Atomic Bomb Doses Reassessed

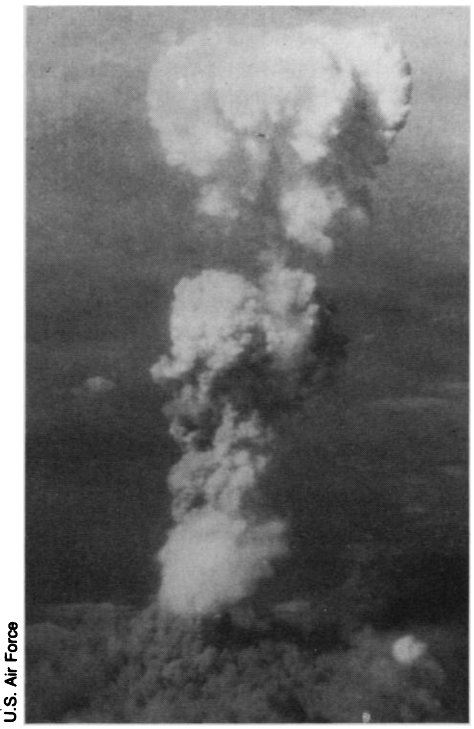
The radiation doses the atomic bomb survivors received have been reassessed; radiation risk estimates are being revised upward

FORTY-THREE years later, U.S. and Japanese physicists are still trying to figure out exactly what happened in August 1945, when the United States dropped two atomic bombs on the cities of Hiroshima and Nagasaki. Crude measurements were taken at the time, but the exact yield of the two atomic bombs, and especially the radiation dose the population received, remain unclear. The answers are of more than academic interest—most of what we know about the biological effects of radiation are based on the study of some 90,000 survivors of those two attacks.

In 1965 Japanese and American scientists came up with a tentative dosimetry for the survivors, and it has guided cancer risk estimates and radiation protection standards throughout the world ever since. It turns out, however, that those calculations were wrong. Hints of the problem surfaced in the mid-1970s, but it has taken a decade to verify what were then startling findings, in part because of the complexity of these retrospective calculations, in part because the topic is so politically charged.

Now the long-awaited reassessment of the atomic bomb dosimetry, a 6-year binational effort, is complete.* As has been expected for several years, the average doses the survivors received were lower than previously believed, and thus risk estimates for radiation will have to be adjusted upward, but exactly how much is the subject of considerable debate.

The new findings have engendered a flurry of studies to reexamine cancer risks from low doses of radiation. Final risk estimates will not be complete for a year or so, but preliminary analyses suggest that the risk of getting cancer from gamma radiation, the most common type of radiation to which the population is exposed, from both background and medical sources, is twofold or more greater than previously believed. Already in Europe environmental groups and hundreds of scientists are clamoring for an immediate revision of the International Commission on Radiological Protection's guidelines for worker protection.



U.S. Air Force

Hiroshima, *6 August 1945.*

The biggest change in the new dosimetry is for Hiroshima, where the proportion of neutrons to gamma rays looks drastically different than was estimated in 1965. "The Nagasaki estimates were pretty close. But they sure were wrong for Hiroshima," says William Ellett of the National Research Council, which provided oversight to the reassessment effort.

The problem is that the Hiroshima bomb was a one-of-a-kind device, essentially a gun that fired one subcritical mass of uranium-235 down a barrel against another mass. No bomb like the Hiroshima one was ever tested, either before or after the attack. By contrast, bombs identical to the Nagasaki weapon were tested at Trinity and later in the Pacific and at the Nevada Test Site. Thus, a substantial body of experimental data existed from which to calculate its yield and the number and type of radiations it emitted.

But for the Hiroshima weapon, such data could be derived only indirectly through comparison with the Nagasaki data and from tests with an unshielded nuclear reactor, perched on a tower, to simulate the bomb. These experiments, conducted in the desert at the Nevada Test Site, indicated that a substantial share of the radiation dose in Hiroshima—about 20%—was delivered in neutrons; the rest in gamma rays. By comparison, the neutron contribution at Nagasaki was minimal. Neutrons are known to be far more effective than gamma rays at inducing cancer, which was thought to explain the higher cancer incidence in Hiroshima relative to Nagasaki.

