National Cancer Institute Cancer Risk Projection Study for the Trinity Nuclear Test
Summary of Findings in *Health Physics*

Background on the Trinity Test

A study to estimate the radiation doses and associated range of excess cancer risk from the world's first test of a nuclear weapon, conducted in 1945 and known as Trinity, was recently completed by a team of researchers from the National Cancer Institute (NCI), part of the National Institutes of Health. Radiation doses that may have been received were estimated for all counties of the state. The team also provided an estimate of how many cancer cases may have occurred in the past and might occur in the future related to this radiation exposure. The findings are being published in the October 2020 issue of the journal *Health Physics*.

The Trinity nuclear test was conducted by the U.S. government as the culmination of the of the Manhattan Project; it took place early in the morning of July 16, 1945, in south-central New Mexico. Just three weeks later, atomic bombs, for which Trinity were the proof-of-principle test, were dropped on Hiroshima and Nagasaki to end the second World War.

In response to longstanding New Mexico community concerns about the possible harmful effects of nuclear testing, the U.S. Congress requested investigation of the radiation exposure and possible effects from the Trinity test.

Estimating Radiation Dose

The nuclear detonation exposed residents of New Mexico to varying levels of radiation from radioactive fallout, depending, in part, on where they lived in the state, how much time they spent inside protective structures in the immediate months after the test, and how much radiation entered their bodies through contaminated food and water. Each of these factors were considered by the NCI research team.

In the days immediately after the Trinity test, the Manhattan Project staff collected measurements of radiation emitted from fallout deposited on the ground. Those data were subsequently analyzed and used by the Weather Service Nuclear Support Office in Las Vegas, NV, to form a map of the fallout pattern that was published in 1987. That map of contamination was used by the NCI researchers as the basis for estimating radiation dose to New Mexico residents at the time of the Trinity test.

In contrast to ground level contamination data, there was limited information on the typical diet of residents of New Mexico in the 1940s-1950 which was also needed to estimate the doses received. To account for internal exposure (resulting from- consumption of contaminated food products), NCI researchers reconstructed typical diets from information they gathered via 13 focus groups and 11 individual interviews with older adults who were still living in the same NM communities where they lived during the 1940s or 1950s.

In addition, the researchers used mathematical models on the physics of radioactivity, fallout and movement of fallout throughout the environment to estimate radiation doses to which people in New Mexico may have been exposed during the year following the test, when most of the exposure was received.

The researchers concluded that only in small geographic areas immediately downwind of the detonation site were the exposures substantially higher than naturally occurring background radiation.

Estimating Cancer Risk

There were no comprehensive sources of data on the number of cancer cases in New Mexico before the test nor over the next 20 years. The New Mexico Tumor Registry began partial collection of data in 1966. As a substitute for the missing New Mexico cancer rates, the researchers used cancer incidence rates from the NCI SEER program, a network of cancer registries across the US which was established in 1973.

The researchers paired the cancer incidence data—the hypothetical baseline rate—with the dose information. Data on dose were prepared for multiple organs using data derived from other populations exposed to radiation on the sensitivity of each organ to radiation exposure. They estimated over the past 75 years, the range for how many excess cancer cases (cancers above the hypothetical baseline number expected without the Trinity test) may have or might occur among the four primary ethnic groups living in New Mexico at the time of the test (i.e., whites, Hispanics, Native Americans, and African Americans), across age groups, and for every county in the state.

The data suggest that perhaps several hundred cancers, primarily thyroid cancer, have already occurred over the 75 years since the test and a small number are projected to occur in the future that would not have occurred in the absence of radiation exposure from Trinity fallout. Most of the excess cancers are projected to have occurred or will occur among residents living in Guadalupe, Lincoln, San Miguel, Socorro, and Torrance counties in 1945. Significant uncertainty in dose estimation had a substantial impact on the total uncertainty around these estimates. Most cancers that have occurred or will occur among the 1945 residents of New Mexico are likely to be cancers unrelated to exposures from Trinity fallout. Finally, with the data available, it is not possible to definitively identify the specific individuals whose cancers might be due to the radiation exposure.

