MINISTRY OF HEALTH
DEPARTMENT OF HEALTH FOR SCOTLAND
MINISTRY OF HOUSING AND LOCAL GOVERNMENT

The Fluoridation of Domestic Water Supplies in North America

as a means of controlling Dental Caries

REPORT OF THE UNITED KINGDOM MISSION

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1953

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REPORT OF THE UNITED KINGDOM MISSION ON THE FLUORIDATION OF DOMESTIC WATER SUPPLIES IN NORTH AMERICA AS A MEANS OF CONTROLLING DENTAL CARIES

To the

Rt. Hon. Iain Macleod, M.P., Minister of Health.

Rt. Hon. James Stuart, M.V.O., M.C., M.P., Secretary of State for Scotland.

Rt. Hon. Harold Macmillan, M.P., Minister of Housing and Local Government.

Medical Research Council.

Introduction

1. The Medical Research Council, in a report to the Minister of Health, recommended that a small mission should visit the United States of America to study the fluoridation of water supplies as a means of reducing the incidence of dental caries. We were appointed as a result of this report.

2. In order to carry out this recommendation in its widest sense it was considered necessary to attempt an evaluation of the dental results obtained from the fluoridation of domestic water supplies in the United States and Canada ; to consider possible effects of fluoridation upon the general health of the community ; to give attention to possible repercussions on industry ; to make a detailed study of the technical processes involved in the fluoridation of water supplies ; and to study the researches in progress at the National Institute for Dental Research at Bethesda and at certain University centres. During our tour we inspected the teeth of a large number of children ; one of us (Miss Forrest) remained in America for an extra period of time to make more detailed dental examinations. Our itinerary is given in Appendix 1.

3. We are conscious of the very great assistance we received from the Surgeon-General of the United States Public Health Service, Dr. Leonard A. Scheele, who with members of his Dental Division went out of his way to ensure that every possible facility was put at our disposal. In particular Assistant Surgeon-General Bruce D. Forsyth, D.D.S., Chief Dental Officer, Dr. John W. Knutson, D.D.S., Chief, Division of Public Dental Health, and Dr. H. Trendley Dean, D.D.S., Director, and Dr. F. A. Arnold, Jr., D.D.S., Associate Director, National Institute of Dental Research, were most helpful in our official enquiries and moreover did much to make our visit personally most happy.

4. We were anxious to assess the reactions of the profession and the public to this latest United States Public Health measure and we were materially assisted in both these directions and in arranging certain of our visits to fluoridation projects and to research departments by Dr. Harold Hillenbrand, D.D.S., Secretary of the American Dental Association, who placed himself and members of his staff at our disposal.

5. We met a large number of civic authorities, public health officials, medical and dental research workers, public dental officers, water engineers, and private medical and dental practitioners, all of whom readily gave us every possible help in our enquiry. In particular, we wish to acknowledge that we were given a considerable amount of unpublished information which has been used in preparing our report.

In addition, we received much kindness and hospitality for which we have personally expressed our gratitude ; but we should like to place on record our appreciation of the welcome and the very real assistance we received wherever we went in the United States and Canada.

The Historical Background

6. As long ago as 1892 Sir James Crichton-Browne suggested that there was some connection between fluoride in the diet and decreased liability to dental caries. Little clinical investigation was made until 1916, when interest was revived by the work of Black and McKay in the United States of America. Their investigations were concerned primarily with mottling of the enamel of teeth that occurs in certain districts. This effect on enamel was observed also in the Maldon area of Essex by Ainsworth (1928) and has been found in all continents. Eventually it was shown that the mottling was associated with abnormally high amounts of fluoride in the water supply (Churchill, 1931 ; Smith and Smith, 1932 ; Ainsworth, 1933 ; Elvove, 1933).

7. It is convenient at this stage to make it clear that fluorides are a fairly common naturally occurring constituent of many waters used for domestic purposes, and indeed few water supplies could be guaranteed to be completely free from fluoride. The concentration varies in Great Britain from a trace to about 6·0 parts per million (p.p.m.) expressed as fluorine, but few water supplies contain more than 1 p.p.m.* The degree of mottling of teeth has been found to vary and to depend very largely upon the quantity of fluorides present in the water (Dean and Elvove, 1937 ; Dean and Arnold, 1943). The latter authors stated that the appearance of teeth which have been exposed to water containing fluorides during the formative period can be correlated with the fluoride content of the water in the district, and they have classified the mottling according to severity into the following six grades: questionable, very mild, mild, moderate, moderately severe and severe. Thus water containing only 1 p.p.m. of fluoride causes no more than questionable or very mild mottling, that is, only an occasional white fleck or spot in the enamel, and even then in only 10 per cent. of the population. Such white flecks are so inconspicuous that they can be detected only by expert examination and to demonstrate them photographically polarised light must be used. In mild mottling, found in association with 1·5 to 2·0 p.p.m. of fluoride white flecks are more widespread, as is shown in the colour print. The effects become progressively more marked with increased amounts until when the concentration approaches 6 p.p.m. the incidence is about 100 per cent. with about 90 per cent. in the severe grade.

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* " Expressed as fluorine ". This is a precise way of expressing fluoride content and all concentrations given in this report should be read in this sense. For the sake of brevity, however, the words will be omitted in subsequent pages.

Colour photograph by the Photographic Department, Dental School, Guy's Hospital.

"Mild" mottling of the teeth in a girl aged 14 years, born in Maldon, Essex. Exposure by polarised light, which accentuates the otherwise inconspicuous white flecks.

"Very mild" mottling sometimes occurs with 1 p.p.m. of fluoride and is less noticeable (see page 2, paragraph 7).

It is the appearance of the severe grades that originally gave rise to the term mottled enamel in which brown staining and marked structural defects occur. It should be emphasised at the outset that this is very different from the appearance resulting from exposure to water containing fluoride at a level of 1 p.p.m.

8. McKay (1929) noted that the incidence of caries was reduced in a district where mottled enamel occurred. Since both phenomena were associated with a high concentration of fluoride in the water supply, a group of workers in the United States examined the dental condition of children living in various districts in relation to the fluoride content of their domestic water supplies. Following a number of well planned field surveys by Dean, Arnold and Elvove (1942), Dean (1951) reported that the caries incidence was about 60 per cent. less in areas where the fluoride content of the water was 1 p.p.m. or more. This beneficial effect has been confirmed by various observers in America and other countries.

9. In Great Britain Weaver (1944 *a* and *b*) reported that the incidence of dental caries was 45 per cent. less in children aged 12 years in South Shields where the fluoride content of the water was estimated to be 1·4 p.p.m. than in North Shields where the amount was only 0·25 p.p.m. He suggested that the effect of the higher fluoride content was in the nature of a delaying action but other studies in this country by Forrest, Parfitt and Bransby (1951) and in America by Deatherage (1943) and Russell and Elvove (1951) have shown that the beneficial effect is carried into adult life, at least up to age 45, but further investigations in the higher age groups are needed (Appendix 7).

10. The accumulated evidence so strongly supported the conclusion that dental caries was much less in areas with naturally fluoridated waters that it was decided in North America to see whether the same result would follow the addition of enough fluoride compound to a low fluoride water supply in order to raise the fluoride content to 1 p.p.m. The first such project was inaugurated in 1945 at Grand Rapids, Michigan, by the United States Public Health Service in co-operation with the State Health Department and the University of Michigan. By December, 1951, fluoridation of public water supplies had become a fairly common practice in North America.

The Dental Effects of Fluoridated Water Supplies

Purpose and general design of fluoridation studies

11. The early projects were introduced to study the effect of fluoridation on the incidence of dental caries. More recently fluoridation has been adopted in many communities in the United States purely as a public health measure.

In a fluoridation study, two nearby towns, comparable in all respects, are chosen, both having an almost fluoride-free domestic water supply, preferably from the same source. The water of one town is fluoridated while that of the other remains untreated, this town serving as the control. Before fluoridation is started the teeth of the children in both towns are examined in detail to ascertain if the caries experience is similar and to determine its prevalence in the various age groups. Further examinations are carried out at yearly intervals and the dental condition of the children in the fluoridation town is compared with that of similar groups in the control town. The pre-fluoridation data also serve as a basis for comparison. The caries incidence may also be compared with that in a town where a similar concentration of fluoride occurs in the water naturally. In practice it is often difficult to obtain all these conditions and in some studies there is no independent control.

Study Areas Visited

12. The areas visited where studies of dental caries in its relation to fluoridation are in progress were: Grand Rapids, Michigan ; Newburgh, New York ; Brantford, Ontario ; Sheboygan, Wisconsin ; Marshall, Texas ; and Evanston, Illinois. In each area the fluoride concentration of the drinking water has been raised to between 1·0 and 1·2 p.p.m. by the addition of sodium fluoride.

13. The studies are limited to schoolchildren between 5 and 16 years of age and for the most part to those who have lived continuously in the district from birth. They are planned to extend over a period of 10 to 15 years. The last permanent teeth, except the third molars, will have erupted at about 12 years, hence at 15 years it will be possible to assess more fully the effect of fluoridated water on the teeth of children who have been exposed to it during the whole of their childhood and pre-natal life. It should be realised that different teeth develop, mineralize (calcify) and erupt at different ages (Appendix 2). Therefore, fluoridation which has been applied for a short period only will show results which vary according to the ages of the children when fluoridation began. In fact, it is only among the younger children that the full benefits of fluoridation can be demonstrated at the present time.

14. The studies vary in scope. Some are concerned mainly with the effect on dental caries incidence, and clinical dental examinations only are made. Others are more elaborate and include X-ray examinations and counts of *Lactobacillus acidophilus* in saliva, regarded by some authorities as an index of susceptibility to dental caries. In some instances, there are general physical examinations and in one study a valuable parallel paediatric research programme has been undertaken, which includes X-ray examination of the developing long bones, analyses of blood and urine, and other tests.

15. The dental examinations are made yearly in school premises and as far as possible by the same observers in each area. A high standard of clinical examination is maintained and there is little variation between the methods employed by the observers in the different studies or in the criteria used for the assessment of caries. Even if there is some difference in the method and criteria adopted, provided they remain the same each year comparison within the individual study is not affected. The criteria of dental caries assessment used in the different studies are recorded in Appendix 3 and the studies themselves are described in Appendix 6.

16. The presentation of the dental findings varies to some extent in the different studies. For the most part reports are made for each successive year on the caries experience in the deciduous and permanent dentitions separately. This is generally expressed as the average number of def (i.e., decayed, extracted or indicated for extraction, and filled) deciduous teeth, and DMF (decayed, missing, and filled) permanent teeth, per child in each age

group. In Brantford and Marshall reports are made for the mixed deciduous and permanent dentition and expressed as the average number of DMF teeth per child. Additional methods of assessing the findings and presenting the data are used in some studies. These are described in Appendix 4.

Some teeth are much more liable to caries than others. In view of this and the different ages at which they develop reports may be based not only on the condition of all the teeth but on that of certain teeth or groups of teeth.

The results of fluoridation studies

17. In all the studies a steady reduction in caries experience has been found and it is most marked among children in the younger age groups although it has been observed to some extent up to 12 years of age. In control cities, no comparable reduction at any age was observed, so the possibility that a change would have occurred without fluoridation in the study areas can be eliminated. The following table shows the incidence of caries among 6-year-old children in the 5 earlier studies. This age group is selected as these children's teeth have been subjected to the influence of fluoride during practically the whole period of development and mineralization and it will be seen that after 5 to 6 years of fluoridation the number of deciduous teeth affected by caries has been reduced by about half. For example, in Grand Rapids, the average number of def deciduous teeth per child had fallen from 6·4 to 3·7. An important point is that a reduction has been observed consistently in all the studies.

The erupted permanent teeth at 6 years of age have been exposed to caries attack for a very short time only, but the difference in caries rate is distinct.

Caries experience among 6 year-old children before and after fluoridation

Study	Number of children aged 6 years examined		*Deciduous Teeth* Average def per 100 children		*Permanent Teeth* Average DMF per 100 children	
	1945	*1951*	*1945*	*1951*	*1945*	*1951*
Grand Rapids ...	1,789	748	643	373	77	26
Muskegon† ...	462	310	717	602	81	75
		1950–51		*1950–51*		*1950–51*
Newburgh	403	427	*571	*266	48	11
Kingston†	343	364	*532	*472	41	40
	1946	*1951*		*1951*		
Sheboygan ...	—	456	480	222	—	—

* These are "df" rates, and do not include missing teeth.
† Control Areas. Practically free from fluoride.

Study	Number of children examined		Deciduous and Permanent Teeth combined Average DMF per 100 children	
	1945	*1951*	*1945*	*1951*
Brantford	556	334	704	355
	1946			
Marshall	63	76	706	305

Note.—The caries rate is sometimes given per child and sometimes per 100 children. For the sake of uniformity they have all been calculated per 100 children in this table and decimal points have been omitted.

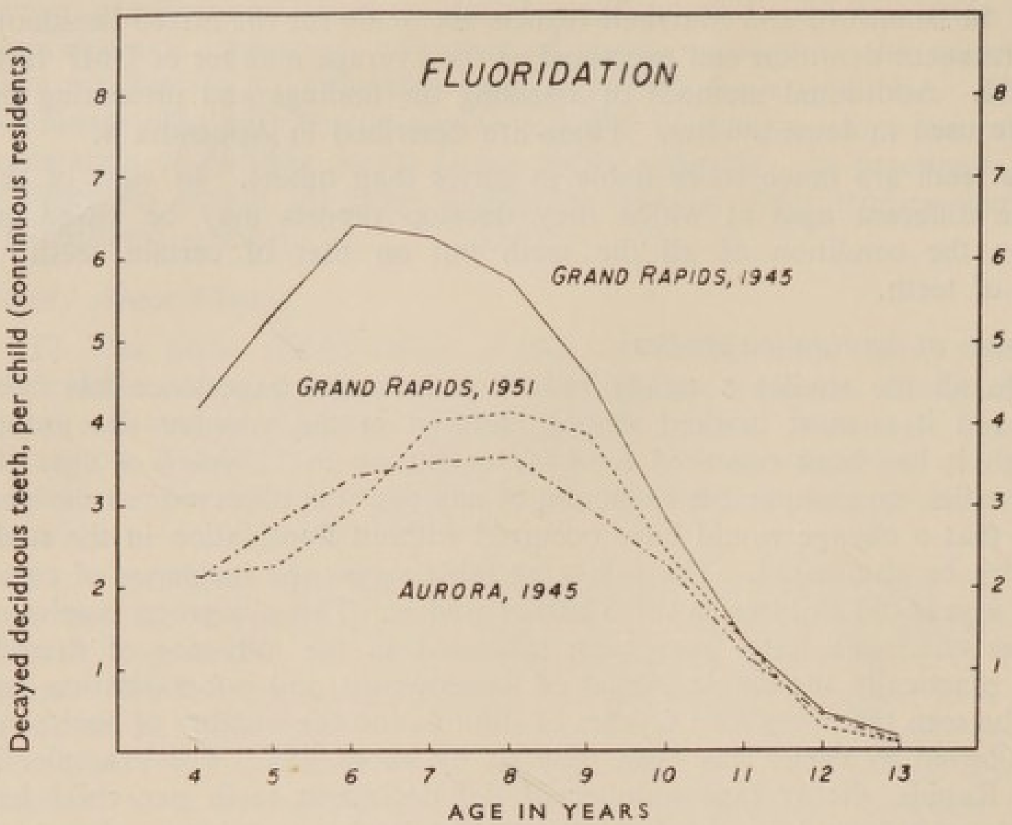

Fig. 1

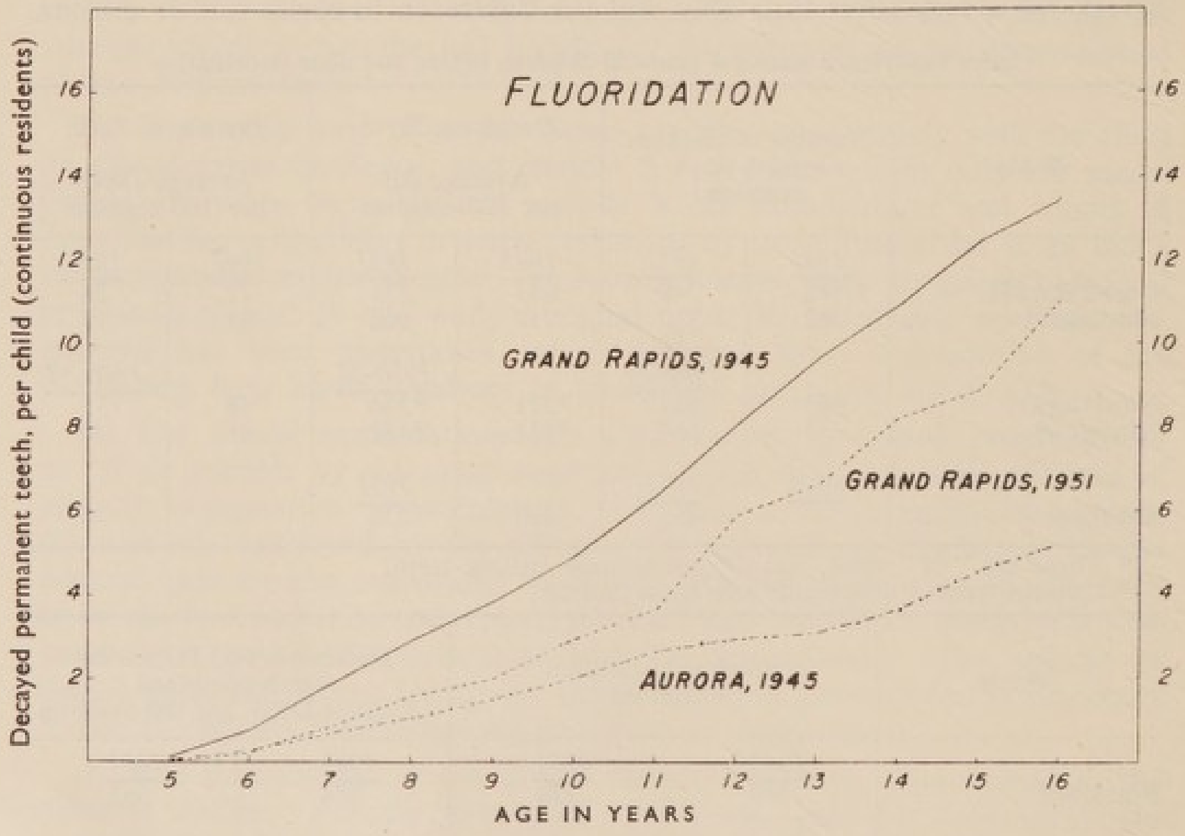

Fig. 2

Note that the curve after fluoridation (Grand Rapids 1951) has approached that of Aurora, particularly among the younger children.

It is interesting to consider also the proportion of children free from dental caries. Unfortunately this information is not always available, and has been presented in different ways. The table which follows gives data from the earlier studies and shows that some years after fluoridation more children in these areas were caries-free.

Children, aged 6 years, free from Caries before and after Fluoridation

Study	Teeth considered	Percentage of Children free from Caries	
		1945	*1951*
Grand Rapids ...	Permanent teeth	65	86
Newburgh... ...	Deciduous cuspids and molars, only ...	18	*1950* 40
Brantford* ...	Permanent teeth	*1948* 47	59
Sheboygan† ...	Deciduous teeth	20	48

* Children aged 6–8 years. † Children aged 5–6 years.

Some studies have included a comparison with the city of Aurora, Ill., where fluorides occur naturally in the drinking water at a level of 1·2 p.p.m. and where the caries rate is low. Since 1945, when fluoridation was introduced in Grand Rapids and Newburgh the dental caries incidence among the children has gradually fallen, and in 1951 the def rate among 6 year-old children was almost the same as that of Aurora, while the DMF rate was less. As an example, Figs. 1 and 2 show a comparison between Grand Rapids and Aurora before and after fluoridation.

In Evanston fluoridation began in 1947, later than in the other studies, so that it has not been in operation for a sufficient length of time to evaluate the effects. Nevertheless the reduction in dental caries incidence in the permanent teeth is similar to the findings of the other investigations. The deciduous teeth, however, are only slightly affected and this differs from the other studies, where caries in the deciduous teeth has been reduced by about half. It is probably due to the fact that the crowns of these teeth among children aged 6 years in 1951 had all been formed and many of them had erupted before fluoridation was started. A description of the individual studies and the dental findings are given in Appendix 6.

18. The mechanism whereby a reduction of dental caries is achieved by fluoridation has not been elucidated and several theories have been advanced in explanation. These are discussed in Appendix 8.

19. In all the studies the teeth are carefully examined for any sign of dental fluorosis (mottled enamel), but in only very few instances has it been found. Even then it has occurred only as an occasional small white fleck on a cusp of a permanent molar or pre-molar, or on the biting edge of a permanent incisor. Otherwise the teeth are unaffected and we confirmed this by personal observation. It is unfortunate that some term other than "fluorosis" has not been found to describe this condition as the name implies a defect. We consider that such small changes in the enamel surface, changes which may occur also from some other cause, and are detectable only by a trained observer, cannot be considered a disadvantage even aesthetically.

In Marshall, Texas, the water is fluoridated to a level of 1 p.p.m. Marshall is in the southernmost State, and has a much higher average day temperature and a greater degree of humidity than have any of the other study areas. It was anticipated that water consumption would be much greater than in the temperate areas so that the intake of fluoride would be considerably more. This may be so, but the effect on the teeth did not appear to be different from that noted in the other study areas.

An appraisal of the results

20. The reported results of the studies leave no doubt that an important reduction in the incidence of dental caries has occurred among younger children as a result of 4 to 6 years fluoridation; that taking into account the time factors concerned, these results are very much those which would have been predicted from the epidemiological surveys; and that the dental benefits are not accompanied by any undesirable manifestations of dental fluorosis. Had these conclusions been derived from a single investigation there might have been room for scepticism; but the striking similarity in the results of several wholly independent enquiries in widely separated areas puts the matter beyond reasonable doubt. The possibility that the conclusions reached have been influenced materially by biassed examination of the teeth can, in our opinion, be discounted (Appendices 3, 4, 5 and 6). It is nevertheless instructive to analyse the nature of these enquiries a little further in order to demonstrate their full significance, as well as their possible limitations.

21. In an ideal experiment, the test data should be compared with control data similar in all respects except with reference to the variable under consideration, in this case the fluoride content of the water supply. Water is not the only source of fluoride; it is also derived from food and may be inhaled in dust or smoke. In no study has a detailed accounting of the total fluoride consumption of subjects been undertaken, although in Evanston studies of fluoride in food have been made. It has been assumed that differences in food consumption between experimental and control subjects are unimportant; that the amounts of fluoride derived from foods in each group are similar; that the inhalation of airborne fluoride is likewise similar (and probably unimportant anyway); and that since experimental and control areas are geographically near, water consumption levels are similar. All these assumptions would seem to be reasonable, and we do not think that the laborious and difficult task of testing them in practice is necessary.

All the communities in the studies described are American urban populations (all northern, except Marshall) of a fairly prosperous type and having similar food habits. Certainly as between each experimental group and its independent control (where present) there is no reason whatever to suspect significant dietary or climatic difference. There has been no major change in American food habits during the past few years which might invalidate comparisons with the base-line data of an individual community in relation to fluoridation. In none of the experimental or control communities are there major industrial differences liable to give rise to important variations in the "inhalation dose" of fluorides. The following table (McClure, 1943) gives estimates of the amount of fluoride ingested from food and water by children under normal conditions in the United States, when the water supply contains 1 p.p.m. fluoride.

Summary of Estimated Daily Intake of Fluorine from Food and from Drinking Water (Drinking Water containing 1 Part per Million of Fluorine and Dry Substance of Food containing 0·1 to 1 Part per Million of Fluorine).

Age, Years	Body Weight* Kg.	*Daily Fluorine Intake*			
		From Drinking Water Mg.	From Food Mg.	Total Daily from Food and Drinking Water, Mg.	Total Daily Mg./Kg. of Body Weight
1 to 3 ...	8 to 16	0·390–0·560	0·027–0·265	0·417–0·825	0·026–0·103
4 to 6 ...	13 to 24	0·520–0·745	0·036–0·360	0·556–1·105	0·023–0·085
7 to 9 ...	16 to 35	0·650–0·930	0·045–0·450	0·695–1·380	0·020–0·068
10 to 12 ...	25 to 54	0·810–1·165	0·056–0·560	0·866–1·725	0·016–0·069

* Figures for weight for ages 1 to 6 years were taken from tables arranged by Woodbury (1921): figures for 6 to 12 years were taken from the Baldwin-Wood weight-height-age table for boys and girls of school age, published by the American Child Health Association.

It will be noted that McClure derives his estimates of the range of total intake by adding together the extremes of the ranges of intake from water and from food separately. This may not be wholly justified, since in practice the amounts of fluoride derived from food and from water need not necessarily increase or decrease in parallel. Nevertheless, some degree of parallelism is not unlikely. If this is so, his figures indicate that fluorides in food normally account for considerably less than half the total intake and variations in the food content of fluoride are not likely to overshadow the difference between an area where the water supply contains 1 p.p.m. fluoride and a control area where there is next to none in the domestic water supply.

22. In all studies except that at Marshall the populations concerned have been predominantly white. In none of the populations is there any reason to suspect the presence of any important degree of malnutrition, and it is most unlikely that lack of calcium or of vitamin D has affected the incidence of dental caries. Indeed, dental authorities in Wisconsin, " the dairy State ", held that despite exceptionally high milk consumption the dental caries rates among school children in Madison are at least as high as elsewhere in the country.

It has been suggested that a high consumption of sugar may to some extent influence the prevalence of dental caries. This theory received support from observations in the United Kingdom (Bransby and Knowles 1949) and Europe (Toverud 1949) that restriction of sugar consumption during the war was accompanied by a fall in the caries rate among children. There was no comparable restriction of sugar consumption in the United States and the level of consumption of candies and other sugar-containing foods remains very high.

23. The general economic and social conditions, besides influencing dietary habits, also have a bearing on the extent and type of dental care available in communities. As has already been stated, all communities in the fluoridation study areas are fairly prosperous, and the number of dentists per head

of the population seems to have been high, at least in comparison with British industrial populations. Where adequate dental treatment is available, and where conservative dentistry is widely practised, the spread of caries may be retarded and lower DMF rates may be expected, especially among older children, than in communities where conservative dentistry is less popular. Again, prophylactic filling of deciduous teeth and first permanent molars may prevent the onset of caries, but in a dental survey teeth containing such fillings will be included in the DMF counts. While these considerations are not of major importance in connection with the validity of the American fluoridation studies, they mean that somewhat different results may be experienced in communities where less conservative dentistry is practised. The results of surveys in England give good hope, however, that fluoridation would yield substantial benefits in this country (para. 9).

The Long Term Prospects of Fluoridation

24. The full results of fluoridation among American children are at present apparent only among the younger age groups. Fortunately it is possible to predict with considerable confidence the kind of result which will eventually be apparent. There is no essential difference between fluoride which occurs naturally in water and that which is added to water in the process of fluoridation and the action on teeth is therefore similar. This is borne out by the fact that the data already available shows complete parallelism in the dental condition of 6-year-old children living in natural fluoride areas and in those who live in fluoridated areas, where the fluoride levels are similar.

The epidemiological work of Dean and others in the United States showed that there is about 60 per cent. less caries among the permanent teeth of children aged 12–14 years, who have been born and brought up in areas where fluorides occur naturally in the water, 1·2 to 1·8 p.p.m., and that 20 to 30 per cent. of these children have no dental caries whatever. In England, Weaver found that the DMF rate among 12-year-old children who had consumed water containing 1·4 p.p.m. fluoride, was about 45 per cent. of that in areas where the water contained little or no fluoride, and that the permanent teeth of 26 per cent. of them were completely sound.

Recent surveys, both in the United States and in England have shown that the continued use of water containing fluoride results in a lower incidence of dental caries at least up to middle age (Appendix 7). In an English survey (Forrest, Parfitt and Bransby, 1951) the reduction in the DMF rate was 35 per cent. at 26–30 years and 25 per cent at 31–35 years, the difference becoming less with increasing age up to 41–45 years. In the American survey (Russell and Elvove, 1951) on the other hand the difference was 61 per cent. at 30–34 years, falling only to 52 per cent. at 40–44 years. In both surveys, English and American, adults in the areas where water contained fluorides not only had a lower caries experience but had fewer missing teeth. The American investigators may have obtained better results because they studied populations among whom the level of conservative dentistry available was considerably higher than among the populations examined in England. A comparison of the English and American findings suggests that for the best dental results, especially among adults, a combination of fluoridation and a high standard of conservative dentistry is needed.

25. In the light of all these findings there can be little doubt that fluoridation will reduce the incidence of dental caries very substantially, not only among children, but also among adults. However, it should be emphasised that fluoridation is not a " cure " for dental caries, and it is not known whether it retards the progress of existing caries. Older children and adults brought up in areas where the water has not contained fluoride cannot expect much direct benefit from fluoridation, which must therefore be regarded as a long term measure. Some individuals who are particularly susceptible may develop severe dental caries despite life-long consumption of fluoridated water.

Even with fluoridation, caries will continue to exist and the need for dental treatment will not decrease. However, the reduction in dental caries which follows fluoridation will do much to reduce the present serious gap between the dental needs of the people and the amount of available treatment.

Possible Hazards

26. The evidence already discussed has shown that the consumption of water containing fluoride in the appropriate amounts does reduce the incidence of dental caries to an important extent, at all events under conditions like those in America and Britain. We are not aware of any authority who questions this view. The theoretical possibility that water to which fluorides have been added artificially may have a different effect on dental caries from water containing fluorides naturally derived has been ruled out by results to date of the fluoridation studies. Yet controversy continues in the United States about fluoridation. In the words of the Select Committee to Investigate the Use of Chemicals in Foods and Cosmetics (1952) (Delaney Report), " The area of controversy concerning the fluoridation of water arises over the question whether a sufficient amount of investigation and study has been completed to justify a recommendation of universal application of this procedure at this time. . . . The majority of scientific opinion is that fluoridation of drinking water in amounts up to one part per million of fluorine is safe. The view of the minority group is not that it is known that the ingestion of fluoridated water at one part per million will result in injury to health, but rather that it is not known with any degree of certainty exactly what subtle physiological effects may ensue, and that a number of important questions still remain unanswered."

27. During our visit to the United States, the public hearings before the Select Committee mentioned above (an official body appointed by the House of Representatives) were going on and were widely reported in the public Press. During the course of these hearings, of which the verbatim record is now available (Hearings before the Select Committee to Investigate the Use of Chemicals in Drugs and Foods, 1952 a), the case against fluoridation was given full prominence. Discussion was also in progress in many communities which were debating whether or not to fluoridate their water supplies. We heard and read much on both sides of the problem. More will be said on the " public relations " aspect later in this report.

Epidemiological evidence of harmlessness

28. Several million people, in America and elsewhere, live in areas where fluorides occur naturally in the water supplies in concentrations of 1 p.p.m. or more. There is no evidence that such naturally fluoridated water differs in any way which is of biological significance from water to which fluorides have been added. Furthermore, chemical evidence indicates strongly that in both kinds of water (naturally and artificially fluoridated) the fluorides at the concentrations concerned are completely ionised ; in other words, it is the fluoride ion which is important and not the kind of fluorine salt from which the ion is derived. If it is accepted that artificially and naturally fluoridated waters have the same biological effects, then evidence of benefit or harm can be derived not only from experience following the addition of fluorides to water, but also from the health experience of the vast number of people who have always consumed water with a high natural fluoride content.

29. The toxic hazard in connection with excessive amounts of fluoride has been well known for at least a quarter of a century, following the demonstration that workers continually exposed to industrial dusts and smokes heavily loaded with fluorides are liable to develop bone deformities, and that the children consuming water containing fluorides (in concentration several times as high as those needed for the control of dental caries) may develop mottled enamel to a degree which might be unsightly. Research into the toxicology of fluorine compounds has been continuous, and the possibility that continued low-level consumption of fluoride might eventually cause undesirable effects has been recognised for many years. This research and awareness has been stimulated by keen scientific and public interest and by not a little controversy. Yet, no definite evidence has been forthcoming that the continued consumption of fluorides at a level of about 1 p.p.m. is in any way harmful to health. This is an impressive fact and one which, in our opinion, makes it quite certain that if any untoward effect is revealed by future research it will be of a relatively trivial order. However, the opinion held by a minority of American scientists that fluoridation policies should not be actively pursued until further research into possible hazards has been undertaken, may be noted. It has been said that fluoridation involves a degree of " calculated risk ". The authorities and communities concerned must decide for themselves what degree of risk is worth accepting. We do not wish to take sides in this matter of opinion, but merely to assert the fact that no risk is at present known to exist. If a risk exists at all, it is so inconspicuous that it has not been revealed by many years of investigation. Millions of people are living in ordinary good health on water containing fluoride in the amounts recommended for caries control (or more), so that the fluoridation of other waters involves no new experience in human welfare. Appendix 9 gives statements by American Authorities on fluoridation policy and the possible hazards involved.

Specific Investigations

30. *Dental fluorosis.* This topic is dealt with elsewhere (para. 7 and Appendices 6 and 9).

