling or in a larger community up to a small metropolitan area. Another advantage is that the cost of this unit (approximately US$1200–$1300, depending on size) is approximately two-thirds of the cost of the conventional equipment. The annual cost should be somewhat lower than that of conventional equipment and operational and maintenance costs should also be lower. The amount of chemicals used is the same as for other equipment (Leo, J. N., personal communication, 1982).

Saturation–suspension cone

In Brazil, the water and sewage authority of the state of Rio Grande do Sul has developed a simple method for feeding sodium silicofluoride solution by means of an upside-down cone charged with a bag of sodium silicofluoride. A constant flow of

DETAIL

Fluoride
injection
point

Water
from well

To
distribution
system

Fluoride injection
point

Pressure relief
valve

Plunger

Sodium
fluoride
(clear plastic
cylinder)

Zeolite
water
softener
(clear
plastic
cylinder)

Needle
control
valve

WHO 85683

Gate valve   Flowmeter
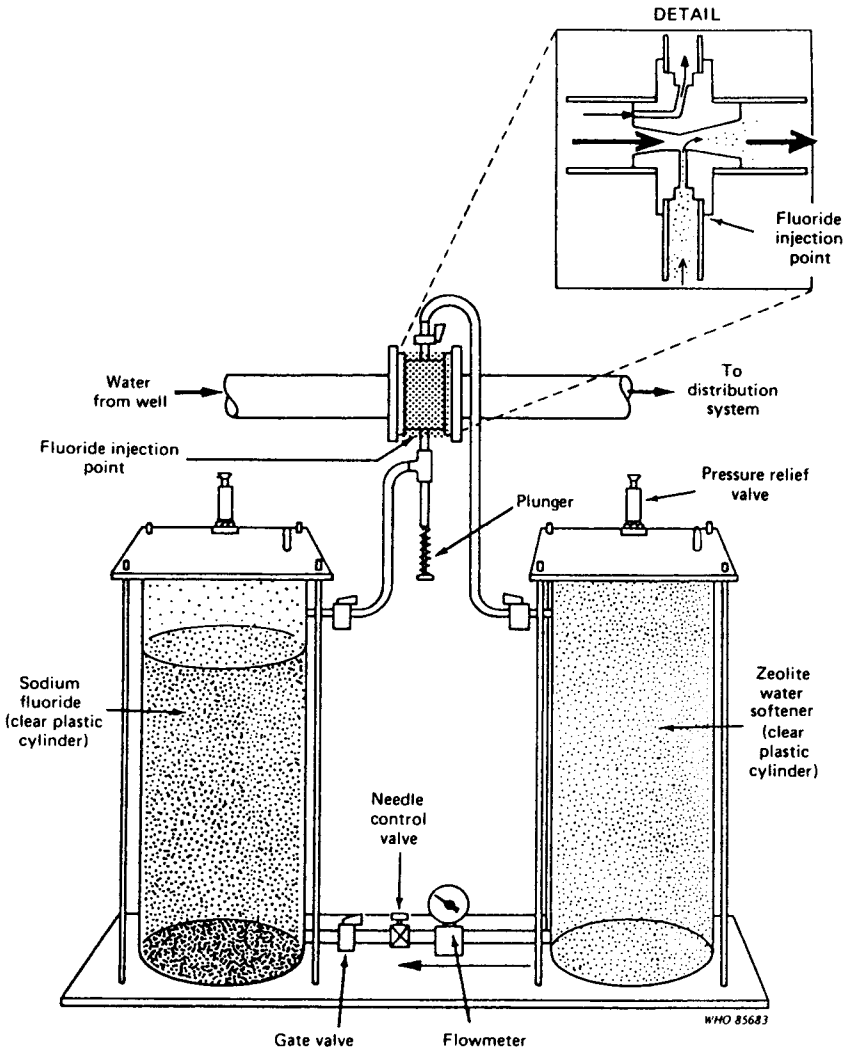
Fig. 15   Venturi fluoridator

water percolates upwards through the bag and the solution is collected at the top by a horizontal perforated plastic pipe, which forms the outlet (see Fig. 16).

The complete installation consists of the following parts:

(a) A cone 0.91 m high and 0.91 m in diameter, mounted upside down on a tripod made of 2-cm diameter rod or galvanized iron tubing.
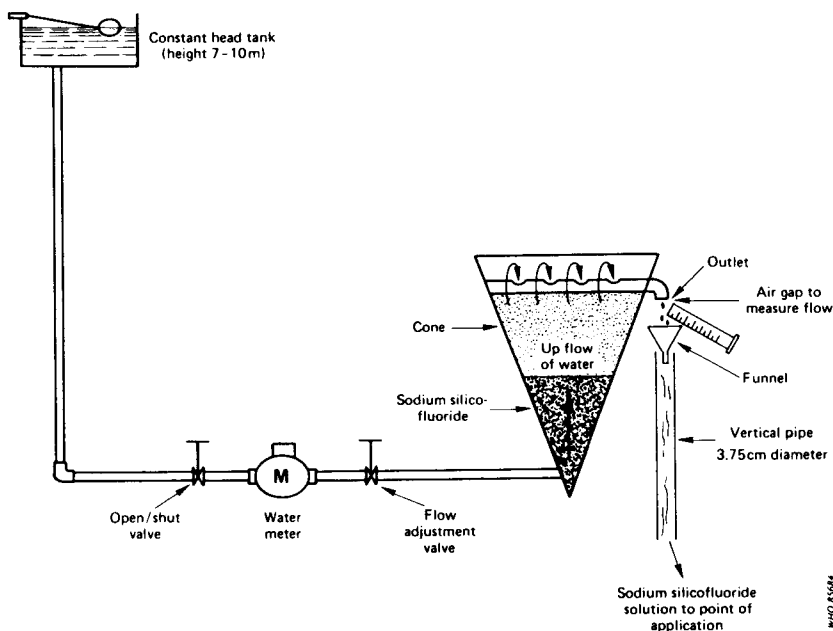
Fig. 16. Saturation-suspension cone for water fluoridation

(b) A elevated constant head tank (7–10-m head) for feeding water to prepare a constant volume of solution.