The limitations of the dose estimation and risk projections are due to several factors, including accuracy of the recall of childhood diet by elderly focus group participants 70 years after the incident, the small number of focus group participants, and the possible differences between the experiences of the select focus group participants and that of all persons alive at the time of the test, the lack of cancer rates from New Mexico for the time period of interest. As a result, there is great uncertainty in the estimates of radiation doses and number of cancer cases possibly attributable to the test, thus no firm estimates can be established.

Acknowledgements

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Additional Research

The NCI research team, with external collaborators, conducted an extensive literature review of published reports on diverse populations exposed to radiation from various sources to determine the

potential for transgenerational effects (that is, adverse pregnancy outcomes and genetic or second generational diseases) and found no evidence for such intergenerational effects. Finally, they evaluated the distribution and implications of the unfissioned plutonium resulting from the detonation.

Publications

The publications on the study of the Trinity test are available without cost either upon request or by a link found on the study website: https://dceg.cancer.gov/trinity. As stated in the introduction to the suite of six papers in *Health Physics*, the authors hope the analysis and findings are of significant value to all persons interested in the health impact of the Trinity nuclear test.

The six papers, each with a short summary, are listed below.

Methods and Findings on Diet and Lifestyle Used to Support Estimation of Radiation Doses from Radioactive Fallout from the Trinity Nuclear Test **(Dr. Nancy Potischman and colleagues)**

The first paper of this series, by Dr. Potischman and colleagues, presents the methods and a summary of data collected primarily on diet, as well as home construction types, time spent outdoors during summer months at different ages, and breastfeeding habits in the 1940s. To assist the investigators who would estimate the range of radiation doses that residents of New Mexico may have received as a result of the Trinity test, Dr. Potischman and co-authors had to understand the typical diet in the 1940s, because consumption of fallout-contaminated food and water is the main way people are exposed internally to fallout radiation. Dr. Potischman and her colleagues began by reviewing the literature to identify typical foods eaten and dietary patterns in New Mexico in the 1940s among different ethnic groups.

The researchers first conducted a small pilot study with people who had lived in New Mexico during the 1940s or 1950s, in order to help design a data collection method. The final study involved 13 focus groups and 11 individual interviews with people over 70 years of age who had lived in New Mexico at the time of the test. The focus groups included discussions with people of the four major ethnic groups in New Mexico.

From those discussions, researchers estimated how much and how frequently people of each ethnicity and age typically ate specific foods. Foods consumed included meat, fresh dairy products, plants, fruit and, of course, drinking water. The team learned about the construction materials of homes, breastfeeding infants—found to be very common—the amount of time people spent outdoors, particularly in the summer, and how communities obtained drinking water.

One of the food items of the most scientific interest was milk. Fresh milk can be a major source of one component of fallout radiation (called Iodine-131, or I-131 for short) that results from cows consuming grass contaminated with radioactive fallout that was deposited on pastureland. The radioactivity on the grass, especially I-131, tends to concentrate in cows' milk and ends up in fresh dairy products. When people consume contaminated milk, the radioactive iodine is concentrated in the thyroid gland. However, I-131 decays rapidly and is virtually gone within two months, so the possibility of significant exposure of the thyroid is for a short time only.

The researchers found that the rate of milk consumption was lowest among people living in mountainous regions and highest among children aged 11-15 years who were living in rural plains areas. However, the youngest age group had the highest doses because of the small size of thyroid gland.

Meat, which transfers much less radioactivity, was not commonly eaten in the summer in most communities, and those who did eat it, consumed relatively small amounts. Most drinking and cooking water came from wells that were covered which tended to protect them from contamination. Many homes were made from adobe which provided more protection from radiation than did wooden structures.

The dietary data for the mid-1940s, about which there was little prior published information, as collected by the research team, are now the best available data on diet in New Mexico for the purposes of radiation dose assessment. The researchers emphasized that the findings are not intended to represent specific individuals, but represent typical behaviors of each ethnic and age group.

The Methodology Used to Assess Radiation Doses from the First Nuclear Weapons Test (Trinity) to the Populations of New Mexico (Dr. André Bouville and colleagues)

The second paper, written by Dr. Bouville and colleagues, describes the methods used to estimate radiation doses that may have been received by the residents of New Mexico in 1945 as a result of the Trinity nuclear test.