31. *Effects on bone.* It is well known that radiological changes can occur in the spinal and other bones among workers exposed to dust con-

taining high concentrations of fluoride, though disability is not common even among men who have been so exposed for many years. We were unable to find any evidence pointing to the existence of skeletal abnormalities among populations using water supplies containing fluoride at the levels recommended for the control of caries, though there is some inconclusive American evidence of radiological changes, unaccompanied by disability, when the level is considerably higher. In the Newburgh–Kingston study, radiographs of children have been studied by an independent expert who did not know which groups the cases came from, with negative results. Studies of fracture incidence and of growth have been made, and no relation to exposure to fluorides has been found. The possibility exists that among malnourished populations exposed to fluoride at a level of about 6 p.p.m. deformity of the spine may occur (Shortt et al. 1937). In Britain a few selected cases of spondylosis deformans associated with malnutrition have been reported by Kemp, Murray and Wilson (1942), but the suggestion that this condition was favoured by small amounts of fluorides in water has not been confirmed.

32. *Cancer.* Public controversy in the United States has caused several other types of possible hazard to receive close attention. One of the most widely publicised was a report from the University of Texas, that water containing fluoride at a level of 1 p.p.m. favoured the development of cancer among mice. This work has several serious technical flaws, and was publicly disclaimed by the Vice-President of the Medical Branch, University of Texas. So far as human cancer is concerned, there is no evidence that the presence of fluoride in the public water supplies has any harmful effect.

33. *Kidney disease.* The suggestion has been made that the continued consumption of fluoridated water may impair kidney function, especially among persons suffering from kidney disease. There seems to be no evidence on this point. However, it is worth noting that atypical clinical effects among cases of nephritis in areas where the water contains natural fluoride even in concentrations above 1 p.p.m. have not been established.

34. *Vital statistics.* While many Americans live in areas where the natural fluoride content of water is about 1 p.p.m. or more it is extremely difficult to make a comprehensive analysis of mortality statistics on the basis of previous exposure to fluorides, and no such analysis has been attempted. Many difficult problems would have to be solved, e.g. relating the death certificate to the habitual place of residence or birth place of each individual. The population in the United States is mobile, and death rates in any particular area may be distorted by special conditions. For example, Colorado Springs (fluoride 2·5 p.p.m.) has been a health resort for many years and many tuberculous and retired people settle there. Nevertheless, vital statistics do not point to any special hazards in fluoridated areas. Some figures from Illinois are given in Appendix 11. A report that certain types of mortality in Grand Rapids had risen steeply since fluoridation began received much publicity recently. The figures quoted were incorrect and no such rise has taken place : indeed mortality rates in Grand Rapids are improving.

35. *The possibility of toxic effects due to cumulative dosage.* Two types may be considered : first, cumulative storage in bone or other tissues until a dangerous level is reached ; second, cumulative effects due to ingestion from several sources simultaneously. In our opinion, neither of these possibilities

is a deterrent to the fluoridation of water, though research should continue. The available evidence is reviewed in Appendix 9 (see also Cox and Hodge, 1950).

36. *Effects on industry.* Fluorides in water, at a level of 1·0 p.p.m. do not give a taste or odour and in spite of persistent questioning we have been unable to learn of an effect on any industry, including bottling, brewing, baking, laundering and chemical manufacture. It was reported at Charlotte N.C., where the water supply is soft, that after fluoridation cracking of ice blocks increased by 50 per cent. This trouble was cured by the addition of 20 p.p.m. of ammonium chloride to the water used for the manufacture of ice. It should be noted however that such difficulties have not been experienced at other places where similar fluoridated waters are used.

When a water is required for boiler-feed purposes the presence of an excessive amount of silica can be troublesome. The addition of sodium silicofluoride to give a concentration of 1·0 p.p.m. as fluorine will also contribute about 0·5 p.p.m. of silica (SiO_2).

The fluoride content of a sewage effluent reflects the level of fluoridation of the water supply but its presence does not affect the normal biological processes of sewage purification. Discharge of a sewage effluent containing fluoride into a river would dilute the fluoride but would not necessarily remove it. Thus such a river water abstracted for domestic use might contain fluoride in low concentration and this would have to be taken into account in any fluoridation programme.

Fluorine Compounds and Methods of Usage

37. It should be made quite clear that the element, fluorine, is not used as such and that the active agent in the prevention of dental caries is the fluoride ion, obtained by the ionisation of inorganic fluorine salts. Hence the term fluoridation and not fluorination is used since the latter suggests an analogy with chlorination in which free chlorine is used in the disinfection of waters.

In theory any fluorine compound which will ionise in aqueous solution should have the same action on teeth but at present only four are used. These are sodium fluoride, sodium silicofluoride, hydro-fluosilicic acid and in one isolated instance hydrofluoric acid.

The use of hydrofluoric acid is not likely to be repeated in the United States and there is little to recommend its adoption in this country. Commercial hydro-fluosilicic acid is a liquid containing about 30 per cent. of the acid, and is used without dilution. It is the fluoridation agent at several installations and there are indications that it is gaining popularity among water engineers (para. 44). Both sodium fluoride and sodium silicofluoride are in general use in the United States, the former and more soluble salt being used particularly by small waterworks supplying up to about half a million gallons per day. The latter salt, hitherto in short supply, is becoming popular with authorities serving large populations. The popularity of sodium silicofluoride is due chiefly to its price, which is about one third that of sodium fluoride. In addition it does not give rise to incrustation troubles in feed lines since calcium silicofluoride is more soluble than calcium fluoride. It is of course the calcium salts naturally occurring in water which give rise to these incrustations, and with hard water it is necessary to instal a supplementary treatment for the solution water which may be base-exchange softening or the use of a metaphosphate. Otherwise the presence or absence of calcium salts in a water seems to have no effect on the action of fluoride in the control of dental caries. This is illustrated both by the dental findings at the study centres and by the epidemiological studies by Dean et al. (1941-2) where the hardness of the water varies from 60 to 300 p.p.m. as $CaCO_3$.

38. The handling of these chemicals, provided simple precautions are taken, is not hazardous and we did not find any evidence of even minor harmful effects on waterworks operators who control large quantities of fluoride salts. The precautions recommended in the United States include the use of rubber gloves and a respirator but although these safety measures were used at some of the places visited, others omitted one or both of them. In our opinion, however, it is advisable to take all possible precautions when large quantities of fluorides are handled and these should include suitable storage facilities, the use of dust extractors, respirators and rubber gloves. In addition the urine of the operators should be tested periodically to ensure that a safe level of fluoride intake is not exceeded.

39. Sodium silicofluoride might well become the chief agent if fluoridation were adopted in this country and the question of its availability would then assume importance. It is a by-product of the phosphate industry and in England is not at present recovered. Whether or not the industry would be interested to the extent of installing recovery plant would depend on the demand and on the price offered, but if these were attractive it would be possible to produce about 700 tons annually. This quantity would be sufficient to raise the fluoride content of over 9,000 million gallons (Imp.) of water to a level of 1·0 p.p.m. and would be ample for all our requirements.

40. It may well be asked why fluorides should be added to water supplies rather than to other commodities where people could exercise a choice especially since less than one per cent. of the fluoride added to a water supply will be used for human consumption and consequently there will be a great wastage of the chemical.

The answer is that all the epidemiological work has been concerned with fluorides in water and it is not known with certainty that fluorides otherwise administered would have similar effects. Of equal importance is the fact that addition of fluoride to milk, as has been suggested, would be impossible to control in the actual addition or in the amount consumed by the child. Similar arguments apply to the addition of fluoride to table salt or other commodity. The wastage of fluoride added to water supplies is not serious and is insignificant in view of the benefits to be expected (para. 45).

41. Nevertheless it is realised that other provision should be made for those who lack a piped water supply, and in the United States limited trials have been carried out by dissolving sodium fluoride tablets in the drinking water. This method, if followed conscientiously, must give the same effect as a fluoridated water supply but the hazards of over-dosage are obvious.

42. The application of solutions of sodium fluoride to the surface of the teeth (topical application) has been used in the United States and considerable success has been claimed in controlling the incidence of dental caries (Appendix 12). The control has not been so effective as that obtained from fluoridated water, and may be of limited duration. In this country, the usefulness of this method has not been demonstrated but an investigation is proceeding under the Ministry of Education. Some 3,700 children in seven areas have been treated and the field work is done by the dental staffs of teaching hospitals and local authorities.

Fluoridation of Water Supplies

43. The addition of a chemical to a water used for domestic purposes, whether it be chlorine for disinfection or alum for flocculation, requires precision apparatus ; mistakes resulting in over or under dosage are not tolerated either by the water authorities or the consumers. Suitable equipment therefore has been developed in this country and elsewhere for the treatment of water and the acceptance of a drinking water as a matter of course by the public is a testimony to the efficiency of the treatment plant. The equipment used in the United States for the fluoridation of water supplies is similar to that commonly used in established water treatment practices and the controlled addition of fluoride presents few difficulties that have not already been met and overcome.

Fluorides at the level used or even in considerably greater concentrations do not affect the taste of the water. In contrast, if too much chlorine were added to water its taste would give immediate warning, and it would be rejected by the consumer. With fluorides the safeguard of taste is absent and it is obligatory for the Water Authorities to ensure by various refinements and control that water containing an excess is not delivered to the consumer.

That this can be done and is being done is proved by the fact that no evidence of overdosage was detected in an examination of the records of the 19 water plants we visited in the United States. These plants ranged in size from that serving a population of 735 and maintained by the local handy-man to one under the control of a fully qualified staff which is supplying over 20 million gallons of water daily to 280,000 people.

It should be realised that the level of fluoride in the water supplied would need to rise greatly before danger of acute fluoride poisoning resulted. The accidental delivery of water containing even 10 times the normal fluoride concentration for a matter of a few hours would be unlikely, on known evidence, to have any undesirable results.

44. Liquid feeders are used by small water undertakings to deliver a solution of sodium fluoride. Similar feeders are also used to deliver hydrofluosilicic acid. This method of fluoridation is attractive and is apparently working without trouble in the United States but it must be remembered that a slight overdose of a relatively dilute solution of sodium fluoride would not be serious whereas an overdose of the same volume of the acid would

give a much greater concentration of fluoride in the water and might therefore constitute a health hazard.

The larger water undertakings use dry feeders with either sodium fluoride or sodium silicofluoride. These feeders deliver a definite amount of the dry chemical, in a unit time, to a solution tank. The solution of the chemical is then either pumped or fed by gravity into the main water supply.

We were impressed with the accuracy of these dry feeders, particularly those of the gravimetric type, which often have devices to give instant visible and audible warning of any variation from the desired rate of feed. When the water supply is of sufficient size we consider that a gravimetric dry feeder using sodium silicofluoride will provide the most satisfactory way of adding fluoride to the water. The methods of fluoridation are described in Appendix 13.

45. After installation of the feeding equipment the cost of fluoridation is very largely the cost of the fluorine compound used. It has been found that additional personnel is not required and that the existing staff in water works can maintain the fluoridation equipment. In the United States sodium fluoride costs about 11 cents per lb. and sodium silicofluoride about 3 cents per lb. The feeding equipment, including installation, costs between 400 and 5,000 dollars depending upon the type and size of feeder. And, of course, in a large water undertaking it may be necessary to duplicate the equipment. A recent estimation of the annual cost of fluoridation for Detroit (Tossy, 1950) with a population of about two and a half millions, gave a per capita cost of 3 cents per annum. In the case of small undertakings the cost varies between 5 and 14 cents per capita but this appears to be the actual cost of the fluoride compound used. More information about the cost of fluoridation is given in Appendix 12.

Public Health Control of Fluoridation

46. In December, 1950, approximately 90 million people in 8,400 United States communities had a piped water supply and by December, 1951, 159 of these, totalling over 4 million people, were adding fluoride to their supplies.

A further 403 communities have, as is required by every State health department, submitted plans for fluoridation of their waters; and it is estimated that in 1953 over 35 million people in 45 States will be receiving fluoridated water. These, together with those receiving water containing naturally derived fluoride in concentrations over 0·9 p.p.m. will mean that 40 per cent. of the United States populations on piped supplies will be receiving fluoride (Appendix 14).

47. The addition of fluoride to water supplies is regarded as a public health measure and records are forwarded weekly to the State health authorities. These records show the gallonage of water pumped, the weight in pounds of fluoride added and the corresponding parts per million, supplied to the consumer. This last figure is checked by daily determinations of the fluoride in the water by the Water Authorities and these figures also are included on the record sheets. Furthermore each State requires weekly samples of water to be sent to the State laboratories where an independent determination is made of the concentration of fluoride in the water.

This system of control is, in our opinion, wise and worthy of consideration: it not only ensures a constant check on the fluoridation of the water but also provides an incentive to the personnel at water plants to see that mistakes do not occur and provides a complete answer to any possible complaint from consumers about the level of fluoridation maintained. When there is any reason to suspect unreliability of the routine test, State laboraties, in addition, use the distillation method which is beyond the scope of many of the smaller Authorities (Appendix 13).

Removal of excess fluoride from water

48. A concentration of fluoride sufficient to cause an unsightly degree of mottled enamel is most undesirable. Investigations are being carried out on methods for removing excessive amounts of fluorides from water, and the one giving most promise is being tested at Bartlett, Texas, where the water contains natural fluoride at a concentration of about 7·0 p.p.m. This method, which involves filtration through activated alumina, is described in Appendix 15. Another method, not often feasible in practice, is to mix the high-fluoride water with one that is almost fluoride-free.

The Public Reaction in America

49. A brief account of how fluoridation policies have been developed in the United States is necessary, since public controversy might be misunderstood in Great Britain as indicating widespread doubt as to the safety and desirability of the measure.

The U.S. Federal Security Agency, of which the Public Health Service is part, does not exercise as much direct control over policy as do the Ministry of Health and the Department of Health for Scotland in this country. In local matters each State is virtually autonomous and autonomy extends to local communities within each state. The decision to introduce fluoridation thus rests with leaders in each community, and Federal and State Authorities advise these leaders on the policies which they think desirable. The initiation of a fluoridation project appears to follow these lines: the local dental and medical organisations pass a resolution requesting the local authority to fluoridate the water supply of the community, and their members also use their personal influence. They are helped in these tasks by material for propaganda provided by bodies such as the American Dental Association. A proposal to introduce fluoridation may give rise to considerable public discussions involving a press campaign, lectures, films, radio talks and other means of arousing interest and spreading information. Finally a meeting is held at which the public votes directly for or against fluoridation. Naturally, in such public discussions, " pressure groups " of all kinds are formed and controversy is by no means uncommon.

50. One of the most heated arguments took place recently in Seattle, where, on 11th March, 1952, the citizens voted by 86,230 to 44,814 against the adoption of fluoridation. A few months earlier the citizens of San Francisco had voted by 114,125 to 88,377 in favour of the measure.

51. When discussing possible hazards we have shown that there is some genuine scientific disagreement about whether fluoridation involves an undesirable public health hazard, although there is at present no sound evidence demonstrating any ill effect. But this is not the whole story. Much of the public reaction appears to be bound up with questions of social philosophy. A measure involving the treatment of a public commodity like water, which must be used as supplied with little or no opportunity for choice by consumers, may raise deeply-felt issues such as those of " mass medication ". Although controversy in the United States has been vigorous it does not appear to signify that doubts as to the wisdom of fluoridation are increasing. In paragraph 27 we noted that a Select Committee of the House of Representatives conducted a public inquiry into the safety and efficacy of fluoridation. It concluded " that a sufficient number of unanswered questions concerning the safety of this program exists as to warrant a conservative attitude ". Nevertheless, very shortly after the publication of the Committee's report, fluoridation of the water supply of Washington D.C. itself was started.

Summary and Conclusions

52. Epidemiological studies in America have demonstrated beyond doubt that among children and adults who have been born and brought up in areas where the drinking water contains fluoride at a level of 1 p.p.m. or more, there is much less dental caries than in areas where the water is free from fluoride. Compared with areas where the drinking water contains little or no fluoride there is about 60 per cent. less dental caries among children aged 12 to 14 years and about six times as many children have permanent teeth which are free from caries (18 to 29 per cent. compared to about 4 per cent.). A few studies among adults, both in England and in the United States show that the effect of fluoride persists at least up to about 40 years of age.

53. In recent years many North American communities whose water supplies contained little or no fluoride have added fluorine compounds to their water. In certain of these communities the dental effects of " fluoridation " have been studied carefully.

54. In our opinion the evidence is conclusive that among children in fluoridation areas there is a reduction in the incidence of dental caries to a level comparable with that experienced where fluoride occurs naturally in the water. To date, a reduction of this extent has been demonstrated only among children up to 6 years of age, because no fluoridation scheme has been in progress for more than 7 years. Data relating to older age groups are as yet insufficient to warrant firm conclusions.

55. There is nothing to suggest that a water containing fluoride, naturally derived, has properties different from those of a water to which fluoride has been added. At the concentration of fluoride used, about 1·0 p.p.m. it is the fluoride ion that is operative and the nature of the salt used is of secondary importance.

We consider that an artificially fluoridated water is similar in its action to one containing naturally derived fluoride. There is therefore sufficient evidence to indicate that the benefits derived by young children will accompany them into adult life. It is realised that time alone can demonstrate the truth of this contention.

56. Doubt has been expressed about the risk of mottled enamel. It has been stated that 10 per cent. of the children drinking fluoridated water may develop very mild mottling of the teeth. This in our opinion is not a hazard. We observed that when mottling occurs it amounts only to an occasional white fleck in the enamel and is so slight that it cannot be recognised without expert examination. The appearance of the teeth is excellent.

57. We have found no scientific evidence that there is any danger to health from the continued consumption of water containing fluoride in low concentration. In the areas where naturally occurring fluorides are present at a level of 1·0 p.p.m. mortality statistics do not indicate any hazard due to fluorides and medical experience in such areas has not produced any evidence of increased morbidity. Many suggestions have been made that certain ill-effects may nevertheless occur. We can only comment that the proving of a negative is extremely difficult. Meanwhile, we are impressed by the fact that millions of people are living in ordinary good health on waters containing fluorides at levels of 1 p.p.m. or more.

We could not find any evidence that fluoridated water had an adverse effect on industrial processes.

The mechanical addition of fluoride to a water supply at any desired level presents few difficulties. With a correctly designed plant and proper controls there is no danger of adding a toxic overdose of fluoride.

58. Methods of administering fluorides in which the individual can exercise a choice are at present few and positive control can be exercised only in the case of topical application of a solution of sodium fluoride. This method has not given the same degree of protection against dental caries as the fluoridation of water, nor has its effect been as lasting. Another method whereby tablets of sodium fluoride are dissolved in the drinking water for an individual or family may have some use in a region lacking a piped supply but its careless use may be ineffectual and even risky. In our opinion fluoridation of water supplies is preferable to all other methods.

Recommendations

1. It follows from our conclusions that we consider fluoridation to be a useful means of reducing the incidence of dental caries in North America. It is reasonable to assume that it would also be useful in this country. We therefore recommend that its adoption in this country should be considered. However, certain investigations are desirable before the general adoption of fluoridation.

2. In our opinion it would be advisable in the first instance to add fluoride to the water supplies of some selected communities. These preliminary fluoridation projects should be regarded as study centres and include full medical and dental examinations at all ages.

Before these fluoridation studies can be started it is necessary:—

(*a*) to obtain baseline information on the incidence of dental caries in children and adults in the selected communities, and if possible in comparable communities that can be used as controls.

(*b*) to assess the required dose of fluoride to be added to water supplies in this country. The best way of determining the present level of ingestion of fluoride is to make a survey of fluoride excretion in the urine of representative children and adults of all age groups throughout the country (Appendix 10).

(*c*) to make sure that adequate supplies of fluorides in the most suitable form are available.

(*d*) to develop the machinery necessary for the controlled addition of fluorides to water supplies under satisfactory conditions with adequate safeguards against errors in dosage and any undue exposure of the operating personnel to the materials handled.

3. In spite of the fact that the evidence of harmlessness is so strong as to be almost conclusive, research into the effects on health and disease of the continued use of waters containing low levels of fluoride should be encouraged.

4. About 10 per cent. of the population of this country lack a piped water supply but many in this category obtain water from privately owned wells, boreholes and springs. Simple methods for the addition of fluorides to such supplies serving small communities should be investigated.

APPENDIX 1

Itinerary of Fluoridation Mission

Professor Stones		
18th–21st February, 1952	New York	Columbia and New York Universities, Dental Research Departments. Guggenheim Clinic.
22nd and 23rd February	Philadelphia	Pennsylvania and Temple Universities, Dental Research Departments.
All Members		
25th February to 1st March	Washington	Including:— Federal Security Agency. National Institute of Dental Research, Bethesda. Armed Forces Institute of Pathology. Bureau of Standards (Professor Stones and Miss Forrest). Georgetown University Dental School (Professor Stones) Filtration plant.
2nd March and 3rd March	Travelling to Wisconsin via Dayton, Ohio and Chicago.	
4th March and 5th March	Wisconsin	Including:— Madison (State Health Department). Sheboygan (School and Filtration plant). Fond-du-Lac. Other filtration plants.
6th March–8th March	Grand Rapids and Muskegon	Schools and Filtration plant.
9th March and 10th March	Ann Arbor, Michigan	Including:— University, Dental Research Department. Filtration plant (Drs. Longwell and Thomson). Schools (Miss Forrest).
11th March–16th March	Chicago	Including:— Evanston. Aurora. American Dental Association. Madison (Dr. Longwell).

17th March		MISSION DIVIDED	
Miss Forrest and Dr. Longwell		*Professor Stones and Dr. Thomson*	
18th March to 21st March ...	Texas, including Austin, Bartlett, Marshall.	17th March and 18th March ...	Chicago, including North Western University and University of Illinois, Dental Research Departments, University of Chicago, Zoller Dental Clinic.
		19th March–22nd March ...	Colorado Springs.

23rd March	MISSION RE-FORMED AT WASHINGTON	
24th March	Washington	Federal Security Agency. National Institute of Dental Research.
	Baltimore	Johns Hopkins School of Preventive Medicine (Dr. Thomson
25th and 26th March	Newburgh	Health Department and Schools. Professor Stones left for Toronto.
27th March	New York	Drs. Longwell and Thomson left for England.
Professor Stones	Toronto	University, Dental Research Department. Canadian Dental Association.
28th March	Brantford	Health Department, filtration plant and school.
30th and 31st March	Montreal	Universities of McGill and Montreal, Dental Research Departments.
1st April	New York	Professor Stones left for England.
Miss Forrest		
28th March	Newburgh and Kingston.	
29th and 30th March	New York.	
31st March	Albany, N.Y.	State Health Department.
1st April	Rochester, N.Y.	University, Dental Research Department. Eastman Dental Dispensary.
2nd April	Lansing, Michigan	State Health Department.
3rd April–5th April	Grand Rapids	Schools.
6th April–10th April	Chicago	Evanston Schools. University of Chicago, Zoller Clinic. University of Illinois, Dental Research Department. American Dental Association.
11th April	Pittsburgh	University, Dental Research Department.
12th April–17th April	Washington	Federal Security Agency. National Institute of Dental Research.
19th April	New York	Guggenheim Clinic.
20th April–22nd April	Philadelphia.	
23rd April	Left for England.	

APPENDIX 2

Dates of Mineralization and Eruption of Teeth

In order that a comparison can be made between the beneficial effect on the incidence of dental caries that is known to exist in districts with natural fluorides in the water supply and the effects of controlled fluoridation, it is necessary that the population must have been in the district and exposed to the water during the whole period of mineralization and eruption of the teeth. It is probably not necessary to be exposed during the earlier period of tooth germ formation.

Deciduous dentition. Tooth germ formation for the different deciduous teeth starts at periods from six to ten weeks in utero.

Mineralization starts at about 5 to 6 months in utero in the various teeth. The enamel of the 1st incisors is completed at 3 months after birth and somewhat later for the other teeth, ending with the 2nd molars at 11 months.

Eruption of the deciduous teeth starts at 6–7 months with the 1st incisors, and the other teeth subsequently erupt at intervals, the 2nd molars being the last to appear at about 24 months.

Permanent dentition. Tooth germ formation for these teeth commences at about 4 months in utero for the 1st molars, 5½ months for the incisors and canines, 7 and 8 months for the 1st and 2nd premolars; at 3 or 4 months after birth for the 2nd molars and 3 years for the 3rd molars.

Mineralization starts at birth in the 1st molars, 3–4 months after birth in the 1st incisors, at somewhat later periods in the other teeth, until at 2½–3 years mineralization commences in the 2nd molars and at 7–10 years in the 3rd molars. The enamel is completed at 2½–3 years in the 1st molars, 4–5 years in the incisors, at somewhat later periods in the other teeth, until at 7–8 years it is completed in the 2nd molars and 12–16 years in the 3rd molars.

Eruption of the permanent teeth starts at about 6 years for the 1st molars, 6–8 years for the incisors and at later periods for the other teeth, the last being at about 12 years for the 2nd molars and 17–21 years for the 3rd molars.

An examination of these data in relation to the time factor necessary for the teeth of a child to be subject to the influence of fluoridation of the domestic water supply throughout the period of tooth formation and eruption reveals the following facts:—

Regarding the deciduous dentition, if the commencement of mineralization is taken as the starting point, the mother must be living continuously in the district for 4 months before parturition. (If the formation of the actual tooth germs is the base line, the requirement would be 8 months before parturition, or practically the whole of the prenatal period.) After birth, if the child then continues to live in the district for 12 months, the enamel of all the deciduous teeth will be completed. A year later, namely, at 24 months, all these teeth will be erupted.

Regarding the permanent dentition, in which mineralization is in the meantime progressing, the child should continue to live in the district until 8 years old for the enamel of all the teeth, excepting the 3rd molars, to be completed, or until 15 years for inclusion of the 3rd molars. Except for the latter, all teeth will be erupted at about 12 years.

These minimum times do not take into account the possibility that a tooth may benefit from further exposure to fluoridated water after eruption.

APPENDIX 3

Criteria of Dental Caries Assessment

It has been recorded that the DMF Index is common to all the studies and that a tooth is regarded as decayed if there is the earliest clinically discernable carious lesion. Hence it is essential to define what is to be regarded as the commencement of caries and this is all the more important if there are several examiners, otherwise the individual variation in assessment will impair the accuracy of the results. In the studies described, the assessment was recorded as being made with a mouth mirror and sharp explorer. In one study, namely, that at Evanston (Blayney and Tucker, 1948), there was an additional radiographic examination, the results of which were counted in the assessment.

It is well known that radiographic examination is of value in the diagnosis of proximal caries in posterior teeth and that it reveals very early caries in this position which may be missed on clinical examination. Trithart and Donnelly (1950) found, from an examination of posterior deciduous and permanent teeth of 254 children of three schools, that there were 54·5, 57·6 and 111 per cent. more cavities respectively detected on radiographic than on clinical examination. They also presented evidence that the percentage of additional cavities found was increased when the clinical examination was not so thorough.

Ast, Finn and Chase (1951) in the Newburgh study examined this aspect and also the question of the individual bias of examiners. A check was made in one examination in which anterior and posterior bite wing radiographs were used. For this particular purpose a comparison was made between the clinical and radiographic DMF rates of the first molar teeth of approximately 2,000 children in Newburgh and Kingston. The assessment was unbiased as the films were intermingled in random order before examination. There was an absolute difference revealed by the radiographic findings at age 7 of 12 DMF upper first molars per 100 molars examined and 16 DMF lower first molars per 100 examined; at age 9 the differences were 13 for the upper and 14 for the lower first molars per 100 examined; at age 11 the differences were 9 for the upper and 6 for the lower first molars per 100 examined. However, just as clinical examination showed that the DMF rate was lower at Newburgh where the water is fluoridated than at Kingston which has a low fluoride content, so consistent differences at each age revealed by radiographic examination were in favour of Newburgh. (Fig. 3.)

To obviate any individual bias it is desirable, when a comparison is being made between the incidence of caries in two districts and there are several participating dentists, that each dentist should examine a similar number of children and adults from each district.

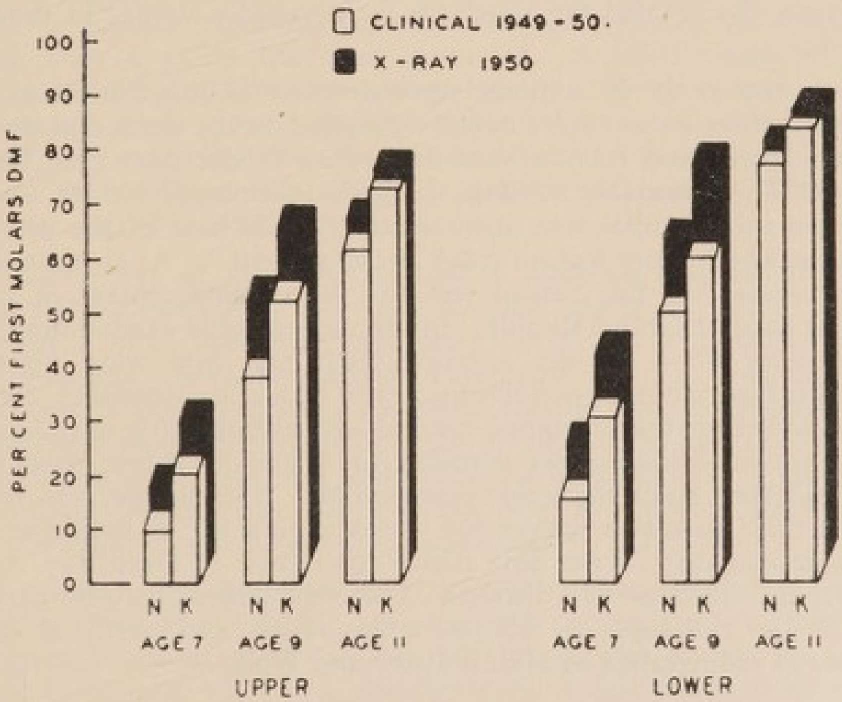

Fig. 3.
Comparative differences in DMF rates of first molars in clinical and roentgenographic examinations of children in Newburgh and Kingston, N.Y. in 1949–1950.

The technical standards prepared by the United States Public Health Service, Washington, are available and are used by various States in dental examinations. These are as follows and are used for the Grand Rapids study where 10 minutes are spent on the examination of each child:—" No abnormality will be recorded positively unless it is demonstrable objectively, beyond the possibility of a doubt. . . . In dental caries, a deep pit or fissure will not be recorded as carious unless there is more evidence than a catch of the explorer (probe). Such other evidence might be the detection of a softened cavity floor on light explorer pressure, visual evidence of backward decay of the enamel, or visual evidence of deterioration by pit or fissure wall. 'Catches' will be tested by rocking the explorer after it enters the pit or fissure. Deep pits or fissures *per se* are not to be considered carious or questionably carious. There must be an actual break of surface continuity demonstrable with the explorer; for example, visual evidence of undermining under a marginal ridge is not accepted evidence of a proximal lesion unless a surface break can be entered with the explorer."

Regarding a definition of when a tooth can be considered to be erupted it is stated that "A permanent tooth is in eruption if any portion projects through the gum."

Similarly at the Newburgh studies a lesion was only counted as carious when the explorer caught—in pit and fissure caries—and when there was definite evidence of caries.

At Brantford, in the original study by Hutton, Linscott and Williams (1951) it appeared that the commencement of caries was indicated if the point of an explorer caught and stuck in a fissure, pit or other suspected cavity, or if there was visible evidence of caries. In the report by Brown (1952) "the lowest limit in size for a carious lesion was defined as one in which the point of an explorer would stick and resist withdrawal, or in which softness was palpable. Hard stained surfaces and enamel imperfections were not recorded as caries. Interproximal edges or roughness capable of holding the explorer point were recorded as caries".

At Marshall (Taylor, 1952) clinical examination only was carried out and caries was considered to have commenced if an explorer caught in a suspected pit or fissure.

At Sheboygan (Bull, 1950) the standards were broadly similar to those used at Grand Rapids.

In the Evanston study 20 minutes were devoted to the clinical examination alone and pre-carious lesions were noted separately on the chart and not included under caries. Pre-carious lesions were defined as "those deep pits, fissures and grooves where a questionable etching along the peripheral border was present, or questionable soft material was demonstrated at the base of the pit, fissure or groove, and yet where there was no frank caries present". At an examination we got the impression that the clinical test for the commencement of caries was similar to that used at Grand Rapids. In the radiographic examination, however, using apical view films for the anterior teeth and bite wing films for the posterior teeth, the minutest radiolucency was taken as indicating caries. The reports were based on the combined clinical and radiographic examinations and hence early proximal caries was revealed to a greater extent than in studies where there had been no radiographic examination. Hill, Blayney and Wolf (1951) reported that their base line figures for caries experience in Evanston and Oak Park were approximately 32 per cent. higher than those of Dean, Jay, Arnold and Elvove (1941) for the same two districts. These differences may be partly due to differences in the technique of clinical examination and partly if not chiefly due to the use of radiographs by Hill, Blayney and Wolf.

APPENDIX 4

Methods of Assessing Dental Caries Findings

In an investigation that is being undertaken to determine whether some system of preventive treatment is effective in reducing the amount of dental caries, it is necessary to have a method of measuring the dental caries experience, past and present, of each individual.

In the Section entitled " The Dental Effects of Fluoridated Water Supplies ", it is noted that in the investigations a comparison has been made between the caries incidence in a community before and some years after the domestic water supply has been fluoridated, and in some cases between the latter and those living in districts where it is practically fluoride free or where there are fluorides at an appreciable concentration naturally in the water supply.

A number of different methods or indices have been devised to assess dental caries and each has advantages and disadvantages. These indices can be divided into two main groups as follows:—

(*a*) For estimating the incidence of dental caries and whether this is increased or decreased by any particular environment.

(*b*) For estimating the degree of dental caries and whether the progress of existing caries is retarded by any particular factor.

