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Acute Radiation Syndrome at Hiroshima and Nagasaki: Not Due to Fallout

It is well-known that the atomic bombings of Hiroshima and Nagasaki exposed the populations of those cities to damaging doses of ionizing radiation (gamma rays and neutrons). Though the majority of the fatalities were caused by either the blast effects or thermal radiation (resulting in severe burns in many cases), ionizing radiation was also an important cause of fatalities. Some people who had survived their blast injuries and/or burns would nonetheless suffer the effects of radiation sickness (acute radiation syndrome) in the three months following the atomic bombings. Those most heavily exposed would die.

Many prominent accounts of the atomic bombings incorrectly attribute this ionizing radiation exposure to nuclear fallout.[2] This mistaken belief leads to an overemphasis on the role that ionizing radiation exposure played in causing casualties from the atomic bombings. It also lends credence to the incorrect reports that significant radiation exposure occurred well after the bombings had taken place, resulting in a number of additional casualties.

This erroneous belief regarding fallout is not that surprising. During the Cold War there was substantial concern about nuclear fallout, as multi-megaton hydrogen bombs could cover large areas with lethal amounts of fallout. However, it is known that significant nuclear fallout only occurs when a nuclear weapon is exploded near the ground. The atomic bombs at Hiroshima and Nagasaki were deliberately exploded high enough to avoid the creation of large quantities of nuclear fallout as well as to enhance the blast effects of the weapons. Despite the knowledge of this fact, some still believe that the "black rain" that fell in the aftermath of the bombings was highly radioactive and caused lethal nuclear fallout. As we will see, the ionizing radiation exposure from nuclear fallout at either city was not high enough to cause cases of acute radiation syndrome. Nor was the exposure from induced radioactivity, which occurs when neutrons from the weapons cause the soil to become somewhat radioactive.

Rather, the cases of acute radiation syndrome were due to the initial nuclear radiation which was emitted in the first minute after the nuclear detonations. This fact has several implications regarding the importance of ionizing radiation exposure at these cities. First, since the exposure occurred just as the weapons were going off, those exposed were also subjected to the blast and thermal effects. As a result, most people died due to these weapon effects and relatively few survived long enough to die from ionizing radiation. Second, acute radiation syndrome resulting from exposure to ionizing radiation resolves itself within a few months. Therefore, accounts of people suffering from acute radiation syndrome many months or years after the atomic attacks are not true. Third, since the ionizing radiation exposure occurred only at the time of the

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[2] See for example, Paul Ham, *Hiroshima Nagasaki: The Real Story of the Atomic Bombings and Their Aftermath*, St. Martin's Press, 2014, pp. 417-422.

bombings, accounts of people coming into the cities soon after the bombings and suffering from the acute radiation syndrome are not true as well.

The exposure of the survivors of the atomic bombings to the initial nuclear radiation has increased their risk for cancer. There are many who believe that the number of excess cancer deaths at Hiroshima and Nagasaki is quite large. However, in terms of fatalities, compared to the 110,000 to 210,000 who died in the immediate aftermath (the first few months) of the atomic bombings, the number of excess cancer deaths that have occurred in the survivors, though significant, is relatively small.

The ionizing radiation exposure at Hiroshima and Nagasaki from fallout and induced radioactivity was not only so low that it did not cause any cases of acute radiation syndrome but it was low enough that it is not thought to have caused a significant increase in number of cancers in the survivors, though there is some controversy on this issue.

Acute Radiation Syndrome

Exposure to high levels of ionizing radiation causes acute radiation syndrome in exposed persons.[3] This syndrome consists of two parts.[4] The first is the gastrointestinal (G.I.) prodrome. It occurs minutes to hours after exposure. It involves nausea, vomiting, anorexia and sometimes diarrhea. This prodrome often resolves after a few days, giving rise to a latent stage where exposed persons may seem normal.

