# Health Effects of Radiation

## Findings of the Radiation Effects Research Foundation

For more than 50 years, the Radiation Effects Research Foundation (RERF) has conducted health follow-up studies on survivors of the August 1945 atomic bombs that devastated the cities of Hiroshima and Nagasaki. With support from Japan and the United States, RERF's mission is to conduct research for peaceful purposes on the medical effects of radiation on man and to contribute to the health and welfare of the atomic-bomb survivors and mankind.

RERF's Hiroshima facilities overlook the city. RERF also has facilities in Nagasaki.

At the time of the bombings, the public and the scientific community had limited understanding of the short- or long-term consequences of exposure to radiation. Through its study of 200,000 survivors and their children—the most extensive study of health effects in a human population ever conducted—RERF has examined the links between radiation exposure and disease, cell and genetic damage, and other factors. The study's strength lies in its very large, well-defined study population, its excellent follow-up, and the fact that there are good estimates of individual radiation exposures.

RERF's research results have become the world's primary guide for radiationinduced health effects, especially cancer. This includes the development of standards for occupational exposure and assessment of the risks from medical exposure sources such as CAT scans and other diagnostic procedures. Additionally, RERF scientists and study results help to illuminate potential health effects in victims of nuclear accidents, current and former workers at nuclear facilities, citizens living in the vicinity of nuclear sites, atomic veterans and other exposed populations. The results also provide an important source of information about risks to those exposed in the womb and about inherited genetic effects in humans following radiation exposure.

RERF's unique mission continues to be vital as nearly half of A-bomb survivors live on, including 90% of those who were under age 10 at the time of the bombings and who are now entering their cancer prone years. In fact, 70% of the cancers attributable to A-bomb radiation are expected to appear in the next 20 years.

### RERF's Research Populations

At the center of RERF's research programs is its Life Span Study (LSS) population, a group of about 120,000 atomic bomb survivors who were still living in Hiroshima and Nagasaki in 1950. About 90,000 of these people were within 10 km (6 miles) of the bombsites, roughly half of whom were within 2.5 km (the core group) and the other half between 2.5 and 10 km where radiation exposures were much lower.

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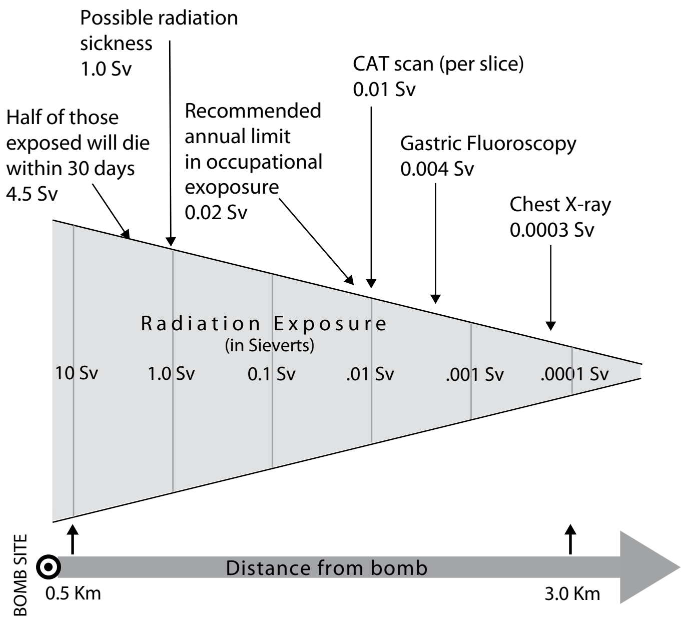


**Figure 1.** The chart shows the approximate radiation exposure (in Sieverts) in relation to a person's distance from the bombsite and provides a comparison with other radiation exposures.

The Adult Health Study sample (initially about 20,000 people) is a subset of the LSS population who have volunteered themselves and their time to undergo physical examinations every two years as part of the study's follow-up. These examinations make it possible to diagnose the full spectrum of diseases not accessible through RERF's comprehensive follow-up on cancer incidence and mortality obtained from Hiroshima and Nagasaki tumor registries and death certificates.