The indices that have been used in the fluoridation studies refer, with the exception of the DMF and df Surfaces Index, to the incidence of dental caries. They are not designed to estimate the progress of existing caries and hence it is not proposed to discuss degree indices and their relative merits, a problem that has been considered by Bransby and Parfitt (1952).

1. DMF Index. In this assessment, introduced by Klein, Palmer and Knutson (1938), D=decayed or carious ; M=missing—presumably due to caries ; F=filled and hence previously carious. It should be noted that this index is used in all the fluoridation studies that are described in this report, and hence it can be used to compare their results.

The advantages of the DMF Index are its simplicity and that it is easily understood. It is usually expressed as the average incidence of dental caries per individual, after a group has been examined. A DMF tooth is counted as 1 and thus for example DMF 3·76 as applied to a group means that 3·76 is the average, though some individuals may have no history of caries and others may have a number of teeth that have been affected. Sometimes the results are assessed on the DMF per 100 children, and in this case the above figure would obviously be altered to DMF 376.

The disadvantage of the DMF is that it takes no account of the degree of caries in that a tooth with only the smallest cavity or filling is counted the same as for a large lesion or restoration or for an extraction. It cannot be used for obtaining information about the degree of caries and whether the progress of caries that is already present has been retarded or accelerated. When used for middle-aged people a further difficulty is that at this period of life parodontal disease becomes more prevalent and according to Klein (1943), the greatest cause of tooth loss. Hence there may be difficulty in deciding whether a tooth is missing as a result of parodontal disease or caries.

2. def Index. This index is only applied to the deciduous teeth and was suggested by Gruebbel (1944). He originally based it on a tabulation of the past or present caries experience of those teeth that are in the mouth at the time of examination, so that a missing tooth is not counted, as there may be

uncertainty about whether it has been shed as a physiological process or due to caries. Hence the observable dental caries prevalence for the deciduous dentition for each child examined is computed by adding the number of decayed teeth indicated for filling (*d*), the number of decayed teeth indicated for extraction, (*e*), and the number of filled teeth (*f*).

In some investigations def or DMF is used for the deciduous dentition.

It can be realised that in the def, DEF or DMF index the main difficulty is that there is no definite information about whether a missing deciduous tooth has been carious. This problem is dealt with in various ways.

Dean, Arnold, and Knutson (1950) at Grand Rapids, Muskegon and Aurora do not include missing deciduous teeth in the count.

Hutton, Linscott and Williams (1951) at Brantford used the DMF index for all teeth. It is stated (Hutton, 1952) that where a deciduous tooth appears to be missing naturally it is not counted as a missing tooth, and that this applies to nearly all the anterior deciduous teeth. However, where there is evidence that a deciduous tooth has been extracted, it is counted as a missing tooth. Such evidence was looked for particularly in the case of missing deciduous molars.

Taylor (1950) at Marshall and Jacksonville has used the DMF index for all teeth.

Bull (1952), referring to his 1950 report of Sheboygan children, states that anterior teeth that are missing are not counted in the Kindergarten surveys of deciduous teeth, as it is assumed that they have been naturally exfoliated. Posterior deciduous teeth that are missing are counted as it is probable that they have been extracted because of caries.

Blayney (1952), referring to studies at Evanston (Hill, Blayney and Wolf, 1950, 1951 and 1952) states that " if some of the deciduous teeth are present at an age which we would normally expect them to be shed and the remaining deciduous teeth are entirely free from caries, then we classify the case as questionable immunity to caries in the deciduous teeth. As for the number of carious lesions in such mouths, it is limited entirely to the teeth which we have had the opportunity to examine. Because of our inability to estimate the caries experience of the teeth that have been lost we believe that we should be very cautious in the evaluation of the overall caries experience of that child ".

3. DF and df Index. This gives the incidence for observed decay and filled teeth. Teeth that are not present are not counted. The capital letters are used for the permanent dentition by Hill, Blayney and Wolf and for the deciduous dentition by Ast, Finn and Chase (1951). The lower case letters are used by Brown (1952) for the deciduous dentition.

4. DMF Permanent Tooth Surfaces and
 df Deciduous Tooth Surfaces.

This is a method of recording the amount of caries by tooth surfaces and has been utilized by Brown (1952). His method of recording values is as follows:— " Both deciduous and permanent tooth caries were recorded giving a value of one cavity to each tooth surface involved, regardless of the number occurring on each surface. On the occlusal surface of the upper molars, the area of the central pit and that of the distal pit was each given a value of one surface. The same was done for the upper second deciduous molars. This gives a value of six surfaces to all upper permanent molars and to the upper second deciduous molars, and a value of five to all other teeth ".

The method aims at estimating the degree of dental caries. One difficulty of an assessment by surfaces is that it does not necessarily indicate the extent of the involvement of the underlying structures.

We were informed that the carious tooth surfaces were recorded in both the Grand Rapids and Evanston studies though the results of this method have not been used.

5. Individual teeth and groups of teeth. In some reports the assessment of caries is based not only on the condition of all the teeth, but also on the incidence in certain teeth or groups of teeth. Thus Brown (1952) uses the DMF rate of permanent upper incisor teeth per child. Ast, Finn and Chase (1951) record the clinical status (i.e. DMF or caries free) per 100 erupted permanent first molars. The latter writers also give the DMF rates per 100 erupted permanent first molars from radiographs alone as well as from clinical examination.

Hill, Blayney and Wolf (1950) give the DMF rate of maxillary anterior permanent teeth and also of mandibular anterior permanent teeth per 100 children, and in 1951 and 1952 the DF rate for these groups of teeth. In addition in 1950 and 1952 they give the caries experience of the occlusal surface of the permanent first molars per 100 children and in 1951 the same assessment for all permanent molars.

6. Caries-free teeth. This method of assessment is given by Brown (1952) for the permanent dentition, and by Hill, Blayney and Wolf (1950, 1952) for the deciduous dentition and by the latter writers in 1951, for the total immunity to caries. It is sometimes applied to certain groups of teeth. Thus Ast, Finn and Chase (1951) use it for caries-free deciduous canines, first and second molars. Hill, Blayney and Wolf also give the figures in 1951 for the permanent molars and in 1952 for the permanent first molars free from occlusal caries experience.

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APPENDIX 5

Dental Examinations

If fluoridation studies were to be undertaken in this country it would be advisable to have a common basis for comparison not only with each other but also with those in the United States. It can be stated that provided the method of examination remains constant in any one study, the assessment of the subsequent rate of caries incidence should not be materially affected, but comparisons of British and American caries rates would not necessarily be possible. It was considered important, therefore, to compare British and American methods of dental examination as well as the systems used in the different study centres for recording and presenting the dental findings.

Special arrangements were made for examination of children at each of the fluoridation study centres and in certain areas with naturally fluoridated water. These examinations were carried out mainly on children aged 5–6 years, since they were the only ones of school age who had been subjected to fluoride for the whole of their lives and were therefore the most likely to show its effect. In addition to caries, the teeth of the children were examined for any appearance of mottled enamel, however slight.

Caries incidence. In all, 352 children were examined in the different study centres and 72 in control areas. When it could be arranged examinations were made by both British and American observers working independently. The findings were recorded separately and compared afterwards. When concurrent examinations were not possible the British findings were compared with the official record cards of the children examined.

In all the study centres close agreement was obtained on clinical examination between the findings of the British and American observers. This was especially the case for " objective caries ", that is, caries involving the dentine. There was some difference of opinion on lesions which involved only the enamel. In current English surveys these are classified as carious but in most of the American studies they are not included. The criteria of dental caries assessment for the various studies are given in detail in Appendix 3.

The charts on which findings are recorded vary considerably. Most of them are diagrammatic and show the exact site as well as the extent of carious lesions. In Grand Rapids, however, a pre-coded system is used and dental conditions are recorded by means of a combination of figures or symbols, each of which represents a particular tooth or tooth surface, a carious lesion graded as to depth, mottled enamel, etc. These details are dictated to recorders. This system, which at first appeared complicated, is in practice quick and efficient: where large numbers are examined and recorders are used it is probably less subject to error than the other systems. A good diagrammatic chart has the advantage, however, that the condition of the mouth is clearly depicted and can be appreciated quickly. Where examiners record their own findings—as in Evanston and Newburgh—a diagrammatic chart is undoubtedly of value.

One of the difficulties in comparing the findings of the American studies was the lack of uniformity in their presentation. For example, in Grand Rapids and Newburgh, reports are made for each age on the permanent and deciduous teeth separately, but while the def index is used for the deciduous teeth in Grand Rapids, the DF index is used in Newburgh. In Sheboygan, as in Grand Rapids, the DMF and def index are used but reports are made for combined age groups and not for each age separately. In Brantford and Marshall the findings are presented for combined deciduous and permanent dentitions and in

Evanston the use of x-rays for diagnosis makes comparison with other studies difficult.

Mottled Enamel. The areas where fluorides occur naturally in the water supplies were visited primarily to study mottled enamel. In all, 75 children were examined in Colorado Springs and Bartlett, where fluorides occur in excessive amounts, and 49 in Aurora, where the drinking water contains 1·2 p.p.m. of fluoride.

In Bartlett, (fluoride 7·0 p.p.m.) an extreme degree of mottling was seen in all age groups. Practically all the teeth were affected to a disfiguring extent and many were badly discoloured. It was of interest to find that in a few instances where the teeth were noticeably free from mottling, those children had consistently drunk fluoride-free water imported in bottles. Among the children examined many appeared to be immune to caries but some had numerous fillings especially in the permanent molars.

In Colorado Springs (fluoride 2·5 p.p.m.) a class of school girls aged 16–17 years who had been born and brought up in the district were nearly all free from caries but some showed mild mottling of the teeth. Other residents of various ages were examined but these were cases who had been specially selected to demonstrate varying degrees of mottled enamel. The degree of mottling observed varied from " very mild " to " severe " but in only a few cases was it associated with much active caries or with many filled teeth.

In Aurora (fluoride 1·2 p.p.m.) no mottling other than that of the " questionable " or " very mild " type was seen, even among older children. A very few children had small white flecks on some of their permanent incisors, but not all these children were natives of Aurora. On the whole the teeth were good and well formed and little caries was observed. The few children with extensive caries among all those examined proved to be newcomers to the district.

In the fluoridation centres and control areas children were examined for mottled enamel as well as for dental caries. The only mottling observed was of the " questionable " or " very mild " grades, even though arrangements were made in one large school in Grand Rapids for examination of the 14 children who had been found to have mottled teeth. In the study areas a good proportion of the younger age groups appeared to be caries-free with well-formed teeth and healthy mouths. The standard of dental care varied considerably and appeared to depend to a large extent on the ability to pay for treatment. In Evanston, for instance, where the economic level is high, and in Brantford, Ontario, where free treatment is available in the school clinic, dental care was outstandingly good. In Grand Rapids, on the other hand, where there is a mixture of races through recent immigration and where the economic level is lower than in Evanston, untreated caries was frequently observed. Many of the children in the older age groups examined had a high caries incidence and in several 16-year-old children practically all the teeth had been filled.

General Conclusions

Among all the children examined only those in areas where fluorides occurred naturally in high concentration in the drinking water had noticeably mottled teeth.

At a level of 1·0 to 1·2 p.p.m. the teeth were well-formed and " questionable " or " very mild " mottling was seen in a very small proportion of the children at all ages. This was so inconspicuous that it could not have been detected if the teeth had not been examined for this specific purpose and certainly would not ordinarily have been noticed.

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In the fluoridation study areas any mottling observed was, at most, " very mild ". The teeth of the younger children examined were usually of good appearance and many were caries-free.

Observations made indicate : —

(*a*) that differences in the caries experience of groups of children could not be accounted for by changes in examination standards. All examinations in connection with the fluoridation studies were made with scrupulous care and examiner bias was negligible ;

(*b*) when similar methods are used a comparison can be made between British and American findings. A British observer obtained results which agreed closely with those of the American observers when the same children were examined independently.

APPENDIX 6

Dental Findings in the Fluoridation Studies

(1) Grand Rapids, Michigan

In *Grand Rapids* fluoridation was started in January, 1945, and this was the first study to be initiated in the United States. The project is under the direction of Drs. H. Trendley Dean and F. A. Arnold, Jnr., Director and Associate Director of The National Institute of Dental Research, U.S. Public Health Service, and the State Health Department and the University of Michigan are also co-operating. Grand Rapids, a manufacturing city of about 175,000 inhabitants, was selected for the project as its water supply, derived from Lake Michigan, was practically fluoride-free. The nearby City of Muskegon was chosen as control since it had a similar water supply and resembled Grand Rapids in type of industry and in social and economic status. This control will shortly be lost, however, as the City Council in Muskegon recently decided to fluoridate their water supply, but comparison is being made with the City of Aurora, Illinois, where fluorides occur naturally in the water at a concentration of 1·2 p.p.m., as well as with the base-line data of Grand Rapids itself.

The study is limited to children, both white and coloured, between the ages of 4 and 16 years. In 1944, before fluoridation started, all the children attending the public schools in the two cities were examined and those children who had lived in the district continuously from birth were compared, a total of 19,680 in Grand Rapids and 4,291 in Muskegon. Since then, representative samples of each age group have been examined yearly and this method will be followed until the study is complete.

Clinical dental examinations are carried out at the same time each year by a team of three dental officers so that the work can be completed in as short a time as possible and to ensure that each child has been exposed to fluoridation for the same length of time. The examiners do not know whether the child being examined is a continuous resident or not. A room with adequate washing facilities is provided at each school and a portable dental chair and good operating light are used. Each tooth is carefully examined, 10 minutes being devoted to each examination which is carried out with the use of mouth mirror and probe. X-rays are not used for diagnosis and as the same method is followed in both cities each year their use would not affect the comparison within the study.

The methods of the examiners and their standards of assessment have been calibrated and their findings are dictated to clerical assistants who enter them on special record cards. The criteria used for the assessment of caries are given in Appendix 3. Any doubtful pit or fissure is noted but is not counted as carious in the survey. It is considered that if these are incipient cavities, caries will have advanced by the next examination and the cavities will be more readily detected. The depth of caries is noted as well as the surfaces involved, and the extent of the fillings is recorded. Care is taken to differentiate between missing teeth which have not yet erupted and those which have been lost because of caries or for some other reason. Pathological conditions are noted and each tooth is carefully examined for signs of dental fluorosis, Dean's classification being used in assessing the degree of any mottling which occurs.

A pre-coded system is employed for recording the data which are then transferred to punch cards for processing by I.B.M. machines. Only some of the information recorded is used for this study but full details are available if they should be required.

Bacteriological examinations are carried out each spring and *Lactobacillus acidophilus* counts are estimated from samples of saliva taken from some of the children in each age group.

In presenting the findings the DMF index is used for the permanent dentition and the def index for the deciduous dentition. (Appendix 4.)

After six years of fluoridation it was found that there was a consistent reduction in caries incidence in Grand Rapids by comparison with the base-line caries rate in the city and with that of Muskegon and Aurora. This is apparent in practically all the age groups studied but it is most noticeable among the younger children who have been exposed to fluoride for the whole of their lives.

In 1945 the def rate among Grand Rapids children aged six years was 6·4 and in 1951 it had fallen to 3·7, which was practically the same as the rate in Aurora where fluorides occur naturally in the drinking water.

The incidence of caries in the permanent teeth of Grand Rapids children in this age group was 66 per cent. less in 1951 and was actually lower than in Aurora. A reduction was also observed in the higher age-groups, though less than among the younger children. The reason for this reduction has not yet been explained but it has been suggested that it may be due to the influence of fluoride during the period of maturation.

Dean, Arnold, Jay and Knutson (1950).
U.S. Public Health Service Unpublished (1952).

GRAND RAPIDS, AURORA AND MUSKEGON

DENTAL CARIES EXPERIENCE, DECIDUOUS TEETH, AMONG CHILDREN AGED 4–13 YEARS

Age	GRAND RAPIDS Fluoridation Area			AURORA Natural fluoride 1·2 p.p.m.	MUSKEGON Low-fluoride control area		
	def Teeth per Child		Percentage Reduction or Increase	def Teeth per Child	def Teeth per Child		Percentage Reduction or Increase
	1944–1945	1950–1951		1945–1946	1944–1945	1950–1951	
4	4·2	2·5	R. 41	2·1	5·1	5·3	I. 4
5	5·4	2·5	R. 54	2·8	6·8	5·6	R. 18
6	6·4	3·7	R. 42	3·4	7·2	6·0	R. 17
7	6·3	4·7	R. 25	3·5	6·7	5·8	R. 13
8	5·8	4·9	R. 16	3·6	6·1	5·1	R. 16
9	4·6	4·2	R. 9	3·0	4·9	4·1	R. 16
10	2·8	2·4	R. 14	2·3	3·1	3·5	I. 13
11	1·3	1·2	R. 8	1·2	1·3	1·1	R. 15
12	0·5	0·2	R. 60	0·4	0·4	0·6	I. 50
13	0·2	0·1	R. 50	0·1	0·2	0·1	R. 50

DENTAL CARIES EXPERIENCE, PERMANENT TEETH, AMONG CHILDREN AGED 5–16 YEARS

Age	GRAND RAPIDS Fluoridation area			AURORA Natural fluoride 1·2 p.p.m.	MUSKEGON Low-fluoride control area		
	DMF Teeth per Child		Percentage Reduction or Increase	DMF Teeth per Child	DMF Teeth per Child		Percentage Reduction or Increase
	1944–1945	1950–1951		1945–1946	1944–1945	1950–1951	
5	0·11	0·028	R. 74	0·06	0·06	0·09	I. 32
6	0·78	0·26	R. 66	0·28	0·81	0·75	R. 8
7	1·89	1·03	R. 45	0·70	1·99	2·01	I. 1
8	2·94	1·77	R. 40	1·04	2·81	2·96	I. 5
9	3·90	2·38	R. 39	1·52	3·81	3·89	I. 2
10	4·92	3·17	R. 36	2·02	4·91	4·53	R. 8
11	6·41	4·36	R. 32	2·67	6·32	5·67	R. 10
12	8·07	7·10	R. 12	2·95	8·66	6·88	R. 21
13	9·73	7·21	R. 26	3·09	9·98	9·58	R. 4
14	10·94	8·55	R. 22	3·64	12·00	12·11	I. 1
15	12·48	10·12	R. 19	4·54	12·86	10·94	R. 15
16	13·50	11·35	R. 16	5·19	14·07	13·91	R. 1

(2) Newburgh, New York

The city of *Newburgh* which has a population of about 35,000, was selected for a fluoridation study as its water supply contained not more than 0·1 p.p.m. of fluorides, and the nearby city of Kingston was chosen as control because its population, climate and economic status were similar to those of Newburgh, and its domestic water supply also was practically fluoride-free. The investigation was initiated by the State Health Department of New York and comprises a dental caries study and a parallel paediatric research programme. Dr. David B. Ast, State Dental Director supervises the study and a specially appointed Committee consisting of specialists in paediatrics, radiology, pharmacology, biochemistry and bacteriology, acted and continues to act in an advisory capacity.

Fluoridation was started in May, 1945, only a few months later than in Grand Rapids, and the two studies are similar in many respects. In Newburgh and Kingston, however, all children between 5 and 12 years of age are included whereas in the Grand Rapids study only those with a history of continuous residence in the district from birth are compared. It was found that the proportion of immigrants in Newburgh and Kingston was too small to affect the comparison.

A pre-fluoridation dental survey was made in 1944 on 3,084 children between 5 and 12 years of age in Newburgh and on 2,812 children in similar age groups in Kingston, the age being counted as from the last birthday. Further examinations have been carried out annually and representative groups of pre-school and older children are included.

The paediatric research study is conducted on a sample of 500–600 children each year in both cities. Medical examinations include complete physical examination, laboratory tests, analysis of blood and urine and radiological examination of hands, fore-arms, and knees as well as special ophthalmological and otological tests of small groups of children. No deleterious effects have so far been found to follow fluoridation of the water.

Salivary *Lactobacillus acidophilus* counts are done annually on a group of 400 children in both cities and it has been found that since fluoridation was started an improvement has occurred among Newburgh children.

Clinical dental examinations of a standard similar to that of the Grand Rapids study are conducted annually, each child being examined at the same time each year. At first they were made by both a dentist and a dental hygienist, each examining half of the children. Bite-wing x-rays were used as a means of calibrating the two examiners to rule out the possibility of variation in their interpretations (Appendix 3). It was found that their standards of assessment agreed closely and it was considered that an examiner bias was unlikely. The amount of caries detected by x-ray was only 12 to 17 per cent. more than that which had been found clinically. At present all the dental examinations are being carried out by the hygienist.

The record card used in this study is diagrammatic and the information noted is not so detailed as in the Grand Rapids study but the exact condition of every tooth is clearly shown as well as the surfaces affected by caries. Missing teeth are recorded together with the reasons for their loss and clinical notes are made of any pathological condition.

In presenting the dental findings the DMF index is used for permanent teeth and the DF index for the deciduous teeth (Appendix 4).

For the permanent dentition the data are presented in different ways. The DMF rate per 100 erupted teeth is the more favoured but to permit of comparison with other studies the rate per 100 children has also been calculated.

In addition, a comparison is made of the caries experience of first permanent molars among children in Newburgh and in Kingston and of caries-free deciduous canines, first and second molars.

In 1950-51, the incidence of dental caries in the deciduous teeth of Newburgh children had been reduced by 60 per cent. at 5 years and by 53 per cent. at 6 years, while in the permanent teeth it was 80 per cent. less at 5 years and 78 per cent. less at 6 years than in 1945. In both age groups the average DMF rate was lower than that of Aurora. A reduction in caries incidence was observed in all age groups and was as much as 27 per cent. at 12 years. In Kingston, on the other hand, caries experience was 31 per cent. less at 5 years but only 2 per cent. less at 6 years and in all other age groups it had increased.

The number of caries-free first permanent molars had increased in Newburgh, whereas in Kingston it had remained unchanged. The comparison was not affected by the amount of dental treatment obtained as that was found to be practically the same in the two cities.

Ast, Finn and Chase (1951).

—— (1952) Personal Communication.

NEWBURGH

DENTAL CARIES EXPERIENCE, DECIDUOUS TEETH, AMONG CHILDREN AGED 5–8 YEARS, IN NEWBURGH AND KINGSTON

Age	NEWBURGH Fluoridation area			KINGSTON Low-fluoride control area		
	DF Teeth per 100 Children		Percentage Reduction or Increase	DF Teeth per 100 Children		Percentage Reduction or Increase
	1944–1945	1950–1951		1945–1946	1950–1951	
5	516·8	204·7	R. 60	412·0	387·5	R. 6
6	571·0	266·3	R. 53	532·1	472·0	R. 11
7	566·5	336·6	R. 41	574·9	475·4	R. 17
8	528·2	382·2	R. 28	502·0	438·4	R. 13

DENTAL CARIES EXPERIENCE, PERMANENT TEETH, AMONG CHILDREN AGED 5–12 YEARS, IN NEWBURGH AND KINGSTON

Age	NEWBURGH Fluoridation area			KINGSTON Low-fluoride control area		
	DMF Teeth per 100 Children		Percentage Reduction or Increase	DMF Teeth per 100 Children		Percentage Reduction or Increase
	1944–1945	1950–1951		1945–1946	1950–1951	
5	17·9	3·5	R. 80	19·2	13·3	R. 31
6	48·1	10·7	R. 78	40·9	39·9	R. 2
7	104·6	54·0	R. 48	108·1	113·3	I. 5
8	194·6	94·6	R. 51	202·3	214·7	I. 6
9	311·3	176·9	R. 43	264·4	312·3	I. 18
10	400·7	233·3	R. 42	378·9	391·8	I. 3
11	483·7	337·2	R. 30	479·5	541·9	I. 13
12	636·2	464·3	R. 27	631·1	672·7	I. 7

(3) Brantford, Ontario

The *Brantford* fluoridation study was started in June, 1945 on the instigation of Dr. W. L. Hutton, Director, Brant County Health Unit. The proposal was originally put forward in 1942 and when visited in March, 1952, this was the only city in Canada to have adopted this preventive measure. The proposal was approved by the local dental and medical societies, the two boards of education, labour unions and other bodies. It was considered that it might take 10 years to assess the final results.

The water originally contained only traces of fluorides and sodium fluoride was added to bring the concentration to 1 p.p.m. though in February, 1949 this was increased to 1·2 p.p.m.

The city population in 1951 was 36,692 with an additional assumed township water population of 6,000.

The teeth of the children had been examined before starting fluoridation, otherwise there was no control. However, the Department of National Health and Welfare, Ottawa became interested in the study and in 1948 appointed Dr. H. K. Brown, Chief of the Dental Health Division, to undertake a controlled study whereby a comparison could be made with the children of Sarnia where the water is practically fluorine-free and of Stratford which contains fluorides at a concentration of 1·3 p.p.m. from a natural source.

In the original study reported by Hutton, Linscott and Williams (1951) about 2,700 children are examined yearly. Base line examinations were made in 1944 and 1945 before fluoridation started and the average figures of these two years is used when comparing with the effects of fluoridation. The tables record the dental condition of the children from 5 to 16 years old with continuous residence in Brantford. The results for each year are considered separately.

The dental examinations are carried out by Dr. B. W. Linscott, the School Dental Officer, who also gives dental treatment to the children from families of the lowest social grade. The examinations are carried out in a dental clinic, the equipment being portable and set up in each of the schools. There is a good operating light and the examination is by mouth mirror and probe, twelve new Weston double-ended probes being used each year.

A record is made on a card of the number of teeth that are decayed, missing and filled, and also that require extraction.

In the yearly tables there are recorded for each age group the DMF rate per child for the deciduous and permanent teeth combined and the percentage reduction for each succeeding year. In addition there are given the yearly percentages of children with perfect teeth.

Comparing the DMF per child, in the prefluoridation period 1944 and 1945 the average at 6 years was 7·04, and in 1951 it was 3·55, a reduction of 50 per cent. At 14 years the reduction was 24 per cent. (Table I). The percentage of children with perfect teeth in 1944 and 1945 was 5·18 and in 1951 was 15·97.

Brown (1952) has made a preliminary report of his results at Brantford, Sarnia and Stratford. Before this study was undertaken the socio-economic status of the three communities was examined and found to be reasonably comparable. All are middle class industrial towns in West Ontario. The average income in Stratford may be a trifle lower than in the other two but not significantly so. Each community is surrounded by an excellent agricultural district with similar products.

Brantford, however, over a period of 15 years has provided more free dental services for children than most Canadian cities, and this has resulted in the ratio of corrected to total defects being higher than in either Sarnia or Stratford. The approximate numbers of children examined are 1,700 at Brantford, 1,700 at Sarnia and 1,300 at Stratford. The age groups are 6–8, 9–11, and 12–14 years and the numbers in each age group are fairly evenly balanced. Only continuous residents who have not been absent for a period of six weeks are included.

All examinations have been conducted by the same examiner, using a portable dental examining light (Castle Specialist No. 46), plane mouth mirrors and No. 5 Clevedent probes.

The tables give for various age groups, the df deciduous teeth and df deciduous tooth surfaces per child examined; the DMF permanent teeth and DMF permanent tooth surfaces per child examined; the percentage of children with caries-free permanent teeth; the DMF permanent upper incisor teeth per child examined.

Comparing the df deciduous teeth for the 6–8 year age group the figures given for 1948 and 1951 respectively are Brantford, 5·0 and 3·6; Sarnia (fluoride-free) 4·9 and 4·9; Stratford (natural fluorides) 2·2 and 2·6 (Table II). The DMF permanent teeth for the 6–8 year age group for 1948 and 1951 respectively are Brantford 1·4 and 0·9; Sarnia 1·6 and 2·0; Stratford 0·4 and 0·8 (Table III). It is interesting to note that while there has been a decrease in caries incidence in Brantford, there has been an increase in caries in the permanent teeth in Sarnia and Stratford where it is presumed there has been no appreciable change in either preventive or treatment services.

Regarding caries-free permanent teeth, there has been an increase in Brantford, thus for the 9–11 age group the figures are 5·7 in 1948 and 17·1 in 1951 (Table IV).

Hutton, Linscott and Williams (1951).
Brown (1952).

TABLE I

CHANGES IN THE DENTAL CARIES EXPERIENCE OF BRANTFORD SCHOOL CHILDREN, 1944–1951

(HUTTON, LINSCOTT AND WILLIAMS)

Age	Average Number of DMF Teeth per Child		Percentage Reduction or Increase
	Pre-Fluoridation 1944 and 1945	Post-Fluoridation 1951	
5	5·74	2·59	R. 55
6	7·04	3·55	R. 50
7	8·44	4·95	R. 43
8	8·84	5·31	R. 39
9	8·78	6·66	R. 24
10	7·55	5·74	R. 25
11	6·42	5·05	R. 21
12	6·94	5·05	R. 27
13	7·98	5·47	R. 31
14	8·67	6·55	R. 24
15 and 16	9·98	8·49	R. 15
TOTAL	7·73	4·92	R. 36

DENTAL CARIES EXPERIENCE OF SCHOOL CHILDREN AT BRANTFORD, SARNIA AND STRATFORD

(BROWN)

TABLE II

df DECIDUOUS TEETH PER CHILD EXAMINED, BY AGE AT EXAMINATION

Survey and Year	6–8 yrs.	9–11 yrs.
Brantford, 1948 (fluoridation started in 1945)	5·0	2·4
Brantford, 1951	3·6	2·2
Sarnia, 1948 (fluoride-free)	4·9	2·5
Sarnia, 1951	4·9	2·4
Stratford, 1948 (Natural-fluoride)	2·2	1·7
Stratford, 1951	2·6	1·8

TABLE III

DMF PERMANENT TEETH PER CHILD EXAMINED, BY AGE AT EXAMINATION

Survey and Year	6–8 yrs.	9–11 yrs.	12–14 yrs.
Brantford, 1948	1·4	4·1	7·7
Brantford, 1951	0·9	2·9	6·1
Sarnia, 1948	1·6	4·2	7·9
Sarnia, 1951	2·0	4·5	8·6
Stratford, 1948	0·4	1·1	2·5
Stratford, 1951	0·8	1·8	3·1

TABLE IV

PERCENTAGE OF CHILDREN EXAMINED HAVING CARIES FREE PERMANENT TEETH, BY AGE AT EXAMINATION

Survey and Year	6–8 yrs.	9–11 yrs.	12–14 yrs.
Brantford, 1948	46·7	5·7	1·2
Brantford, 1951	59·2	17·1	4·3
Sarnia, 1948	41·0	6·1	0·6
Sarnia, 1951	32·7	3·6	1·2
Stratford, 1948	78·4	52·1	27·2
Stratford, 1951	65·2	35·7	22·0

(4) Sheboygan, Wisconsin

There are more fluoridation schemes in *Wisconsin* than any other State ; in 1951, 72 communities were adding fluorides to their water supplies and a further 37 proposed to do so. Almost all these projects were undertaken as a public health measure but in Sheboygan, a city of about 42,000 inhabitants and the first in Wisconsin to add fluorides to the communal water supply, a dental caries investigation is in progress. The Fluorine Committee of the Dental Society of Wisconsin were so firmly convinced by the large amount of available evidence that one p.p.m. of naturally occurring fluoride in drinking water inhibits dental caries that they recommended that the Sheboygan water supply should be fluoridated to the same level. This was started in February, 1946, although it had been planned two years earlier.

The investigation is under the direction of Dr. F. A. Bull, Dental Director to the State of Wisconsin and the City Council of Sheboygan are co-operating in the scheme. Dr. Finke, a private dental practitioner in Sheboygan, shares with Dr. Bull the responsibility for dental examinations.

The study comprises all the white children in the three age groups, 5–6, 9–10 and 12–14 years of age attending schools in the city—about 2,500 in all. Clinical oral examinations are carried out annually and a comparison is made with the base-line data obtained by a pre-fluoridation survey.

Two simple forms are used for recording the dental findings, one for the deciduous dentition and the other for the permanent dentition. For the children in the 5–6 year age group the deciduous dentition, only, is considered and the def index is used. For the older children reports are made on the permanent dentition, caries being expressed as the average DMF teeth per child.

In 1951 after five years of fluoridation it was found that the incidence of caries among 5–6 year old children had been reduced by 53·7 per cent. and that the number of children with deciduous teeth free from caries was almost 1½ times as great. A reduction in caries experience was also observed among the older children and was as much as 30 per cent. at 9–10 years and 23 per cent. at 12–14 years.

Bull (1950).
—— (1952) Personal communication.

SHEBOYGAN

DENTAL CARIES EXPERIENCE, DECIDUOUS TEETH, AMONG CHILDREN AGED 5–6 YEARS

Age	Percentage of Children free from Caries		Percentage Reduction or Increase	Average Number of def Teeth per Child		Percentage Reduction or Increase
	1945	1951		1945	1951	
5–6	20·4	47·8	I. 134·1	4·80	2·22	R. 53·7

DENTAL CARIES EXPERIENCE, PERMANENT TEETH, AMONG CHILDREN AGED 9–10 AND 12–14 YEARS

Age	Average Number of DMF Teeth per Child		Percentage Reduction or Increase
	1945	1951	
9–10	3·03	2·12	R. 30·0
12–14	8·54	6·54	R. 23·4

(5) Marshall, Texas

In the State of *Texas* the effect of fluoride on dental conditions is of particular interest. In many areas water supplies contain excessive amounts of fluorides, and dental surveys in Bartlett on the eastern side of the State and in the Panhandle and other parts of West Texas have shown that this is associated with a high degree of dental fluorosis. In other parts of the State the water is fluoride-free. One of these areas is the mid-Texas city of Marshall, with a population of 22,500, which draws its water from the nearby Lake Caddo. A high incidence of caries was observed among the Marshall children.