Some days to weeks later, the second part of the acute radiation syndrome begins, which is the manifest illness phase. The presentation of the illness in this phase depends upon the dose received. Relatively low doses give rise to the bone marrow syndrome. This involves damage to the bone marrow which causes a reduction in white blood cells and platelets leading to infections and hemorrhages. Depending on the dose received, within three months the exposed person will either recover or die.[5] At somewhat higher doses, the manifest illness phase will result in the gastrointestinal (G.I.) syndrome. This syndrome involves severe damage to the G.I. system. This syndrome almost always results in death within a week or so after exposure.[6] At very high

[3] Radiation exposure is measured in units called Grays (Gy). "Gray," U.S. Nuclear Regulatory Commission. https://www.nrc.gov/reading-rm/basic-ref/glossary/gray-gy.html In all cases, the descriptions here of the acute radiation syndrome are for whole body exposures and for high exposure rates of at least 0.6 Gy/hr.

[4] The descriptions in this section are taken mainly from "Time Phases of the Acute Radiation Syndrome," Radiation Emergency Medical Management, U.S. Department of Health & Human Services, January 19, 2023. https://remm.hhs.gov/ars_summary.htm#timephases, "Early (Acute) Effects of Radiation," U.S. Nuclear Regulatory Commission, October 10, 2010. https://www.nrc.gov/docs/ML1122/ML11229A693.pdf and Clarence C. Lushbaugh, "The Impact of Estimates of Human Radiation Tolerance upon Radiation Emergency Management," *The Control of Exposure of the Public to Ionizing Radiation in the Event of Accident or Attack*, Proceedings of a Symposium held April 27-29, 1981, in Reston Virginia. National Council on Radiation Protection and Measurements, May 15, 1982.

[5] At Hiroshima and Nagasaki, there was a peak of deaths between 20 and 40 days after exposure which is thought to be due to the bone marrow syndrome. However, a few deaths occurred past day 80. See: *Sources, Effects and Risks of Ionizing Radiation: United Nations Scientific Committee on the Effects of Atomic Radiation, 1988 Report to the General Assembly,* Annex G, "Early Effects in Man of High Doses of Radiation," United Nations, 1988 Table 4. https://www.unscear.org/unscear/uploads/documents/publications/UNSCEAR_1988_Annex-G.pdf

[6] Deaths at Hiroshima and Nagasaki peaked between 6 and 9 days after exposure which is thought to be due to the G.I. syndrome. Ibid.

doses, the central nervous system syndrome occurs. The exposed person collapses almost immediately and death occurs within a few days.[7]

Since relatively few people have ever been exposed to high doses of ionizing radiation, sources vary to some extent as to the dose levels required to cause various aspects of the acute radiation syndrome. Therefore, the numbers given here should be considered approximate. To make them relevant to Hiroshima and Nagasaki, the descriptions of the various syndromes assume very limited medical care.

Below exposures of about 0.5 Gy, there are no obvious effects, though some changes in the blood are detectable. Between 0.5 Gy and 1 Gy, some people may exhibit the G.I. prodrome but there is no manifest illness phase. Between 1 Gy and 2 Gy, most people will suffer from the G.I. prodrome as well as mild versions of the bone marrow syndrome but few if any should die. Somewhere in the range between 2 Gy and 2.5 Gy a significant number of deaths will occur though no more than 5% to 10% of those who are exposed. At about 4 Gy, 50% of those exposed will die. This increases to 100% around 6 Gy. The deaths in the 2 to 6 Gy range are due to the bone marrow syndrome. Doses higher than about 6 to10 Gy will result in the G.I. syndrome and doses higher than about 30 to 50 Gy will result in the central nervous system syndrome.

