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# Cryolite Spray Residues and Human Health

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Spraying beans with cryolite in Tennessee for control of Mexican bean beetle.

KNOXVILLE, TENNESSEE

# CONTENTS

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## INTRODUCTION

Although spray residues on fruits and vegetables constitute a major agricultural problem, no comprehensive scientific study of the subject appears to have been made. A few writers have called attention to it, but have sought to play on the fears of the public. The recent monograph on "Fluorine Intoxication," by Roholm (1937), treats primarily of fluorine as a cause of osteosclerosis. The work deals with the enormous doses required to produce this phenomenon through the breathing of fluorine dusts, but contains no experimental data on the ingestion of very small amounts, such as occur in spray residues.

The Royal Commission, in a 2-volume report, presents the only document that discusses arsenical poisoning with any degree of thoroughness. As a result of its studies, a tolerance of .01 grain of arsenic per gallon of beer or pound of foodstuffs was decreed. This beer tolerance, put into force in 1903, is the basis for our present tolerance on fruits. But the document in question touches only upon the subject of dissolved arsenic in beer, which is a liquid, and hence throws no light on our present residue situation, which has to do with solids or powders. In the absence of definite studies related to the fruit and vegetable industries, the report of the Royal Commission is more confusing than enlightening. The Food and Drug Administration recognizes this fact so well that it has recently appointed a committee to review the research program on the toxicity of lead and arsenic.

In 1933 the same tolerance of .01 grain per pound was arbitrarily placed on fluorine, several compounds of which have recently been developed and proposed as arsenical substitutes for the control of insects. Fluorides in water supplies, in amounts equivalent to 1 p.p.m.[2] of fluorine, are believed to be the cause of the mottled enamel of teeth (Smith, 1931). In the absence of more definite information on the toxicity of fluorine as a spray residue, it was as-

[1]Dr. Florence L. MacLeod, Evelyn Utley, and Dorothy Baker rendered valuable assistance in feeding laboratory animals; and H. V. Churchhill aided in making fluorine determinations.

[2]Unless otherwise noted, "p.p.m." or "parts per million" in this bulletin refers to fluorine, and not to fluorides.

sumed by the Secretary of Agriculture that fluorine could not be more poisonous than arsenic.

This study is an attempt to gather definite experimental data on the toxicity of fluorine in drinking-water, as compared with that of cryolite in spray residues, and the bearing of such data on the present tolerance of .01 grain of fluorine per pound of foodstuffs.

## LITERATURE

McClure (1933) and DeEds (1933) both have reviewed the literature on fluorine. Such references as bear on the subject will be discussed, however, in their appropriate places.

## OCCURRENCE OF FLUORINE

Prof. V. M. Goldschmidt, in a recent address, in which he gave estimates of the relative abundance of the chemical elements in the earth's crust, placed fluorine seventeenth, as shown in the following table:

| | | Grams per ton |
|---|---|---|
| 1. | Oxygen | 494,000 |
| 2. | Silicon | 276,000 |
| 3. | Aluminum | 88,000 |
| 4. | Iron | 51,000 |
| 5. | Calcium | 36,300 |
| 6. | Sodium | 28,300 |
| 7. | Magnesium | 21,000 |
| 8. | Titanium | 6,300 |
| 9. | Potassium | 2,590 |
| 10. | Manganese | 930 |
| 11. | Phosphorus | 786 |
| 12. | Sulfur | 500 |
| 13. | Chlorine | 480 |
| 14. | Strontium | 420 |
| 15. | Barium | 390 |
| 16. | Rubidium | 310 |
| 17. | Fluorine | 270 |
| | Lead | 16 |
| | Arsenic | 5 |

The proportion of fluorine to calcium in the earth's crust is, roughly, the same as that found in the bones of vertebrates.

The principal fluorine-bearing minerals are fluorspar, cryolite, and apatite. Chemical analyses show an average of .03 percent fluorine present in soils (Steinkoenig, 1919). Two Arizona soils showed, respectively, 343 and 355 p.p.m. of fluorine. One soil sample at Knoxville had 178 p.p.m. of fluorine. The arsenic content of soils averages only about 5 parts per million (Young, 1935). In sea water, fluorine averages 1-1.4 mg. per liter, while arsenic averages only .02 mg. Mineral springs, especially hot springs, often carry much fluorine. The fluorine in sea water in contact with phosphates is believed to be the origin of the fluorine in phosphate rock and fossil bones (Jacob, 1933).

Being present in the soil, flourine is taken up by plants in an amount which is found to average 2 or more parts per million. Arsenic averages .05 part per million in plants. Thus, fluorine is about 50 times as abundant as arsenic in both soils and plants. Similar proportions may be found to exist in man and animals.

## EXPERIMENTAL

### METHODS

Three fluorine compounds were used in this investigation; namely, sodium fluoride, cryolite, and calcium fluoride. The cryolite used was a synthetic commercial product composed of very finely divided particles suitable for insecticide purposes. The sodium and calcium fluorides were Baker's C. P. products. The rats used were 28 days old, raised on diet B of Sherman and Campbell (composed of ⅔ whole wheat, ⅓ whole-milk powder, and salt amounting to 2 percent of the wheat). After the 28th day, whole rice, because of its somewhat lower natural fluorine content, was substituted for the wheat. The animals were weighed each week, the incisors were examined, and the presence or absence of striations was noted. According to Sebrell (1933) and associates, the tooth changes in rats given water from a mottled-enamel area were no different from those produced by a synthetic drinking-water to which was added sodium fluoride. These changes were characterized by the appearance of brown striations on the lower incisors. "Mottling" and "striations" will therefore be considered as synonymous in this bulletin.

There was no difficulty in seeing the striations when diets were employed containing 14 p.p.m. or more of fluorine. Below these concentrations the striations became faint, and a hand-lens examination of the incisors of the live rats was found inadequate. It was decided, therefore, to make an autopsy of the animals and examine each tooth under a binocular, magnifying 12 diameters, with the aid of a daylight lamp. This procedure enabled us to note effects of fluorine at much lower levels than those recorded by Smith and Leverton (1934).

### THE RAT, A SUITABLE TEST ANIMAL

Since flourine has a specific affinity for teeth, there is a much more sensitive test than that of growth. The growing incisors of the rat renew themselves in 30 days, and show the presence of fluorine by means of striations, or so-called bleached areas, that are very definite. Normally, the incisor teeth of a rat are orange-colored. When high concentrations of fluorine (14 p.p.m. or more) are fed, the orange color alternates with fine white lines, producing a striated effect. With the smaller concentrations, the striations become faint and difficult to detect. They are readily seen, however, under a microscope with a daylight lamp, or in photographs made with a blue filter.

Smith and Leverton (1934), because they were unable to note effects on the teeth of rats unless the fluorine-bearing waters were concentrated 10 times, concluded that fluorine is 10 times more toxic to the teeth of human beings than to rat incisors, which grow at a more rapid rate. DeEds (1934) also suggested that "human subjects appear to be more susceptible to fluorine poisoning than do rats," for he found that it required 24.5 p.p.m. of fluorine as cryolite to produce bleaching in the teeth of rats.

On the other hand, nutrition workers are agreed that the rat is the most suitable animal for nutrition studies. Sherman (1936) remarks that the nutrition of the rat is closely similar to that of the human being, and that "the opportunity for nutritional improvement is similar on the whole in the two species." Roholm (1937) makes the following statement: "The rat is particularly suitable as an experimental animal, since its incisors grow from persistent pulp. In the case of a rat which receives adequate food with the addition of NaF, the pigment which gives the incisors their normal color disappears. Horizontal band-like strips of milky-white enamel alternate with bands of normal enamel." He says further: "It is typical that the changes are first recognizable on the lower incisors which grow quickest."

The rat is very sensitive to poisons, and, in the case of arsenic, is known to be even more susceptible than a human being. When all the conditions are made comparable—by the use of a diet cooked with fluorine-bearing water, in place of the customary raw diet in feeding rats—and a good binocular is employed, it is possible, with a daylight lamp or a camera with a blue filter, to detect from 1 to 2 parts per million of fluorine in a water supply when used for drinking and cooking purposes. (The proportions used in cooking are given elsewhere). It is evident that enamel-forming cells are acted upon by fluorine, whether they are present in a rat or a human being, and the way is open for a scientific study of the effect of fluorine in water when employed either for drinking or cooking, in comparison with fluoride insecticides used as powders.

## TOXICITY OF FLUORIDES IN POWDERED FORM

In order to get a fair basis of comparison, we incorporated in the diet apples that had been heavily sprayed with cryolite. The peel was removed, dried, and powdered, and then analyzed for fluorine.

This powdered apple peel was mixed with the Sherman B diet in the proportion giving 15 p.p.m. of fluorine in the total diet. At the end of six weeks the teeth became striated, and no difference in the character of the teeth could be observed from the cryolite fed with apple peel and cryolite powder incorporated in the diet. Since the latter method is less time-consuming and apparently suitable for the purpose in hand, the powdered fluorides were mixed with the diet to determine their toxicity.

From 4 to 7 parts per million of fluorine in the form of cryolite produced border-line cases.

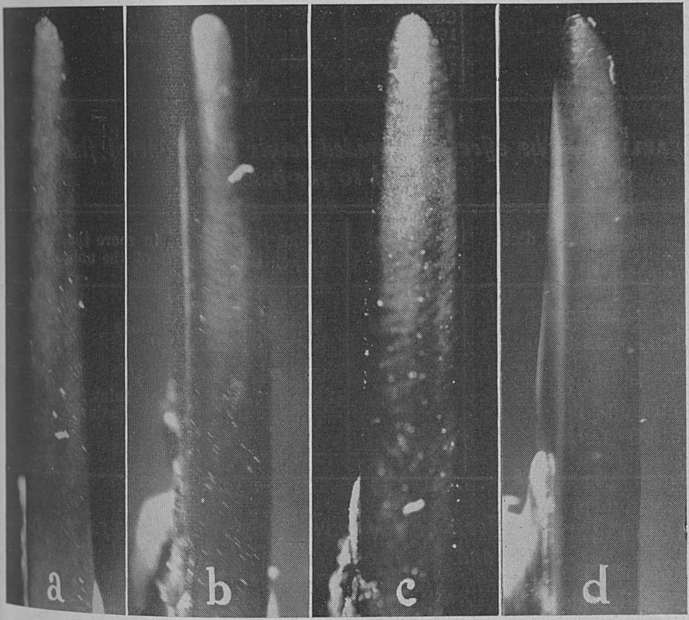


**Fig. 1—Effects of various levels of fluoride in the diet upon the production of striations on the teeth of albino rats.**

a—2 p.p.m. of fluorine as sodium fluoride in the drinking-water. No striations.

b—4 p.p.m. of fluorine in the drinking-water. Striations visible.

c—Diet of beans and dried milk. Beans cooked in water containing 1 p.p.m. of fluorine. Rat also received 2 p.p.m. of flourine in the drinking-water. Note definite striations.

d—7 p.p.m. of fluorine in the form of cryolite. No striations.

When cryolite was used at the rate of 4 parts of fluorine per million, or .4 mg. of fluorine per kilogram of body weight, no striations were visible (table 2). Two percent bone meal, equivalent to 9.6 parts of fluorine per million of diet, failed to show any striations on the teeth.

