CHAPTER 16

Water Fluoridation

WITH OVER 123 million people in the United States drinking fluoridated water as of 1983, the physiology of fluoride has become not only a subject of intense scientific interest to the public health dentist, but a nationwide political issue as well. Fluoridation may profitably be examined from a number of points of view: the epidemiology of fluoride intake both in respect to dental fluorosis (mottled enamel) and in respect to caries reduction, the safety of fluoridation, the dental benefits of fluoridation in both the endemic and the test areas, fluoridation as an engineering project, and finally the legal, political, and economic impact of fluoridation. Voluminous literature is available on all of these facets of the problem, but space limitations permit only brief considerations of most of it here.

EPIDEMIOLOGY OF FLUOROSIS

The effect of fluoride on man constitutes a story which has unfolded over more than half a century in the United States and has attracted widespread attention from the epidemiologists. There are in fact two stories, which form a continuum: the story of the harmful effects of fluoride in large doses, which came first, and the story of dental benefits from small doses.

The first important mention of the brown stain known now as dental fluorosis occurred in 1902 in El Paso County, Colorado, although in 1888 a family emigrating from Mexico to Germany had been recognized as having the same condition. In Colorado, Frederic S. McKay gave systematic attention to the mottling and brown staining he found on the teeth of many of his patients and even hypothesized that the defect was due to the water supply. By 1908 he had studied enough cases and interested enough of his colleagues in the problem to invite Dr. G. V. Black, then Dean of Northwestern University Dental School, to join him in a local study. Black's visit to Colorado gained national attention for the brown staining of enamel, and cases were reported soon thereafter from many parts of the country. The name "Colorado brown stain" eventually gave way to that of mottled enamel. The process soon became associated with communal water supplies, usually (though not always) from deep wells, but at that time analysis of water supplies for small quantities of fluoride had not been perfected and the etiologic agent was not identified till more than two decades later. Various degrees of mottling were identified, from the mild mottling which involves only a few chalky white spots on the surface of the enamel, to moderate mottling where large areas of white are mixed with brown, and finally to the severe mottling where brown predominates and hypoplasia of the teeth becomes evident.

As mottled enamel became documented in an ever-widening geographical area, confirmation of the deep-well hypothesis was found in several localities. In Britton, South Dakota, in 1916 a study revealed uniform mottling of enamel among the children brought up in the town since a new deep well had been added to the communal water supply in 1898. In 1925, citizens of Oakley, Idaho, where mottling was prevalent, undertook to test the deep-

well hypothesis by changing from a warm spring-water supply (artesian water) to another shallower water supply. In succeeding years, the children on the new water supply developed no mottling, but the children brought up on the old supply were not cured.

It is interesting to note that in 1925 also, McCollum, Bunting, and others, who were studying the elements known to occur in teeth by feeding them in excess to rats, developed staining in incisors of these animals following ingestion of large quantities of fluoride. This fact remained for several years unrelated to the occurrence of mottled enamel in human beings.

Studies initiated in 1928 in Bauxite, Arkansas, led to the final discovery that mottled enamel was associated with fluoride in water. An exceptionally high incidence of mottling occurred in this town, and action upon the problem was more far-reaching than usual because of the presence there of a plant of Republic Mining and Manufacturing Company, a subsidiary of the Aluminum Corporation of America. Samples of Bauxite water eventually came to the laboratory of H. V. Churchill, chief chemist for Alcoa, who initiated spectographic study. Thirteen and seven-tenths parts per million of fluoride were found in the Bauxite water, a finding which impressed Churchill and was eventually transmitted to McKay in 1931. McKay then arranged for reanalysis of the water supplies in Britton, South Dakota, Oakley, Idaho, and elsewhere. Reports of high fluoride were soon assembled. Subsequent rechecking in many parts of the United States soon developed a striking correlation between mottled enamel and a fluoride content of public water ranging from 2 to 13 parts per million. It is interesting to note that two other sets of observers (the Smiths in Arizona and Velu in France) also connected fluoride with mottled enamel about the same time as did Churchill, though their ideas did not happen to spark such extensive further study.

The coexistence of low dental caries and mottled enamel had excited comment from McKay, even in the early years of his investigation. After the discovery that fluoride correlated with mottled enamel in 1931, several other investigators also noted this inverse relation. It remained for Dr. H. Trendley Dean, on duty with the U.S. Public Health Service, to make a thorough documentation of the degree of mottled enamel and degree of caries at different concentrations of fluoride in order to permit reliable statistical analysis. Dean's studies took him all over the United States. The magnitude of this task can be imagined from inspection of Fig. 53, which shows the situation in map form. Populations on natural fluoride water were in 1977 estimated at about 10 million. As it became obvious that large reductions in caries incidence were associated with the occasional appearance of enamel opacities that were in no way disfiguring, the term *mottled enamel* gave way to the more exact term *dental fluorosis*.

Dean developed a classification for dental fluorosis which has become a standard in epidemiological work.[1] From it, an index of dental fluorosis can be computed for a group. The classification which is illustrated in Fig. 54, can be abbreviated as follows:

Normal enamel. Weight 0.0.

Questionable mottling. Normal translucency is varied by a few white flecks or white spots. Weight 0.5.

Very mild mottling. Small, opaque, paper-white areas are scattered over the teeth, involving less than 25 percent of the surface. Summits of cusps of bicuspids and second molars are commonly affected. Weight 1.0.

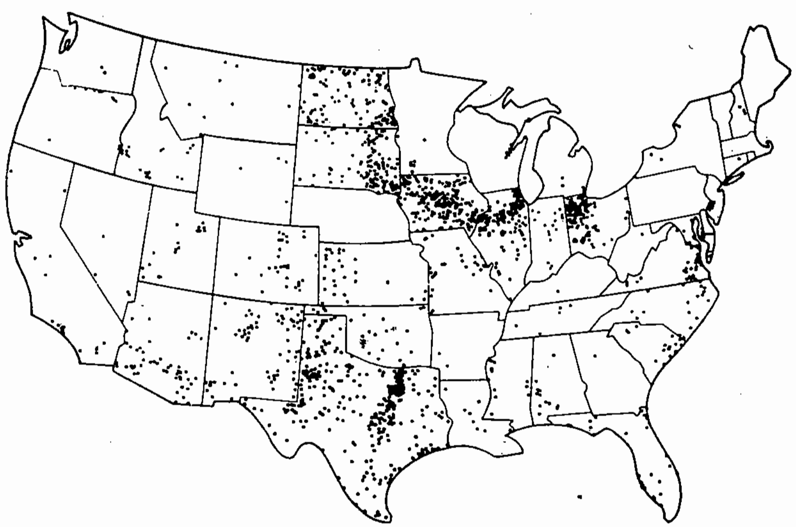

Figure 53. Communities using naturally fluoridated water with 0.7 ppm fluoride or more, 1957. [Public Health Service, National Institute of Dental Research.]

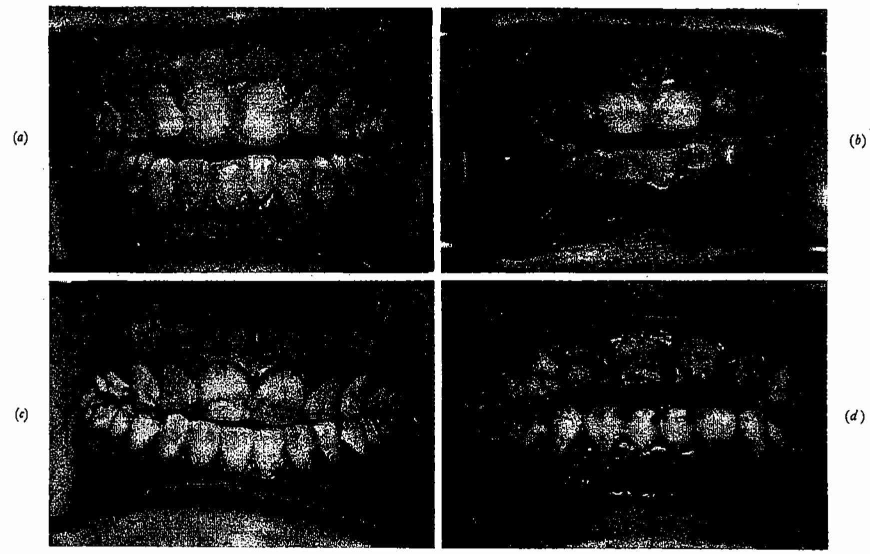

Figure 54. Types of dental fluorosis: (*a*) very mild; (*b*) mild; (*c*) moderate; (*d*) severe.

Mild mottling. The white opaque areas are more extensive but do not involve more than 50 percent of the surface. Weight 2.0.

Moderate mottling. All enamel surfaces are affected and those subject to attrition show marked wear. Brown stain is a frequent disfiguring feature. Weight 3.0.

Severe mottling. All enamel surfaces are affected and hypoplasia is so marked that tooth form may be altered. A major diagnostic sign is discrete or confluent pitting. Brown stains are widespread and the teeth often present a corroded appearance. Weight 4.0.

The *Index of Dental Fluorosis* of a group is computed by averaging the weights assigned to the individuals in the group: one weight figure per person. Since scores are easiest to tally in groups, the formula becomes:

$$\text{Index} = \frac{\text{sum of } f \times w}{n}$$

where f is frequency, w is weight, and n is number of cases examined.

A more sensitive index has recently been devised and applied by Horowitz et al., which is called the *Tooth Surface Index of Fluorosis* (TSIF).[2] They use a score scale of 0 to 7 and record it for 2 surfaces on each anterior tooth and 3 surfaces on each posterior tooth. The percentage distribution of scores is then computed for either an individual or a group of individuals. These percentage distributions follow the same general pattern as Dean's index but allow greater discrimination as to the public health effect of fluorosis in a given locality. The index has proved sufficiently sensitive to distinguish between communities with four different fluoride levels as to both prevalence and severity of fluorosis.