(c) A 2-cm diameter connecting pipe from the constant head tank to the lower end of the cone. A shut-off valve and a flow-regulation valve are inserted in the line, as well as a water meter or flow meter to measure the instant flow of water and the accumulative flow in a given period of time. The 2-cm diameter inlet is reduced in diameter at the lower end of the cone to 1.2 cm.

(d) A surface collector consisting of a horizontal perforated 2.5-cm diameter pipe collects the solution and discharges it into a wide-mouth funnel, which is connected to a 3.75-cm diameter pipe. This pipe feeds the solution to the point of application.

The cone must be built of a corrosion-resistant material, such as stainless steel, fibre glass, or standard steel with a (polyvinyl)chloride lining.

It is charged with a 45-kg bag of sodium silicofluoride. If the consumption of chemical is 20 kg/day, this amount must be added daily. In any case, it is recommended that the quantity of salt in the cone be never less than 25 kg.

Technical considerations

It is important to remember that fluoridation can easily be integrated into general water treatment plants; it is a minor part of the process and does not need extra personnel. For this reason, once the installation has been made, the principal cost of fluoridation is that of the cost of the fluoride used.

When discussing the choice of fluorides it is important to consider ease of manipulation of the different products. To avoid problems inherent in dosing, such as obstruction of pipes and the hazard of toxic dusts, it may be more appropriate to use a liquid fluosilicic acid rather than fluorides in powder form.

It is also important to realize that, although fluorides such as sodium fluoride (NaF), sodium silicofluoride (Na_2SiF_6), and hydrofluosilicic acid (H_2SiF_6) are produced in factories, once they are dissolved in water they give fluoride ions identical to those produced by the solution of a naturally occurring fluoride compound such as calcium fluoride (CaF_2).

(a) Maintenance and control

The system of fluoridation must be carefully maintained in order to ensure maximum efficiency at all times. A sufficient quantity of spare parts to ensure the maintenance of the system should be available.

The dosage of the chemical product should be controlled in order to ensure that a uniform concentration of fluoride ions is maintained at all times and in all parts of the network. Samples should be taken from all parts of the system. For example, in Canada, in the province of Quebec, four control mechanisms for the fluoridation of water have been established: analytical control at the water treatment plant, analysis of samples from different parts of the water distribution network, control of the quality of these analyses, and control of the quality of the fluoride chemical used (8).

(b) Control at the water treatment plant

Analytical control at the plant consists of determination of the fluoride content of water as it leaves the treatment plant and also in the water network. Such controls can be made with a specific ion electrode. It is extremely important that the water plant operators be trained in these procedures.

Analysis of the fluoride content of the water is vital in order to determine whether fluoridation of the water is being implemented at the optimum concentration. Only via these

analyses can the continued normal operation of the system be monitored. Any variation in the level of fluoride should be noted and the operator should make an immediate correction.

The analyses of the water leaving the treatment plant should be made several times a day and those of the water in the distribution network at least once per day. These analytical determinations should be noted on an official recording sheet and means of the daily determinations included in a report register. A copy of this register should be sent each month to the responsible authority.

(c) Control of the quality of analysis

In order to control the quality and accuracy of the fluoride analyses, the responsible authority should send three "blind" samples each month for analysis at the water treatment plant. The results of the analysis of these samples should be returned within 48 hours to the responsible authority. If any difference from the known content exists, then technical assistance to correct the analysis technique should be sought.

(d) Control of the quality of water in network

Once a week, personnel from the water plant should take samples from the distribution network and send them for analysis to a responsible, independent laboratory. Such analyses will enable the validity of the monthly reports to be checked and should indicate any inherent anomalies in the distribution network. These determinations should be noted also in a register and should be used for preference over all others as a record of the period of application of fluoridation in the region and the fluctuations in concentration during that period.

(e) Control of the quality of fluorides used

Each time a delivery of fluorides is received, samples of the product should be analysed in order to verify that they correspond to the criteria of quality approved by the responsible authorities. This check ensures that the supplier of the chemical has fulfilled the contract. If not, the consignment should be replaced.

Partial removal of fluorides

The technology of partial defluoridation has been well developed and tested, and equipment units are readily available from specialized engineering firms. Experimental work and

practical applications of techniques for partial defluoridation have been carried out in Argentina, India, Mexico, and the USA. Emphasis in India has been on developing a local material as the absorbing medium to reduce costs. At various times in recent years, United States agencies and companies have received inquiries about defluoridation from Australia, China, Kenya, Libyan Arab Jamahiriya, and South Africa, but there has been no further news of developments, and the literature does not indicate much activity.

Where defluoridation has been put into practice in the treatment of public water supplies in the USA, the process has been effective (72). The partial removal of fluoride should be recommended where there are no other suitable available sources of drinking-water of lower fluoride content.

The purpose of partial defluoridation of water supplies is to reduce the fluoride concentration to the optimal value so as to avoid any occurrence of undesirable dental fluorosis and also to avoid any other adverse effects. It may be achieved in the following ways:[1]

— at a central water treatment plant by absorption of fluoride in a suitable medium by means of an ion-exchange process;

— by the use of smaller units using similar principles of operation to that above, installed in homes and other places where drinking-water is made available for children;

— by bringing water of lower fluoride content from some other source to mix with and dilute the high-fluoride water;

— by providing bottled lower-fluoride water separately to homes and other places where children drink water.

