Health effects of nuclear weapons testing

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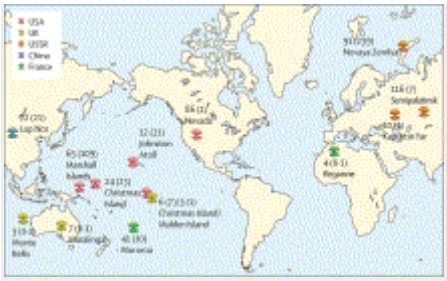
Nuclear weapons were virtually unknown to the world before Aug 6, 1945, when the first atomic bomb was used against Japan in Hiroshima and the second 3 days later in Nagasaki. The 70th anniversary of this event is marked in the *Lancet* Series From Hiroshima and Nagasaki to Fukushima.[1, 2, 3] The legacy of the atomic bomb extended far beyond Japan with atomic weapons testing programmes conducted worldwide for the next three and a half decades. Just 3 weeks before the atomic bomb attacks on Japan, the first nuclear explosion in history had taken place in secrecy in the desert of New Mexico, USA, when scientists working for the Manhattan Project tested the experimental nuclear bomb codenamed Trinity. That test ushered in an era of atmospheric nuclear testing by the USA, the USSR, the UK, China, and France that continued at sites around the world until 1980 (figure). During those years, more than 500 atomic weapons were tested in the atmosphere with a total explosive force equal to about 20 000 Hiroshima bombs.[4] A detailed picture of the late effects of exposure to ionising radiation, namely increased risk of cancer, would not become well understood until years after the start of atmospheric nuclear weapons testing.



Figure

Main atmospheric nuclear weapons test sites used between 1945 and 1980

The numbers shown at each test site indicate the number of tests with the total energy yield in equivalent megatons of trinitrotoluene shown in parentheses. Adapted and reproduced by permission of *American Scientist*, magazine of Sigma Xi, The Scientific Research Society.

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Atmospheric nuclear tests were conducted in unpopulated areas, and led to exposure at downwind locations from radioactive fallout carried by wind currents rather than from direct gamma-ray radiation, which is emitted at the explosion site in the first seconds after a detonation. Each nuclear explosion creates hundreds of radionuclides, many with half-lives of 3 months or less, so that their energy is mostly delivered within the first few months after a detonation. The health risk to the public from nuclear weapons testing arose from exposure to the radioactive byproducts. Radioactive fallout from atmospheric nuclear weapons testing was dispersed worldwide, resulting in measurable radioactivity on every continent.[5] Nuclear tests varied considerably in size. In comparison with the Hiroshima bomb that had an explosive energy of about 15 000 tons of trinitrotoluene (TNT), tests ranged in size from less than 1000 tons to 50 million tons of TNT. Although larger nuclear tests produced more radioactive debris, the very large tests sent their contamination into the very high atmosphere where much of the radioactivity decayed before falling to the ground. The contamination of air and foodstuffs resulted in some internal exposure to ionising radiation among almost all people born since 1945, while gamma rays emitted from radioactive fallout deposited on the ground resulted in low-level external exposure. Although such radiation exposure continues today, it is at very low levels.[4]

The main health concern from exposure to ionising radiation emitted from radioactive fallout is the development of thyroid cancer among people exposed in childhood.[4, 6] The thyroid gland cannot distinguish stable iodine, a necessary dietary mineral, from radioactive varieties of iodine, such as iodine-131, produced in a nuclear explosion. The thyroid, most sensitive to radiation at a young age, can receive an internal dose after consumption of contaminated foods, for example fresh milk and other dairy products that accumulate radioactive iodine when dairy animals graze contaminated pastures.[6]

In the USA, atomic weapons testing at the US Government's Nevada test site exposed the public across the entire country, although most people were exposed to only fairly low doses of ionising radiation. Those youngest at the time of exposure would have received the largest radiation dose because the ingested radioactive iodine would be concentrated in a smaller gland. The per person internal radiation dose to the thyroid for the 160 million people alive in the USA during the 1950s was about 0·02 Gy (dose averaged over all birth years), which is equivalent to about 7 years of natural background radiation.[6] However, those youngest at the time of exposure received radiation doses up to 0·3 Gy. External and internal radiation doses to organs other than the thyroid were much smaller.

The largest fraction of the dose was received within a few months after each atomic weapons test, although longer-lived radionuclides, such as caesium-137 and strontium-90 with half-lives of about 30 years, continue to contribute very small doses of ionising radiation to the world's population.[4, 7, 8]

Unlike the small average exposure to ionising radiation in the continental USA, nuclear testing by the USA in the Marshall Islands in the Pacific Ocean resulted in very high doses of ionising radiation (about 7·6 Gy to the thyroid, 1·6 Gy to bone marrow, and more than 1 Gy to colon and stomach) among a group of 82 people due to unforeseen changes in wind direction.[9] Similarly, early atomic weapons tests by the USSR led to radioactive fallout in Kazakhstan and moderately high doses of ionising radiation of 1–2 Gy to the thyroid among the inhabitants of several villages, which each had populations of a few hundred people.[8, 10, 11]

The health effects of exposure to ionising radiation from radioactive fallout can, for the most part, be described as small excesses over baseline rates for thyroid cancer or leukaemia, two of the most radiogenic malignant diseases.[12] A few studies of the health risks of nuclear weapons testing have been undertaken in the USA and other countries, including the Marshall Islands, Kazakhstan, French Polynesia, and Nordic countries.[13, 14, 15, 16, 17, 18, 19] Excess cancer risks have only been clearly shown in populations exposed to high doses of ionising radiation from radioactive fallout.[16]

Given the difficulty of observing a small excess of cancer cases against the large number that would occur in the absence of exposure to ionising radiation, the potential public health impact of nuclear weapons testing can only be predicted by models. Risk modelling studies of exposure to ionising radiation from the Nevada Test Site in the USA suggest that an extra 49 000 (95% CI 11 300–212 000) cases of thyroid cancer would be expected to occur among US residents alive at the time of the testing—an excess of about 12% over the 400 000 cases of thyroid cancer expected to develop in the absence of fallout.[20] Almost all of the radiation-related cases of thyroid cancer would be among individuals younger than 20 years during the period 1951–57.[20] In addition, there could be as many as 11 000 deaths from non-thyroid cancers related to fallout among those US residents, with leukaemia making up 10% of the total.[20] Large uncertainties are inherent in these projections.

Although exposure to ionising radiation from nuclear weapons testing occurred some 50–60 years ago, a substantial fraction (less than half) of the predicted total number of excess radiation-related cancers are yet to occur since the risk persists

for many decades after exposure.[11, 20] The effect of nuclear testing on the world's overall cancer burden has been small, although very substantial to those individuals affected by it.

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