They estimated the amount of radioactivity deposited on the ground from the 63 most important radioactive isotopes that were created in the detonation. To get information about where the fallout was deposited within the state of New Mexico, they relied primarily on a fallout deposition map developed by the Weather Service Nuclear Support Office in Las Vegas, Nevada, using direct measurements of radiation emitted from fallout on the ground collected by Manhattan Project staff in the immediate days after the test.

The authors explained modeling strategies for 13 different ways residents may have been exposed, including being exposed to radioactive fallout as it was deposited in the immediate hours/days after detonation, inhaling radioactive particles that reached the ground or dust that had been contaminated by fallout, drinking contaminated water, and eating nine common types of food.

Because reliable estimates of internal radiation doses received in the past cannot be derived directly from any kind of measurement taken today, the investigators created mathematical models for each exposure pathway. They then applied these models to population groups with the following attributes: men and women; four major ethnic groups (Whites, Hispanics, Native Americans, and African Americans); seven age groups (in utero, 0-1 year, 1-2 years, 3-7 years, 8-12 years, 13-17 years, and adult); three environment types (plains, mountain, or combination of plains and mountains); and two population densities (rural or urban). All counties of New Mexico were included in the analysis.

To develop exposure models that could be applied to each population group, the scientists used information about diet and housing gathered by Dr. Potischman and her colleagues as well as data from reports and publications on how fallout moved in the environment. The authors also considered other important issues about exposure: the amount of radioactivity that accumulates in the breast milk of nursing mothers, and the commercial movement of cows' milk from one part of the state to another.

The latter factor was important for people who lived, for example, in a low-exposure area but obtained milk from a dairy or store that received milk from a higher exposure area. New Mexico, like all states, moved milk from low consumption areas to high consumption areas, though the movement of commercial foods was more limited in the 1940s than today.

Finally, the authors describe the methods by which uncertainty of each estimate of external and internal dose was to be made.

Estimated Radiation Doses Received from the 1945 Trinity Nuclear Test (Dr. Steven Simon and colleagues)

The paper by Dr. Simon and colleagues provides an estimation of radiation doses to specific body organs that people in New Mexico may have received from the Trinity test. The paper reports on findings from the exposure models described by Dr. Bouville and colleagues using the collected dietary and other types of data described in paper by Dr. Potischman. The researchers estimated doses to the five organs or tissues at greatest risk of cancer from exposure to fallout (thyroid, active bone marrow for leukemia, stomach, colon) for both men and women in the four ethnic groups, in all age groups, and all counties. An additional organ, the lung, was also included because of interest in the potential for lung cancer as a result of inhalation of radioactive debris.

The research team used the fallout pattern, the data on diet and housing types, and the dose models to estimate exposure over the year following the Trinity test, when most all of the dose is received. They estimated the dose from external exposure, which is exposure received while the fallout is being deposited and, more importantly, from the fallout deposited on the ground. They also estimated the dose from internal exposure, which is exposure due to consumption of contaminated foods, including mothers' breast milk and drinking water, as well as from inhalation of contaminated air and dust.

The team assessed the dose to each of the five organs from external and internal exposure and demonstrated the contribution of each category of food to the total internal radiation doses received. The dose estimation process was lengthy and involved more than 120 million calculations to estimate the organ doses for all the population groups in all counties of New Mexico.

Except for dose to the thyroid gland, external radiation from fallout on the ground was the greatest source of exposure. Drinking fresh cows' milk contributed the greatest part of the internal dose to the thyroid gland—the organ that received the highest doses. Typically, the next largest contribution to internal dose was due to eating leafy vegetables that were being grown at the time the fallout was deposited. Eating fruits and other types of vegetables and inhaling fallout were much smaller contributors to dose, by comparison.

Because the Trinity fallout pattern varied considerably across the state, the estimated organ doses also varied considerably, with the highest doses received directly to the northeast of the detonation site and at locations close to the center of the Trinity fallout cloud that moved in the northeast direction.

The authors note that there are many uncertainties in the results of an assessment of an event so long in the past. They account for those uncertainties in dose estimates by presenting an upper and lower bound of dose—an uncertainty interval, which can be interpreted as the range in which they believe the true dose likely lies.

For the most part, exposures were highest among whites and Hispanics, predominantly because of where they lived, similar but sometimes lower for African Americans, and lowest among Native Americans whose communities were located in areas of the state outside the center of the fallout pattern. They emphasize that they cannot derive the dose for any specific person because sufficient information does not exist.