Initial Nuclear Radiation

Initial nuclear radiation is defined as the radiation released by a nuclear explosion within one minute after the explosion.[8] This radiation consists of three main components. The first component consists of the air-secondary gamma rays. Neutrons generated by the explosion are absorbed in the air (mainly in nitrogen-14) and this process generates these gamma rays. The second component consists of the fission product gamma rays which are given off by the decay of the fission products from the explosion while they are in the air but still relatively close to the ground. At Hiroshima and Nagasaki, the magnitude of the second component was about twice that of the first. The third component consists of the neutrons themselves. The equivalence of neutrons to gamma rays is measured by a factor known as "relative biological effectiveness" (RBE). For the acute radiation syndrome, the RBE of neutrons is about the same as that of gamma rays.[9] At Hiroshima the neutrons contributed only about 5% of the total dose of ionizing radiation and at Nagasaki they contributed only about 1% of the total dose of ionizing radiation.[10] Given the yields of the Hiroshima and Nagasaki weapons, half of the gamma ray

[7] No doubt some people near ground zero were exposed to doses high enough to cause the central nervous system syndrome but no survivors were seen with this syndrome.
[8] Samuel Glasstone and Philip J. Dolan, *The Effects of Nuclear Weapons*, 3rd ed., U.S. Department of Defense and U.S. Department of Energy, 1977, Chapter VIII, "Initial Nuclear Radiation," p. 324. https://www.osti.gov/biblio/6852629
[9] Ibid., p. 577.
[10] This is at the distance where people would have been exposed to about 4 Gy. Closer to ground zero the percentage of the neutron dose is higher but few people this close to ground zero would survive long enough to suffer from the acute radiation syndrome.

dose is delivered in about one half second after the explosion and virtually all of the dose is delivered within ten seconds.[11]

A great deal of effort has been expended determining the initial nuclear radiation doses at Hiroshima and Nagasaki. The latest calculations are contained in the "Dosimetry System 2002" (DS02) published in 2005.[12] As with the blast and thermal radiation effects, the initial nuclear radiation doses are highest at ground zero and decline with increasing distance. At Hiroshima the dose was about 4.5 Gy at one kilometer from ground zero.[13] My calculations show that at this distance, the blast overpressure was about 12 psi and the thermal radiation about 30 cal/cm^2. Since blast overpressures of 5 psi would have destroyed most structures in Hiroshima and third degree burns result from thermal radiation of only about 7 cal/cm^2, most people within one kilometer from ground zero would have not survived long enough to suffer the effects of acute radiation syndrome. It has been estimated that 30% of the people who died at Hiroshima received a lethal dose of radiation but only 5% to 15% of the total fatalities were from ionizing radiation.[14]

Nuclear Fallout

If a nuclear weapon is exploded near or on the ground, the weapon's fireball will vaporize part of the ground.[15] The minerals in the soil have a high melting point and as the fireball starts to cool, the particles solidify and "fall out" of the cloud. These fallout particles accumulate on the ground and carry radioactive fission products. Near where the weapon was detonated the fallout can give off sufficient ionizing radiation to be lethal within hours.

However, it is known that the weapons at Hiroshima and Nagasaki were deliberately exploded high enough so that the weapons' fireballs did not touch the ground and fallout involving particles of solidified soil did not occur. The maximum height of burst below which the fallout is "appreciable" is determined by scaling the yield of the weapon to the 0.4 power and multiplying by 180 to get the results in feet.[16] For the 16 kiloton yield of the Hiroshima weapon, the maximum height of burst to generate appreciable fallout is 546 feet, which equals 166 meters. For the 21 kiloton yield of the Nagasaki weapon, the maximum height of burst to

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[11] Samuel Glasstone and Philip J. Dolan, *The Effects of Nuclear Weapons*, 3rd ed., U.S. Department of Defense and U.S. Department of Energy, 1977, Chapter VIII, "Initial Nuclear Radiation," p. 341. https://www.osti.gov/biblio/6852629

[12] Robert T. Santoro et. al., Chapter 3, "Radiation Transport Calculations for Hiroshima and Nagasaki," *Reassessment of the Atomic Bomb Radiation Dosimetry for Hiroshima and Nagasaki: Dosimetry System 2002, DS02,* Radiation Effects Research Foundation, 2005, p. 186 & p. 192. https://www.rerf.or.jp/library/scidata/scids/ds02/index.html

[13] Ibid., p.186.

