Strontium-90 Absorption by Deciduous Teeth

Analysis of teeth provides a practicable method of monitoring strontium-90 uptake by human populations.

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In 1958 Kalckar proposed that deciduous teeth collected on a large-scale, world-wide basis could be used to study the accumulation in children of radioactive material from nuclear test fallout (*1*). Strontium-90, which follows the metabolic pathways of calcium, is deposited in bones and teeth. Absorption is greatest during the period of growth. Thus, children, who presumably have a higher biological radiosensitivity than adults, accumulate the radioisotope more readily. The amount of radiation delivered to bone marrow, with possible effects in leukemogenesis, is important.

Monitoring strontium-90 absorption in children is made difficult by the scarcity of adequate bone samples, which must be obtained at autopsy. By contrast, deciduous teeth, which have a chemical composition similar to bone, are plentiful and should be readily available for study.

While the suggestion that teeth could be used for monitoring strontium-90 uptake in bones was soundly based on then available information, at the start the feasibility of such a project was not clear. There was doubt whether the community cooperation required by a large-scale collection program could be obtained. How large the samples of teeth would have to be to yield meaningful data was not known. Although similarities of strontium and calcium metabolism in teeth and bones were suspected, there was no direct evidence that teeth and bones developing in the same biologic environment accumulated these minerals in the same ratio. In addition, the relative effects of prenatal and postnatal tooth development on strontium-90 deposition might introduce difficulties in interpreting the data.

The present article is addressed to these questions. The results reported show that deciduous teeth can be usefully employed as a means of monitoring strontium-90 uptake in man.

Tooth-Collection Program

The decision to start a tooth collection from the St. Louis area was reached in December 1958 (*2*). There was a great sense of urgency about starting the collection, since teeth that were then being shed were formed before significant fallout had occurred and thus were expected to yield essential baseline information. An empirical yearly goal of 50,000 deciduous teeth of all types was set.

Since this number represented an appreciable fraction of the total number of teeth shed by the juvenile population of St. Louis, the cooperation of the community was required. Sponsorship of the tooth survey was undertaken by a citizens' group, the Greater St. Louis Citizens' Committee for Nuclear Information (*3*) in cooperation with the schools of dentistry at Washington and St. Louis Universities (*4*). In order to explain the purposes of the survey to the public without arousing alarm as a result of misunderstanding, a program of community education in the area of nuclear energy was conducted by speakers of the committee. Community health officials, the St. Louis Dental Society, private dentists and dental clinics, all school superintendents, librarians, the St. Louis Pharmaceutical Association, and many church, YMCA, YWCA, and Scout groups supported the program. Newspapers and radio and television stations generously provided publicity as a public service.

In order to obtain the necessary data relevant to environmental factors that might affect the uptake of strontium-90 by teeth, certain background information was requested with each tooth submitted. The standard form included questions concerning the child's date of birth, the date the tooth was lost, the residence of the mother during pregnancy, the residence of the child during the first year of life, duration of breast feeding, duration of formula feeding, kind of milk used in the formula, and other milk used during the first year. The questionnaire was a detachable section of the form and became a permanent record card for each tooth.

One million tooth survey forms have so far been distributed through schools, libraries, dental organizations, dentists, pediatricians, and other agencies. After a tooth, with background information, has been received by mail, the donor is sent a button ("I gave my tooth to science") and a new information form. Teeth are then cataloged by members of the Women's Auxiliary of the St. Louis Dental Society. Each tooth is unwrapped and placed in a separate, numbered envelope. This file number is added to the corresponding record card, which is checked for completeness. Parents are contacted by telephone and asked to supply missing information. When several teeth from the same child arrive with a single form, additional cards are prepared. A pedodontist (*5*) then examines each tooth and records the type and the presence of caries, amalgam, or root on the record card. Teeth are stored by number. Record cards are filed in categories according to month of birth, type of tooth, type of infant feeding (breast or bottle), and presence or absence of caries.