Calcium fluoride, at 15 parts of fluorine per million, is capable of producing faint striations (Smith and Leverton, 1934). At 7 p.p.m., however, no striations were visible. Smith (1935) makes the follow-

TABLE 1—*The effects of graded levels of fluorides, when dissolved in the drinking-water, upon the production of striations on the lower incisors of albino rats.*

| Fluorine in drink | Source | Diet | Results in more than 50 percent of the animals |
|---|---|---|---|
| p.p.m. | | | |
| 1 | NaF | Basal | No striations |
| 2 | " | " | " " |
| 3 | " | " | " " |
| 4 | " | " | Striations faint |
| 7 | " | " | " distinct |
| 11 | $CaF_2$ | " | " " |
| 11 | $CaF_2$ + 1% $CaHPO_4$ | " | No striations |
| 20 | $CaF_2$ + 1% $CaHPO_4$ | " | " " |

TABLE 2—*The effects of graded levels of powdered fluorides when added to the basal diet.*

| Fluorine in diet | Source | Diet | Results in more than 50 percent of the animals |
|---|---|---|---|
| p.p.m. | | | |
| 2 | Cryolite | Basal | No striations |
| 4 | " | " | " " |
| 5 | " | " | " " |
| 7 | " | " | " " |
| 11 | " | " | Striations faint |
| 14 | " | " | " distinct |
| 11 | NaF | " | " " |
| 7 | $CaF_2$ | " | No striations |

TABLE 3—*The effects on the lower incisors of albino rats, of cooking beans and bran, or rice, in the diet to dryness, in water containing graded levels of sodium fluoride, and using sodium fluoride in the drinking-water.*

| Fluorine in cooking-water | Estimated residue of fluorine in diet | Fluorine in drink | Results in more than 50 percent of the animals |
|---|---|---|---|
| p.p.m. | p.p.m. | p.p.m. | |
| 1 | 2.3 | 1 | No striations |
| 1 | 2.8 | 2 | Striations distinct |
| 2 | 4.5 | 2 | " " |

ing observation: "Our study on rats of the comparative toxicity of fluorine compounds has shown that from the standpoint of the initial damaging effect upon the teeth all are equally poisonous." Smith and Leverton (1934) say: "The amount of fluorine required to cause initial damage to the rat incisors was so small that differences in solubility of the compound were not a factor." With our technic we were able to observe effects of smaller amounts, close to limiting values. Difference in solubility is thus found to be a very important factor, and accounts for the fact that calcium fluoride is worthless as an insecticide.

## TOXICITY OF FLUORIDES IN SOLUTION

Although it is well known that materials in solution are more toxic than the powdered forms, it seemed desirable to get as exact data as possible in the case of fluorides, since mottling of teeth is caused by solutions of fluorides. Faint striations were produced in 50 percent of the animals by sodium fluoride given in the drinking-water at the rate of 4 parts of fluorine per million (table 1). As the animals drank about 10 or 11 cc. of water, this is equivalent to .4 mg. per kilogram of body weight. According to these figures, a 30-pound child will require only 6 mg. of fluorine, in water used for drinking only, to produce mottling.

## TOXICITY OF FLUORIDES IN SOLUTION USED FOR BOTH DRINKING AND COOKING

The toxicity of fluorine will naturally depend upon the amount ingested. In the case of fluorides occurring in water supplies which are used for both drinking and cooking, the latter use must be taken into consideration in order to determine the total effect of the fluorine. The diets of rats ordinarily are not cooked, but in our work a cooked diet of beans or rice was fed so that the fluorine added in cooking might be evaluated. A solution of sodium fluoride containing 1 part of fluorine per million was used. This is the smallest amount found to affect human teeth. Five-hundred grams of beans or rice, to which 1700 cc. of the above solution was added, were cooked to dryness in about an hour. This proportion was used in all of the cooked diets. Cooking thus raises the fluorine content of the diet to 2.38 p.p.m.

Definite striations were produced by the bean diet, cooked in water containing 1 part per million of fluorine as sodium fluoride, with 2 parts per million of fluorine as sodium fluoride used in the drinking-water (table 3). On a rice diet cooked with 1 p.p.m. of fluorine in the water, and with 1 part per million of fluorine as sodium fluoride in the drinking-water, the striations were produced in 1 animal out of 5. On a diet of 50 percent bran and 50 percent beans, with 1/6 milk powder, 2 of the animals showed striations with no fluorine added to the diet. Thus it would appear that water with 1 or 2 p.p.m. of fluorine, when used for both drinking and cooking, is potent in effecting changes in the incisor teeth of albino rats.

### EFFECT OF PHOSPHATES ON TOXICITY OF FLUORINE

Fluorides are classed as calcium precipitants, and are thought to deprive the animal organism of necessary calcium. Dean (1934), of the U. S. Public Health Service, acting on this assumption, fed 5 percent calcium carbonate, but was unable to note any counteracting effect on the toxicity of sodium fluoride in the drinking-water.

One of the authors found that phosphates had a marked influence in nullifying the effect of sodium fluoride used in watering plants, while sodium salts increased the toxicity (Fig. 2). Loew (1905) also noted that the toxicity of sodium fluoride to plants is reduced when the soil is rich in calcium and phosphorus. With these results in mind, we added 2 percent dicalcium phosphate to the basal diet, containing 40 p.p.m. of fluorine as calcium fluoride. The effect was markedly beneficial, the striations being faint or indeterminate, whereas only 15 p.p.m. will produce definite striations without the phosphates. It appears that calcium fluoride and dicalcium phosphate may form an adsorption complex, or an apatite, or a highly insoluble fluophosphate. Possibly a common ion effect is involved. No such effect was detected with 15 p.p.m. as sodium fluoride. In Arizona, certain alkali soils are known to be unfit for plant growth. Breazeale (1926) has shown that the alkali salts prevent the ionization and absorption of phosphates. No doubt the alkaline drinking-waters of the West produce a synergistic effect by hindering the absorption of phosphates.

### TOXICITY OF PHOSPHATE ROCK

Kick (1935) and coworkers found that 1 percent or more of phosphate rock added to the ration of pigs, caused a degeneration of the epithelium of the convoluted tubules and a fibrosis of the kidney. No such effect was noted with sodium fluoride or calcium fluoride. The toxicity of phosphate rock is further emphasized by the work of McClure and Mitchell (1931), who report that "there were indications that rock phosphate exerted a greater detrimental effect than synthetic mixtures of tricalcium phosphate and calcium fluoride containing like percentages of fluorine." All these reports of the toxicity of phosphate rock would indicate that there may be some deleterious agent present in the rock in addition to the fluorine. It is well known that phosphate rock is high in silica, containing from 2 to 10 percent. In the presence of acid in the stomach of an animal, the silica and fluorine might form a fluosilicate, which is known to be much more toxic than the simple fluorides.

### QUANTITIES OF WATER CONSUMED AT VARIOUS TEMPERATURES

Denver, Colorado, reported the first case of mottled enamel in the United States, in 1916. The trouble seems to be most prevalent and most severe in the arid states of the Southwest, notably in

Texas, western Kansas, and Arizona. More recently, well waters from various communities in Illinois have shown from 1 to 2 parts per million of fluorine, and a few waters up to 3 or 4 p.p.m. These waters were high in minerals, averaging 1500 p.p.m. Mottled enamel of the milder type is present in these communities, many of which have public water supplies. Joilet, Illinois, for example, with a population of 42,993, has 1.4 p.p.m. of fluorine in its water supply. The waters of the Eastern States are practically free of fluorine, and, barring a few exceptional cases, mottled teeth are unknown in the East. Outside of the United States, important endemic areas occur in Argentina, North Africa, and Italy. It is of interest to note that the communities in which mottled enamel is endemic obtain their water from wells and are located either in volcanic regions or regions of hot or dry climates. The latter conditions necessitate the intake of large quantities of water for effective dissipation of heat.

According to Smith (1930), "southern Arizona has a mild winter climate, but the summers are hot." It is so situated that it receives a maximum of sunshine and a minimum of rainfall and has an exceptionally low relative humidity, which may reach below 5 percent. A maximum of 127° F. has been recorded for the State and a minimum of 3.10 inches of rainfall for a whole year. During the summer months, temperatures of from 100° F. to 110° F. are recorded for many consecutive weeks. Smith also remarks: "The low humidity which prevails in Arizona enhances evaporation to such an extent that from 76 to 121 inches of water evaporate annually. This is from 4 to 29 times the amount of water which falls as rain." This increased evaporation dries up water supplies and concentrates the salts to such an extent as to make the water unsuitable for irrigation. Paucity of water is the striking characteristic of deserts. There is not enough rain to produce leaching, and hence the soil becomes laden with salts, including fluorides. In such regions the shallow wells contain a large percentage of dissolved minerals, and mottled enamel shows a higher incidence. The water requirements of plants under semi-arid conditions are practically double those in humid regions.

Water is ingested in greater amounts than all other substances combined, so that the severity of mottled enamel will depend on the quantity of water consumed in drinking and cooking. Smith and Leverton (1934) estimate a daily intake of from 4 to 8 glasses of water. Biological phenomena are often governed, however, not by averages, but by the extremes encountered. Careful studies would undoubtedly show that with the lower concentrations of fluorine, the mottling is produced by the larger quantities of water consumed in summer plus the greater quantity of cooked food consumed in winter. The need of the body for water is determined largely by environment and metabolism. Under the same environmental conditions, some people sweat much more than others, and children more than adults.

The rate of water loss is governed by temperature, relative humidity, winds, rate of metabolism, and clothing (Rowntree, 1922). As much as 300 percent more water may be lost from the skin when the relative humidity is decreased from 69 to 31 percent. Hard work in hot weather may increase the water loss to 276 grams each hour. Flack and Hill (1919) record the loss of 10 liters of water from the body during a ride at a temperature of 113° F. in southern California. They also note: "In a dry atmosphere, such as the stokehole of a steamer in the tropics, the men are kept cool by sweating. The amount of drink required may be enormous, that is, 15 pints of water a day. Sweat may vary from an insensible perspiration to as much as 1 liter an hour."

The fluid intake and output in India is commonly as much as 13 liters each day (Hunt, 1912). Vernon Bailey (1923) says: "In June, 1889, the section foreman at Tacha, Arizona, a station on the Southern Pacific Railroad between Maricopa and Yuma, told me that four gallons of water to a man was the least amount on which he could keep his crew at work 10 hours a day along the railroad in hot weather . . . . In the Death Valley country in the scorching heat of June, 1891, a gallon canteen of warm water would keep me comfortable all day in the saddle, while others less accustomed to the desert could barely survive on twice that amount of water." Actual records of water consumption by children in Arizona show that from 3 to 4 pints a day were ingested during the summer months. On hot days this was increased to 5 pints. Adults working in fields consumed from 1½ to 2 gallons of water.

It is thus apparent that under hot, dry climatic conditions, 13 times as much water may be ingested as in cool regions. This means that with a water supply containing 1 p.p.m. of fluorine, 4 glasses of water a day in a cool climate would supply 1 mg., but in a hot climate up to 13 mg. might be swallowed. As shown elsewhere, 6 mg. of fluorine must be ingested each day to produce mottling.

During periods of high water consumption (5 pints a day) by children, 2½ mg. of fluorine is ingested from a water containing 1 p.p.m. of fluorine. When to this are added the amounts concentrated through cooking, 6 mg. or more will be ingested daily from a water supply with as little as 1 p.p.m. of fluorine. We also obtained some experimental data along this line by keeping rats at different temperatures.

The white rat does not perspire, and therefore does not stand high temperatures well. Nevertheless, the water consumption averaged more at 100° F. than at 88° F., as shown in table 4. At 70° F., the water and food consumption both were increased. It is of interest to note the large amount of water which evaporated. At 70° F. only 2.7 cc. evaporated from the dishes, but at 100° F. 20.5 cc.

