bomb. Estimates of primary radiation (gamma rays and neutrons) from measurements systematically exceed those under DS86 and DS02 further than 1.5 km from the hypocentre, and the discrepancies increase with distance. Even for primary radiation, estimates of exposure under DS86 and DS02 cannot therefore be applied to distances more than 1.5 km from the hypocentre. Furthermore, DS02 does not take any account of residual radiation.

Physical aspects of internal exposure

The fallout from the atomic bombs of Hiroshima and Nagasaki included:

- 3.6×10^{24} nuclei of fission products,
- $(2.5) \times 10^{24}$ nuclei of neutron-irradiated material from bomb equipment and container,
- 10^{26} nuclei of unfissioned uranium-235 or 2.5×10^{25} plutonium-239 respectively.

Shortly after the explosion, a plasma fireball was formed by nuclei and ionized in the atmosphere which rose and developed into an atomic cloud. The central part of the mushroom cloud rose above the tropopause (surface between troposphere and stratosphere) by 15 km or more and the remainder spread along the tropopause over a region with a radius of 15 to 20 km. This was followed by fallout, including many tiny particles containing a variety of radioactive nuclei of differing half-lives, capable of causing severe damage from residual radiation.

The survivors close to the hypocentre were exposed to primary radiation externally. Their exposed dose can be roughly estimated if their place of exposure is known. Survivors and people who entered the region near the hypocentre after the explosion were also exposed to emissions from material irradiated by the primary neutron beam; their degree of exposure can be estimated by calculation and measurement data if their actions or behaviour were known. However, it is difficult to estimate the radiation dose from fallout in terms of physical measurement some time after the explosion because most of the small particles were carried varying distances by the wind and the radioactive material came down as the so-called 'black rain'. Some was washed away by the heavy rain accompanying typhoons. It is also difficult to estimate the effects of internal exposure by inhalation or ingestion of radioactive fallout and other irradiated material by physical methods.

When radioactive material enters the body, if it is water- or fat-soluble it will spread throughout the body, and some radioactive elements are concentrated and perhaps become deposited in specific organs. For example, iodine concentrates in the thyroid, and phosphorus and cobalt in bone marrow. In such cases the amounts of radioactivity taken into the

body can be estimated from urinary excretion. On the other hand, when tiny insoluble radioactive particles enter the body, the particles may be deposited, for example in the lung, without change in size, and can continuously irradiate surrounding cells; a particle with a radius of one micron can contain more than a billion radioactive nuclei. In this instance, it is difficult to detect these particles from outside the body or from analysing urine and faeces. The effects of such particles depend on their size, the nature of the radioactive elements present and their half-life, and the type of radiation emitted (alpha, beta or gamma). Biological methods are then more important for the estimation of effective external and internal exposure. Biological methods include data on incidence rates of acute chronic radiation-induced disease, and analysis of the frequency of chromosomal aberrations, especially among survivors further from the hypocentre and later visitors to the sites who were not severely exposed to the primary radiation.

The difference between uniform external exposure and internal exposure from a radioactive small particle is illustrated in Figure 3. As shown in this figure, it is difficult to represent the effects of internal exposure to cells near the radioactive particle in terms of commonly used radiation dose units; these represent averaged doses over an organ.

Estimation of residual radiation from incidence of acute radiation disease

Many studies of acute radiation disease among survivors of the atomic bombing of Hiroshima and Nagasaki show small but significant increased incidence of acute radiation diseases among survivors in the region where the primary radiation scarcely reached. Figure 4a shows the incidence of epilation and/or purpura among survivors exposed outdoors

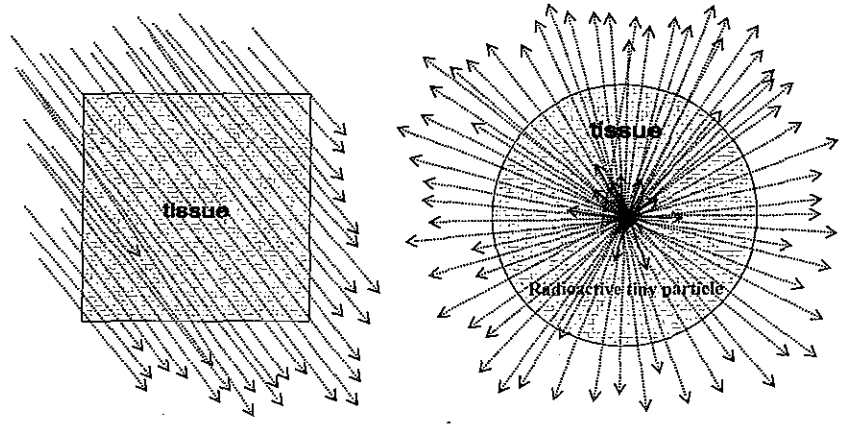

Figure 3. External and internal exposure to radiation.

