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Jill Lipoti
State of New Jersey

TO:

Chairman Meserve

FOR SIGNATURE OF : ** PRI ** CRC NO: 00-0680

Chairman

DESC:

Addressing Issues by the Radiation and Public Health Project on Strontium-90 in Deciduous Teeth as a Factor in Early Childhood Cancer

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SUBJECT:	Concerns an article entitled "Strontium-90 in Deciduous Teeth as a Factor in Early Childhood Cancer"		
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Robert C. Shinn, Jr.
Commissioner

November 1, 2000

Richard A. Meserve, Ph.D., J.D., Chairman
Nuclear Regulatory Commission
Washington, DC 20555

Dear Chairman Meserve:

It was a pleasure to meet with you during your site visit of the Salem/ Hope Creek nuclear generating stations. The thoughts that you expressed during the working lunch and during our meeting showed that we share many of the same concerns. I hope we will enjoy a good working relationship where we are free to openly and honestly discuss our opinions. We may not always agree, but we will at least foster communication between state and federal levels of government. As I mentioned, we already have a good working relationship with Region 1, through the leadership of Hub Miller.

As promised, enclosed is a copy of the article published in the International Journal of Health Services entitled "Strontium-90 in deciduous teeth as a factor in early childhood cancer." In Figure 3, nuclear reactor sites in New Jersey, New York, and Connecticut are implicated in the rise in breast cancer in Suffolk and Nassau Counties on Long Island. However, many other implications are discussed. On page 533, the statistical link between radioactivity and childhood cancer is used to explain the increases in a number of diseases among children. Low birth weight, congenital hypothyroidism, acute ear infections, asthma, and infant bronchiolitis are all discussed as they relate to damage to immune systems. A synergistic link of radiation with indoor pesticide use is postulated.

As we host public hearings and meetings to meet our respective statutory and regulatory obligations and to meet the public's expectations for open and effective government, both state and federal officials are asked to respond to these studies. In answer to various letters and emails, New Jersey's Bureau of Nuclear Engineering has developed some standard answers, but our expertise is limited. It would be useful if the Nuclear Regulatory Commission could take the lead and produce some talking points that generically address some of the points raised by the Radiation and Public Health Project.

Again, thank you for meeting with me, and I look forward to our continued communication and cooperation.

Sincerely,

Jill Lipoti

Jill Lipoti, Ph.D.,
Assistant Director

Enclosure

c: Hub Miller, Region 1 Administrator

BAYWOOD REPRINTS

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Strontium-90 in Deciduous Teeth as a Factor in Early Childhood Cancer

Jay M. Gould, Ernest J. Sternglass, Janette D. Sherman, Jerry Brown, William McDonnell, and Joseph J. Mangano

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STRONTIUM-90 IN DECIDUOUS TEETH AS A FACTOR IN EARLY CHILDHOOD CANCER

Jay M. Gould, Ernest J. Sternglass, Janette D. Sherman,
Jerry Brown, William McDonnell, and Joseph J. Mangano

Strontium-90 concentrations in deciduous (baby) teeth of 515 children born mainly after the end of worldwide atmospheric nuclear bomb tests in 1980 are found to equal the concentrations in children born during atmospheric tests in the late 1950s. Recent Sr-90 concentrations in the New York–New Jersey–Long Island metropolitan area have exceeded the expected downward trend seen in both baby teeth and adult bone after the 1963 ban on atmospheric testing. Sharp rises and declines are also seen in Miami, Florida. In Suffolk County, Long Island, Sr-90 concentrations in baby teeth were significantly correlated with cancer incidence for children 0 to 4 years of age. A similar correlation of childhood malignancies with the rise and decline of Sr-90 in deciduous teeth occurred during the peak years of fallout in the 1950s and 1960s. Independent support for the relation between nuclear releases and childhood cancer is provided by a significant correlation with total alpha and beta activities in local surface water in Suffolk County. These results strongly support a major role of nuclear reactor releases in the increase of cancer and other immune-system-related disorders in young American children since the early 1980s.

In 1954, three years after the initial atmospheric nuclear weapons tests in Nevada, U.S. public health officials began monitoring levels of in vivo radioactivity (1–3). Programs focused on measuring strontium-90 in human bone and teeth because of the known biochemical actions and physical behavior of this radioisotope and the feasibility of measuring Sr-90 years after it enters the human body, due to its long physical half-life (28.7 years). Between 1954 and 1982, the U.S. Atomic Energy Commission measured Sr-90 concentrations in the vertebrae of healthy adults who died in accidents in New York City, Chicago, and San Francisco, and also calculated the dietary uptake of Sr-90 by adults during this period (3). From 1962 to 1971, the U.S. Public Health Service's Bureau of Radiological Health operated a program measuring Sr-90 concentrations in the

International Journal of Health Services, Volume 30, Number 3, Pages 515–539, 2000

vertebrae and ribs of deceased persons under 25 years of age in 34 U.S. locations (4).

From 1954 to 1964, the average level of Sr-90 in picocuries per gram of calcium in the vertebrae of New York adults rose from under 0.1 to 2.2, more than a 20-fold increase. The estimated dietary uptake of Sr-90 by adults rose 30-fold, from 1 picocurie per gram of calcium in 1954 to 29.8 in 1964. The 1964 peak in Sr-90 concentration occurred just after ratification of the Partial Test Ban Treaty by the United States that ended American, British, and Soviet atmospheric nuclear weapons tests, while a relatively small number of French and Chinese tests continued. (Underground tests replaced atmospheric tests in the nations that signed the treaty.) Strontium-90 levels in New York and San Francisco declined sharply after the cessation of aboveground testing. In the years 1964–1970, dietary uptake of Sr-90 by adults declined on average by 15.7 percent each year. The Public Health Service's data show a similar increase and decline before and after the peak of 1964. Federal support for this Sr-90 measurement effort was withdrawn in 1982.

The U.S. government also participated in a study measuring Sr-90 concentrations in the deciduous (baby) teeth of about 60,000 children, conducted by the Committee for Nuclear Information in St. Louis, Missouri, starting in 1958. The use of deciduous teeth made possible the collection of large samples, rather than relying on autopsy results (5). The deciduous tooth analysis showed a rise in Sr-90 levels from 0.77 picocuries per gram of calcium for 1954 births to a peak of 11.03 for 1964 births, just after the Test Ban Treaty (6). From 1964 to 1970, Sr-90 levels in St. Louis baby teeth fell by more than half (Figure 1), about the same average annual rate of decline (15.7 percent) detected in adult uptake in those years (see Figure 2). One exception to this pattern occurred from late 1958 to 1961, when the United States and Soviet Union observed a voluntary moratorium on nuclear testing.

Average concentrations of Sr-90 in teeth increased moderately in the early 1950s, but began to rise more rapidly after 1954 with the sharp elevation of atmospheric Sr-90 from thermonuclear bomb tests, the fallout from which ascended into the stratosphere and returned to earth in precipitation over a two- or three-year period. After the 1958–1961 moratorium, atomic and hydrogen bomb tests were resumed in the fall of 1961 with the detonation of a 50-megaton bomb by the Soviet Union in northern Siberia, equal to more than 3,000 Hiroshima bombs (7).

Trends in Sr-90 levels in deciduous teeth from 1960 to 1970 in Connecticut, the only state with an established tumor registry during that period, are significantly correlated ($R = .78$; $P < .001$) with temporal changes in cancer incidence among children 0 to 4 years of age (each year represents a three-year moving average). Because trends in Sr-90 concentrations in cow's milk in St. Louis are similar to those in Hartford, Connecticut, and elsewhere in the United States (8), similar temporal changes of radioactivity in teeth can be assumed for the entire nation. Childhood cancer in Connecticut reached a peak in 1964, before plummeting in

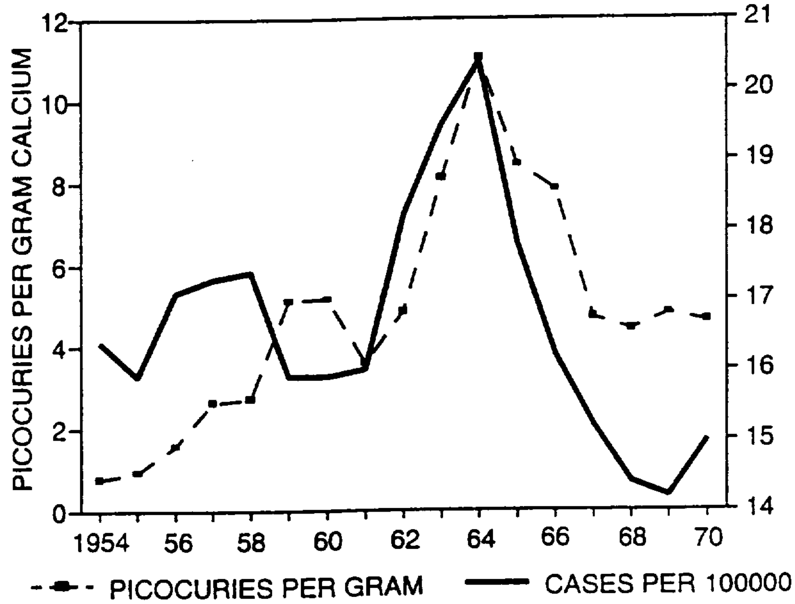

Figure 1. Average strontium-90 in St. Louis deciduous teeth and rate of cancer in Connecticut children age 0 to 4, three-year moving averages, 1954–1970.