The dissemination of forms, cataloging, record keeping, and filing involved a great deal of labor, which was accomplished with the aid of large numbers of dedicated volunteer workers (*6*). The only salaried person was a secretary.

In the 2½ years since January 1959, 61,000 teeth have been collected. Of these, 14,500 were obtained in 1959, 27,000 in 1960, and 19,500 in the first

The author, an internist, was vice-president and director of the Baby Tooth Survey, Greater St. Louis Citizens' Committee for Nuclear Information, 1959–1961.

Table 1. Concentration of strontium-90 in three pools of teeth and bones obtained from stillborn infants. The bones were analyzed individually, and the errors indicated reflect the standard errors derived in the separate analyses. Only one analysis could be made for each pool of teeth; the errors refer to standard deviations due to analytical errors.

Pool	Number of infants	Concentration ($\mu\mu c$ of Sr^{90} per gram of Ca)	
		Bone	Tooth pool
A	10	1.04 ± 0.105	1.55 ± 0.09
B	15	1.22 ± 0.119	1.08 ± 0.08
C	18	1.27 ± 0.123	1.14 ± 0.08

half of 1961. At the present collecting rate, 750 teeth are received, on the average, every week.

Approximately 10 percent of the teeth received thus far were sent from beyond the confines of the geographical area under study, which included Greater St. Louis and environs within 100 miles. Another 15 percent came from children who had lived elsewhere at the time of birth. Over 95 percent of the local teeth were accompanied by all the background information requested on the form.

Of 20,439 teeth collected from children born in the St. Louis area during 1959 and 1960, there were 11,656 incisors, 2652 cuspids, 3161 first molars, and 2967 second molars. The peak birth years for child donors of incisors were 1952 and 1953. For donors of cuspids and first and second molars, the peak year of birth was 1950. The percentages of those breast-fed for 1 month or longer were 29, 50, 54, and 38 percent, respectively, for donors of incisors, cuspids, first molars, and second molars. The incidence of caries among incisors was 5.4 percent; among cuspids, 15.2 percent; among first molars, 67.1 percent; and among second molars, 78 percent. No difference in the incidence of caries in breast- and bottle-fed groups was noted.

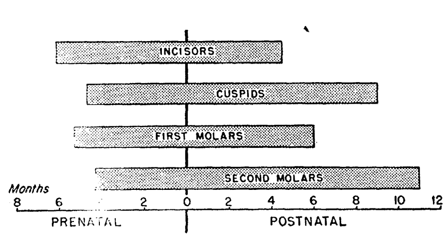

Fig. 1. Approximate periods of calcification of deciduous teeth by types. [Based on a table by Schour and Massler (*19*) and modified in accordance with recent studies of Kraus (*8*)]

Strontium-90 Analyses of Shed Deciduous Teeth

After calcification, tooth enamel is a nonviable structure that can be altered only be mechanical means and by ion-exchange from surface contacts or permeation (*7*, p. 91). Dentin continues to be laid down in very small amounts during the life of the tooth (*7*, p. 139). For all practical purposes, however, the tooth may be considered a stable structure and can thus be expected to retain the mineral composition acquired at the time of its formation. The deciduous tooth, therefore, promises to provide information concerning the amount of strontium-90 uptake during the year of the donor's birth, some 5 to 12 years prior to the time of shedding.

Calcification begins after the 12th intrauterine week (*8*) and becomes complete during the first year of life (*7*, p. 45). The exact calcification period is still in doubt, and much individual variation occurs (*8*). Approximate periods of calcification are shown in Fig. 1. Root development continues after the first year, but since the root is resorbed before shedding, this time period is not involved in the study of shed teeth.

In the study under discussion, incisor teeth from children born during the last two quarters of the years 1951 through 1954 were analyzed, if the mothers had spent the prenatal period in St. Louis and the children had lived in the area during the first year of life. Severely decayed teeth and teeth of children fed milk substitutes were excluded. The number of teeth from one child was limited to two per sample. The child donors of teeth in samples designated "breast-fed" had been breast-fed for 1 month or more; donors of teeth in samples designated "bottle-fed" had received no breast milk.