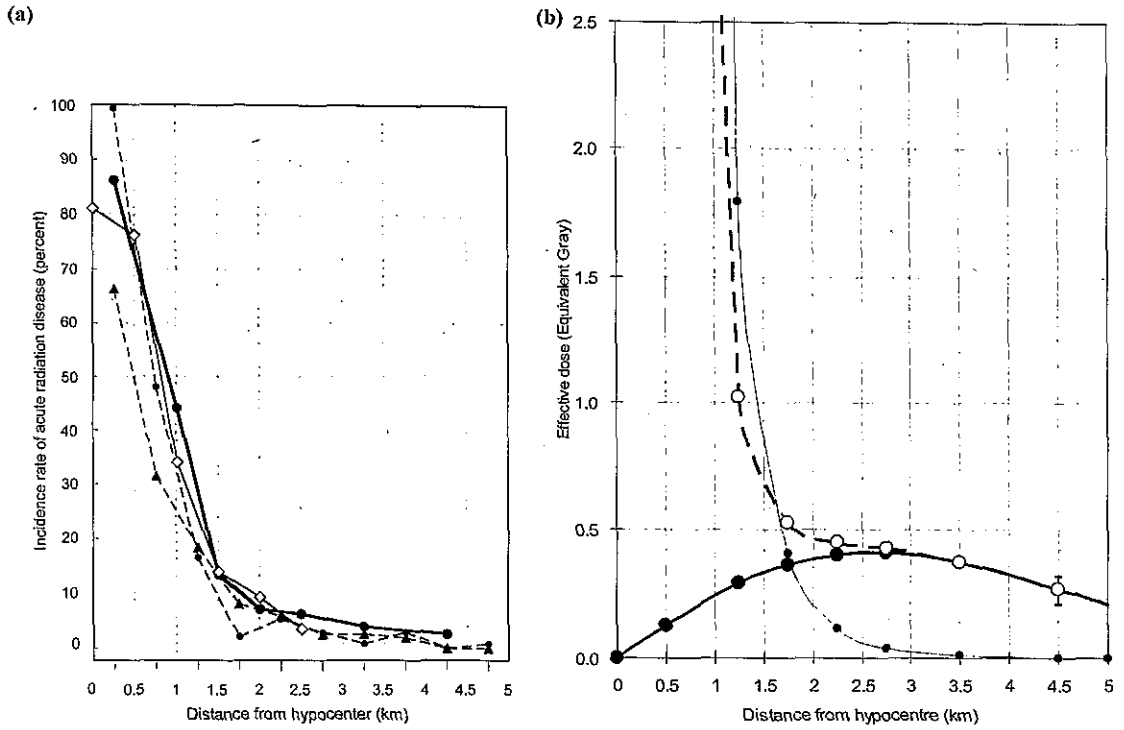

Figure 4. (a) Incidence of acute radiation disease in Hiroshima survivors. Bold full line with larger closed circles: epilation and/or purpura (*Source*: Ref. 3). Thin full line with open squares: epilation (*Source:* Tokyo University). Broken line with smaller closed circles: epilation (*Source*: Ref. 4). Broken line with closed triangles: purpura (*Source*: Ref. 4).]. (b) Calculated effective exposed dose to Hiroshima survivors. Broken line with open circles: total exposed dose. Thin continuous line with smaller closed circles: estimation of arrived primary radiation dose. Bold continuous line with larger closed circles: contribution from fallout. (*Source*: modified from Ref. 3; further details available from author).

[3], the epilation rates obtained by Tokyo Imperial University and the incidence of epilation and purpura among survivors exposed indoors found by a Hiroshima doctor [4]. Figure 4b shows the total radiation dose to survivors exposed outdoors as estimated from the incidence of epilation and purpura [4], with relative contribution from fallout and estimates of the primary radiation. (Details of calculations and uncertainties can be obtained from the author.)

Present estimates of fallout effects suggest that it came down over a wide region under the mushroom cloud. Near the hypocentre there was only weak fallout due to rising air currents following the mushroom cloud and firestorm. The exposure effects of fallout rise with increasing distance from the hypocentre and exceed those of the primary radiation at a distance between 1.5 km and 1.7 km. The effects of fallout reach a peak between 2.0 km and 3.0 km from the hypocentre, then decrease slowly due to dispersion and decay of radioactivity over time.