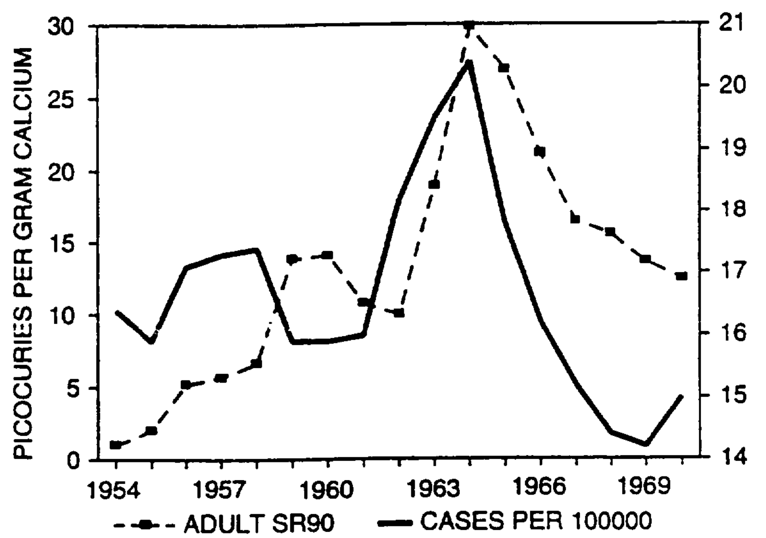

Figure 2. Average strontium-90 uptake in New York City adult diet and rate of cancer in Connecticut children age 0 to 4, three-year moving averages, 1954–1970.

the latter half of the 1960s (Figure 1). The Committee for Nuclear Information study on deciduous teeth ended in the early 1970s, when federal support for the project ceased.

The high correlation between radioactivity in deciduous teeth and cancer in young children in the period 1954–1970 is paralleled by a similar relationship with the adult dietary uptake of Sr-90 as estimated by the U.S. Department of Energy (successor to the Atomic Energy Commission) from 1954 to 1982 (3). The correlation coefficient between childhood cancer and adult dietary uptake of Sr-90 is .79 ($P < .001$) for the years 1960 to 1970 (Figure 2), the period when the latter indicator reflected the high Sr-90 levels in the diets of pregnant women.

Figures 1 and 2 support the well-known finding that exposure to toxic agents is most harmful to the developing embryo and fetus, in humans and other animals. Throughout intrauterine life, the developing fetus undergoes rapid cell growth, self-programmed cell death (apoptosis), and cell rearrangement. Unrepaired damage to the rapidly growing and rearranging fetal cells becomes magnified with time, increasing the risk of cancer, congenital malformations, underweight births, brain damage, and fetal/infant deaths. The developing infant is similarly susceptible to cellular and metabolic damage (9).

At ten weeks of prenatal development, when the fetus is a little over 1.5 inches in length, the enamel organs and dental papillae form; some formation begins two weeks earlier (10). Stem cells of the hematopoietic system originate in the bone marrow at about 12 weeks of prenatal development (11), giving rise to the B-lymphocytes, whose progeny make humeral antibodies, and the T-lymphocytes involved in cellular immune responses (12). Fetuses can be harmed by very low-dose radiation, as first demonstrated in the 1950s when exposure to pelvic X-rays in utero was linked with elevated levels of leukemia and cancer deaths before age ten (13, 14).

U.S. health officials have not monitored radioactivity in humans since 1982. Moreover, the Environmental Protection Agency (EPA) program of reporting barium-140, cesium-137, and iodine-131 in pasteurized milk for each of 60 U.S. cities ceased in 1990 after 33 years of operation (15). Although the last atmospheric weapons test was detonated in China in 1980, the presence of nuclear power reactors has grown in the past two decades. From 1982 to 1991, the number of operating U.S. reactors increased from 72 to 111, providing power in 32 of the 50 states (in which 85 percent of the 1990 U.S. population resided), and electricity generation by these plants increased from 278,000 to 613,000 gigawatt hours, before leveling off in the 1990s (16). During this period, cancer incidence in 11 U.S. states and cities rose 40.4 percent for children 0 to 4 years of age and 53.7 percent for those under 1-year-old, a time when average levels of Cs-137 and I-131 in milk doubled (17).

Continuing measurements of in vivo radioactivity in other nations have revealed unexpected and significant trends. West German researchers documented a tenfold increase in Sr-90 in deciduous teeth for children born in 1987 compared with those born in 1983–1985, due to fallout from the Chernobyl accident—a relative increase comparable to that observed in St. Louis from 1954 to 1964 (18).

Without a system for monitoring the presence of key radioactive isotopes such as Sr-90 in the human body, no definitive assessment of the health effects of exposure to man-made radioactivity can be made. The average annual decline in adult Sr-90 uptake after 1970 was only about 5 percent, compared with the 15.7 percent annual decline in Sr-90 uptake levels in adults from 1964 to 1970 (3), reflecting perhaps the proliferation of large nuclear power reactors in the 1970s and emissions from flawed underground tests. Cancer incidence in children age 0 to 4 in Connecticut—a small state with four operating nuclear reactors—was as low as 14.42 per 100,000 in the late 1960s, then reached 21.95 per 100,000 in the late 1980s, a jump of over 52 percent (19). This trend suggests that additional recent data on in vivo radioactivity in the United States are needed, particularly given the puzzling decision of the Department of Energy to terminate measures of Sr-90 in adults in 1982. In that year, dietary Sr-90 uptake remained at the same level of 5.6 picocuries per gram of calcium as in 1981, comparable to the that in the late 1950s. The last Department of Energy report observed, "There has been some indication of slightly higher values for young adults during the last several years. These individuals were children during the period of greatest Sr-90 deposition." One might predict from this statement that adult Sr-90 levels would rise in the 1980s and 1990s as baby boomers accounted for increasing proportions of the adult population and an increasing number of nuclear power plants came on line (3).

METHODS

In 1996, the Radiation and Public Health Project (RPHP), a New York City–based research organization, began collecting deciduous teeth and analyzing them for Sr-90 concentrations. The aim of the study is to document present levels and historical trends of Sr-90 in human bodies since the end of all atmospheric bomb tests in 1980. The RPHP will compare current Sr-90 patterns (when most of this radionuclide is taken up from nuclear power reactor emissions) with those of 35 to 50 years ago (when most in vivo Sr-90 represented bomb test fallout).

The initial geographic focus of the study was Suffolk County, New York, a 922 square mile area making up the eastern three-quarters of Long Island, with a 1990 population of 1,321,864 (Figure 3). We selected Suffolk because, for more than a decade, the county has been the subject of numerous studies in the medical literature owing to its consistently high levels of breast cancer incidence and mortality (20, 21). Rates in the suburban areas of Suffolk County and Nassau County (adjacent to the western border of Suffolk) began to exceed even the high rate in New York City in the late 1970s. Moreover, a recent study by RPHP researchers linked the rise in breast cancer in both Suffolk and Nassau to fission products in the diet and water, produced by airborne releases from nearby nuclear plants (22).

Suffolk is the site of Brookhaven National Laboratory (BNL), a research facility located near the town of Upton in western Suffolk, some 60 miles from the eastern end of Long Island. BNL has operated two or three nuclear research reactors at various times since 1951, which have released significant quantities of radioactive elements into the local air and ground and surface waters.

As shown in Figure 3, Suffolk is also proximate to several other reactors operating in the 1980s and 1990s. The earliest to begin operation was the Indian Point Plant Unit 1 in 1962, followed by the much larger Units 2 and 3 in 1973 and 1976. Indian Point is located on the Hudson River some 30 miles north of Manhattan. The prevailing winds from the northwest in the winter months move the airborne releases from Indian point toward western Suffolk, as indicated by the wind distribution measured at BNL (Figure 3).