Root material was removed from each tooth by grinding off all fragments below the cervical region of the tooth. Small decayed areas and amalgam were ground off. These were present in about 3 percent of the teeth. For studies of teeth from donors born in the years before 1953, a sample weighing about 12 grams, comprised of about 90 incisor teeth, was used. Because of the substantial increase in environmental strontium-90 in 1953 and later, the sample size was reduced in studies of teeth from donors born in 1953 and 1954 (Table 1).

For each quarter studied, equal numbers of teeth for the three component months were pooled. The teeth were selected at random from all teeth in the collection that fulfilled the requirements of the sample.

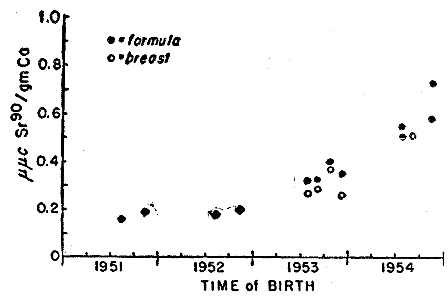

Fig. 2. Early time course of deposition of strontium-90 in deciduous teeth. The unexpectedly small difference between findings for teeth of formula-fed and teeth of breast-fed children may reflect the relatively brief period of breast feeding in some samples.

All strontium-90 analyses were made at Isotopes, Incorporated, Westwood, New Jersey, by a modification of the method of Volchok (*9*).

The data are shown in Fig. 2 and Table 2. The upward trend with time may be correlated with increasing dietary concentrations of strontium-90.

A small fraction of the strontium-90 in normally shed teeth is undoubtedly added after tooth formation has been completed. A high degree of permeability of intact enamel and dentin to urea has been demonstrated by Wainwright and Lemoine (*10*). Armstrong and Barnum (*11*) reported calcium-45 and phosphorus-32 in the teeth of mature animals shortly after administration of the tracers. The extent to which strontium-90 may appear in teeth as a result of exchange phenomena is not

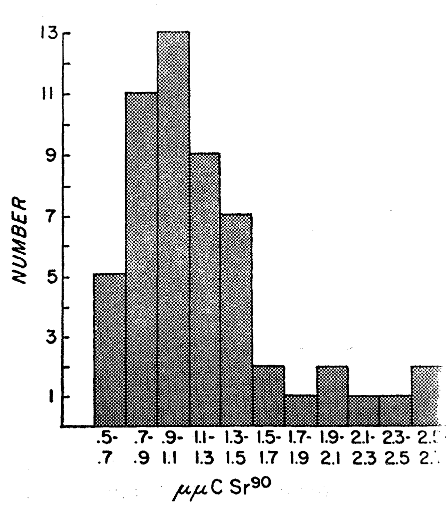

Fig. 3. Frequency distribution of strontium-90 concentration in fetal skeletons.

clear at present. The concentration of approximately 0.18 micromicrocurie per gram of calcium in 1951 and 1952 undoubtedly represents a maximum estimate for this mode of strontium-90 accretion, since some environmental strontium-90 was already present in these years.

It had been expected that the concentration of strontium-90 would be lower in deciduous teeth of breast-fed than in those of bottle-fed donors. A recent study by Lough, Hamada, and Comar (*12*) showed that the ratio of strontium-90 to calcium in breast milk was only one-tenth that in the mother's diet. Furthermore, Widdowson *et al.* (*13*) have recently reported negative strontium balances in breast-fed babies. For these reasons, the finding of comparable concentrations of strontium-90 in teeth of bottle-fed and breast-fed children was surprising, and additional studies are indicated. In only one sample (Table 2, No. 11) did there appear to be a substantial difference. The duration of breast feeding was 6 months or longer for 35 percent of the tooth donors represented by this sample. For other samples, only 15 to 21 percent of the donors had been breast-fed for this length of time. In future studies, the requirement of a minimum period of breast feeding of 4 months for donors of samples designated "breast-fed" may magnify differences that are barely suggested in the initial study.