In its recent epidemiological study, the RERF used as its non-exposed control group survivors exposed to a primary radiation dose estimated under DS86 as less than 0.005 Sv, corresponding to a distance of 2.7 km from the Hiroshima hypocentre. These survivors received an estimated fallout dose equivalent to acute external exposure of 0.3–0.7 Gy gamma ray, 60–140 times the primary radiation dose estimated under DS86. This explains why the criteria of the Ministry of Health, Labour and Welfare based on the RERF epidemiological study differ from the actual state of survivors affected by fallout.

Radiation effects for arrivals after the bombing

The incidence of acute radiation disease (one or more of fever, diarrhoea, purpura, and epilation) has been examined among those who entered the region within 1 km of the hypocentre of Hiroshima up to 34 days from the day of the bombing on 6 August 1945 [4]. Figure 5a shows the overall incidence rate for arrivals at various times after the bombing, and Figure 5b shows the estimated total effective dose to these arrivals. (Details of the underlying assumptions and calculations available from the author.) For an entrant on 6 August 1945, the cumulative effective dose is 1.49 ± 0.38 Gy, but decreases exponentially and is almost halved for those arriving one week after the bombing. In comparison (not shown), the cumulative external exposure from neutron-irradiated material at the hypocentre is 0.8 Gy; at 500 m it is 0.09 Gy, and at 1000 m it is 0.0017 Gy. The large discrepancy between exposure effects estimated from acute radiation disease among those entering after the bombing and measured external accumulated dose suggests that the effects of radiation from chronic internal exposure due to internal radioactivity were large compared to those of external exposure.

Experimentally measured primary radiation doses from both gamma rays and neutrons systematically exceed the doses calculated from DS86 and

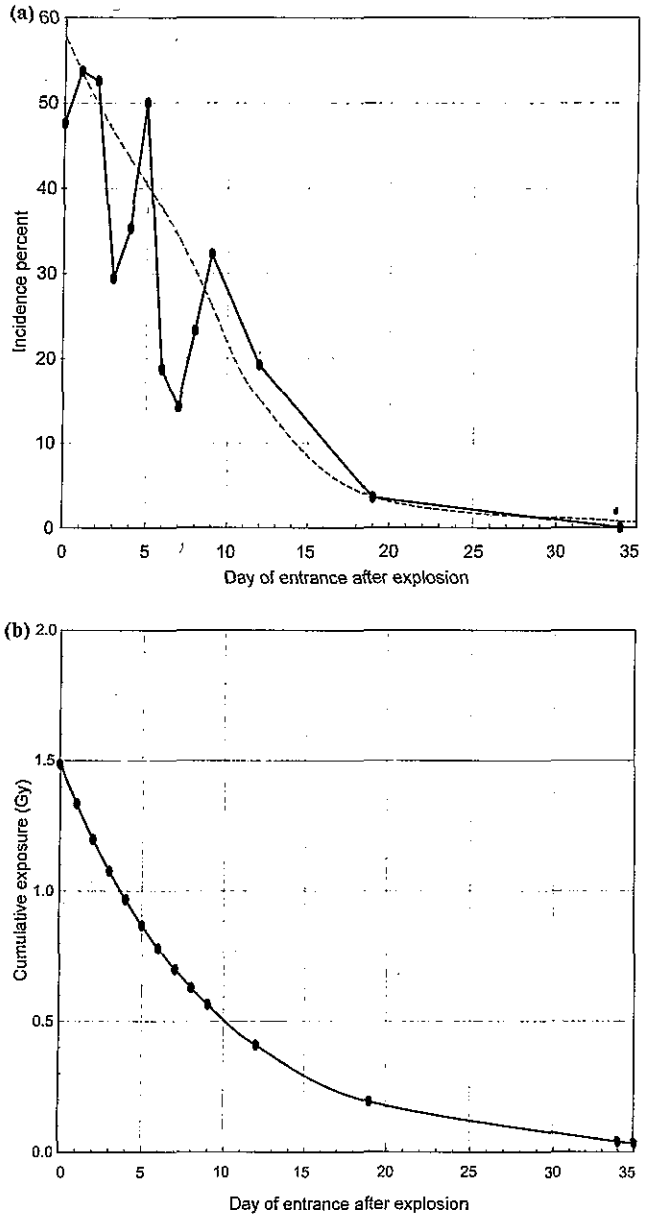

Figure 5. (a) Change of incidence rate of acute radiation disease in arrivals after bombing. Bold line with closed circles: overall incidence. Broken line: best fit line by chi-squared test. (*Source*: adapted from Ref. 4). (b) Estimated effective dose to arrivals after bombing. (*Source*: author's calculations).