Practical aspects of water fluoridation

Almost by definition, community water fluoridation is a procedure for use in countries with a fair level of economic

---

[1] Further information on methods of partial removal of fluoride from drinking-water supplies may be obtained from: United States Environmental Protection Agency WH-550, 401 M Street, SW, Washington, DC, 20460, USA; Water Protection Environmental Services, Tunneys Pasture, Ottawa, Canada; Division of Environmental Health Protection, Pan American Health Organization, 525–23rd Street, NW, Washington, DC, 20037, USA. Suppliers of equipment include: Rubel & Hager, Engineers, Tucson, AZ, USA, and Aluminium Company of America, Pittsburgh, PA, USA.

development, for it is only practical if: (a) there is a municipal water supply reaching a reasonable number of homes; (b) people drink this water rather than water from individual wells or rainwater tanks; (c) suitable equipment is available in a treatment plant or pumping station; (d) a supply of a suitable fluoride chemical is assured; (e) there are workers in the water treatment plant able to maintain the system and keep adequate records; and (f) there is sufficient money available for the initial installation and running costs. Also, the level of dental caries must be sufficiently high, or the risk of increasing prevalence of caries sufficiently grave, to justify the investment.

In many economically developing countries, the basic provision of adequate supplies of safe drinking-water is still a major public health problem in itself. In such cases, fluoridation can hardly be considered. But with dental caries becoming an increasing problem in many developing countries (47), it is urged that water fluoridation be considered as soon as safe drinking-water supplies have become available and have been piped to urban populations.

In some European countries, fluoridation is feasible but is not implemented for political reasons. But in view of the good results achieved in those countries where it has been extensively used for many years, water fluoridation must always be considered as a public health measure. Not only is it safe, but water fluoridation is by far the most effective and efficient method of bringing the benefits of a continuous low concentration of fluoride to a whole community (12).

Of course, even where water fluoridation is common practice, operational problems can remain. In the USA, for example, fluoride levels in drinking-waters of many cities have not been maintained at consistent levels, frequently because of operator negligence (66, 69).

In the USA, fluoridation was assessed in 1981 by the US Public Health Service as costing an average of US$0.35 per person per year. The cost in large cities ranged from $0.20 to $0.40 per person per year, while in smaller cities it varied from $0.50 to $2.50 per person per year. However, these figures are an overestimate of the true direct costs because they are derived from the total cost of equipment and installation, plus one year's supply of chemical, divided by the population to be served. Fluoridation equipment typically lasts 10–15 years, and therefore a truer estimate should include some amortization of the equipment. Table 6 gives some examples of how these direct costs are assessed in communities in England, Hong Kong,

Table 6. Estimated annual cost per person of fluoridation in 1981 for Hong Kong, Watford (England), and for selected cities in the USA

City	Population	Water treatment plants[b]	Fluoride injection points[b]	Total cost of equipment	Annual cost of chemical (US $)	Annual per capita cost (US $)		Less equipment cost (US $)
						Non-amortized	Amortized	
Hong Kong	5 100 000	14	14	NA	98 500	-	-	0.02[c]
Chicago, Illinois	4 000 000	NA	NA	NA	144 840	-	-	0.035[d]
St. Louis County, Missouri	1 036 200	4	5	350 000	75 000	0.41	0.11	
Denver, Colorado	900 000	3	5	130 000	45 000	0.19	0.06	
Kansas City, Missouri	600 000	1	1	700 000	60 000	0.22	0.11	
Birmingham, Alabama	500 000	4	4	690 000	77 140	1.24	0.24	
New Orleans, Louisiana	500 000	2	2	25 000	21 500	0.08	0.04	
St. Louis, Missouri	450 790	2	2	150 000	99 057	0.39	0.23	
Albuquerque, New Mexico	350 000	0	20	229 000	63 000	0.83	0.25	
Ft. Lauderdale, Florida	250 000	NA	NA	300 000	37 500	1.35	0.27	
Macon, Georgia	120 000	1	2	48 200	26 800	0.63	0.26	
Ann Arbor, Michigan	105 000	1	1	17 000[e]	8 555	0.24		
Waco, Texas	102 000	2	2	40 000	13 700	0.52	0.17	
Shreveport, Louisiana	100 000	2	4	100 000	11 000	0.55	0.10	
Montgomery, Alabama	100 000	1	3	40 000	21 460	0.34	0.14	
Watford, England	77 000	2	2	72 000	4 894	1.00	0.16	
Port Arthur, Texas	70 000	2	1	18 000	7 000	0.36	0.13	
Lakeland, Florida	93 700	NA	NA	68 389	9 699	0.83	0.18	

Table 6 *(continued)*

City	Population	Water treatment plants[b]	Fluoride injection points[b]	Total cost of equipment	Annual cost of chemical (US $)	Annual per capita cost (US $)		Less equipment cost (US $)
						Non-amortized	Amortized	
Baytown, Texas	56 600	2	2	16 000	2000	0.32	0.06	
Farmington, New Mexico	55 000	2	3	23 000	9200	0.59	0.17	
Hallsdale Powell Utility District, Tennessee	32 890	4	4	4 007	3025	0.21	0.10	
Brigham City, Utah	17 000	1	1	15 000	8500	1.38	0.59	
Bolivar, Tennessee	9 197	1	1	4 650	1425	0.66	0.21	
Foley, Alabama	5 000	1	3	5 100	918	1.21	0.29	
Centerville, Tennessee	4 352	1	1	5 330	856	1.42	0.32	
Floresville, Texas	4 224	2 (wells)	2	4 000	2000	1.42	0.57	
Taos, New Mexico	3 500	0	3	3 245	1500	1.35	0.52	
Sibley, Iowa	3 051	1	1	5 017	1200	1.64	0.52	
Helper, Utah	2 600	1	1	2 600	3600	2.38	1.48	
Monroe City, Missouri	2 548	1	1	2 000	265	0.89	0.18	
Mason, W. Virginia	2 500	1	1	1 550	1700	1.30	0.74	
New Cumberland, W. Virginia	1 700	1	2	2 890	1070	2.33	0.80	
Hawthorne, Florida	1 500	NA	NA	5 520	3698	6.15	2.83	
Montezuma, Iowa	1 485	1	1	3 813	400	2.57	0.50	
Keanney, Missouri	1 433	1	1	2 000	307	1.61	0.35	
Goldfield, Iowa	789	1	1	3 410	450	4.32	0.96	

[a] Sources: US Public Health Service, Centers for Disease Control, Dental Disease Prevention Activity;
City of Ann Arbor Water Treatment Plant; Colne Valley Water Company, Watford.
[b] NA = not available or not known.
[c] Includes $7000 annual monitoring costs.
[d] Cost of chemicals and monitoring costs exclusive of equipment costs.
[e] Estimated replacement cost with volumetric feeder.

and the USA. This table includes two columns for per capita costs. The first is derived from the method used by the US Public Health Service and the second, which yields considerably lower figures, allows for depreciation of the equipment over 10 years using the straight-line depreciation method.