[14] Samuel Glasstone and Philip J. Dolan, *The Effects of Nuclear Weapons*, 3rd ed., U.S. Department of Defense and U.S. Department of Energy, 1977, Chapter XII, "Biological Effects," p. 545. https://www.osti.gov/biblio/6852629

[15] Samuel Glasstone and Philip J. Dolan, *The Effects of Nuclear Weapons*, 3rd ed., U.S. Department of Defense and U.S. Department of Energy, 1977, Chapter II, "Descriptions of Nuclear Explosions," pp. 36-37. https://www.osti.gov/biblio/6852629

[16] Ibid., p. 71.

generate appreciable fallout is 608 feet, which equals 186 meters. The actual heights of burst were 600 meters and 503 meters respectively, which were well above these limits.[17]

The focus has instead been on a phenomenon known as "black rain." The black rain began within the first hour after the explosions and went on for several hours. It was caused by the fires burning in the cities and was black due to soot. It has been claimed that the black rain was highly radioactive. This seems unlikely since the rain did not start until at least 15 minutes after the explosions and the heat from each explosion would have quickly lofted most of the weapon's fission products into the stratosphere. Ham has incorrectly stated that the low hills around Hiroshima and Nagasaki contained the weapons' mushroom clouds. However, these hills are lower than the height of the weapons' detonations and would not have affected the mushroom clouds.[18]

Surveys taken in early October 1945 showed only small areas of fallout, which were in sparsely populated areas outside of the cities. The highest level of fallout at either city was found outside of Nagasaki about three kilometers east of ground zero in the Nishiyama district. Though there are substantial uncertainties in extrapolating the October data back to the time of the explosion, the estimates of the maximum possible accumulated dose are less than 1 Gy. One estimate is between 0.12-0.24 Gy.[19] Another estimate is 0.24-0.75 Gy.[20] Since these estimates assume that a person is exposed to the maximum dose for days at a time nonstop, more realistic estimates will all be below 0.5 Gy.

The highest fallout doses near Hiroshima were in the Koi-Takasu area, about three kilometers west of ground zero. They were significantly lower than the doses at Nagasaki and are estimated by these same two sources to be either 0.006-0.02 Gy or 0.02-0.2 Gy respectively. Clearly the fallout doses, even in these isolated places outside of the cities, were not high enough to cause any serious forms of acute radiation syndrome.

Induced Radioactivity

The neutrons given off in the nuclear explosions are absorbed by elements in the ground to form various radioactive isotopes. Unlike the nuclear fallout at Hiroshima and Nagasaki, the highest levels of radiation exposure from these isotopes would be in the cities themselves, centered directly at ground zero. Since several of the key radioactive isotopes have rather short half-lives, the exposure rate falls off rather quickly.[21] The highest exposures would occur immediately after

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[17] George D. Kerr, Robert W. Young, Harry M. Cullings, Robert F. Christy, Chapter 1, "Bomb Parameters," *Reassessment of the Atomic Bomb Radiation Dosimetry for Hiroshima and Nagasaki: Dosimetry System 2002, DS02,* Volume 1, Radiation Effects Research Foundation, 2005, pp. 42-43. https://www.rerf.or.jp/library/scidata/scids/ds02/index.html

[18] Paul Ham, *Hiroshima Nagasaki: The Real Story of the Atomic Bombings and Their Aftermath*, St. Martin's Press, 2014, p. 422.

[19] Shunzo Okajima, Shoichiro Fujita and John H. Harley, Chapter 6, "Radiation Doses From Residual Radioactivity," *US-Japan Joint Reassessment of Atomic Bomb Radiation Dosimetry in Hiroshima and Nagasaki: DS86, Dosimetry System 1986*, Volume 1, Radiation Effects Research Foundation, p. 224. https://www.rerf.or.jp/en/library/list-e/scids/ds86-en/

[20] *Hiroshima and Nagasaki: The Physical, Medical and Social Effects of the Atomic Bombings*, The Committee for the Compilation of Materials on Damage Caused by the Atomic Bombs in Hiroshima and Nagasaki, 1981, p. 79.