The scores are as follows:

Numerical score	*Descriptive criteria*
0	Enamel shows no evidence of fluorosis.
1	Enamel shows definite evidence of fluorosis, namely areas with parchment-white color that total less than one-third of the visible enamel surface. This category includes fluorosis confined only to incisal edges of anterior teeth and cusp tips of posterior teeth ("snowcapping").
2	Parchment-white fluorosis totals at least one-third of the visible surface, but less than two-thirds.
3	Parchment-white fluorosis totals at least two-thirds of the visible surface.
4	Enamel shows staining in conjunction with any of the preceding levels of fluorosis. Staining is defined as an area of definite discoloration that may range from light to very dark brown.
5	Discrete pitting of the enamel exists, unaccompanied by evidence of staining of intact enamel. A pit is defined as a definite physical defect in the enamel surface with a rough floor that is surrounded by a wall of intact enamel. The pitted area is usually stained or differs in color from the surrounding enamel.
6	Both discrete pitting and staining of the intact enamel exist.
7	Confluent pitting of the enamel surface exists. Large areas of enamel may be missing and the anatomy of the tooth may be altered. Dark-brown stain is usually present.

The next step forward involved more accurate studies in areas where fluoride in water supplies was low enough not to cause mottling as a public health problem. Comparisons were therefore made between white children aged 12 to 14 years in Galesburg, Illinois, with 1.9 parts per million fluoride, and in Quincy, Illinois, a nearby city on the Mississippi River, with no appreciable fluoride.[3] Later, a series of studies was made among similar children in Chicago suburbs, some of them using Lake Michigan water with no appreciable fluoride and others using deep-well water with fluoride contents ranging from 0.5 to 1.8 parts per million.[4] These studies showed surprisingly regular decreases in dental caries in the temperate zone as fluoride concentrations increased from zero up to about 2 parts per million. These data, coupled with Dean's earlier data on endemic fluorosis, are shown in graphic form in Fig. 55. A low spot shows where the two curves on this figure cross

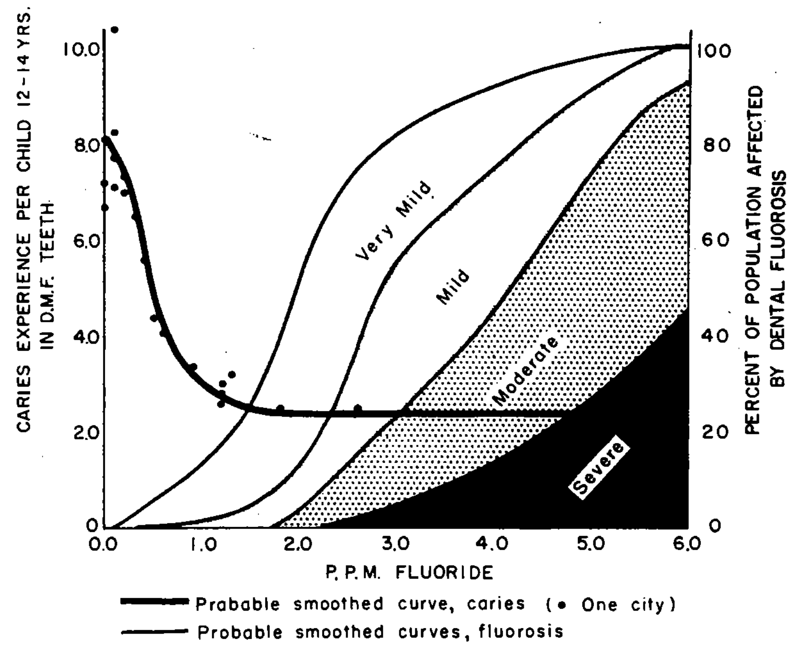

Figure 55. Dental caries and dental fluorosis related to fluoride in public water supply. [Adapted from H. T. Dean, New York Symposium (1945); *Int. Dent. J. 4*, 311–337 (1954).]

near 1.0 part per million. At this concentration most of the benefits in caries reductions at all ages have already been realized through the addition of fluoride, while mottling as a public health problem has not yet appeared. On the basis of such evidence the U.S. Public Health Service later recommended the fluoridation of water supplies with from 1.0 to 1.5 parts per million.

The descriptive and analytical epidemiology of fluoride was now fairly complete. Certain points, of course, still remained to be proved. Dean stated quite frankly in his report on Galesburg and Quincy that he had demonstrated no more than a correlation between fluoride and low caries, and that trace elements or other factors correlated with fluoride content in the water might easily be the causative factor in the caries reduction. The next step lay in an attempt to benefit mankind through the prevention of dental caries. In order to do this, it was necessary to demonstrate (1) that fluoride at a concentration approximating 1 part per million in the water supply was safe and (2) that added fluoride did in fact produce the dental benefits associated with natural fluoride in the endemic fluoride areas. Only when this last attempt had been made could it be said with assurance that fluoride caused, and was not merely associated with, low caries. Trials of water *fluoridation* thus became necessary. Fluoridation was *defined* as the adjustment of a water supply to a fluoride content such that reductions of 50 to 70 percent in dental caries would occur without damage to teeth or other structures. A more current definition omits any reference to specific percentages of reduction. The sharp drop in caries incidence among children in developed countries has reduced the further benefits now possible in newly fluoridated areas. Fluorides in various forms and community water fluoridation in particular, however, have received the probable credit for these reductions; they are not to be construed as indicating lesser efficacy in areas still showing high caries. The definition should now include reference to *significant* reductions.

SAFETY OF FLUORIDATION

Any plan for alteration of the fluoride content of a communal water supply requires a thorough understanding of any possible harmful effects upon human beings of the doses likely to be used

or of the accidental overdoses which are possible. The importance of the matter is underlined by the fact that concentrated sodium fluoride powder is known to the public as a rat poison. Fluoride actually produces a wide spectrum of physiologic activity, both normal and abnormal, in the human being. It can be considered a nutrient, a drug, or a poison, entirely on the basis of the dosage used. This same statement, of course, can be made concerning many familiar elements. Small quantities of iodine act to prevent a deficiency disease, goiter, and to this extent are an essential nutrient. Tincture of iodine applied to a wound serves the purpose of a drug. Iodine if swallowed in large quantities constitutes a poison, and iodine bottled for the medicine cabinet is therefore so labeled. Even table salt (NaCl) and water can be fatal in gross overdose to the exclusion of other substances. In short, *the best definition for a poison is "too much."*

The mechanism by which fluoride acts on teeth is considered to be chiefly a replacement of hydroxyapatite by less soluble fluorapatite in the crystalline structure of the enamel. Possible additional mechanisms are indicated by the fact that fluoride favors the precipitation of calcium phosphate from saturated solutions and that it inhibits some and apparently stimulates other types of enzyme action.[5] Catalytic action upon enamel crystallization may also be involved. The probably higher concentration of fluoride in bacterial plaque close to the tooth surface permits reactions not typical of the concentrations of fluoride found in saliva or other body fluids.

Fluoride is present in small quantities in practically all common foods. Exclusive of drinking water, the average diet in the United States has been calculated to provide 0.2 to 0.3 milligram of fluoride daily.[6] Diets involving large quantities of seafood or tea will rise above this level. One cup of tea alone supplies approximately 0.12 milligram of fluoride. Geographical variations in the fluoride content of a normal diet, however, appear to be unimportant in most areas, since they are small in comparison with fluoride available from drinking water. One liter of water with a fluoride content of 1 part per million contains 1 milligram of fluoride ion. Average daily water intake in the temperate zone may be estimated at from 1 to 1.5 liters per day, hence a dosage of from 1 to 1.5 milligram of fluoride. This is five times the quantity normally available from food.

Table 37 gives a broad and approximated picture of the physiological and pathological effects of fluoride at a wide variety of doses, both chronic and acute.

A mass of literature exists on the safety of water fluoridation. There are several competent recent reviews of this literature, among which are those of Hodge, Smith, and McClure.[7,8,9]

The metabolism of fluoride involves rapid absorption of 90 percent or more of soluble fluoride, the reappearance of perhaps half this fluoride in the urine, and the storage of the rest in bone and teeth. There is no evidence for storage of fluoride in soft tissues. Urinary excretion is prompt and responds in sensitive fashion even to low doses of fluoride. Gradual accumulation of fluoride does occur in bone and tooth structure as age advances. Bone

Table 37. Human responses to fluoride.

Concentration of fluoride dose[a]	Medium	Time	Effect
		In man	
1 ppm[b]	Water	Lifetime	Dental caries reduction
2 ppm or more	Water	During tooth formation	Dental fluorosis
5 ppm	Water or air	Years	No osteosclerosis
8 ppm	Water	Years	10% osteosclerosis
20–80 mg/day or more	Water or air	Years	Crippling fluorosis
		In animals	
50 ppm	Food or water	Years	Thyroid changes
100 ppm	Food or water	Months	Growth retardation
>125 ppm	Food or water	Months	Kidney changes
2.5–5.0 gm	Acute dose	2–4 hours	Death

a. Attainment of these doses of fluoride ion requires approximately twice the weight of sodium fluoride.
b. In temperate zone, less in tropics.

fluoride content is also greater at a given age in communities where there is fluoride in the water, though a slowing or cessation of accumulation appears to occur some 10 years after the initiation of a water-fluoridation program.[10] Recognizable bone changes do not appear in significant proportions of a population until the fluoride is from 4 to 8 ppm, and then take the form of increased or decreased bone density, with or without coarsened trabeculation, excluding osteoporotic change.[9] Larger fluoride exposures, estimated at 20 to 80 milligrams or more per day inhaled as an industrial dust for periods of 10 to 20 years, produced crippling fluorosis in cryolite workers.[11]

One function of fluoride in the system appears to be to improve calcium balance and delay deleterious excretion of calcium.[12] As a result, there appears to be less osteoporosis, or decreased bone density, in fluoride areas than in fluoride-deficient areas.[13] Visible calcification of the aorta is also reduced. This leads to the hypothesis that optimal fluoride ingestion may in time prove to be helpful in the partial and highly beneficial prevention of osteoporosis, as well as other associated problems among older citizens.