Excess risk for cancer and other diseases due to radiation exposure is calculated by comparing incidence of disease over a range of radiation doses. Dose estimations are based on information on location and shielding obtained from survivors in the late 1940s and 1950s. In 1986, a committee of U.S. and Japanese physicists developed for RERF a new system to estimate individual dose. Known as Dosimetry System 1986 (DS86), the system combines location and shielding information with theoretical models developed by nuclear physicists for the amount of radiation released from each bomb, how the radiation was transported through air, and how it was affected by passage through physical structures and human tissue. The system is currently being revised and improved.

Survivors who were beyond about 2.5–3.0 km of the bomsites received a dose of less than 0.005 Sv (Sieverts, a unit that measures radiation dose). Most of those within about 2 km received a dose of at least 0.005 Sv, and the mean dose of that group is about 0.2 Sv. Radiation dose decreased roughly by half for every 200-meter increase in distance from the bombsites. By comparison, people in the U.S. are typically exposed to .002–.003 Sv of radiation per year in their daily life from naturally occurring radiation (see Figure 1). About 2,300 Life Span Study survivors, those close to the bombsites, received doses greater than 1 Sv.

## Other RERF Study Populations

Beginning shortly after the war and continuing until 1960, researchers established a study population of about 3,000 persons exposed to the bombings while in their mother's wombs (in utero). Various special investigations have been made on this group and the data are currently being followed up for mortality and cancer incidence information. Although by the early 1950s it had become apparent that there was no evidence suggesting genetic changes in the children born later to survivors (i.e., those not exposed in the womb), researchers recognized the need for continued follow-up on children of survivors and established a study population known as the F1 sample. The F1 study comprises 77,000 children, of which about 30,000 have at least one parent who received a dose greater than 0.005 Sv.

## Early Radiation Effects

If received at high enough doses, the first effects of radiation are the killing of cells and tissues. Illnesses collectively called "acute radiation syndrome" may occur a few days after exposure to high-dose radiation (1 Sv or more). Principal signs and symptoms are diarrhea from damage to the intestines, reduced blood cell counts and bleeding from damage to bone marrow, hair loss due to damaged hair-root cells, and temporary male sterility.

Through interviews with survivors shortly after the bombings, researchers estimated that the distance from the bombsites at which 50 percent of people survived to be 1,000 to 1,200 meters (about two-thirds to three-fourths of a mile) in Hiroshima and 1,000 to 1,300 meters in Nagasaki. As methods for estimating individual radiation have improved, researchers later estimated the bone marrow dose at which 50 percent of people survived (LD50) to be about 3.5–4.5 Sv. The closer people were to the bombsites, the greater the dose of radiation, as well as the severe effects of the blast and heat, and there is no information on classification of immediate deaths.

The immune system is also vulnerable to radiation immediately after exposure. In people who received large doses of A-bomb radiation, two vital parts of the immune system— lymphocytes and bone marrow stem cells—were severely damaged. Two months after exposure, marrow stem cells recovered and death due to infection generally ended. Studies in recent years have indicated some longer-lasting radiation effects on the immune system, though much smaller than described above.

One of the most important findings is that exposure to radiation increases rates of most types of cancer, basically in proportion to radiation dose.

## Radiation's Link To Cancers

Excess cancer risk is a delayed effect of radiation exposure, although it is not possible to distinguish whether a cancer in a particular person is caused by radiation or other factors. In contrast to early effects of radiation that kill cells and damage tissues, late radiation effects result from genetic changes in living cells. One of the most important findings is that exposure to radiation increases rates of most types of cancer, basically in proportion to radiation dose.

The exact mechanisms that lead to cancer are not clear, but it is believed that the process requires a series of mutations accumulated over periods of years. Because it takes many years before a cell and its descendants acquire a sufficient number of changes to result in clinical disease, excess cancers attributable to radiation (except leukemia) are often not evident until decades after exposure.

## Link to Leukemia

Excess leukemia was the earliest delayed effect of radiation exposure seen in A-bomb survivors, first noted by a Japanese physician in the late 1940s. A registry of leukemia and related disorders was established to track cases.

Because leukemia is a rare disease, the absolute number of leukemia cases among A-bomb survivors is relatively small even though the percentage increase in risk is high. Leukemia accounts for only about 3% of all cancer deaths and less than 1% of all deaths, although it presently constitutes about 20% of all excess Life Span Study cancer deaths. As of 1990, there were 176 leukemia deaths among 51,114 Life Span Study survivors with a bone marrow dose of at least 0.005 Sv. The group had 87 deaths beyond expected deaths from leukemia, which means that 49% of the cases were attributable to radiation.