The findings indicate that only in small geographic areas immediately downwind of the detonation site were the exposures substantially higher than naturally occurring background radiation. While most counties had external doses less than 1 mGy, the largest external doses to any persons in one or two counties were about 100 mGy after accounting for shielding of homes and the amount of time typically spent outdoors in the summer. The largest doses would have occurred in Torrance and Guadalupe counties. For comparison, the natural background external radiation dose in New Mexico is between 2 and 3 mGy per year, leading to between 140 and 210 mGy over the lifetime of most adults.

Dr. Simon and colleagues also compared doses received from Trinity, Nevada Test Site fallout, and global fallout (global referring to nuclear tests in other countries). When averaged across the state, age groups, and populations, the external doses from the three sources were very similar, about 1.6, 2.5, 1.1 mGy from Trinity, Nevada tests, and global tests, respectively.

Finally, a comparison was made of the fallout pattern, which was the basis for their dose estimation, with an independent data set, that being x-ray film badges distributed across New Mexico prior to Trinity. Dr. Simon and colleagues reported excellent agreement of the film-badge data with the reconstructed fallout pattern, giving the investigators confidence in the fallout pattern they used.

Extensive tables of best estimates of dose to each of the five organs for the seven age groups and four ethnicities in all 31 counties are provided.

Projected Cancer Risks to Residents of New Mexico from Exposure to Trinity Radioactive Fallout **(Dr. Elizabeth Cahoon and colleagues)**

Dr. Cahoon and colleagues estimated the possible ranges of excess cancer risk across the state (that is, the number of cases in addition to those normally expected) that may have resulted from the Trinity exposures. For that purpose, Dr. Cahoon and colleagues relied on the organ dose estimates presented in the paper by Dr. Simon. They concluded that some excess cancer cases were likely to have resulted from exposure to Trinity fallout though the exact number is highly uncertain. The excess cases would be limited to those alive at the time of the Trinity test as the exposure to those born in subsequent years would be too small to expect any additional cases. Moreover, the investigators acknowledge that with today's scientific understanding and the available data it is nearly impossible to derive the cause of any specific person's cancer or other disease or to say definitively if radiation was the important factor in causing it.

A significant difficulty to estimating and projecting the number of excess cases was due, in part, because there was no cancer registry in New Mexico before the nuclear test nor during the following 20 years. The New Mexico Tumor Registry began in 1966 and, even then, took years before it achieved a complete annual census of the cancers arising across New Mexico. Hence, it is not possible to know, with certainty, if cancer rates changed in New Mexico in the first decades after the test compared to before the test. The researchers were forced to estimate the background (also called baseline) cancer rate before the Trinity test for each of the four ethnic groups using information in the NCI SEER data registry from 1975-2015 and other historical data sources.

The investigators applied the estimated baseline rate of cancer (the rate of cancer occurrence before the Trinity test took place) along with data on the sensitivity of each organ to radiation, the latter determined from studies of other populations exposed to radiation including Japanese survivors of atomic bombs.

The authors wrote that the cancer types and the percentage of cancers that could have been attributed to Trinity fallout varied by county of residence in 1945 in a pattern similar to the geographic pattern of fallout contamination. The largest number of excess cancer cases were projected to have occurred among people living in the five counties that received the greatest levels of fallout exposure — Guadalupe, Lincoln, San Miguel, Socorro, and Torrance.

The authors note that the possible excess cancer cases they estimated are based on the most detailed dose reconstruction to date and rely on well-established methods in epidemiology. However, they also acknowledge that there are many uncertainties in the dose estimations and other factors that go into the models. As a result, the estimated radiation-related excess cancer risk is not precise. For that reason, the authors provide a range (also called uncertainty interval) in which they believe the true number of excess cancers is likely to lie. The uncertainty interval expresses that the number of possible cancers caused by the Trinity test is unlikely to be zero, but also unlikely to be greater than the upper range estimated in the paper by Cahoon et al., which is up to approximately 1,000 cases across all cancer types over the past 75 years. Among types of cancer, the fraction of cancer cases attributable to radiation exposure was highest for thyroid cancer. That is because the thyroid gland is the primary organ that concentrates radioactive byproducts—in this case, radioactive iodine (I-131).

