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12. I thank Dr. G. Hoffman of the Army Chemical Center Research Laboratory for the pure materials. He obtained the cannabidiolic acid diacetate from Dr. O. E. Schultz, Kiel, Germany. The results for this reference compound, which does not occur naturally in marihuana, are included in Table 1. I thank A. L. Mills for the petroleum ether extractions, and L. W. Haddaway for the diazomethane treatment.
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21 February 1963

Strontium-90 Content of Deciduous Human Incisors

Abstract. *The concentrations of strontium-90 in deciduous incisor teeth of children born in St. Louis between 1949 to 1957 are in accord with estimated bone levels, suggesting that human deciduous teeth are useful as an index of strontium-90 accumulation during the time the teeth are formed.*

In 1958 Kalckar suggested that the radioactive content of deciduous teeth could be used as an index of the accumulation of radioactivity and the body burden of various nuclides in children (*1*). More recently, Reiss has presented preliminary data to indicate the feasibility of such measurements (*2*). We now present findings for the strontium-90 content of noncarious deciduous incisor teeth of children born in St. Louis during the years from 1949 through 1957.

Strontium-90 analyses were performed on ashed samples by the method developed by the New York Operations Office of the U.S. Atomic Energy Commission (*3*). For teeth of children born between 1949 and 1952, when strontium-90 concentrations were low, samples weighing approximately 10 g (70 incisor crowns) were used. The weight of the samples was successively decreased to 2 to 3 grams for the period 1955–57. The collection procedure, classification, and preparation of the teeth have been described (*2*). Pooled samples consisting of teeth from the first and last 6 months of each year were analyzed, but the data obtained for the entire year were averaged. Enamel and dentin were separated by the flotation method of Battistone and Burnett (*4*). To obtain sufficient material for enamel-dentin analysis, samples for the birth years 1952 and 1956 contained 400 and 150 teeth, respectively. Calcium determinations were performed on each sample by oxalate precipitation and permanganate titration.

Human incisor crowns develop during a 6-month prenatal and 5-month postnatal period (*2*), and at the birth date of the child the crown of the tooth is approximately 70 percent calcified (*5*). Figure 1 shows that the strontium-90 content of incisor teeth from bottle-fed children increased slowly between 1949 and 1953 but began to increase markedly between 1954 and 1955. The strontium-90 content between 1955 and 1957 continued to increase but at a slower rate than that for 1954 and 1955. The sharp increase in strontium-90 content of teeth between 1954 and 1955 coincides with a period of extensive nuclear testing begun in 1953. One factor which has not been adequately measured and which may account for the small amount of strontium-90 for teeth of children born before 1952 is that of external strontium-90 accretion during the 5 to 7 years the teeth remained in the body before they were shed. This factor, although presumably small, may account for part of the concentration (0.18 pc/g of calcium) in the teeth of children born in 1949.

Table 1 compares the strontium-90 distribution between the enamel and dentin of incisor crowns for teeth of children born in 1952 (three samples) and 1956 (five samples). Because there were no significant differences for strontium-90 distribution for these age groups, the data for the samples have been pooled. Enamel, which contains 38.5 percent of the tooth-crown calcium, contains a smaller percentage (32 percent) of the crown strontium-90, while dentin, containing 61.5 percent of the crown calcium, contains 68 percent of the crown strontium-90. The differences between strontium-90 content of enamel and dentin may be due to the continual formation of secondary dentin and to exchange with blood strontium-90 during a period of increasing strontium-90 concentration. Because many of the teeth had undergone various degrees of normal attrition, the dentin in these samples represents a somewhat greater proportion of the total mass of the crown than would be expected for crowns in which no enamel attrition had occurred. Nonetheless, the

Table 1. Distribution of calcium and strontium-90 between dentin and enamel of deciduous incisors. Values are given as percentage distribution of the substances in the entire crown on a dry weight basis. The ratios of 1.20 and 0.90 are significantly different from 1.00 with a probability of $\ll .01$.

Calcium	Sr^{90}	Ca/Sr^{90}
	Enamel	
38.5 ± 3.3	32.0 ± 3.5	1.20
	Dentin	
61.5 ± 3.3	68.0 ± 2.9	0.90

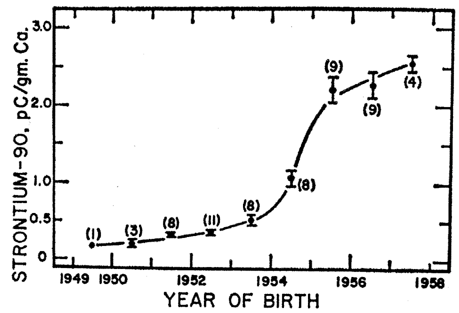

Fig. 1. Strontium-90 content of deciduous incisors from bottle-fed children versus year of birth. Vertical lines are standard error of the mean for number of samples in parentheses.

Table 2. Comparison of strontium-90 content of noncarious incisors from breast-fed and bottle-fed children born from 1951 to 1957. Values are average values ± standard error of the mean. Numbers of samples in parentheses. Differences between teeth of breast-fed and bottle-fed children for the years 1953–56 are significantly different at $P = <.01$. Values for bone are taken from published papers (*7*).