Practical use has been made of this hypothesis in the treatment of osteoporosis. Parkins lists several instances where doses up to 60 milligrams of sodium fluoride per day, coupled with calcium and sometimes vitamin D, have led to the deposition of new normal bone in persons with osteoporotic lesions, without toxic effects.[14] The positive value of this therapy is still open to controversy, however, and further study is needed.

A number of large-scale studies have been made over the years of the morbidity and mortality of populations exposed both to natural fluoride near the optimum level of 1 part per million and to fluoridated water at the same level. The most comprehensive of these seem to have been made in the period from 1950 to 1960. The Bartlett-Cameron study contrasted a natural low-fluoride community with one having 8 parts fluoride per million in the water supply.[9] The medical study accompanying the Newburgh-Kingston fluoridation trial followed the populations of these two cities—one on fluoridated water and the other a fluoride-free control.[9] A large study was made of autopsy material from communities with 1.0 to 4.0 parts per million in the drinking water, both natural and adjusted. A comparison of mortality rates was made for 32 cities whose water supplies contained more than 0.7 part per million from natural sources.[15] Each of these cities was randomly paired with a neighboring city containing less than 0.25 part per million. The total population for all cities exceeded 2,000,000. All these studies agree in showing no abnormalities, pathologic effects, or mortality changes that can be related to fluoride in the drinking water, aside from possible dental fluorosis, as discussed below.

More detailed studies of specific pathologic conditions show a similar result. Diabetes and nephritis have been studied without any evidence of fluoride correlation. In the state of Wisconsin the Department of Public Health found no evidence of any correlation between the diabetes death rates in cities with varying amounts of natural fluoride in the water supply. Studies with laboratory animals in which kidneys have been damaged have indicated no disability in the excretion of waterborne fluorides at levels as high as 15.0 parts per million. Hagen et al. also found no difference in the frequency of death from nephritis in fluoride communities and in nonfluoride areas.[15] An increase in the death rate among cancer-susceptible laboratory animals exposed to high-fluoride waters has been noted and has given rise to a fear that cancer might be accelerated in man. There is no evidence among human beings to support this theory, and the cancer mortality in the 32 fluoride cities already referred to is slightly though not significantly less than that in the control cities of the same study.[15] Fig. 56 illustrates the more important findings of this study. A similar study of 22 fluoridated and 22 nonfluoridated cities in the 1970s shows similar results.[16]

Abnormalities of growth, as in height, weight, bone formation as a result of fracture experience; or in other areas as a result of Down Syndrome, have been carefully investigated, and no evidence of a causative relation with fluoride has been found.[17] Needleman et al. report no relationship with Down Syndrome in Massachusetts.[18] Another study shows similar results in England, where recording of the frequency of Down Syndrome and other birth defects is more complete than in the United States.[19]

It is generally agreed that the earliest sign of abnormality due to fluoride in the drinking water is enamel opacity or more serious *dental fluorosis*. Evidence from many areas has been combined in

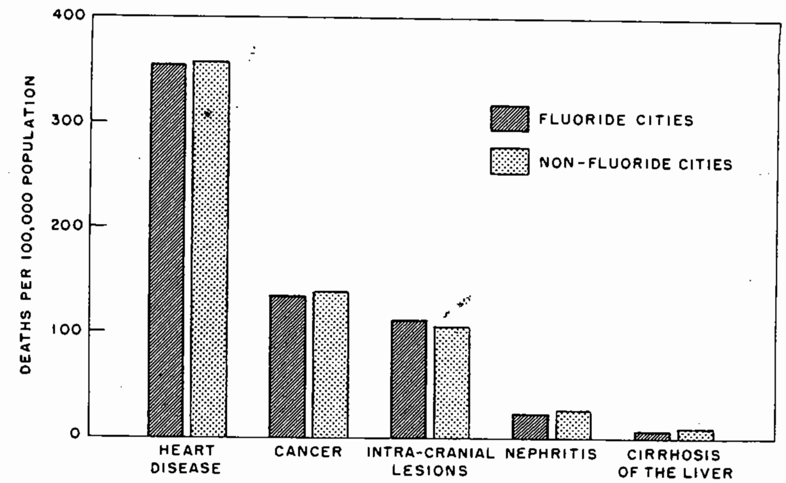

Figure 56. Deaths from five causes in fluoride and nonfluoride cities by age, race, and sex, 1940–1950. [Public Health Service, National Institute of Dental Research.]

Fig. 55 to show the gradual increase of these conditions with increasing fluoride concentration *after* the major reductions in dental caries have been attained. The figures are based upon water consumption characteristic of the North Temperate Zone. A concentration of 1 part per million marks an obvious low point in the two sets of curves; a higher mean temperature, with greater daily water consumption, would move all curves to the left and produce a low point (hence an optimum intake) at a lower concentration, perhaps 0.7 part per million, a concentration actually used in some Southern states. Extensive studies at optimum levels indicate that perhaps 10 percent of those whose teeth were formed on fluoridated water show some degree of mild enamel opacity above the questionable level. Typical of such studies is Russell's report on dental fluorosis in Grand Rapids during the seventeenth year of fluoridation.[20] Eight percent of the white children in this community showed either very mild or mild fluorosis, and 14 percent of the black children showed similar conditions. It is to be remembered that these mild opacities are not unattractive from an esthetic point of view and are matched by nonfluoride opacities and by the early signs of formation of dental caries in the nonfluoride areas. The nonfluoride opacities are usually found in even greater frequency. Thus, 32 cases of very mild or mild fluoride opacities in addition to 36 nonfluoride opacities were observed among 438 Newburgh schoolchildren after 10 years of fluoridation (a 15 percent rate), whereas 612 Kingston children showed 115 nonfluoride opacities (a 19 percent rate). Water fluoridation at optimum levels has never produced positive discoloration of the yellow or brown variety commonly associated with the term mottling. The teeth of children in fluoridated communities in general appear more attractive than the teeth of children in nearby control areas. Even in areas of excess natural fluoride, the stains of moderate fluorosis can be "erased" by the new bonding techniques of operative dentistry.[21]

Where fluorosis is reported in fluoridated areas, it is important to take careful case histories. Some years ago the dosage of fluoride recommended for supplementation, often with vitamins, for children in the first two years of life was .5 milligram per day. Moderate fluorosis was occasionally caused by this dosage, and the dosage was later dropped to .25 milligram, as shown in Chapter 12. Opponents of fluoridation are likely to blame fluoridation for the fluorosis thus caused. Another phenomenon occasionally blamed on fluoridation is the diffuse yellowish discoloration of a number of teeth resulting from heavy dosages of tetracycline for severe illness in early childhood.

The literature on nonfluoride opacities is scanty, but Zimmermann reports some distinguishing characteristics as a result of a study in Illinois and Maryland:

Appearance. Ideopathic (nonfluoride) opacities are more opaque and more oval, often involving the summits of the cusps of posterior teeth. Fluorosed teeth more commonly exhibit horizontal striations, or striae extending down the cuspal ridges of posterior teeth.

Distribution. Ideopathic lesions are not ordinarily found in a definite symmetrical pattern: fluoride lesions are usually bilaterally distributed.

Frequency. Ideopathic lesions seldom affect more than 1 or 2 teeth; fluoride lesions usually involve several teeth.[22]

Reports in years past described a few cases in which symptoms of systemic disability were attributed to the ingestion of fluoridated water of a concentration in the region of 1 part per million.

Typical complaints include "gnawing sensations in the stomach after eating," "stiffness and pain in the spine," "severe muscular pain in the arms and legs," "fingernails brittle," and so forth. It is claimed that some of the symptoms were promptly relieved by a change to water containing no fluoride. Evidence of direct causation is lacking in these studies, and they are not matched by controls. If cases of this sort are to be taken seriously, causation by, not mere association with, fluoridated water must be shown, as well as systemic damage comparable to that arising from dental disease. In July 1971, the Executive Committee of the American Academy of Allergy stated unanimously: "There is no evidence of allergy or intolerance to fluoride as used in the fluoridation of community water supplies."[23]

The attitude of the Commission on Chronic Illness (1954) toward the whole question of the possible toxicity of water with 1 part per million of fluoride is worthy of quotation: "The collection of negative evidence such as this [on excretion patterns for damaged kidneys] for an absolute determination of no possible effects of fluorides in persons suffering from chronic illnesses is an endless and extremely complicated undertaking. Generally speaking, consideration of the primary factors in the causation of such illnesses far overshadows any minor or secondary effects which, in the light of present knowledge, could be assumed from ingestion of trace amounts of fluoride in drinking water." The Commission concluded that "extensive research into the toxicology of fluorine compounds has revealed no definite evidence that the continued consumption of drinking water containing fluorides at a level of about 1 part per million is in any way harmful to the health of adults or those suffering from chronic illness of any kind."[24] It therefore urged American communities to adopt this public health measure "as a positive step in the prevention of the chronic disease dental caries." This recommendation has been consistently confirmed in the subsequent three decades.