TABLE 4—*Food and water consumed by albino rats at different room temperatures.*

| Temperature | Relative humidity | Evaporation from cups | Food consumed | Water consumed |
|---|---|---|---|---|
| °F | Percent | cc. | gm. | cc. |
| 70 | 71 | 2.7 | 13.7 | 16.6 |
| 80 | .... | 6.54 | 10.8 | 13.3 |
| 88 | .... | 7.0 | 8.5 | 11.0 |
| 100 | 38 | 20.5 | 8.3 | 16.5 |
| 100 (with fan) | 39 | 35.0 | 9.5 | 10.5 |

evaporated, or nearly as much as the animals drank. With a small fan in the cabinet the evaporation increased to 35 cc.

In another evaporation test, from a 50-cc. beaker, 5 cc. disappeared in 24 hours at 78° F., while 28 cc. evaporated at 110° F. When a 200-cc. beaker was used, 10 cc. disappeared at 78° F. and 45 cc. at 110° F. These figures indicate that in warm climates, where temperatures of 110° F. are reached, the salt content of a water bucket may concentrate almost 100 percent upon standing for 24 hours. Often a deposit of salt is visible around the sides of a water bucket.

The factor of evaporation is of special importance on the Great Plains, for the prevailing wind velocities are higher there than in any other section of the United States. These velocities may average as high as 18 miles per hour. This rate of air movement produces rapid evaporation, intensifies drouth caused by rainfall deficiencies and high temperatures, and promotes dust blowing.

It is possible, therefore, that in the southwestern part of the United States, where mottled teeth are endemic, the high evaporation rate in the summer months is an important factor in concentrating the fluorine in the water supplies. This fact, coupled with lack of rainfall to dilute the salt, is sufficient to explain the prevalence of high concentrations of fluorides in the water supplies in arid climates or in regions with hot summers.

## FLUORINE IN FOOD PRODUCTS AND BEVERAGES

By the present method of analysis (Willard and Winter, 1933), food products show various amounts of fluorine. H. V. Churchill and coworkers (1937) found by this method that phosphates are sometimes carried over into the distillate and tend to give higher values than are actually present. When a double-distillation was used, the phosphate interference appeared to be eliminated, and the values shown in table 5 were obtained for various food products.

Apples were found to contain .2 p.p.m. of fluorine. One lot of apples from southern Illinois that had not been sprayed with cryolite

TABLE 5—*Fluorine content of various foods and products.*

| | p.p.m. |
|---|---|
| Apples (pulp) | .20 |
| Cabbage | .59 |
| Spinach | .95 |
| Yeast tablets | 2.00 |
| Rice (whole) | 1.00 |
| Corn | 1.00 |
| Wheat (Idaho) | .30 |
| Wheat (Tennessee) | .30 |
| Wheat (Fulcaster, Tennessee) | .90 |
| Wheat (Ceres, North Dakota) | 1.00 |
| Wheat (Turkey, Arizona) | 2.00 |
| Bran (Tennessee) | .30 |
| Wheat germ, commercial (a) | 1.70 |
| Wheat germ, commercial (b) | 4.00 |
| Corn germ | 15.00 |
| Cottonseed meal | 12.00 |
| Prepared baby food containing 2 percent bone meal | 12.00 |
| Dog food | 9.00 |
| Sardines | 7.30 |
| Fish (no bones) | 0.00 |
| Mackerel (with bones) | 3.90 |
| Salt pork | 1.10 |
| Salmon (canned) | 4.50 |
| Bone meal | 450.00 |
| Baking powder (phosphate) | 228.00 |
| Teakettle scale (Arizona) | 8,072.00 |
| Tea (English Breakfast) | 66.00 |
| Tea (gunpowder) | 67.00 |
| Tea (Oolong) | 41.00 |
| Whole-milk powder | .30 |

showed a natural fluorine content of 1.4 p.p.m., which is equal to the tolerance.

Certain brands of baking powder contain up to 500 p.p.m. Baking powders made from phosphate rock may contain .5 percent fluorine. Dr. E. W. Schwartze calculates that the daily intake of flourine will approximate from 4.45 to 35.55 mg. if the powders contain .5 percent fluorine. In terms of NaF, this would represent an extreme range of from 7.7 to 78.1 mg. per man, or .13 to 1.3 mg. per kilogram of body weight (Sollman, 1921).

Our own analysis showed a well-known brand of phosphate baking powder to contain 228 p.p.m. of fluorine. A recipe for making biscuits calls for 4 teaspoonfuls of baking powder to 2 cups of flour. Made in this way, biscuits will contain about 10 p.p.m. of fluorine; yet no one is known to have suffered mottled enamel from baking-powder biscuits. An exclusive diet of such biscuits by children from 1 to 8 years of age might produce tooth changes—but there is, of course, no real danger from this source.

Cottonseed meal was found to contain 12 p.p.m. of fluorine. When fed to rats, in a diet consisting of ⅔ cottonseed meal and ⅓ milk powder, it produced no noticeable effect on the teeth.

Of all the tissues of the body, bones contain by far the most fluorine, ranging from 300 to 700 p.p.m. The bones of marine animals contain 10 times as much fluorine as those of land animals, while fossil bones may contain up to 3.48 percent (Jacob, 1933). Bone meal finds extensive use as a mineral supplement for animal feeding and in baby foods, since the calcium is in a readily available form. A question naturally arises as to the injurious effect of the fluorine in bone meal, especially in prepared baby foods, some of which were found to contain 2 percent bone meal, or 12 p.p.m. of fluorine. When fed alone to rats, the baby food, consisting mostly of cooked cereal plus 2 percent bone meal, produced definite striations in one animal. When ⅔ baby food was fed with ⅓ milk powder, no visible striations resulted.

In actual practice, prepared baby foods are fed along with milk and other foods, so that the danger of producing mottling is small or non-existent.

Stearns and Jeans (1934) tested the utilization of several calcium salts for children and found the calcium and phosphate retention of bone meal to be equal to that of equivalent quantities of milk, and more dependable than other sources. Tisdall and coworkers (1930) utilized 2 percent bone meal in a cereal mixture for hospital children to improve the calcium and iron content of the diet. This mixture was composed of—

| | |
|---|---|
| Wheat meal | 15 percent |
| Oatmeal | 18 " |
| Corn meal | 10 " |
| Wheat germ | 15 " |
| Bone meal | 2 " |
| Dried brewer's yeast | 1 " |
| Alfalfa | 1 " |

This is the basis of some of the baby foods on the market, containing, as it does, appreciable amounts of many elements that are known to be essential for normal nutrition.

Under natural conditions, bones are consumed by man and animals. According to Stefansson, Eskimos subsist largely on raw and boiled fish, which because of the bones, contains large amounts of fluorine. Just how much fish Eskimo children eat is not known. It is known, however, that they gnaw bones and cartilage, which supply calcium (Mellanby, 1934). Eskimos are free from dental caries—and their teeth are among the best in the world. McCollum (1927) records that "when lion cubs are fed liver, fat and bone of a character such that they can eat a considerable amount, they grow to be strong and beautiful animals . . . . In the wild state, while still very young they eat and chew soft bones." Bone meal fed to pigs in rations estimated to contain 5 p.p.m. of fluorine caused a marked increase in strength of the bones (Forbes, 1921).

Morrison (1936) recommends the use of a mineral supplement for farm animals where the calcium content of the ration is low, and also "a phosphorus supplement which is entirely safe, such as steamed bone meal." Bone meal is also recommended for range cattle in Texas (Schmidt, 1926).

Hart and Elvehjem (1936) report 740 p.p.m. of fluorine in Menhaden fish meal. Large amounts such as this may be expected because of the high content of fluorine in sea water. A group of heifers fed a ration containing 5 percent white fish meal made from cod and haddock, produced calves of generally better health and vigor than a group fed linseed meal. Fish meal was especially valuable in supplying iodine (Monroe, 1937).

A sample of the fish meal used by Monroe was found to contain 233 p.p.m. of fluorine. The animals were thus given about 10 p.p.m. of fluorine in their diet, upon which they thrived. Other samples of fish meal contained up to 203 p.p.m. of fluorine.

When the milk supply is scanty, other sources of calcium, such as leafy vegetables and bones, are made use of in human food. The calcium requirements have been extensively investigated by Sherman (1934), from whom we quote as follows:

"Bone constitutes another important source of dietary calcium in China. Thus, Hoh, Williams and Pease (1934) have prepared the dish well known in China as 'sweet-sour spare-ribs,' made by breaking the rib bones into relatively small pieces and cooking them (with more or less of the accompanying meat) in sweetened vinegar, and on analysis have found that a single serving of such a dish supplies as much calcium as the American estimate of a day's need."

Sherman says further: "Bones are, in fact, much more largely and widely utilized as human food than the people of western Europe and their descendants in the United States seem to realize. Nearly all other peoples are much more accustomed to eat the soft ends and porous interiors of the large bones of their prey, or of such domestic animals as they may use for food,—while the bones of birds and small game are often munched entire, just as we eat the bits of brittle toast. Studies of the food habits of the peoples of both the Near and Far East, of Eskimos, of American Indians, and of native African races have shown that all these peoples make large use of bones as food. The more carnivorous of these peoples have abundant supplies of these bones (relative to their total food supplies, at least), while others in addition to the bones of such meat, game, and fish as they can obtain, also make a much larger use than we are willing to do of the green-leaf foods which contain relatively more calcium than do the other plant products commonly used as food."

In this connection, mention may be made of the natural occurrence of relatively large quantities of benzoic acid in cranberries, oxalic acid in spinach, and barium in Brazil nuts. All of these are deleterious agents. However, in the quantities in which these chemical substances occur in foods, either naturally or added, they appear to be harmless when a mixed diet is employed; and there is no reason to discard good and useful foods because of them.

The widespread use of canned fish, salmon, sardines, salt pork, and phosphate baking powders, and the fact that mottled enamel is localized according to the water supply, only serve to emphasize the much greater effective toxicity of fluorine in solution.

Among the beverages, tea was found to be especially rich in fluorine. Reid (1936) reports one Chinese tea to contain 175.78 mg. of fluorine per 100 grams of dry substance. Our own analyses showed one one tea to contain 67 and another 80 p.p.m. of fluorine—these teas being of the gunpowder type. When the animals were given an 8 percent infusion of the tea containing 67 p.p.m. as their only source of drinking-water, they showed definite striations. This would be equivalent to about 5 parts per million in the drinking-water. The striations closely approximated in character those produced by the addition of 5 p.p.m. of fluorine in the drinking-water. This experiment, together with the one on bone meal, indicates that the effect of fluorine occurring naturally in foods is similar to that of added flourine in the drinking-water or in the diet.

## EFFECT OF FLUORINE ON PLANTS

The more-or-less insoluble compounds, such as cryolite and calcium fluoride, are not injurious to plant foliage (Marcovitch, 1934). The soluble fluorides, such as sodium fluoride, will injure plants when applied to the leaves or roots. This fluorine injury appears to be intensified by the presence of other sodium salts, as shown by the following experiment: A solution of sodium flouride, 1 part to 2800 parts of water, caused no foliage injury when used as a spray. Sodium bicarbonate (1-1000) likewise caused no injury. But when the two were used together, severe injury followed. The balance between ions in an organism may be expressed as follows:

$$\frac{Ca + Mg + H}{Na + K + OH}$$

With this formula as a guide, there was produced in the combination of sodium fluoride and sodium bicarbonate an increase in the denominator, which caused the injury. In the presence of other monovalent ions, foliage injury was produced with sodium fluoride in the concentration 1-60,000.

