Bulletin of the Atomic Scientists

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/rbul20

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To cite this article: Robert Alvarez & Joseph Mangano (2021) I gave my baby tooth to science: Project Sunshine's role in the Limited Test Ban Treaty and cutting-edge pollution research, Bulletin of the Atomic Scientists, 77:6, 312-317, DOI: 10.1080/00963402.2021.1989207

To link to this article: https://doi.org/10.1080/00963402.2021.1989207

Published online: 15 Nov 2021.

BULLETIN OF THE ATOMIC SCIENTISTS
2021, VOL. 77, NO. 6, 312–317
https://doi.org/10.1080/00963402.2021.1989207

Routledge
Taylor & Francis Group

OTHER FEATURES

I gave my baby tooth to science: Project Sunshine's role in the Limited Test Ban Treaty and cutting-edge pollution research

Robert Alvarez and Joseph Mangano

ABSTRACT
How many nuclear weapons can be detonated in support of weapons development or during a war before imperiling humans from radioactive fallout? That's the question the Atomic Energy Commission asked in the 1950s. To find the answer, scientists, citizens, and later the St. Louis Committee for Nuclear Information looked at baby teeth where strontium 90 – a radioactive isotope – is absorbed as if were calcium. The work combined scientific research with a political movement aimed at ending the nuclear arms race. It also played a role in the ratification of the 1963 Limited Test Ban Treaty. The wisdom and extraordinary effort of preserving these baby teeth for some 60 years opened doors for cutting-edge research involving an array of pollutants.

KEYWORDS
Baby tooth survey; atomic energy commission; nuclear weapons fallout; atomic era; strontium 90; St. Louis committee for nuclear information

How many nuclear weapons can be detonated in support of weapons development or during a war before imperiling humans from radioactive fallout? That's the question the Atomic Energy Commission (AEC) asked in the 1950s. To find the answer, independent scientists and citizens turned to baby teeth. Lots and lots of baby teeth.

Why baby teeth? The AEC collected human tissues from around the globe (Eckelmann, Kulp, and Schulert 1957) to understand the cumulative impacts of radioactive fallout from nuclear testing. The most commonly measured isotope in these tissues – strontium 90 – is absorbed as if were calcium. This isotope lodges in human bone tissue for many years and was the principal contaminant of concern in fallout investigations known as Project Gabriel and Project Sunshine done in the early 1950s. This effort, which started as a health study, later inspired a political movement to end nuclear weapons testing.

"The most worldwide destruction could come from radioactive poisons," researchers at Los Alamos National Laboratory speculated in 1945. They suspected that radioactive fallout from 10,000 megatons exploded in the open air might be enough to threaten human life on the planet (Manhattan District History Project Y 1961).

Edward Teller, the prime mover in developing thermonuclear weapons, enthused over building a 10,000 megaton "gadget" during a meeting of the AEC's General Advisory Committee in July 1954. This "shocked" committee member Walter Whitman, head of the department of chemical engineering at MIT because "it would contaminate the earth" (U.S. Atomic Energy Commission 1954a).

At the time, Project Sunshine was secret. More than 1,500 human samples were collected in this effort, including many from deceased children in Europe and Australia without parental consent (ABC News Live 2005). The United States also developed registries to study the uptake of plutonium from weapons fallout of human tissue samples collected from deceased members of the US general public (McInroy 1995) and deceased nuclear workers (Washington State University 2021).

Scientists recommend a landmark baby tooth study

Atmospheric testing of hundreds of nuclear weapons continued, leading Herman Kalckar, a biologist with the National Institutes of Health, to propose an international program measuring strontium 90 in baby teeth. In his August 1958 *Nature* article, Kalckar wrote:

> The official public health agencies of every nation . . . should organize a large-scale collection of milk teeth . . . and conduct measurements of radioactivity on this material . . . Such an International Milk Teeth Radiation Census would contribute important information concerning the amount and kind of radiation received by the most sensitive section of any population namely, the children (Kalckar 1958).