Acute Toxicity

It is well known that fluorides in solid form are used as roach and rodent poisons. Acute toxicity in man probably begins about the level of 250 milligrams of sodium fluoride in one retained dose, although this amount has been taken at one time without harm.[25]

Nausea and vomiting are among the first signs of acute morbidity to be expected. A lethal dose for an adult would probably represent from 5 to 10 grams (5,000 to 10,000 milligrams). With such concentration, acute gastrointestinal irritation would develop almost immediately. Nausea, vomiting, diarrhea, and a state of shock would soon follow. Death would be expected within 2 to 4 hours, but if the victim survived beyond 4 hours recovery would be probable. Prompt kidney excretion of fluoride occurs if cellular mechanisms are not overwhelmed. Since 5 grams of sodium fluoride would produce only half that weight of fluoride ion, it can be seen that drinking water fluoridated at 1 part per million, and consumed at the rate of approximately 1 liter per day, carries with it a safety factor of about 2,500 in respect to death.

The question of the danger inherent in the breakdown or sabotage of fluoride-addition machinery is raised from time to time. Recognizable intoxication might be anticipated if a concentration of fluoride in the drinking water were reached sufficient to provide 250 milligrams of sodium fluoride in an 8-ounce glass of water. To obtain this concentration would require more than 4 tons of sodium fluoride per million gallons of water processed.[26] Since the average hoppers in water-treatment plants providing several million gallons per day usually contain only 200 to 500 pounds of powder, the virtual impossibility of such an accident is obvious. A saboteur intent on harming a population could find far easier ways to accomplish his objective.

Fluoride as a Nutrient

Exactly opposed to its status as a toxic agent is the status of fluoride as a nutrient. No human bones or teeth have ever failed to show fluoride when analyzed for it. More than this fact is needed, however, before fluoride can be termed an essential nutrient. Evidence is beginning to accumulate. Complete resistance to dental caries is attained so rarely in areas of fluoride-deficient water, perhaps because dietary fluoride accumulates so slowly in children and young adults, that caries appear to be, in part at least, a fluoride-deficiency disease. Bone structure, too, appears to suffer in fluoride-deficient areas, as has been mentioned.

Taking these facts and others into consideration, the National Research Council, as early as 1958, termed fluoride a "nutrient important for formation of caries-resistant enamel." In 1980 the Council defined the ranges of "estimated safe and adequate" intake for fluoride.[27]

Topical Fluoride Therapy

Since topical therapy involves no planned systemic ingestion of fluoride and operates only on erupted teeth, considerations of chronic toxicity, including possible alteration of formative human enamel (dental fluorosis), do not apply. Accidental swallowing of small amounts of correctly prepared solutions used during a treatment involve dosage so small that considerations of acute toxicity do not apply either.

The standardized methods of therapy which have resulted from these trials are set forth in Chapter 12. Despite occasional claims of greater success, caries reductions have seldom exceeded 40 percent under research conditions and are probably much less in service situations. This fact, coupled with the expense and professional time needed, has made it obvious that topical therapy cannot even closely approximate the cost efficiency of water fluoridation where the latter is possible.

DENTAL BENEFITS

Our first evidence of the dental benefits of water fluoridation came from the endemic low-fluoride areas. Typically, the caries findings were reported in numbers of DMF teeth, and reductions in caries approximated 60 percent. At least three other measures of interest are available, however, from the data assembled in this series of studies. Arnold calculated in 1943 that fluoridation to a level of 1 part per million decreases the number of missing permanent first molars by three-fourths, prevents all but about 5 percent of caries in the proximal surfaces of the four upper incisors, and increases six times the number of children age 12–14 who will show no caries experience.[28]

In subsequent years Russell and Elvove and Englander et al. demonstrated that similar benefits attended *adult* populations in an area of continuous residence.[29,30] Figs. 57 and 58 show differences between the native adults of Boulder, Colorado, where the water is essentially fluoride-free, and Colorado Springs, Colorado,

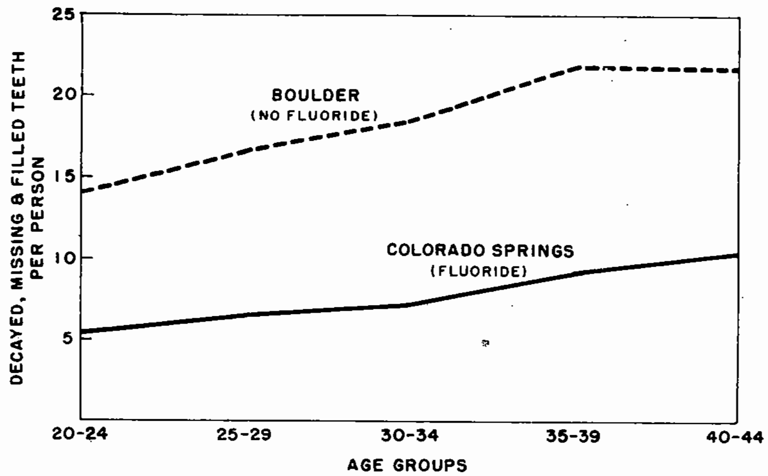

Figure 57. Decayed, missing, and filled teeth per adult in fluoride and nonfluoride communities. [Public Health Service, National Institute of Dental Research.]

where the water contained 2.5 parts per million of fluoride. Reductions in DMF permanent teeth in the latter community are seen to maintain a level approximately 60 percent lower than in the former community, and permanent-tooth mortality is likewise seen to run at a level approximately one-fifth as high.

Three pilot fluoridation studies were started in 1945: Grand Rapids, Michigan, with Muskegon as a control; Newburgh, New York, with Kingston as a control; and Brantford, Ontario. Each was designed to be a 10-year study, but after 5 years it became so apparent that the trial cities would duplicate the experience seen in cities of similar natural fluoride concentration that the U.S. Public Health Service gave its endorsement, stating that "communities desiring to fluoridate their communal water supply should be strongly encouraged to do so."[31] Since that time an increasing number of communities have recorded their experiences.

Table 38 summarizes studies in 14 communities where records of dental-caries experience are available at both the beginning and the end of a 10-year period of fluoridation. One should note that reductions of about 50 percent are the most commonly seen. Where the youngest ages at which caries of the permanent teeth can be

studied are the only ones reported (ages 6 through 8), however, the reductions are invariably larger. Since the older children in the 10-year communities had some of their teeth formed before the fluoride was introduced, and since the most important effect of fluoridation appears to be upon the formation of tooth structure before teeth erupt into the mouth, it is obvious that the older children in these communities have received incomplete benefits. The younger children, however, show results which clearly approximate findings in the endemic fluoride areas.

Certain studies of periods longer than 10 years are available. A report from Grand Rapids, Michigan, after 15 years of fluoridation shows total caries experience to have been lowered by 50 to 63 percent in children 12 to 14 and 48 to 50 percent in those 15 or 16 years of age.[32] Fig. 59 shows the dental-caries experience in terms of decayed, missing, and filled teeth (DMF) per child for Grand Rapids as compared with that in Aurora, Illinois, the best documented natural fluoride community.

Newburgh, New York, after 15 years of fluoridation shows reduction of 70.1 percent in dental-caries experience as compared with the control city of Kingston among children 13 or 14 years of age, and reductions of 89.1 percent in number of missing teeth

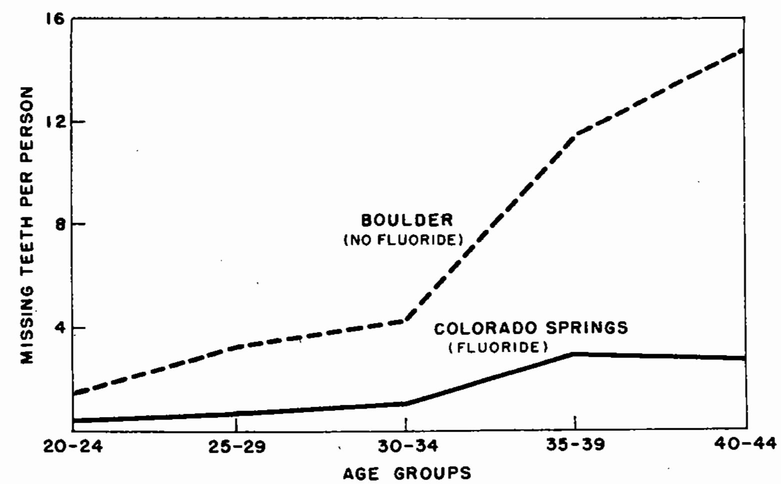

Figure 58. Missing teeth per adult in fluoride and nonfluoride communities. [Public Health Service, National Institute of Dental Research.]

Table 38. Reductions in decayed, missing, and filled permanent teeth among children in communities after 10 years of fluoridation.

Community	Age studied (yrs.)	Reduction (%)
Grand Junction, Colo.	6	94.0
New Britain, Conn.	6–16	44.6
District of Columbia	6	59.1
Evanston, Ill.	6	91.3
	7	64.6
	8	62.6
Fort Wayne, Ind.	6–10	50.0
Hopkinsville, Ky.	? (children)	56.0
Louisville, Ky.	1st 3 grades	62.1
Hagerstown, Md.	7, 9, 11, 13	57.0
Grand Rapids, Mich.	6	75.0
	7	63.0
	8	57.0
	9	50.0
	10	52.0
Newburgh, N.Y.	6–9	58.0
	10–12	57.0
	13–14	48.0
	16	41.0
Charlotte, N.C.	6—11	60.0
Chattanooga, Tenn.	6–14	70.8
Marshall, Texas	7–15	54.0
Brantford, Ont.	6	60.0
	7	67.0
	8	54.0
	9	46.0
	10	41.0
	11–13	44.0
	14–16	35.0

per child.[33] Reports from various states show large increases in totally caries-free teenagers after 15 or more years of fluoridation. In Philadelphia, caries-free 14-year-olds showed an increase from 4.2 to 23.0 percent; in Wisconsin, they went from 1.5 to 14.7 percent.