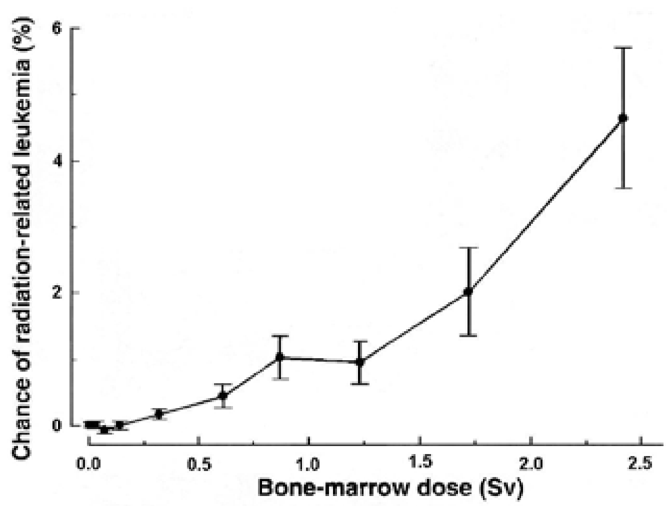


Figure 2. The figure shows how the percentage of survivors who developed leukemia changes with dose. The points are estimates of this percentage for various dose groups, and the vertical bars describe uncertainty in these estimates.

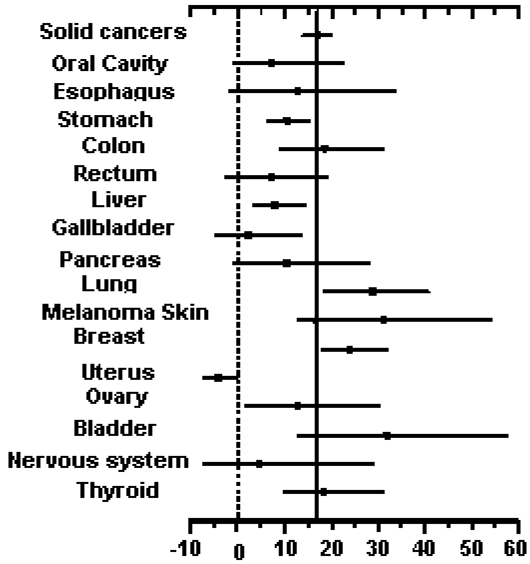


Figure 3. The figure shows how radiation has affected the rate of solid cancer incidence in survivors. The points are estimates of the percentage increase in rates standardized for a female survivor exposed at age 30 who received a dose of 0.2 Sv. The horizontal lines describe uncertainty in the estimates (the uncertainties are large as a result of a low number of cases). The solid vertical line indicates the estimated excess rate for all solid cancers as a group.

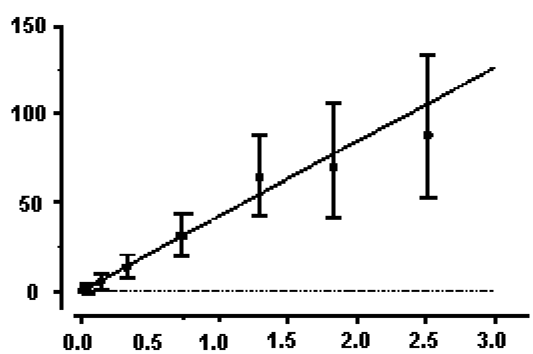


Figure 4. The figure illustrates the relationship between dose and the rate of solid cancer incidence. Risk estimates are standardized for a male exposed at age 30. The points represent risk estimates for various radiation dose groups. The vertical lines describe uncertainty in these estimates.

A-bomb related leukemia has shown the following characteristics:

1. Incidence of leukemia rose almost in direct proportion to dose.
2. The risk for leukemia was much higher for those exposed as children than for those exposed as adults.
3. Incidence of radiation-related leukemia peaked at 7– 8 years after exposure.

## Link to Solid Cancers

By about 1956, researchers found an increase in rates for solid cancers (those other than leukemia). This increase would prove to be the most important late effect of radiation exposure seen in A-bomb survivors. As of 1990, there were 4,565 solid cancer deaths in the 51,114 LSS survivors with a bone marrow dose of 0.005 Sv or greater, which was 335 more solid cancer deaths than would have been expected in a similar but unexposed population—about 8% attributable to radiation.