The first point to notice from Table 6 is that fluoridation is extraordinarily cheap, with or without allowance for amortization of equipment. Next, the per capita cost can be seen to decrease as the size of the community increases a phenomenon referred to by economists as an economy of scale. The cost of chemicals alone is low. When equipment costs are included, the larger the population size, the cheaper fluoridation is, whether or not the equipment is amortized over a 5- or a 10-year period.

Evaluation and safety

Fluoridation of community water supplies is the least expensive and most effective way of providing fluoride to large groups of people of all ages. It has the advantage that it can be evaluated in direct comparison with areas where the natural fluoride content of the water is high. Water fluoridation has now been in operation for almost 40 years. It has been implemented in more than 20 countries in different parts of the world, in various geographical and climatic conditions. Probably few other health measures have been so critically evaluated.

Of equal importance with efficacy is the safety of consuming fluoridated water. The question of possible secondary effects caused by fluorides taken in optimal concentrations throughout life has been the object of thorough medical investigations, which have failed to show any impairment of general health. Longitudinal paediatric studies comparing children living in areas rich and poor in fluorides exclude any systemic effects on development, growth, and health, as well as any significant differences in the incidence of congenital anomalies (e.g., Down's syndrome), and of cardiovascular, allergic or other diseases. Likewise, in studies of adults, no differences in the incidence of cancer or in the death rate of old people could be shown. The only difference was a lower prevalence of caries in areas of high fluoride water content. All these reports have considered the adjustment of the water fluoride content to about 1 mg of F^-/litre to be safe (*16, 22, 36, 53, 58, 59, 70*).

However, the situation is quite different in cases of excessive fluoride intake, such as may occur in areas with a high

concentration of fluoride (2.0–10.0 mg of F^-/litre), or in industrially polluted drinking-water. Secondary effects in the form of dental and skeletal fluorosis or other conditions might appear, both in man and in animals, in such an environment. Partial defluoridation is required in these situations (30, 31). Investigations in areas having a high fluoride concentration (e.g., in Midland, Texas, where the level is 5–7 mg of F^-/litre) indicate a higher anticaries effect but at the cost of unsightly dental fluorosis (21). This aspect has recently been considered by Driscoll et al. (18) who reported that, with respect to dental caries, the findings show that higher than optimal concentrations of fluoride in drinking-water do, indeed, provide better caries protection than an optimal concentration does. Nevertheless, the prevalence and degree of severity of fluorosis clearly increased at two and three times the optimal levels, although most of the children still had no more than mild fluorosis and many had none. The similarity in fluorosis scores at these two fluoride levels was apparent, but there was a marked increase in prevalence and severity at 4 times the optimal level.The authors concluded that if communities wish to minimize the occurrence of both severe fluorosis and obvious cosmetic changes, it may be appropriate for them to accept an upper limit of three times the optimal level of fluoride in the drinking water.

Legal aspects

Legislation providing for water fluoridation is of two types. It may be mandatory, requiring a ministry of health or communities of a certain size to fluoridate their public water supplies if they are deficient in fluorides. Alternatively, the legislation may be of the permissive or "enabling" type, empowering the ministry of health or a local government to institute fluoridation. The difference is important, as discussed below. In a few countries, principally Canada and the USA, legislation of either the mandatory or enabling type may allow or require a popular vote (57).

Mandatory laws

Mandatory laws requiring fluoridation of public water supplies that are fluoride-deficient have been enacted in Brazil, Bulgaria, Greece, Ireland and six states of the USA and Washington, D.C.

The earliest national statute is the Health (Fluoridation of Water Supplies) Act, 1960 of Ireland, requiring the health authority to make all arrangements necessary for the fluoridation of piped water supplied to the public as well as to carry out a survey of dental caries among schoolchildren and a study of the composition of the water supply (*32, 54*).

During the parliamentary debates on the bill, the only real disagreement between the Government and the Opposition was over the mandatory provision that used the word "shall" rather than "may". The Government prevailed on this point. Thus, the important feature of the law is that the decision to fluoridate is made by the Ministry for Health and not by the local authorities. A lawsuit filed by a housewife in the Dublin region attacked the constitutionality of the law on the grounds that it was at variance with the constitutional guarantee to protect the family as an entity, it infringed the right of parents to educate their children, and it violated the constitutional guarantees of the personal rights of the citizen, including the right to bodily integrity (*35*). In July 1964, after an exhaustive and now famous legal review of the scientific evidence on fluoridation, the Supreme Court of the Republic of Ireland rejected all these arguments and held the Fluoridation Act to be constitutional. (*32*).

In Bulgaria, in 1972, the Ministry of Architecture and Public Works and the Ministry of Public Health jointly issued an Instruction concerning the fluoridation of water intended for drinking and domestic purposes. The Instruction makes fluoridation mandatory when the water has a natural fluoride content below 0.5 mg/litre and when the prevalence of dental caries in the population exceeds 25%.

Brazil was one of the first Latin American countries to provide for water fluoridation. Since 1974, the Ministry of Health has been empowered to issue national rules and standards for the fluoridation of water, taking account of the natural fluoride content of the drinking-water, the dental health status of the population, and other matters.

Argentina has also adopted a mandatory fluoridation law. On 30 September 1975, the National Congress of Argentina approved a law requiring "the fluoridation and defluoridation of public water supplies in the whole country to the optimal level of fluoridation" (*19*).

In Greece, health regulations issued in 1974 provide for the compulsory fluoridation of water-supply systems serving more than 10 000 persons. Fluoridation may also be required for other

water-supply systems on public health grounds where it can be safely and successfully implemented.