All these studies make it apparent that there is no longer any reason to doubt the fact that adjustment of a community water supply to optimum fluoride concentration produces results similar

to those seen in the natural fluoride communities. The reductions are not as extensive in developed areas now, however, as they were a generation ago.

It is possible that water fluoridation also has a favorable effect on dental diseases and conditions other than dental caries. Russell has studied the severity of *periodontal disease* in fluoride and nonfluoride areas, and his findings suggest lower severity in the former.[34] The Russell and Elvove study on adults indicates a similar result.[29] The graph on missing teeth shows a widening difference between Boulder and Colorado Springs above age 34, when teeth are more commonly lost from periodontal disease than from caries. Ast, reporting findings from Newburgh, New York (fluoridated), and Kingston (control), states that 35 percent of the chil-

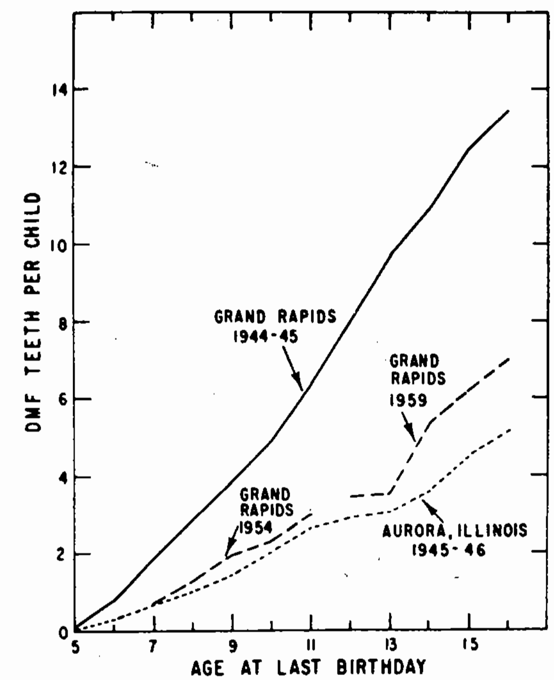

Figure 59. Dental caries in children after 10 and 15 years of fluoridation, Grand Rapids, Michigan, and Aurora, Illinois. [Copyright, American Dental Association. Reprinted by permission.]

dren in the former city and only 13 percent in the latter had normal *occlusion*.[35] The definition of normal occlusion in this instance is a rigid one, even minor deviations from an ideal occlusion being considered abnormal.

These varied benefits from water fluoridation are impressive. Beyond them, Arnold's analysis of the endemic areas shows that reductions in DMF teeth may actually underestimate reductions in man-hours needed for dental care.[28] Proximal lesions of dental caries are inhibited considerably more than pit-and-fissure occlusal lesions and the former take far more time to restore, especially on posterior teeth.

The question is often raised of the value to a fetus of fluoride supplements taken by a mother during pregnancy. The few studies available on this matter seem to give conflicting evidence. Some report later reductions of caries in the deciduous teeth and others do not. There is reason to doubt the ability of brief elevations of fluoride blood level to send appreciable amounts of fluoride across the placental barrier.

MECHANICS OF FLUORIDATION

The adjustment of fluoride concentration in a communal water supply presents a mechanical problem familiar to most waterworks engineers. The feeding machinery used to add fluoride resembles closely, or may be identical with, the machinery used for adding other chemicals. The knowledge of inorganic chemistry needed for manipulation of the chemicals and monitoring of the resulting water lies within the training of any competent waterworks engineer, and the Environmental Protection Agency has developed a specific manual of instructions.[36]

Feeding machinery used for adding fluoride is of two general types, (1) solution feeders, where a hand or mechanically prepared saturated solution of fluoride is fed into the water main at a carefully controlled rate, and (2) dry feeders, where solid material is fed into a dissolving tank at a measured rate by automatic machinery and the resulting concentrated solution is carried to the water main in a volume of water which is sufficient to assure that none of the solid material remains undissolved.

The solution feeders are of two types. The first, most useful in small communities, involves placing a powder such as a sodium fluoride in a vat and letting water remain on top of it until saturation has occurred. The saturated solution is then drawn off at a known rate into the main conduit, while another vat is filled to start a new saturation process. Two vats can be used alternately. The second method involves liquid delivered by tank trucks at known concentration and stored as a fluid in large tanks. Electrically controlled machinery then injects the fluid into the water main. This method is now becoming more popular than solid feeding for large cities. Solid feeding got off to an earlier start for cities, however, because of the initial work with sodium fluoride.

A number of different *fluorine compounds* will supply useful quantities of fluoride ion. Table 39 shows those compounds that are in most common use.[37] Dissociated fluoride ion is the active ingredient in all instances; results are similar regardless of the compound used.

Sodium fluoride was the material used in the original pilot programs started in 1945, but considerations of cost are now shifting the balance in favor of sodium silicofluoride. Fluosilicic acid is used where ease of diluting a material already in liquid form outweighs cost considerations, but its corrosive nature requires careful supervision. Experimental work is now being conducted with fluorspar (calcium fluoride), a material costing only about one-third as much as sodium silicofluoride but difficult to dissolve.

Fig. 60 illustrates a typical volumetric dry feeder with hopper above, electrically operated feeding device in the center, and solution tank below. The measurement machinery may operate to deliver either a measured volume or a measured weight of dry

Table 39. Sources of fluoride ion and their utilization in United States, 1960.

Chemical	Population served
Sodium silicofluoride	25,092,573
Sodium fluoride	5,360,543
Fluosilicic acid (hydrofluosilicic acid)	10,626,715
Ammonium fluosilicate	66,367
Calcium fluoride	7,296
Others, and adjusted natural fluoride	1,047,621

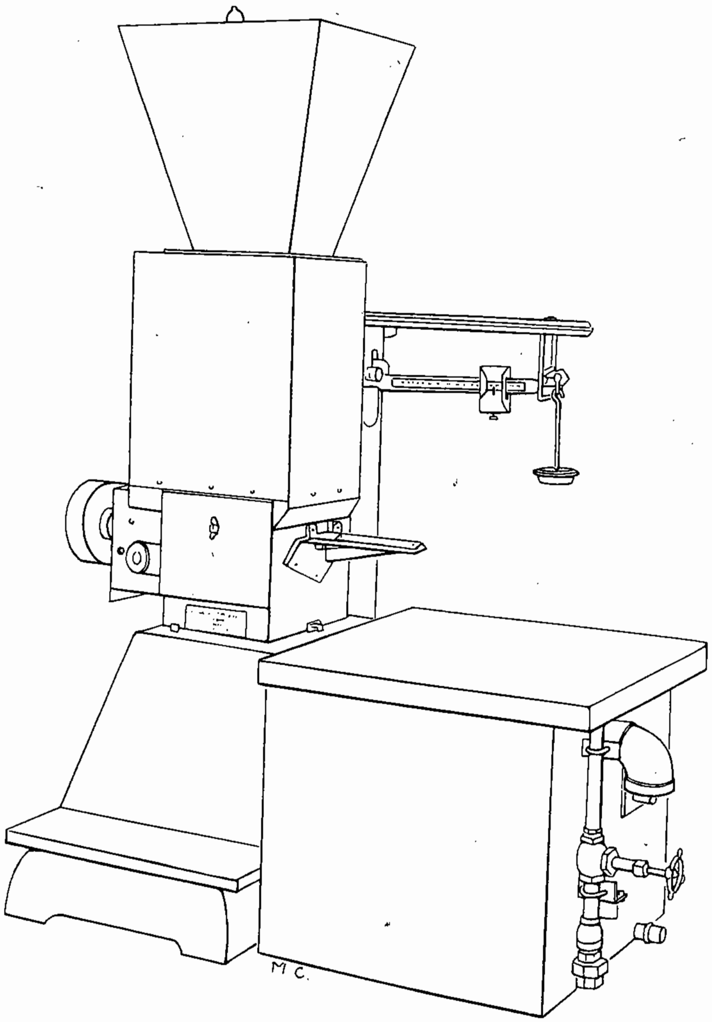

Figure 60. Volumetric fluoridator. [Wallace and Tiernan, Inc.]

chemical within a given time interval. The former type is simpler, less expensive, and probably more commonly used. It is very easy to have the hopper attached by a canvas mesh to the rest of the machine and suspended from a balance in such a way that the

hopper can be weighed at any time, thus determining the weight of powder which has been discharged since previous weighing. This device, shown in Fig. 60, permits both volumetric and gravimetric control in one machine.

Fig. 61 shows a typical scheme for water treatment in an urban area of approximately 70,000 population. Fluoridation of the water treated in this plant is merely the final step in a long chain of operations which includes use of charcoal, alum, gaseous chlorine, and Calgon (a corrosion-control agent), as well as other chemicals on occasion. The dry feeder used to add sodium silicofluoride, though operating in a different part of the water-filtration cycle, stands in this plant alongside similar dry feeders used for adding alum and charcoal. No extra personnel has been added to the staff of the plant, either to operate the fluoride machinery or to monitor the water after fluoridation. Sacks of fluoride are stored on the second floor of the building and an enclosure has been made around the chute which leads into the fluoride hopper in order to limit the tracking of powder around the area where the sacks of fluoride are opened. There is a hood right over the opening of the chute with exhaust-ventilation machinery to carry away from the operator any dust which may arise during the dumping of sacks into the chute. If ventilation machinery were not available, it would be absolutely essential for the operator to wear a dust mask at this stage of the process.