Significant excess risks are seen for many of the major types of cancer, including cancers of the stomach, lung, liver, colon, bladder, breast, ovary, thyroid, and skin. Because most cancers are caused by factors other than radiation (e.g. smoking, chemical exposures), and because cancers are very common diseases especially in aging populations, RERF researchers are now examining individual types of cancer more carefully to determine what role radiation plays in the mechanism of cancer causation and how it might interact with other cancer risk factors.

For most solid cancers, acute radiation exposure at any age increases one's cancer risk for the rest of life. As survivors have aged, excess rates have increased in accordance with background rates, although somewhat less rapidly. For the average radiation dose of survivors within 2,500 meters (about 0.2 Sv), there is about a 10 % increase above normal age-specific rates.

A-bomb related solid cancers show the following characteristics:

1. Risks of solid cancers increase in direct proportion to dose.
2. The percentage increase in risk was greater for those exposed as children, at least in the early part of the follow-up.
3. Increased risks of solid cancers do not diminish but last throughout a lifetime. There is a marked radiation effect when survivors reach the age at which cancers most often occur.

## Non-cancer Effects of Radiation

Clinical researchers conducting the Adult Health Study (the subset of the LSS group that receives biennial clinical examinations) have analyzed the relationship between radiation exposure and a number of selected noncancer disorders. Some radiation effects have been found in the Life Span Study population, with statistically significant excess risks for cardiovascular, digestive, respiratory and non-malignant thyroid diseases. Although mechanisms for such effects are not presently understood, careful epidemiological investigation has indicated that these appear to be actual radiation effects.

Radiation studies also show a pattern of growth retardation for survivors who were exposed to the bomb's radiation in childhood. Early investigations of possible accelerated aging have largely been supplanted by study of more specific non-cancer diseases, although there remains some interest in generalized aging. Of the diseases most specifically associated with aging (arteriosclerosis, senile cataract, dementia, osteoporosis, arthritis), the clearest evidence of increased risk with radiation exposure is for arteriosclerosis.

The considerable epidemiological differences among radiation-related leukemia, solid cancers and non-cancer diseases are illustrated in Figure 5.

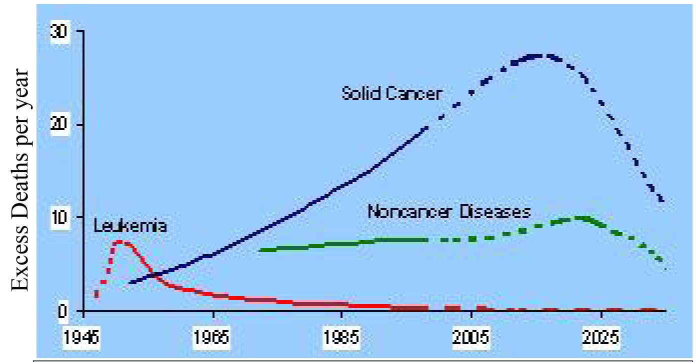


Figure 5. The epidemiological differences among radiation-associated leukemia, solid cancer and noncancer diseases are evident in this graph showing estimated past and future radiation-associated mortality per year in the Life Span Study cohort by calendar year. There are uncertainties for both observed (solid curves) and unobserved (dashed curves).

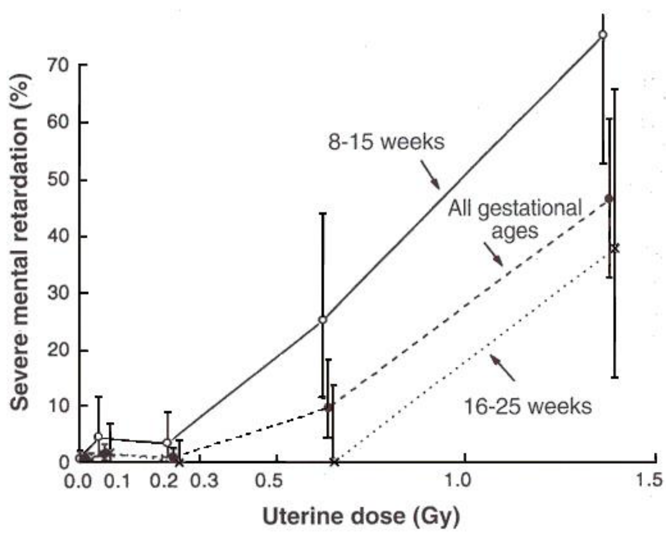


Figure 6. The figure plots the percentage risk of severe mental retardation for those exposed in the womb against the mothers' uterine dose measured in Grays. Those exposed at a gestational age of 8–15 weeks were most at risk. There were 2,800 people in this study. For gamma irradiation, 1 Gray (Gy) is approximately equal to 1 Sievert.