In another set of experiments, bean seedlings in sand were watered each morning for two weeks with a solution of sodium fluoride (1-2000), with no visible effect on the plants. When these plants were also watered with a solution of potassium bicarbonate

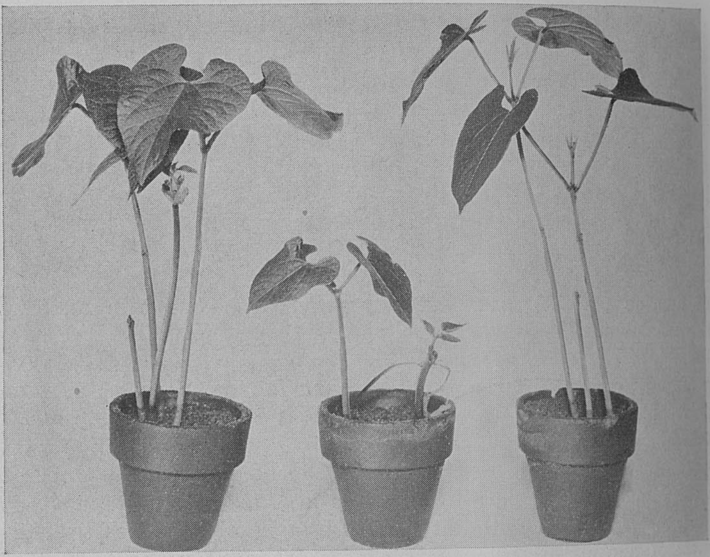

**Fig. 2—Effects of sodium fluoride and alkali on the growth of bean seedlings. (Photo. Aug., 1935).**

Left—Bean seedling in sand, watered with a solution of potassium bicarbonate 1-300, showing **approximately normal growth.**

Right—Bean seedling watered with sodium fluoride 1-2000.

Center—Bean seedling stunted when watered with a combination of sodium fluoride 1-2000 and potassium bicarbonate 1-300, showing the effect of monovalent ions.

(1-300) in the late afternoon, the combination produced a severe stunting of the plants. The potassium bicarbonate (1-300) alone did not affect the plants.

A solution of NaF (1-1000) used for watering bean seedlings causes severe stunting. When these seedlings were watered with NaF (1-1000) in the morning and again with a complete nutrient in the late afternoon, the stunting effect almost disappeared. Calcium chloride (1-1600) plus $NaHSO_4$ (1-1500) also appeared to detoxify the fluorine. Why the complete nutrient should act as an antidote is indicated by the work of Bartholomew (1935). He believes that fluorine is precipitated in the roots as calcium fluophosphate, or apatite. The presence of phosphate and calcium in the complete nutrient supplied the necessary elements for the formation of apatite.

No doubt the presence of phosphates in soil prevents any great absorption of fluorine that may be present. C. A. Mooers used large amounts of $Na_2SiF_6$ on spring oats, soybeans, and other crops, on a Cumberland loam soil, under controlled conditions, to note the effects of fluorine. As much as 250 pounds per acre produced no injury, and even showed an increased yield over the controls with no fluorine. It appears that plants tolerate fluorine much better than they do arsenic,

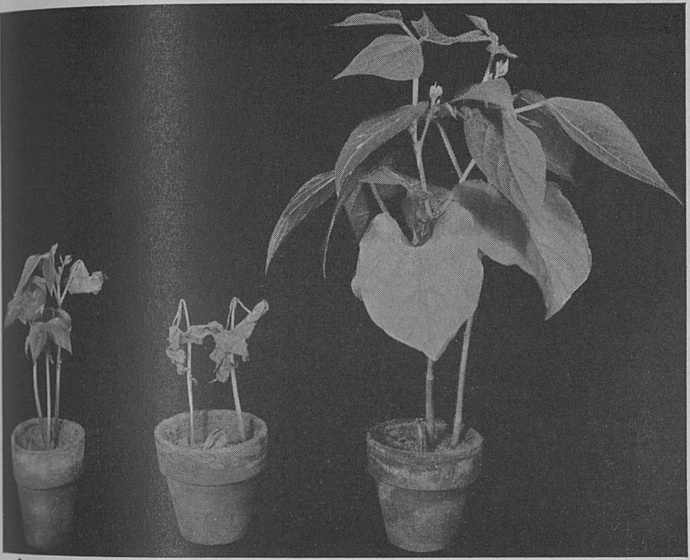

Fig. 3—Bean seedlings, showing how phosphates antagonize fluorine toxicity. (Photo. Sept., 1935).

Left—Stunted when watered with sodium fluoride 1-2000 and sodium chloride 1-300, in the morning.

Center—Watered same as left, but also late in afternoon with magnesium sulfate 1-800, calcium chloride 1-800, and potassium chloride 1-800.

Right—Watered in morning with sodium fluoride 1-2000 and sodium chloride 1-300; and in afternoon with magnesium sulphate 1-800, calcium chloride 1-1600, potassium chloride 1-800, and dicalcium phosphate 1-800; showing effect of phosphate in antagonizing fluorine by the probable formation of insoluble apatite.

for the latter is injurious to seedlings growing in a solution of 1 part in a million.

## EFFECT OF FLUORINE ON SOIL

The continued use of arsenic for the control of insect pests, in many instances, results in soil poisoning. On the sandy soils of South Carolina, for example, dusting with calcium arsenate for the control of the boll weevil has made the soil unfit for cowpeas. A similar situation is becoming increasingly evident in the Pacific Northwest and other sections of the country (Vandecaveye, Horner, and Keaton, 1936).

The fluorine in the soil was given special attention by MacIntire (1935). Applications of 1500 pounds of barium fluosilicate per acre were made to soil in lysimeters, and the exchange effects and ultimate fate of the fluorine were determined. The following conclusions were reached: "It is therefore indicated that during the 3 years subsequent to the single incorporation of $BaSiF_6$ the abundance of replaceable calcium in the unlimed soil had induced an extensive formation of calcium fluoride." "The ultimate fate of added fluorine—formation of calcium fluoride—would be the same for additions of sodium silicofluoride, cryolite, and other fluorine compounds. It is therefore apparent that no deleterious effect is to be expected from the amounts of fluorine that are used as sprays and dusts, and that no cumulative effect could result from their continued use." "The repressive effect that supplemental calcium salts exert upon $CaF_2$ solubility in the soil are considered to obviate any cumulative toxic effect from increments derived from dusts and sprays of fluorine materials and from $CaF_2$ introduced by additions of phosphatic fertilizers."

## COMPARATIVE TOXICITY OF LEAD, ARSENIC, AND FLUORINE

Since regulatory authorities have established the same tolerance for arsenic and fluorine, namely, .01 grain per pound, the natural assumption is that these elements are equally toxic. This is very far from the truth, as is shown by the figures in table 6, on the minimum lethal dose.

TABLE 6—*Acute toxicity of various substances.*

| Compound | Minimum lethal dose |
|---|---|
| Potassium arsenite | 5 mg. per kg. (Sollman, 1922) |
| Calcium arsenite | 8 " " " (Kuhn, 1929) |
| Calcium arsenate | 38 " " " (Kuhn, 1929) |
| Sodium fluoride | 200 " " " (Marcovitch, 1928) |
| Barium fluoride | 200 " " " (Kuhn, 1929) |
| Lead arsenate | 500 " " " (Kuhn, 1929) |
| Cryolite | 13,500 " " " (not fatal, Marcovitch, 1937) |

Using two soluble salts, we see that on an acute-toxicity basis, $KAsO_2$ is 40 times as toxic to dogs as NaF. Muehlberger writes: "I have been unable to kill dogs with cryolite at any dose as high as 500 mg. per Kgm." In our own work we fed cryolite to rats in the proportion of 13,500 mg. per kilogram of body weight without fatality. The cryolite was mixed with the food so that the mixture contained 15 percent cryolite, and this was consumed within 20 hours. For a person weighing 60 kilograms, 13,500 mg. per kilogram is equivalent to 1½ pounds of cryolite. It may be confidently asserted, therefore, that cryolite cannot cause the death of a human being. No fatalities resulting from it have ever been recorded. In this connection, it should be mentioned that for insects, cryolite has a median lethal dose of .05-.07 mg. per gram of insect weight, while lead arsenate has an M. L. D. of .09 mg. per gram (Shepard and Carter, 1933; Hansberry and Richardson, 1936). Cryolite has, therefore, an acute toxicity as great as lead arsenate to insects, but is not likely to cause fatality to man or animals. In this respect, cryolite satisfies the requirements for an ideal insecticide by having a high factor of safety for mammals.

Roholm (1937) also concludes that "only a part of the fluorine content of cryolite is toxic to mammals in contrast to insects," and "Cryolite and calcium fluoride have a much lower toxicity than sodium fluoride and the possibility of acute intoxication is without practical interest."

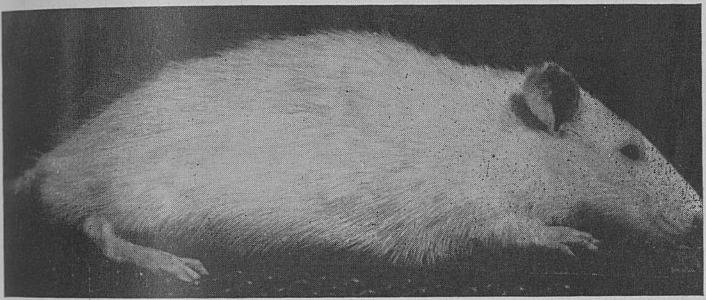

**Fig. 4—Male rat which had received 13,500 mgs. of cryolite per kilogram of body weight.**

This dose was consumed within 20 hours without fatality, and is equivalent to 1½ pounds for an adult person. No fatalities have ever been reported for cryolite, which has, therefore, a high factor of safety for mammals.

Of more importance to us from the spray-residue standpoint is the minimum chronic toxicity.

Sollman (1921) made an extended study of arsenic on rats, and some of his figures are shown in table 7.

TABLE 7—*Chronic toxicity of various compounds.*

| Compound | Minimum dose in mg. per kg. per day | p.p.m in diet | p.p.b.[1] in diet |
|---|---|---|---|
| Arsenic trioxide ....... | .00005 | .0007 | .7 |
| Lead acetate ......... | .0007 | .0098 | 9.8 |
| Lead arsenate ....... | .40 | 5.60 | 5,600 |
| Cryolite ............. | 1.00 (affects teeth) | 14.00 | 14,000 |
| Sodium fluoride....... | 155.00 (affects growth) | 210.00 | 210,000 |

[1]p.p.b. = parts per billion.

From the figures in table 7 it appears that arsenic is 20,000 times as toxic as cryolite; while if we employ the growth factor, arsenic is 300,000 times as toxic as sodium fluoride.

Table 7 also emphasizes the great difference in toxicity between the different arsenicals. Talbert (1933) fed .4 mg. per kilogram of $As_2O_3$ as lead arsenate without ill effects to rats; yet .00005 of $As_2O_3$ in solution will affect growth. This represents a difference of several thousand times. We know also that the insoluble $BaSO_4$ is non-toxic, whereas the soluble $BaCl_2$ is very toxic.