It is of interest to note that in this one State excess fluorides are being removed from the water in Bartlett to prevent dental fluorosis, while fluorides up to 1 p.p.m. are being added to the water in Marshall to reduce dental caries.

Fluoridation was started in Marshall in May, 1946. The scheme was initiated by the State Health Department of Texas in co-operation with the City Council of Marshall, and the study is under the direction of Dr. Edward Taylor, the State Dental Director.

The neighbouring town of Jacksonville with a fluoride-free water supply was selected as control, but although caries experience in the two areas was compared after 2½ years of fluoridation, the most valuable basis for comparison is the base line data of Marshall itself.

The average incidence of caries amongst coloured children has been found to differ from that of white children, and a comparison would be affected if both were included. The study is therefore confined to white public-school children from 6–16 years of age who were born and brought up in Marshall. Children who have at any time lived away from the city for a period of two months or more are excluded. Approximately 2,000 children were examined when the study commenced, and of these 63 were in the 6-year age group. The total number seen has been smaller in subsequent years, but an average of 65 children has been maintained in the younger age groups.

Clinical dental examinations are carried out annually by one Dental Officer working in school premises, and his findings are recorded by trained assistants. The condition of each tooth is depicted on a diagrammatic chart. Missing teeth, carious and filled surfaces, and arrested caries are noted, as well as occlusion and gingival conditions. A special note is made of any mottled enamel. Medical examinations are provided for the younger children but *Lactobacillus acidophilus* counts have been discontinued.

As in the original Brantford study, caries experience is assessed on the combined deciduous and permanent dentition, and expressed as the average number of DMF teeth per child. The reduction in caries incidence is also calculated for each age group.

Since fluoridation began caries incidence has been steadily reduced, especially in the younger age groups. In 1951 the 6-year old children who had been exposed to fluorine for the whole of their lives had 3·05 DMF teeth, whereas the DMF rate for this age group in 1945 was 7·06. The reduction in the higher age groups was much less marked, but it could be observed up to 11 years of age.

Taylor (1950).
—— Unpublished (1952).

DENTAL CARIES EXPERIENCE, PERMANENT AND DECIDUOUS TEETH COMBINED, AMONG CHILDREN AGED 6–16 YEARS

Age	Average Number of DMF Teeth per Child		Percentage Reduction or Increase
	1944–1945	1951	
6	7·06	3·05	R. 57
7	8·77	5·62	R. 36
8	8·97	6·62	R. 26
9	7·56	7·33	R. 3
10	7·58	6·82	R. 10
11	6·70	5·91	R. 12
12	6·46	6·53	I. 1
13	7·03	8·95	I. 27
14	8·20	9·77	I. 19
15	9·73	8·2	R. 16
16	12·0	10·2	R. 15

(6) Evanston, Illinois

Evanston is one of the suburbs of Chicago, a city in itself, with a population of 85,000, on the shores of Lake Michigan, from which it draws a fluoride-free water supply. In February, 1947 the City Council, on the recommendation of local medical and dental bodies, decided to carry out a fluoridation/dental caries investigation and the fluoride content of the water supply was therefore raised to 1 p.p.m. The dental survey was placed under the directorship of Professor J. C. Blaney of the Walter G. Zoller Memorial Dental Clinic, University of Chicago, who is carrying out one of the most elaborate investigations.

Thorough clinical examinations are made in school premises by a team of three dentists, and full-mouth x-rays are taken by a radiographer. Random samples of saliva are collected for bacteriological tests. The examiners record their findings on a diagrammatic chart and in addition a comprehensive record card is kept for each child. For this purpose the parents are interviewed and such items as diet and illnesses of the child and the history of the mother's pregnancy are noted. Provision is also made for the results of blood and urine tests. Twenty minutes are devoted to each examination so the complete survey extends over the greater part of the school year but each child is examined within the same period of time as far as possible.

In recording the dental findings the site of the carious lesion is noted as well as the tooth surfaces affected ; so also, missing teeth, teeth which need extraction, the occlusion, pathological conditions, and enamel dystrophies. Doubtful pits and fissures on the occlusal surfaces of molars are classified as pre-carious lesions. Carious cavities diagnosed from the x-ray films are entered later on the charts and as many as 50 per cent. of the lesions recorded are stated to be detected in this way.

The study includes only white children attending public schools in the city who have lived in the area continuously from birth. Children who have been absent for two consecutive months are excluded. The age groups especially studied are those of 6, 7, and 8 years and of 12, 13, and 14 years, the age being counted as the nearest birthday.

The control for the study is the neighbouring community of Oak Park which has a similar water supply, and a comparison is also made with the base-line data of Evanston itself. Before fluoridation started a dental survey was made of 4,375 children in the selected groups in Evanston and of 2,493 children in Oak Park. Further examinations have been carried out each year since 1947 and will continue until 1962.

The findings are presented for the 6, 7 and 8-year old children jointly and in a similar manner for the older children, the def index being used for the deciduous teeth and the DMF index for the permanent dentition. The incidence of caries among the children aged 6–8 years is compared with the base-line data of Evanston itself while the caries experience of children aged 12–14 years is compared with that of Oak Park.

In 1951, caries incidence in the permanent teeth of children aged 6 years was 74 per cent. less than in 1947. Pre-carious lesions on permanent tooth surfaces were reduced by 79 per cent. and there were 100 per cent. less carious or filled maxillary anterior teeth.

On the other hand there was only a slight reduction, 7 per cent., in the caries rate of the deciduous teeth of 6-year children, and for the combined 6–8-year age group caries incidence was higher than in 1947. It should be noted that the crowns of the deciduous dentition of these children were already mineralized before fluoridation started whereas those of the average permanent teeth were only partly mineralized.

Caries experience among 12, 13, and 14-year children was compared with that of Oak Park after two years of fluoridation as well as with the original data for Evanston, and it was found that the DMF rate was reduced in each of these age groups by 12 per cent. It is considered, however, that this can be attributed partly to improved oral hygiene in the study area.

Blaney and Tucker (1948).
Hill, Blaney and Wolf (1950, 1951, 1952).

EVANSTON, ILL.

DENTAL CARIES EXPERIENCE OF 6 YEAR OLD CHILDREN AFTER 47–58 MONTHS OF FLUORIDATED WATER

	Rates per 100 Children		Percentage Reduction or Increase
	1946	1951	
def Deciduous Teeth	482·86	449·63	R. 7
DMF Permanent Teeth	46·85	12·36	R. 74
Occlusal Surface of First Permanent Molars with Caries experience	40·13	7·93	R. 80
Carious or Filled Maxillary Anterior Permanent Teeth	0·65	0·00	R. 100
Pre-carious Lesions on Permanent Tooth Surfaces	50·32	10·52	R. 79

APPENDIX 7

Studies on Adults

Numerous epidemiological studies have shown conclusively that children born and brought up in areas where the drinking water contains about 1 p.p.m. of fluoride have a low incidence of dental caries. The evidence from studies of adults is less extensive and there is some difference between the preliminary conclusions of American and British observers. The earlier American investigators (Deatherage, 1943; McKay, 1948) concluded that the protection afforded to the teeth of children was maintained in adult life and this was confirmed by Russell and Elvove (1951). In England, on the other hand, Weaver (1944, 1948, 1950) suggested that the consumption of water containing fluorides had a delaying action on the onset of caries rather than a lasting preventive effect; up to 30 years of age or so, a given incidence among adults was obtained about 5 years later than in areas where the water contained little or no fluoride. More extensive surveys by Forrest, Parfitt, and Bransby (1951) yielded results broadly similar to those of Weaver but the "postponement" amounted to about 10 years and was still appreciable in middle age.

It is not possible to explain the difference between the American and English findings from the published results. However, the authors of the latest and most extensive English survey (Forrest, Parfitt, and Bransby) have made available more detailed figures than they published and a detailed comparison of their results with those of Russell and Elvove (1951) is instructive.

The English surveys were made in three high fluoride areas: South Shields, Colchester, and Slough (0·82 to 1·45 p.p.m.), and in three low fluoride areas, North Shields, Ipswich, and Reading (0·07 to 0·3 p.p.m.), and examinations of adults were limited to women attending ante-natal and child welfare clinics who were natives of the district. The American surveys were made in Colorado Springs (fluoride 2·5 p.p.m.) and in Boulder (0·025 p.p.m.) and covered an approximately random sample of adults (continuous residents) both male and female, up to the age group 40–44. The methods of dental examination were similar in England and America but the English observers included deep pits and fissures in the enamel as "caries" whereas the American observers did not consider lesions to be carious unless the dentine was involved. In both studies the results were expressed in terms of the DMF index.

Table I summarises the findings and also gives the D, M and F rates separately. Considering the total DMF rates alone (the only basis of comparison possible from the findings already published) it is seen that subjects in Colorado Springs had rates which were 50 to 60 per cent. lower than subjects in Boulder at all ages and even at age 40–44 the Colorado Springs residents had a DMF rate lower than that of Boulder residents at 20–24. In England the reduction of DMF rates in high fluoride areas as compared with low fluoride areas fell from 38 per cent. at age 21–25 to 17 per cent. at age 41–45. Furthermore, the DMF rate among subjects aged 36–40 and 41–45 in the high fluoride areas was comparable respectively with that of subjects in the low fluoride areas ten years younger.

The difference between the American and the English findings might be explained on three grounds: (*a*) the fact that Colorado Springs water contains 2·5 p.p.m. fluoride compared with 0·8 to 1·45 p.p.m. in the English high fluoride areas, (*b*) the difference in the criteria adopted for diagnosing caries, and (*c*) differences between the populations studied which might affect the DMF rates.

(*a*) Epidemiological work on children aged 12–14 suggests that DMF rates are not reduced much further when the drinking water contains more than

TABLE I

INCIDENCE OF DENTAL CARIES AMONG ADULTS IN ENGLAND AND THE UNITED STATES OF AMERICA, SHOWING THE AVERAGE NUMBER OF DECAYED, MISSING AND FILLED TEETH PER SUBJECT

England

Age in Years	Combined Low Fluoride Areas (0·07–0·3 p.p.m.F.)					Combined High Fluoride Areas (0·82–1·45 p.p.m.F.)					Percentage reduction in High compared with Low Fluoride Areas
	No. Exam.	D.	M.	F.	DMF Rate	No. Exam.	D.	M.	F.	DMF Rate	
21–25 ...	92	7·7	6·7	1·7	16·1	91	4·6	3·6	1·8	10·0	38·0
26–30 ...	107	5·8	11·9	1·6	19·3	69	3·6	6·7	2·2	12·5	35·0
31–35 ...	40	5·2	14·6	1·6	21·4	61	3·7	11·1	1·4	16·2	25·0
36–40 ...	30	3·4	18·4	1·0	22·8	23	2·9	15·3	1·0	19·2	16·0
41–45 ...	5	1·4	25·0	0·0	26·4	7	1·8	19·4	0·8	22·0	17·0
			All ages	...	19·1			All ages	...	13·4	

U.S.A.*

	Boulder (0·025 p.p.m.F.)					Colorado Springs (2·5 p.p.m.F.)					
20–24 ...	51	1·1	1·2	11·7	14·0	72	0·2	0·6	4·6	5·4	61·5
25–29 ...	41	1·2	2·5	12·8	16·5	101	0·3	0·9	5·3	6·5	60·6
30–34 ...	29	1·1	4·0	13·1	18·3	82	0·1	1·1	5·8	7·1	61·2
35–39 ...	22	0·6	11·4	9·8	21·8	75	0·2	3·2	5·8	9·2	57·8
40–44 ...	12	0·91	12·08	8·66	21·7	55	0·1	3·1	7·1	10·3	52·5
			All ages	...	17·2			All ages	...	7·5	

* Rates do not include the third permanent molars.

1 p.p.m. of fluoride (Dean, Arnold and Elvove, 1942). If this is true of adults also, reason (*a*) is not likely to be influential.

(*b*) Caries would be diagnosed slightly more frequently on the English than on the American standard and this may account in part for the difference in the incidence of decayed teeth (D).

(*c*) There are conspicuous differences between the American and the English groups studied. It is reasonable to suppose that the absence of men from the English samples does not affect the issue seriously but the English women, attenders at maternity and child welfare clinics, were mostly working class people. The American subjects were possibly a more representative sample of adults in their areas and in both Colorado Springs and Boulder there is an unusually high proportion of professional and business people with a high standard of living. The amount and nature of dental treatment tend to vary according to the social and economic status of the population, regular dental attention and conservative treatment being more common among the well-to-do.

TABLE II

MISSING (M) TEETH AS PERCENTAGE OF TOTAL DMF TEETH

England

Age in Years	Combined Low-Fluoride Areas 0·07–0·3 p.p.m.F.	Combined High-Fluoride Areas 0·82–1·45 p.p.m.F.
21–25	41·4	36·0
26–30	61·6	53·6
31–35	67·9	68·5
36–40	80·7	79·7
41–45	94·7	88·2
All ages	58·5	54·2

U.S.A.

Age in Years	Boulder 0·025 p.p.m.F.	Colorado 2·5 p.p.m.F.
20–24	8·6	11·1
25–29	15·1	13·8
30–34	21·8	15·5
35–39	52·3	34·8
40–44	55·7	30·1
All ages	22·7	20·0

Table II shows that in the English groups the percentage of missing teeth among the total decayed, missing and filled (DMF) teeth rose with age from 41 to 95 per cent. in the low fluoride areas and from 36 to 88 per cent. in the high fluoride areas. By contrast, the percentages in Boulder rose from 9 to 56 per cent. and in Colorado Springs from 11 to 30 per cent. In the younger age groups extractions were roughly four times as common in the English groups as compared with American.

The American investigators differentiated between teeth extracted for caries and those extracted for other reasons and their results indicate that most of the extractions were on account of caries in Boulder and in Colorado Springs. This differentiation was not possible in England but the steeply rising extraction

(M) rate suggests that many teeth were removed for reasons other than caries, such as parodontal disease or for denture-planning purposes. This is further supported by the fact that both D and F rates actually fell as age increased in both English groups.

It is difficult, therefore, to come to any clear conclusion as to the effect of fluoride on the incidence of caries among adults in England and it is not justifiable to conclude that the rise of DMF rates is entirely due to the progress of caries, nor that the effect of fluorides on caries is merely one of postponement. Obviously more information is required on the dental condition of adults in high and low fluoride areas. Meanwhile, the available evidence shows that in England there is a clear superiority in high fluoride areas in respect of the over-all dental condition as assessed by the DMF rates at least up to middle age. That an even greater superiority has been found in the American groups suggests strongly that, for the best results, fluoridation must be accompanied by a high standard of conservative dentistry.

APPENDIX 8

Mechanism of Dental Caries Reduction by Fluoridation of the Domestic Water Supply

(a) **Fluorine Content of Teeth**

The enamel and dentine of all teeth contain fluorine. It has now been shown that the amount is increased when there is a higher concentration of fluorides in the drinking water to which the teeth have been continuously exposed. (Table 1.) Thus McClure and Likins (1951) have shown that the teeth of people living during the whole period of tooth formation and eruption in Aurora, where the fluoride content of the domestic water is 1·2 p.p.m., contain more fluorine than those in Washington, D.C., where the domestic water contains 0·0 to 0·2 p.p.m. In the enamel this increase is from 0.0102 per cent. in Washington to 0·0135 per cent. in Aurora (about 30 per cent.), and in the dentine from 0·0240 per cent. to 0·0360 per cent. in these cities respectively (about 60 per cent.). It has already been mentioned that the people in Aurora have a low dental caries experience and that the teeth are of good appearance. It must not, however, be inferred from this that a sound tooth contains more fluorine than a carious tooth in the same individual as this is not the case according to McClure (1948).

The details of the fluorine deposition have not been fully elucidated. The inorganic part of enamel and dentine is composed of apatites. Gerould (1945) who has undertaken work on tooth structure with the electron microscope using surface replica techniques has applied this method of study to the mechanism of fluorine deposition in fluorosed teeth. Though the results are only provisional and based on limited data, his preliminary observations of electron micrograph comparisons of cleaved and unetched normal and fluorosed enamel and dentine show no significant differences indicating that the dispersion of the fluorine is such that it does not greatly influence the fracture pattern of the normal apatite. The external enamel surfaces of fluorosed teeth (without etching) show a tendency to a greater microscopic roughness than the normal teeth. He suggests that fluorine entering into a tooth during the formative period and period of mineralization is laid down, not in the form of calcium fluoride, but probably in the form of acid resistant calcium fluorapatite, as a fine dispersion throughout the hydroxy and carbonate apatites.

(b) **Theories of the Mechanism of Dental Caries Reduction**

We were informed that the mode of action whereby fluorides in the domestic water supply effected a reduction in the incidence of dental caries had not been elucidated. Four theories have been considered and these will be described.

1. *Reduction of enamel solubility in acids*

A widely supported theory of the cause of caries ascribes it to the production of acid from the fermentation of carbohydrate. It is said that at an incipient carious lesion there is a slight alteration of the pH towards the acid side. The possibility that an increase in the fluorine content of the enamel may reduce the solubility in acid has been suggested. Volker (1940) reported that the presence of fluoride in large amounts in the diets of experimental rats decreased the solubility of both enamel and dentine. He was doubtful, however, whether the small increases in fluorine found in fluorosed teeth in man would affect the solubility in acid. This we consider is still an open question and one in which further evidence would be desirable.

2. *Inhibition on the tooth surface of bacterial and enzymatic processes*

It is known that fluorides in the water at the low concentrations under discussion have no effect on bacterial growth or on enzymes. Consequently the presence of fluorides in the water anywhere near a level of 1 p.p.m. would not reduce the oral flora including the *Lactobacillus acidophilus.* It has however been suggested that the increased fluorine content of the enamel might have a local anti-bacterial and anti-enzymatic action, and that this would affect the bacteria and enzymes at the actual tooth surface. Hence the activity of bacteria and enzymes, either acidogenic or proteolytic, would be inhibited. This suggestion is speculative.

TABLE I

FLUORINE CONTENT OF TEETH

Investigators	Teeth from districts with 0·3 p.p.m. and under in the domestic waters — Percent. F.		District	Teeth from districts with over 1 p.p.m. in the domestic waters — Percent. F.		District and and fluoride concentration of water p.p.m.
	Enamel	Dentine		Enamel	Dentine	
Bowes and Murray (1936)	0·025	0·025	London	0·032	0·073	Maldon—nearly 6
Ockerse (1941) ...	0·0153	0·0268	Knysna, South Africa	0·0445	0·0755	Calvinia, South Africa—1·5
McClure and Likins (1951)	0·0102	0·0240	Washington, D.C.	0·0345	0·0762	Panhandle, West Texas—2·5–5·0
				0·0135	0·0360	Aurora—1·2

3. *Salivary effects.*

Any question of an increase of fluorides in the saliva seems to be ruled out in view of the observation made by McClure (1941). He reports that there is no material difference in the fluoride content of the saliva of children whether the drinking water contains fluorides or not. He concludes that the salivary secretion is not concerned in the question. Martin and Hill (1950) find that for 12–14 and 6–8 year old children in Evanston the average fluoride content of the saliva is 0·20 and 0·25 p.p.m. respectively; also that there is no apparent relationship between the fluoride content of the saliva and either the oral *L. acidophilus* count or the prevalence of caries.

4. *Topical effect on the tooth surface.*

It has been pointed out by Dean, Arnold and Elvove (1942), Weaver (1944a, b) and Brown (1952) that the reduced caries incidence in districts with fluorides in the domestic water supply is much greater in the permanent upper incisor teeth than in the molars. On the other hand, in the deciduous teeth of five-year-old children at Maldon, Coumoulos (1945) has recorded that though there is less caries experience than in London, the caries distribution is similar in both districts. In view of the beneficial effect on the permanent maxillary incisors it has been suggested that the fluoridated drinking water as it flushes over the teeth has a direct topical effect on the surface of the enamel.

It must be mentioned that there have been several reports that a reduction in the incidence of caries is effected by topical applications of a much higher concentration of sodium fluoride, namely a 2 per cent. solution (Appendix 12). Regarding the question of a chemical change in the surface of the enamel, resulting from topical applications of high concentrations, preliminary work by Volker *et al.* (1940) using radioactive isotopes suggested that a sodium fluoride solution reacted with enamel and dentine *in vitro,* with the result that subsequently the solubility of both these tissues in acid was reduced. Gerould (1945) who immersed extracted teeth for a month in a 4 per cent. solution of sodium fluoride, stated that subsequent examination by electron diffraction and X-ray diffraction indicated that the fluoride entered the surface of the enamel to form a type of acid-resistant calcium fluoride. According to Syrrist (1949) electron micrographs taken of the outermost layer of enamel treated with fluoride solution *in vivo* suggest that it is more dense than untreated enamel ; the layer however is only 3–4 microns thick.

Scott, Picard and Wyckoff (1950), from treatment of enamel slabs with sodium fluoride solutions, usually 2 per cent., report that electron micrographs of replicas of the enamel slabs show few visible changes if treatment is for less than seven days. Small amounts of deposits were noted after 7 days and these increased after 15- to 30-day treatments. Preliminary but inconclusive tests were made of the relative acid solubilities of untreated enamel and enamel after immersion in NaF. Electron diffraction patterns were made from the surfaces of enamel slabs before and after immersion in NaF solutions for periods from 3 minutes to 30 days. In all cases the original apatite pattern was converted to that of calcium fluoride. This pattern, however, reverted to that of the apatite when specimens that had been treated for 3 minutes were washed for 90 minutes in water ; though in specimens that had been treated with the sodium fluoride solution for 30 days, and subsequently washed in water for 6 days, the reversion did not occur in all cases.

In any case it is necessary to be guarded about drawing any conclusions when comparing the effect of the topical application of such high concentrations with that of a fluoridated domestic water supply at a dilution of 1 p.p.m.

APPENDIX 9

STATEMENTS ON FLUORIDATION POLICY AND ITS POSSIBLE HAZARDS

Statement by the Council on Pharmacy and Chemistry and Council on Foods and Nutrition, American Medical Association (J. Amer. Medical Assoc. 1951, **147,** 1359).

Fluoridation of Water Supplies

The Council on Pharmacy and Chemistry and the Council on Foods and Nutrition have been requested to state their opinion regarding the safety of fluoridation of water supplies, a procedure which has now been adopted by more than 140 cities.

The Councils are unaware of any evidence that fluoridation of community water supplies up to a concentration of one part per million would lead to structural changes in the bones or to an increase in the incidence of fractures. The only difficulty so far revealed is a possible increase in mottling of the tooth enamel. The available evidence based on thousands of observations indicates that the incidence of mottling of the enamel in children who drink water containing fluoride up to a concentration of one part in a million is minimal and detectable only by careful dental examination. It occurs only in a small percentage of children and is so slight as not to present a problem from the point of view of appearance or strength of the teeth. Evidence of toxicity other than the effect on enamel has not been reported in communities where the water supply has several times this concentration. After considering the evidence available at this time, the Councils believe that the use of drinking water containing up to one part per million of fluoride is safe. However, the use of products which are naturally high in fluoride contents, such as bone meal tablets, or of lozenges, dentifrices, or chewing gum, to which fluoride has been added, should be avoided where the drinking water has been fluoridated. In places where children are subjected to warm temperatures and consequently drink large amounts of water, a lower concentration of fluoride may be necessary to avoid mottling of the teeth.

Extract from Report of the Ad Hoc Committee on Fluoridation of Water Supplies, November, 1951. United States National Research Council (Division of Medical Sciences).

There is an extensive literature on the pharmacology and toxicology of fluorine and its compounds. This has been reviewed by several authors (McClure, 1946; Cox and Hodge, 1950; Heyroth, 1951; Smith, 1951). Only those parts of it which deal with the cumulative action of fluorides are pertinent to the question of the safety of fluoridation. Chronic fluoride intoxication characterized by bone, joint and other tissue changes has been the cause of impaired skeletal function in Danish workmen exposed to fluoride dusts as an occupational hazard (Roholm, 1937). The presence of concentrations of fluorides in excess of 5 p.p.m. in water supplies in certain parts of the world has been reported to have given rise to a number of cases of chronic fluorosis, but the reported data are inadequate to establish the threshold concentration at which storage may be expected to occur to a potentially harmful extent. A radiologic survey at Bartlett, Texas, where the water contains 8 p.p.m., revealed an increased bone density not associated with functional impairment in 11 per cent. of those examined (Dean, 1944), but roentgenologic examinations of a limited number of persons living in areas where the water contained from 1·2 to 3 p.p.m., revealed no evidence of fluorosis (Hodges *et al*, 1941).

The fluoride concentrations in the urine of normal teen-age boys and young men closely approximate numerically those in their drinking water in regions where the water supplies contain from 0·2 to 4·7 p.p.m. (McClure, 1946). Fluorine balance studies furnish additional evidence that the human body eliminates the major portion of food- and water-borne fluoride when the quatities ingested do not exceed 4·0 to 5·0 mg. of fluoride daily (McClure, 1951), although the daily ingestion of 6·0 mg. led to demonstrable storage (Machle and Largent, 1943).

In the accumulated experience there is no evidence that the prolonged ingestion of drinking water with a mean concentration of fluorides below the level causing mottled enamel would have adverse physiological effects. Since the water supplies in various parts of the country contain considerably greater amounts, it is desirable that epidemiologic surveys of the incidence of chronic fluorosis be made in those regions, and that further balance studies be undertaken in order to establish the facts in regard to the storage of fluoride at moderately elevated levels of intake.

(References are included in the main bibliography.)

Extract from cyclostyled report presented to the Cincinnati Board of Health, 26th January, 1951, by Francis F. Heyroth, M.D., Kettering Laboratory in the Department of Preventive Medicine and Industrial Health, University of Cincinnati.

The Toxicity of Fluorides

The poisonous nature of sodium fluoride is a matter of common knowledge, since it is widely used as a roach poison. A few years ago in Pittsburgh, powdered sodium fluoride was accidentally used in place of baking powder in the kitchen of a large dining room with the result that 52 persons became ill and 11 of them died (17). However, the acute toxic effects of fluorides have little if any, bearing upon the hazards associated with the presence of fluoride to the extent of 1 p.p.m. in drinking water, and any hazards that may arise from the fluoridation of water will be those that result from the cumulative action of fluorides.

That a form of chronic systemic intoxication by fluoride (fluorosis) exists was demonstrated by the occurrence in Morocco of a disease of animals known as *darmous*, an affection of the teeth and mandibles of sheep and cattle, pastured on soil contaminated by dusts of phosphate deposits that were high in fluoride content (18). In volcanic regions of Iceland the disease also occurs and is there known as *gaddur*. In a more severe form, the condition has also occurred among animals in the vicinity of plants manufacturing superphosphate fertilisers or reducing aluminium from its ores. In some instances the condition simulates osteomalacia, and has been called fluorine cachexia. Mr. Largent of the Kettering Laboratory has investigated a case in which cattle had been exposed for five to nine years. Their gait was stiff-legged, their hock-joints were swollen, and lumps were palpable on the metatarsals, metacarpals, and ribs. Their teeth were irregularly worn, and their milk output was deficient. That they had stored excessive amounts of fluoride was demonstrated by the fact that eight months after removal from the area one of the cows continued to excrete daily amounts of fluoride greatly in excess of those ingested in the diet.

In order to learn something of the quantitative relationship between the daily intake, its duration, and the development of signs of poisoning, a great many experiments have been performed in which various fluoride-containing compounds have been incorporated at various levels in the diet of animals of several species. It is unnecessary to record here the detailed results of each of these. Dependent upon the level of the dietary intake experimental animals have shown various types of response. At levels above 0·09 per cent. of fluoride in the diet, rats die after a few days to a few months, following a period of inanition characterised by lethargy and weakness. When the food contains lesser amounts, but more than 0·03 per cent., an unhealthy appearance with lessened appetite and growth is usually noted. Levels greater than about 0·011 to 0·023 per cent. cause some inhibition of growth, the effect increasing rapidly with increasing fluoride content in the food.

Only at levels of dosage (15 to 30 mg. of fluoride per kg. of body weight of animal per day) high enough to produce impairment of growth have histological changes in the organs been reported by most who have searched for them.

Ingested fluoride is stored chiefly in the bones and teeth. Little is stored in most of the soft tissues with the possible exception of the thyroid gland.

In the Kettering Laboratory, two litter-mate dogs were given 65mg. of fluoride daily, one as sodium fluoride and the other as cryolite, over a period of 65 months. These amounts were equivalent to 3·2 to 4·1 mg. per kg. per day. No skeletal abnormalities could be detected by X-ray examinations, and no signs of illness appeared, except in the case of a third litter-mate which was given no fluoride. When the animals were killed no striking abnormalities could be found in their bones. Similar observations have been made by Biester, Greenwood and Nelson (19). On the other hand, the bones of rabbits fed for 47 to 92 days on a diet that contained from 245 to 763 p.p.m., or, in some cases, 2,980 p.p.m. (equivalent to from 12 to 50 mg. per kg. of body weight per day) showed numerous small areas of abnormal porosity, along with placques on the mandible, ranging from wart-like exostoses to extensive general deposits (20). There was also a bulging of the mandibles with a bulge on the medial surface slightly below the margin of the molars. None of these changes could be detected by radiological examinations during life. The fluoride content of these bones was about 17 times the normal value.

Chronic fluorosis has also been found to occur among men exposed in industry to dusts containing large amounts of fluorides. While investigating the incidence of tuberculosis and silicosis among Danish workers with cryolite, Møller and Gudjonsson (21) unexpectedly encountered an increased density in the X-rays of the bones of 30 of 78 of these men. The condition was studied thoroughly by Roholm (22). Two cases are recorded in the U.S. medical literature, one being that a 58-year old man who had been exposed for 30 years to sodium fluoride as a dust (23). The other was that of a man who had had 18 years of exposure to rock phosphate dust (24). The latter, who was in a hospital because of luetic aortitis, had exhibited no arthritic symptoms, but careful examination revealed some slight limitation of motion of the lower spine. The other had complained only of fatigue and headaches. Members of the staff of the Kettering Laboratory have examined the X-rays of a large number of men long employed in three factories in which they were exposed to considerable amounts of both hydrogen fluoride vapour and fluoride-containing dusts and have found a considerable number of cases of fluorosis.

The X-rays showed as intitial changes an abnormal density with the trabeculae increased, thickened and blurred. This appeared in all bones, but especially the vertebral column and pelvis. Spicule formation was sometimes seen at the muscle attachments which, like the spinal ligaments, were sometimes calcified. In one of the Danish cases, ankylotic changes had progressed to a degree which caused a very severe impairment of function. In the United States no pain or discomfort was found in association with the development of the bony changes, which occurred very gradually, and the condition when slight had no effect on the productivity of the worker or on his life expectancy. Of Roholm's (22) patients, 53 per cent. suffered nausea and loss of appetite, 46 per cent. had shortness of breath, and 28 per cent. had localised rheumatic pains. Some were anaemic, and it has been suggested that this may have been due to the encroachment of the bone upon the marrow cavity. There is no evidence that disability has ever preceded the development of changes detectable by radiographic means.

Numerous cases of human skeletal fluorosis attributed to an unduly high content of fluoride in the drinking water have been reported to have occurred in several parts of the world. At Yunnan, in China, four or five cases have been described involving elderly persons who drank water containing 5·9, 6·3 or 13·1 p.p.m. Malnutrition may have been a contributing factor (25). Systemic poisoning has been found by Ockerse (5) in South Africa where the fluoride content in the water is often extremely high. Six natives exposed for 19 years to water with 11·78 p.p.m. had characteristic X-ray changes and stiffness of the lumbar, thoracic, and cervical regions, while 2 years of exposure to 9·3 p.p.m. caused detectable changes in the bones of a European. A large number of cases have been reported to have occurred on the Madras Presidency in India, where the water has from 2 to 10 p.p.m., but the reports are difficult to evaluate, because of the lack of control observations in other fluoride-low areas or because malnutrition was prevalent, or because many of the diagnoses were made without the evidence afforded by X-rays. Furthermore, the high temperatures in the region may have increased the daily intake of water.

A series of at least 9 cases has been reported to have occurred in the Argentine Republic (26). In one, death was due to uremia, and the bone ash was found to contain 0·97 per cent. of fluoride. There is much uncertainty as to the fluoride content of the water consumed by the affected persons. In many areas in the Argentine Republic it exceeds 2 p.p.m., and in one, it was known to have been 16 p.p.m.

In the United States only one case has been attributed to the fluoride content of the drinking water (27). It was that of a 22-year-old soldier who had lived most of his life in several regions of high fluoride content. From birth he lived for 7 years in a region where the fluoride content of the water was 12 p.p.m. Subsequently, he lived for 2 years where it was 5·7 p.p.m., and then for 7 years where it was 4·4 p.p.m. After a break of 2 years, during which he lived where the content was low, he again spent 7 years in the region where it was 4·4 p.p.m. The condition was found incidentally during a stay in a hospital following a minor operation. Anaemia and severe kidney disease were also present. In a test for kidney impairment, no dye was excreted in 2 hours. Uremia developed and the patient died. At necropsy, the findings were chronic bilateral pyelonephritis, acute right pyonephrosis, and bilateral hydroureter with ureteritis. In this case, no stiffness of the spine was present, and the question was raised as to whether the kidney disease had so interfered with the normal excretory mechanism for fluorides as to make the rate of storage abnormally great. (Rabbits suffering temporarily from experimentally induced uranium nephritis excrete greatly reduced quantities of fluoride in their urine during the period of acute intoxication, while being maintained on a high intake of fluoride in their drinking water (28). A somewhat similar case (26) is that of a young woman in Argentina with bilateral uretero-hydronephrosis and complete extrophy of the bladder, who died at the age of 23 after having exhibited the radiologic signs of fluorosis. Knowledge of the fluoride content of the water she ingested is lacking.