Another nuclear plant, Oyster Creek, is located some 60 miles to the southwest on the New Jersey coast near the town of Toms River; it began operation in 1969. The prevailing winds in the summer months move from the southwest toward western Long Island, so the plumes of airborne activity from Oyster Creek cross

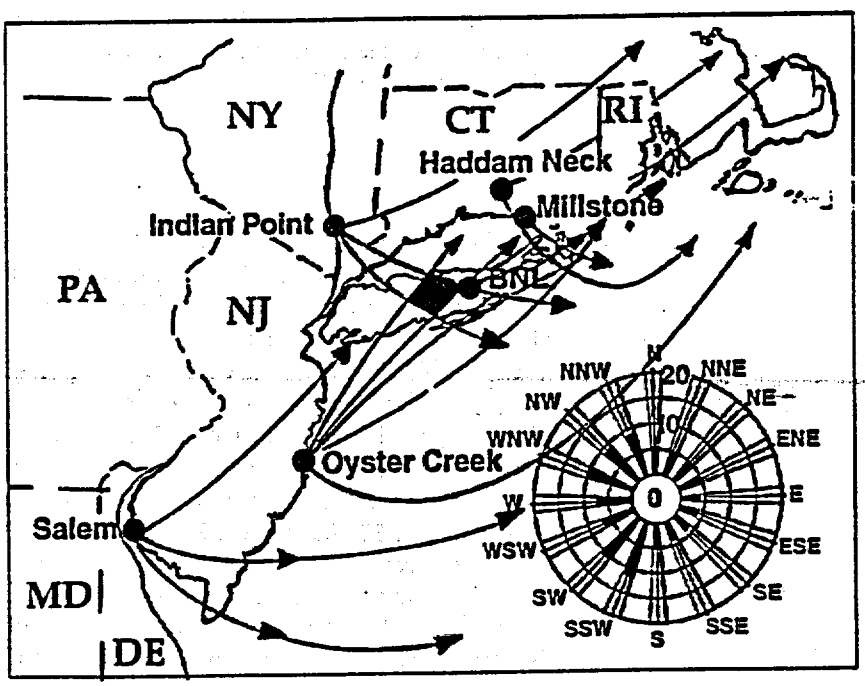

Figure 3. Nuclear reactor sites and prevailing winds near Suffolk County, New York.

those from Indian Point in the area of Suffolk, just to the west of BNL. Thus the western part of Suffolk receives airborne emissions from three nuclear sites for most of the year, making it the most heavily exposed part of the county. Furthermore, of the 76 nuclear sites in the nation, the Oyster Creek plant has reported the second highest airborne releases of radionuclides with a physical half-life of eight days or more, releasing a total of 76.8 curies since 1970. This far exceeds the release of 14.2 curies reported for Three Mile Island Unit 2 during the 1979 accident (23).

This highly exposed area of western Suffolk is where 17 of the 18 communities with breast cancer incidence rates above the county average are located, as reported by the New York State Department of Health for the period 1978–1987 (22). It is also the area where 19 recent cases of an extremely rare form of childhood cancer, rhabdomyosarcoma, have been identified (24). Finally, in 1997, 79 hospital discharges for cancer in residents age 0 to 9 occurred in 11 contiguous five-digit zip code areas (1990 population 162,187) located 10 to 15 miles northwest of BNL; there were zero admissions from easternmost Suffolk, known as the North and South forks (1990 population 65,416) (25).

Two nuclear plants in Connecticut to the north of Suffolk are Haddam Neck near Middletown and Millstone near New London. The three Millstone reactors are only 11 miles north of the northeastern tip of Suffolk County. Although the prevailing winds are directed toward the eastern part of Suffolk only in the winter months, these reactors, like those at Oyster Creek, have had a substandard record of radioactive emissions, releasing 32.6 curies of long-lived fission products since 1970—the third highest release among all U.S. nuclear plants (23). In the winter of 1995–96, the Nuclear Regulatory Commission ordered all three Millstone reactors closed for safety violations. Unit 1 was shut down permanently, and the other two did not operate for 27 months and 40 months while extensive physical and management improvements were made. Thyroid cancer, the risk of which increases after exposure to radioactive iodine found in all reactor emissions, reached significantly high levels in New London (near Millstone) in the late 1980s and early 1990s before the plant was closed (26).

One other nuclear plant along the northeastern Atlantic coast, less than 100 miles from the eastern end of Suffolk, is the Pilgrim plant, 25 miles south of Boston near Plymouth. It began operation in 1972 and experienced a series of severe problems, including a major accidental release of radioactive gases in 1982 that was detected all over New England (27). An abnormally high incidence of leukemia was reported around this plant (28).

Precipitation brings down 90 percent of airborne radioactivity to earth, introducing it into the food chain (29). Thus the rain and snow in Suffolk recharge the aquifers supplying the drinking water for the wells all over Suffolk County with contamination from radioactive particles released from these facilities.

Deciduous teeth, usually shed between the ages of 5 and 12, were selected for study because they represent a stable calcified tissue similar to bone but in which rates of turnover, exchange, remodeling, and accretion are minimal or absent. Thus the deciduous tooth may be considered a stable structure and can be taken to reflect the mineral composition acquired at the time of its formation (5, 6). It therefore provides information about Sr-90 uptake during the year of the child's birth. A portion of the calcium and Sr-90 is drawn from the mother's bone, in addition to the mother's dietary intake during pregnancy, and another portion is derived from the infant's diet in the year after birth for all types of teeth (5). Thus, for the purposes of the present study, there is no need to measure incisors, cuspids, and molars separately. Wide variations in Sr-90 occur because of dietary differences and the time of year when the child is born (5), so many teeth are needed to obtain meaningful yearly average values. Given an adequate number of teeth for a given area (i.e., a three-digit zip code area), it is possible to obtain accurate historical data on the body burden of Sr-90 not only for the child but also for the mother in the year of the infant's birth. Deciduous teeth therefore provide a much more accurate indication that individuals in certain locations received radiation exposures from fission products at a given time. This information cannot be determined from single monthly or yearly milk measurements aggregated for a large geographic area.

Following previous studies, the RPHP effort focused on Sr-90 because of the reliability of detecting this long-lived radionuclide, due to its extended half-life of 28.7 years. Relative levels of this pure beta-particle-emitting isotope are also a proxy for several dozen other short- and long-lived radioactive fission products emitting gamma rays and alpha and beta particles. found in bomb test fallout and power reactor emissions. Discarded baby teeth are used because of the greater ease of collecting large numbers of these than bones from autopsies. The majority of the teeth studied in the initial phase have been obtained in response to a mass mailing to 15,000 randomly selected households with children age 6 to 18 in early 1999. Donors also submitted teeth after learning of the project from print, radio, and television stories. A toll-free telephone number and Web site are other ways in which the public has been able to obtain information on tooth donation.[1]

Each potential donor is mailed a package containing a letter, several articles describing the study, and an envelope in which to send teeth to the RPHP. In addition to the tooth (some contributors send multiple teeth), the following information is requested on the envelope:

- Mother's name
- Phone number
- Address
- Child's name
- Birth date (month, day, year)

[1] The toll-free number is 800-582-3716; the Web site is http://www.radiation.org.

- Birth weight (pounds, ounces)
- Location where mother carried the baby (city, state, county, zip code)
- Location where child was born (city, state, county, zip code)
- Location during first year of life (city, state, county, zip code)—also second and third year
- Water source (well, municipal water, bottled water, other)
- Mother's age at birth of child
- Age of child when tooth was lost or date of tooth loss

The RPHP assures donors of the confidentiality of all information identifying mothers and children.

The initial mailing of envelopes targeted selected populations, representing those exposed to different degrees of radioactivity from reactors in and around Long Island according to their geographic location. The more heavily exposed populations include children living in western Suffolk County (zip codes beginning 117), mid–New Jersey, near the Oyster Creek reactor (zip codes 087), and the greater Miami area, near the two Turkey Point reactors (zip codes 330 and 331). Less exposed populations were residents of parts of eastern Suffolk (zip codes 119) and parts of Queens, New York, and northwestern New Jersey. As of October 1, 1999, the RPHP had received about 1,400 teeth, a majority of them a direct result of the early 1999 mailing. The response rate for this unsolicited mailing has been greater than 3 percent.

Upon receipt of envelopes containing teeth, an RPHP staff member assigns a unique control number to each tooth and logs it into a computerized database. Teeth are periodically sent in batches to a radiochemistry laboratory in Waterloo, Ontario. Laboratory personnel document Sr-90 concentrations by separately measuring Sr-90 activity (in picocuries) and calcium weight (in grams) in the teeth. Waterloo researchers are blinded from any information about each tooth. The techniques employed for this purpose are explained in the Appendix.

Strontium-90 readings for each tooth at the time it was lost by the child are converted to levels at birth, creating a standardized measure that can be compared regardless of how old the tooth is. This conversion is made using the decay rate of a 28.7-year half-life for the radionuclide, using the month of birth and the month of tooth analysis.