Because the presence of neutrons complicated the Hiroshima data, Nagasaki, with its lower cancer incidence, became the basis for defining health effects of low doses of low-LET radiation, the most common type of radiation to which workers and the population are exposed. Both gamma rays and x-rays are forms of low-LET radiation. Neutrons are a form of high-LET radiation.†

But according to the new calculations, the neutrons at Hiroshima did not really exist, at least not in the number previously assumed. "What we blamed on the neutrons we now have to attribute to gamma rays," says Ellett. "Now we are pretty sure it was gamma rays causing the cancer."

The problem first came to light in the mid-1970s when researchers working on computer simulations of the two bombs realized the neutron component had been substantially overestimated. But the data were discrepant and were met with considerable resistance, in part because they necessitated rethinking risk estimates for low-LET radiation (*Science*, 22 May 1981; 19 June 1981; 2 October 1981).

In 1981, in the face of mounting evidence, both the U.S. Department of Energy and the Japanese Ministry of Health established working groups to reassess the Hiroshima and Nagasaki dosimetry. They joined forces in 1983, under the auspices of the Radiation Effects Research Foundation in Hiroshima, a joint U.S.-Japanese foundation. The U.S. effort was led by Robert F.

**US-Japan Joint Reassessment of Atomic Bomb Radiation Dosimetry in Hiroshima and Nagasaki, Final Report*, Radiation Effects Research Foundation, Hiroshima, Japan, 1987. Available from William H. Ellett, RERF Office, National Research Council, 2101 Constitution Ave. NW, Washington, DC 20418.

†LET, for linear energy transfer, is a measure of the energy loss of the ray per unit of distance traveled.

Christy of the California Institute of Technology; the Japanese, by Eizo Tajima of the Nuclear Safety Commission.

One of the first tasks was to build a mock-up of the Hiroshima bomb, which was done at Los Alamos National Laboratory, to help calculate the number of neutrons and gamma rays emitted by the weapon. These measurements are the starting point for subsequent calculations of radiation transport, shielding, and, ultimately, the dose each individual received. The replica, which was run as a slow nuclear reactor, and Monte Carlo computer calculations revealed that, contrary to earlier calculations, neutrons were greatly attenuated by the heavy metal in the Hiroshima bomb.

The neutron dose is also affected by their transport through the air. The original neutron measurements, which underlay the 1965 dosimetry, were made in the Nevada desert following bomb tests. What this earlier work failed to factor in, however, was the humid conditions in Japan when the bombs were dropped. The higher the humidity, the greater the absorption of neutrons by the air. Thus, not only were there fewer neutrons to begin with, but they were further diminished by the humidity.

This new information leads to a dramatically different estimate of the doses in the air. At Hiroshima the neutron dose is 10% of what was previously believed—2% of the total instead of 20%—and the gamma dose was 2 to 3.5 times higher, depending on the distance from the hypocenter. Some uncertainty remains about the exact neutron dose at Hiroshima, however, as calculations do not agree with measurements taken earlier in Japan. At Nagasaki the changes were smaller; the gamma ray dose was slightly reduced, and the neutron dose, believed to be low to begin with, was reduced by a factor of 2.

Not only were the original estimates for the neutron dose off; every factor relevant to the dosimetry was revised during the reassessment. The yield of the Hiroshima bomb was adjusted upward about 20%, from 12.5 kilotons to 15 kilotons; the Nagasaki bomb yield was revised slightly downward from 22 to 21 kilotons.

For estimating radiation risks, the figure of most interest is body dose, and more specifically, organ dose. As part of its continuing medical followup of the survivors, the Radiation Effects Research Foundation has collected data on 93,741 persons who were in the cities at the time of the blast. Roughly 20,000 were within 1.2 miles of the hypocenter and thus received large doses. For 18,500 of those, detailed histories are available on exactly where they were, and in what position and orientation, at the time of the blast.

Within 1.2 miles, most of those who survived were shielded in some way from thermal effects of the bombs. According to the new calculations, houses provided roughly twice as much shielding as was allowed for in the previous dosimetry. The new shielding estimates are based on computer simulations that take into effect clusters of houses, not just single houses, their orientation, and the terrain. The earlier dosimetry relied on replicas of single houses built at the weapons test site.