The cases of chronic fluorosis ascribed in the literature to the presence of fluoride in the water provide little reliable information as to the threshold value at which harmful storage may be expected to begin. In 1940, McClure (29) was of the opinion that water containing from 3 to 16 p.p.m. could not be regarded as safe until further epidemiologic evidence had been provided.

Evidence bearing on the Safety of Fluoridation

About 1946, workers of the U.S. Public Health Service expressed the opinion that fluoridation should not be undertaken until epidemiologic data comparable in reliability to those secured in regard to the incidence of caries and mottled enamel had been obtained on the health of old people who had lived for long periods in areas of known high and low fluoride concentrations in the drinking water. Unfortunately, such data have not been provided, except to a very limited extent. Hodges (30) found no X-ray evidence of fluorosis in 86 subjects ranging in age from 7·5 to 71 years who had been exposed, in some instances, so long as 61 years to the water of Kempton, Illinois, which contains from 1·2 to 3 p.p.m. He also examined 31 subjects who had had from 18 to 68 years of exposure to the water of Bureau, Illinois, which contains 2·5 p.p.m., and again found no generalised skeletal sclerosis. However, in testimony offered at the Food Residue Tolerance Hearings on Cryolite in 1944, Dean stated that a radiologic survey at Bartlett, Texas, where the water contains 8 p.p.m. revealed an incidence of 11 per cent. of cases having increased bone density, but no impairment of function. This survey does not appear to have been published.

McClure (7) found that the number of fractures reported by 1450 high-school boys and by 1700 draftees bore no relation to the fluoride content of the water of the areas in which they had lived. Furthermore, careful pediatric observations, including X-ray studies, on the children in the Newburgh experiment have failed thus far to demonstrate any deviation from normal skeletal maturation and no increases in radiologic density (31). However, data obtained on children or young adults have little bearing upon the problem of chronic fluorosis in the aged.

The incidence of kidney disease, at least in young men, does not appear to be greater in areas where the water has a moderately elevated fluoride content. In 101 samples of the urine of young men living in areas in which the water had 2·0 to 5·0 p.p.m., no more instances of occult blood, albumin or sugar were found than in 394 specimens from men living in areas with 0·0 to 0·3 p.p.m. (7).

Studies of the metabolic fate and storage of ingested fluorides offer further evidence as to the safety of fluoridation. On the assumption that 1200 to 1600 c.c. of water represents the average daily intake of water in temperate climates, the daily intake of fluoride in water with 1 p.p.m. would be 1·2 to 1·6 mg. Children up to the age of 12 might ingest 0·8 to 1·1 mg. When the water contains 4 to 5 p.p.m., the daily intake by adults might be 4·8 to 8·0 m.g., or 0·07 to 0·12 mg. per kg., and Biester, Greenwood and Nelson (19) estimated that the intake in areas where the water contained 8 to 10 p.p.m. might be so much as 0·45 mg. per kg. It has been estimated that the affected Danish cryolite workers may have ingested 25 to 30 mg. daily for long periods (22).

From brief balance studies upon human subjects, McClure (7) was of the opinion that when the amount ingested daily does not exceed 4 or 5 mg., the excretion of fluoride in the urine and perspiration is great enough to prevent the storage of significant amounts in the skeletal tissues. However, the results of balance studies on human subjects in the Kettering Laboratory suggest that storage may begin at a somewhat lower level than that found by McClure. That considerable storage occurred when 6 mg. in addition to that from dietary sources was ingested daily for 183 days was shown by the fact that during the succeeding 11 weeks the excretions contained about 50 per cent. more than was ingested in the normal diet. The observations on one of the subjects indicated that during a period of 3 years more than 2 g. had been stored in his bones. Some of our more recent observations indicate that the efficiency with which fluoride is eliminated may increase when the ingestion of abnormal amounts is continued for long periods.*

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* See note on page 59.

Data on the urinary excretion of fluoride by exposed workers offer the most satisfactory evidence for the safety of fluoridation. Urinary concentrations associated with various degrees of fluorosis and those which appear to be safe may with some assurance be compared with those encountered among large groups of persons living in areas where the water contains known fluoride concentrations.

The average urinary concentration found by Roholm (22) among cryolite workers was 16 p.p.m., the range being 2·4 to 43·4 p.p.m in proportion to the severity of exposure. In our industrial surveys, questionable fluorosis was found in some men with urinary concentrations of 3·8 mg. per litre†, but others with no signs of fluorosis gave an average concentration of 4·8 p.p.m. The urine of men with moderate fluorosis had, on the average, 5·5 mg. per litre, while that of those with severe fluorosis averaged 6·8 mg. per litre.

McClure (7) made over 1900 determinations of the urinary fluoride concentrations of high-school boys and draftees and found that when the water contained from 0·2 p.p.m. to 4·7 p.p.m. the urinary fluoride concentration closely approximated that in the drinking water numerically. When the drinking water contained less than 0·2 p.p.m., most of the urinary fluoride was derived from that contained in the diet. No observations were made by McClure on persons living in areas with water that contained more than 4·7 p.p.m., but Machle (33) found some evidence that where the water contained 8·1 p.p.m., the urinary concentration tended to be 6·4 mg. per litre or somewhat less than that which would have been predicted by extrapolation from McClure's data. Prior to fluoridation of the water at Grand Rapids (0·1 p.p.m.) 264 samples of urine from 12–17 year-old boys contained, on the average, 0·2 p.p.m. One month after fluoridation to 1 p.p.m., 315 samples contained 0·65 p.p.m.

From these data it appears extremely unlikely that the presence of 1 p.p.m. in the water would give rise to urinary concentrations which have been associated with detectable changes of the bones in industrial workers.

Additional evidence is afforded by the results of fluoride determinations in the bones of a few persons known to have had chronic fluorosis. According to Roholm (22), normal human bones contain on the average 0·09 per cent. of fluoride (range 0·06 to 0·21 per cent.), while 2 of his cases of fluorosis had bones with 0·65 to 0·72 per cent. The long bones of the case of Wolff and Kerr (34), who had non-disabling fluorosis, contained 0·18 to 0·29 per cent., while the ribs, sternum, and vertebra had from 0·56 to 0·70 per cent. They concluded that the skeletal tolerance was of the order of 0·2 to 0·3 per cent. of fluoride.

The complete retention of all the fluoride ingested in the form of drinking water containing 1 p.p.m.—most of this would be excreted—would result in the storage of about 0·58 g. per year, and in the course of 80 years, the total amount stored might be 47 g. This represents about 1·0 per cent. of the weight of a human skeleton, a value only 3 to 5 times the skeletal tolerance of 0·2 to 0·3 per cent. estimated from the data of Wolff and Kerr. This crude calculation is in rough agreement with the other lines of evidence.

The question of the effect of water containing 1 p.p.m. upon patients with severe impairment of kidney function requires special consideration in view of the fact that radiologic evidence of chronic fluorosis has been found in 2 persons with severe kidney disease who died at the early ages of 22 and 23 years, respectively. It is very likely that the life expectancy of persons with a degree of functional impairment of the kidney great enough to increase significantly the rate of storage of fluoride would be too short for skeletal damage involving functional impairment to become manifest. However, this question has not been adequately studied. It is highly desirable that in a region where the water

† mg. per litre=p.p.m.

contains 1 p.p.m., determinations of the ability of the kidney to excrete fluorides be made on large numbers of hospitalized patients with chronic kidney disease of various types and degrees of severity, and that the results be compared with those obtained upon healthy persons. In any event, the risk that such patients might be harmed by the fluoridation of water appears to be small in comparison with the dental benefits to be obtained. It should be possible for physicians who have the care of patients with severe chronic kidney disease to recommend the use of imported fluoride-free water should this be necessary.

In general, consideration of the available evidence indicates that the risk to the public health from fluoridation of the water is negligible. Nevertheless, it is desirable to consider by what means any harmful effects of fluoridation might be detected in the population as a whole before the manifestations of chronic fluorosis had progressed to a disabling degree. Dental examinations among school children would certainly reveal the occurrence of mottled enamel long before any skeletal effects could be expected to become manifest. That persons who had migrated into the community after their enamel had calcified might develop fluorosis without exhibiting mottling is of little importance, because if the water were capable of so affecting them it would certainly cause mottling in the children. Determinations of the urinary fluoride concentrations at intervals of a few years might serve as an additional safeguard. There is some difference of opinion as to whether early bony changes would be detectable on the small films used in X-ray surveys for tuberculosis, but the radiologists at the Health Centre would, in all likelihood, be able to detect them on large films.

The possibility that there may be other sources of fluoride than the water supply must be considered. Industries in which actual cases of disabling fluorosis have occurred do not exist in Cincinnati at present, although the lesser hazards encountered in magnesium founding and in the handling of sodium fluoride may exist to some extent. It seems incumbent upon industries possessed of such hazards to eliminate them by bringing their fluoride exposure within currently accepted safe limits.

Fruits and vegetables may be contaminated with residual fluoride dusts following the use of fluoride-containing insecticides in orchards and fields. The control of such fruits and vegetables as may enter interstate commerce lies in the province of the U.S. Food and Drug Administration, which in the near future will set a tolerance limit compatible with the presence of 1 p.p.m. in the drinking water.

In cities where fluoridation of the water has been introduced, there have been no complaints of significance from industrial users of the water, and no harm to lawns or plants has been seen. The taste of the water is unaffected. In so far as fluoride contributes nothing to the value of water used for purposes other than drinking, an element of wastefulness is involved. It is perhaps for this reason that the American Water Works Association believes that the cost of fluoridation should be covered by funds allocated by municipalities for the promotion of health rather than be made a charge against the user.

Some have objected to fluoridation on the ground that it represents " involuntary mass medication ". This term is not an appropriate one, for no claims are made that fluoridation of water exerts any therapeutic action. It cannot bring about a repair of the damage wrought by caries. It might be called mass prophylaxis, but even this is not an entirely suitable term since it might imply, to some minds at least, that some foreign substance is being added to the water. Actually all that is proposed is that the concentration of a substance naturally present in the water supply be increased to a level which has been demonstrated to be optimal for dental health.

The Attorney-General of the State of Michigan has given an opinion (6) that, once authorities responsible for the public health have approved fluoridation, there would be no legal method by which an individual not injured by it, but nonsympathetic to it, could prevent it. As to liability, he states that it would involve no change in the responsibility of the utility. Negligence in performing the fluoridation which results in damage would have to be shown in order to establish liability. Either under- or over-fluoridation might be construed as negligence.

Should fluoridation be undertaken, adequate precautions should be taken to ensure the safety of employees at the Water Works who may be engaged in the handling of the fluorides. The charging of the hoppers is a dusty operation, and while so engaged the operators should wear suitable toxic dust respirators. Dust collectors consisting of bag filters operating under positive air pressure vented to the outside have been recommended. Some observations should be made to learn whether the contamination of the air in the neighbourhood exceeds safe limits and, if so, methods for preventing it should be adopted.

Determinations of the fluoride content of the air in the Sheboygan plant during actual operation have revealed that the only place in which amounts in excess of those regarded as safe were found was in the breathing zone of the operator while emptying a barrel of sodium fluoride into the hopper. The urinary fluoride concentrations of the operators were not significantly higher than those of unexposed employees.

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* *Note by British Mission.* (See p. 55.)

A recent report by Largent (A.M.A. Arch. Indust. Hyg. Occup. Med. 1952 **6,** 43) describes balance experiments on 4 human subjects. The following is part of his summary:

> "By means of balance experiments on human subjects, indirect evidence has been obtained that fluoride may be stored in human tissues over periods of months or years during which as little as 3 mg., as NaF., was ingested daily.
>
> Corresponding evidence of storage of fluoride was obtained in a resident, aged 20, of Amarillo, Texas, where the drinking water contains fluoride in concentrations varying from 2·4 to 4·4 p.p.m."

These biochemical findings were not associated with any radiological or other evidence of bone abnormalities, and there is at present no reason to believe that such storage of fluoride leads to undesirable physiological effects.

APPENDIX 10

THE ASSESSMENT OF DOSAGE FOR FLUORIDATION IN THE UNITED KINGDOM

When the total consumption of fluorides is about 1·5 mg. daily, urinary excretion accounts for at least 90 per cent. of the intake (McClure, 1951). In other words, measurement of urinary excretion may be a useful method of assessing the total intake of fluorine from water and other sources. British food habits differ appreciably from those prevalent in America and the quantity of drinking water consumed by individuals may well be less than is usual in America. Again, tea drinking is a habit in this country and there is reason to believe that it is not confined to adults. Many teas are rich in fluoride and recent determinations made in the Government Laboratory indicate that a concentration of 1·0 p.p.m. in a cup of tea is not unusual, so that in this country fluorides may already be administered to children in significant amounts.

In assessing the appropriate dosage of fluorides for dental caries control in the United Kingdom, the best guide appears to be the total intake figures given by McClure (1943). On this basis, the appropriate total intake of children aged one to 12 years is of the order of 0·05 mg. per Kg. body weight (taking a figure approximately midway between the extreme limits of intake quoted by McClure).

The available evidence suggests that the level of fluoridation of water appropriate for the United Kingdom will not differ greatly from that which has already been adopted in the United States.

APPENDIX 11

Mortality Experience in Illinois State, in Relation to Fluoride Content of Water

Copy of letter dated 20th November, 1951, from the Chief Statistician, U.S. Government Bureau of Statistics to the Deputy Director, Bureau of Dental Health, Illinois State.

In compliance with your request there are presented herewith mortality data for Aurora, Galesburg, Joliet, and Kewanee, all cities with natural fluorine present in the public water supply, and similar data for 18 other Illinois cities that do not have fluoridated water supplies.

Crude death rates were computed for the 22 cities mentioned above. The rates were computed for four cause of death classifications; All causes, Heart disease, Cancer, and Nephritis. In order to eliminate some of the variability from year to year which is inherently present when dealing with small areas, the rates were averaged for each class, city and cause of death. (The group, all causes, covered an 11 year period, 1940-50, and the three selected cause groups covered a 10 year period 1940-1949.)

The 22 cities have been grouped into three population classes based on the 1st April, 1950, census enumeration; 15,000 to 24,999, 25,000 to 39,999, and over 40,000 inhabitants. Each of the population groups has been placed in a separate table showing each city's average crude death rate for each of the four cause of death classifications. In addition, the average rates for each population group and the State averages have been included for each cause of death.

While a conclusive analysis cannot be made from these rates, because they are not directly comparable, certain self-evident factors which are discernible in the tables may be summarised as follows:—

A. Aurora and Joliet, Illinois

The cities of Aurora and Joliet have approximately the same total population, (although the sex and age composition may be quite different) and are listed in Table A with six other Illinois cities which have a 1950 population count of more than 40,000.

Joliet shows a higher mortality rate than all the other cities listed except for Quincy; however, that of Aurora, which also has natural fluoride present in the city water supply, is indicated to be approximately the same as the four average mortality rates computed both for the eight-city group and for the State of Illinois. Although Joliet's general death rate is noticeably higher than the average of both the eight-city group, and of the State, certainly Quincy's is noticeably greater also. If it is to be assumed that the fluorine present in Joliet's Water system is responsible for the indicated higher mortality rates then two other pertinent points must be examined.

1. Aurora, with natural fluoridation, shows no deviation from the norm; either from the average of the eight cities of 40,000 population and over, or from the State as a whole.

2. Quincy, with no fluoridation, has a higher general mortality than any of the eight cities including Joliet.

It is obvious that the population of both Joliet, and Quincy, taken as a whole, face a greater risk of dying than in the other six cities; however, to attribute Joliet's death rate to fluoridated water would not be a valid conclusion, in view of the fact that Aurora shows no greater mortality risk than average. It is far more probable that both Quincy and Joliet have a higher crude mortality rate due to the composition of the population; i.e., sex, race, age, socio-economic level, predominant occupation, etc.

TABLE A.—AVERAGE MORTALITY RATES 1940–1950 FOR EIGHT CITIES OF 40,000 OR MORE POPULATION AS ENUMERATED APRIL 1, 1950, BY U.S. CENSUS.

	1950 Population Census Enumer-ation	Average Crude Death Rate*				Parts per Million Fluoride Content
		All Causes (1940–1950)	Heart (1940–1949)	Cancer (1940–1949)	Nephritis (1940–1949)	
Aurora†	50,576	11·7	3·9	1·7	0·6	1·2
Joliet†	51,601	14·2	4·3	2·2	1·1	1·1
Quincy	41,450	14·5	5·5	1·8	1·3	0·1
Berwyn	51,280	9·0	3·1	1·7	0·7	0·0
Oak Park	63,529	10·6	4·1	1·7	0·9	0·0
Decatur	66,269	11·1	3·6	1·6	0·7	0·2
Springfield	81,628	12·6	3·9	1·8	1·0	0·1
Peoria	111,856	11·2	3·7	1·6	0·8	0·3
Eight-City Average		11·5	4·0	1·6	0·9	
State Average ...		11·2	3·9	1·6	0·8	

TABLE B.—AVERAGE MORTALITY RATES 1940–1950 FOR SEVEN CITIES OF 25,000 TO 39,999 POPULATION AS ENUMERATED APRIL 1, 1950, BY U.S. CENSUS.

Galesburg† ...	31,425	13·2	4·7	1·7	0·9	2·0
Kankakee	25,856	11·0	4·0	1·7	0·6	0·2
Alton	32,550	11·1	3·2	1·4	0·8	0·3
Belleville	32,721	11·8	3·7	1·6	0·9	0·2
Bloomington ...	34,163	13·6	5·0	1·8	0·8	0·1
Moline	37,397	10·3	3·6	1·5	0·6	0·1
Danville	37,864	14·1	4·6	2·0	1·2	0·2
Seven-City Average		12·1	4·1	1·7	0·8	
State Average ...		11·2	3·9	1·6	0·8	

TABLE C.—AVERAGE MORTALITY RATES 1940–1950 FOR SEVEN CITIES OF 15,000 TO 24,999 POPULATION AS ENUMERATED APRIL 1, 1950, BY U.S. CENSUS.

Kewanee†	16,821	12·6	4·0	1·8	1·4	0·8
Centralia	13,863	12·2	3·5	1·6	0·8	0·4
Mt. Vernon ...	15,600	12·3	3·5	1·4	0·6	0·3
Streator	16,469	12·4	4·0	1·8	0·8	0·3
Mattoon	17,547	12·7	4·0	1·7	1·2	0·2
Blue Island ...	17,622	10·5	3·7	1·6	0·9	0·0
Freeport	22,467	13·3	4·6	2·0	1·1	0·0
Seven-City Average		12·3	3·9	1·7	1·0	
State Average ...		11·2	3·9	1·6	0·8	

* Rates per 1,000 estimated mid-year population; averaged over an eleven year period for all causes and a ten year period for selected causes.

† Indicates cities with natural fluoride present in the public water supply.

B. Galesburg, Illinois

Mortality rate for Galesburg which has natural fluorine in its water supply, is listed in Table B with six other cities ranging in population size from 25,856 to 37,864. This city shows a slightly higher mortality rate than that for the State as a whole, and for the average of this group of cities. However, it will be noted that Bloomington and Danville have death rates which are greater than those for Galesburg. Of this seven city group; three cities are slightly higher than average, two approximately normal, and two show slightly better mortality rates than the average.

C. Kewanee, Illinois

Kewanee, a city of 16,821, with natural fluoride, and six other cities with populations within the range of 13,863 to 22,467, are listed in Table C, showing the average death rates for the period 1940–1950. Mortality for Kewanee is generally somewhat higher than for the State as a whole, but is almost identical with the average rates for the seven-city group. In fact, six of the seven cities listed seem to have no real statistical difference existing among them (only the crude rate for Blue Island, all causes, is noticeably lower than the other six cities).

It is unfortunate that no sex and age distributions are available for these cities in order that adjusted death rates might be computed. Certainly such rates would offer a more valid method of comparing the actual risk of death which exists in these communities. The crude rates which have been computed do not offer any positive clue as to why there is a difference between mortality risks existing in cities with or without fluorine in their water; however, there is no valid evidence present herein to indicate that the presence of fluorine will increase the risk of death.

In order to establish adequately the true effect of fluoridated water on mortality, much more information would be needed on the living population to determine the specific mortality rates, and a great deal of research would be required to statistically evaluate the data.

The conclusions drawn herefrom are necessarily negative, but it is hoped that they may be of use to you. Under the prevailing circumstances, this report is the best available until additional information is available from the Census Bureau, and resources available for a detailed analysis.

APPENDIX 12

Fluorine Compounds and Methods of Usage

Fluorine Compounds—General

The most common fluoridating compounds at present used in America are sodium fluoride and sodium silicofluoride and these two salts differ quite markedly in their solubilities in water.

McClure (1950) states that "the physiological effects of different fluoride salts will depend on their absorbability from the intestinal tract". In drinking water when the concentration applied is of the order of 1·0 p.p.m. the effects of the differences in solubility of different fluorine compounds tend to disappear, and the readiness with which they yield fluoride ions is the chief factor governing their use as fluoridating agents for the prevention of dental caries.

In dilute aqueous solution the ionisation of sodium fluoride is simple, but that of sodium silicofluoride is somewhat more complicated. The following reaction has been put forward (Ryas and Slutskaye, 1940) to account for the presence of fluoride ions in dilute aqueous solutions:—

$$Na_2Si\,F_6 \longrightarrow 2\,Na^+ + Si\,F_6^{=}$$

$$2H_2O + Si\,F_6^{=} \longrightarrow 4H^+ + 6F^- + SiO_2$$

In experiments on rats (McClure, 1950) it was shown that there were no physiological differences between the actions of sodium fluoride and sodium silicofluoride administered in their drinking water. In an extension of this work (Zipkin and McClure, 1951) comparisons were made between sodium fluoride (NaF) sodium silicofluoride (Na_2SiF_6) potassium perfluorophosphate (KPF_6) sodium monofluorophosphate (Na_2PO_3F), sodium monofluoroacetate ($CH_2FCOONa$) and sodium perfluoroacetate (CF_3 COONa) and it was found that KPF_6, and CF_3COONa appeared to be physiologically inert. The suggestion was made that "there seems to be a relation of 'saturation' of fluorine in complex fluorides (perfluoro compounds) to the physiological stability of fluorine". Thus the perfluoro compounds are not metabolised to inorganic fluorides whereas the evidence so far available shows that the fluorides in use produce fluoride ions in aqueous solution, and function as caries inhibitors. It also happens that the perfluoro compounds are difficult to determine chemically, sodium perfluoroacetate in particular not being very amenable to the Willard and Winter perchloric acid distillation method.

Although work has been carried out on the availability of fluoride from different compounds, that most commonly used in the United States is sodium fluoride. However, now that the cheaper sodium silicofluoride is becoming more readily procurable a number of water undertakings are using this chemical and others have changed over from the use of sodium fluoride in favour of the silicofluoride. The use of hydrofluosilicic acid is growing in popularity and some water engineers are quite enthusiastic about the ease of its application in waterworks practice. All are in agreement that hydrofluoric acid, although applied successfully at Madison, Wisconsin, is too dangerous to handle and presents problems in feeding equipment which do not arise with any of the other compounds available. It is understood that its use will not be contemplated in any future fluoridation scheme.

The use of calcium fluoride has been considered because it is the cheapest source of fluoride. Its low solubility 0·004 g. per 100 ml. at 25° C however has ruled it out as it would be difficult to feed. Maier (1950) suggests that

PLATE 1
Solution feed of sodium fluoride. Proportioneer feeder.
Crestwood, Wis.

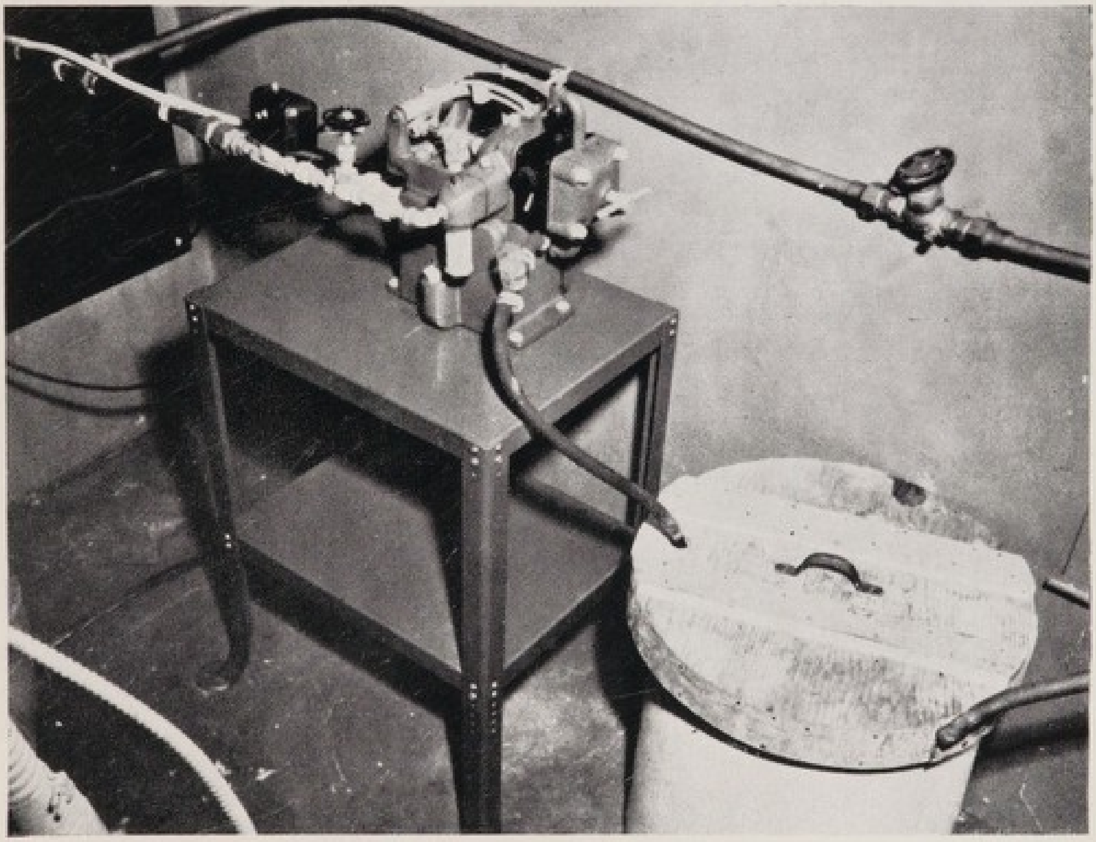


PLATE 2
Solution feed of sodium fluoride. Wallace and Tiernan feeder.
Middleton, Wis.

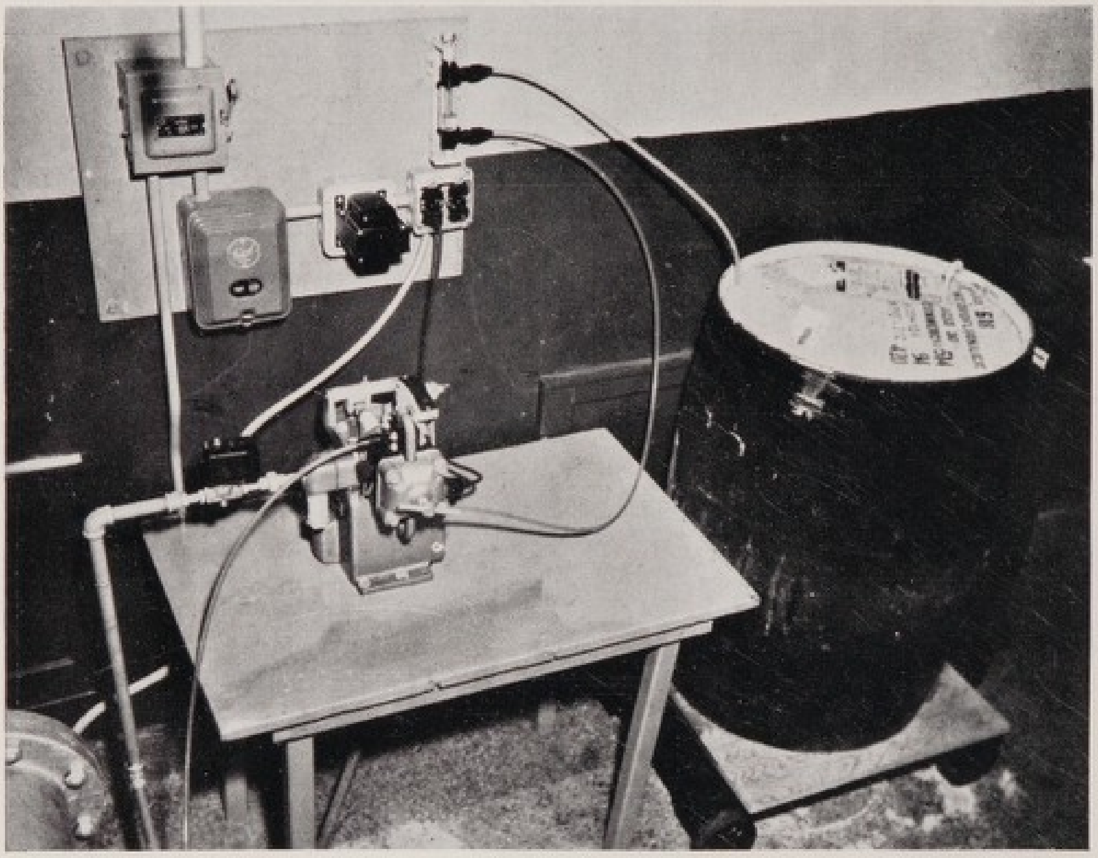


PLATE 3
Liquid feed of hydrofluosilicic acid. Wallace and Tiernan feeder.
Menomonee Falls, Wis.

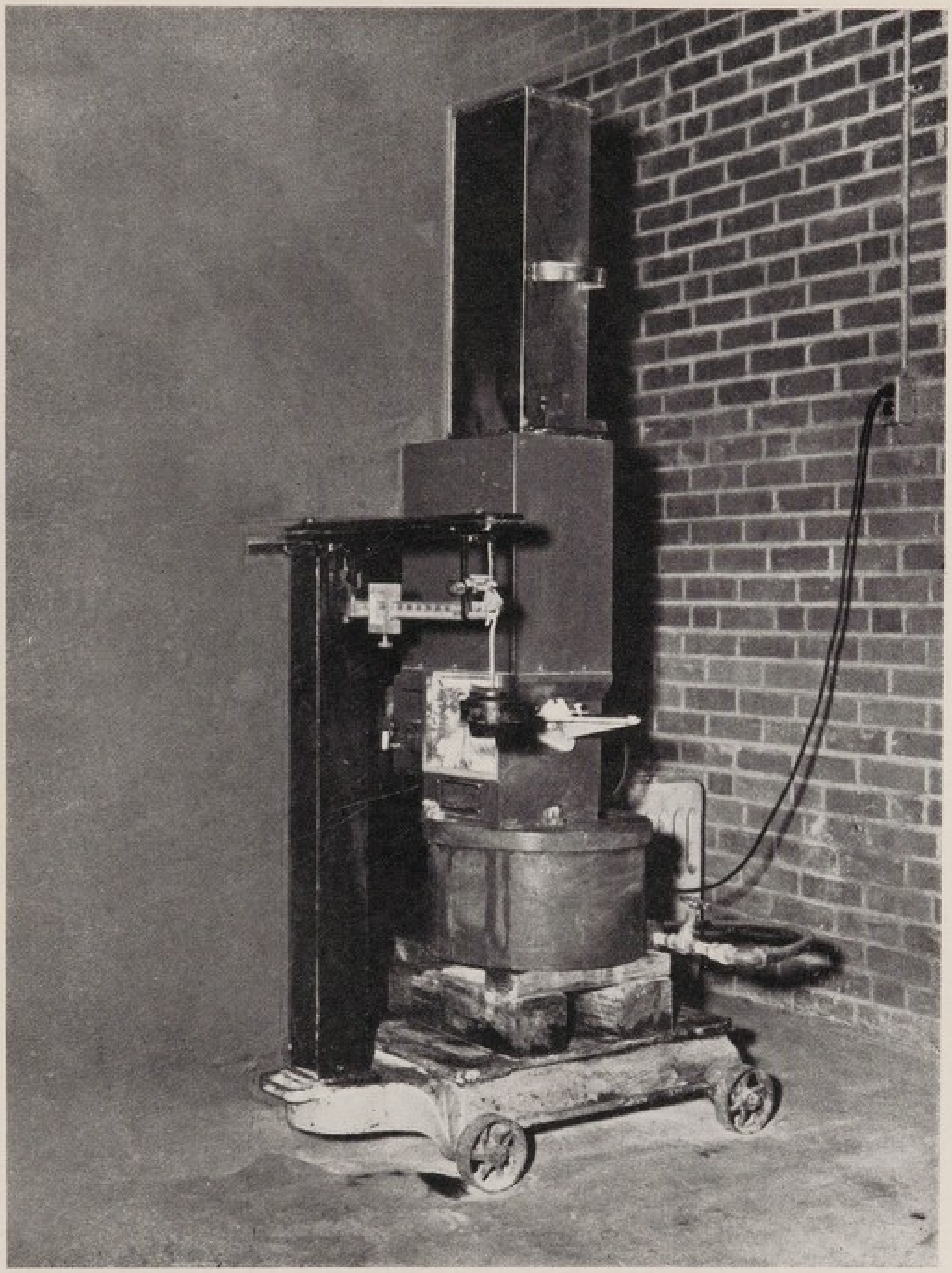


PLATE 4

Volumetric feed of sodium fluoride (Wallace and Tiernan) fitted with removable extension to hopper. Marshall, Texas.