RESULTS

As of October 1, 1999, 515 teeth had been analyzed for Sr-90 concentration. Of these, 476 were from children born during the years 1979 to 1994, but with only 15 teeth for 1993–1994, not enough to provide high statistical reliability for these years. Table 1 indicates the geographic distribution of the teeth, based on where the mother carried the child, along with the average and maximum concentrations for each of four zip code areas accounting for 374 of the most recent teeth

Table 1

Average and maximum concentrations of Sr-90 in deciduous teeth received by RPHP by October 1, 1999, by zip code area, 1979–1994 births

Area	No. of teeth	Sr-90, picocuries per gram of calcium	
		Average	Maximum
Western Suffolk County, New York (zip 117)	185	1.56 ± .05	9.29
Eastern Suffolk County, New York (zip 119)	119	1.02 ± .06	7.26
Dade County (Miami), Florida (zips 330, 331)	38	2.80 ± .10	17.87
Ocean County, New Jersey (zip 087)	32	1.54 ± .11	7.37
All other	102	1.43 ± .07	8.39
All locations	476	1.50 ± .03	17.87

Note: Since the standard error (SE) of individual observations is ±0.7 (Appendix), the SE of the counting procedure is $\pm 0.7/\sqrt{n}$, where n is number of teeth.

analyzed. Few teeth from less-exposed control areas in New York and New Jersey have been received and are thus omitted from this analysis.

The mean concentration of Sr-90 for all 476 teeth is 1.50 picocuries per gram of calcium, roughly equivalent to that found in St. Louis children born in 1956, five years after the start of atmospheric testing in Nevada. The standard error for this average is ±0.03. While the mean level for Dade County, Florida (Miami), teeth is highest (2.80), averages for the entire period of 1979–1994 from all four areas greatly exceed the level of about 0.2 picocuries per gram of calcium that would have been expected if post–Test Ban Treaty (1964–1970) declines observed in St. Louis teeth had continued (Figure 4). Only 135 (28.4 percent) of the teeth had Sr-90 levels of 0.2 picocuries per gram of calcium, while 67 (14.1 percent) of the sample had readings of 3.0 or higher, about fifteen times greater than the projected values; the largest single value was 17.87. Annual averages of Sr-90 concentrations in the RPHP study sample are variable, but both averages and peak values rose to their highest levels in 1988, two years after arrival of Chernobyl fallout. Average measurements rose from 1.48 to 1.51 picocuries per gram of calcium (2.2 percent) from 1981–1987 (n = 190) to 1988–1994 (n = 276).

Figure 4 shows the RPHP results since 1979, compared with prior measures of Sr-90 in St. Louis baby teeth and in New York City adult dietary uptake. Since Sr-90 levels in both the adult uptake and the St. Louis baby teeth declined on

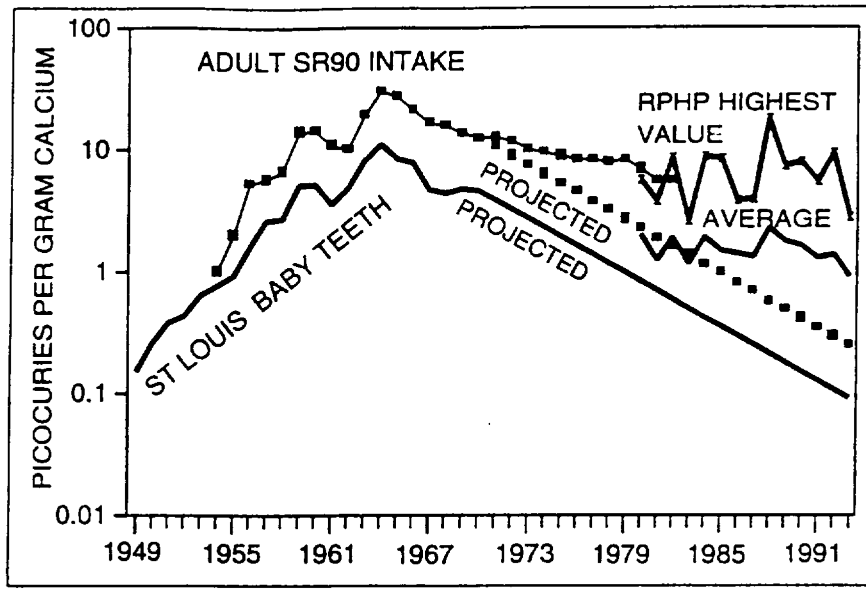

Figure 4. Strontium-90 in St. Louis deciduous teeth (measured and projected), in New York City adult diet (measured and projected), and in the 476 RPHP deciduous teeth (1980–1993).

average by 15.7 percent each year over the years 1964–1970, this annual percentage decline is used to project the expected Sr-90 levels in baby teeth from 1970 to 1994. It is clear that the RPHP levels are far higher—about three times higher—than the levels expected based on the assumption that no additional Sr-90 was introduced into the atmosphere after 1970, a significant difference (*P* value is infinitesimal). The annual adult dietary uptake in any given year is closely related to the dietary uptake of pregnant women and thus to the level observed in the deciduous teeth of children born in that year. Note, for example, that the adult uptake of Sr-90 rose 6 percent (7.8 to 8.3 picocuries per gram of calcium) from 1978 to 1979, the year of the Three Mile Island accident, and then declined 23 percent, to 5.6, in the following two years when the two Three Mile Island reactors were shut down. This accords with the relatively high values found in the RPHP averages in the early 1980s, followed by a rise in 1986 and subsequent decline associated with the arrival and subsequent decay of Chernobyl radiation. Further corroboration is reflected in the observed EPA measures of high radioactivity in milk and water in May and June of 1986 (15).

An in-depth analysis can be performed on Suffolk County children, who contributed 304 (64 percent) of the 476 teeth tested. Figure 5 shows a comparison of the mean annual Sr-90 concentrations in teeth and the cancer incidence in

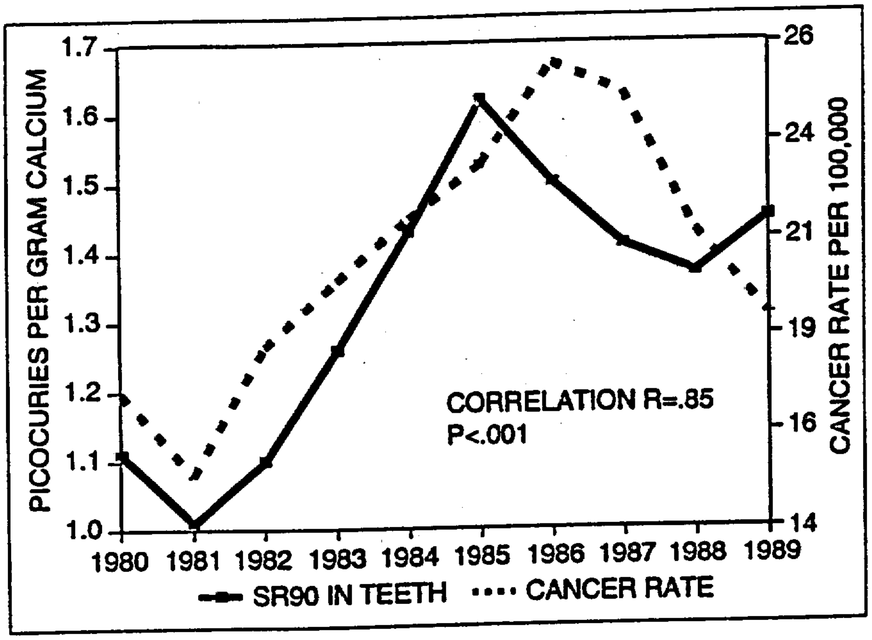

Figure 5. Average strontium-90 in deciduous teeth, 1980–1989, and rate of cancer in children age 0 to 4, 1983–1992, three-year moving averages, Suffolk County.

children age 0 to 4 in the county (30). A three-year latency between relative radiation level and cancer diagnosis is assumed, that is, Sr-90 concentrations for the period 1980–1989 are matched with cancer incidence for 1983–1992. A three-year delay between the Suffolk Sr-90 measures at birth and the incidence of cancer in 0- to 4-year-olds was found to give the best fit. This agrees with the observation that childhood leukemia and brain cancer, which make up a major share of all childhood malignancies, are most frequently diagnosed between the second and fifth years of life. Three-year averages are used; for example, the cancer rate for 1989 represents cancer cases per population for the years 1988–1990 combined. Using three-year totals enhances the significance of the analysis, since for some individual years the RPHP had received as few as five teeth, so that annual Sr-90 averages are subject to statistical variation; this variation is reduced by the three-year moving average without affecting turning points. The number of newly diagnosed cancer cases in 0- to 4-year-olds over three years varies from a low of 41 to a high of 73.

The analysis of Sr-90 in teeth was not conducted for births after 1990. As mentioned earlier, the only birth years for which substantial numbers of teeth were received are 1991 and 1992. Furthermore, most of the recent teeth being donated are from children born in the 1990s, and this pattern will likely continue into the future. While patterns for 1980s births appear to be set, those for the 1990s may well change in the future, and reporting present totals would be premature.