In designing a water fluoridation installation it is important to apply the fluoride at a point where the risk of losing it in subsequent treatment is at a minimum. Alum-coagulation and activated-carbon treatment at low pH values are both processes which tend to remove a small amount of fluoride. The addition of fluoride, therefore, should occur after these processes have been completed, though not necessarily after filtration. Fluoridation, of course, need not occur at the water-filtration plant. Local pumping stations are equally suitable localities. Thus if one filtration plant serves several communities but each community has its own local pumping station, fluoridation is possible for an individual community in the system without involving the others.

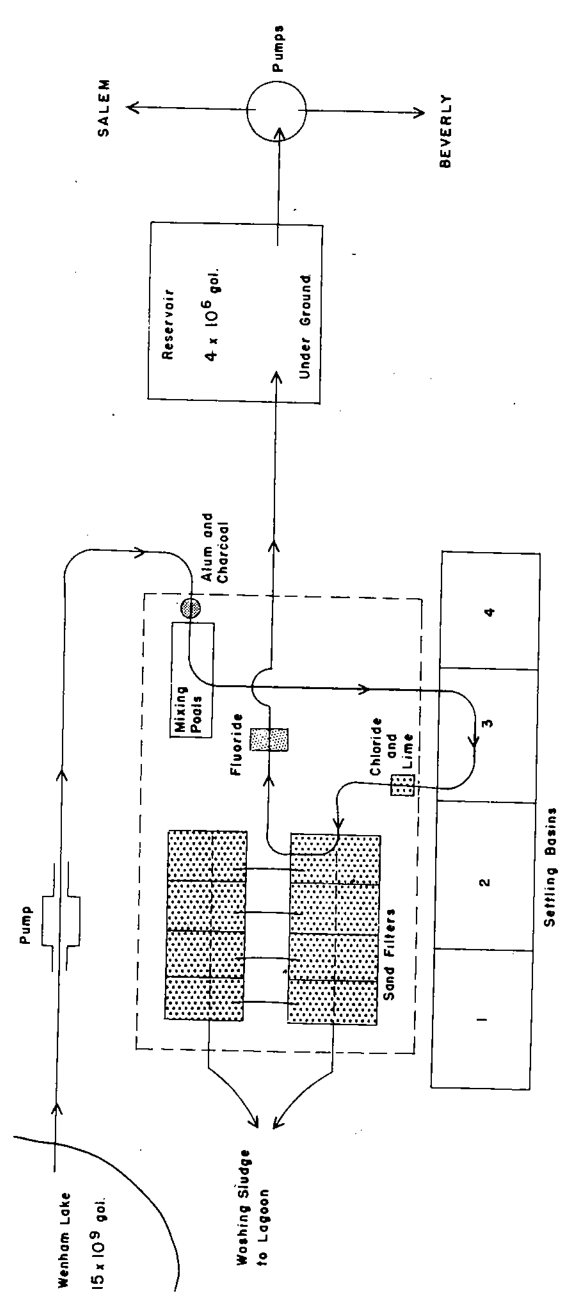

Figure 61. Sequence of water-treatment procedures in Salem-Beverly water filtration plant, North Beverly, Massachusetts.

Fluoride Concentration

The concentration of fluoride in treated water is a matter needing careful consideration. Evidence has been given for the use of a concentration of 1.0 part per million (1.0 milligram per liter) of fluoride ion. This is the concentration produced in most of the fluoridation installations throughout the United States today, and is also the concentration recommended by the U.S. Public Health Service. Most of the work on water fluoridation, however, has been done in the north central area of the United States, where average water consumption per person may not necessarily equal that in other parts of the country. Total fluoride dosage per day is the ultimate measure which must be used if dental caries is to be reduced without objectionable dental fluorosis being caused in the process. In hot climates, where water consumption is greater per person per day, the concentration of fluoride must be less in order to produce the optimum intake of 1 to 1.5 milligrams per person per day. Maier considers that 10 percent incidence of endemic fluorosis is the maximum which can be tolerated. Fluorosis at this level in the population would be entirely of the mildest variety, with no darkening of teeth and merely those slight whitish enamel opacities which are so difficult to distinguish from the early signs of caries. Such opacities occur in a manner and to an extent which is not in the least objectionable.

For practical purposes the U.S. Public Health Service sets up the standards for fluoride to which water-supply systems used by carriers and others subject to federal quarantine regulations must conform. Table 40 gives optimum fluoride concentrations for certain ranges of annual average maximum daily air temperatures.[38] A regulation of the Environmental Protection Agency of March 17, 1986, sets a top limit of 4 milligrams per liter for naturally fluoridated water supplies only.

Variability in individual water consumption is frequently cited as a reason for expecting pathologic effects among residents of fluoridated communities. It is true that individual water consumption does vary. Detailed studies are few. One by Galagan et al. shows a standard deviation so great that it is obvious that some children are drinking more than the average amount of water for their ages and body weights, and others drinking less.[39] Another

Table 40. Fluoride levels recommended for cool and warm climates.

Annual avg. maximum daily air temperatures[a]	Recommended control limits F concentrations in parts per million		
	Lower	Optimum	Upper
50.0–53.7	0.9	1.2	1.7
53.8–58.3	.8	1.1	1.5
58.4–63.8	.8	1.0	1.3
63.9–70.6	.7	0.9	1.2
70.7–79.2	.7	.8	1.0
79.3–90.5	.6	.7	0.8

a. Based on temperature data obtained for a minimum of 5 years.

study by Walker and his associates of some 800 children in widely separated areas throughout the United States shows small variability.[40] Nevertheless, the important fact is that populations available for study both in natural fluoride and in fluoridated areas are large enough so that all degrees of variability may be expected to have occurred. The fact that *no* true mottling (fluorosis above the mild level) or other signs of fluoride toxicity have been demonstrated in these areas is impressive evidence that variability in individual water drinking is unimportant.

Monitoring

Although small hourly variations in concentrations are of little consequence where the safety factors are as great as they are with water fluoridation, regular monitoring of water supplies is essential even at the smallest installation. State health departments usually have requirements for such monitoring. Four methods for monitoring are available:

1. Hourly check of the weight of chemical fed into the hopper. Dry feeders, if well maintained and adjusted, should be accurate well within 5 percent, and this is actually a greater degree of accuracy than exists with any of the chemical tests so far devised.
2. Colorimetric chemical testing through addition of zirconium-alizarin reagent, the result to be compared with standard color samples. Methods of this sort include the Scott-Sanchis, the Megregian-Maier, and the SPADNS. Accuracy is to within approximately 0.1 to 0.2 parts per million of fluoride. Testing is usually done once or twice daily upon the effluent water.
3. Less frequent colorimetric testing is advisable (perhaps at weekly intervals) upon water at various parts of the distribution system, both near to and distant from the point of fluoride addition.
4. Continuous electronic measuring and controlling of fluoride concentration in water is available. The addition of small quantities of fluoride ion to the water supply produces extremely small changes in the electroconductivity of that water, and measurement of the change in conductivity will disclose the concentration of fluoride provided no other change has occurred in the water between the point at which conductivity is first and last recorded.

Fig. 62 shows such an installation at the Salem-Beverly (Massachusetts) water-filtration plant. The conductivity difference recorder is an electronic device with a pen which makes a continuous record upon a revolving disk. Differences in conductivity, expressed originally in electrical units, are later translated into parts

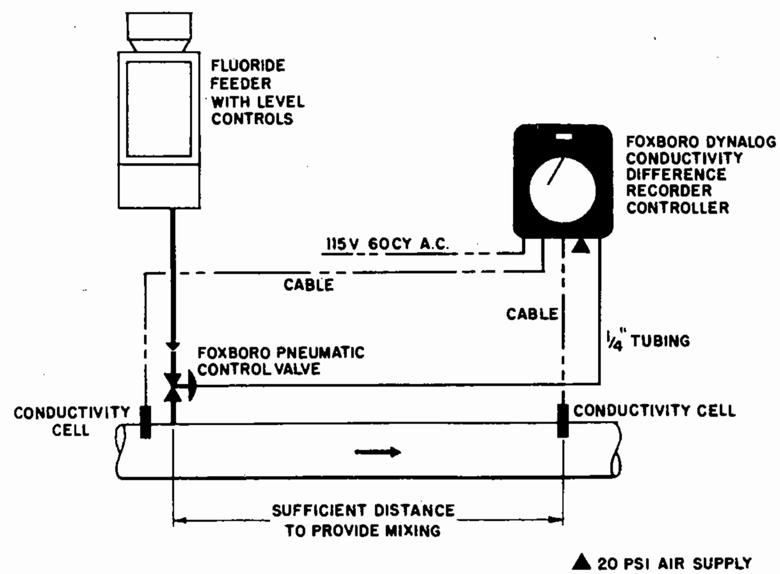

Figure 62. Diagram of fluoride concentration recorder installation. [Courtesy, Foxboro Company.]

per million of fluoride. Variations in concentration beyond a predetermined range activate machinery which will turn off or restart the fluoride feeder.

For portable use, a simple electrode (Orion) is available, giving direct readings of fluoride concentration. The electrode sensing element is a lanthanum fluoride single-crystal membrane which separates an internal filling solution from the sample solution. This single crystal is an ionic conductor for fluoride ion, and fluoride ion alone.

Long-term average errors in adding fluoride to water supplies are completely avoidable in view of the large quantities of chemical involved, and even short-term variations can be controlled with a high degree of precision. In almost 3,000 tests of processed water over a 10-year period in Grand Rapids, Michigan, over 99 percent of the test findings were between 0.8 and 1.2 parts per million. Other cities have shown similar results.