In response, the St. Louis Committee for Nuclear Information and scientists at Washington University, beginning in December 1958, began assembling the most significant collection of human samples in the atmospheric bomb test era. Parents of children born after World War II donated 320,000 baby teeth. Unlike

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the AEC, which had shrouded its human tissue collection in secrecy, the baby tooth survey was widely advertised. The survey's goal was to demonstrate that a child's absorption of consequential radioactive elements from nuclear testing was not an abstract issue. The survey was deliberate in combining scientific research with a political movement to end the nuclear arms race.

The baby tooth survey showed that America's children from the "baby boom" generation were absorbing strontium 90 from nuclear weapons testing. While the survey results played an important role in the ratification of the Limited Test Ban Treaty in 1963, the treaty did not slow the pace of nuclear buildup. Still, the treaty became the first, little-recognized, global environmental agreement to stem the poisoning of the planet. Also, the wisdom and extraordinary effort of preserving these baby teeth for some 60 years opened doors for cutting-edge research involving an array of pollutants.

Citizen scientists collect 320,000 teeth

Schools, libraries, parent-teacher associations, churches, dental offices, scout groups, and other community organizations volunteered to help the St. Louis Committee for Nuclear Information collect baby teeth. Each tooth was placed in a small envelope and given a unique number. In addition, information was collected on small index cards about the tooth and tooth donor. Washington University set up a speaker's bureau to increase public knowledge about the program, in which they recruited luminaries like Benjamin Spock and Linus Pauling to speak on behalf of the tooth study.

While St. Louis remained the center of the program, activists in other states contributed teeth as well. Teeth were prepared for strontium 90 lab testing by volunteers, who sent them to Harold Rosenthal, a chemist at Washington University. Rosenthal then measured the ratio of strontium 90 to calcium. Lab costs were covered by grants from the US Public Health Service and the Danforth Foundation.

The teeth were crushed into powder and placed in a liquid solution, which removed decay and fillings. They were divided into separate, homogenous groups according to the uptake of strontium 90 in teeth. These groups were based on tooth type (molars, incisors, or cuspids), location (by metropolitan area), infant-feeding status (bottle-fed or breast-fed), and birth year and month. Since most strontium 90 in baby teeth is taken up late in pregnancy and early infancy, birth date was a key data element in the study.

Every child donating teeth to the committee was rewarded with a small metal button that children wore on their clothing. The button had a picture of a smiling boy with a gap in his front teeth, with the words "I Gave My Tooth to Science" below the picture. Decades later, thousands of children from that era recall the button, and some have even saved them. The artwork for the teeth is now part of a collection in the Smithsonian Institution.

Tooth study results hasten test ban treaty

The tooth study results were compelling: Average strontium 90 in St. Louis incisors for bottle-fed persons born in the last half of 1954 were more than three times the amount found in incisors with the same profile in the last half of 1951: 0.588 picocuries strontium 90 per gram of calcium as opposed to 0.188 (Reiss 1961). These results were published in late 1961 in *Science* by Louise Reiss, an internist who ran the study.

This rise was consistent with the ongoing bomb tests in Nevada, which began in January 1951. Several years later, Rosenthal published a journal article that showed that for St. Louis births, the strontium 90 average concentration increased sevenfold from 1951 to 1957 (Rosenthal 1963). Eventually, the increase was calculated to be 20- to 80-fold from 1950 to 1963 births (Rosenthal 1969).

Study results were sent to President John F. Kennedy's science advisor Jerome Wiesner, who discussed them with the president. Kennedy was growing concerned about the buildup of fallout and the need for a ban on aboveground nuclear tests. Historical accounts from that period document Kennedy's concern, including one written by Kennedy's advisor and biographer, Theodore Sorenson:

> And I told him that it was washed out of the clouds by the rain, that it would be brought to earth by rain, and he said, looking out the window, 'You mean it's in the rain out there?'—and I said 'Yes'; and he looked out the window, looked very sad, and didn't say a word for several minutes (Sorenson 1965).