Table 2. Concentrations of strontium-90 in deciduous teeth.

Sample No.	Date of birth		Infant feeding	Number of teeth	Weight of sample (g)	Calcium (g)	Strontium-90 (μμc per gram of Ca)
	Year	Quarter					
1	1951	3	Formula	90	11.67	3.31	0.155 ± 0.029
2	1951	4	Formula	90	13.80	3.66	0.193 ± 0.029
3	1952	3	Formula	90	12.31	3.45	0.188 ± 0.021
4	1952	4	Formula	90	10.18	2.84	0.204 ± 0.036
5	1953	3	Formula	90	9.23	2.60	0.324 ± 0.030
6	1953	3	Formula	75	9.15	2.67	0.320 ± 0.050
7	1953	3	Breast	66	8.88	2.34	0.270 ± 0.050
8	1953	3	Breast	72	9.59	2.70	0.286 ± 0.025
9	1953	4	Formula	75	8.48	2.47	0.40 ± 0.030
10	1953	4	Formula	78	8.33	2.26	0.357 ± 0.034
11	1953	4	Breast	66	7.75	2.27	0.260 ± 0.040
12	1953	4	Breast	72	8.27	2.33	0.369 ± 0.025
13	1954	3	Formula	72	7.06	2.02	0.500 ± 0.070
14	1954	3	Formula	81	8.13	2.32	0.545 ± 0.035
15	1954	3	Breast	75	8.06	2.24	0.509 ± 0.042
16	1954	3	Formula	75	8.11	2.28	0.581 ± 0.025
17	1954	3	Formula	78	7.71	2.15	0.725 ± 0.058

Comparison of Strontium-90 Uptake by Teeth and Bone

If the concentration of strontium-90 in teeth is to serve as an indication of the concentration in bone, it is important to know the relative rate of uptake of strontium-90 and calcium by teeth and bones developing in the same biological environment. This information was sought by comparing the ratios of strontium-90 to calcium in teeth and in bones of stillborn infants (*14*).

Deciduous teeth were dissected from the jaws of 43 stillborn infants with crown-to-heel measurements ranging from 19 to 21 inches. The teeth were air-dried to a constant weight, and three pools of teeth were prepared. Within a given pool each fetus contributed an equal weight of tooth material.

The bones were freed of much soft tissue, by dissection, and heated in water at 170°C for 5 hours. The remaining soft tissue was then removed manually, and the bones were dried for 5 hours at 220°C. Total skeletons were analyzed individually. Three skeletons were analyzed in three parts: skull, long bones, ribs and vertebrae.

In Table 1, the mean level of strontium-90 in the individual fetal skeletons is compared with the concentration of strontium-90 in the corresponding tooth pools. There was a close correlation in the concentration of strontium-90 in bones and in teeth, and deviations from a 1-to-1 ratio appeared to be random.

The total skeleton and the teeth of one 7-month-old infant born in February 1959 were analyzed separately. A bone level of 4.5 μμc and a tooth level of 3.9 μμc of strontium-90 per gram of calcium were found. The difference in concentration probably results from a relatively greater postnatal increment of bone than of tooth, as discussed later.

A comparison of strontium-90 levels found in the skull, in the long bones, and in the ribs and vertebrae of three skeletons is shown in Table 3. The variation is random and falls within the analytical error of the method. This is in agreement with the findings of Schulert (*15*) and Kulp (*16*), who reported a uniform distribution of strontium-90 in bones of infants and children.

The frequency distribution for strontium-90 concentration in the total fetal skeletons is given in Fig. 3. In conformity with previous studies (*16*), the distribution is skewed towards the higher concentration. The data are shown in scattergram form in Fig. 4.

In an effort to determine what factors contribute to the observed variations in strontium-90 levels in fetal bone, the dietary histories of mothers of stillborn infants born in 1959 and 1960 were analyzed. Hospital records were abstracted by a trained social worker, who then interviewed the 28 mothers who could be located.