Once fluoridation facilities are in operation, the measurements of concentration need careful and continuous monitoring. The chief risk in cases of careless operation is underexposure to the point of loss of benefit. Significant overexposure cannot exist without the purchase and introduction of large amounts of unneeded chemicals. Health or water departments have various ranges of concentration above and below optimal that they consider acceptable, and percentages of total time during which failure of compliance can be tolerated. These matters are easily computed at a given installation. Kuthy et al., in a study of 249 Illinois water supplies, identified four community or staffing characteristics they found significant in relation to compliance: source of water supply, operator turnover, classification of operator, and community size.[41] In general, the better levels of compliance were associated with surface water supplies, low chief operator turnover in a 5-year period, high operator classification, and large community size.

ECONOMICS OF FLUORIDATION

The operating cost of supplementary fluoride added to a water supply usually runs from 20 to 50 cents per person per year. Where there is one filtration plant or other favorable location for addition, the lower figure is likely. Higher costs accompany multiple points for addition and other engineering problems. Installation costs often approximate 1 year's cost of operation but can run higher. The highest to come to my attention so far is in the city of Newton, Massachusetts, and even here it averages out to less than $1.50 per person in the community.

Opponents of water fluoridation have claimed that tablets for individual dosage could be bought in bulk and dispensed free at about 15 cents per person per year, and that this method of fluoride supplementation therefore compares favorably with water fluoridation. The estimate is incorrect in that costs of dispensing and packaging the material, arranging for individual prescription to each consumer, and distribution and monitoring of supplies—all of them necessary costs—have been omitted. More common estimates of the cost of properly dispensed and packaged fluoride tablets or drops approximate 1 cent per day, or $3.65 per person per year. Even here, the costs of prescription and distribution are neglected, as well as the psychological barriers to consistent long-term use of such supplements. Tablets are safe and effective for school classroom use when properly supervised. The costs of supervision are such, however, that community or school water fluoridation, when possible, is more cost-effective.

The known dental benefits of water fluoridation permit an estimation of the money value to the public of the healthy teeth that now will not require restorative dental treatment. One study in the Newburgh-Kingston series shows the cost of initial dental care to have been reduced by fluoridation from $32.38 to $14.16 among children 12 to 13 years of age, and yearly maintenance costs lowered from $11.00 to $5.90.[42] An estimate made by the writer in which the total cost of all restorative dentistry needed through the age of 16 on permanent teeth of children in Cambridge, Massachusetts, was compared with a similar estimate for Danvers, Massachusetts. The Cambridge estimate was based on the dental-decay rate found in the prefluoridation survey of 1959, and the Danvers estimate on rates after 8 years of fluoridation. The saving in cost was $303 per person. Several studies of cost savings such as these have led to cost-benefit ratios where 1 dollar spent on fluoridation is compared with the dollar value of savings in children's dentistry. These ratios have run all the way from 35 to 60, though they are smaller today. This matter is discussed in detail in Chapter 19.

The decreasing need for dental treatment among the young people in a fluoridated community does not necessarily mean a diminution in demand for dental treatment in the community, since it has been brought out elsewhere that only a small fraction of needed dental treatment is now rendered in most parts of this country. The result of water fluoridation is actually a facilitation of extension of dental care to a much larger proportion of the population than now receives it, and better completion of maintenance care. Where adults who formerly lost all their teeth at an early age now keep and restore part of their natural dentition, demand for dental care should even increase per person. Dentists in fluoridated communities have been shown to remain fully occupied, but with older patients.[43,44]

Opponents of fluoridation occasionally claim that fluorides even at 1 part per million will corrode pipes, or will cause accumulation of fluoride in the iron or calcium carbonate tubercles that occasionally form within water pipes for other reasons. The first claim is chemically illogical and unsupported by any complaint from water departments in areas of both natural fluoride and fluoridation. It has also been chemically tested by the Massachusetts Department of Public Health and found to be without basis.[45] Accumulation of fluoride in tubercles is equally unimportant in view of the obvious difficulty of getting the fluoride back into solution. The point has been investigated carefully in many large cities, however, and the results of these studies have shown conclusively that fluoride residuals can be maintained satisfactorily. In San Francisco, for instance, an average of 640 tests taken throughout the system over a 1-year period showed a variation of only 0.04 part per million from the average dose actually added to the water plus its natural fluoride content.[46]

LEGAL AND POLITICAL ACTION

Fluoridation of a communal water supply is obviously a governmental problem requiring whatever authorization and control may be in effect in the area concerned. In a democratic country it is obviously the will of the people that must ultimately decide whether fluoridation will take place or not. Political action should ordinarily be undertaken at the level of government where the control of the communal water supply rests, though several states have

passed mandatory fluoridation laws for communities over certain sizes. Two main methods are available at the local level: executive decision by elected or appointed officials, and referendum.

The issue of education is one which may often determine the wisdom of a given approach to the enactment of fluoride legislation in a community. Fluoridation is a complicated issue upon which to inform the great mass of a voting population. Scientific facts are easily distorted, emotions are easily aroused, as by the use of such terms as "rat poison." Judgmental evaluation on the part of a voter does not operate as reliably on a scientific problem as it does upon the choice of candidate who can be seen and heard as a person. The very mass of material necessary to an understanding of the fluoridation issue makes it inevitable that many voters who have attempted such an understanding will go to the polls with incomplete knowledge. Such knowledge may prove inadequate to stimulate affirmative votes, or may actually backfire by transforming uninformed proponents into semi-informed opponents. For these reasons referenda on fluoridation represent an inefficient use of the democratic process and in general are to be discouraged. Where inevitable, they should be preceded by a good educational campaign.

A much more informed decision can be obtained if a community is willing to entrust the fluoridation decision to a group of delegated or appointed officials, as it entrusts so many other issues of a complex scientific or legal nature. A city council, a health department, or a city water board is not only a small group to educate, but also one with specialized experience which permits the understanding of the fluoridation issue far more quickly than would be the case in an unselected group—and with responsibility for more detailed study.

The legal validity of water fluoridation has been thoroughly tested in the United States during the past decades, and has been invariably confirmed. The National Institute of Municipal Law Officers made an exhaustive study of water fluoridation and published a report upon the matter in 1952. Among the conclusions reached by this group were:

> Fluoridation is not an unconstitutional invasion of the right of religious freedom.

Fluoridation is a constitutionally permissible exercise of the municipal police power.

Fluoridation to the recommended concentration will not create municipal tort liability.

Neither fluoridation nor the use of municipally fluoridated water in food manufacturing is precluded by the Federal Food, Drug, and Cosmetic Act.[47]

The reasoning behind these statements deserves some examination.

Water fluoridation has been opposed frequently as "compulsory mass medication." The contention has been that majorities do not have the right to compel minorities to ingest "medicine" without their consent. Actually, neither the word "compulsory" nor the phrase "mass medication" is applicable to water fluoridation. Nonfluoride bottled water is available for purchase quite easily in most large communities, and in rural areas citizens can dig their own wells. The fluoridation of a communal water supply through municipal action is, therefore, in no sense compulsion. No citizen is ordered not to drink whatever water he pleases in the sense that he would be ordered not to drive on the left-hand side of the street. Neither is fluoridation "medication." Medication is the cure of a disease; water fluoridation is for prevention, and for nutrition of healthy tooth structure.

In the eyes of the National Institute of Municipal Law Officers there is a "very close analogy" to fluoridation to be found in the compulsory food-enrichment laws. At the time of their report the enrichment of flour and bread was voluntary in 22 states, mandatory by local law in 26 states and 3 territories. It is incorrect and irrelevant to call fluoridation compulsion merely because it imposes a financial penalty upon minorities which wish to avoid it. Majorities are always taxing minorities to finance public improvements. A particularly clearcut example lies in school taxes, which parents are in no way able to escape if they wish to send their children to private school and which people with no children must also pay.

The First Amendment to the Constitution guarantees the right to religious freedom, but this right is not beyond interference by a state or municipality. The religious guarantees of the First Amendment embrace two concepts—freedom to believe and freedom to

act. "The first is absolute, but in the nature of things the second cannot be. Conduct remains subject to regulations for the protection of society."[48] The National Institute of Municipal Law Officers report cites various examples in which a distinction has been made on such matters. Polygamy may be conceived of as a religious duty, but the state may also punish it as a crime. During the Prohibition era the federal government had authority to limit the quantity of wine that could be used for sacramental purposes. Courts have been especially reluctant to interfere with measures for the welfare of children on the grounds that they conflict with religious freedom.

Many lawsuits have arisen on the subject of water fluoridation. Of these, six reached the U.S. Supreme Court, but all were denied review. Fifteen or more have been settled at state level. In every instance the validity of water fluoridation was upheld.[49]

The setting of standards for monitoring of fluoridated water is a common function for a state health department, but state legislation on the initiation of water fluoridation is rare. Several states now require fluoridation, either in any approved water supply or in the water supplies of communities over a certain minimum population. Connecticut was the first state to enact such legislation; Minnesota, Illinois, and Delaware have followed suit. Kentucky and Michigan have regulations of a similar general import. There are three or four states that require referendum by the local community before the initiation of fluoridation.

COMMUNITY ACTION

The recommendation of water fluoridation as a public health measure has thrown dentists into a situation entirely new to them. In the first place, fluoridation is the first preventive measure they have been called upon to implement at the community rather than the individual level. In the second place, it has evoked an emotional opposition of an intensity seldom seen even in the field of public health. With all its embarrassments, the situation has its good points. It makes the dentist a part of his community in a sense that he never has been before. It has made for him a host of new friends in the field of public health and medicine. It has compelled him to study the social background for the acceptance of public health measures. This latter matter has been more thoroughly dealt with in Chapter 10. Finally, it has involved him in the practical political tactics by which community consent to a public health measure may be obtained.