[21] One of the key isotopes, Mn-56, has a half-life of 2.6 hours.

the explosions near ground zero but all of the people near ground zero would have been killed by some combination of the blast effects, thermal effects or initial nuclear radiation. Fires burning in these areas would have prevented other people from entering this area for many hours after the explosions. The latest calculations, using the DS02 dosimetry system, show that a person entering ground zero at Hiroshima one day after the explosion and staying there for one week nonstop would receive a dose of about 0.2 Gy.[22] For Nagasaki the same calculation yields a dose of 0.04 Gy. The neutron intensity falls off rapidly from ground zero so that at one half a kilometer away, the dose is reduced by a factor of ten and at one kilometer away it is reduced by a factor of 300 to 400.[23] Clearly, the induced radioactivity was not sufficient to cause acute radiation syndrome in the survivors.

This conclusion is reinforced by a study which reviewed the doses received by two people who entered Hiroshima the day after the bombing and reported symptoms consistent with acute radiation syndrome.[24] Their doses were estimated to be 0.1 Gy and 0.03 Gy. These doses are below those that would cause these people to suffer from acute radiation syndrome and demonstrate that other causes must be responsible for these reported symptoms.

Some have suggested that induced radioactivity could give rise to a different kind of fallout. The winds associated with the blast wave could scour the ground and loft some of the radioactive soil into the air and they would then be deposited some distance away from ground zero. However, even assuming that a relatively large fraction of the soil is lofted, the dose received by exposed persons would be quite small (no more than about 0.01 Gy).[25]

Comparing the Immediate Fatalities to the Longer-Term Cancer Deaths

It is well known that the populations that were exposed to ionizing radiation at Hiroshima and Nagasaki have had an elevated cancer risk and that a number of cancer related deaths have occurred. But it is sometimes hard to judge how significant these cancer deaths are, as many public discussions of this issue are often just qualitative. A further complication is that even in populations that have not been exposed to nuclear explosions, cancer is a major cause of death. For example, in the U.S. in 2021, cancer was the second leading cause of death, just behind heart disease.[26] Therefore, one is concerned not with how many survivors of the atomic bombings die of cancer but rather how many *excess* cancer deaths occur in this population.

The Life Span Study (LSS) has been following mortality and cancer in about 120,000 atomic bomb survivors and control subjects since 1950. This study was conducted initially by the

[22] Tetsuji Imanaka, Satoru Endo, Kenichi Tanaka and Kiyoshi Shizuma, "Gamma-ray exposure from neutron-induced radionuclides in soil in Hiroshima and Nagasaki based on DS02 calculations," *Radiation Environmental Biophysics*, Vol. 47, 2008, p. 335. https://link.springer.com/article/10.1007/s00411-008-0164-1

[23] Ibid.

[24] Tetsuji Imanaka, Satoru Endo, Noriyuki Kawano and Kenichi Tanaka, "Radiation Exposure and Disease Questionnaires of Early Entrants After the Hiroshima Bombing," *Radiation Protection Dosimetry*, Vol. 149, No. 1, 2012. https://academic.oup.com/rpd/article/149/1/91/1603047?login=true

[25] Gregory D. Spriggs and Stephen D. Egbert, *Total Residual Radiation Source Term Produced by the Hiroshima Explosion*, LLNL-TR-814785, Lawrence Livermore National Laboratory, February 22, 2017, p. 22. https://www.osti.gov/servlets/purl/1668494

[26] Jiaquan Xu, et. al., "Mortality in the United States, 2021," NCHS Data Brief, Centers for Disease Control and Prevention, No. 456, December 2022. https://www.cdc.gov/nchs/data/databriefs/db456.pdf

Atomic Bomb Casualty Commission and currently is being conducted by the Radiation Effects Research Foundation (RERF) which is a joint Japanese/U.S. effort. The cancers are placed in two categories: leukemia or solid cancers.