The body, on the other hand, provided less shielding to the organs than previously thought. How much shielding the tissues and other organs provide to a specific organ depends on the individual's sex, size, weight, posture, and orientation at the time of the blast. It is estimated, for example, that the dose to the breast can vary by 30% depending on which direction in a room a woman was standing.

"You aren't going to turn the radiation protection system upside down overnight."

As part of the new reassessment, doses for each of 15 organs have been calculated for about 75,000 of the survivors to date. To measure how radiation is transferred through the body to the organs, the working group constructed phantoms—mathematical models that represent typical Japanese adults, adolescents, and children in 1945.

The net result of all these physical changes is that a significant number of the survivors received lower radiation doses than previously estimated, though details in each city vary. What this all means in terms of radiation risks is trickier to sort out and is already being hotly debated. Both the National Research Council's Committee on the Biological Effects of Ionizing Radiation (BEIR) and the United Nations Scientific Committee on the Effects of Ionizing Radiation (UNSCEAR) have studies under way that should be complete in a year or two. Their pronouncements have generally been regarded as gospel in the past.

Even without a definitive risk assessment, several people say, there is no question that the risk must now be regarded as higher. How much higher depends on the assumptions used about the relative biological effectiveness of neutrons and gamma rays, and on which models are used to extrapolate from high to low doses, a contentious subject at best.

Relative biological effectiveness, or RBE, is essentially a measure of how much more effective neutrons are at inducing cancer than are gamma rays. The best estimate now for neutron RBE is 20, which means they are 20 times more effective than are gamma rays, though the exact measurement has yet to be determined.

Risk comparisons between the two dosimetries change dramatically according to what RBE is assigned. If an RBE of 1 is used—that is, if neutrons and gamma rays are treated as if they are equally carcinogenic— then the two dosimetries look remarkably similar. But if an RBE of 20 is selected, the new dose is about half of the old dose, and thus the risk is twofold greater. .

Dale Preston and Donald Pierce of the Radiation Effects Research Foundation have compared the risk estimates under the two dosimetries. They find, using an RBE of 20, that for leukemia the risk estimate is a factor of two larger with the new dosimetry; for other cancers, 50% larger.

To get a firmer fix on the change, Preston and Pierce recalculated the National Research Council's most recent risk estimates, published in the 1980 BEIR report, "The Effects on Populations of Exposure to Low Levels of Ionizing Radiation." The BEIR committee calculated that there would be 2.3 excess cancer deaths among 10,000 persons exposed to a single dose of 1 rem (10 millisieverts). Preston and Pierce now put that number at about 5 to 10 excess cancer deaths under the new dosimetry. And if you assume the relationship between dose and response is linear, adds Preston, then the number of excess deaths would be 16.

Which dose-response model to use is also a contentious subject. After a very public fight, the 1980 BEIR committee switched, at the last minute, from a linear model to a linear-quadratic model, which results in lower risk estimates. Committee chairman Edward P. Radford of the University of Pittsburgh wrote an impassioned dissent from the report, claiming that it underestimates the risk of low-LET radiation.

Preston suspects that as the new data are examined, there will be a move toward adopting a more linear model. Although abundant experimental data suggest that the dose-response relationship with gamma radiation is nonlinear, he says, with the new Japanese data, "the relationship looks linear at doses of 50 to 300 rads." Warren Sinclair, president of the National Council on Radiation Protection (NCRP), concurs about the model. Evidence for the linear-quadratic model "is not that strong" in humans, he says. "The relationship could simply be linear."

"I will reserve judgment until I see the data, but I would be surprised if one could distinguish unambiguously between the linear-quadratic and the linear model. It's a judgment call," says Arthur Upton of New York University, who has the unenviable task of chairing the BEIR-V study, the NRC's reexamination of radiation risk estimates, and an ICRP study as well. Much of the BEIR committee's efforts, he says, will be devoted to just that question.