The correlation between Sr-90 and childhood cancer in the 1980s includes a three-year latency period, whereas the correlation in the 1960s occurred with no latency (Figure 1). During the peak fallout years of large-scale hydrogen bomb tests in 1961 and 1962, as in the 1961 50-megaton Soviet test, the long-lived Sr-90 was injected into the stratosphere, then drifted down into the lower atmosphere over a period of years. This led to a delayed peak of in vivo Sr-90 of some two to four years after the immediate exposure of the fetus and young infant to the short-lived fallout brought down in 1961–1962. Given that childhood cancer for the 0- to 4-year group is also typically diagnosed some two to four years after birth, the peaks in Sr-90 and 0- to 4-year-old cancer incidence occurred at about the same time.

By contrast, releases from nuclear reactors do not reach the stratosphere and are brought down by rain or snow in a matter of hours, days, or weeks. Strontium-90, together with the many short-lived isotopes that produce the greatest exposure to the embryo and fetus, rapidly enters the air that is inhaled, the food chain, and the drinking water in the shallow wells in Suffolk. For nuclear plant releases after the last Chinese atmospheric test of 1980, we would expect a two- to four-year lag in 0- to 4-year-old cancer incidence after Sr-90 is deposited in the newly formed tooth enamel. As a result, Sr-90 in deciduous teeth can serve as an indicator of the time of principal exposure only after the end of large-scale hydrogen bomb tests. But it is not the principal source of radiation exposure leading to early childhood cancer, which is mainly due to the much more abundant short-lived isotopes transferred to the fetus through the placenta, such as barium-140, iodine-131, and strontium-89, which accompany Sr-90.

Strontium-90 buildup in Suffolk baby teeth during the early 1980s and modest reduction in the late 1980s appear to be matched (three years later) by similar patterns in cancer incidence. The peak levels of Sr-90 during the late 1980s, up about 50 percent from early in the decade, strongly suggest the important role played by the Chernobyl radiation cloud that reached the United States in May 1986. For the entire ten-year period, the two measures are correlated ($R = .85$; $P < .001$) (Figure 5). This linkage is similar to that between St. Louis baby teeth and Connecticut childhood cancer in the 1950s and 1960s, discussed earlier.

While RPHP teeth provide the only in vivo concentrations of radioactivity, comprehensive measurements of beta- and alpha-particle emitters in local waters taken by the New York State Department of Health can also be contrasted with trends in childhood cancer incidence (31). One of the two areas sampled in Suffolk County is located in the eastern part of BNL where the Peconic River originates; the other is at Fisher's Island, in the far northeast part of the county, 10 miles south-southeast of the Millstone nuclear complex in Connecticut.

State officials record monthly levels of total gross alpha, gross beta, and tritium activity in water (Figure 6). Gross beta activity is of particular interest because Sr-90 is a beta emitter. At various sites around New York State, this isotope makes up between 20 and 50 percent of gross beta activity. Other radionuclides included in the gross beta measurement are the thyroid-seeking I-131 and bone-seeking Sr-89 and Ba-140. Gross beta levels in the Peconic River and in the ponds near BNL in the 1980s and early 1990s are about five times greater than those in the water tested in Albany, which is not located near any major nuclear power plants. Annual averages vary due to unusually high readings for one or two months of the year. For example, 11 of 12 monthly measurements in the Peconic River in 1992 were between 2 and 7 picocuries of gross beta per liter of water; the other, taken on November 16, was 130. No other testing site in New York State showed any similar rise in November of that year, meaning that releases from BNL are the likely source. Relatively high activity levels in the water occurred in 1982, 1986, 1991, 1992, and 1993.

When gross beta activity trends in the Peconic River from 1984–1993 are compared with cancer incidence in 0- to 4-year-olds from 1987 to 1996 in Suffolk County, there is a strong correlation ($R = .87$; $P < .0001$), greater than that found for Sr-90 concentrations in Suffolk teeth (Figure 7). Again, three-year moving averages are used to enhance the statistical validity of both averages.

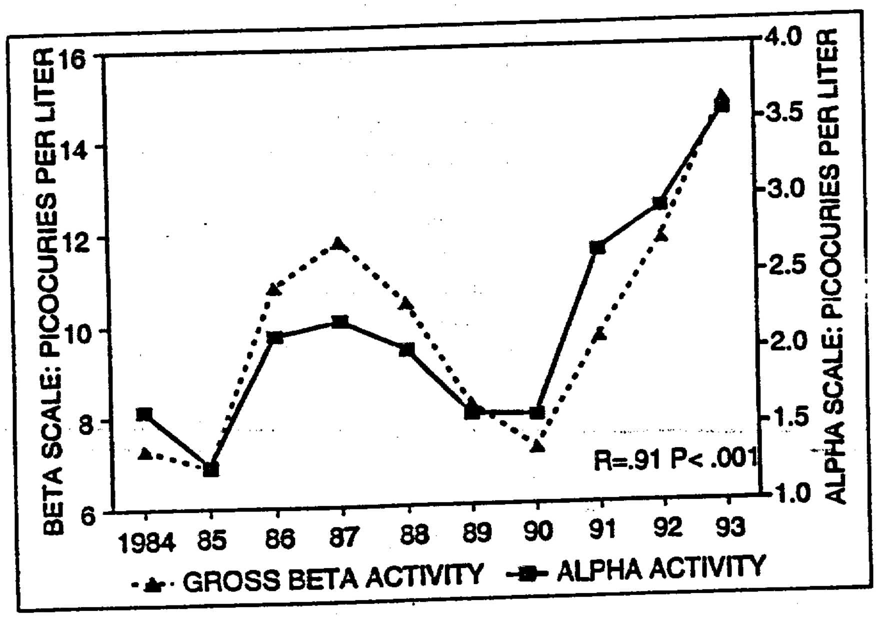

Figure 6. Gross alpha and beta activity in the Peconic River, three-year moving averages, 1984–1993.

Gross alpha activity represents radionuclides such as plutonium-239 and other transuranic elements produced in nuclear reactors, all with high toxicity. From 1982 to 1993, high gross alpha readings in the Peconic River occurred during the same monitoring periods that produced peaks in gross beta activity, resulting in similar trends in average concentrations from 1984 to 1993. This finding indicates that alpha activity is not due to natural sources such as radium, radon, or thorium. Hence, gross alpha activity in the Peconic River is also correlated with cancer incidence in children age 0 to 4 in Suffolk (Figure 8), presuming a three-year latency period from exposure to diagnosis ($R = .63$; $P < .001$).

Tritium levels in the Peconic River are generally about ten times greater than in Albany. No strong correlation between annual averages of tritium and cancer incidence in 0- to 4-year-olds exists. However, the same pattern of periodically elevated levels in the Peconic and nearby ponds is observed as for gross beta and gross alpha activities. In 1992, all tritium readings were below 4,200 picocuries per liter, with two exceptions: the July 31 and September 14 measurements were 8,600 and 16,200, respectively.

The New York State health department also measures Sr-90 concentrations in Peconic River fish each year. From 1982 to 1993, an average Sr-90 level of 243.2 picocuries per kilogram (entire body without the head) was found in 62 fish near BNL, with a high of 1,070 recorded on August 1, 1992. Strontium-90 concentrations in Peconic River fish were 15 times greater than those found in 28 fish sampled in West Valley, 40 miles south of Buffalo and the site of a nuclear waste dump. Not enough data on fish are available to attempt a meaningful year-by-year correlation with childhood cancer.

A simple reliability test of the RPHP data can be made using Sr-90 readings in teeth from persons born during the same time that Sr-90 levels in St. Louis teeth were being measured. Of the 20 teeth contributed by persons born between 1957 and 1970, 16 were from those who spent the gestation period in New York, New Jersey, or Connecticut. Strontium-90 averages for both the St. Louis and the RPHP study teeth show a rise to 1965–1967 before dropping in 1968–1970 (Table 2). St. Louis teeth had higher Sr-90 values, commensurate with higher Sr-90 values in the city's raw milk (about double that of New York City milk) during these years (8).