In the atomic bomb survivors, leukemia deaths peaked in the early 1950s and became much less significant by the 1980s. Leukemia is a relatively rare cancer and the increase in leukemia cases noted in the early 1950s in these survivors was quite significant. The excess number of leukemia cases, especially in children was the first indication that the radiation exposure due to the atomic bombings would lead to a significant rise in cancer cases. As of 2002, there were 219 cases of leukemia observed in the LSS cohort, of which 98 (45%) were excess.[27]

Solid cancers have a latency period of about a decade, so it was not until later in the 1950s that an increase in solid cancers was detected. The number of excess cancer deaths has continued to rise, with a majority occurring since 1980. As of 1998, there have been 7,851 cases of solid cancers observed in the LSS cohort, of which 850 (11%) were excess.[28]

The total of excess cancers is 948. Since more cancers will have occurred since this analysis was performed, I rounded the number to an even 1,000. Since the LSS is only tracking about one-third of the survivors, the likely total number of excess cancers is around 3,000.

The number of excess cancers is undoubtably sizable. However, compared to the 110,000 to 210,000 people who are believed to have died in the few months after the atomic bombings at Hiroshima and Nagasaki, the number of excess cancers is small.[29] Indeed, the 100,000 person uncertainty range in number of people dying in the first few months after the atomic bombing is significantly larger than the total number of excess cancer deaths. Further since the majority of the solid cancer deaths occurred a number of decades after the atomic bombings, the loss of years of life is significantly less than the 3,000 excess cancer deaths would imply. In terms of fatalities, the excess cancer deaths are a relatively minor result of the atomic bombings.

Fallout, Induced Radioactivity and the Cancer Risk from Radiation Exposure

While the exposures to ionizing radiation at Hiroshima or Nagasaki from either fallout or induced radioactivity were not sufficiently high to cause acute radiation syndrome, the high-end estimates of exposure would, on their face, be sufficient to cause a significant increase in cancers. But the areas of high exposure only involved small sparsely populated areas and these high-end exposure estimates assume that people remained at the region of highest dose nonstop. Given the small number of people exposed and that, realistically, people in their daily

[27] Evan B. Douple *et. al.*, "Long-term Radiation-Related Health Effects in a Unique Human Population: Lessons Learned from the Atomic Bomb Survivors of Hiroshima and Nagasaki," *Disaster Medicine and Public Health Preparedness*, Vol. 5, Suppl. 1, March 2011, p. 20. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3907953/pdf/nihms548445.pdf

[28] Ibid., p. 22.

[29] For a good discussion of the sources of these widely divergent fatality estimates see: Alex Wellerstein, "Counting the dead at Hiroshima and Nagasaki," *Bulletin of the Atomic Scientists*, August 2, 2020. https://thebulletin.org/2020/08/counting-the-dead-at-hiroshima-and-nagasaki/ Note Wellerstein also calculates that the total number of excess cancer deaths is around 3,000.

movements would not always be in these areas of highest dose, it is unclear how important either fallout or induced radioactivity (residual radiation) was in elevating the cancer risk.

The general view is that the impact of the residual radiation exposure at Hiroshima and Nagasaki on cancer rates experienced by the survivors is negligible. This determination is critical to our current understanding of the cancer risks from ionizing radiation, which relies heavily on data from the survivors of the atomic bombings. Indeed, the latest evaluation of the cancer risks from ionizing radiation exposure (BEIR VII) has stated: "…the LSS cohort of A-bomb survivors serves as the single most important source of data for evaluating risks of low-linear energy transfer radiation at low and moderate doses."[30]

The work of the RERF does not attempt to estimate the exposure from fallout or induced radioactivity. The RERF concluded that: "…it is thought that exposure to residual radiation [fallout or induced radioactivity] does not notably affect the LSS estimates."[31] In particular, the RERF points out that only "several hundred" people were exposed to high radiation doses by fallout at Nagasaki. Other RERF work has shown that regarding the black rain: "For incidence of solid cancers and leukemia, no significantly elevated rain exposure risks were observed in either city."[32] Instead, the RERF only considers exposure to the initial nuclear radiation.