## Effects of Fetal Exposure

Fetal brains are damaged by radiation, at least at moderately high doses. RERF's examination of the in utero study population (about 3,000 people) has revealed a correlation between radiation exposure and both mental retardation and microcephaly (small head size). Approximately 1,100 pregnant women are thought to have been exposed within 2 km of the bombsites, receiving a dose of more than 0.005 Sv. About 150 of them received doses greater than 0.5 Sv. The frequency of severe mental retardation was dose-dependent for survivors exposed before birth at either 8–15 or 16–25 weeks of their mother's pregnancy, with effects especially marked in the former group. Dose-related decreases in school performance and IQ scores have also been observed among the in utero group after excluding severely mentally retarded children.

## Genetic Effects on Children of Survivors

One of the earliest concerns in the aftermath of the atomic bombings was how radiation might affect the children of survivors. Efforts to detect genetic effects began in the late 1940s and continue. Thus far, no evidence of increased genetic effects has been found. RERF is now using recently developed tests that are more sensitive to confirm these results, and has recently begun clinical examinations of children of survivors to gain more information. Genetic effects can only be caused by radiation damage to sperm and ovarian cells.

Recent advances in molecular biology make it possible to evaluate genetic effects at the gene (DNA) level. RERF scientist are preserving blood samples that can be used for such studies. Monitoring of deaths and cancer incidence in the children of survivors continues, and a clinical study will be undertaken to evaluate potential radiation effects on late-onset genetic disorders.

## Future Directions for RERF

Although Hiroshima and Nagasaki were hopefully the last cities to experience an atomic bombing, there are still many potential sources of radiation exposure. Since the 1986 nuclear accident at Chernobyl, RERF has been increasingly involved in the studies of radiation effects in other populations. Recently, RERF entered a contract with the U.S. National Cancer Institute (NCI) to provide direct support for efforts to strengthen the epidemiological studies of workers and community members exposed to radiation as a consequence of plutonium production in the Ural Mountains of the Russian Federation.

There is still much to learn about radiation effects. New developments in molecular biology, such as the sequence of the human genome released in 2001, are bringing new ways to look at the unique data collected in Hiroshima and Nagasaki. Future research directions include trying to learn more about just how the radiation exposure causes excess cancer.

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A primary practical use of RERF research results is to set standards for protection against medical and occupational exposures to radiation, and the analytical techniques developed at RERF have been applied to all kinds of environmental exposures, not just to radiation. One advantages of the RERF studies is that there are people exposed from low to high doses, of both sexes, and at every age. In fact, the vast majority of the study population had small doses in the range of interest for radiation protection for medical procedures, on-the-job exposures and other radiation sources. RERF continues to work with standards-setting bodies worldwide to set standards for radiation protection.

## Frequently Asked Questions

### Q1. How many people died as a result of the atomic bombings?

Deaths caused by the atomic bombings include those that occurred on the days of the bombings due to the overwhelming force and heat of the blasts as well as later deaths attributable to radiation exposure. The total number of deaths is not know precisely because military personnel records in each city were destroyed, entire families perished leaving no one to report deaths, and unknown numbers of forced laborers were present in both cities.

In Hiroshima, an estimated 90,000 to 166,000 deaths occurred within two to four months of the bombing in a total population of 340,000 to 350,000. In Nagasaki, 60,000 to 80,000 died in a population of 250,000 to 270,000.

## Q2. How long were Hiroshima and Nagasaki radioactive after the bombings?

Doses from residual radioactivity in both cities are now far below the annual background dose for naturally occurring radiation (0.001–0.003 Sv). Radioactivity was over 90% depleted by one week after the bombings and was less than background within one year.