At Knoxville there is about .1 p.p.m. of fluorine in the water supply, which is probably close to the average for all localities. The fluorine in the waters at St. David, Arizona, runs from 3.8 to 7.2 p.p.m. These figures are about 50 times the average fluorine content of potable water and represent nearly the upper limits of the presence of fluorine, although in a few localities from 14 to 18 p.p.m. have been found. It is true that 7.2 p.p.m. is not a very large figure; but few waters in the United States will test more than that, while the majority will probably test around .1 or .2 p.p.m. or less.

A recent report of arsenical poisoning gives us a direct comparison of toxicity to humans when arsenic occurs in a water supply. At Madoc, Ontario, Wyllie (1937) reports several deaths from the use of an arsenical water supply which was found to contain .7 grain of arsenic per imperial gallon, or approximately 9.8 p.p.m. The scale from the household kettle, which had been used for a considerable time, yielded 4000 parts of arsenic as $As_2O_3$ per million parts of scale, or .4 percent. Note should be made of the fact that the arsenic was present in very fine particles, in suspension, and not in solution, which might have made it more toxic than it would otherwise have been.

In Arizona and elsewhere, water supplies are known to contain 10 parts, or more, of fluorine per million; yet, even when used for both drinking and cooking, the water produces no discernible symptoms in adults. Such fluorine-bearing waters may be used during the entire adult life of an individual with little or no effect on health. In order to cause fatalities, the water would have to contain from 300 to 500 p.p.m. of fluorine. The experience in Ontario demonstrates beyond the shadow of a doubt that arsenic is from 30 to 50 times more toxic than fluorine to human beings and that the two cannot be classed together.

The same conclusions may be reached on biological grounds. Persons who have given thought to man's environment marvel at the fitness which has been acquired through the process of adaptation. Man has literally learned, through countless generations, to live with arsenic and fluorine, and has become adapted to them in proportion to his contacts. Fluorine is about 50 times as abundant as arsenic in the earth's crust, in soils, in plants, and in animals. It is reasonable to conclude, therefore, that man's tolerance of fluorine is perhaps 50 times as great.

## NON-POISONOUS SUBSTITUTES FOR ARSENICALS

Because of their alleged non-poisonous character, organic insecticides are being advocated to some extent as arsenical substitutes. In this class fall pyrethrum, derris, and tobacco. Pyrethrum has only a limited use, for it deteriorates rapidly in the presence of sunlight. Moreover, a large number of workers handling pyrethrum substances in the manufacture of fly sprays have been found to be subject to dermatitis. From 6 to 8 milligrams of pyrethrin per kilogram of body weight is sufficient to cause death when injected intravenously (Swartz, 1934). Derris also is unstable, but somewhat less so than pyrethrum. "The organic stomach poisons, rotenone[1] and the like, are practically all fugitive, temperamental, unstable, almost impossible to standardize, subject to serious deterioration with age and climatic influences." (Metcalf, 1937).

Recent work has shown that derris cannot be classed as a non-poisonous material and in some respects is almost as poisonous as arsenic. Ambrose and Hoag (1936) give the minimum lethal dose of derris for rats as 100 mg. per kilogram of body weight. Their "experiments . . . indicate that rotenone may under certain circumstances be distinctly toxic to warm blooded animals and must therefore be considered as potentially toxic to man." Why nicotine should be classed as non-poisonous is a mystery, since its poisonous character is well known. Recent workers have found that the use of tobacco in smoking affects the circulation. A drop of nicotine will kill a dog.

## FLUORINE IN THE NUTRITION OF PLANTS AND ANIMALS

Fluorine is found in milk, in the yolk of eggs, and in new-born animals. Maze (1914) found fluorine to be essential to the growth of corn. Hutton and Daniels (1925) report: "The addition to milk of those unusual mineral substances present in milk in low concentration, namely, manganese, fluorine, and aluminum together with sodium silicate, has resulted in the production of 5 generations of normal young." When they fed rats exclusively on milk, the animals seldom reproduced. Steinkoenig (1919) points out that fluorine is an "agent of formation and consolidation of the skeletons of all animals. ... Gautier regards fluorine as the agent which fixes phosphorus in the cell to form an organic nitrogenous compound. . . . The constant occurrence of fluorine in the living tissue of both animal and plant and its association with phosphorus is a strong indication that it plays an important role in the life of the cell."

Fluorides are constituents of the teeth and bones, probably existing as highly insoluble fluophosphates. The bones act as storehouses for calcium, which element might be too easily dissipated during lactation if bones consisted simply of calcium phosphate.

Some workers believe that the hardness of teeth is in a measure due to the presence of fluophosphates, and they regard fluorine as an essential element. Recently, Sharples and McCollum, in an attempt to answer this question, fed a diet as nearly fluorine-free as possible. With a diet containing as little as 1 part of fluorine to 10,000,000 parts of the ration, growth was normal, and they conclude,

[1] The active principle of derris.

therefore, that fluorine is not essential in nutrition, at least above a minimum of 1 part in 10,000,000.

In the case of boron, Eaton (1935) found grape leaves showing boron-deficiency symptoms when supplied with solutions having .05 p.p.m. of boron derived from impurities. When the solutions contained 5 p.p.m. of boron, the leaves showed injury. From the above figures it appears that boron and fluorine may be similar, as far as their presence in small quantities is concerned. Until we can obtain a nutrient solution or diet below 1 part of fluorine in 20,000,000, we cannot generalize as to the role of fluorine in nutrition.

Elements that are essential to the health of the animal are retained when the minimum threshold value is reached. Some of our work appears to support this view. The control animals on rice and milk received approximately .6 p.p.m. of fluorine in their diets, or .2 mg. over a period of 5 weeks. With the bones analyzing 36 p.p.m. of fluorine, it appears that all of the fluorine was stored and practically none excreted. Similar evidence may be gleaned from the work of Sharples and McCollum (1933). On their low fluorine diet of .1 p.p.m., the animals ingested about 1/40 mg. of fluorine and the bones analyzed 6 p.p.m., which appears to account for all of the fluorine.

## FLUORINE CONTENT OF BONES AND TEETH

In the higher animals, fluorine is present in all the tissues, but occurs in the largest amounts in the bones and teeth. Additions of fluorine to the diet result in increased deposition of fluorine in bones and teeth. Increased fluorine content of the bones also takes place during the growth of the animal.

The effect of very small additions of fluorine to the diet are not always clearly evident so far as striations on the teeth are concerned. Ellis and Maynard (1936) suggest that analysis for fluorine is a more sensitive measure than enamel pigment. They fed sodium fluoride and bone meal to white rats at a level of 8 to 14 p.p.m. The teeth of the controls averaged 81 p.p.m. Sodium fluoride (8 p.p.m.) in the diet gave 228 p.p.m. of fluorine, while bone meal (8 p.p.m.) gave 220 p.p.m. of fluorine. They conclude that sodium fluoride and bone meal are equally effective in causing these changes. According to Ellis and Maynard (1936), "the fluorine content of the bones and teeth increases with age during growth." A series of teeth from rats 29 to 98 days old showed no regular increase in fluorine content. In fact, the animals 98 days old had only 16 p.p.m. of fluorine, as shown in table 8.

Our own work (table 8) included still smaller quantities than those employed by Ellis and Maynard. The teeth of the controls averaged 36 p.p.m. This is considerably less than the figure reported by Ellis and Maynard and is probably due to the double distillation employed in our work to eliminate phosphate interference (Churchill, 1937).

Cryolite at 4 p.p.m. shows no important differences from the controls, except in the case of one animal, which showed 105 p.p.m. Sodium fluoride at 1 p.p.m. in the drinking-water likewise shows no marked difference, but at 4 p.p.m. the teeth showed up to 273 p.p.m.

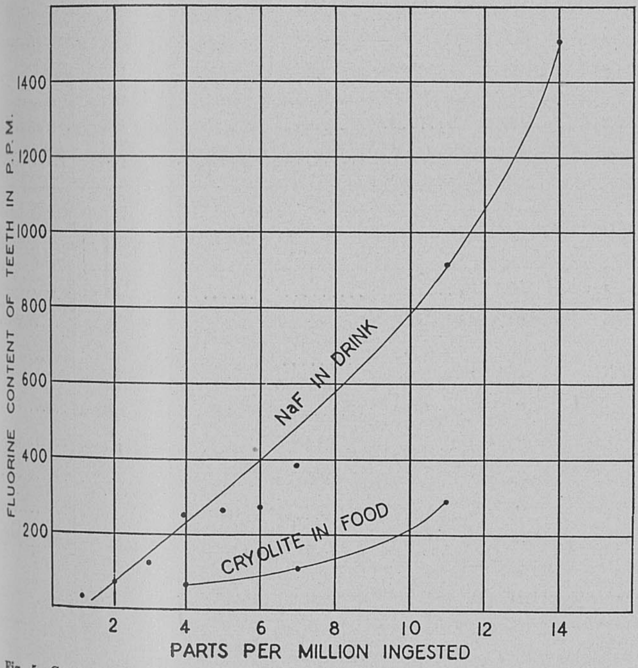


Fig. 5—Comparison of sodium fluoride in drinking-water and cryolite in diet, on the fluorine content of teeth.

Clearly, fluorine in the drinking-water at 4 p.p.m. is more toxic than cryolite at the same level. At 14 p.p.m. of sodium fluoride in the drinking-water, the teeth analyzed 1531 p.p.m. at the end of 12 weeks. It is of interest to note that whereas 1 p.p.m. of sodium fluoride in the drink gave 34 p.p.m., the same amount used for both drinking and cooking increased the fluorine content of the teeth to 121.

Sharples and McCollum (1933) found the bones of rats to contain from 100 to 800 p.p.m., depending on the diet fed. On a very low fluorine diet (.1 p.p.m.), only from 6 to 25 p.p.m. of fluorine was found.

In our work, the control rats with no fluorine supplement showed 36 and 65 p.p.m. of fluorine in the bones (table 9). Sodium fluoride 2 p.p.m. in the drink gave 80 and 95 p.p.m.; cryolite 4 p.p.m. gave

TABLE 8—*Fluorine content of teeth as influenced by various fluorine additions to diet over a period of 5 to 10 weeks.*

| Fluorine in diet | Source | 5 weeks | 6 weeks | 8 weeks | 10 weeks | Notes |
|---|---|---|---|---|---|---|
| p.p.m. | | p.p.m. | p.p.m. | p.p.m. | p.p.m. | |
| ............. | Control[1] | ........ | 27 | 51 | 37 | Average 36 |
| 4 | Cryolite | 48 | 105 | .......... | 32 | ................ |
| 7 | " | 68<br>99 | 96 | 95 | 194 | ................ |
| 7 | NaF | ......... | .......... | .......... | 220 | ................ |
| 11 | Cryolite | 323 | .......... | .......... | 247 | ................ |
| **Fluorine in drink** | | | | | | |
| 1 | NaF | ........ | ........... | .......... | 34 | ................ |
| 2 | " | 65 | 91 | .......... | 48 | ................ |
| 3 | " | 187<br>113 | .......... | .......... | 68 | ................ |
| 4 | " | 127 | .......... | 259 | 273 | ................ |
| 5 | " | ......... | 270 | .......... | .......... | ................ |
| 6 | " | ......... | 274 | .......... | .......... | ................ |
| 11 | " | ......... | .......... | 917 | .......... | ................ |
| 14 | " | ......... | .......... | .......... | 1531<br>483 | ................ |
| **Fluorine in drink plus cooking** | | | | | | |
| 1 | NaF | ......... | 121 | .......... | .......... | ................ |
| 2 | " | ......... | .......... | 148 | .......... | ................ |
| 2 | " | ......... | .......... | 380 | .......... | Beans substituted for wheat and cooked in water with 1 p.p.m. of fluorine |

[1]Control:
1 week ...............45 p.p.m.
2 weeks...............24 p.p.m.
4 weeks.......... ....54 p.p.m.
14 weeks.......... ....16 p.p.m.