Physician Eric Reiss, husband of Louise and another concerned physician from Washington University, testified to the US Senate in August 1963 during which he cited the buildup of fallout in humans as a critical reason to support the treaty. Soon after, the Senate overwhelmingly voted for the test ban, Kennedy signed the treaty, and aboveground tests from the superpowers ended permanently.

Barry Commoner, a Washington University biologist and primary organizer opposing nuclear weapons testing, led an effort to collect and analyze baby teeth from children around the country. He sought to speed the enactment of a ban on atmospheric testing. According to Commoner:

> The US Senate was a nest of cold-warriors and, according to common wisdom, was unlikely to ratify the [Limited Test Ban] treaty. But the Senate was besieged by letters, many of them from parents who abhorred the idea of raising their children with radioactive fallout embedded in their bodies. What convinced the senators was not so much their constituents' fear of radiation, but that they were informed; they knew how to spell 'strontium 90′ and could explain precisely why it was so dangerous. The treaty was easily ratified (Hall 1997).

Thus, the baby tooth survey played a key role in the establishment of the first modern international environmental treaty, which mitigated further poisoning of the planet by radioactive detritus. The baby tooth survey demonstrated that, by joining movements to protect the human environment, scientists and citizens can make a positive difference.

Tooth study was halted before understanding health effects

The baby tooth study was designed to speed the passage of the treaty, but it also raised concerns about health hazards from fallout. In particular, some proposed that baby teeth could be used to calculate excess risk. A story in *Newsweek* magazine stated:

> But what about the children who have done their growing while strontium 90 levels were high—are they liable to develop cancer? No one can answer with certainty, but St. Louis's 'Operation Tooth' is one way scientists have of finding out (Newsweek 1960).

"We wanted to do a 10- to 15-year follow-up health study. We always said the value of the research could only be borne out by tracking children 15 years later," said Yvonne Logan, a Committee for Nuclear Information member who took over operations for the tooth study in the early 1960s (Logan 2003). However, no such attempt was made due to technical issues of accurately testing single teeth.

The study continued after the treaty. A major fire struck the Committee for Nuclear Information offices in January 1968, though the large collection of teeth and cards survived as they were kept in fire-proof metal file cabinets. When the federal and foundation grants ended in 1970, tooth collection and testing also ended.

Few studies of health hazards from bomb fallout

Six thermonuclear weapon tests conducted between March 1 and May 14, 1954 in the Marshall Islands – known as the Castle series – caused some of the most significant health and environmental impacts of US atmospheric weapons testing. Totaling some 48 megatons of explosive force, they had negative impacts around the world. The first explosion, known as Bravo, produced an explosive yield of approximately 15 megatons, which was 1,000 times the destructive power of the Hiroshima atomic bomb. Because of its size and other factors, Bravo also spawned what the US Radiochemical Society (http://www.radiochemistry.org/history/nuke_tests/castle/index.html) describes as "the worst radiological disaster in US history" (U.S. Radiochemical Society 2019). The people of Rongelap and Uterik atolls suffered severe impacts 200 miles away from the blast, including more than seven dozen people who received tissue-destructive radiation doses comparable to Japanese atomic bomb survivors (von Eschenbach 2005). Over the years, several US government studies have documented that residents suffered from a high rate of thyroid disease from ingesting radioactive iodine. In 2010, researchers from the National Cancer Institute concluded that "our calculations project a substantial burden of radiation-related cancer in the more heavily-exposed Marshallese population groups . . . " (Land et al. 2010).

The AEC found that these enormous thermonuclear explosions created hazards 5,000 miles away in the United States. In November 1954, months after the six H-Bomb tests known as Castle in the Marshall Islands, the AEC's director of the Biology and Medicine Division, John C. Bugher, reported to the General Advisory Committee that radioactive iodine from the Castle tests:

> can be detected in thyroids all over the US . . . It is estimated that everyone in the US [160 million people] received a dose of 1 rep in the thyroid as a result of Castle. (U.S. Atomic Energy Commission 1954b).