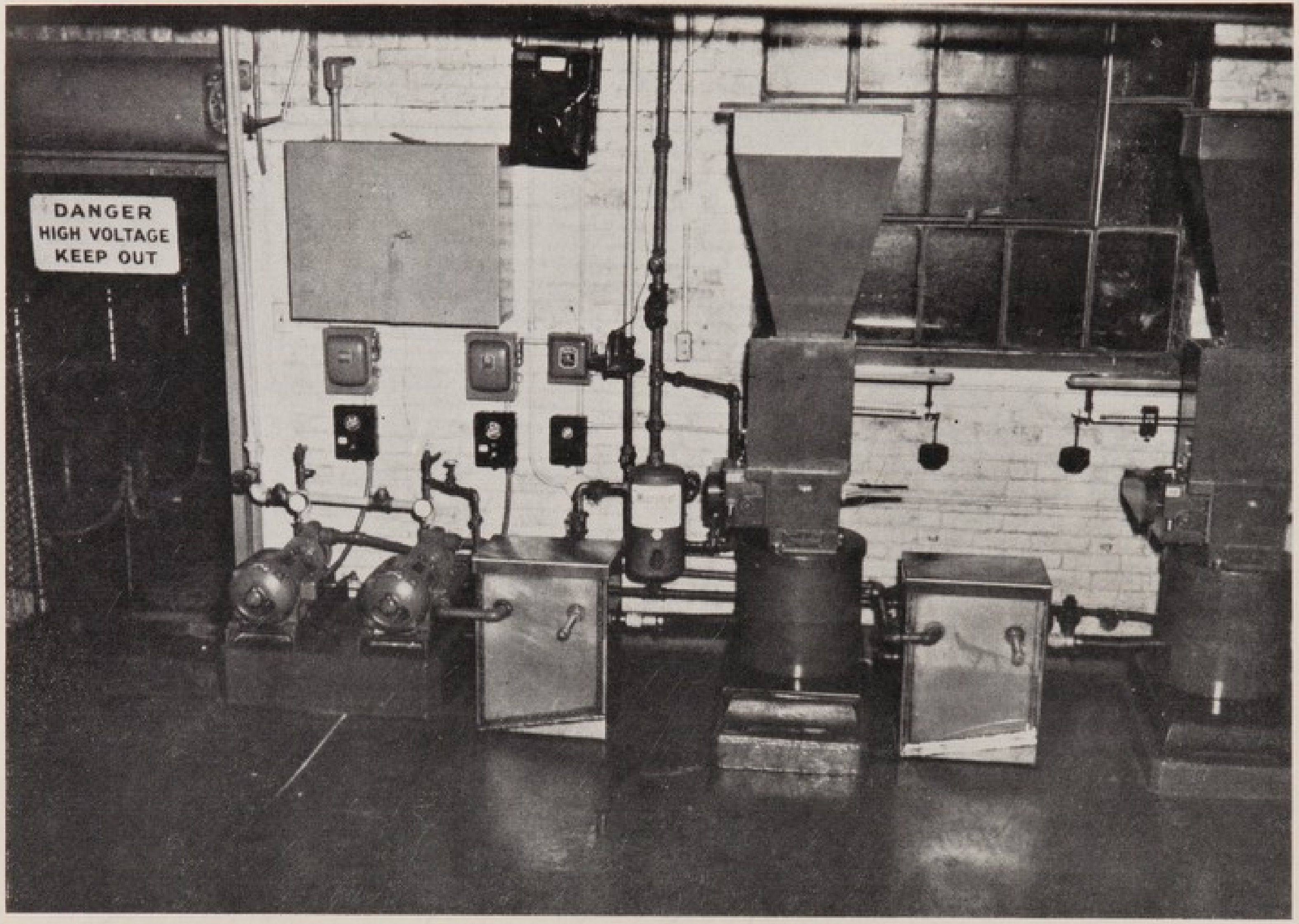
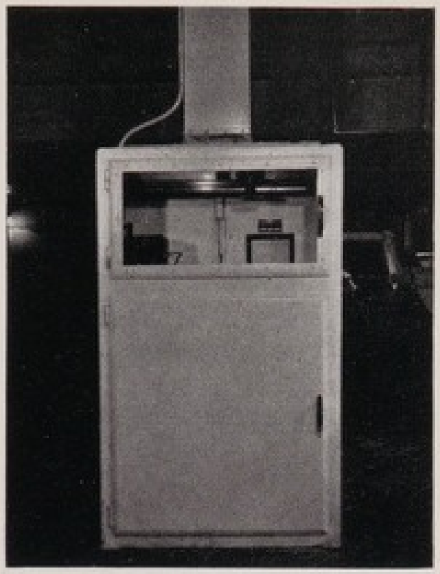


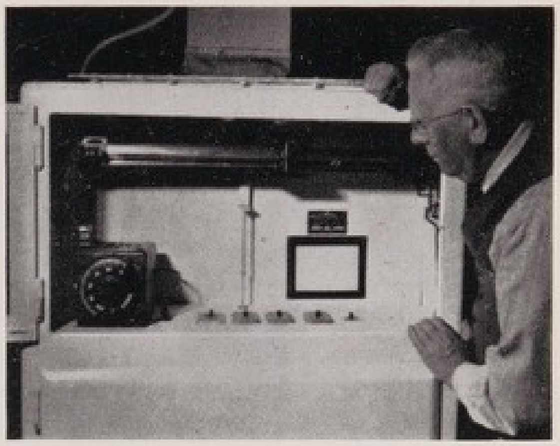
PLATE 5

Volumetric feed of sodium silico-fluoride (Wallace and Tiernan) fitted with additional solution tanks. Watertown, Wis.



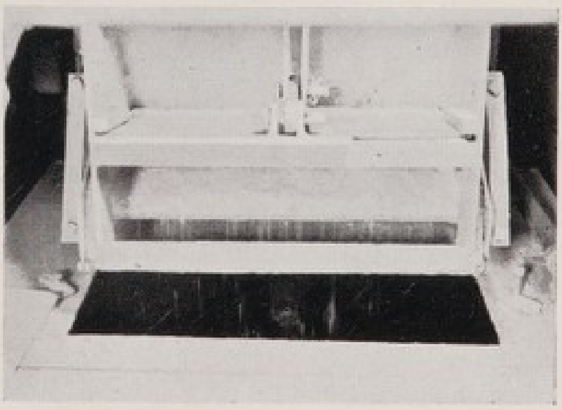
The complete feeder.

Filling the hopper, situated on the floor above the feeder. Dust extractor (Omega) is fitted.



The beam and counterpoise.

The bottom of the hopper and the solution tank.



The chemical falling into the solution tank.

PLATE 6

Grand Rapids. Gravimetric feed of Sodium Fluoride (Omega).

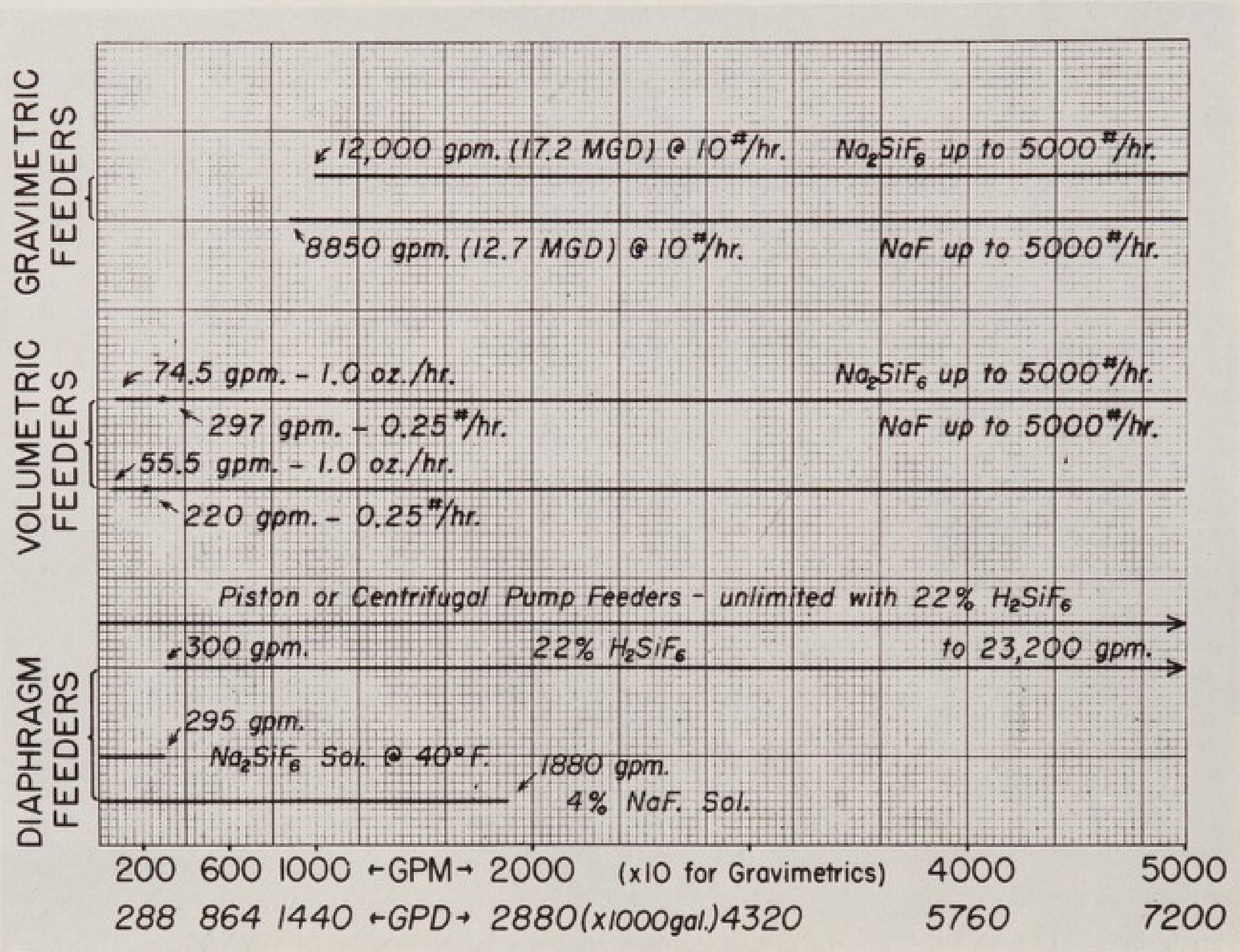


PLATE 7

Chart showing potentialities of different kinds of feeder (Maier 1952).

it might be found to be suitable if fed directly to the water, in a large water supply plant.

It has been reported that stannous fluoride is more effective than either sodium fluoride or sodium silicofluoride in preventing dental caries.

This salt is not used at present in America and the following opinion has been expressed by Dean (1952) about new fluoridation agents in general; "Reliable evidence must be available (as it is in the case of sodium fluoride occurring naturally in public water supplies) that the proposed new fluoridating agent will not be injurious to health even when ingested as part of the daily diet over a period of many years."

Fluoride Compounds used in the United States

The four compounds in use in the United States are given in Table I and a short account of their properties is also included. The quantities in lb. of chemical required to add 1 p.p.m. to one million gallons (imperial) of water can be used as basic figures for computing the size of feeder and solution tank.

TABLE I

FLUORIDE COMPOUNDS AND THEIR CHARACTERISTICS

Chemical	Formula	Purity of Commercial Chemical per cent.	Fluorine in Commercial Chemical per cent.	Solubility at 25° C g./100 ml.	1 p.p.m. F Treatment of 1 million gal. (imperial) Quantity lb.	Cost per lb. Cents.	Cost per lb. of commercially available F Cents.
Sodium Fluoride (90 per cent.)	NaF	94	42·5	4·05	—	10·5	24·8
Sodium Fluoride (98 per cent.)	NaF	98	44·4	4·05	22·5	11·5	26·0
Sodium Silicofluoride ...	Na_2SiF_6	98·8	60·0	0·762	16·7	3·23	5·4
Hydrofluosilicic acid	H_2SiF_6	30·0	23·7	liquid	42·2*	5·0	21·0
Hydrofluoric acid	HF	60·0	57·0	liquid	17·6†	13·5	23·7

* Specific gravity 1·26.
† Specific gravity 1·24.

Sodium Fluoride

This is a white substance (the commercial compound is tinted Nile blue for identification), odourless, non-hydroscopic and is available in America either powdered or in crystal form. The powdered form is available in several grades, containing 90 to 98 per cent. NaF by weight. The density of the material varies from 38 to 90 lb. per cubic foot. Usually the compound is a very fine powder but the heavy material is coarser and produces less dust when handled. The material commonly used has a density of 65 lb. per cubic foot. The solubility of sodium fluoride is relatively constant over a wide temperature range, being 4 per cent. by weight. The saturated solution has a pH about 6·5 and is not seriously corrosive.

Sodium Silicofluoride

This is a crystalline non-hygroscopic salt. It is available in two grades; the regular, weighing 72 lb. per cubic feet and the higher grade, weighing 55 lb. per cubic feet. Its solubility is low being between 0·43 per cent. at 32° F.

and 0·62 per cent. at 60° F. The saturated solution has a pH of about 3·5 and is corrosive. Recommended materials in connection with its use include plastic, rubber and nickel alloys particularly monel metal.

Hydrofluosilicic Acid

Commercial grades vary in strength, the most commonly used being about 30 per cent. This acid is a transparent, colourless, and slightly fuming liquid with a pungent odour. Hydrofluosilicic acid is corrosive to metals and necessitates the use of rubber or plastic materials for its conveyance.

The acid is not corrosive to skin or clothing and accidental contact or spillage of this compound has not caused any injury or discomfort. It decomposes into hydrofluoric acid (2HF) and silicon tetrafluoride (SiF_4). These decomposition products exist at the surface of strong solutions and the small concentration of HF may attack the glass above the solution level. For this reason sight gauges on the feed equipment made of glass are unsuitable and plastic material must be used.

The acid is generally shipped in rubber lined containers.

Flural

A new chemical "Flural" has recently been produced on pilot plant scale and is intended for use when both flocculation and fluoridation of a water is required. Its composition can be varied and the following are typical of the two grades of Flural now available in test quantities:—

	1	*2*
F. Content	16 per cent.	11 per cent.
Available Al_2O_3	21 per cent.	26 per cent.
Equivalent of filter Alum (lb.) ...	1·7	1·5
Ratio F : Al.	2 : 1	1 : 1
Insoluble matter	4 per cent.	1 per cent.
Water	18 per cent.	15 per cent.

It is claimed that "Flural" will be cheaper to use than alum and a fluoride and that there will be less danger of overdosing as fluoride above a level of 1 p.p.m. will be partially removed, presumably by the excess of alum which will also be present.

This substance is still in the experimental stage and although it has been tested by several authorities it is not being used at present.

Precautions recommended when handling fluorides

The American Waterworks Association (1950) has drawn up a specification for sodium fluoride, which defines required characteristics and limits the amount of impurities to be tolerated. Methods of testing and precautions to be taken in handling the material are also included. It states: "sodium fluoride dust is toxic. Men handling this material should wear protective clothing, respirators and goggles. They should be given detailed safety instructions. All equipment for handling sodium fluoride, such as storage bunkers, weigh hoppers and dry feed machines, should be provided with devices to keep the dust hazard at a minimum."

In America each State issues to each waterworks operator an instruction sheet detailing the precautions that must be observed in handling fluoride compounds. These include the following:—

1. Each operator should wear rubber gloves whenever fluoride compounds are transferred or solutions are made.

2. An individual respirator of an approved type, should be worn when transferring dry chemicals.

3. The rubber gloves and respirators should be washed in water after use and stored in a dust free cabinet.

4. The hands should also be washed after the rubber gloves are removed.

5. Fluoride compounds or solutions should be segregated from other chemicals at water works plants.

6. The sediment in the bottom of solution tanks or containers should be emptied into the sewer or disposed of by burial where sewers are not available.

7. Spillage should be kept to a minimum. Dry sweeping or brushing of areas where dusts of fluoride compounds settle should be avoided. Removal should be by mopping or hosing with water.

In addition, they state that " dust collectors are desirable in conjunction with dry chemical hoppers, storage bins or bulk containers and should be provided by large installations ".

Choice of Fluoride Compound to be used

Maier (1952) has suggested an order of " Desirability " of the three Fluorine Compounds in general use in the fluoridation of Water Supplies.

He compares such factors as cost, solubility, storage and feeder space requirements, corrosiveness, incrustation in feeder and hazard to operators and shows that sodium silicofluoride is cheaper to use than either sodium fluoride or hydrofluosilicic acid ; it also requires less storage space and does not give rise to as many incrustation problems in the feeder as does sodium fluoride. On the other hand sodium silicofluoride is the least soluble of the three chemicals and is slightly more corrosive than sodium fluoride although better than hydrofluosilicic acid in this respect.

Operating Difficulties experienced with Fluorine Compounds

It has been reported in Wisconsin that difficulties have been encountered through clogging of solution piping by accumulated deposits of inert materials. Foreign materials such as pieces of heavy paper, wood splinters, nails and staples have been found in compounds described as 98 per cent. pure white sodium fluoride. Excess moisture content has also resulted in similar troubles due to lumping of the chemical while in storage. These difficulties can be and are being overcome by giving more consideration to the packaging of the compound and a specification covering this aspect of supply would appear to be desirable.

Incrustation problems, however, are more serious than those occasioned by excessive moisture or extraneous materials. Sodium fluoride when added to water reacts with the calcium in the water and forms the relatively insoluble calcium fluoride. Softening the solution water has not, in all cases, prevented its formation though the use of a metaphosphate (Micromet Calgon etc.) which sequesters calcium and also forms a protective film on the pipe, has resulted in a great improvement in the control of this factor. These incrustations build up chiefly at the point of contact between the fluoride solution and the water supply and it is essential that means should be provided to facilitate the cleaning of these feed lines.

Sodium silicofluoride also has a tendency to form incrustations although the greater solubility of calcium silicofluoride renders this less serious and normal maintenance procedure has been sufficient to keep this trouble under control.

Media for the Administration of Fluorides

It has been established by Dean, Arnold and Elvove (1942), that water containing naturally derived fluoride up to a concentration of about 1 p.p.m. has an inhibitory effect on the incidence of dental caries. It is not definitely known that fluorides in food are assimilated to the same extent as are fluorides in water, although the evidence tends to show, in the case of soluble fluorides, that there is little essential difference.

The possibility of administering fluorides by enrichment of the milk supplied to children has been considered but while fluorides can satisfactorily be added to milk such a procedure is not considered feasible as the high number of milk centres could not be adequately inspected and lack of proper control and supervision would inevitably result in widely fluctuating concentrations of fluoride. The fluoride content of cow's milk varies from 0·1 to 0·2 p.p.m. and attempts (Ariz. Agric. Exp. Stn., 1941) have been made to increase this concentration by giving the animals water containing varying amounts up to 500 p.p.m. of fluoride. The ensuing concentration of fluoride in the milk varied only from 0·2 to 0·4 p.p.m. and at the higher levels of fluoride addition the water tasted salty and its consumption and the yield of milk were both reduced. In any case the consumption of milk or any other food is not universal and appetites vary widely for any of these foods. Furthermore variable conditions in the body may affect the assimilation of the fluoride and the food itself may in some cases, because of its calcium content, nullify the effect of the fluoride.

It has been suggested that fluorides might be added to table salt, but it is doubtful if infants or young children use this commodity, and in any case the control of the amount of fluoride administered would be almost impossible.

Dentifrices and mouth washes containing fluoride are available on the American market, but there is no evidence that they have had any effect on the onset of dental caries.

It is emphasised in the United States that drinking water is the best medium for distributing fluorides in a regular and controlled manner. The argument that only a very small percentage of the water is used for drinking or cooking by the age groups deriving benefit, is met by the small cost that such treatment entails, especially when this is compared with the saving in money and dental care which results. It is realised, in America, that only a limited proportion of the population is served by public water supplies and that other means are necessary to reach the substantial number of children who live in the rural and more isolated regions which still lack a piped water supply.

Tablets of sodium fluoride have been tested by research workers on their own children. Each tablet contains 2·21 mg. of sodium fluoride (1·0 mg. fluorine). The tablets are dissolved in the water used for drinking purposes and the daily dose for children is equivalent to one-third of one tablet up to 2 years old, half a tablet from 2 to 3 years old and one tablet from 3 to 10 years old.

It is reported that under these conditions, tablets of sodium fluoride have been effective in inhibiting dental caries and indeed one would not anticipate otherwise. It must be emphasised, however, that the experimental group was highly selective and that there was scrupulous attention to administration. In the hands of less careful parents similar results might not be obtained perhaps because of irregularities in giving the tablets and the danger would also arise that some parents would argue that if one tablet was good two or more would be better and thus perchance be led to give an excessive dose. Nevertheless in the absence of a fluoridated water supply this method of application would have a limited use.

Tablets containing calcium fluoride with vitamin C and D, calcium, phosphorous, etc., are available on the market but nothing is known of their action and the marketing of similar tablets could not be recommended until something was known of their physiological effects.

A baby food "Pablum" is widely used in America. It is made of ground wheat, corn and bone meal and has an overall content of 10 p.p.m. fluorine. A baby of 10 lb. weight is estimated to require about 25 gm. "Pablum" per day which would correspond to a dose of about 0·25 mg. fluorine per day. The amount of absorption of fluorine from a diet of bone meal was found by McClure (1945) to be about 50 per cent. so that the available fluorine from this source would not be very material and other sources of fluorine would be necessary to inhibit dental caries.

Dehydrated cereals are becoming popular as baby foods and a question arises here about the ultimate dose of fluorine applied if the water is also fluoridated and the baby food is prepared before dehydration with fluoridated water. In this event a somewhat larger amount of fluoride may be ingested than might be considered desirable.

Topical application of fluorides

Among the investigations proceeding on methods of administering fluorides where a piped water supply is not available probably the most important one is the topical application to the tooth surface of solutions of fluorides. Various techniques have been employed by different workers and several fluoride salts at various concentrations in aqueous solution have been used. In the United States a reduction in the incidence of dental caries from 20 to 40 per cent. has been claimed. Sodium fluoride solution has been most frequently used, the concentration varying from 2 per cent. to 0·1 (Knutson *et al,* 1943, 1946, 1947; Bibby, 1944; Klinkenberg and Bibby, 1950). The pH of the solution has been found to be of importance. *In vitro* experiments suggested that an acid solution would be more effective, but clinical investigations in this country by Stones, Lawton, Bransby and Hartley (1949) report negative results using a solution adjusted to a pH of 4·0. Knutson (1951) recommends a 2 per cent. unbuffered solution of sodium fluoride in distilled water, and a series of four applications at approximately weekly intervals. He suggests that these be repeated at ages, 3, 7, 10 and 13 or in accordance with the tooth eruption pattern of the individual child. Before the first application of each series, teeth cleansing with rubber cap and pumice is important (Adler and Straub, 1950). The teeth are then isolated with cotton wool rolls and dried by blowing with compressed air, after which the solution is applied and allowed to remain for four minutes. A 40 per cent. reduction in dental caries has been claimed as a result of this treatment and it is further claimed that virtually every child treated with topical fluorides is benefited. It has also been advocated that topical fluoride treatment be carried out in areas where fluoridation of water is practised until such time as the full effect of fluoridation is reached. This is suggested with the idea of giving protection to the older age groups not born and reared in a fluoridation area, and this may be economic and beneficial. For children, however, who have always used water containing at least 0·4 p.p.m. fluorine no reduction was observed in the incidence of new caries in the permanent teeth, as a result of topical application (Downs and Pelton, 1950). The authors, however, recommend the continuation of this study using a larger number of children, before final decisions are made.

Cost of Fluoridation of Water

1. In Wisconsin, based upon experience in 17 communities (Phair, 1951).

	Dry Feed						Solution Feed			
	NaF			Na_2SiF_6			NaF			H_2SiF_6
	Low	High	Ave.	Low	High	Ave.	Low	High	Ave.	One only
Installation (Dollars)	600	3,600	1,700	912	4,700	2,500	413	3,645	1,113	500
Chemical per lb. (Cents)	11¼	15	12½	5	8	6½	11½	13	12½	9
Labour (Dollars)...	146	1,741	760	511	1,141	823	100	1,000	500	275
Installation *per capita* (Cents)	2	55	27	7	78	17	8	220	65	18
Labour *per capita* (Cents)	0·3	20	9	1½	9	4	2	52	16	3
Chemical *per capita* (Cents)	4	13	9	2½	9	5	5	18	12	22½
Total *per capita*, first year (Cents)	15	80	43	7	26	16	34	141	75	34

Notes:—

1. Variations arise due to:—
   Size of the community and per capita use of water.
2. In no instances were additional employees necessary because of fluoridation. Costs represent an estimate of the proportion of time due to fluoridation.
3. All small communities.

2. *Estimated Annual cost of Fluoridation*—1 *p.p.m. F—for Detroit* (*Tossy*, 1950).

	Dollars
(*a*) *Sodium Fluoride* at 11·5 Cents per lb.	278,084·49
Actual Pumpage at 20·4 lb./million gallons	321,763·33
Amortized cost of Equipment (10 years)	1,400·00
Total Annual Cost	323,163·33
(*b*) *Sodium Silicofluoride*	
Actual Pumpage	69,605·81
Amortized cost of Equipment (10 years)	1,400·00
Total Annual Cost	71,005·81

Note:—No extra personnel will be required for operation, testing or maintenance.

Water Pumpage and Cost Distribution	*Dollars*
Annual Pumpage in Gallons (U.S.)	137,154,300,000
As Drinking water for population	200,653,998
As Drinking water for children (0–8 years)	33,390,839
Population served	2,418,126
Population children (0–8 years)	365,927
Pumpage cost per capita	5·00
Pumpage cost per child (0–8 years)	33·00
Total operating revenue, fiscal year	12,020,795·00
Additional cost of Fluoridation (Na_2SiF_6)	71,005·00

	Cents
Cost per capita per year	3
Cost per child (0–8 years)	19
Cost per gallon (all water)	0·0005
Cost per gallon, all drinking water	0·032
Cost per gallon, drinking water, children 0–8 years	0·21

Cost of Topical Application

Hypothetical Community of 50,000 population.

Work done by full time Dental Hygienist. Salary 3,000 Dollars per year, travelling maximum 50 Dollars per month. 7,500 children may be expected to attend elementary schools.

Cost of Fluoride applications per child. Once every three years	1·50 to 2·00 Dollars
Total cost per child for the three series of application stages, 7, 10 and 13 years	4·50 to 6·00 Dollars
Annual cost to community per child	50 to 70 Cents
Annual cost per capita	8 to 10 Cents

If salaries increase cost of topical application will also increase.

Comparison of Cost (Annual) in Cents per capita

Water Fluoridation	3
Topical Application	8–10

Comment

From these costing figures it is clear that it is more economical to add fluorides to water supplies which are used by the entire population than to give topical applications of solutions of sodium fluoride to the children. Apart from the saving in money there is also a saving in dental manpower which is of great importance and, furthermore, the benefits to be derived by the children are also greater with fluoridated waters and these may well be of a more permanent nature.

APPENDIX 13

Fluoridation of Public Water Supplies in the United States

Maier (1950) has stated that " the mechanics of feeding fluorides are no more involved than those for other chemicals used in water purification " and we are in complete agreement with his statement. With certain refinements the fluoride feeding equipment used in America is similar to that used in waterworks practice generally.

In one instance only is there a departure from orthodox methods and that is at Madison, Wisconsin where hydrofluoric acid is used. This installation is unique and is unlikely to be repeated in America and its use in this country could not be recommended.

Methods of Fluoridation Used

The standard methods of adding fluorides are as follows:—

(1) Solution feed of sodium fluoride,

(*a*) 3·0 to 3·5 per cent. solution,

(*b*) saturated solution.

(2) Liquid feed of hydrofluosilicic acid.

(3) Dry feed of sodium fluoride or sodium silicofluoride.

Solution and Liquid Feeders

The equipment used for feeding sodium fluoride solution is similar to that in general use in this country for adding hypochlorite in routine disinfection of water.

One solution feeder seen during our visit, supplied by Proportioneers Ltd., was a positive displacement, diaphragm pump constructed of materials resistant to the corrosive action of fluorides; the delivering parts being made of methacrylate, natural rubber, neoprene and polyvinyl plastic. Different models of this instrument have adjustable feed rates between 0·2 to 5·5 and 0·2 to 8·0 gallons per hour and can deal with water discharge pressures up to 100 lb. p.s.i. These feeders are essentially constant rate feeders but the motor can be electrically cross-connected with the water pump to give automatic control. In addition, the feeding rates can be varied in proportion to fluctuating water flows by solenoid valves actuated either by a Venturi or a water meter. These feeders are now provided with check valves which prevent syphonage when a negative pressure in the discharge line arises.

Another solution feeder, by Wallace and Teirnan, also constructed of corrosion resistant materials, operates against a wide range of pressure, using a balanced diaphragm. During the suction stroke when fluoride solution is drawn into the pumping chamber, the reverse side of the diaphragm is open to the atmosphere. While the fluoride is being pumped, water is admitted behind the diaphragm so that the pressures on both sides of the diaphragm are equal. Just before the next suction stroke, the pressure behind the diaphragm is released, completing the pumping cycle. A syphon breaker is incorporated in the discharge connection of these feeders.

Two types of balanced diaphragm feeders are available; one is operated by an electric motor while the other is powered by a built-in water motor controlled by a water meter for fully automatic proportional flow control.

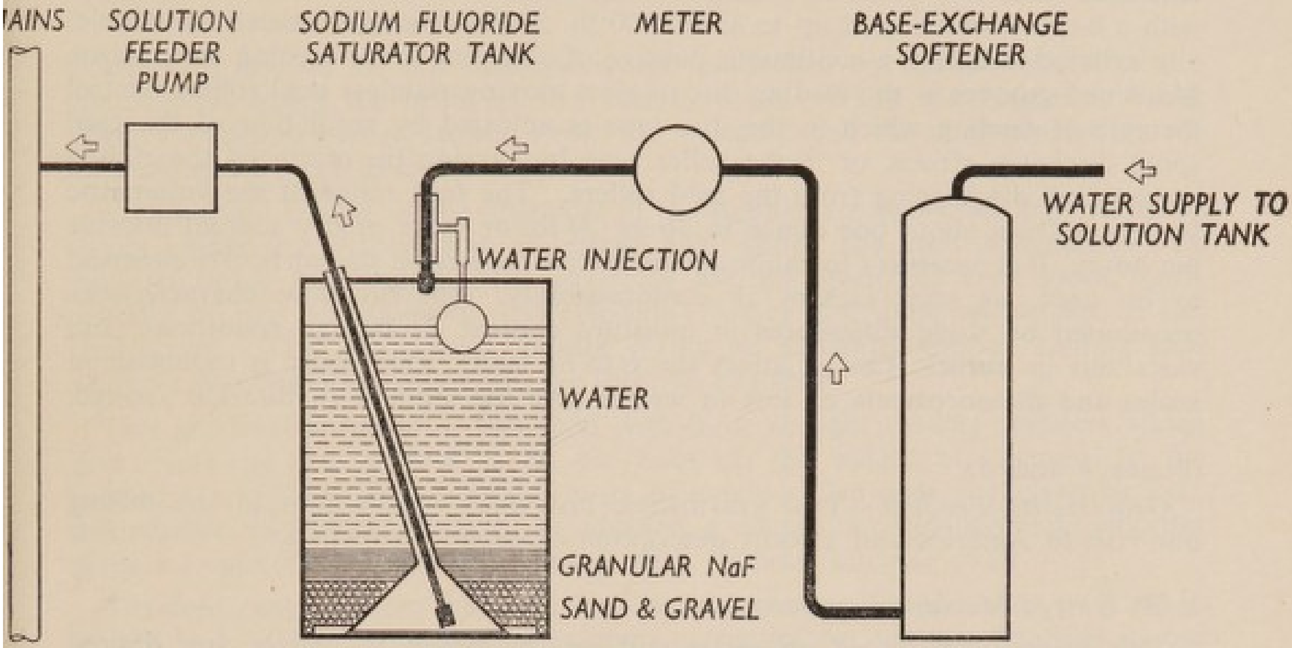
Solution feed of Sodium Fluoride

A 3 to 4 per cent. solution of sodium fluoride is made up in a ceramic crock and a solution feeder injects this solution at a predetermined rate into the discharge side of the water pump. If a 3 per cent. solution of sodium fluoride is used an injection rate of 6 gallons per hour will add 1 p.p.m. fluorine to approximately 80,000 imperial gallons of water (Plates 1 and 2).

If the calcium content of the solution water exceed 60 p.p.m. as $CaCO_3$ it should be removed by base-exchange softening to prevent precipitation of calcium fluoride; the concentration of magnesium may reach about 200 p.p.m. expressed as $CaCO_3$ before precipitation becomes objectionable. It is general practice in America to instal water softeners for the solution water in order to remove maintenance and control difficulties.