No correlation could be found between milk intake and strontium-90 levels in the infants' bone, or between findings for groups on poor and on adequate diets. A diet was classed as poor when it was grossly deficient in both calcium and protein. Nearly all the mothers ate fresh green vegetables daily, especially turnip and mustard greens. The wide variation in fetal-bone levels found during the summer months may be related to the increased and more varied consumption of fresh leafy vegetables. It is interesting to note that the lowest strontium-90 level (0.53 μμc per gram of calcium) occurred in the stillborn infant of a 28-year-old mother who subsisted chiefly on a diet of white bread and meat. She drank no milk, ate no cereals, and ate vegetables or fruit once a week.

Only three of the mothers took supplemental calcium during pregnancy. No correlation with fetal levels of strontium-90 could be found.

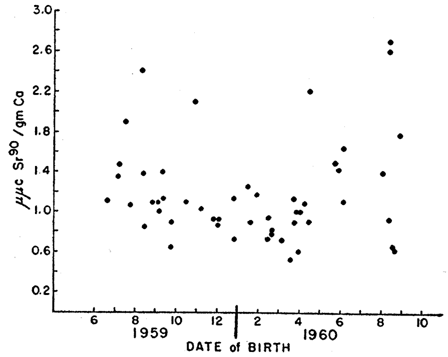

Fig. 4. Scattergram relating strontium-90 concentrations in fetal skeletons to time of birth.

Prenatal Tooth Formation

Since the portion of the deciduous tooth formed prenatally accumulates less strontium-90 than the portion formed postnatally, owing to placental discrimination against strontium (*17*), it is important to know how much of the tooth is formed prenatally. This was determined from the average weights of the four tooth types at birth and at the time of shedding.

Teeth from 33 full-term stillborn infants were dried to a constant weight and weighed individually. The gestational period of the fetus was determined from the hospital chart and the crown-heel length. For comparison, noncarious shed teeth were weighed. All root material was removed to the neck of the tooth so that the tooth would be representative of shed teeth as used for strontium-90 analysis. The average weight of 69 pooled upper central incisors and of 106 pooled upper lateral and lower incisors was determined; 50 cuspids, 50 first molars, and 50 second molars were weighed individually.

The results of these weighings are given in Table 4. The measurements show that in shed, rootless teeth, 32 percent of the average incisor, 6 percent of the cuspid, 17 percent of the first molar, and 5 percent of the second molar are formed prenatally.

These values do not allow for abrasion of deciduous teeth—a consideration which Bryant (*18*) mentions as a disadvantage in using these teeth for monitoring purposes. Only loss of the prenatally formed portion would affect the relationships given in Table 4. Since enamel deposition begins at the dentin-enamel junction and proceeds peripherally (*7*, p. 81), it appears likely that only postnatally formed tooth would be abraded from the molars and cuspids. The incisive margins of the incisors, however, appear to be complete at the time of birth. Abrasion thus could cause some loss of prenatally formed incisor tooth crown. Many incisors in the collection give the appearance of having been filed off down through dentin. It appears possible that in the average shed incisor only 75 to 80 percent of the prenatal portion may remain.

The degree of attrition by abrasion and the chronology for the material lost from the tooth conceivably could be determined from the position of the neonatal ring on section of the tooth. This ring, an accentuation of incremental calcification rings laid down at known time intervals in the enamel and dentin, is a landmark which separates the prenatal and postnatal portion of the deciduous tooth (*7*, p. 82; *19*).

Table 3. Concentrations of strontium-90 (in $\mu\mu c$ per gram of calcium) in different portions of the fetal skeleton. Errors refer to variation in the analysis (standard deviation).

Skull	Long bones	Ribs and vertebrae
	Sample number 44	
0.785 ± 0.033	0.919 ± 0.051	0.802 ± 0.034
	Sample number 51	
0.795 ± 0.028	0.725 ± 0.032	0.741 ± 0.014
	Sample number 59	
1.18 ± 0.04	1.11 ± 0.04	1.14 ± 0.03

Table 4. Data on the weight of teeth from full-term stillborn infants and of shed deciduous teeth, from a study of prenatal tooth formation (see text).