The American Dental Association has put out advice on the subjects of methods and media.[50] Chief among its recommendations is the formation of a citizens' committee to include a wide representation of leaders of opinion and professional people in the community. As part of this committee, and beyond it, must be a strong group of lay people willing to work and to raise money for expenses. The parents of young children are among the best people to look for here.

The citizens' committee operates fully as effectively through personal contact with members of the community as it does through arranging the intelligent use of mass media such as newspaper and radio. One point, however, has become increasingly clear. The public can hardly be expected to take more than a lukewarm interest if fluoridation is presented as a single issue. Far more interest is likely to be aroused if the primary emphasis of the campaign is upon dental health in the broad sense. The citizens' committee can therefore concern itself with the whole problem of dental health at the community level, with particular interest in the school dental health education program. This not only will permit the urging of water fluoridation in a broader, more logical setting, but also will give the committee other constructive objectives in case temporary blocks are thrown in the path of the fluoridation issue.

Voluminous literature, both professional and lay, now exists on all aspects of the fluoridation question. Some of the best scientific sources are listed among the references for this chapter. Any community group desiring to initiate water fluoridation would do well to scan current printed accounts of the "fluoridation fights" reported in their part of the country at the time. Citizens' groups in large cities have put out some excellent literature on matters both factual and strategic. Some of the literature of the American Dental Association provides answers to criticisms made by the opponents of water fluoridation.[51] The U.S. Public Health Service provides various publications of value to the health professional.

For dentists and dental hygienists entering a fluoridation controversy, a few "do's" and "don'ts" are in order:

DO prepare yourselves on detailed facts concerning the benefits and safety of fluoridation, including the findings, localities, and authors of important studies on these matters.

DO learn something about the water supply of your community. Learn about or survey the dental status of the community through school-based samples (not just dental patients) and publicize your findings.

DO select opportunities for public statements which permit your audience to listen to reason without undue interruption. You, in turn, must also listen to their reasons.

DO clear your appearances or writings with your local dental society. Codes of ethics usually require this, and the society will also wish to help you.

DO maintain dignity and reserve sufficient to protect your status as a professional in the field.

DON'T engage in formal debate unless forced to by circumstances. The rules of debate give emotion a status equal to that of reason, assume equal "facts" on both sides of an issue, and give opponents of the issue that last word.

DON'T ridicule opponents of fluoridation. Fanatics often lead them, supplying irrelevant or false information, but the majority will usually be, and should always be assumed to be, sincere.

DON'T lose your "cool."

DON'T give up. Time is on your side.

Endorsement and Use of Fluoridation

Many national organizations in the health field have had reason to study and influence the adoption or nonadoption of a public measure such as water fluoridation. Each organization will study the measure from its own point of view and then express an opinion which is to be taken in the light of its own experience. Thus the endorsement of the American Dental Association, first given in 1950, carries most weight in the field of dental benefits, though of course this association has studied other aspects of the problem as well. The American Medical Association endorsed water fluoridation in December 1951 and again, after reviews of subsequent evidence, in

December 1957 and December 1974. In all instances their endorsement has carried greatest weight in the field of systemic safety. The American Waterworks Association endorsement carries greatest weight in the field of engineering. The U.S. Public Health Service, first endorsing fluoridation in 1945, did so on a multidisciplinary basis supported by the best first-hand dental epidemiological work in the country. The World Health Organization unanimously adopted a resolution in 1969 encouraging fluoridation.[52]

Many lay organizations, studying the matter from a well-rounded but not expert point of view, have given endorsements which should carry great public force. Among these are the American Legion, the Child Study Association of America, the American School Health Association, and the American Federation of Labor and Congress of Industrial Organizations.

As of the end of 1980 it was estimated by the U.S. Public Health Service that, not including communities with natural fluoride, 106,170,000 people in 8,278 communities were receiving controlled fluoridation. The greatest utilization has occurred in the larger communities. New York, Chicago, Philadelphia, Baltimore, Cleveland, Detroit, Washington, D.C., St. Louis, Milwaukee, Boston, and San Francisco all fluoridate. More than 10 million people also use natural fluoridation.

Table 41, provided by the Canadian Dental Association in 1983, gives a worldwide picture of fluoridation in 32 different countries. The size of the country varies all the way from Hong Kong to the United States; the total of almost 250 million people is what counts. Percentage proportions of populations vary widely. Ireland, one of the few countries where fluoridation is compulsory, shows only 48 percent compliance, perhaps because large segments of the population are not on community water supplies. Australia, on a voluntary basis, shows 65 percent compliance; New Zealand, 54 percent. The United States shows 53 percent compliance; Canada, 35 percent. Sweden, a high caries state in times past, is unlisted, since fluoridation is illegal there.

School Fluoridation

Where community water supplies are not fluoridated or where, as in rural areas, none exist, the larger public schools can have a water supply fluoridated to 4 or 5 parts per million. A limited daytime exposure to this concentration of fluoride is estimated to

Table 41. Countries reported to be large users of fluoridation.

Country	As of	Serving	First adjusted	Information source
Argentina	Dec. 1980	1,150,000	1969	Pan Am. Health Org.
Aruba-Curacao	Dec. 1980	0,200,000	1968	Pan Am. Health Org.
Australia	Dec. 1982	9,950,000	1956	Aust. Dept. Health
Brazil	Dec. 1980	19,500,000	1953	Pan Am. Health Org.
Canada (est.)	Dec. 1980	8,800,000	1945	Cdn. Dent. Assn.
Chile	Dec. 1980	4,100,000	1953	Pan Am. Health Org.
Colombia	Dec. 1980	8,470,000	1953	Pan Am. Health Org.
Costa Rica	Dec. 1980	0,650,000	1976	Pan Am. Health Org.
Cuba	Dec. 1980	0,100,000	1974	Pan Am. Health Org.
Czechoslovakia	Oct. 1980	2,500,000	1956	F.D.I. letter
Dominican Republic	Dec. 1980	0,300,000	—	Pan Am. Health Org.
Ecuador	Dec. 1980	1,300,000	1961	Pan Am. Health Org.
El Salvador	Dec. 1980	0,210,000	—	Pan Am. Health Org.
German Dem. Rep.	Dec. 1975	1,200,000	1952	28th World Health Assembly
Guatemala	Dec. 1980	0,700,000	1961	Pan Am. Health Org.
Hong Kong	Dec. 1974	3,900,000	1961	Fed. Dentaire Int.
Ireland	Apr. 1978	1,700,000	1964	Fed. Dentaire Int.
Israel	Apr. 1978	0,200,000	1977	Fed. Dentaire Int.
Malaysia	Oct. 1978	6,600,000	1966	Asst. Dir. Dent. Ser.
Mexico	Dec. 1980	4,700,000	1960	Pan Am. Health Org.
New Zealand	July 1979	1,740,000	1954	New Zealand Dent. Assembly
Nicaragua	Dec. 1980	0,260,000	(Natural F)	Pan Am. Health Org.
Panama	Dec. 1980	0,600,000	1950	Pan Am. Health Org.
Paraguay	Dec. 1980	0,500,000	1961	Pan Am. Health Org.
Poland	Dec. 1974	2,300,000	1967	28th World Health Assembly
Singapore	Dec. 1974	2,200,000	1958	Fed. Dentaire Int.
Switzerland	Apr. 1978	0,200,000	1972	Fed. Dentaire Int.
UK	Sept. 1982	5,500,000	1955	Fluoridation Soc.
USA (est.)	Dec. 1980	123,000,000	1945	US Fluor. Census (est.)
USSR (est.)	Dec. 1974	30,000,000	1960	Eur. Org. for Promotion of Water Fluor.
Venezuela	Dec. 1980	1,200,000	1952	Pan Am. Health Org.
Yugoslavia	Oct. 1980	3,000,000	(Natural F)	F.D.I. letter
		246.7 million		

give school children approximately the same total dosage as they would receive from 1 part per million in a 24-hour day. A carefully documented 12-year U.S. Public Health Service study of such an installation showed a 39 percent reduction in DMF teeth for continuously exposed children.[53] Thirteen states now have one or more fluoridated school water supplies. These serve over 124,000 children in almost 400 schools (1977).[54]

Other Sources of Systemic Fluoride

The supplementation of fluoride by tablets or drops on the part of residents of unfluoridated areas is taken up in Chapter 12.

The addition of fluoride to various foodstuffs follows essentially the same pattern as that involved in the use of tablets or drops. One small-scale study has been made in which homogenized milk was fortified with a dose of 1 milligram of fluoride, in the form of sodium fluoride, per half-pint container. Reductions in dental caries that appeared to approximate those of water fluoridation were obtained after a period of 4½ years.[55] Fluoridated salt and milk have been used in Switzerland with somewhat less success.[56] All these methods involve problems of supervision and cost that put them out of the level of practicality of community water fluoridation. They are to be considered, however, where community fluoridation is impossible.

Municipal Defluoridation

Communities which find themselves unable to obtain a natural water supply with less than 3 parts per million of fluoride will wish to reduce this concentration in order to reduce dental fluorosis in children's teeth. The U.S. Public Health Service has designed and acquired experience in the use of defluoridation machinery.[57] Calcined (activated) alumina is most commonly used as an absorbing agent. Installation of equipment and an alumina bed cost approximately $15,000 in 1963, and operating costs ran about $52 per million gallons of treated water. Costs such as these are believed to be within the resources of many communities using high-fluoride water, though only 11 plants designed for fluoride removal were operating in 1963.