In 1975, the Canadian Province of Quebec passed legislation making water fluoridation mandatory. The deadline for implementation was to be the end of 1978. An administrative plan to monitor fluoridation was adopted in 1977, and a subsidy has been made available to cover the costs of equipment and installation, despite strong objection to the fluoridation programme from its opponents (14).

In the USA, the first mandatory fluoridation laws were municipal ordinances passed by large or medium-sized cities. Some of these cities have been fluoridating their water supplies for 25–30 years, during which time dramatic improvement has taken place in the dental health of the people. A number of these ordinances were challenged as an unconstitutional invasion of personal liberty, as invalid "class legislation" benefiting only children, and as a violation of the constitutional guarantee of religious liberty, but the courts have systematically rejected all such arguments. The highest courts of 13 states have upheld the legality of water fluoridation (56). The Supreme Court of the USA has dismissed appeals or refused review in six of these cases; accordingly, the decisions of the state high courts still stand and mandatory fluoridation is officially recognized as a constitutional exercise of the power of each state to protect the public health, safety, and welfare.

At least one of the constituent republics in Yugoslavia has also enacted mandatory fluoridation legislation. In 1971, the Socialist Republic of Serbia passed a law making community water fluoridation compulsory, but it has not yet been implemented because of technical difficulties with the water treatment plants in Belgrade and other cities (Ramic, H., personal communication, 1982).

Permissive or enabling legislation

Permissive or enabling legislation authorizes the national health authorities or local governments to institute community water fluoridation. While such legislation does not automatically lead to fluoridated water supplies, it opens the way for health officials or units of local government to act on the matter. There are two types of enabling legislation: one type authorizes health officials to act, and the other type authorizes local government officials to act.

Examples of enabling legislation that permits the health

authorities to act are found in the permissive legislation in Australian States. The Australian Department of Health reports that, in 1982, 66 % of Australian people were using fluoridated water—one of the highest national percentages. In New South Wales, Tasmania, Victoria, and Western Australia, for example, the health authorities may define the conditions when fluoride may or must be added to the water supply. The legislation of New South Wales, first passed in 1957, provides for the establishment of a Fluoridation of Public Water Supplies Advisory Committee with power to initiate and refer to the Board of Health proposals concerning the addition of fluoride to public water supplies. A water supply authority may add fluoride to any public water supply with approval of the Board. The legislation also deals with the procedure for keeping records of the addition of fluoride and for analysing the water for fluoride content, as well as the precautions to be taken by water supply authorities to protect the operators.

Legislation in the German Democratic Republic also authorizes fluoridation. Legislation passed in 1970 provides that fluoridation of drinking-water may be carried out by means of approved fluoride compounds and installations licensed by the Ministry of Health. A licence from the public health authorities is required before fluoridation measures can be adopted. Fluoridation must be carried out so that the fluoride content of the drinking water is at the level of 1 mg/litre $\pm$ 10 %. Provision is made for suspending fluoridation if the level exceeds 1.3 mg/litre and for repeated analyses of the fluorine content of the water both before and after the fluoridation treatment.

In Israel, authority to introduce community water fluoridation rests with the health officials. The fluoridation system must be fitted with an automatic meter to determine the level of fluoride in the water, which must be continuously monitored.

In the USA, permissive legislation is exemplified by the 1980 statute in the State of Massachusetts empowering the State Commissioner of Public Health to recommend levels of fluorides in the public water supply of any city, town, or district considered optimum for dental health. The Commissioner is required to notify the local board of health of his findings, and the board may, if it considers doing so in the best interest of the inhabitants of the city, town, or district, order the fluoride content of the water supply to be suitably adjusted.

In the Federal Republic of Germany, the Foodstuffs and Consumer Goods Law of 1974 authorizes the Federal Government to grant permission for fluoride to be added to

drinking-water in order to prevent dental caries. The state (*Länder*) governments, however, must apply for this permission.

In the Netherlands, ministerial permission was given to water works to fluoridate their water supplies. However, this permission was challenged in a legal action and in 1973 the Supreme Court of the Netherlands held that it lacked a legislative foundation and conflicted with the obligation upon the owners of the water supplies to provide a separate, unfluoridated water supply. The ministerial authorization was not withdrawn, but fluoridation was effectively discontinued when local courts granted injunctions against fluoridation by the individual waterworks. In 1976, the Government submitted to Parliament a bill to authorize fluoridation, but the proposal was withdrawn when the bill met with opposition (König, personal communication).

Thus, a common type of enabling legislation is that authorizing health authorities to introduce fluoridation. Such legislation leaves the discretion with the health authorities and requires a separate action for each community or water supply system. Another type of enabling legislation, which is perhaps less common, authorizes units of local government to introduce fluoridation. The principal examples of this type of legislation are found in Canada and the USA.

In Canada, seven of the ten provinces have provincial legislation authorizing the municipalities within their provinces to fluoridate their public water supplies, either by administrative action of local government officials or on the basis of a referendum (*14*).

In the USA, the states of Alaska and Nevada have legislation authorizing the governing body of any city, town, or community to provide for fluoridation in accordance with a prescribed procedure. The Alaskan statute states that fluorides reduce dental caries and that public water supplies that do not have an adequate quantity of naturally occurring fluorides should be treated to raise the fluoride content to the optimum level. The legislation in Nevada provides that whenever a governing body of any city, town, or county receives a proposal from a supplier of water, public health authority, or other persons for adjusting the level of fluorides in the water supply, it must submit the issue to the voters at the next general election.

Legislation enabling local governments to add fluoride to water supplies was passed in Sweden in 1962, but the law was repealed in 1971. In 1977, however, the Swedish National Board of Health and Welfare issued an order affirming that a fluoride

content in drinking-water of at least 0.7–0.8 mg/litre prevents dental caries and prescribing that where the content is below that level, supplementary fluoride in the form of tablets should be given to provide the desired protection against dental caries.