Although fallout from today's weapons and certain types of accidents could be a major radiation source, this was not the case with the Hiroshima and Nagasaki bombs. Fallout from today's bombs would largely result from interaction with the ground soil of direct radiation emissions from the bombs. Those used in Japan were relatively small by current standards with detonation about 600 meters from the ground. The only substantial radiation exposure from the bombs at Hiroshima and Nagasaki was in the form of direct gamma rays and neutrons, and this was a virtually instantaneous exposure. The neutron component, which has a greater biological effect than gamma rays, was small—less than 1 %.

## Q3. What percentage of A-bomb survivors are included in the RERF studies?

In the 1950 Japanese national census, approximately 280,000 people indicated that they had been exposed to the atomic bombs. RERF's study population probably includes about 50% of those exposed within about 2,500 meters of the bombsites in an effort to include as many survivors in that group as possible. These percentages are not precise because the census did not record location of exposure in reference to the bomb hypocenters. A sample of comparable size was selected from those exposed at greater than 2,500 meters from the bombs where radiation exposures were very small.

## Q4. What percentage of A-bomb survivors within the study populations have died?

As of 2000, about 45% were alive, but more than 90% of those exposed under the age of 10 were still living. Projections suggest that in 2020 those percentages will be about 20% and 60% respectively.

## Q5. How is information about the A-bomb survivors obtained?

Information about radiation effects in the atomic bomb survivors is obtained in many ways, some utilizing the full Life Span Study and other study populations. One ongoing method is mortality follow-up, checking for registrations of death and the cause of death. A second ongoing method is checking registrations of cancer diagnoses made by local hospitals and physicians to the cancer registries in Hiroshima and Nagasaki prefectures. Mail surveys asking about lifestyle and other factors have been sent approximately every 10 years to the Life Span Study cohort members. Each person in the Adult Health Study is clinically examined every two years.

Chromosome aberrations and blood proteins have been examined in a sample of approximately 8,000 and 24,000 children (respectively) born to one or two radiation exposed parents to assess possible genetic damage passed on to children. No radiation effects have been seen. Approximately 76,000 children were examined at birth and at age 9 months, between 1948 and 1954, for possible congenital birth defects. Plans are being made to assess the health status of children of atomic-bomb survivors based on mail questionnaires and clinical examinations.

## About the Radiation Effects Research Foundation

RERF was originally established by the U.S. National Academy of Sciences in 1947 as the Atomic Bomb Casualty Commission (ABCC) to undertake an extensive surveillance of the health of the atomic bomb survivors, The Japanese Institute of Health of the Ministry of Health and Welfare joined ABCC in its research in 1948. In April 1975, ABCC was reorganized into the nonprofit, bi-national Radiation Effects Research Foundation. Annual funding for RERF is provided by the Japanese Government through the Ministry of Health, Labour and Welfare, and by the U.S. Government through the Department of Energy (DOE). The National Academies, through its Board on Radiation Effects Research (BRER), serves as a liaison to RERF for the DOE and provides assistance and support.

RERF collaborates on research projects with physicians and scientists from other research institutes, universities and hospitals to expand its research fields and strengthen findings on A-bomb survivors. RERF is currently involved in the tissue and tumor registries in Hiroshima and Nagasaki; site-specific cancer studies that include case review by external pathologists; and a re-evaluation of the DS86 dosimetry system that includes both Japanese and American physicists.

RERF runs several programs through the departments listed below.

The Department of Epidemiology conducts studies on 120,000 A-bomb survivors primarily with regard to cancer incidence and causes of deaths. The department endeavors to clarify the risks associated with human exposure to ionizing radiation.

The Department of Statistics analyzes interdisciplinary information collected to study radiation effects, lends statistical support and advice to radiation scientists, and assists with data management.

The Department of Clinical Studies conducts biennial health examinations on A-bomb survivors to detect diseases and any radiation-induced health effects. The survivors are informed of all examination results and referred to specialized hospitals when necessary.

The Department of Genetics conducts studies to determine whether there are increased mutations in children of A-bomb survivors. It also measures chromosome aberrations in the blood cells of the survivors and residual radiation signals in teeth.

The Department of Radiobiology studies mechanisms responsible for radiation effects including effects on the immune system and cancer induction.

The Department of Information Technology is responsible for managing and storing information for use in various studies, maintaining computers, and sending information to world computer networks.

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