DS02 in the region more distant than 1.5 km from the hypocentre, and the discrepancy increases with distance. Even for primary radiation doses, DS86 and DS02 estimates should not be applied to distances beyond 1.5 km from the hypocentre. The incidence of acute radiation diseases for survivors of the bombing beyond 1.5–1.7 km again shows that the effects of internal exposure due to radioactive fallout are more severe than those from external exposure to primary radiation. Application of DS86 or DS02 criteria to estimate the exposure of distant survivors and later entrants is therefore mistaken.

Estimation of fallout radiation from chromosomal aberrations

Chromosomal abnormalities appear in the nuclei of irradiated cells. The frequency of chromosomal abnormalities in circulating lymphocytes of survivors of the Hiroshima atomic bombing has been compared with 11 non-irradiated healthy controls visiting the Japan Red Cross Central Hospital in Tokyo between April 1967 and March 1968 [5]. It was found that aberrations occurred in survivors from areas scarcely reached by the primary radiation. The internal radiation dose can be estimated from the rate of chromosomal aberrations, but the estimated dose at a distance from the hypocentre cannot be explained by primary irradiation.

More than 1.6 km from the hypocentre, the effects of internal exposure from fallout as estimated from frequency of chromosomal aberration exceeded that of primary irradiation. It should be noted that the estimated dose based on the frequency of chromosomal aberration in circulating lymphocytes represents the effects averaged over the whole body. Local effects from insoluble radioactive particles, which are considered in the incidence rates of acute diseases, are not included. Yet the RERF has denied the existence of chromosomal aberrations at a distance from the hypocentre.

Problems of epidemiological studies in the RERF

There are serious problems in the epidemiological studies of survivors by the RERF. The contribution of residual radiation to the estimated dose of exposed survivors is neglected, originating with the initial interview of survivors by the ABCC. The other serious problem is in the selection of non-irradiated controls. The ABCC and RERF epidemiological studies used survivors themselves as non-exposed controls. In the recent RERF investigations survivors who received less than 0.005 Sv according to DS86 criteria, and the 'not in city' group of surviving early visitors to the area are used as the control group. As shown above, these and survivors from a distance were affected by residual radiation estimated at more than 0.1–0.5 Gy, many times more than the RERF's figure of 0.005 Sv. Thus the

ABCC and RERF studies cannot be used to estimate exposure to these survivors.

An analysis of chronic diseases among the RERF control cohort, using all Japanese as controls, was used to examine the effects of exposure to fallout and induced radioactivity [6]. The standard relative risks, mortality ratios, and incidence rates of various diseases in the RERF control group, compared with all Japanese, is shown in Figure 6 as closed and open circles for those exposed to less than 0.09 Gy according to the T65D criteria and in the 'not in city' groups respectively. The standard risks for mortality from all causes and all diseases are less than unity, indicating that the RERF control cohort is healthier than the Japanese average. As Alice Stewart pointed out [7] their greater overall fitness enabled them to survive despite exposure to radiation. However, the high relative risk of death from leukaemia and cancer of the respiratory system and the incidence of thyroid and female breast cancer in the RERF control group (in both survivors from a distance and post-bombing arrivals) show that they had been affected by fallout and induced residual radiation. The relative risk of mortality from leukaemia for all arrivals in the 'not in city' group is less than 1 (Figure 6), but of 4500 arrivals within three days of the bombing in this group there were six cases of leukaemia. The relative risk for leukaemia mortality of early post-bombing arrivals is about 2 (Figure 6). Dr Schmitz-Feuerhake has also discussed these findings in her further publications [8, 9]. She concluded that:

> to take a control from the survivors themselves or from early and late entrants cannot be accepted.... Further investigations should make use of the fact that the survivors who were at great distance from the explosions and the NIC group, including about 82,000 persons in the RERF sample, represent the largest and most well investigated human collective showing evidently low-LET effects in the low-dose range [8].