As was discussed above, the RERF has calculated DS02 to characterize the ionizing radiation field at Hiroshima and Nagasaki. The RERF determined the dose received by each person by determining where that person was at the time of the explosion and how much shielding might have been between that person and the nuclear explosion. The development of cancer in the exposed persons and the controls (persons who were not in the city at the time of the nuclear attacks) is then used to determine the cancer risk associated with various levels of exposure to ionizing radiation.

Some have claimed that the residual radiation at Hiroshima and Nagasaki could have been significant enough to affect the RERF's estimates of ionizing radiation exposure and thereby the cancer risk.[33] Note that if this view were found to be correct, then the estimates of the cancer risk caused by exposure to a given dose of ionizing radiation, which up to now have been based on the RERF analysis, would be reduced, since the ionizing radiation exposure of the survivors would be higher than in the RERF's calculations.

This possible diminution of the cancer risk resulting from exposure to a given dose of ionizing radiation would seem to be counter-intuitive but an examination of the factors involved

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[30] *Health Risks From Exposure to Low Levels of Ionizing Radiation: BEIR VII Phase 2*, National Research Council, The National Academies Press, 2006, p. 141. https://nap.nationalacademies.org/catalog/11340/health-risks-from-exposure-to-low-levels-of-ionizing-radiation

[31] Kotaro Ozasa, "Epidemiological research on radiation-induced cancer in atomic bomb survivors," *Journal of Radiation Research*, Vol. 57, No. S1, 2016, p. i114. https://academic.oup.com/jrr/article/57/S1/i112/2580473

[32] Ritsu Sakata et. al., "Long-Term Effects of the Rain Exposure Shortly after the Atomic Bombings in Hiroshima and Nagasaki," *Radiation Research*, Vol. 182, 2014, p .599. https://bioone.org/journals/radiation-research/volume-182/issue-6/RR13822.1/Long-Term-Effects-of-the-Rain-Exposure-Shortly-after-the/10.1667/RR13822.1.full

[33] George D. Kerr, et. al., "Workshop Report on Atomic Bomb Dosimetry—Review of Dose Related Factors for the Evaluation of Exposures to Residual Radiation at Hiroshima and Nagasaki," *Health Physics Society*, Vol. 109, No. 6, 2015, p. 596. https://journals.lww.com/health-physics/abstract/2015/12000/workshop_report_on_atomic_bomb_dosimetry_review_of.21.aspx

demonstrate that it is correct. The number of excess cancers resulting from the atomic bombings is fixed, as it is the actual number of excess cancers that have been found in the survivors by the LSS. The exposure to the initial nuclear radiation at Hiroshima and Nagasaki is well known and has been determined by RERF analysis. Using the RERF data, the excess cancer risk is found by comparing the exposure to the initial nuclear radiation to that number of excess cancers that resulted. If there were also a significant exposure to residual radiation, then the radiation exposure of the survivors would be the sum of the initial nuclear radiation exposure plus the residual radiation exposure. Since this would be larger than just the initial radiation exposure, yet the resulting excess cancers are the same, the cancer risk per a given dose of radiation exposure would be lower than if the only source of significant radiation exposure were the initial nuclear radiation.

The RERF has specifically addressed the issue of possible significant residual radiation exposure.[34] The RERF has stated that while there may have been some residual radiation exposure, the magnitude of this exposure would be smaller than the uncertainty bounds of the RERF's estimates of the cancer risks from initial nuclear radiation exposure. The RERF cites an analysis of the activities of some Japanese military personnel who spent the period from August 7 to August 13 near ground zero clearing rubble. It has been estimated that their maximum exposure was 0.1 Gy and the average exposure was 0.013Gy. No increase in cancer deaths were seen in this group. Still, some controversy exists, though those claiming that there were higher ionizing radiation exposures from residual radiation have not provided any analytical basis for how this exposure might have occurred.[35]

Conclusions

The residual radiation exposures at Hiroshima and Nagasaki were not high enough to cause acute radiation syndrome. This conclusion is supported by the authoritative publication *The Effects of Nuclear Weapons,* which stated: "The effect of the residual radiation, in the form of early fallout and induced radioactivity, was negligible."[36]

The weapons at these cities were exploded at a high enough altitude to preclude the production of much fallout. The highest levels of fallout at either city was in a small sparsely populated area east if Nagasaki, where the highest likely dose was less than 0.5 Gy. Some have expressed concern that the "black rain" that fell after the explosions was highly radioactive. However, analysis has shown that there was no increase in cancers in areas where this rain fell demonstrating that the radioactivity contained in this rain was minimal.