104 and 131.3; and cryolite 7 p.p.m. gave 224 and 254.1 p.p.m. of fluorine. The rice-and-milk diet contained approximately .6 p.p.m. of fluorine, and appears to have been nearly all deposited in the bones. With the cryolite at 4 p.p.m. in the diet, only 27 percent was retained.

Bone meal as commonly fed to stock or humans contains from 300 to 500 p.p.m. of fluorine. According to the fluorine values found by ourselves and Ellis and Maynard (1936) and Sharples and McCollum (1933), low fluorine supplements are not appreciably cumulative and do not materially alter the range normally found in control animals.

In view of the fact that the teeth show the first effects of diets supplemented with fluorine, the fluorine content of the teeth is of the most interest and importance.

Ellis and Maynard, using sodium fluoride and bone meal 8 p.p.m. in the diet, found no differences between the two supplements in the fluorine content of the bones and teeth. However, we employed still lower levels, such as 4 p.p.m. of fluorine as cryolite, and the fluorine content of the teeth was not greatly different from that of the controls. These low levels do not appear to be effective in causing tooth changes. This was confirmed by the microscopic pigment observations.

TABLE 9—*Fluorine content of bones as affected by fluorine additions in the diet.*

| Fluorine supplement | Time on ration | Fluorine content |
|---|---|---|
| | Days | p.p.m. |
| Rice and milk, no fluorine........ | 35 | 36.0<br>65.0 |
| Cryolite, 4 p.p.m. ................ | 35 | 104.0<br>131.3 |
| Cryolite, 7 p.p.m. ................ | 35 | 224.0<br>254.1 |
| Sodium fluoride, 2 p.p.m. (in drink) | 35 | 80.0<br>95.0 |

## MODE OF ACTION OF FLUORINE

Fluorides are classed as calcium precipitants because of the formation of the relatively insoluble calcium flouride in the presence of calcium salts. Calcium fluophosphate, however, is much less soluble than calcium fluoride, and where phosphates are present the likelihood of the formation of apatite is suggested. Just why the teeth of fluorine-fed animals exhibit a ringed appearance is not known, but Smith (1934) thinks the explanation may be the intermittent, or night-eating, habit of the rat. Or it may possibly be the variation in the rate of growth of the teeth.

The principal inorganic constituents of bone are calcium, phosphorus, and carbon. According to a theory advanced by Howland and Kramer, these substances diffuse into the interstitial spaces; and if for any cause the carbon dioxide tension falls below normal, there is an increase in alkalinity—a condition that favors the precipitation of calcium salts. The variation in hydrogen-ion concentration might thus explain the striated, or mottled, appearance of the teeth.

Kick (1935) and coworkers report that the teeth of fluorine-fed animals showed increased amounts of magnesium and decreased amounts of carbonates. Morgulis (1931), in examining the bones of marine fishes, also found decreased percentages of carbonates. The bones of marine animals are known to be much higher in fluorine than those of the higher vertebrates on land. It is thus possible that the normal apatite, or calcium fluophosphate, in teeth is replaced by a magnesium fluophosphate.

## FLUORINE CONTENT OF INSECTS

It is known that insects are susceptible to fluorine poisoning, and the question arises as to possible causes. So far as we are aware, our analyses of insects for fluorine are the first ever made. We found that the larvae of the Colorado potato beetle, *Leptinotarsa decemlineata*, have less than 1 part of fluorine per million of body weight. It is likely that other insects contain even smaller amounts. Mammals, on the other hand, show from 40 to 50 parts of fluorine per million of body weight. It thus appears that, compared with higher animals, insects have small amounts of fluorine.

The calcium and phosphorus contents are also small in comparison with those of mammals, as shown in table 10.

TABLE 10—*Calcium and phosphorus contents of potato-beetle larvae.*

| Number of beetles | Live weight | Ash | | Calcium (Ca) | | | Phosphorus (P) | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Weight | Percent of live weight | Weight | Percent of ash | Percent of live weight | Weight | Percent of ash | Percent of live weight |
| | gm. | gm. | | gm. | | | gm. | | |
| 1000 | 107.6 | 1.535 | 1.43 | 0.0455 | 2.96 | 0.042 | 0.2068 | 13.5 | 0.192 |

Potato-beetle larvae contain only .042 percent calcium and .192 percent phosphorus, whereas mammals tend to give values of 1.5 percent calcium and .75 percent phosphorus (Sherman and MacLeod, 1925; Sherman and Quinn, 1926). Here again, much greater stores are shown to exist in the higher animals than in insects; the calcium and phosphorus being located principally in the bones. This fact may be advanced as a plausible reason for the greater resistance of mammals to fluorine.

## EXCRETION

Ingested fluorine is excreted largely by the way of the kidney. Urine examined from 3 individual humans showed 1.8, 1.9 and .6 parts per million of fluorine. Assuming that these figures represent half of the total excretion, it is probable that the diet contained approximately 1 to 2 parts per million of natural fluorine.

With increased doses of fluorine, about ¼ to ½ of the fluorine is retained, the remainder being excreted, largely through the urine. Upon cessation of ingestion of fluorine, the retained fluorine diminishes and is excreted (Roholm, 1937).

Kick and coworkers (1935) found that "approximately 30 percent of the fluorine ingested as 'untreated' rock phosphate, sodium fluosilicate, and sodium fluoride was retained in the body. In the case of calcium fluoride less than 2 percent of the ingested fluorine was absorbed and this was excreted quantitatively in the urine."

## PREVENTION OF MOTTLED ENAMEL BY MEANS OF PHOSPHATES

From the wide distribution of apatite, $Ca_{10}F_2(PO_4)_6$, it is but natural to infer that fluorine has a strong affinity for phosphates. As apatite has a very low solubility (1.5 p.p.m. of fluorine), it may be formed by the addition of tricalcium phosphate to a solution of calcium fluoride. One hundred cc. of a saturated solution of $CaF_2$ (19.93 p.p.m. of fluorine) was reduced to only 3.14 p.p.m. following the addition of 1 gram of dicalcium phosphate, as shown in table 11. When ½ gram of disodium phosphate was added to this mixture, in order to produce a common ion effect, only 1.40 p.p.m. of fluorine was present in solution.

Acting upon the above evidence that apatite or an adsorption complex was formed, we prepared and fed a saturated solution of $CaF_2$ in the drinking-water, to which was added 1 percent $CaHPO_4$, the solution then being filtered. The animals showed no striations from water so treated, whereas only 11 p.p.m. of $CaF_2$ in the drinking-water without phosphates produced distinct striations. With a good grade of tricalcium phosphate, it may be possible to reduce the fluorine content below 1 p.p.m. A commercial concern manufacturing phosphates is said to be engaged now in developing a relatively fluorine-free tricalcium phosphate to be used for the removal of fluorine from water. These results would seem to be of considerable importance, for it may be practicable to remove fluorine from drinking-water and do away with mottled enamel simply by adding a form of inexpensive phosphate. More recently defluorite, or activated alumina, has given good results in the removal of fluorides from natural waters (Swope and Hess, 1937). Elvove (1937) reports that magnesium oxide is both effective and economical for the removal of fluorides in solution.

TABLE 11—*Determination of fluorine in solutions and their removal by phosphates.*

| Material | Fluorine content per cc. | |
|---|---|---|
| | mg. | p.p.m. |
| $CaF_2$ saturated solution | .01993 | 19.93 |
| $CaF_2 + CaHPO_4$ | .003141 | 3.141 |
| $CaF_2 + Ca_3(PO_4)_2$ | .00221 | 2.21 |
| $CaF_2$ ½ saturated + $Ca_3(PO_4)_2$ | .001876 | 1.876 |
| $CaF_2 + CaHPO_4 + Na_2H_2(PO_4)_2$ | .001407 | 1.407 |
| $CaF_2$ ½ saturated + $CaCO_3$ | .003377 | 3.377 |
| $CaF_2$ saturated + $CaCO_3$ | .005812 | 5.812 |
| Apatite ($Ca_5(PO_4)_3$ Cl.F) | .001501 | 1.501 |
| $CaF_2 + CaH_4(PO_4)_2$ | .007973 | 7.7973 |
| Raw rock phosphate, water solubility of | .001219 | 1.219 |

## FINDINGS OF THE ROYAL COMMISSION

We will briefly summarize the Report of the Royal Commission (1900) appointed to inquire into arsenical poisoning, since their findings are the basis of the present arsenical tolerance, which to some extent probably influenced the tolerance of fluorine.

During the latter part of 1900, in Manchester, England, there occurred exceptional sickness and 70 deaths, resulting from the drinking of beer which had become contaminated with arsenic. This arsenic was introduced into the brewing sugars by way of a highly arsenical sulfuric acid, which showed an arsenic content of 1.5 percent. The quantities of arsenic detected in these sugars ranged from .56 to 9.7 grains per pound, while the quantities of arsenic found in the beer ranged from less than ¼ to 3 grains per gallon.

Several physicians studied these cases of poisoning and attempted to determine the range of toxicity by having the beers analyzed. Dr. E. S. Reynolds testified that even in susceptible persons he never noticed that .01 grain of arsenic produced any symptoms. Mr. William Thompson, chemist, testified that more than .01 grain of arsenic represented a contamination. In view of arsenical contamination from the burning of coal, an arsenic-free beer is impossible; but the brewers could without difficulty produce a beer with less than .01 grain to the gallon. In answer to the question "Is it those ideas which have led you to suggest the limit of .01 of a grain?" Mr. Thompson replied, "Yes, and one other—that the smallest quantity of arsenic which has been in beer to which injurious effects have been rightly or wrongly attributed was, I think, double the quantity. Therefore, I think from that point of view I would be on the safe side." Mr. Otto

Hehner, chemist, testified that .01 grain per gallon of beer, calculated back to malt, would come to .01 grain per pound of malt. Since the Committee's method of analysis for arsenic was accurate within .01 grain per gallon, and for the reasons stated, the Committee suggested that the above limit should be fixed. The tolerance is therefore .01 grain per gallon of liquids and .01 grain per pound of solid food. Many of the beer drinkers consumed a half gallon of beer daily, and heavy drinkers up to nearly 3 gallons. Note should be made of the fact that the arsenic in the beer was present as $As_2O_3$ in solution—a form which is known to be nearly 100 times more toxic than the relatively insoluble arsenates used in spraying. The British tolerance, however, gives full recognition to the fact that dissolved arsenic in beer is very toxic:

.01 of a grain per gallon of liquid
(.001 of a grain per pound of liquid)[1]
or
.01 of a grain per pound of food (solid).

The potency of chemicals in solution is strongly reflected in the fact that mottled enamel is also caused by a water solution of a chemical, namely, fluorine. When one takes into account the fact that beer is not used for cooking, while potable waters bearing fluorides are employed for boiling, stewing, baking, and preparing beverages, the difference between parts per million for liquids and parts per million for solids becomes even more pronounced.