This estimate represents nearly half of the per capita dose estimated decades later for members of the US public by the National Cancer Institute from 100 open-air nuclear tests in Nevada (National Cancer Institute 2019). Bugher also "cautioned against the use of milk in heavily contaminated areas" and "that strontium 90 in the New York milk supply has increased" (U.S. Atomic Energy Commission 1954b).

Despite this, official studies on US health casualties from aboveground bomb testing have been scant. In 1999, the National Cancer Institute released a study

based on estimated radioactive iodine 131 in bomb fallout in each US county from atmospheric tests in Nevada from 1951 to 1963. From these data, the institute estimated 11,300 to 212,000 thyroid cancers occurred in Americans who were under 20 years of age at time of exposure (Institute of Medicine and National Research Council 1999).

In September 1998, a US Senate investigation found that this congressionally mandated study was mismanaged and that the National Cancer Institute withheld key findings from the public for nearly five years (U.S. Senate Committee on Governmental Affairs 1998).

Subsequently, the US Centers for Disease Control and Prevention estimated 15,000 fatal cancers among Americans alive from 1951 to 2000 caused by worldwide atmospheric bomb test fallout. The report did not consider internal radiation exposure from breathing and ingesting radioactive particles such as strontium 90 (*The Guardian* 2002).

In 2017, University of Arizona economics professor Keith Meyers looked at dose estimates of iodine 131 levels in milk from Nevada tests and estimated that 395,000 to 695,000 excess US deaths occurred during the years 1951 to 1973. Meyers went further by making a rough calculation that the test ban treaty saved 11.7 to 24.0 million US lives (Meyers 2017). The wide spread in these results, which represented one of the few attempts to address fallout, suggests that impact on disease and death rates was still not well understood.

Found teeth launch health studies

Several European nations emulated St. Louis's tooth study efforts to track fallout. The Radiation and Public Health Project, a research and education group primarily interested in nuclear power reactors, also used the tooth study as a prototype for its own study of the same mix of radioactive chemicals (including strontium 90) in nuclear weapons tests. To date, the Radiation and Public Health Project study includes 5,000 baby teeth close to six US nuclear power plants. That study was the subject of five journal articles showing high and rising strontium 90 levels in teeth near reactors.

In the summer of 2001, Washington University biology professor Daniel Kohl, who had been on the faculty since the 1960s and was well acquainted with the original tooth study, led an inspection of a school-owned storage unit at Tyson Valley just outside of St. Louis. Kohl and his colleagues found long shoe boxes filled with teeth in envelopes attached to small index cards. He notified biology department administrators, who had no interest in retaining the teeth. He then called Commoner, who also did not want the teeth, but recommended they be given to the Radiation and Public Health Project. The teeth were donated soon after.

The project found that a large number of teeth – about 100,000 – had never been tested. Apparently, whoever stored the teeth had forgotten they were there. Because strontium 90 decays slowly, the chemical still could be measured in teeth. Tooth donors and their parents reacted in numerous media articles with a combination of nostalgia, pride, and interest in knowing more about the human health hazards of fallout.

As a health research organization, the Radiation and Public Health Project's interest in the teeth was not to track patterns of strontium 90 over time, as Washington University had done, but to use teeth to estimate correlations of health hazards from fallout. The long period of time since teeth were donated was actually an advantage, since tooth donors were now well into adulthood, and could be identified through death records and public databases such as voter registration files.

In 2011, the project's members published an article in the *International Journal of Health Services* using the St. Louis teeth. Twenty incisors from male bottle-fed St. Louis tooth donors born 1958–1960 who died of cancer by age 50 had more than double the strontium 90 concentration than in 40 incisors from controls who had no major health problems at age 50 (Mangano and Sherman 2011). The difference was statistically significant and received attention from media, including from the *New York Times*.