Dangers of 'usable' nuclear weapons and 'earth-penetrating' nuclear weapons

The US government has been considering the development of 'usable' and 'earth-penetrating' nuclear weapons. This shows little concern for the dangers of atomic bombing and especially neglects the effects of residual radiation and the possibly severe consequences of internal exposure. The Hiroshima and Nagasaki bombs were exploded at heights above ground of 600 m and 500 m respectively, somewhat weakening the radioactive fallout, and the neutron beam that induced the residual radiation was diminished before reaching ground level. On the other hand, an 'earth-penetrating' nuclear weapon would explode only a few tens of metres underground. Its fireball could cause a strong radioactive pyroclastic flow, a

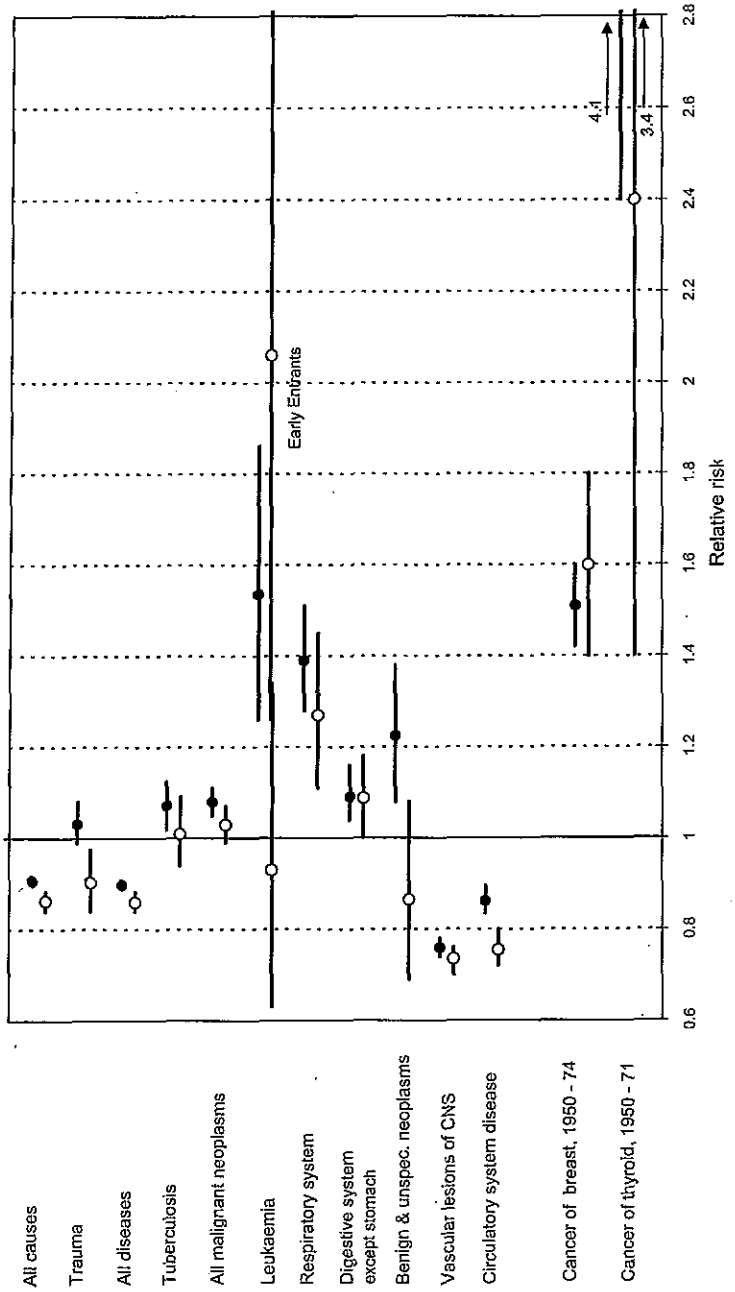

Figure 6. Relative risk of various diseases in the RERF control group. Closed circles: exposure < 0.09 Gy group (T65D criteria). Open circles; 'not in city' group. (*Source*: Ref. 6).

stream of heated rocks and ash containing highly radioactive material, which could lead to major fallout.

The total deaths from cancer caused by fallout downwind from nuclear weapon tests and accidents at nuclear facilities between 1945 and 1989 has been estimated at 1,116,000 [10]. This used an ICPR model constructed from the RERF studies in which the effects of internal exposure were given little attention. If cancer deaths from the effects of internal exposure to residual radiation is 50 times more than that of the ICRP model, total deaths from cancer caused by fallout could be more than 50 million, which is almost one per cent of total world population.

As a scientist and survivor of the Hiroshima atomic bombing, I believe that if there had not been a US-imposed cover-up of the severe effects of internal exposure from residual radiation before the nuclear tests of the 1950s and 1960s, these tests would have been banned and perhaps much ill-health and loss of human life avoided. A successful lawsuit by the survivors will contribute to the movement towards elimination of nuclear weapons more than 60 years after the atomic bombing by pointing out that nuclear weapon should never be used because of the severe effects of internal radiation exposure.

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