Solution feed of a saturated solution of sodium fluoride

The weighing out of a definite amount of sodium fluoride to prepare a 3 or 3·5 per cent. solution may give rise to dosing variations, depending on the care exercised by the operator and, moreover, it involves the daily handling of small amounts of the chemical. The sodium fluoride saturator overcomes both these difficulties and eliminates the need for a balance or scales. It makes use of the fact that the solubility of sodium fluoride is relatively constant over a wide temperature range, being of the order of 4 per cent. Water is allowed to trickle through a bed of crystalline sodium fluoride (20 to 40 mesh particle size) and sufficient contact time is allowed to make a saturated solution. The apparatus consists of a stainless steel tank, 24 inches in diameter and 30 inches high giving a capacity of about 8 cubic feet and capable of containing up to 300 to 400 lb. of sodium fluoride. The tank has a hollow inverted cone centrally positioned at the bottom which is surrounded by filter sand which constitutes a bed for the solid sodium fluoride; the feed pipe suction is inside the hollow cone. Water which can be metered, is added by means of a float valve and these additions thus correspond to the rate of feed of a 4 per cent. solution of sodium fluoride. Injection of this solution against pressure is done by using a solution feeder such as has been described.



Diagrammatic sketch of sodium fluoride Saturator (Proportioneer Ltd).

The solution water for the saturator is always base-exchange softened but nevertheless precipitates do form in the tanks. These can be controlled by periodic back washing of the tank which brings the sludge to the surface where it can be removed.

Liquid feed hydrofluosilicic acid

The application of hydrofluosilicic acid (30 per cent.) is becoming popular in America; no special equipment is required, suction being taken direct from the drum in which the acid is delivered. This drum is mounted on scales and the loss in weight recorded; the treatment of one million gallons (imperial) to a level of 1 p.p.m. requires the addition of 42·2 lb. of hydrofluosilicic acid (30 per cent.) (Plate 3).

It must be realised that overdosing with fluoride, using this acid as compared to a relatively dilute solution of sodium fluoride or sodium silicofluoride, could lead to serious consequences unless rigid precautions were taken to make this impossible.

Although solution feeders are now equipped with check valves to prevent syphonage of solution, a failure might occur, and as an additional safeguard hydrofluosilicic acid should be injected into the water supply system against pressure, at a point where no negative head can be foreseen.

In Wisconsin where this acid is used such conditions are now compulsory.

Dry Feed of Sodium Fluoride or Sodium Silicofluoride

The machines for dry feeding of a fluoride are also similar to those in daily use at many waterworks. They fall into two classes: (1) Volumetric Feeders which deliver a measured volume within a given time and (2) Gravimetric Feeders which deliver a definite weight within a given time.

Volumetric Feeders are in common use for supplies from 2 to 5 million gallons (U.S.) per day and have a rated accuracy of delivery of $\pm$ 3 per cent. although in practice a uniformity within 1 per cent. by weight has been recorded where the chemical itself has been of uniform composition. These feeders are equipped with a hopper which hold up to about 200 lb. of fluoride and which is mechanically agitated to ensure a continuous passage of chemical to the feeding mechanism. Machined grooves in the feeding disc or slow moving stainless steel rollers control the rate of feeding which in the disc type is adjusted by regulation of the feed spout discharge stroke, or in the roller type by varying the width of the ribbon of chemical discharging from the feed rollers. The feed range of the volumetric feeders is from about one ounce to about 20 lb. or more of dry sodium fluoride per hour. It is necessary to calibrate volumetric feeders on the particular chemical to be used, as such factors as compressibility, different flow characteristics occasioned by slight differences in moisture content or storage conditions, and variations in particle size all affect the rate of feed. The feeder is mounted on scales and measurements of loss in weight give the amount of fluoride applied.

(Plates 4 and 5).

Gravimetric Feeders.—Two gravimetric instruments were seen in use during our visit to America and a short description of each follows:—

1. *By Omega Machine Company*

This feeder is mounted on scales and can be preset to deliver any desired amount of chemical per minute. The rate of feed is determined by the rate at which the counterpoise on the beam is moved towards zero by a mechanically driven lead screw. When the beam is thrown off balance a rubber wedge, attached to the beam, rises and allows chemical to be shaken off a vibrating plate at the bottom of the feed hopper, until the scale is again balanced. In the older models there is a danger of flooding and consequent over-dosing when filling the hopper or if arching of the chemical occurs in the hopper. Under these conditions entrained air may give the chemical pronounced flow characteristics and it will then flood the solution box. To overcome these dangers the hopper is fitted with a vibrator to prevent arching of the chemical and in the older models a shutter is inserted at the bottom of the hopper during filling operations. The use of this shutter depends on the personal factor and the new models of this machine are fitted with a mechanically operated Rotolock feeder at the bottom of the hopper which rotates at a speed synchronised with the movement of the beam. This device will prevent the free passage of chemical to the dissolver and thus avoid the danger of overfeeding due to these causes.

These feeders are equipped with an alarm system which rings a bell and flashes lights when the beam, for any reason, is displaced to a greater extent than that necessary for the preset rate of feed. They, unlike volumetric feeders can be fitted with a mechanically operated chart recorder which shows:—(*a*) when the feeder is started or stopped (*b*) when the hopper is filled (*c*) the amount of chemical added to the hopper, and (*d*) the amount fed during any period of time, from which, in conjunction with the records of the amount of water pumped, the rate of feed can be calculated.

The hopper which usually extends to the floor above, where the fluoride chemicals are stored, can hold about 200 cubic feet of material and it is customary to add several bags of 100 lb. or a barrel of 350-450 lb. at once. When this is done it is necessary to mount a dust collector on the hopper. The Omega dust collector consists of a series of *bags* hung in a steel chamber which act in a manner similar to that of a vacuum cleaner. They have a capacity of 400 cubic feet per minute and automatically return the dust to the hopper without handling.

Gravimetric feeders of this type will deliver as little as 1 lb. per hour but are generally used for rates upwards of 10 lb. per hour, equivalent to a supply of 10 million gallons (U.S.) per day. They are capable of feed rates up to about 5,000 lb. of chemicals per hour (Plate 6).

2. *By Wallace and Tiernan*

The rate of feed on this machine is also controlled by the movement of the counterpoise along the beam of the built-in scale. When the hopper is being filled, a switch is turned from " Feed " to " Load " and the counterpoise moves back along the beam as chemical is added.

Arching and caking of the chemical in the hopper are prevented by two alternately oscillating diaphragms on either side above the feed mechanism. A two-directional feed mechanism discharges fluoride from the feed spout, horizontally in two directions by the combined rotary and axial movement of the feed screw. This mechanism besides giving an accurate rate of feeding also prevents flooding of chemical into the solution chamber.

This gravimetric feeder is equipped with three straight reading registers which give:—(1) the rate of feed in lb. per hour (2) the weight of chemical in the hopper at any time (3) the weight, in lb. of chemical fed over any given period; this register may be set at zero. In addition, a continuous loss-of-weight-recorder gives a continuous, permanent record on a 24-hour circular chart.

The feed range is from 0·01 to 1·2 cubic feet of chemical per hour, or a range of 120 to 1. The approximate maximum capacities for various fluorides in use are heavy sodium fluoride 80 lb. per hour, sodium silicofluoride 100 lb. per hour. The hopper, which has a capacity of 4 cubic feet, is equipped with a dust collector, the remainder of the feeder is completely sealed to prevent the escape of fluoride.

Solution or Dissolver Tanks

Both volumetric and gravimetric dry feeders are equipped with solution tanks, incorporated into the main body of the feeder.

It is important that these tanks are of such a capacity and have such a flow of water through them as to ensure that a solution and not a slurry of the chemical is fed to the supply. It is true that undissolved fluoride may dissolve in the supply line before reaching the first consumer but this could not be relied upon and control of the rate of feed at the plant would be rendered extremely difficult.

Harper (1951) has given a dissolver size formula based on the view, that has been substantiated in the laboratory and in practice, that about one-fourth of the ultimate solubility of the chemical can be obtained in a continuous dissolver in five minutes. In the case of sodium fluoride, a 1·0 per cent. solution is obtained with approximately 10 gallons (imperial) of water per pound of chemical.

With, for example, a rate of feed of sodium fluoride of 10 lb. per hour 100 gallons (imperial) of water per hour or 1·67 gallons per minute, will be required. A five minute retention, which is considered convenient, will then require a $1{\cdot}7 \times 5 = 8{\cdot}35$ gallon (imperial) dissolver.

Thus the formula for the size of the solution or dissolver tank when sodium fluoride is used is 0·83 gallons (imperial) capacity for each pound per hour of chemical fed, the rate of flow of solution water through the tank being at least 10 gallons per hour. Similarly for sodium silico-fluoride the solubility in a continuous dissolver is taken as 0·2 per cent., so that the tank will require to be five times the capacity of that used for sodium fluoride (i.e. 4·1 gallons) and the rate of flow of solution water will then be 50 gallons per hour.

The smallest dissolvers manufactured hold about 4 gallons (imperial) and it is not considered economical to make smaller units especially as very small water jets tend to become blocked up with deposit. When more than 20 lb. per hour of dry chemical is fed it is advisable to have efficient baffling in the dissolvers to prevent a straight through passage of undissolved chemical to the supply.

Both volumetric and gravimetric feeders are mounted on scales but it is not advisable to mount the solution or dissolver tanks on scales particularly in the case of small feeders. If they are so mounted small differences in water levels and effects of condensation water in humid weather will affect the weighings, irrespective of the rate of feed, and inaccurate records will be obtained.

Treatment of Solution Water

Troubles can arise due to the formation of scale particularly when the fluoride solution is injected into a main against pressure by means of an Eductor. With a gravity feed in the absence of turbulent conditions a sludge rather than a calcium or magnesium scale is formed and little trouble is experienced. When scaling is experienced the most satisfactory treatment has been the addition of a polyphosphate such as calgon or micromet. The dose cannot be predicted but amounts varying from 7 p.p.m. to 15 p.p.m. have been effective. It has also been observed that incrustation is less when a large volume of water passes through the solution chamber and since no wastage of water is involved this procedure commends itself.

Point of Application

In a water to which no treatment is given, the point of application is not important provided complete mixing is realised. When treatment consists simply of chlorination, the fluoride can also be added at any convenient point, even along with the chlorine.

If the water is filtered and the load on the filters is light it is not likely that any significant amount of fluoride will be lost provided of course that undissolved chemical is not passed forward to the filter. On the other hand, if coagulation with alum is carried out and fluoride is added prior to filtration a loss of fluoride will occur, the extent of this loss depending upon the amount of alum used and the efficiency of flocculation and sedimentation of the floc.

One method of removing fluoride from water is by lime softening in presence of magnesium salts, so that the addition of fluoride prior to lime softening will result in the loss, perhaps appreciable, of fluoride. Incidentally, it is stated (Maier 1950) that base-exchange softeners used in homes will not remove fluoride but more work would have to be undertaken before this conclusion could be extended to base-exchange softening carried out by a water company.

In general it can be stated that the best point to add fluoride to water is after treatment, if any, has taken place and at a point where complete mixing is certain. Addition of fluoride to the clear well has in one place, described later, resulted in variable concentrations to the distribution system depending on whether the water was gravity fed or pumped. Other examples of the loss of fluoride due to coagulation or lime softening are also described later in this chapter.

Choice of Chemical and Feeder

The choice of fluoridation apparatus will depend primarily on the amount of water passing the point of application per minute. It may be that even a supply for a small community, pumping only about 100,000 gallons per day, will require a feeder that would normally be used on a large supply because of a heavy rate of pumping over a short period. For the small supply with a reasonably continuous rate of pumping a sodium fluoride saturator seems the most suitable method of adding fluoride. This method, although introduced fairly recently, is giving satisfaction in America and it does cut out errors that could arise in making up 3 to 4 per cent. solutions of sodium fluoride. The use of hydrofluosilicic acid in a small undertaking where adequate control and maintenance personnel may not be available must be attended with risks of overdosing which, considering the strength of the chemical used, might be serious.

Whatever apparatus is chosen the following points must be borne in mind, however small or large the water supply may be:—

1. *Simplicity.* The feeding device should be mechanically simple and should also be robust and not liable to sudden and frequent breakdowns. It should be accurate and the control for rate of feed should be accessible and easy to operate. The feed line should be free from complications and in this connection a gravity feed is less troublesome than a pressure feed, if this arrangement is possible.

2. *Safety Factor.* The storage of dry chemical should be so arranged that the handling of chemical is kept at a minimum. With the small supply using only a few pounds of chemical per day this requires no special planning but when a hundred or more pounds are used daily, suitable storage should be arranged near the feeding hopper. Utilisation of the floor above the feeder with an extended hopper into this upper floor is the best answer, and under these conditions satisfactory storage and handling of the dry chemical ensues.

3. *Economical Factor.* This assumes importance in the large supplies and the chief factor is the price of the fluoride compound used.

4. *Record and Test.* Whatever feeding equipment is used, a reliable record should be kept of the gallons of water pumped and the amount of fluoride used. A permanent record of the amount of fluoride used can be obtained with gravimetric feeders and these records should be maintained. At present there is no machine operating in America which relates the amount of fluoride added with the volume of water pumped, but it is understood that work is proceeding on this project although it is not known if it has yet gone past the drawing board to prototype stage. Tests for fluoride in the treated water should be compared with the computed amount of fluoride added.

The selection of a feeder might be governed by the availability of fluoride compound; sodium fluoride, sodium silicofluoride or hydrofluosilicic acid can all be used with the larger supplies; the first two can be used with the volumetric or gravimetric feeder whereas the acid only requires a solution feeder. In the smaller supplies sodium silicofluoride is unsuitable because of its low solubility.

Factors which will influence the choice of feeder and chemical in any water undertaking are the existing layout of the plant, whether the water is coagulated, softened or filtered, the point selected for the application of the fluoride and the space available for the feeder and for the storage of dry chemical. It may not be possible for every water undertaking to instal the ideal fluoridation unit but the compromise that incorporates most of the points given above will prove, in practice, to be the most satisfactory.

Maier (1952) provided a chart, not yet published, giving the potentialities of various types of feeders (Plate 7).

He recommends gravimetric feeders for rates from 10 lb. per hour upwards. Volumetric feeders now range from 1 ounce per hour up to 5,000 lb. per hour but are not recommended for the higher rates. Solution feeders delivering hydrofluosilicic acid can be used for any supply, however large, while with a saturated solution of sodium fluoride they can deliver up to 1,880 gallons (U.S.) per minute for a supply of approximately 2 million gallons per day.

Test and Control

The method of testing for fluorides, at water plants, in America, as in England, is a colorimetric one depending on the decolorisation of a zirconium-alizarin lake, in acid solution. The method usually employed is that of Sanchis—modified by Scott. This method is described fully in the Standard Methods for the Examination of Water and Sewage (A.P.H.A. 1946) and is subject to interference by more than 500 p.p.m. of chloride as (Cl), 150 p.p.m. alkalinity as $CaCO_3$, or 0·1 p.p.m. aluminium when low fluoride readings are obtained. High fluoride readings are obtained when sulphate as (SO_4) exceeds 150, phosphates as (PO_4) exceed 1·6 to 3·3 p.p.m. or metaphosphates exceed 0·3 as $(PO_3)_6$, or chlorine (free) exceeds 0·02 p.p.m. A modified reagent by Lamar (1945) is more stable and interference by other ions is reduced. For example, chloride up to 2,500 p.p.m. as Cl, alkalinity up to 400 p.p.m. as $CaCO_3$, and sulphate up to 1,000 p.p.m. as SO_4 do not affect the reagent.

Many water undertakings use the Scott-Sanchis method and make up standards of sodium fluoride for visual comparison, but others use a comparator and glass standards. Permanent liquid standards using the Lamar reagent are also available and are used quite extensively.

Megregian and Maier (1952) have tested the zirconium-alizarin lake at different ratios of alizarin to zirconium and found, using a spectro-photometer, that the ratio of 7·5 of alizarin to 1·0 (by weight) of zirconium gave the greatest colour increment per unit of fluoride, provided a satisfactory range of fluoride concentration and produced a standard curve which followed Beer's law. On this basis they suggested a method for the estimation of fluorides using a spectrophotometer which they claimed was sensitive to small increments of fluoride over a range of 0·0 to 3·0 p.p.m. The colours given by the modified lake are too intense for visual comparison and a further modification was suggested for use in laboratories where a spectro-photometer was not available by which concentrations of fluoride up to 2·0 p.p.m. could be read with an accuracy of 0·02 p.p.m. Note has also been taken of the interference by other ions and correction curves are given for interference by phosphates and by aluminium.

Chlorine, a common constituent of many waters is easily removed by thiosulphate or arsenite and these reagents in small excess did not interfere with the method. We have tried out this technique since returning to England and can substantiate the claim made for the spectro-photometric method which we found easy to manipulate and very satisfactory. The visual method is a slight advance on the Scott-Sanchis method but even with a standard solution of fluoride in distilled water we found a difficulty in recognising increments of 0·02 p.p.m.; steps of 0·04 p.p.m., on the other hand, were easy to differentiate.

We have also found that different batches of alizarin obtained from different sources did not react uniformly, and some even did not produce much colour. Alizarin, as purchased, is only about 60 per cent. pure and we found that recrystallisation from glacial acetic acid gave a product with uniform properties as regards the production of the lake.

It is obvious that the uniformity of the alizarin used in preparation of the lake is very important, especially if a definite ratio of alizarin to zirconium (by weight) is to have any meaning, and recrystallisation from glacial acetic acid, which is easily done, would seem to be a wise precaution.

Daily tests of the water for fluoride are carried out at all water undertakings in America which add fluoride to their supplies. Samples are taken at the plant itself and from the distribution mains, the number depending on the size of the supply. The results obtained are entered each day on a work sheet, together with the gallonage pumped and the amount of fluoride chemical added. Copies of these work sheets are forwarded each month to the State Health Department, who also receive and examine weekly samples of water from each plant.

In this way the Health Department is kept fully informed of the amount of fluoride supplied to the public through its water supply and at the same time they have for comparison their own analytical figures for the fluoride content of the water. This analysis done by the State Health Department is important from another aspect, in that the direct colorimetric test sometimes suffers interference by other ions present in the water. Now, treatment with a metaphosphate is common in water works, especially those adding fluorides, and an erroneous figure may be obtained unless the sample is distilled. The distillation method, using perchloric acid is not one that every waterworks laboratory could undertake but it is done by the State Laboratory whenever necessary, and shows by direct measurement any inaccuracies due to interference with the direct colorimetric method. We are of the opinion that this system of control is wise and may be necessary to convince public opinion that an excess of fluoride is not being added to the water supply.

Safety Measures for Water Works Personnel

These can be summed up by stating that the handling of fluoride chemical should be kept to a minimum.

Personal protective measures such as wearing gloves, respirators and washing have already been described, but other considerations in planning the feed unit should be noted. In the case of a small supply using a few pounds only per day of chemical little planning is required and with ordinary care there is no need to use dust extractors. If the crystalline form of sodium fluoride can be used it would be an advantage.

With large supplies, exceeding 10 million gallons per day, the unit should be planned to embrace as many of the following points as possible:—

1. The fluoride chemical should be stored in a dry room convenient to the loading hopper. If floors are of concrete the chemical should be raised by battens to allow free circulation of air underneath.

2. The hopper of the feeder should hold one complete container of chemical so that the number of filling operations is kept to a minimum.

3. The filling opening of the hopper should be at a convenient height ; the use of step ladders should be avoided. In the larger supplies the hopper usually extends through to the floor overhead where the chemical is stored ; the filler opening here can be arranged to take one container which can be emptied after the door to the opening has been closed, thus minimising escape of dust.

4. The provision of dust extractors in the larger supplies, where one or more containers are emptied into the hopper at a time, is essential. Zufelt (1950) described some experiments at Sheboygan to test the air in the vicinity

of the feeder during filling operations. Sodium fluoride, dense white 90 per cent. purity, was used and 375 lb. were added at one time. The following results were obtained.

	F as HF mg./M³
Near feeder, on lower floor, before filling	0·04
Chemical storage room, before filling	0·025
Chemical storage room (breathing zone of operator) during filling	8·89
Near feeder, immediately after filling	0·134
Near feeder, 15 minutes after filling	0·050
Chemical storage room, 30 minutes after filling	0·119

According to the U.S. Bureau of Mines the maximum allowable concentration for fluoride dust, in an 8 hour day of continuous exposure, 5 days per week, is 2·5 mg. HF/M³. The only point where this figure was exceeded was at the hopper during actual filling operations, occupying about 5 minutes, and never more than once per day. The hazard shown by the tests was not considered to be serious, but since this test was carried out Sheboygan have changed over from 375 lb. barrels to 100 lb. sacks, which can be inserted into the filler opening and thus create less dust. Any increase in fluoride absorption in the individual is reflected in the content of fluoride in the urinary excretion and consequently samples of urine of plant personnel were examined. The following results were obtained:—

	F as HF p.p.m. (mg. per litre)
A. Control Samples	
1. Department Superintendent	0·44
2. Office Manager	0·10
3. Office Clerk	0·40
Average	0·31
B. Plant Samples	
4. Plant Superintendent Chemist...	0·88
5. Filter Plant Operator	1·04
6. Filter Plant Operator	1·58
7. Filter Plant Operator	0·52
8. Filter Plant Operator	0·20
9. Relief Filter Plant Operator	0·10
Average	0·72

During the filling operations the men wear gloves and respirators but even so those handling sodium fluoride were absorbing approximately twice the normal amount of fluoride.

Fluoridation Plants visited in the United States

An effort was made to visit a representative selection of the water companies actually adding fluorides to their water supplies.

In arranging this programme, convenience from the point of view of the distances apart of these plants had to be considered but, in all, 19 such plants were inspected. These varied from the small supply for a population of less than 1,000, using a solution feed of sodium fluoride, to the large supply catering for a population of over a quarter of a million people, where a gravimetric feed of sodium silicofluoride is used.

The following table gives a list of the places visited, together with their population, water consumption and the method used to add fluoride.

Place	Population	Water Consumption U.S. gallons		Fluoridation Unit
		Per day ×1,000	Per Capita	
Belleville, Wis.... ...	735	58	79	Sodium fluoride solution feeder.
Crestwood, Wis. ...	800	25	31	Sodium fluoride solution feeder.
New Glarus, Wis. ...	1,229	70	57	Sodium fluoride saturator.
Mount Horet, Wis. ...	1,716	83	48	Liquid feed of hydrofluosilicic acid.
Menomonee Falls, Wis.	2,469	216	87	Liquid feed of hydrofluosilicic acid.
Evansville, Wis. ...	2,500	141	56	Volumetric feeder: sodium silicofluoride.
Mayville, Wis.... ...	3,000	561	129	Sodium fluoride saturator.
Hastings, Mich. ...	6,060	664	109	Volumetric feeder: sodium silicofluoride.
Watertown, Wis. ...	12,417	1,037	84	Volumetric feeder: sodium silicofluoride.
Marshall, Texas ...	22,500	2,490	110	Volumetric feeder: sodium fluoride.
Fond du Lac, Wis. ...	30,000	2,905	97	Volumetric feeder: sodium silicofluoride.
Newburgh, N.Y. ...	34,500	1,328	38	Volumetric feeder: sodium fluoride.
Sheboygan, Wis. ...	42,365	4,565	108	Gravimetric feeder: sodium fluoride.
Brantford, Ontario ...	42,600	4,500	106	Volumetric feeder: sodium fluoride.
Ann Arbor, Mich. ...	47,279	5,810	122	Gravimetric feeder: sodium silicofluoride.
Evanstown, Ill. ...	85,000	10,790	127	Gravimetric feeder: sodium fluoride.
Madison, Wis.... ...	100,000	9,960	100	Oil Pressure system: hydrofluoric acid.
Grand Rapids, Mich....	175,647	23,900	142	Gravimetric teeder: sodium fluoride.
Washington Sub-S. Comm.	280,000	21,165	76	Gravimetric feeder: sodium silicofluoride.

It will be observed that solution feeders are used for supplies up to about half a million gallons per day, volumetric feeders between this and four and a half million gallons and gravimetric feeders for supplies greater than five million gallons per day. Hydrofluosilicic acid was in use at two small undertakings each serving about 2,500 people.

A more detailed account of each place visited may be of interest.

BELLEVILLE, WISCONSIN	Fluoridation commenced August, 1951. Solution feed of sodium fluoride.
Source of supply	Well 325 feet deep.
Water hardness	308 p.p.m. as $CaCO_3$.
Alkalinity...	316 p.p.m. as $CaCO_3$.

Five pounds of sodium fluoride are dissolved in 20 gallons (U.S.) of unsoftened water in a glazed earthenware crock. A white precipitate, presumably calcium fluoride, was noted at the bottom of the crock. A solenoid valve is incorporated in the circuit which operates the solution feeder when water is being pumped. The pumping rate was stated to be 300 gallons per minute and the feeder was set to deliver at a rate of 58 gallons per 24 hours, equivalent to a dose of 1·6 p.p.m. Daily tests of the water at the plant gave figures of 1·0 p.p.m. and these were confirmed by the State Laboratory. The disagreement with the calculated addition of 1·6 p.p.m. implies, (1) that the strength of the fluoride solution was not constant, or (2) that the calibration of the feeder was not accurate. The amount of fluoride solution used is gauged by a dip stick in the crock but a more exact computation of the amount actually added would be to relate daily weight of fluoride used with volume of water pumped.

CRESTWOOD, WISCONSIN	Fluoridation commenced October, 1950. Solution feed of sodium fluoride.
Source of Supply	Borehole 300 feet deep.
Water hardness	275 p.p.m. as $CaCO_3$.

This is similar to Belleville except that the water for making up the sodium fluoride solution is base-exchange softened. A 3·7 per cent. solution of sodium fluoride, in all 25 gallons, is made up once a week, about four gallons being used each day.

The feed lines at both these places are of polythene and fluoride solution is injected into the discharge side of the water pump. Neither of these plants is supervised by a full-time or specially qualified operator; local handymen look after the units along with their regular work.

NEW GLARUS, WISCONSIN	Fluoridation commenced 18th February, 1952. Sodium fluoride saturator.
Source of supply	Well 465 feet deep.
Water hardness	300 p.p.m. as $CaCO_3$.
Alkalinity...	290 p.p.m. as $CaCO_3$.
Iron	0·3 p.p.m.

The raw water here is treated with Calgon initially at a rate of 5 p.p.m. now reduced to 2·5 p.p.m. to sequester the iron, and the feed water to the sodium fluoride saturator is base-exchange softened. It is also metered and a float in the saturator is adjusted to admit 10 gallons of water when that quantity of saturated solution of sodium fluoride has been used. Actually less than 10 gallons is used daily so that the float is manually tipped. A solution feeder injects the saturated solution against a water pressure of approximately 75 lb. p.s.i.

The volume of feed water to the saturator is recorded each day together with the pumping rate so that the dose of fluoride can be calculated. This works out at about 1·3 p.p.m. but samples of water examined locally give a reading of 1·0 p.p.m. as compared with a State laboratory figure of 1·3 p.p.m.

It is known that metaphosphate interferes with the direct colorimetric determination of fluoride tending to give slightly high readings and it has been arranged to have check estimations made by distillation with perchloric acid. This unit had been in operation for only a few weeks at the time of our visit but appeared to be giving little or no trouble apart from the determination of fluoride in the water.

MOUNT HOREB, WISCONSIN ...	Fluoridation commenced February, 1952. Liquid feed of hydrofluosilicic acid.
Source of supply	Wells 250 feet deep.
Water hardness	284 to 390 p.p.m. as $CaCO_3$.
Alkalinity...	264 to 311 p.p.m. as $CaCO_3$.

The drum of hydrofluosilicic acid is mounted on scales and a daily record is kept of its loss in weight. The acid is injected into the supply against pressure by a solution feeder which is actuated by a solenoid valve to operate when water is being pumped. Water is pumped at a rate of about 325–350 gallons per minute and pumping is intermittent; the feeder is set to deliver hydrofluosilicic acid at a rate of 1·67 gallons per 24 hours but the amount actually used varies between 0·38 and 0·56 gallons which should give a concentration of fluoride ion between 1·1 and 1·6 p.p.m.

Daily tests confirmed by the State Laboratory agree with the calculated additions, the variability of the dose being due to difficulty in setting the rate of feed on the solution feeder. The trouble is apparently due to the very low rate of feed and the setting right at the lower end of the scale does not allow much latitude for adjustment. The plant which is in charge of the local handyman, had only been in operation for a few weeks and it will be interesting to learn how the question of control is solved. We feel, however, that in a small supply of this nature, a sodium fluoride saturator would have been more suitable.

MENOMONEE FALLS, WISCONSIN ...	Fluoridation commenced September, 1951. Liquid feed of hydrofluosilicic acid.
Source of supply	Wells 1,100 to 1,394 feet deep.
Water hardness	400 p.p.m. as $CaCO_3$.
Alkalinity...	350 p.p.m. as $CaCO_3$.

This unit is similar to that used at Mount Horeb except that the rate of feed is slightly higher, the feeder being set to deliver approximately 2·2 gallons in 24 hours. Thus although the setting is near the lower end of the scale there remains some latitude for adjustment and no troubles are being experienced. The following two examples of the calculated amount of fluoride added and that found in the water were picked at random.

Water Pumped	*H_2SiF_6 used*		*Found in water*
gallons	*lb.*	*p.p.m. F.*	*p.p.m. F.*
224,000	10·0	1·3	1·3
260,000	8·0	0·9	1·1

The operator in charge of this unit is the local policeman.

EVANSVILLE, WISCONSIN	Fluoridation commenced March, 1950. Volumetric feed of sodium silicofluoride.
Source of supply	Well 1,014 feet deep.
Raw water	Hardness 350 p.p.m. as $CaCO_3$ (Mg as $CaCO_3$ 170).
	Alkalinity 318 p.p.m. as $CaCO_3$ (Mg as $CaCO_3$ 170).
	Iron 3·4 p.p.m.
	Manganese 0·16 p.p.m.

Water Treatment

The water is aerated to precipitate iron and is then softened with lime, added as a slurry, at the rate of 3 lb. per 1,000 gallons. After settlement for about four hours, the water is filtered through sand at a rate of about 2 gallons per square foot per minute. After filtration the water is recarbonated before distribution.

Fluoridation

A volumetric feeder (roller type) by Wallace and Tiernan is used and about 2·5 lb. of sodium silicofluoride is used each day. The pumping rate is 750 gallons per minute and fluoride solution is injected into the mains by an eductor system with a solenoid valve in circuit. The fluoride delivery pipe has an air vent to prevent syphonage from the solution box. The feeder is equipped with an oversize solution box, of about 2 to 3 times the normal capacity, but even so the bottom of the tank was covered with a white deposit which has to be cleaned out each week.

There is obviously a loss of fluoride here and the reason for this is that insufficient water is passed through the solution tank. The present flow of solution water is the limit of eductor capacity, so this will also have to be increased.

The fluoride is added prior to lime softening, and as the magnesium hardness is considerable a loss of fluoride due to its removal by the precipitate of magnesium hydroxide would also be expected. Sodium fluoride was used at the inception of this fluoridation scheme, later being replaced by sodium silico-fluoride but other conditions were unaltered. Some results were picked out, at random, from the log sheets and the concentrations of fluoride ion added were calculated and compared with those found in the water.

Sodium fluoride as p.p.m. F.	*Found in Water*	
Added	*Locally*	*By State laboratory*
1·64	0·9	1·0
1·6	1·2	0·8
1·7	1·1	1·1
1·6	1·1	1·1

Sodium silicofluoride as p.p.m. F.	*Found in Water*	
Added	*Locally*	*By State laboratory*
2·2	1·2	—
2·2	1·2	1·4
1·1	1·1	1·2
2·2	1·1	—

From these figures there would appear to be a considerable loss of fluoride, amounting on the average to about 40 per cent. There is little doubt that the main reason for this loss is the addition of fluoride prior to lime softening rather than to the finished water, though an insufficient flow of water to the solution tank is also a contributory factor.

MAYVILLE, WISCONSIN ... ... Fluoridation commenced September, 1950.
Sodium fluoride saturator.
Source of supply ... ... Wells 800 to 900 feet deep.
Water hardness ... ... 296 p.p.m. as $CaCO_3$.
Alkalinity... ... ... 246 p.p.m. as $CaCO_3$.

The unit here is similar to that already described at New Glarus except that Calgon is not used. The solution water is base-exchange softened and the crystalline form of sodium fluoride is used.

Samples of water examined locally give results which agree with those obtained at the State Laboratory and also with the amount of fluoride added to the water.

HASTINGS, MICHIGAN ... ... Fluoridation commenced January, 1951.
Volumetric feed of sodium silicofluoride.
Source of supply ... ... Well.
Water hardness ... ... 360 p.p.m. as $CaCO_3$.

Pumping is intermittent and is at a rate of about 913 gallons per minute; the feeder is started by means of a solenoid valve and operates only when water is being pumped. The rate of feed of chemical is about 11·5 lb. per 24 hours and the solution water is treated with a metaphosphate (Micromet). The fluoride solution from the solution box is further diluted in a constant-level, float-ball operated tank before being pumped into the main under pressure.

The plant operator, who is a State qualified attendant, wears gloves when filling the hopper but little dust is raised by the small quantity of chemical handled each day and the use of a respirator is not considered necessary.

Samples of water both from the plant and the distribution system are tested daily at the plant by means of a Taylor comparator which used the Lamar reagent and permanent coloured liquid standards. In addition, weekly samples are forwarded to the State laboratory and agreement between the two sets of samples is good.

At the commencement of fluoridation the concentration of fluoride ion found in the water did not agree with the amount added, but now the agreement is reasonably good. The following figures which are the monthly averages for all samples examined illustrate this point.