DISCUSSION

For the first time in nearly two decades, in vivo levels of radioactivity have been measured in the United States, in a study by the Radiation and Public Health Project. Average concentrations of Sr-90 in deciduous teeth in New York's Long Island, the central part of New Jersey, and the Miami area in Florida are far greater than would be expected if the initial decreases measured in St. Louis teeth during the years following U.S., Soviet, and British large-scale atmospheric tests (1964–1970) had continued. Yearly averages fluctuated, and rose slightly for

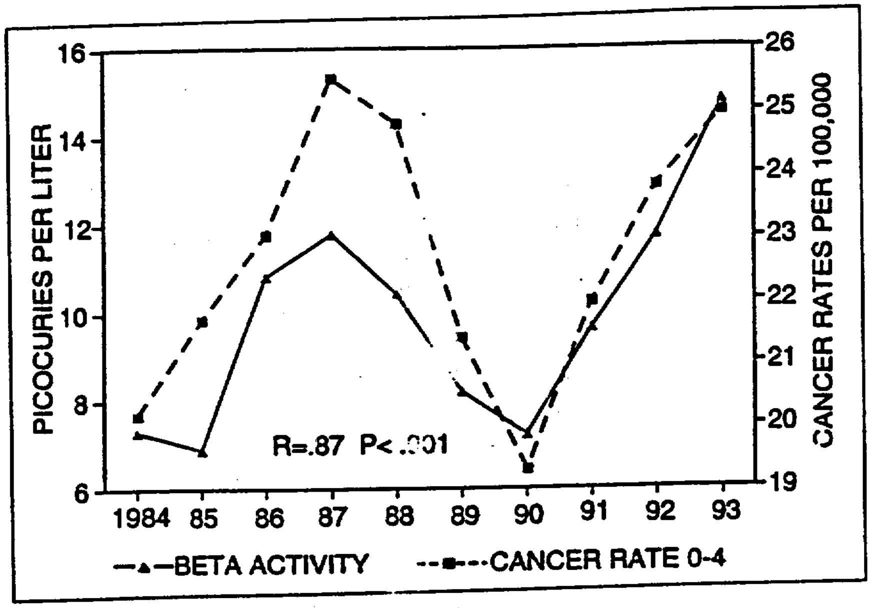

Figure 7. Gross beta activity in the Peconic River, 1984–1993, and rate of cancer in Suffolk County children age 0 to 4, 1987–1996, three-year moving averages.

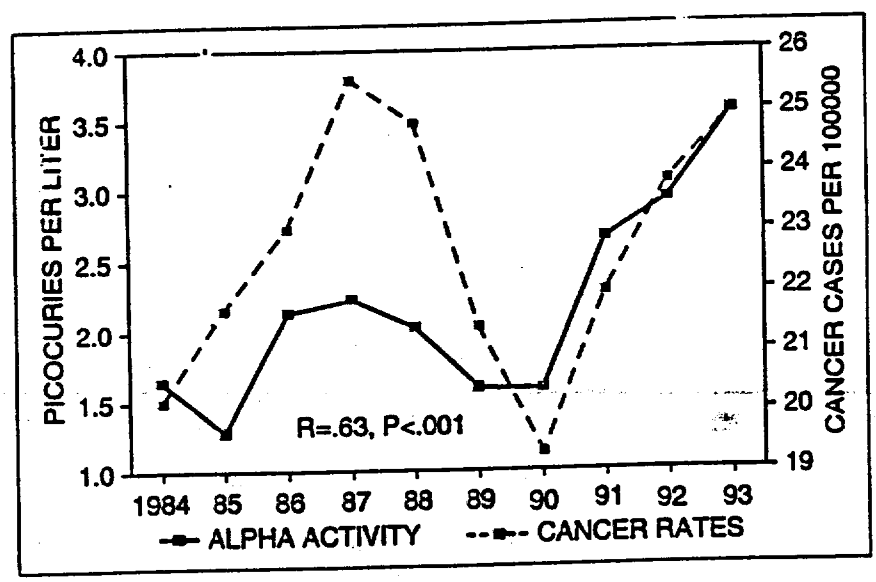

Figure 8. Gross alpha activity in the Peconic River, 1984–1993, and rate of cancer in Suffolk County children age 0 to 4, 1987–1996, three-year moving averages.

Table 2

Average Sr-90 concentrations in deciduous teeth, St. Louis and RPHP (New York metropolitan area), 1957–1970 births

	Average Sr-90, picocuries per gram of calcium	
Birth year	St. Louis	RPHP (n)
1957–62	4.0	3.5 (5)
1965–67	7.0	5.3 (6)
1968–70	4.6	2.2 (5)

children born in the 1980s and early 1990s; thus, the gap between observed and expected levels is growing. This finding indicates that factors other than atmospheric bomb testing account for current levels of Sr-90 in American children. Because of the observed temporal and geographic patterns, the likeliest source is emissions from nuclear power reactors.

Just over one-quarter of the teeth analyzed in our study contained expected low levels of Sr-90 concentrations, while 14 percent had levels 15 times or more than expected. This large variation suggests that differences in dietary intake of pregnant women—such as the amount of calcium in the diet—may affect fetal Sr-90 concentration. Moreover, the geographic origin of food and the type of water consumed (public water, well water, or bottled water) are factors in determining Sr-90 content in deciduous teeth. Month of birth is also a factor; monthly variations in airborne reactor emissions that are inhaled affect fetal concentrations of radioactivity, as do nuclear reactor accidents such as Three Mile Island and Chernobyl.

The connection between low-level radiation exposure and early childhood cancer is well documented. Small variations in background radiation levels and cancer in young children have been linked (32, 33). Subjection to pelvic X-rays in utero raises the risk of dying from cancer before age 10, with an especially high risk for those X-rayed early in the pregnancy (13, 14). Exposure to dietary radioactivity resulting from bomb test fallout has been correlated with leukemia in children (34). Elevated levels of childhood cancers have been found near nuclear power reactors in the United States (35–37) and in other nations (38–44). Decreased cancer incidence in children under 5 was demonstrated in the Sacramento, California, area immediately after the 1989 shutdown of the Rancho Seco reactor (45). However, none of these studies had the benefit of radioactivity counts in the body, instead relying on degree of proximity to reactors, soil deposition, or dietary levels. The correlation between Sr-90 in baby teeth and cancer before age 5 in Suffolk County is the first documented linkage between low-dose radioactivity levels in the human body due to fission products many years after exposure and elevated risk of disease.

Specifically related to Sr-90 is the extremely rare form of childhood cancer known as rhabdomyosarcoma. Bone, teeth, blood cells, and lymphoid tissue all originate from the mesenchymal layer during development (10). Leukemia and sarcomas are malignancies derived from mesenchymal cells (46), and these account for 30 and 5 percent of pediatric cancers, respectively (47). Rhabdomyosarcoma has an annual incidence of 4.5 per million children under age 15 (48), so the multiple cases reported in Suffolk County in recent years are most likely not the result of chance (24). In test animals, rhabdomyosarcoma has been induced by exposure to the beta radiation from Sr-90 applied to the skin (49).

Observations about health risks posed by Sr-90 in deciduous teeth in Suffolk County children are supported by additional correlations between cancer and gross beta/gross alpha activity in waters near Brookhaven National Laboratory and the nearby nuclear power plants. Strontium-90 is just one beta emitter, typically making up 20 to 50 percent of gross beta activity in New York State water. The high correlation coefficient between gross beta levels and childhood cancer indicates that multiple radionuclides, not just Sr-90, affect fetal and infant health and thus health in later life. Other bone-seeking isotopes emitting beta particles have similar biological actions and present similar health risks to humans.

The finding that gross alpha activity has similar temporal trends as beta activity and correlates with the rises and declines of childhood cancer incidence is important because it further supports the hypothesis that emissions from nuclear reactors are the principal source of recent environmental radioactivity. The observed rises and declines cannot be due to naturally occurring alpha emitters such as radium and radon.

A few gross alpha and beta readings in the Peconic River have been ten or more times greater than the typical levels, suggesting that BNL reactors may be a major source of the fluctuations in observed alpha and beta activity; neither the county's only other monitoring station (Fisher's Island) nor any other site in New York State shows simultaneous sharp fluctuations. The water in the Peconic, along with all surface water in the county, is not used for drinking; Long Islanders consume water drawn from aquifers underlying the island (50). Airborne releases not only are inhaled, but also enter wells via precipitation, affecting consumers of both private and municipal well water in the county. Since the well water is also used locally to produce crops such as fruits, vegetables, and potatoes, food becomes an additional vector for uptake of radioactivity.

Brookhaven emissions should be viewed as only one contributor to radioactivity levels in Suffolk County deciduous teeth. The county is located near several other nuclear power reactors, and is subjected to a concentration of reported large airborne emissions unmatched anywhere else in the nation. The western part of Suffolk lies only 40 miles southeast of Indian Point, which had extremely high airborne releases in 1985 and 1986 (23). Indian Point operators have had to shut down the reactors periodically because of safety concerns; one reactor (Unit 3) was closed from 1993 to 1995. New York State Health Department monitoring data show that gross beta levels in the Hudson River near Indian Point have frequently been two or three times greater than those in the Peconic River (31). Since many of these releases are airborne, they will reach Suffolk via prevailing winds and precipitation.