Risk estimates are also being revised in light of the new cancer mortality data among the atomic bomb survivors, which, according to Upton, "are causing total risk to appear much larger than it did a few years ago." In the past 11 years the number of excess deaths among the survivors has risen from about 100 to 300. The increase is occurring, he and others say, because the population is reaching the age when cancers typically occur. As the incidence of "normal" cancers increases with age, so, too, does the incidence of excess cancers. Japanese women who are now in their 40s and who were heavily irradiated as children are showing a marked increase in breast cancer, Upton says. The Japanese data are also showing that relative risk is greater for those who were exposed in utero or as children than it is for those exposed as adults.

When the mortality data and new dosimetry are combined, says Sinclair, radiation risks appear to be a factor of 2 or 3 higher than earlier estimates. For the young, risk could be up by a factor of 5 or 6, he suspects. And if the dose-response curve turns out to be linear, the risk estimate would rise by a factor of 2 again.

Opinion is divided, however, on whether the new dosimetry warrants a revision in radiation protection standards. Almost as soon as the new dosimetry was released, Friends of the Earth and hundreds of scientists petitioned the International Commission on Radiological Protection, which recommends protection standards for radiation workers and the public, to reduce its recommended exposures for radiation workers by a factor of 5, from 50 millisieverts to 10 millisieverts. The ICRP has deferred any decision until its risk assessment, as well as those of the NRC and the UN committees, are complete, which may be 1 or 2 years.

In the United States, the National Council on Radiation Protection will also wait until those studies are complete. "We need a sound evaluation before we take such a step. You aren't going to turn the radiation protection system upside down overnight," Sinclair says. Britain, however, is expected to immediately lower its occupational standard by 70%, down to 15 millisieverts , thus breaking ranks with the ICRP. ■

LESLIE ROBERTS

Broad Attack Launched on the Nervous System

In the past few years, research on molecular and cellular phenomena has dominated the field of neurosciences and its annual meeting. But this year, organizers balanced these reports with presentations about the neurobiology of whole-animal learning and behavior. The result was an updated overview of what is known about nervous system structure and function. More than 11,000 researchers met from 16 to 21 November in New Orleans for the 17th Annual Meeting of the Society for Neuroscience to bridge the gaps between molecules and man.

Thanks for the Memory

Patty's garden is full of marigolds. "After a 5-minute delay, a patient with amnesia will only remember the key word 'marigolds' 20 to 30% of the time," says Larry Squire of the Veterans Administration Medical Center and University of California at San Diego. "And after 24 hours the patient cannot recall any part of a new passage."

It may be a common misconception that patients with amnesia only have trouble remembering past events. As Squire indicates, they have trouble learning new things. Their loss is often selective, however. Squire, Stuart Zola-Morgan, also of San Diego, and David Amaral of the Salk Institute in La Jolla recently found that patient RB had damage only to a small subdivision of the most primitive part of his cerebral cortex, but the lesion drastically affected his ability to learn.

RB developed anterograde amnesia (had difficulty forming new memories) after heart surgery and a major episode of ischemia, in which the blood supply to the brain was blocked. He recently died at the age of 57, permitting the California researchers to determine precisely what regions of his brain had been damaged by the ischemia. They correlated this information with the results of psychological tests they had administered to RB during the 5-year period from his ischemia to his death.

The damage to RB's brain was restricted to a small region on both sides. "We saw a complete loss, bilaterally, of the CA1 pyramidal cells of the hippocampus," said Squire at the meeting. "We postulate that this loss resulted from the toxic effects of an excitatory neurotransmitter." Other brain regions also thought to be involved in memory were normal.

Interestingly, RB could recall events from the 1940s to the late 1970s as well as or better than control subjects. He remembered public events, famous faces, and TV programs. He also recalled events from his own life without impairment. These abilities distinguish him from other patients, who have retrograde amnesia and have forgotten events backward in time from the brain injury incident. But RB had great difficulty in new learning situations. He could not recall stories, diagrams, or unrelated word pairs presented to him. In these respects, he resembled other patients with amnesia.

Despite their learning impairments, many

A section through RB's brain

Looks normal except for a loss of cells in a small region of the hippocampus (small arrows marked with H on the left and with a large arrow on the right). [*S. Zola-Morgan* et al., J. Neurosci. *6*, *2950 (1986)*]