Referenda on water fluoridation

An important feature of the experience with community water fluoridation in Canada and the USA has been the resort to popular referenda to decide the issue. In the 1960s, fluoridation was introduced in many places after referenda, but in recent years the opponents of fluoridation have become better organized and have more often than not succeeded in defeating proposals to introduce this measure. In 1980, 41 referenda on fluoridation were held in the USA. According to the US Centers for Disease Control, only eight of these referenda resulted in the acceptance of fluoridation, and in 33 communities proposals for fluoridation were defeated (11).

The reasons for rejecting a proven benefit to health when it is submitted to a popular vote have been the subject of many studies by social scientists (24). In essence, the phenomenon of the public's voting against its own interest is explained by a number of factors: (1) ignorance and confusion on the part of the public about the dental health benefits of fluoridation; (2) ambivalence of the public towards science and its by-products, with greater reservations about scientific findings concerning the human body than about those that are external to the individual, e.g., space exploration; (3) misrepresentation of the scientific and technical information involved, enabling the opposition to distort the issues and frighten the public (24, 33, 56). It has been pointed out that opponents of fluoridation need only sow a seed of doubt to ensure a "no" vote, whereas supporters need to prove beyond all question that fluoridation is safe and desirable in order to obtain a "yes" vote.

The only Canadian province that requires a popular vote on fluoridation is Alberta. If the measure is rejected, the issue cannot be proposed again for at least two years. Once fluoridation has been approved by a referendum, there is no deadline specified for implementation, and a second referendum may even be called for to reaffirm the will of the voters, as happened in Raymond, Alberta.

Five states in the USA (Delaware, Maine, Nevada, New Hampshire, and Utah) have laws that require a public vote before fluoridation can be introduced. Nevada, for example, requires

that the issue be put to the ballot routinely in every community where water fluoridation is sought. The impact of mandatory referenda is demonstrated by the fact that the states with mandatory referenda are among those with the least fluoridation (*42*). In Michigan, Nebraska, and Massachusetts a popular vote may be requested on petition of a certain number of registered voters, but it is not mandatory.

Summary of requirements for introducing community water fluoridation

1. Attainment by the country of a fair level of economic development.
2. Availability of a municipal water supply reaching a large number of homes.
3. Evidence that people drink water from the municipal supply rather than water from individual wells or rainwater tanks.
4. Availability of the requisite equipment needed in a treatment plant or pumping station.
5. Availability of a reliable supply of fluoride chemical of acceptable quality.
6. Availability of trained workers in the water treatment plant who are able to maintain the system and keep adequate records.
7. Availability of sufficient money for initial installation and running costs.
8. A level of dental caries in the community that is high or moderate, or firm indications that the caries level is increasing.
9. Appropriate legislation authorizing community water fluoridation.

References

1. ADLER, P. The connections between dental caries experience and water-borne fluorides in a population with low caries incidence. *Journal of dental research*, **30**: 368–387 (1951).
2. AKSJUK, A. F. Hygienische Aspekte der Fluoridierung von Trinkwasser in verschiedenen klimatisch-geographischen Gebieten der UdSSR. [Hygienic aspects of the fluoridation of drinking-water in different climatic-geographic areas of the USSR]. *Zeitschrift für die gesamte Hygiene und ihre Grenzgebiete*, **23**: 85–87 (1977).
3. ARNOLD, F. A. ET AL. The effect of fluoridated public water supplies on dental caries prevalence. 10th year of the Grand Rapids—

Muskegon Study. *Public health reports (Washington)*, **71**: 652–658 (1956).

4. ARNOLD, F. A. ET AL. Fifteenth year of the Grand Rapids fluoridation study. *Journal of the American Dental Association*, **65**: 780–785 (1962).

5. BACKER DIRKS, O. The benefits of water fluoridation. *Caries research*, **8** (Suppl.): 2, (1974).

6. BASIJAN, G. V. ET AL. [Dental caries in transpolar conditions (according to data of examination of school children in the Murmansk region)]. *Stomatologija*, **49**: 78 (1970) (in Russian).

7. BAUER, F. ET AL. Beurteilung der karies-protektiven Wirkung von Fluoriden auf Grund von Modellen fur den zeitlichen Verlauf des Kariesbefalls der bleibenden Zahne. [Assessment of the caries-protective action of fluorides on the basis of models for the time-course of caries attack of the remaining teeth]. *Zahn-, Mund- und Kieferheilkunde*, **68**: 214–230 (1980).

8. BELLEMARE, M. *Normes et directives sur la fluoruration des eaux de consommation*. [Norms and directives for the fluoridation of drinking-water]. Canada, Government of Quebec, 1976.

9. BINDER, K. Karies und fluorreiches Trinkwasser–Kritische Betrachtung. [Caries and fluoride-rich drinking water—Critical evaluation]. *Osterreichische Zeitschrift für Stomatologie*, **62**: 14–18 (1965).

10. BOJANINI, J. N. ET AL. Beneficios de siete años de fluororación de aguas en Medellín. [Benefits of seven years of water fluoridation in Medellin]. In: *Seminario internacional de fluororación*. Washington DC, Pan American Health Organization, 1977 (Document No. FDH/61).

11. BORISKIN, J. ET AL. The 1980 fluoridation campaigns: a discussion of results. *Journal of public health dentistry*, **41**: 138 (1981).

12. BURT, B.A. *The relative efficiency of methods of caries prevention in dental public health*. Ann Arbor, University of Michigan, 1979, p. 14–15.

13. BÜTTNER, W. ET AL. Correlations between fluoride concentrations of human plasma, saliva and sweat following low and high fluoride intake. *Helvetica odontologica acta*, **17**: 56–60 (1973).

14. CANADIAN DENTAL ASSOCIATION. Water fluoridation in Canada: a status report 1980. *Canadian Dental Association journal*, **47** (Suppl.): 1–8 (1981). [See also: Mémoire présenté à la Commission Parlementaire sur la fluoration des eaux de consommation par l' Association des Chirurgiens-Dentistes du Québec, *Journal dentaire du Québec*, **12** (3): 22, 24, 26 (1975); ROY, A. La fluoration des eaux de consommation, *Journal dentaire du. Québec*, **12** (6–7): 16 (1975)].