Tooth type	Average weight at birth (mg)*	Range (mg)	Average weight at shedding (mg)†	Range (mg)	Portion of shed tooth formed at birth (%)
Upper central incisors	61	46–85	169	Pooled	36
Other incisors	30	16–54	96	Pooled	31
Weighted average for all incisors					32
Cuspids	14	9–24	222	136–304	6
First molars	52	35–72	307	125–490	17
Second molars	32	13–45	592	330–862	5

* Data based on teeth from 33 full-term stillborn infants. † Data based on 50 or more teeth.

Discussion

The data given here substantiate the feasibility of using deciduous teeth for monitoring the body burden of strontium-90 in growing children. Tooth and bones developing in the same biologic environment *in utero* accumulate strontium and calcium in the same ratio. Knowledge of the extent of prenatal and postnatal tooth formation and the degree of placental discrimination against strontium makes it possible to calculate fetal-bone and fetal-tooth concentrations of strontium-90 from concentrations measured in shed teeth.

A placental discrimination factor of approximately 2 for calcium against strontium-90 was found by Comar in animals (*17*). With a discrimination factor of 4 from diet to bone (*20*), the total discrimination factor from the mother's diet to the fetus might be expected to be 8. Kulp observed that the concentration of strontium-90 in fetal bone averaged only one-twelfth of that in the mother's diet (*16*). The average levels of strontium-90 in total skeletons of 54 stillborn infants of the St. Louis area born from June 1959 through August 1960 was 1.2 $\mu\mu c$ per gram of calcium. This is in agreement with the average concentration in fetal bone in areas of Western culture (*16*). Studies in St. Louis made by Consumers Union in November 1959 (*21*) revealed a level of 15.9 $\mu\mu c$ of strontium-90 per gram of calcium in the total diet. United States Public Health Service total-diet studies show a level of 11.1 for Chicago (300 miles northeast of St. Louis) in May 1960 (*22*). If a mean of these dietary values is taken as representative of the diet in St. Louis, the ratio of level in diet to level in fetal bone in the St. Louis study is 9.

Calculations of concentrations of strontium-90 in fetal bone may be made from shed teeth as follows: Incisors are formed prenatally to the extent of 32 percent (Table 4). If the diet-to-tooth ratio is 1 to 12 prenatally and 1 to 4 postnatally, the concentration of strontium-90 added to the tooth postnatally would be 3 times that added prenatally if dietary strontium-90 remains constant. With these assumptions, the concentration of strontium-90 in the fetus can be found. If *pre* equals prenatal concentration of strontium-90 (in micromicrocuries per gram of calcium), *post* equals postnatal concentration, S equals concentration in shed tooth, and *post* equals 3 *pre*, then $0.32\ pre + 0.68\ post = S$, and $pre = S/2.36$.

The measured average level of strontium-90 in incisor teeth of children born in 1954 was 0.51 $\mu\mu c$ per gram of calcium (*23*). From this value the strontium-90 concentration is estimated to have been 0.22 $\mu\mu c$ in fetal bone, 2.6 $\mu\mu c$ in the diet, and 0.65 $\mu\mu c$ in newly formed (postnatal) bones and teeth. The average concentration for strontium-90 in teeth in children born in 1951 and 1952, when fallout was low, may represent strontium-90 appearing in teeth as a result of direct exchange with dietary strontium-90. If this concentration (0.18 $\mu\mu c$ per gram of calcium) is subtracted from 0.51 $\mu\mu$c, the calculations yield 0.14, 1.7, and 0.42 $\mu\mu$c per gram of calcium for fetal bones and teeth, diet, and newly formed bone and teeth, respectively. These values may be compared to 0.12 $\mu\mu$c per gram of calcium reported by Libby (*24*) for fetal bones of children born in Chicago in 1954, and with the average dietary level of 2.0 $\mu\mu$c for areas of Western culture reported by Kulp for that year (*16*).