	Gallons pumped	*Fluoride added lb.*	*Fluoride added p.p.m. F.*	*Fluoride found p.p.m. F.*
March, 1951	885,000	6	0·5	0·8 to 1·0
February, 1952	733,827	10·5	1·03	1·0 to 1·2

WATERTOWN, WISCONSIN	Fluoridation commenced December, 1950. Volumetric feed of sodium silicofluoride, sodium fluoride was used at inception of scheme.
Source of supply	3 wells 760 to 1,145 feet deep.
Raw water	Hardness 300 p.p.m. as $CaCO_3$. Alkalinity 296 p.p.m. as $CaCO_3$. Iron 0·6 p.p.m. Fluorides 0·2 p.p.m.

Pumping here is intermittent and the feeder is synchronised by means of a venturi with the amount of water being pumped, approximately 1,300 gallons per minute. From 15 to 17 lb. of sodium silicofluoride are used daily and as at Hastings a further dilution of the fluoride is arranged before it is pumped into supply on the discharge side of the water pump.

The solution feed water is treated with micromet but even so when sodium fluoride was used the glands of the solution pumps became blocked owing to the formation of calcium fluoride. Since sodium silicofluoride was used this trouble has disappeared.

There is very little headroom over the hopper and filling is done using a pail and scoop, the operator wearing gloves and a respirator.

The dose of fluoride ion added is 1·0 p.p.m. making with the natural content of 0·2 p.p.m. a total of 1·2 p.p.m. and the examinations of samples both locally and by the State laboratory are confirmatory.

MARSHALL, TEXAS	Study centre. Fluoridation commenced May, 1946. Volumetric feed of sodium fluoride.
Source of supply	Lake Caddo.
Raw water	Hardness 60 to 65 p.p.m. as $CaCO_3$. Alkalinity 35 to 40 p.p.m. as $CaCO_3$. pH 6·8 to 7·0. Fluoride 0·2 p.p.m.

Water Treatment

The water is aerated and prechlorinated (dose about 3·5 p.p.m.). Alum, approximately 34 p.p.m. and activated carbon, approximately 18 p.p.m. are added and mixed by paddle stirrers. After about 6 to 8 hours sedimentation the water passes through sand filters at a rate of 2 gallons per sq. foot per minute. Final adjustment of the pH of the water to about 8·5 is made with lime and post-chlorination to a level of 1 p.p.m. (Cl) in the finished water is arranged.

Fluoridation

The volumetric feeder by Wallace and Tiernan is similar to those already described except that a removable extension to the hopper is provided. This extension is removed and a weighed quantity of sodium fluoride is placed in it, the extension is then refitted on the hopper and a slide shutter is removed allowing the chemical to flow into the hopper. The feeder is mounted on scales but no record is kept of the loss in weight, reliance being placed on the original weighing of the fluoride.

About 30 lb. of sodium fluoride are added three times each day and the operator does not wear gloves or a respirator, it being considered that little dust is produced by this procedure. It was noted however that in carrying the filled extension to the hopper some fluoride was spilled on the floor.

The fluoride solution is gravity fed to the mixing tank, that is, prior to sedimentation and filtration. It was observed that the "floc" did not settle readily and some was carried on to the filters. Under these circumstances some loss of fluoride might be expected and a few records were abstracted to investigate this point.

Samples are examined daily at the plant and weekly by the State laboratory and the figures given below are the monthly averages of all such samples.

	Fluoride as p.p.m. F.				
	Added	Natural	Total	Present in finished water	Per cent. loss
June, 1951	0·96	0·1	1·06	0·92	13
July, 1951	0·98	0·2	1·18	0·92	22
October, 1951 ...	1·18	0·2	1·38	1·0	27
January, 1952 ...	0·92	0·15	1·07	1·07	0
February, 1952 ...	0·93	0·2	1·13	1·0	11

The dose of alum has to be varied according to the condition of the raw water; greater doses being used when the water becomes turbid or when algal growths are prevalent.

The maximum loss of fluoride took place during the summer months when the alum dose was at its maximum but even in February a loss of 10 per cent. was experienced.

FOND DU LAC, WISCONSIN ... Fluoridation commenced July, 1950.
Volumetric feed of sodium silicofluoride.

This supply is similar in hardness to that already described at Watertown and the method of fluoridation is the same except that an eductor system is used to inject the fluoride solution into the mains. As in Watertown sodium fluoride was used at first and the solution feed water was treated with micromet which however did not prevent blockage in the feed line. Again when sodium silicofluoride was substituted for the sodium fluoride troubles of this nature were eliminated.

NEWBURGH, N.Y.	Study centre. Fluoridation commenced May, 1945. Volumetric feed of sodium fluoride.
Source of supply	Surface water. Algae growths in spring and summer checked by copper sulphate blown on the surface of the water as a powder.
Raw water	Hardness 70·0 p.p.m. as $CaCO_3$. Alkalinity 50 to 60 p.p.m. as $CaCO_3$. pH 7·1 to 8·4. Fluoride 0·1 p.p.m.

Water Treatment

Prechlorination at a rate of 3·5 p.p.m. followed by coagulation with alum, 15 to 21 p.p.m. Activated carbon 4–10 p.p.m. is added and mixing is by a low head aerator. Settlement is about 4 hours and filtration rate is about 2 gallons per square foot per minute. Lime is added to bring the pH of the treated water to about 8·4.

Fluoridation

The feeder is similar to that used at Marshall and an extension to the hopper is used but the operator here uses gloves and a respirator. Between 1·75 lb. and 5 lb. of sodium fluoride are used each hour depending on the filter rate and the dose is manually adjusted. The fluoride solution is fed through rubber hose to an ejector system of brass and galvanised iron and injected into the pipe leading to the clear well. The iron corrodes and has to be renewed yearly. Previously fluoride solution was gravity fed to the clear well but mixing was incomplete and variable amounts were found in the distribution system, depending on whether the water was pumped or gravity fed to supply. For example, after pumping to the high level distribution the water contained 2·5 p.p.m. whereas the gravity fed supply had only about 0·5 p.p.m. Daily samples from both the plant and distribution system now give similar readings, varying between 1·0 and 1·15 p.p.m. and 10 samples bi-monthly examined by the State laboratory are confirmatory.

SHEBOYGAN, WISCONSIN	Study centre. Fluoridation commenced February, 1946. Gravimetric feed of sodium fluoride.
Source of supply	Lake Michigan.
Raw water	Hardness 135 p.p.m. as $CaCO_3$. Alkalinity 114 p.p.m. as $CaCO_3$. pH 8·4. Fluoride 0·1 to 0·15 p.p.m.

Water Treatment

Prechlorination with 1·0 to 1·7 p.p.m. (Cl) followed by coagulation with about 10 p.p.m. of alum. Mixing is done by large paddles on horizontal shafts parallel to water flow. Sedimentation time is between 3 and 6½ hours, followed by rapid sand filtration. The capacity of the filters is about 2 million gallons in 24 hours and the runs vary between 48 hours in winter to about eight hours in summer between back washings. The practice of bumping or shaking the filter beds is used to lengthen the effective time of filtration.

Fluoridation

The gravimetric feeder is by the Omega Machine Co. and is fitted with a chart recorder which gives a permanent record of the loss in weight of fluoride in the hopper. The hopper extends into the floor above with a flexible connection so that the scales are not affected and the chemical is also stored on this upper floor. The feeder is not equipped with a Rotolock device and during filling operations has to be shut down and a shutter inserted at the base of the hopper to prevent flooding of the solution tank. A complete barrel of sodium fluoride (375 lb.) is used at each filling and two or three of these are used weekly; the operators, five of whom take it in turn to fill the hopper, wear rubber gloves and use a respirator and a dust collector is also fitted to the hopper. The maximum delivery capacity of this feeder is 10 lb. per hour but the actual rate is about 6 lb. per hour.

Sodium fluoride solution is fed by means of a rubber hose pipe to the channel carrying filtered water to the clear well. Turbulence at this point together with retention for several hours in the clear well ensure adequate mixing. The feed line from the solution box is air vented to prevent syphonage.

Samples of the finished water both from the plant and from the distribution system are tested daily and weekly samples are examined by the State laboratory.

The following figures which are monthly averages of all samples tested are typical of the results obtained.

Year and Month	Gallons × 100 treated	Fluoride added		Natural p.p.m. F.	Total p.p.m. F.	p.p.m. F. Found in Water		
		lb. NaF.	p.p.m. F.			At Plant	Range	In System
1946—								
March ...	5,570	95	0·87	0·09	0·96	0·89	—	0·87
June ...	6,501	112·7	0·88	0·14	1·02	0·92	—	0·95
July... ...	8,074	136·8	0·87	0·15	1·02	0·99	0·85 to 1·05	0·98
1951—								
November ...	6,065	116·2	1·0	0·11	1·11	1·12	0·95 to 1·15	1·12

It is interesting to note that when fluoridation was started the dose was 0·84 p.p.m. and it took five days for this amount to be obtained at the outer ends of the 126 mile system of water mains.

Brantford, Ontario, Canada ...	Study centre. Fluoridation commenced June, 1945. Volumetric feed of sodium fluoride.
Source of supply	The Grand River.
Raw water	Hardness 300 p.p.m. as $CaCO_3$ (Magnesium=150 p.p.m. as $CaCO_3$). Alkalinity 180 p.p.m. as $CaCO_3$. pH 8·1. Fluoride absent.

Water Treatment

Prechlorination with 4 to 12 p.p.m. (Cl) followed by coagulation with about 14 p.p.m. of alum. Sedimentation for 3½ hours and then filtration. Post chlorination to give a residual of 0·3 to 0·5 p.p.m. (Cl) in the distribution system.

Fluoridation

A volumetric feeder by Wallace and Tiernan is used and an unusual feature of this unit is that a solution tank is not used, the sodium fluoride powder being added in solid form direct to the clear well at a point of great water turbulence. The rate of dosing is adjusted manually according to the amount of water being filtered ; at a water flow of 5 million gallons per day 5·85 lb. of sodium fluoride per hour are used. Trouble was experienced at this plant due to faulty packaging of the fluoride. Miscellaneous objects were present which caused jamming of the feeder, but since the chemical was obtained in paper board containers these troubles have been eradicated.

Samples of water are tested daily by the Scott-Sanchis method and results round about 1·1 p.p.m. are obtained. For example, in 1951 the average for the year was 1·2 p.p.m. with a variation between 0·75 and 1·45 p.p.m., however the figures below 1·1 p.p.m. and above 1·3 p.p.m. were few in number.

ANN ARBOR, MICHIGAN	Fluoridation commenced December, 1951. Gravimetric feed of sodium silicofluoride.
Source of supply	Deep well and River Huron (80 per cent. river water).
Raw water	*River* *Wells*
	Hardness as $CaCO_3$ 240 p.p.m. 350 p.p.m.
	Alkalinity as $CaCO_3$ 200 p.p.m. 225 p.p.m.

Water Treatment

Prechlorination with about 4·0 p.p.m. chlorine followed by excess lime and soda ash softening with split treatment and recirculation of $CaCO_3$ sludge. Excess lime is removed by recirculation and mixing with about 20 per cent. of the raw water. Rapid sand filtration at rate of two gallons per square foot per minute, the filter runs being about 56 hours.

Softened Water	Alkalinity 35 p.p.m. as $CaCO_3$. pH 10·2.

Fluoridation

The gravimetric feeder is by Omega Machine Company and is fitted with a Rotolock to prevent flooding of the solution tank with the chemical and with a recorder giving the pounds of chemical used each hour.

The capacity of the feeder is 0·15 to 15 lb. of sodium silicofluoride per hour and is set to deliver about 2·5 lb. per hour corresponding to about 0·8 p.p.m. in the water. The solution tank is of stainless steel and has a capacity of 65 gallons, and a flow through of 14,000 gallons in 24 hours ; the fluoride solution is gravity fed with a free drop into the clear well. Trouble is being experienced through arching of the chemical in the hopper and the alarm bell of the feeder rings frequently. It is necessary for the operator to poke down the chemical in the hopper, the mechanical vibrator not being able to deal with this extent of arching. This trouble is attributed to the poor quality of the silicofluoride in use and arrangements have been taken to obtain a free flowing form of fluoride. Daily samples of water have an average fluoride ion content of about 0·9 p.p.m. but when arching has been excessive readings as low as 0·4 p.p.m. have been obtained.

Evanston, Illinois ... ... Study centre. Fluoridation commenced February, 1947.
Gravimetric feed of sodium fluoride.

Source of supply ... ... Lake Michigan.

This water is similar to that used at Sheboygan and its general treatment follows the same lines. The gravimetric feeder is also by the Omega Machine Company and the set-up is like that at Sheboygan. The fluoride solution is gravity fed through a rubber hose to the clear well and sometimes trouble was experienced through air-locks in the hose piping. This was cured by breaking the line by a funnel arrangement giving in effect a free fall; the head over the discharge point is about 10 feet. Scale builds up in the rubber delivery pipe but this is not serious and the pipe only requires cleaning every six months.

Samples are examined every day and examples of the results obtained are given below:—

	Filter Plant			Distribution System		
	No. of samples	p.p.m. F.	Range	No. of samples	p.p.m. F.	Range
1947 ...	350	1·05	0·4 to 1·6	302	1·03	0·9 to 1·1
1949 ...	365	1·03	0·5 to 1·1	255	1·02	0·8 to 1·15
1951 ...	363	1·04	0·85 to 1·3	144	1·01	0·85 to 1·15

The minimum results were of short duration and were due to the shutting down of the feeder for readjustments.

Madison, Wisconsin ... ... Fluoridation commenced June, 1948.

Madison obtains its water from a number of wells and the water is fluoridated at each pumping station. A visit was made to Well No. 6 which yields 3,000,000 U.S. gallons per day and requires the addition of five gallons hydrofluoric acid (70 per cent.) per day or 0·21 gallons per hour. The dosing apparatus consists of two steel tanks of capacities 30 to 40 gallons. The smaller tank is filled with a white Russian mineral oil of a density (0·9) less than that of hydrofluoric acid (1·2); the larger tank contains the hydrofluoric acid. The two tanks are connected by a motor driven micropump which is electrically interconnected with the water pump and which forces the oil through an inlet at the top of the hydrofluoric acid tank and displaces a corresponding volume of the acid, through a pipe leading directly to the water reservoir. The use of the smaller tank for the oil is to ensure that oil is never pumped into the distribution system. Oil is forced back into the smaller tank when the larger tank is replenished with acid. The filling operations take place outside the building by connecting the acid drum to the filler line by means of a nipple in a tapped plug, a valve and a half union. Protective clothing is worn by the operators, but even so, burns have been reported. Auxiliary equipment includes a sight glass on the smaller tank and a low level float which operates a red light when less than five gallons of hydrofluoric acid remains in the larger tank. Relief valves, back-pressure valves and bypasses are provided so that the equipment will not be damaged by excessive pressure nor can hydrofluoric acid be syphoned into the water system if a vacuum occurs in the eduction line of the deep well pump. The plant is well designed and, under very thorough supervision is efficient. For example, in 1951, 1,561 samples of water gave an average fluoride content of 1·07 p.p.m., the variation being between 0·96 and 1·12 p.p.m.

GRAND RAPIDS, MICHIGAN ...	Study centre. Fluoridation commenced January, 1945.
	Gravimetric feed of sodium fluoride.
Source of supply	Lake Michigan.

The treatment at Gand Rapids is similar to that used at Sheboygan and Evanston.

Two gravimetric feeders by Omega Machine Company are in operation and about 600 lb. of sodium fluoride are used daily. Each machine delivers about 12·5 lb. per hour to about 625,000 gallon of water per hour, the fluoride solution being gravity fed to the clear well.

The feeders are not equipped with the Rotolock device to prevent flooding of the solution tanks while the hoppers are being filled and rely on the insertion of a shutter at the bottom of the hopper. It was found that overdosing occurred through failure of the operator to insert this shutter and now the filling operations are entrusted to two men, each with his specific role. The second, for example, does not fill the hopper until a signal from the first informs him that the shutter is inserted and the dust extractor switched on.

Daily tests of the raw water, that from the clear well and from three to four plant taps are carried out and in addition weekly tests are made from four points in the distribution system.

The water, as delivered contains an average of 1·13 p.p.m. with a range of 1·07 to 1·2 and the results are consistent throughout.

WASHINGTON SUBURBAN SANITARY COMMISSION.	Fluoridation commenced 1952. Gravimetric feed of sodium silicofluoride.
Source of supply	Paturent River and N.W. branch of Anacostia River.
Raw water	Soft water, alkalinity about 25 p.p.m. as $CaCO_3$.

Water Treatment

Prechlorination with about 4 p.p.m. of chlorine and coagulation with alum. The dose of alum is about 10 p.p.m. but is varied according to the turbidity of the water. Under turbid condition or when the alkalinity is very low, sodium carbonate, sodium aluminate or lime is used in conjunction with the alum. Mixing is done by air-o-mix machines and retention before rapid filtration is about five hours. The filter effluent is treated with lime to a pH of 8·4 to reduce corrosion of pipes. Post-chlorination or dechlorination with sodium bisulphite is carried out as necessary to maintain a residual chlorine, mainly free, of 1·4 p.p.m. in the reservoir ; residuals up to 1·0 p.p.m. are found in the distribution system.

Fluoridation

The gravimetric feeder is by Wallace and Tiernan and has already been described. About 14·8 lb. per hour of sodium silicofluoride is used to give a fluoride concentration of about 1·0 p.p.m. The feed records show that a steady rate of feed is being maintained and examination of samples of water each day gives confirmatory results.

General Impression

At all the places visited which covered both the very small and the reasonably large supplies fluoride was being added in controlled amounts and little significant deviation from the arranged dose was observed.

Some installations had some slight difficulty at the commencement of their fluoridation scheme in maintaining a steady rate of feed but the error has resulted in a small dose rather than an overdose. These and other difficulties have been influenced by the following factors:—

1. Difficulty has been experienced in adjusting the feeder to the correct rate of feed and this has occured when the dose desired is obtained at the lower or upper limit of the rate of feed scale. Adjustment should be obtained somewhat about the middle of the feed scale.

2. Arching in the hopper was only serious at one installation and was due to the grade of chemical used but it is conceivable that similar troubles could be occasioned by unsuitable storage conditions of the chemical under which its moisture content was allowed to increase.

3. When any loss of fluoride occurs there may be an underdose in the water unless a surplus is used to compensate for this loss in which case the process may become uneconomical and a steady rate of feed difficult to maintain.

A loss can occur when the solution tank is too small or when insufficient water passes through the tank. In either case fluoride remains undissolved in the tank and is thereby wasted.

On the other hand if fluoride is added prior to filtration, particularly with alum flocculation when " floc " is also carried forward to the filters a loss of an appreciable amount of chemical takes place and as this amount will vary with the amount of alum used the maintenance of a steady rate of dosing will again be difficult.

In the one installation described where fluoride was added prior to lime softening a serious loss of chemical occurred and as lime softening in presence of magnesium salts is one of the methods for the removal of fluorides from water, application at this point is not recommended.

4. The risks of overdosing are minimised by regular checks on the amounts of chemical used and hourly or more frequent inspections would seem desirable. Whenever possible it is desirable to have a continuous permanent record.

Solution feeders now have check valves incorporated which prevent syphonage, these were found to be essential and notice should be taken if a negative pressure in the mains is likely to arise. Suitable air vents should also be incorporated to prevent syphonage.

In dry feeders the danger due to flooding of the solution box is perhaps not very serious for even if the chemical passed straight through the hopper most of it would spill on the floor and the pumps or gravity feed would not handle the powder or slurry. Nevertheless, attention has to be paid to this risk and the provision of a Rotolock or some other device to prevent free flowing chemical from direct access to the solution box is necessary.

5. For the small supplies using a solution feed of sodium fluoride, the saturator is considered the best arrangement as this removes the need to weigh out a definite amount of chemical. Liquid feed of hydrofluosilicic acid is attractive but it is doubtful in our opinion if it should be used unless under trained supervision as if overdosing occurs it will be more serious than if a dilute solution of sodium fluoride is used.

6. For the large supplies where a volumetric or gravimetric feed is used, preference should be given to the gravimetric unit using sodium silicofluoride. This choice of feeder is based on the following considerations:—

(*a*) It has a greater accuracy of feed than the volumetric type.

(*b*) It can be fitted with a continuous permanent recorder giving the weight of fluoride added.

(*c*) It can be fitted with an alarm system, which calls immediate attention to any irregularities in the rate of feed.

The use of sodium silicofluoride has advantages in that:—

(*d*) Calcium silicofluoride is more soluble than calcium fluoride and in a hard water there is less trouble due to blocking of the feed line. At two installations visited trouble was caused by the precipitation of calcium fluoride and the use of micromet in the solution feed water did not provide a remedy.

(*e*) Sodium silicofluoride will probably cost less than sodium fluoride.

(*f*) Although solutions of sodium silicofluoride are more corrosive than those of sodium fluoride they are not as active as might have been expected and solution tanks of stainless steel, also used for solution of sodium fluoride, have proved satisfactory.

7. Whatever method is used for adding fluorides to the water the point of application should carefully be selected so as to ensure complete mixing before the water reaches the first consumer. In this connection the addition of dry chemical direct to the clear well might in many cases give rise to fluctuating levels of fluoride ion in the water supply, and is a practice that normally would not be recommended.

U.S. Policy of Testing

The American Water Works Association (1949) has published a recommended policy including control which summarises various points dealt with in this report.

Fluoridation of water supplies is a public health measure and therefore the health authorities should be satisfied that the correct amount of fluoride is present in the water. The practice in America of having samples examined independently at the State laboratories in our opinion is sound and it also helps the water company especially if other ions are present which affect the standard colorimetric estimation of the fluoride ion and require recourse to the distillation method.

Health Hazards to Works Personnel

The practice of wearing gloves and a respirator is fairly general and no discomfort has been reported by any operator handling fluorides. In one or two places using small amounts of chemical daily no special precautions are taken and none may be necessary but we feel that as the prescribed precautions are wise and not onerous it would be as well to observe them. Where large amounts of chemical are handled dust extractors are always used and in addition the personal protective measures are generally observed. While the operational hazard may be small or non-existent when all precautions are taken, we feel that especially in the larger units, a few urinary tests should be carried out to ensure that an excessive amount of fluoride is not being ingested by any operator at the water plant.

APPENDIX 14

Public Water Supplies in the United States and those adding Fluoride

In 1948, figures given by the United States Public Health Service show that 16,747 communities with an estimated population of 93,455,135 were served by public supplies of which 64·6 per cent. were derived from ground sources, 29·6 per cent. from surface sources and 5·8 per cent. from both ground and surface sources.

A later survey in 1950 divided the Public Water Supplies into two categories, those serving populations over 50,000 and those serving populations between 1,000 and 50,000 people. In the former, 200 communities with a total population of 54,000,000 were served by 269 water authorities, while in the latter, 8,200 communities containing 35,000,000 people were served by 6,723 authorities.

The per capita use of water in the larger population groups is given as about 152 gallons (U.S.) per day whereas the level in the smaller population centres is about 117 gallons (U.S.) per day.

In all, the United States Geological Survey indicated in 1948 that municipal sytems used 12,000,000,000 gallons of water daily; rural consumers used 3,000,000,000, private industry used 70,000,000,000 and irrigation used 95,000,000,000.

Naturally occurring Fluorides in Public Water Supplies

Fluorides occurring naturally in water are derived from volcanic rocks of the early tertiary period. Cryolite ($AlF_3 3NaF$) is found in igneous rocks and Fluorspar (CaF_2) is found in veins in sedimentary rocks. Commercial deposits of Fluorspar occur in Illinois and Kentucky. Phosphate deposits in Florida, Tennessee and Kentucky contain 4 per cent. of fluorine present as fluorapatite ($3Ca_3(PO_4)_2 CaF_2$) and this compound is also present in many soils and in the bones and teeth of animals. In the coastal plain region an important source of fluorapatite is the remnants of marine life. Fluosilicates (silicofluorides) are also found in phosphatic rocks.

Fluorides are usually found in ground waters from sandstone and limestone formations and many wells and boreholes yielding water with an appreciable concentration of fluoride are drilled into the Cambrian " Potsdam " Sandstones. It was stated that deep wells yielding water at a temperature of 80° to 90° F. usually contained fluoride.

Fluorides in rocks are not very soluble and as a result the concentrations found in water do not often exceed 2·0 p.p.m.; nevertheless there are many endemic areas and concentrations up to about 14 p.p.m. have been detected. It has been suggested that solutions of insoluble fluorides may have been obtained through the action of sulphuric acid formed by the decomposition of pyrites which is often deposited in the vicinity of fluoride bearing rocks.

A survey (Hill, Jelinek and Blayney, 1949), of water supplies in 30 of the 48 States proved that fluorides were a constituent of many waters used by fairly large sections of the community. Many of these waters contain a concentration of fluoride, up to 1·0 p.p.m. that can be described as beneficial but a by no means negligible proportion contain higher amounts of fluoride which give rise to fluorosis of varying degrees of severity.

The following table gives the number of people in 6,299 communities who use water supplies containing various concentrations of fluoride.

p.p.m. Fluorine	*Population*
0·0 to 0·5	32,072,330
0·6 to 0·99	1,863,310
1·0 to 1·5	1,293,915
1·6 to 2·0	920,671
2·1 to 3·0	626,177
3·1 to 5·0	127,243
5·1 and higher	40,151

The highest concentrations of fluoride were found in Texas and South Dakota but all the States use water in which fluoride is a natural constituent for domestic purposes. It is important to note that approximately 4·3 per cent. of the entire population of the United States use water containing natural fluorides at a concentration of 0·5 p.p.m. or more.

Communities who have approved Fluoridation of their Water Supplies

From the preceding sections it is clear that many waters in America contain too little fluoride to give protection against the onset of dental caries. Fluoride is a common constituent of most waters although it may be present only as traces of the order of 0·1 p.p.m. and for dental protection it is necessary to augment this amount so that together with that derived from food and other beverages the total intake of each individual per day varies from 0·5 to about 1·5 mg. according to age. To achieve this end water has to be fortified with fluorides to a level of about 1·0 p.p.m. Consumption of water under various conditions of air temperature and humidity may influence the dose and in this connection the important factor is not the mean annual temperature but rather the maximum day temperature or the difference between day and night readings. In other words the amount of fluoride added to the water should take into account its consumption. Information is being sought on this aspect of fluoridation and studies are proceeding in Arizona, New Mexico, and California, but results are not yet available. In the meantime it has been assumed (McClure, 1943), that the average consumption of drinking water by an adult is about 1,200 c.c. or about 2 pints per day and on this basis the addition of 1·0 p.p.m. fluoride as (F) to a water would give a total daily ingestion of approximately 1·4 mg. fluorine.

The extent of fluoridation of public water supplies in the United States up to December, 1951, was as follows:—

	States	Places	Population
In operation	37	159	4,175,259
Approved	32 (and DC)	136	11,086,392
Under consideration	41	267	18,482,243
Total	45 (and DC)	562	33,743,894

It is estimated that during the year 1952–53 the following position may be reached:—

(*a*) People receiving natural fluoride-bearing water (0·9 p.p.m. or more as F.)	4,000,000
(*b*) People receiving fluoride-treated water	35,431,088
Total	39,431,088

This would mean that around 40 per cent. of the population obtaining water from public supplies would be getting fluoride in excess of 0·9 p.p.m.

Wisconsin has been a pioneer in the fluoridation of water as a Public Health measure and in that State alone 73 places with a total population of 672,843 are adding fluoride to their water supply. In addition 37 cities in Wisconsin have approved fluoridation of their Public Water Supplies and of these, 12 have had their plans approved by the State and 6 have submitted their plans.

APPENDIX 15

Removal of Fluoride from water in the United States

The occurrence of fluoride in water in its natural state is by no means uncommon in America and approximately 1,714,242 people in 32 States are served by waters containing more than 1·5 p.p.m. In Texas and in South Dakota particularly there are many regions where the concentration of fluoride, naturally occurring, is sufficient to produce a degree of enamel mottling which amounts to a disfigurement and draws attention to the urgent need for remedial measures.

It is recognised in the United States that it is just as important to remove excess fluoride which would give rise to unsightly enamel mottling as it is to add enough fluoride to bring the concentration in the water up to the level where the incidence of dental caries is reduced.

It is only the authorities serving small rural communities who are confronted by the problem of excess fluoride in their water supplies and as they are not equipped to undertake a scientific investigation on the removal of fluoride, the United States Public Health Service has undertaken this work and Mr. F. Maier, Director Sanitary Engineer has been responsible for the plant erected at Bartlett, Texas, which will be described later.

Various methods have been suggested for the removal of fluoride from water and while it is not proposed to describe these in detail a brief mention is given below:—

1. By granular tricalcium phosphate, magnesium oxide or hydroxide (Elvove 1937).
2. By treatment with alum.
3. By lime-soda softening in presence of magnesium salts.
4. By hydroxyapatite anion exchange.
5. By activated alumina.

Treatment with alum was not effective (Boruff 1937), although during the flocculation of water some fluoride is removed, the amount depends on the amount of alum used and the cations present in the water.

A fluoride concentration of 1·7 p.p.m. was reduced to 1·0 p.p.m. by lime-soda softening at a pH of 10·1 in the presence of 27 p.p.m. magnesium (Scott et al 1937). At higher fluoride levels 3·5 p.p.m. was reduced to 1·0 p.p.m. when 146 p.p.m. of magnesium was present. If the natural magnesium content of the water is low it is considered practical to add magnesium in the form of calcined magnesite or the less expensive dolomite lime. This process has the additional advantage in that it also removes silica from the water.

Removal of fluoride by calcium hydroxyapatite which is converted into a fluo-apatite is practised at South Dakota. This process is efficient in removing fluoride but, as described later, is uneconomical in that there is a serious wastage of apatite during its regeneration by caustic soda followed by acid.

The most promising treatment actually tested is by filtration through a bed of activated alumina and it is considered that future plants for the removal of fluoride will utilise this method.

Description of Two plants for the removal of fluoride from water

1. Bartlett, Texas

This plant was visited in March, 1952 and its layout and working was described to us by Mr. F. Maier of the United States Public Health Service who was largely responsible for its construction.

Natural Fluoride	About 7 p.p.m.
Population	1,760.
Water Consumption ...	Average about 90,600 gallons (U.S.) per day. Peak loads about 270,000 gallons.
Method	Filtration through activated alumina.

The method was tested out on a pilot scale plant using about 10 cubic feet of activated alumina. The fluoride content of the water was first reduced to zero but after the passage of about 5,000 gallons of water through the bed the concentration of fluoride increased fairly slowly to 0·4 p.p.m. between 5,000 and 8,000 gallons of filtrate. After a further 600–700 gallons had passed through the bed, fluoride increased rapidly.

The full scale plant came into operation during March, 1952 and at the time of our visit was still in the experimental state.

The plant consists of a circular tank, 11 feet 6 inches in diameter containing a bed of activated alumina 5 feet 3 inches deep, approximately 500 cubic feet.

The rate of filtration through the alumina bed is about 240 gallons (U.S.) per minute but this may be increased to about 400 g.p.m. The length of run before regeneration of the alumina becomes necessary is estimated to be about 800,000 gallons (U.S.) to give an effluent with a fluoride content of 1·0 p.p.m.

Regeneration of the alumina is accomplished by back washing with about 5,200 gallons (U.S.) of a 0·75 per cent. solution of caustic soda. This is followed by a water rinse and finally excess alkalinity is neutralised with 0·05 N sulphuric acid. About 50 per cent. of the caustic soda is recovered and run back into the soda tank.

Regeneration with caustic soda has to be carefully controlled, as when the exchange reaction in the bed is complete its alkalinity rises steeply and at this stage washing with water should be commenced; otherwise too much water and acid are required to remove alkalinity.

Consideration and probably more experience is required to determine the concentration of fluoride in the water at which regeneration of the activated alumina should be commenced, so that the maximum economy consistent with a suitable fluoride level is reached.

The cost of this treatment is not yet available, but it is expected to be moderate and of the same order or perhaps less than that of lime-soda softening. It is considered, however, that the cost is not of prime importance in comparison with the benefits likely to ensue when a water is delivered to the consumer which will not only cease to produce mottled enamel in the children's teeth, but which will be active in preventing dental caries.

South Dakota

It was not possible to visit South Dakota but the following information about this fluoride-removal plant was supplied by Mr. F. Maier.

Natural Fluorine	6·7 p.p.m.
Population	1,800.
Water Consumption ...	Average 85,000 gallons (U.S.) per day. In summer about 170,000 gallons.

Fluoride is reduced to about 1·5 p.p.m. by filtration through a bed containing approximately 300 cubic feet of apatite (90 per cent.) and bone char (10 per cent.). The plant was designed to deal with a flow of 250 gallons (U.S.) per minute but the actual rate is 150 g.p.m. The run is about 200,000 gallons and towards the end of this there is a rapid increase of fluoride in the effluent.

Regeneration of the medium is by washing with about 3,640 gallons of a 1 per cent. solution of caustic soda, followed by a water rinse and final removal of excess alkalinity with carbon dioxide.

During the regeneration process there is a serious loss of apatite which in one year amounts to more than 100 per cent. Apatite is being replaced by bone char and this medium will eventually constitute the entire bed.

There is no knowledge of costs because of the loss of apatite.

General

It is considered that the fluoride-removal process using apatite or bone char will not be as efficient, from every aspect, as that using activated alumina and it is quite likely that future plants will be similar to that used at Bartlett.

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