To date, no attempts have been made to replicate results of the Washington University study or the Radiation and Public Health Project study of strontium 90 in US baby teeth. In future studies, the 100,000 teeth may be crucial. That is, the teeth represent evidence of exposure – intake of long-lived radioisotopes from bomb test fallout – which should help with risk estimation based on retrospective dose reconstruction and dispersion modeling (National Research Council, Committee on the Biological Effects of Ionizing Radiation 1990). These uncertainties in risk estimation for bomb test fallout are similar to that of estimating risks to US nuclear weapons workers who were individually measured for exposure. For instance, the Department of Health and Human Services has declared that dose reconstruction for thousands of workers at several nuclear sites, such as Hanford, the Nevada Test Site and Los Alamos have proven infeasible, especially during the first decades of operation. This has restricted the department's abilities to offer compensation (Centers for Disease Control and Prevention 2021).

A Harvard University grant opens up tooth research

Planning a study based on such a large collection of teeth has been extremely difficult. Information remained on the small index cards, and sifting through thousands of teeth was cumbersome and inefficient. In 2019, Harvard public health professor Marc Weisskopf, who had met Radiation and Public Health Project Executive Director Joseph Mangano a few years earlier, obtained a five-year grant from the National Institutes of Health to study health hazards of early-life exposure to heavy metals using a sample of 1,000 teeth.

The first year of the grant was mostly spent entering data on the teeth and donors into an automated spreadsheet. That work was done by the Radiation and Public Health Project and a contractor. The final tally of teeth was greater than previously thought; the collection consists of nearly 100,000 teeth, all from persons born between 1946 and 1965. While the majority of teeth are from the St. Louis area, at least 12 teeth from persons born in each of the 50 states, plus 45 foreign countries, exist.

Teeth can be studied for scientific research purposes beyond radiation and heavy metals, including for insight into pesticides, fluoride, genetics, dental research, and anthropology. The Radiation and Public Health Project makes teeth available for any of these efforts. Largely forgotten for the several decades, the baby tooth collection's intrinsic scientific value to human health research is unique given its size and its portrait of the large generation of "baby boomers" born after World War II. These data address the still-unresolved legacy of radioactive fallout and provide rare human evidence of potentially harmful substances found outside of the nuclear industries.

The St. Louis baby tooth study relied on the simple acts of donating children's baby teeth for scientific research. This grassroots movement, driven by citizen participation, documented increasing levels of toxic radiation in human bodies from nuclear weapons tests. Evidence from the study helped speed the passage of the treaty banning these tests. University of North Carolina epidemiologist Steven Wing stated that:

> By joining movements for human rights and social justice, health scientists can identify research questions that are relevant to public health, develop methods that are appropriate to answering those questions, and contribute to efforts to reduce health inequalities (Wing 2016).

The St. Louis tooth study was a groundbreaking example of Wing's call to join political movements to protect the environment. Decades after the study began, the discovery of a large number of untested teeth spanning an entire generation offers support for his belief that such movements can document health problems, answer questions about health, and reduce inequalities by providing important and enduring scientific evidence.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Funding

This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

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Robert Alvarez is a senior scholar at the Institute for Policy Studies and served as senior policy adviser to the Energy Department's secretary and deputy assistant secretary for national security and the environment from 1993 to 1999. During this tenure, he led teams in North Korea to establish control of nuclear weapons materials. He also coordinated the Energy Department's nuclear material strategic planning and established the department's first asset management program. Before joining the Energy Department, Alvarez served for five years as a senior investigator for the US Senate Committee on Governmental Affairs, chaired by Sen. John Glenn, and as one of the Senate's primary staff experts on the US nuclear weapons program. In 1975, Alvarez helped found and direct the Environmental Policy Institute, a respected national public interest organization. He also helped organize a successful lawsuit on behalf of the family of Karen Silkwood, a nuclear worker and active union member who was killed under mysterious circumstances in 1974. Alvarez has published articles in *Science*, the *Bulletin of Atomic Scientists, Technology Review*, and *The Washington Post*. He has been featured in television programs such as *NOVA* and *60 Minutes*.

Joseph Mangano, MPH, MBA, is the executive director for the Radiation and Public Health Project in New York and has served the organization since 1989. He is the author of 38 medical journal articles and the books *Radioactive Baby Teeth: The Cancer Link* (2008), *Mad Science: The Nuclear Power Experiment* (2012), and *Low-Level Radiation and Immune Disease: An Atomic Era Legacy* (1998).

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