## FLUOROSIS—A WATER-BORNE DISEASE

The influence of water in our daily lives is little appreciated. Man's first home was by the waterside. Like the beaver, he needs a plentiful supply of water, drinking liberally several times a day or partaking of beverages such as tea, coffee, or fruit juices. The average quantity required daily by the human body is about 3 quarts. This is derived from the food eaten; from fruit juices; from boiled water, as in tea, coffee, and soup; from a well; or from a city tap. Larger amounts of water are consumed in cooking than in drinking. The recipe for rice calls for 3½ cups of water to ½ cup of rice. A cup of cereal requires 3 cups of water, and is boiled for an hour. Some of the less tender meats require from 3 to 5 hours' simmering and boiling to make them edible. Dried fruits when stewed require much water. The home-canning of fruits and vegetables likewise calls for quantities of water. Even bread requires almost half of its weight in water to prepare it for baking. Water is also added when foods are warmed over. During sickness and convalescence it is a common

[1] A British gallon equals 10 pounds.

practice to use fluid diets, composed largely of broths, soup, and fruit-juice drinks, which are made with quantities of water. In many homes it is the custom to keep a teakettle of water simmering on the stove in order always to have a ready supply of hot water. In some cases the salts in the water precipitate out to such an extent as to necessitate frequent removal of the scale to prevent clogging of the neck of the kettle. We obtained a sample of such scale from a district in Arizona where the fluorine in the drinking-water was 8 p.p.m. This scale yielded 8072 p.p.m. of fluorine, and emphasizes the fact that fluorine may become many times more concentrated than it was in the original water. To see if any effect on the teeth could be obtained, we fed this scale to rats at the rate of 15 p.p.m. of fluorine. Within a few weeks the teeth showed very definite striations.

One part of fluorine per million of water could easily be concentrated in a teakettle to 3 p.p.m. If this same water were used in cooking beans, the fluorine would concentrate 3½ times more by evaporation. The beans would thus have fluorine added, in the process of cooking and boiling, to the extent of 10 to 11 parts per million, from a water supply showing only 1 p.p.m. Since the boiling point of water is lower at the higher altitudes of Arizona than at sea level, a still larger concentration of fluorine might result. Thus, Brown and Picard (1936), in their table showing increased boiling times for different altitudes in Arizona, recommend 50 percent longer boiling at Tucson (elevation 2423 feet) than at sea level. For the higher elevations, from 200 to 250 percent increased boiling time is advised.

An analogous situation, showing how a toxic material like boron in a water supply may become concentrated, is discussed by Eaton in his bulletin on "Boron in Soils and Irrigation Waters": "Transpiration by the plant and evaporation from the soil both serve to increase the concentration of the soil solution above the concentration of the water applied. It is the concentration of salt in the soil solution and not the concentration in the irrigation water which determines plant reactions. The concentration of the different salts in the soil solution may exceed by many times that in the water applied."

Heller (1930) has shown that a material like common salt (sodium chloride) when given to rats in a 1 percent solution to drink, is toxic, while 2 percent of the weight of the grain ration is regularly fed to rats in the standard diets without any ill effect. Dean and collaborators (1934) also found that "Five hundred p.p.m. of sodium flouride in the drinking water produced a relatively greater toxicity than 500 p.p.m. of sodium fluoride in the diet."

It is of interest to note that Smith (1931) observed that mottled enamel is not found among domesticated animals in St. David, Arizona. In this region, mottled enamel is severe among the human population, as the waters have 3.8 p.p.m. or more of fluorine. This also serves to emphasize the fact that fairly large amounts of fluorine, even in the water supply, may be innocuous when the water is used for drinking only, as is the case with animals. Recently, mottled enamel has been observed among cattle in Texas (Dean, 1935).

Dean (1936), of the United States Public Health Service, makes this significant statement: "In the light of present knowledge, mottled enamel is a water-borne disease associated with the ingestion of toxic amounts of fluoride present in the water used for drinking and cooking during the period of tooth calcification." The importance of using fluorine-bearing water for cooking is given no consideration by Smith, in Arizona, except in Technical Bulletin No. 61, in which the following statement occurs: "The use of fluorine-containing water for cooking purposes is not safe if the concentration of fluorine is high. Mottled enamel of the permanent teeth has been observed in children who have used water containing 12 parts per million of fluorine for cooking and other household purposes, but not for drinking."

Recently, Smith and Smith (1935) reported true mottling of the temporary teeth of artificially fed children in a fluorine-water area. They maintain that this must have been brought about during postnatal calcification when the children were receiving milk foods prepared with fluorine-containing water.

McKay (1932), who has had wide experience with mottled enamel and was the first to associate the enamel defect with water, also mentions the importance of cooking as follows: "Upon the assumption of ½ gallon water intake per day, a person in an area supplied with water containing 1 p.p.m. fluorine would receive 1.89 mg. per day. Let us not fail to include also what would be received through foods cooked in the same water." Following is an excerpt from a private communication of Dr. McKay: "The defect of the teeth known as mottled enamel is not produced in so far as my knowledge is concerned in any other way than by the ingestion during the years of enamel calcification of water containing one or two parts per million fluorine. This small dosage must necessarily continue over a long period of time reckoned in months, and I cannot conceive that any given individual is likely to receive enough fluorine in constant dosage from fluorine-sprayed fruit to produce this defect of the enamel."

## AGE LIMIT OF SUSCEPTIBILITY TO MOTTLED ENAMEL

There is a definite age limit to the production of mottled enamel by fluorides. After the teeth are calcified they are no longer susceptible. It seems that fluorine exerts its action on the enamel-forming cells, which disappear after the tooth is formed. According to Logan and Kronfeld (table 12), authorities on the chronology of human dentition, the first evidence of calcification in the incisors is from 3 to 4 months after birth, excepting the superior lateral, which begins its calcification at the age of one year. The crowns of all the incisors are completed during the fourth and fifth years, erupting several years later. The bicuspids and first molars complete their calcification of the crowns by the seventh year, and the second molars by the eighth year. There is thus a definite age limit within which humans may develop mottled enamel, when toxic amounts of fluorine used for both drinking and cooking must be ingested.

TABLE 12—*Chronology of the human dentition (permanent)*
(Logan and Kronfeld)

| | Tooth | First evidence of calcification | Crown completed |
|---|---|---|---|
| Upper jaw | Central incisor | 3 -4 mos. | 4 -5 yrs. |
| | Lateral incisor | 1 yr. | 4 -5 yrs. |
| | Cuspid | 4 -5 mos. | 6 -7 yrs. |
| | First bicuspid | 1½-1¾ yrs. | 5 -6 yrs. |
| | Second bicuspid | 2 -2¼ yrs. | 6 -7 yrs. |
| | First molar | At birth | 2½-3 yrs. |
| | Second molar | 2½-3 yrs. | 7 -8 yrs. |
| | Third molar | 7 -9 yrs. | 13 -16 yrs. |
| Lower jaw | Central incisor | 3 -4 mos. | 4 -5 yrs. |
| | Lateral incisor | 3 -4 mos. | 4 -5 yrs. |
| | Cuspid | 4 -5 mos. | 6 -7 yrs. |
| | First bicuspid | 1¾-2 yrs. | 5 -6 yrs. |
| | Second bicuspid | 2¼-2½ yrs. | 6 -7 yrs. |
| | First molar | At birth | 2½-3 yrs. |
| | Second molar | 2½-3 yrs. | 7 -8 yrs. |
| | Third molar | 8 -10 yrs. | 12 -16 yrs. |

## FOOD OF CHILDREN

We have discussed the numerous ways in which water may be consumed in daily life. We will now consider the food of children. During the first year of a baby's life, the food generally consumed is milk, either alone or modified by water. Boiled water is given between meals. For the first 2 years of life, raw sprayed food does not enter the diet. On the other hand, when a water supply containing fluorides is employed, large quantities are consumed, even during the first 2 years of life, through drinking and cooked foods.

Children up to 3 or 4 years are still largely incapable of eating raw apples; and when attempts are made to eat them, the core and stem and calyx ends, which contain most of the spray residue, are usually discarded. Generally the apples are peeled, or consumed as apple sauce. For the first 8 years of life, when the child is most susceptible, it does not come into contact with fluorine spray residues to an appreciable extent. On the other hand, to avoid large intakes of fluorine in a mottled-enamel area, other methods than boiling or cooking a child's food should be practiced. A minimum amount of fluorine will be concentrated if the food is baked, parboiled, steamed, or fried.

## INCIDENCE OF MOTTLED ENAMEL

The incidence of mottled enamel and the percentage distribution of its severity have been studied by Dean (1936). Waters with fluorine in amounts not exceding 1 p.p.m. are of no public-health significance. Dean observes: "From the continuous use of water containing about 1 part per million, it is probable that the very mildest forms of mottled enamel may develop in about 10 percent of the group."

Formerly it was believed that children who drank water containing as little as 1 p.p.m. of fluorine would, without exception, have mottled teeth. According to Dean, however, there are 90 percent possible exceptions with a water supply containing 1 p.p.m. of fluorine. Dean further states: "In waters containing 1.7 or 1.8 parts per million, the incidence may be expected to rise to 40 or 50 percent, although the percentage distribution of severity would be largely of the 'very mild' and 'mild' types." It is noteworthy that even with 4 parts per million the incidence is only 90 percent—and some children escape mottled enamel altogether. A probable explanation is that some families do less cooking than others, and consequently swallow less fluorine. This tends to support the data obtained in our work with rats, which indicates that 3 or 4 p.p.m. of fluorine, added in the drinking-water only, is required to produce faint striations. When a water supply contained 4 parts of fluorine per million, about 60 percent of the children showed moderate to severe mottling. In these cases, probably more cooking was practiced, resulting in greater concentration.

## THE PROBLEM OF THE INSECT MENACE

From tales told by explorers who were completely deprived of fresh fruits and vegetables, we get some appreciation of the value of these foods. We have fresh fruits and vegetables throughout the year—an advantage that our parents could hardly have dreamed of. This has been made possible by the development of transportation, refrigeration, and insect control. The full benefits of the recent discoveries of vitamins and minerals in fruits and vegetables, and their value in the diet, thus become capable of realization. But even our milk supply, which nutritionists are agreed is most essential for the proper development of the young, is continually in danger of pollution from flies.

Few people not directly concerned realize the constant and relentless warfare that the agriculturist must wage against hordes of injurious insects in order to arrest their remarkable productivity. To aid him in his efforts to preserve our food supply, the farmer looks to the entomologist. Long before the pink apple flowers make their appearance, a battle has been fought against the San Jose scale by means of oil sprays. With the resumption of growth in the spring, the tree is beset by lice, caterpillars, weevils, worms, and other pests too numerous to mention. The entomologist, by studying the habits of insects and devising spray practices, helps the farmer to cope with all these destructive competitors. Spraying adds to the cost of apples, so that only a small proportion of the people of our country get enough apples to eat.

Certain agencies, posing as confidential consumers' guides, object to spraying on the ground that it involves danger of poisoning. Lead and arsenic especially are condemned, as well as "other poisonous insecticides which leave dangerous residues," such as "fluosilicates, fluorides, zinc compounds, mercury, magnesium, manganese, selenium compounds . . . ."

Such statements, when made without qualification, are misleading. Mercury is not used on edible portions of plants. Magnesium is an important element naturally present in many foods, to the extent of several thousand parts per million. According to Sollman, magnesium is not sufficiently absorbed by the alimentary tract to cause toxic effects. The traces found on plants in added form would be much too small to note. Manganese is an essential element, and, according to Sollman, manganese salts administered by mouth produce no noticeable effects. Zinc is another essential element, and the same authority states that no systemic effects are produced under therapeutic conditions. As to fluorides and fluosilicates, this bulletin points out that the danger from eating fluorine-sprayed apples is negligible.