15. CARMICHAEL, C.L. ET AL. The effect of fluoridation upon the relationship between caries experience and social class in 5-year old children in Newcastle and Northumberland. *British dental journal*, **149**: 163–167 (1980).

16. CLEMMESEN, J. The alleged association between artificial fluoridation

of water supplies and cancer: a review. *Bulletin of the World Health Organization*, **61**: 871–883 (1983).

17. DEAN, A. J. ET AL. Domestic water and dental caries. V. Additional studies of the relation of fluoride domestic waters to dental caries experience in 4,425 white children aged 12–14 years of 13 cities in 4 states. *Public health reports (Washington)*, **57**: 1155–1179 (1942).

18. DRISCOLL, W. S., ET AL. Prevalence of dental caries and dental fluorosis in areas with optimal and above optimal water fluoride concentrations. *Journal of the American Dental Association*, **107**, 42–47 (1983).

19. Editorial. *Revista de la Asociación Odontológica Argentina*, **63**: 223 (1975).

20. EICHENBAUM, I. W. ET AL. Impact of fluoridation in a private pedodontic practice. *Journal of dentistry for children*, **48**: 211–214 (1981).

21. ENGLANDER, H. R. & DE PAOLA, P.F. Enhanced anticaries action from drinking water containing 5 ppm fluoride. *Journal of the American Dental Association*, **98**: 35–39 (1979).

22. ERICSSON, Y. Report on the safety of drinking water fluoridation. *Caries research*, **8** (Suppl): 16–27 (1974).

23. ERICSSON, Y. & SUNDIN, B. Emaljfluoros och Karies i ett svenskt fluoromrade. [Enamel fluorosis and caries in a fluoridated area in Sweden.] *Svensk tandläkare-tidskrift*, **53**: 127–136 (1960).

24. FRANKLIN, J. & ALLUKIAN, M. Sixteen referenda on fluoridation in Massachusetts; an analysis. *Journal of public health dentistry*, **33** (2): 96–103. (1973).

25. FORREST, J. R. Caries incidence and enamel defects in areas with different levels of fluoride in the drinking water. *British dental journal*, **100**: 195–200 (1956).

26. GALAGAN, D. J. ET AL. Climate and fluid intake. *Public health reports (Washington)*, **72**: 484 (1957).

27. GILODY, C. J. ET AL. A dental caries and fluoride study of 19 Nebraska cities. *Journal of the Nebraska Dental Association*, **31**: 3–13 (1954).

28. GUZMAN, R. M. Programa de fluoruración de las aguas en Puerto Rico [Water fluoridation programme in Puerto Rico]. In: *Seminario de fluoruración*. Washington DC, Pan American Health Organization, 1977 (Document No. FDH/61).

29. HAUSEN, H. ET AL. Caries in permanent dentition and social class of children participating in public dental care in fluoridated and nonfluoridated areas. *Community dentistry and oral epidemiology*, **9**: 289–291 (1981).

30. HOROWITZ, H. S. & HEIFETZ, S. B. The effect of partial defluoridation of a water supply on dental fluorosis—final results in Bartlett, Texas after 17 years. *American journal of public health*, **62**: 767–769 (1972).

31. HOROWITZ, H. S., ET AL. Partial defluoridation of a community water

supply and dental fluorosis. *Health service report,* **87**: 451–455 (1972).

32. IRELAND. Health (Fluoridation of Water Supplies) Act, 1960. *International digest of health legislation,* **15**: 537 (1964).

33. ISMAN, R. Fluoridation: strategies for success. *American journal of public health,* **71**: 717–721 (1981).

34. JACKSON, D. ET AL. Life-long benefits of fluoride in drinking water. *British dental journal,* **134**: 419 (1973).

35. KENNY, J. The legal issues in the fluoridation case. *Journal of the Irish Dental Association,* **18**, 56–58 (1972).

36. KINLEN, L. & DOLL, R. Fluoridation of water supplies and cancer mortality. III. A re-examination of mortality in cities in the USA. *Journal of epidemiology and community health,* **35**: 239–244 (1981).

37. KLIACHKINA, L. M. ET AL. [Effect of water fluoridation on the prevalence and incidence of caries of the permanent teeth of Leningrad schoolchildren]. *Stomatologija,* **60** (4): 52–53 (1981) (in Russian).

38. KUNZEL, W. Auswirkungen kariesvorbeugender Massnahmen (Trinkwasserfluoridierung) auf Inhalt und Struktur der kinderstomatologischen Betreuung. [Consequences of caries-preventive measures (drinking-water fluoridation) for the content and structure of the stomatological care of children]. *Deutsche Stomatologie,* **21**: 777–792, 841–853, 937–945 (1971).

39. KUNZEL, W. Effect of an interruption in water fluoridation on the caries prevalence of the primary and secondary dentition. *Caries research,* **14**: 304–310 (1980).

40. KUNZEL, W. Reduction in caries after 7 years of water fluoridation under climatic conditions in Cuba. *Caries research,* **16**: 272–276 (1982).

41. LEMKE, C. W. ET AL. Controller fluoridation: the dental effects of discontinuation in Antigo, Wisconsin. *Journal of the American Dental Association,* **80**: 782 (1970).

42. LEUKHART, C. S. An update on water fluoridation; triumphs and challenges. *Pediatric dentistry,* **1**: 32 (1979).

43. LEWIS, F. D. & LEATHERWOOD, E. C. Effect of natural fluorides on caries incidence in three Georgia cities. *Public health reports (Washington),* **74**: 127–131 (1959).

44. LONG, J. G. & STOWE, E. Monitoring fluoride in Vermont's drinking water *Journal of public health dentistry,* **33**: 13–22 (1973).

45. McCLURE, F. J. *Water fluoridation: the search and the victory,* Bethesda, National Institute of Dental Research, 1970.