These calculations, based on analyses of shed teeth, are not unduly sensitive to errors in the assumptions. If 20 percent of the prenatally formed incisor is lost by abrasion, the estimated level in fetal bone is increased by only 5 percent. If the ratio of level in diet to level in fetal tooth is 1 to 10 rather than 1 to 12, the estimate is changed by approximately 13 percent.

Since 1953, and particularly since 1957, many data have been accumulated on bone levels of strontium-90 in the fetus and in the child. The concentration of strontium-90 in newly formed bone can be estimated with ease from concurrent values for fetal bone (*16*). It is pertinent, therefore, to point out the special contributions which can be made to this body of knowledge by the early analysis of deciduous teeth. A large population can be sampled to provide a continuous record of strontium-90 absorption in man which will span the entire fallout period anywhere in the world. Thus, areas not previously studied can be made to yield a history of fallout, and gaps in chronological records elsewhere can be filled.

The experience in St. Louis suggests that tooth collection can be considerably simplified. This large collection was planned not only for a monitoring program but also for a much more extended investigation now being conducted by the Washington University School of Dentistry (*25*). The low concentrations of strontium-90 in the early years of fallout made it impossible to assess, before the initiation of this study, the size of the pools of teeth that would be required. At present it appears that much less extensive collections than ours could suffice to indicate the annual uptake of strontium-90. As the result of a modified analytic method reported by Butler (*26*), the requisite size of pools for analysis may be greatly reduced. This is encouraging, since a tooth-collection program on a large scale requires much organization, as is indicated by the description of the collecting activities.

On the basis of our experience, certain recommendations can be made concerning the size and composition of a deciduous-tooth collection suitable for the monitoring of strontium-90 absorption. Incisors are considered to be the type of tooth most useful for such a study. They can be collected most easily, for the program appears to have the greatest psychological appeal for the younger children, who are just beginning to lose their deciduous teeth. The incidence of caries is low, and a shorter period of time elapses between formation and shedding of the tooth than in the case of cuspids and molars.

Five thousand incisor teeth a year collected on a continuing basis from any area should, after 2 years, yield adequate data on absorption of strontium-90 approximately 7 years before the start of the collection, if the general characteristics of the St. Louis collection prevail. Where it is desirable to monitor an earlier fallout period, a larger number of deciduous teeth of all types should be collected.

Conclusions

1) Teeth and bones developing in the same biologic environment accumulate strontium-90 and calcium in the same ratio.

2) Collection of teeth can be accomplished on a large scale.

3) Analysis of deciduous teeth can provide information concerning strontium-90 deposition in bone.

References and Notes

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2. The collection program was supported by the Leukemia Guild of Missouri and Illinois. The analyses were made through grants from Consumers Union, Inc., and from the Cancer Research Committee, Washington University (American Cancer Society). I wish especially to thank Irving Michelson of Consumers Union for his help and encouragement.
3. The Greater St. Louis Citizens' Committee for Nuclear Information is an educational group in the field of nuclear energy, composed of scientists and laymen.
4. The program was planned and executed with the guidance of an advisory group composed of the following members: Dean Leroy Boling and Drs. John T. Bird, Jr., John E. Gilster, and Harold L. Rosenthal, of the Washington University School of Dentistry; Dean Stephen P. Forrest and Drs. Donald E. Flieder and Jules M. Snitzer, of the St. Louis University School of Dentistry; Drs. Eric Reiss and Alfred S. Schwartz, of the Washington University School of Medicine; Dr. Barry Commoner of the department of biology, Washington University; and Drs. E. S. Khalifah, Florence Rich, and P. G. Vierheller.
5. I am particularly indebted to Dr. Florence Rich, who personally examined and classified all of the teeth.
6. Mrs. Joseph P. Logan, associate director of the survey, supervised much of the organizational work.
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