One point must be clearly understood, so far as spray residues are concerned, and that is that the only clear-cut evidence against

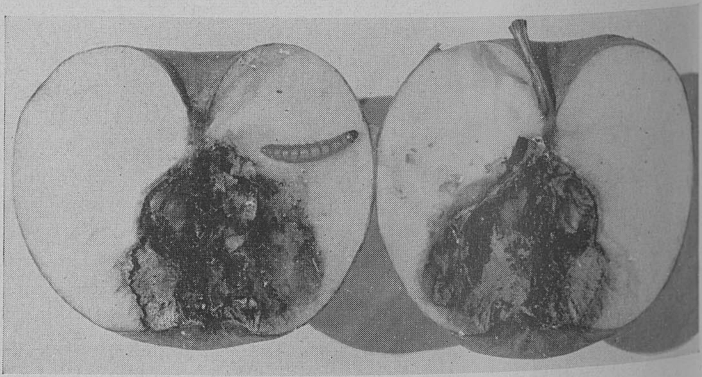

**Fig. 6—Work of the codling moth on an apple from an unsprayed tree.** Such an apple does not have a palate appeal. According to H. W. Wiley, the offering of apples for sale that are infected by insect life is a form of adulteration.

minute amounts of lead, arsenic, or flourine has come through the ingestion of these elements in liquid form. When lead pipes are used for water-carrying, or arsenical beer is swallowed, or fluorine-bearing water is used for drinking and cooking, then small amounts are definitely harmful. There is an erroneous tendency, when the cause of slight fevers and stomach disorders is unknown, to attribute them to spray residue.

On the other hand, H. W. Wiley, author of the Pure Food Law, in his book on "Foods and Their Adulteration," calls attention to a form of adulteration consisting of worms in apples. He says: "The chief forms of debasement . . . consist in offering apples which are infected by insect life." The advantage in having fruit to eat appears to be more than sufficient to counterbalance the trouble and expense of modern spray and washing practices. This view is expressed by Schuette (1933) in these words: "Obviously a malformed, scarred or 'inhabited' piece of fruit or vegetable does not carry the sales or palate appeal of one without these blemishes, when all other factors are equal. And so, it seems, it is a situation that cannot be avoided because of a fear of eating and being poisoned—rather it is one of poisoning that one may eat." Insecticides are essential if we are to have an adequate supply of good fruit at reasonable prices, and restrictions on their use should be no more severe than is necessary to protect human health.

## ARE CRYOLITE-SPRAYED FRUITS INJURIOUS TO HEALTH?

According to the Food and Drug Act of 1906, an article of food is considered adulterated if it contains any added poisonous or other deleterious ingredient which may render such article injurious to health. The question we are concerned with, therefore, is whether foods which have been sprayed or dusted with fluorine salts, such as cryolite, in order to protect them against insects, are injurious to health.

From experimental work described in the foregoing pages, it appears that 4 p.p.m. in the total diet, or .4 mg. of fluorine per kilogram of body weight, is not injurious to the teeth or health of the animal. For a 30-pound child this is equivalent to 6 mg. per day. Analyses of cryolite-sprayed apples show that if they are not washed, average residues of 6 parts per million, or 2.5 mg. per pound, may be expected. One apple might contain nearly 1 mg. of fluorine. Children are in the habit of throwing away the core and the calyx and stem ends, where most of the residues are located. But even if a child ate all of the apple, and an allowance of ½ mg. for sprayed cabbage or celery were made, a total of only 1½ mg. of fluorine per day might be consumed on sprayed fruits and vegetables.

In the case of a benzoic acid investigation, the Referee Board of consulting scientific experts, with Ira Remsen (1909) as chairman, used 300 grams of benzoated food per day for each subject. This amount represents about 20 percent of the total diet. In actual practice, sprayed food would constitute much less than 20 percent of the diet. Still, if we assume that 20 percent of the diet is sprayed with fluorine, we have 20 parts per million, which would not be injurious to health. As a matter of fact, such a quantity would not be likely to occur under practical conditions. Oranges contain .2 parts per million of fluorine. One lot of oranges dusted with cryolite when they were small had no detectable amounts of added fluorine in the juice or rind. To prohibit the use of cryolite on oranges because of imaginary danger is absurd. The only possible conclusion we can draw is that the spray residues on fruits and vegetables sprayed with cryolite have no deleterious or poisonous effect and are not injurious to health.

## CONCLUSION

In this study we have attempted to gather such scientific data and information as would furnish us with an answer to the question: Do fruits and vegetables which have been sprayed with cryolite contain any added poisonous or deleterious ingredient that may render such foods injurious to health? Our work with white rats, which were found to be as susceptible to mottled enamel as human beings, indicates that in the case of most of the animals a daily dose of .4 mg. of fluorine (as cryolite) per kilogram of body weight, or 4 parts per million in the total diet, will not produce striations on the teeth. Assuming that 20 percent of the diet is sprayed, apples with from 5 to 10 p.p.m. of fluorine will not be injurious. A child weighing 30 pounds requires about 6 mg. of fluorine daily to produce a mild case of mottled teeth, whereas in practice a possible average total of only 1½ mg. of fluorine may be ingested from sprayed fruits and vegetables.

One part of dissolved fluorine per million in a water supply is at least 10 times as toxic as the relatively insoluble powdered form occurring as spray residue. This is due in part to the fact that water is used for cooking, which concentrates the fluorine. The British tolerance of .01 grain of arsenic per gallon of beer recognizes the greater toxicity of liquids, even though beer is not used for cooking.

In addition, the high temperatures of the summer months, especially in arid states, necessitate a vast consumption of water, ranging from 7 to 13 liters, or more, per day. Assuming that 10 percent of our food may be sprayed, the consumption of water is more than 30 times as great as that of sprayed food. Under such conditions it is easily possible to swallow enough fluorine to cause tooth mottling when using a water supply containing 1 part per million of fluorine. The situation is aptly stated by Dean, of the Public Health Service, as follows: "In the light of present knowledge, mottled enamel is a water-borne disease associated with the ingestion of toxic amounts of fluoride present in the water used for drinking and cooking during the period of tooth calcification."

Practical experience points in the same direction. People have been consuming foods containing from 1 to 12 parts of fluorine per million for countless generations; yet no one is known to have suffered from tooth mottling except when the fluorine was ingested in the water supply. Marine foods, such as salmon and sardines, contain from 4.5 to 7.3 p.p.m. of fluorine. People have always eaten bones and bone meal (containing 450 p.p.m. or more) without harm and have benefited by the calcium and phosphorus supplied. Eskimos, who subsist largely on fish, have excellent teeth.

Our studies indicate that the present tolerance of .01 grain per pound of foodstuffs, or 1.4 p.p.m., is not based on fact, but was applied arbitrarily, and should be raised.

From the data obtained, it is concluded that in cryolite we have the long-sought-for arsenical substitute—a material that is reasonably safe to human health in the quantities used for spraying fruits and vegetables, is an effective insecticide, is harmless to foliage, and economical in price.

## SUMMARY

Certain fluorine compounds are now in use as arsenical substitutes for the control of insect pests. A study was made of the toxicity of cryolite in the amounts occurring as spray residues on fruits, and the relation of these residues to human health.

The white rat was used in evaluating the toxicity of cryolite and other fluorine compounds. The incisors were removed and examined with a binocular microscope, with the aid of a daylight lamp. In the previous work of Smith (1935) the amount of fluorine swallowed in cooking was not taken into account. Starting with water which contained 1 p.p.m. of fluorine, and cooking the grain to dryness, we obtained a product with 2.3 p.p.m. of added fluorine. When such water was also used for drinking, and the above technic was followed, levels of fluorine close to 1 p.p.m. could be detected. The rat is thus shown to be as sensitive as human beings to fluorine, so far as the production of striations on the teeth is concerned.

When the fluorine compounds were used as powders in the whole diet, the lowest levels that produced striations in some of the animals, in parts of fluorine per million, were as follows: Cryolite, 7; sodium fluoride, 7; calcium fluoride, 15.

When water was used for drinking only, sodium fluoride produced striations at 4 parts of fluorine per million.

When the water was used for both drinking and cooking, as described above, sodium fluoride in a concentration of 1 to 2 parts of

fluorine per million produced faint striations. At 2 parts per million, the effect was more pronounced.

The average daily water intake of the white rat is about 10 cc. at a temperature of 78° F. This may be increased to 27 cc. at 98° F. The average intake of water for human beings is from 4 to 8 glasses a day in cool weather. This may be increased to from 7 to 13 liters or more per day in hot, dry climates.

All foods and beverages examined contained more or less fluorine, ranging up to 7.5 p.p.m., or more. Phosphate baking powders analyzed 282 p.p.m.; sardines with bones, 7.3 p.p.m.; tea, 67-80 p.p.m. Baby foods containing 2 percent bone meal showed 12 parts per million of fluorine.

The studies on acute toxicity show that for potassium arsenite 5 mg. per kilogram of body weight is the minimum lethal dose for dogs, while sodium fluoride has an M. L. D. of 200 mg. per kilogram. An acute dose of cryolite appears to be incapable of causing death, as 13,500 mg. per kilogram was fed without fatality.

On a chronic basis, the smallest amount of fluorine as cryolite that will affect teeth is .7 mg. per kilogram, while arsenic trioxide will interfere with growth in amounts as small as .00005-.0015 mg. per kilogram. Fluorides are therefore at least several hundred times safer than arsenic. This is also indicated by the fact that 9.8 p.p.m. of arsenic in a water supply caused death in a few months, while the same amount of fluorine produces no visible effect on adults.

The teeth of control animals with no fluorine additions averaged 36 p.p.m. of fluorine. Four p.p.m. of fluorine added in the form of cryolite showed no important difference, while the same amount in the drinking-water as sodium fluoride raised the fluorine content to 273 p.p.m. One p.p.m. of fluorine in the drinking-water showed 34 p.p.m. in the teeth, while the same water used also in preparing a cooked diet showed 121 p.p.m. in the teeth.

On plants, monovalent salts increased the toxicity of sodium fluoride used in the water supply, while phosphate fertilizers antagonized the effect of a 1-1000 solution of sodium fluoride.

Fluorides act as calcium precipitants in the body, with the probable formation of apatite or a fluophosphate of calcium or magnesium.

Tricalcium phosphate, when placed in a dilute solution of calcium fluoride containing 20 p.p.m. of fluorine, is capable of reducing the fluorine content to 1.5 p.p.m., or below. This may offer a simple, practical means of removing fluorine from drinking-water where no other methods are available.

The British tolerance on arsenic is .01 grain per pound of foodstuffs, or .01 grain per gallon of beer, thus clearly recognizing the greater toxicity of a liquid poison. A similar recognition for fluorine would prevent the confusion that now exists, and raise the tolerance to .1 grain per pound of foodstuffs.

Fluorosis is a water-borne disease, endemic in hot, arid climates, where well water is used. In summer, large quantities of water are required for cooling the skin by evaporation. Large amounts of fluorine-bearing water are also used in cooking, which concentrates the salts. A sample of teakettle scale from Arizona was found to test 8072 parts of fluorine per million, and when fed to rats at the rate of 15 p.p.m. produced tooth striations.

Results of our investigation indicate that in practice, fluorine-sprayed fruits or vegetables cannot be injurious to health. The present tolerance of .01 grain of fluorine per pound of foodstuffs was determined upon arbitrarily because of the lack of a factual basis. With the information now available, there seems to be sufficient ground for contesting the validity of the present tolerance on fluorine.

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