As shown in Figure 3, another highly troubled reactor (Oyster Creek) is situated 60 to 70 miles southwest of western Suffolk. Prevailing winds from the southwest place Suffolk directly downwind of the reactor, reported to have released 76.8 trillion picocuries of airborne long-lived fission products since 1970. Finally, in winter months windborne emissions from the equally troubled Haddam Neck and Millstone reactors in Connecticut reach eastern Suffolk county.

One important result of the present study is the confirmation that the fetus, because of its rapid cell growth, is much more sensitive than adults and even children to the harm caused by small exposures to radiation (51, 52). Energy released by alpha, beta, and gamma activity disrupts cellular membranes, alters DNA, and changes hormones—all crucial to normal growth. When elevated rates of disease occur in early childhood, they often reflect insults during the fetal period. In particular, early childhood cancers have been described as delayed congenital defects, or late effects of in utero mutations (53). The greater the insult to the developing fetus, the greater is the risk of developing cancer and other disorders, particularly in the earliest stages of life. In New York State, with a majority of the population living within 50 miles of the troubled Indian Point reactors, cancer incidence in children under 1 increased 97.8 percent from 1980–1982 to 1991–1993, compared with 35.2 percent for all children under 5 years of age (54). Because of the small number of annual cases in children under 1 year old in Suffolk County, the State Department of Health declined to make these data available owing to confidentiality concerns.

Demonstrating a statistical and clinical link between radioactivity and childhood cancer helps explain increases in a number of diseases among American infants and young children since the early 1980s because of damage to their immune systems. From 1984 to 1992, rates of birth weights under 2,500 grams (55), congenital hypothyroidism (56), and acute ear infections in 0- to 5-year-olds (57) rose, by 5.4, 46.3, and 75.9 percent, respectively. During the same period, asthma, which had previously reached its highest incidence during the years of atmospheric testing, became an epidemic affecting all Americans, particularly the youngest. From about 1980 to the mid-1990s, asthma in children age 0 to 4 surged in terms of prevalence (58), rate of physician office visits (59), and hospitalization rate (60), by 160.4, 65.5 and 60.5 percent, respectively. The increase in the asthma hospitalization rate (86.2 percent) during the first year of life was especially large (61), as was the increase in hospitalizations for infant bronchiolitis (141.9 percent)

(62). Radiation may interact synergistically with the increased indoor use of pesticides, particularly organophosphates, which also produce both immediate and delayed pulmonary symptoms.

Our study is limited in several ways. Strontium-90 is but one radionuclide of dozens found in the environment, so an absolute determination of total radiation doses received is impossible. It is not feasible to measure concentrations of short-lived isotopes in vivo on a large scale, and measurements of soft tissue–seeking isotopes such as the gamma-emitting Cs-137 using whole body counters is quite difficult and costly. Another limitation of measuring Sr-90 levels in deciduous teeth is that the measured levels cannot be attributed to releases from individual sources such as a particular reactor, except in the case of Miami which has only a single nuclear plant within 100 miles.

At present, the study is also limited by the relatively small number of teeth received from all areas except for Suffolk County. Teeth from children born between 1984 and 1992 account for about 85 percent of teeth received thus far, preventing any meaningful analysis of very recent trends. However, continued tooth collection will permit more detailed examinations of trends, of patterns in small areas, and of relationships of radioactivity to infant and child health. Many submissions in 1999 represent children born in the early 1990s, as they begin to shed their baby teeth.

This report highlights the critical need for expanded measurement of radioactivity in the diet and in thousands of baby teeth, from the zip code areas studied here and from elsewhere. Continued emissions of fission products and their entry into the environment make this process an essential public health function, and more detailed analyses should be conducted to determine the extent to which the presently permitted nuclear plant emissions play a role in increasing disease risks to the developing infant and child.

In conclusion, Sr-90 levels in deciduous teeth for children born during the 1980s and early 1990s are currently equal to those observed in the mid-1950s and are much greater than the levels expected after cessation of all atmospheric weapons tests. The observation of rises and declines of Sr-90 levels in deciduous teeth following known large radioactive releases into the environment, measured independently by state and federal agencies, means that these levels reflect recent reactor releases, not past bomb test fallout.

The evidence linking the changing levels of Sr-90 in baby teeth with changes in childhood cancer rates both during atmospheric nuclear testing and when, as today, radioactive emissions result only from reactor releases indicates that the developing embryo, fetus, and young infant are affected by reactor emissions far more than expected on the basis of past studies of adults. Thus, any extrapolations from the effects of high doses on adults—such as those used to establish present permissible releases based on the study of Hiroshima and Nagasaki bomb survivors—underestimate by hundreds to thousands of times the risk of childhood leukemia, cancer, and other illnesses caused by lower doses of fission products released into the environment.

Our results using in vivo measurements of a long-lived fission product such as Sr-90 as a marker for radiation exposure at the time of birth strongly support the hypothesis that the recent epidemic rise in the incidence of immune- and hormone-related diseases among children—such as cancer, asthma, low birth weight, hypothyroidism, ear infections, and bronchiolitis, as documented in recent publications—is most likely due to the unexpectedly severe effect of nuclear reactor releases, often synergistically increased by chemicals and air pollutants.

APPENDIX
DETERMINATION OF STRONTIUM-90 TO CALCIUM RATIO

Strontium-90 in deciduous teeth was determined under the direction of Hari D. Sharma, Professor Emeritus of Radiochemistry and president of REMS, Inc., Waterloo, Ontario, Canada, using the following procedure.

A tooth is dried for 12 hours at 110°C, then ground to a fine powder. Approximately 0.1 gram of the powder is weighed in a vial, then digested for a few hours with 0.5 milliliter of concentrated nitric acid along with solutions containing 5 milligrams of Sr^{2+} and 2 milligrams of Y^{3+} carriers at about 110°C on a sand bath. The solution is not evaporated to dryness. The digested powder is transferred to a centrifuge tube by rinsing with tritium-free water. Carbonates of Sr, Y, and Ca are precipitated by addition of a saturated solution of sodium carbonate, then centrifuged. The carbonates are repeatedly washed with a dilute solution of sodium carbonate to remove any coloration from the precipitate. The precipitate is dissolved in hydrochloric acid, and the pH is adjusted to 1.5 to 2 to make a volume of 2 milliliters, of which 0.1 milliliter is set aside for the determination of calcium. The remaining 1.9 milliliters are mixed with 9.1 milliliters of scintillation cocktail Ultima Gold AB, supplied by Packard Bioscience BV in a special vial for counting. A blank with appropriate amounts of Ca^{2+}, Sr^{2+}, and Y^{3+} is prepared for recording the background.

The activity in the vial with the dissolved tooth is counted four times, 100 minutes each time, for a total of 400 minutes, with a Wallac WDY 1220X Quantulus low-level scintillation spectrometer. The spectrometer has special features so that the background count-rate in the 400 to 1,000 channels is 2.25 ± 0.02 counts per minute. The background has been counted for over 5,000 minutes so that the error associated with the background measurement is about 1 percent. The overall uncertainty or one sigma associated with the measurement of Sr-90 per gram of calcium is ±0.7 picocuries per gram of calcium.

The efficiency of counting was established using a calibrated solution of Sr-90/Y-90 obtained from the National Institute of Standards and Technology, using the following procedure. The calibrated solution is diluted in water containing a few milligrams of Sr^{2+} solution, and the count-rate from an aliquot of the solution is recorded in channel numbers ranging from 400 to 1,000 in order to determine the counting efficiency for the beta particles emitted by Sr-90 and Y-90. It is ensured that the Y-90 is in secular equilibrium with its parent Sr-90 in the solution. The counting efficiency was found to be 1.67 counts per decay of Sr-90 with 1.9 milliliters of Sr-90/Y-90 solution with 25 milligrams of Ca^{2+}, 5 milligrams of Sr^{2+}, 2 milligrams of Y^{3+}, and 9.1 milliliters of the scintillation cocktail.

The calcium content was determined using a Varian A–A 1475 atomic absorption spectrophotometer by flame spectroscopy at a wave length of 422.7 nanometers, using acetylene plus air as fuel.