The Likelihood of Adverse Pregnancy Outcomes and Genetic Disease (Transgenerational Effects) from Exposure to Radioactive Fallout from the 1945 Trinity Atomic Bomb Test **(Dr. John Boice)**

The paper by Dr. Boice examined the evidence for adverse pregnancy outcomes following radiation exposure the evidence for the induction of genetic diseases (i.e., among second or additional generations – also called, transgenerational effects) that might affect their descendants.

Dr. Boice examined published reports from studies of cancer occurrence among other populations in New Mexico who were exposed to radiation from a variety of sources, including those who lived near various facilities including the Los Alamos National Laboratory and the uranium mill in Grants, New Mexico. Dr. Boice studied the rate of cancer occurrence among successive generations of various groups including military veterans and scientists who participated in the Trinity test. He also examined transgenerational effects in other diverse populations exposed to radiation, including those living in areas with high natural background radiation and in populations living near nuclear facilities. Included in the analysis were examinations of transgenerational effects in the offspring of childhood, adolescent, and young adult cancer survivors who had been treated with radiation; in the offspring of Japanese atomic bomb survivors; and in the offspring of radiation-exposed workers.

Dr. Boice concluded that there is no evidence to suggest transgenerational effects occurred as a result of exposure to fallout from the Trinity test or, for that matter, from any radiation exposure in history. For Trinity, three primary reasons were the basis of their conclusions. First, in all large-scale comprehensive studies of exposed populations, no genetic effects have been demonstrated in children of exposed parents. Second, the estimated doses from Trinity as reported in the dose estimation paper, are much lower than doses received by other studied populations such as survivors of the atomic bombings in Japan, where no transgenerational effects have been observed. Finally, there was no evidence of increased cancer rates among the scientific, military, and professional participants at the Trinity test and at other nuclear weapons tests who received much higher doses than New Mexico residents downwind from the Trinity site.

The overall findings of this paper were consistent with the published scientific literature that suggests that intergenerational effects either do not occur or, at most, occur at such a low frequency that the effects cannot be conclusively observed. This consistency suggests that intergenerational effects from Trinity are extremely unlikely.

Accounting for Unfissioned Plutonium from the Trinity Atomic Bomb Test **(Mr. Harold Beck and colleagues)**

The paper by Mr. Beck and colleagues estimates the amount, distribution, and health implications of unfissioned plutonium from the Trinity test that was deposited downwind from the Trinity test site. It is known that, because Trinity was the first nuclear test, limitations in its design resulted in a low efficiency for transforming the plutonium in the device into a nuclear explosion (by fission, or splitting, of the plutonium atoms). Hence, much of the plutonium in the device did not undergo nuclear fission and simply became part of the fallout. The unfissioned plutonium was first vaporized in the intense heat of the fireball of the test and, after cooling, formed particles that were deposited downwind from the test site along with the rest of the radioactive debris produced in the explosion. The amount of unfissioned plutonium contaminating New Mexico has been an issue of concern to residents of the state, particularly for those near the test site.

Using published data from measurements of soil samples collected over many years after the test, Mr. Beck and colleagues estimated the geographic distribution of the unfissioned plutonium across the state and concluded that about 80% of the unfissioned plutonium was likely to have been deposited within the state of New Mexico, most of it in a relatively small area about 30-100 km downwind from the test site. The paper by Beck and colleagues presents a map of the derived plutonium deposition in 1945, similar in shape and characteristics to the fallout map presented by Simon and colleagues that was developed from the historical fallout measurements.

Mr. Beck and colleagues calculated that, even in the areas where the most unfissioned plutonium fell, the concentration of plutonium in the topmost layer of soil (that is, the layer which is most available to contaminate persons in the vicinity), was lower than the 1977 “action” level as determined by the U.S. Environmental Protection Agency. This means that the concentration in the surface soil was below the level at which action was required for it to be reduced for health protection. Additionally, Beck and co-authors explain that over the successive years, the concentration of plutonium that was originally at the surface of the ground, has been reduced because of natural processes that continually move the contamination downward to deeper levels of the soil below the surface.

The researchers concluded that the original amounts deposited at each location were less than levels normally considered as requiring remediation by the EPA and, thus, not likely to have caused significant health risks to the downwind population. Because the levels in surface soil today are about 30% of the levels immediately after the detonation, the researchers concluded that the plutonium today is less of a hazard than decades ago.