The greatest exposure to induced radioactivity would occur immediately after the explosions near ground zero but the people in this area would all have been killed by some combination of

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[34] "RERF's View on Residual Radiation," Radiation Effects Research Foundation, December 8, 2012. https://www.rerf.or.jp/uploads/2017/09/residualrad_ps_e.pdf

[35] George D. Kerr, et. al., "Workshop Report on Atomic Bomb Dosimetry—Review of Dose Related Factors for the Evaluation of Exposures to Residual Radiation at Hiroshima and Nagasaki," *Health Physics Society*, Vol. 109, No. 6, 2015, p. 596. https://journals.lww.com/health-physics/abstract/2015/12000/workshop_report_on_atomic_bomb_dosimetry_review_of.21.aspx

[36] Samuel Glasstone and Philip J. Dolan, *The Effects of Nuclear Weapons*, 3rd ed., U.S. Department of Defense and U.S. Department of Energy, 1977, Chapter XII, "Biological Effects," p. 575. https://www.osti.gov/biblio/6852629

the blast effects, thermal effects or initial nuclear radiation. The fires burning in the cities would have prevented other people from entering these areas for many hours after the explosions. The highest exposures to induced radioactivity at Hiroshima would have been in the range of 0.1-0.2 Gy. The highest exposures to induced radioactivity at Nagasaki would have been significantly lower (0.04 Gy). Fallout caused by the lofting of soil containing induced radioactivity at either city would have resulted in very minimal exposure (0.01 Gy).

As a result, all of the cases of acute radiation syndrome at Hiroshima and Nagasaki were caused by the exposure to initial nuclear radiation which would have been delivered in less than one minute after the explosions. Therefore, only people near the explosions would have received high doses of ionizing radiation. However, most such people would have been killed by the blast or thermal radiation given off by the blasts. It is estimated that only 5% to 15% of the fatalities at Hiroshima and Nagasaki were the result of exposure to ionizing radiation. In addition, since people suffering from acute radiation syndrome either die or recover within a few months, accounts of people suffering from this syndrome many months or years later are not true. Further, since the calculated doses of people who were not in the cities at the time of the explosions but entered later are no more than about 0.1 Gy, accounts of people suffering from acute radiation syndrome due to exposure received on entering the cities sometime after the explosions are not true as well.

The number of excess cancer deaths resulting from the atomic bombings is around 3,000. While this number is undoubtably sizable, compared to the 110,000 to 210,000 people believed to have died in the few months after the bombings, the excess cancer deaths are a relatively minor result of the atomic bombings.

The ionizing radiation exposure at Hiroshima and Nagasaki from fallout and induced radioactivity was not only so low that it did not cause any cases of acute radiation syndrome but it was also low enough that it is not thought to have caused a significant increase in the number of cancers in the survivors. The RERF has stated that while there may have been some residual radiation exposure, the magnitude of this exposure would be smaller than the uncertainty bounds of the RERF's estimates of the cancer risks from the initial nuclear radiation exposure.

Still, some controversy exists on this issue, though those claiming that there were higher ionizing radiation exposures from residual radiation have not provided any analytical basis for how this exposure might have occurred. If this view that there were higher levels of exposure to residual radiation were found to be correct, then the estimates of the cancer risk caused by exposure to a given dose of ionizing radiation, which up to now have been based on the RERF analysis, would be reduced, since the ionizing radiation exposure of the survivors would be higher than in the RERF's calculations.