REFERENCES

1. Kulp, J. L., Eckelmann, W. R., and Schulert, A. R. Strontium-90 in man. *Science* 125: 219–224, 1957.
2. Weiss, E. S., et al. Strontium-90 content of human bones (1961–1963). *Radiol. Health Data*, May 1964, pp. 231–239.
3. Klusek, C. S. *Strontium-90 in Human Bone in the U.S., 1982.* EML-435. U.S. Department of Energy, New York, 1984.
4. Baratta, E. J., Ferri, E. S., and Wall, M. A. Strontium-90 in human bones in the United States, 1962–1966. *Radiol. Health Data Rep.*, April 1970, pp. 183–186.
5. Reiss, L. Z. Strontium-90 absorption by deciduous teeth. *Science* 134: 1669-1673, 1961.
6. Rosenthal, H. L. Accumulation of environmental 90-Sr in teeth of children. Proceedings of the Ninth Annual Hanford Biology Symposium. In *Radiation Biology of the Fetal and Juvenile Mammal*, edited by M. R. Sikow and D. D. Mahlum. U.S. Atomic Energy Commission, December 1969.
7. Norris, R. S., and Cochran, T. B. *United States Nuclear Tests, July 1945 to 31 December 1992.* Natural Resources Defense Council, Washington, D.C., 1994.
8. Campbell, J. E., and Murthy, G. K. Summary of results from the raw milk sampling program, June 1957–April 1963. *Radiol. Health Data*, October 1963, pp. 511–519.
9. Sherman, J. D. *Chemical Exposure and Disease.* Princeton Scientific Publishing, Princeton, 1994.
10. Arey, L. B. *Developmental Anatomy*, Ed. 6. W. B. Saunders, Philadelphia, 1954.
11. Fitzgerald, M. J. T., and Fitzgerald, M. *Human Embryology.* Bailliere Tindall, Philadelphia, 1994.
12. Carson, B. M. *Human Embryology and Developmental Biology.* C. V. Mosby, 1994, St. Louis, 1994.
13. Stewart, A., Webb, J., and Hewitt, D. A survey of childhood malignancies. *BMJ* 1: 1495–1508, 1958.
14. MacMahon, B. Prenatal x-ray exposure and childhood cancer. *J. Natnl. Cancer Inst.* 28: 1173-1191, 1962.
15. U.S. Environmental Protection Agency. *Environmental Radiation Data.* Montgomery Ala., 1991 and following years.
16. Licensee data is compiled by the Nuclear Regulatory Commission, Washington, D.C., Available from: http://www.nrc.gov

17. Mangano, J. J. A rise in the incidence of childhood cancer in the United States. *Int. J. Health Serv.* 29: 393–408, 1999.
18. Scholz, R. *Ten Years After Chernobyl: The Rise of Strontium-90 in Baby Teeth.* Radiation and Public Health Project, New York, 1997.
19. National Cancer Institute. *Forty-five Years of Cancer Incidence in Connecticut: 1935–79.* NIH Publication No. 86-2652. Bethesda, MD., 1986.
20. Polednak, A. P. Cancer mortality in a higher-income black population in New York State: Comparison with rates in the United States as a whole. *Cancer* 66: 1654–1660, 1990.
21. Kulldorff, M., et al. Breast cancer clusters in the northeast United States: A geographic analysis. *Am. J. Epidemiol.* 146: 161–170, 1997.
22. Sternglass, E. J., and Gould, J. M. The Long Island Breast Cancer Epidemic: Evidence for a Relation to the Releases of Hazardous Nuclear Wastes. CMA Occasional Paper, Long Island University School of Public Service, July 1994.
23. Brookhaven National Laboratory. *Radioactive Materials Released from Nuclear Power Plants, 1993.* NUREG/CR–2907, BNL–NUREG–51581, Vol. 14. Upton, N.Y., December 1995.
24. Gould, J. M., et al. The Strontium-90 Baby Teeth Study and Childhood Cancer. Presentation to Collegium Ramazzini, Carpi, Italy, October 31, 1999.
25. New York State Department of Health. Data from Statewide Planning and Research Cooperative System, Albany, N.Y., 1997.
26. Mangano, J. J. A post-Chernobyl rise in thyroid cancer in Connecticut, USA. *Eur. J. Cancer Prev.* 5: 75–81, 1996.
27. Sternglass, E. J. Birthweight and Infant Mortality Changes in Massachusetts Following Releases from the Pilgrim Nuclear Power Plant. Submitted to the Massachusetts Legislature, June 10, 1986.
28. Clapp, R. W., et al. Leukemia near Massachusetts nuclear power plant. *Lancet* 336: 1324–1325, 1987.
29. United Nations. *Report on the United Nations Scientific Committee on the Effects of Atomic Radiation.* New York, 1962.
30. Cancer Registry, New York State Department of Health, Albany, N.Y. Data provided April 1999.
31. Bureau of Environmental Radiation Protection. *Annual Report of Environmental Radiation Levels in New York State, 1982–93.* New York State Department of Health, Albany, 1994.
32. Knox, E., et al. Background radiation and childhood cancers. *J. Radiol. Protection* 8: 9–18, 1988.
33. Hatch, M., and Susser, M. Background radiation and childhood cancers within ten miles of a U.S. nuclear plant. *Int. J. Epidemiol.* 19: 546-552, 1990.
34. Archer, V. E. Association of nuclear fallout with leukemia in the United States. *Arch. Environ. Health* 42: 263–271, 1987.
35. Johnson, C. J. Cancer incidence in an area contaminated with radionuclides near a nuclear installation. *Ambio* 10: 176–182, 1981.
36. Goldsmith, J. Childhood leukemia mortality before 1970 among populations near two U.S. nuclear installations. *Lancet* 340: 1443–1444, 1989.
37. Jablon, S., Hrubek, Z., and Boice, J. D. Cancer in populations living near nuclear facilities. *JAMA* 265: 1403–1408, 1991.

38. Heasman, M., et al. Childhood leukemia in Northern Scotland. *Lancet* 266: 385, 1986.
39. Roman, E., et al. Childhood leukemia in the West Berkshire and Bainstoke and North Hampshire Authorities in relation to nuclear establishments in the vicinity. *BMJ* 294: 597–602, 1989.
40. Gardner, M., et al. Results of a case-control study of leukemia and lymphoma among young people near Sellafield nuclear processing plant in West Cumbria. *BMJ* 300: 423–429, 1990.
41. Viel, J., and Richardson, S. Childhood leukemia around the La Hague nuclear waste reprocessing plant. *BMJ* 300: 580–581, 1990.
42. Goldsmith, J. Nuclear installations and childhood cancer in the UK: Mortality and incidence for 0–9-year-old children 1971–1980. *Science in the Total Environment* 127: 13–35, 1992.
43. Michaelis, J., et al. Incidence of childhood malignancies in the vicinity of West German nuclear power plants. *Cancer Causes and Control* 3: 255–264, 1992.
44. Schmitz-Feuerhake, I., et al. Leukemia in the proximity of a German boiling-water nuclear reactor: Evidence of population exposure by chromosome studies and environmental radioactivity. *Environ. Health Perspect.* 105: 1499–1504, 1997.
45. Mangano, J. J. Improvements in local infant health after nuclear power reactor closing. *J. Environ. Epidemiol. Toxicol.* 2: 32–36, 2000.
46. Gofman, J. W. *Radiation and Human Health.* Sierra Club, San Francisco, 1981.
47. Rudolph, A. M. (ed.). *Rudolph's Pediatrics.* Appleton and Lange, Stamford, Conn., 1996.
48. Dagher, R., and Helman, L. Rhabdomyosarcoma: An overview. *Oncologist* 4: 34–44, 1999.
49. Gupta, A., et al. Experimental induction of rhabdomyosarcoma in mice with fractionated doses of B-radiation. *J. Cancer Res. Clin. Oncol.* 125: 257–267, 1999.
50. Sternglass, E. J., and Gould, J. M. Breast cancer: Evidence for a relation to fission products in the diet. *Int. J. Health Serv.* 23: 783–804, 1993.
51. Gofman, J. W. *Radiation-Induced Cancer from Low-Dose Exposure: An Independent Analysis.* CNR Books, San Francisco, 1990.
52. Upton, A. C. Biological basis for assessing carcinogenic risk of low-level radiation. *Carcinogenesis* 10: 381–401, 1985.
53. Greene, G. *Alice Stewart: The Woman Who Knew Too Much.* University of Michigan Press, Ann Arbor, 1999.
54. Cancer Registry, New York State Department of Health, Albany NY. Data provided June 1997.
55. National Center for Health Statistics. *Vital Statistics of the United States.* U.S. Department of Health and Human Services, Washington D.C., various years.
56. Personal correspondence, newborn screening programs, 30 U.S. states. 1995.
57. Division of Health Interview Statistics. *National Health Information Survey.* U.S. Centers for Disease Control and Prevention, Hyattsville, Md., various years.
58. Division of Health Interview Statistics. *National Health Interview Survey.* U.S. Centers for Disease Control and Prevention, Washington, D.C., various years.
59. Division of Health Interview Statistics. *National Ambulatory Medical Care Survey.* U.S. Centers for Disease Control and Prevention, Washington, D.C., various years.
60. From the Centers for Disease Control. *JAMA* 275: 1535–1536, 1996.

61. Leiss, J. K., and Santz, D. A. Home pesticide use. *Am. J. Public Health* 85: 249–252, 1995.
62. Shay, D. K., et al. Bronchiolitis-associated hospitalizations among US children, 1980–1996. *JAMA* 282: 1440-1446, 1999.

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