46. MARTHALER, T. M. Fluoride supplements for systemic effects in caries prevention. In: Johansen, E. et al., ed. *Continuing education on the use of fluorides,* Boulder, Westview Press, 1979, p. 33.

47. MØLLER, I. J. Impact of oral diseases across cultures. *International dental journal,* **28**: 376 (1978).

48. MØLLER, I. J. Fluorides and dental fluorosis. *International dental journal,* **32**: 135–147 (1982).

49. MURRAY, J. J Adult dental health in fluoride and non-fluoride areas. I. Mean DMF values by age. *Journal of dental research*, **131**: 391 (1971).

50. MURRAY, J. J. & RUGG-GUNN, A. J. A review of the effectiveness of artificial water fluoridation throughout the world. In: *ORCA XXVI Congress, Scotland, 1979*, Abstract No. 65.

51. MYERS, H.M. Fluorides and dental fluorosis. Basel, Karger, 1978.

52. NEVITT, A. ET AL. Missouri's fluoride and dental caries study. *Journal of the Missouri Dental Association*, **33**: 10–26 (1953).

53. NEWBRUN, E. The safety of water fluoridation. *Journal of the American Dental Association*, **94**: 301–304 (1977).

54. O'HICKEY, S. Water fluoridation and dental care in Ireland: background, introduction and development. *Journal of the Irish Dental Association*, **22**: 61–66 (1976).

55. ROCK, W. P. ET AL. Dental caries experience in Birmingham and Wolverhampton school children following the fluoridation of Birmingham water in 1964. *British dental journal*, **150**: 61–66 (1981).

56. ROEMER, R. Water fluoridation: public health responsibility and the democratic process. *American journal of public health*, **55**: 1337, 1339–1341 (1965). [See also Strong, G. A. Liberty, religion and fluoridation. *Santa Clara Lawyer*, **8**: 37, (1967); Conway, B. J. Legal aspects of municipal fluoridation. *Journal of the American Water Works Association*, **50**: 1330 (1958)].

57. ROEMER, R. Legislation on fluorides and dental health. *International digest of health legislation*, **34**: 3–31 (1983).

58. ROGOT, E. ET AL. Trends in urban mortality in relation to fluoridation status. *American journal of epidemiology*, **107**: 104–110 (1978).

59. ROYAL COLLEGE OF PHYSICIANS. *Fluoride, teeth and health*. London, Pitman Medical, 1976.

60. RUGG-GUNN, A. J. ET AL. Caries experience of 5 year old children living in four communities in N.E. England receiving different water fluoride levels. *British dental journal*, **150**: 9–12 (1981).

61. RUSSAK, S. A. ET AL. [Dental caries in children of the Estonian SSR as a function of the fluoride content of drinking-water.] *Stomatologija*, **59** (5): 73–74 (1980) (in Russian).

62. RUSSELL, A. L. & ELVOVE, E. Domestic water and dental caries. VII. A study of the fluoride dental caries relationship in an adult population. *Public health reports (Washington)*, **66**: 1389 (1951).

63. RUSSELL, A. L. & HAMILTON, P. M. Dental caries in permanent first molars after eight years of fluoridation. *Archives of oral biology*, **6** (Special Suppl.): 50 (1961).

64. RYBAKOV, A. I. & ALIMSKIJ, A. V. *Experimentalnaja i klinitscheskaja stomatologija [Experimental and clinical dentistry]*. Moscow, 1979, pp. 5–99.

65. RYBAKOV, A. I. [Approaches and perspectives in the prevention of oral diseases in children.] *Stomatologija* **47** (9) (1968).

66. SHANNON, I. L. The problem of maintaining the fluoride level in

fluoridating the water supply. *Texas dental journal,* **98**: 6–8 (1980).

67. SPROUSE, L. W. & LUTTRELL, G. *A manual for small community fluoridation.* Kentucky, Dental Health Division, Department for Human Resources, 1981.

68. STAMM, J. W., & BANTING, D. W. Comparison of root caries in adults with lifelong residence in fluoridated and non-fluoridated communities. *Journal of dental research,* **59** (Special issue A): 405 (1980) (Abstract No. 552, IADR).

69. STRIFFLER, D. F. & RODER, D. M. Fluoridation revisited: implementation and surveillance of fluoridation. In: Silverman, S. L. & Tryon, A. F., ed. *Community dentistry,* Littleton, Wright PSG 1980, pp. 209–225.

70. TAVES, D. R. Fluoridation and cancer mortality. In: Hiatt H. H. et al., ed. *Origins of human cancer,* Vol. 4. Coldspring Harbor, NY, Coldspring Harbor Laboratory, 1977, pp. 357–366.

71. TIJMES, M. B. Programa nacional de fluoruración del agua potable en Chile [National programme of drinking-water fluoridation in Chile]. In: *Seminario internacional de fluoruración.* Washington, DC, Pan American Health Organization, 1977 (Document No. FDH/61).

72. US ENVIRONMENTAL PROTECTION AGENCY, OFFICE OF WATER SUPPLY. *Removal of excess fluoride from drinking water,* Washington, DC, US Government Printing Office 1978 (Technical Report EPA 570/9–78–001).

73. VINES, J. J. & CLAVERO, J. Investigación de la relación entre la incidencia de caries y contenido del ion fluor en les aguas de abastecimiento [Investigation of the relation between caries incidence and the content of fluoride ion in the water supplies]. *Revista de sanidad e higiene pública,* **42**: 401–431 (1968).

74. WIGDOROWICZ-MAKOWEROWA, N. [Effect of 8 years of water fluoridation in Wrocaw on the course of dental caries in children and adolescents.] *Czasopismo stomatologiczne,* **33**: 773–778 (1980) (in Polish).

75. ZAPATA, M. G. Experiencia prática de la fluoruración en las empresas públicas de Medellín, Colombia, durante el período 1969–76. [Practical experience in the fluoridation of public water supplies in Medellín, Colombia, during the period 1969–76] In: *Seminario internacional de fluoruración.* Washington, DC, Pan American Health Organization, 1977 (Document No. FDH/61).