Strontium-90 (pc/g Ca)		
Teeth of children fed by		Bone
Breast	Bottle	
	1951	
0.27 ± 0.05 (3)	0.30 ± 0.03 (8)	0.28
	1952	
0.33 ± 0.02 (7)	0.36 ± 0.02 (11)	0.38
	1953	
0.43 ± 0.04 (7)	0.54 ± 0.03 (8)	0.56
	1954	
0.79 ± 0.05 (8)	1.04 ± 0.10 (8)	0.67
	1955	
1.30 ± 0.11 (9)	2.21 ± 0.18 (9)	1.04
	1956	
1.84 ± 0.21 (6)	2.26 ± 0.16 (9)	1.8
	1957	
	2.56 ± 0.11 (4)	2.1

distribution data may be applied to the data shown in Fig. 1 because the teeth used in all of our studies underwent essentially the same amount of attrition.

A comparison of the strontium-90 content of incisor crowns from children who were breast-fed for 6 weeks or more after birth and for children who were bottle-fed is shown in Table 2. For all of the samples analyzed, the average time of breast feeding was 25 weeks. During 1951 and 1952 the strontium-90 content of incisor crowns of breast-fed children was lower than but not significantly different from that found for bottle-fed children. However, in succeeding years, between 1953 and 1956, when the strontium-90 content of the teeth was increasing at a rapid rate, the teeth of breast-fed children contained 25 percent less strontium-90 than comparable bottle-fed children. Since 70 percent of the tooth crown is formed *in utero* and under the influence of the placental barrier, the small differences found between breast- and bottle-fed children suggests that the teeth of bottle-fed children accumulate small amounts of additional strontium-90 by exchange from the diet.

Although bone strontium-90 levels were not measured in our study, it is possible to compare the values for teeth with values obtained by other investigators for bone. Kulp (*6*) found that strontium-90 levels in the bones of nine North American children 1 to 2 years old for 1957–58 averaged 1.8 pc of Sr^{90} per gram of Ca; for German children during the first year of life in 1958 the value was 2.1 pc of Sr^{90} per gram of Ca. These values are only slightly lower than the value of 2.56 ± 0.11 pc (standard error) found in four samples of incisor teeth from St. Louis children born during 1957 and may be assumed to be comparable within the analytical error of the estimates. Kulp has also estimated that the peak value in bones of 1-year-old children during 1958–59 would be 2.5 pc of Sr^{90} per gram of Ca, a value which is in accord with our data for teeth. Further comparison of bone values for children 0 to 4 years old, corrected to the approximate time of birth, with our values for teeth are shown in Table 2 for the years 1951–1957. The bone levels represent average values, for various bones of the body may vary in strontium-90 content (see *7*).

Our data suggest that human teeth are useful as an index of strontium-90 accumulation during the time the teeth are formed and that the tooth strontium-90 content would represent the maximum cumulative body burden attainable if dietary strontium-90 remains at a constant level during and after the time the teeth are formed (*8*).

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11 February 1963

Xenon Tetrafluoride: Heat of Formation

Abstract. *Calorimetric measurements of the heat of reaction of xenon tetrafluoride with aqueous iodide solution give −60 kilocalories per mole for the standard heat of formation, or an average thermochemical bond energy of about 31 kilocalories.*

Heats of formation of chemical compounds are a fundamental measure of stability and bond strength. There appear to have been thus far no such measurements reported for any of the rare-gas compounds; we have accordingly measured the heat of reaction of xenon tetrafluoride with aqueous potassium iodide solution to derive its heat of formation.

Xenon tetrafluoride was prepared in a flow system (*1*). Weighed samples (112 to 193 mg) were reacted with 380 ml of degassed water containing 0.0190 mole of KI and 0.00038 mole of HCl in a sealed calorimeter (*2*) fabricated of tantalum. Under these conditions the XeF_4 is quantitatively reduced, partly by oxidizing water (*3*),

$$XeF_4 + 2H_2O \rightarrow Xe + 4HF + O_2, \quad (1)$$

but mostly by oxidizing iodide (*4*),

$$XeF_4 + 4I^- \rightarrow Xe + 4F^- + 2I_2 \quad (2)$$

The xenon and oxygen were pumped off after the run, separated, and measured in a gas buret. The amounts of iodine and fluoride in the solution were determined by titration with thiosulfate and thorium nitrate, respectively. The amount of xenon in all cases was 99.0 percent of the theoretical. From 5 to 10 percent of the XeF_4 followed the reaction of Eq. 1. The total amount of oxygen plus iodine was about 95 percent of the theoretical, the total fluoride about 98 percent; however, there was some evidence that iodine and fluoride were being lost by slow reaction with the calorimeter vessel.

There were four runs; the observed heats of reaction ranged from −188.8 to −193.0 kcal per mole of XeF_4. Corrections were applied for the heat of solution of that fraction of the xenon which was dissolved in the solution. Equilibrium constants for the dissociation of HF and the formation of I_3^- from I_2 and I^- were used to calculate the concentrations of individual species for each run; the ratio, F^- to HF ranged from 4.0 to 6.1 and that of I_3^- to I_2 from 27.1 to 31.6. From the values in the literature (*5*) for the heats of formation of the products and the other reactants, the standard heat of formation of crystalline XeF_4 was then calculated individually from each run; results were −60.2, −60.7, −59.6, and −60.0 kcal per mole.