Medicine and the Bomb

Long-term effects of radiation

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This is the third in a series of four articles giving a medical view of nuclear war. The first two articles dealt with nuclear explosions and acute radiation sickness.

In the context of nuclear power the long-term effects of environmental contamination by radioactive compounds are causing great concern. In the context of war these effects are relatively much less important.

Sources of long-term damage from radiation are twofold. People who have been exposed to doses of radiation from initial early fallout but have recovered from the acute effects may, nevertheless, suffer long-term damage from their exposure. Those who have not been exposed to early fallout, however, may be exposed to delayed fallout; the hazards from delayed fallout are almost exclusively from ingesting strontium, caesium, and carbon isotopes present in food, and the damage caused is relatively unimportant compared with that caused by the brief doses from initial radiation and early fallout.

Around 80% of the radioactive fallout of a ground-burst nuclear explosion descends locally, where its radioactivity decays according to the $t^{-1.2}$ rule. Nuclear explosions high in the atmosphere—airbursts—have less fallout, since of themselves

they produce only the finest radioactive dust, which descends very slowly. The more gradual the descent the greater the proportion of their radioactivity which will have decayed before the fallout reaches the ground.

Delayed fallout

For the inhabitants of countries not attacked directly by nuclear weapons, the fallout that matters is that of long-lived isotopes. Since the particles that reach the troposphere take days to descend and the stratospheric fallout takes years to return to the earth's surface, via the troposphere, the radioactivity of the short-lived products is of no practical importance.

In fact only a few radioactive isotopes are, simultaneously, produced in large amounts by nuclear explosions; have half lives measured in years rather than months or days; and emit substantial amounts of radiation. Some of these are shown in the table.

Major radioactive isotopes

	Half life
Caesium-137	30 years
Strontium-89	55 days
Strontium-90	28 years
Carbon-14	5600 years

How these radioactive isotopes are distributed in the upper atmosphere, how and where they come to earth, and how they behave once they have reached the earth's surface have all been studied in depth from follow-up of fallout from the nuclear tests carried out before the test ban treaty of 1958. Long-lived fission products from these tests reached their maximum concentration in rain and air in the United Kingdom in 1963-4; these same concentrations have now dropped to 1% of the maximum levels.

Particles in the troposphere fall to earth gradually over several months—mainly through the scavenging effect of rain or snow. The tropospheric debris is carried round the earth from west to east, and the bulk of the fallout is confined to a relatively narrow belt centred on the target areas which spreads to a width of about 30° of latitude. Distribution will be irregular because of dependence on winds and rain.

Debris that reaches the upper stratosphere—above 70 000 feet—will be fairly evenly distributed between the hemispheres. Particles that do not reach this height will tend to fall out into the troposphere in the hemisphere where the explosion occurred. The major proportion of stratospheric fallout will reach the earth in temperate latitudes, but otherwise the pattern of fallout is little influenced by where the bombs exploded. The peak deposition would be at latitude 45° (in the northern hemisphere this runs through Portland, Oregon; Minneapolis, Ottawa, Bordeaux, Turin, Venice, Belgrade, the Crimea, Tashkent, and Vladivostock), tapering off towards the Poles and the Equator. Thus the inhabitants of Venice would get the same amount of fallout from 4000 megatons exploded over the United

Fireball of a nuclear bomb detonated under the sea during tests at Eniwetok Atoll.

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Peak deposition of stratospheric fallout in northern hemisphere would occur along the latitude of 45°.

States as from 4000 megatons exploded over the European USSR. The amount of fallout depends partly on latitude and rate of fall on rainfall: the heavier the rainfall the heavier the fallout. Relatively arid countries will receive less than average fallout. The persistence of the radioisotopes once deposited is also, however, dependent on climate and rainfall. Many of the soluble particles would be washed away in surface water, eventually reaching the oceans.

The important isotopes in delayed fallout are caesium-137 and strontium-90. Caesium emits gamma-rays as it decays and once inside the body becomes fairly uniformly distributed. It is, however, excreted within a few months. Strontium-90, on the other hand, concentrates in bone and stays in the body much longer, though its hazard as a source of radiation is no longer thought to be very great because, unlike caesium-137, it does not irradiate the whole body uniformly. These isotopes find their way into the body mainly through incorporation in natural food chains—plants, grass, cattle, milk, butter, cheese—though for strontium-90 each step in the chain reduces the amount of the isotope passed on to the next step. It has been calculated that the debris from many thousands of megatons of fission would have to be added to the stratospheric reservoir before the delayed fallout from these weapons would produce an average concentration in the human body equal to the recommended maximum value for people exposed to strontium-90 occupationally of two microcuries per kilogram of calcium.

Biological effects

Late effects of brief doses of radiation include the formation of cataracts, leukaemia, retarded development of unborn children, and infertility in men. Like the more acute effects these arise from changes in cells induced by radiation.

Some of the bomb survivors in Japan started to develop cataracts about five years later; nearly all of them had suffered loss of hair shortly after the explosion and so had probably received radiation doses of over 300 rads. Much lower doses—about 5% of the LD₅₀ dose (about 450 rads)—induced aspermia in men, which lasted from several months to several years depending on the dose. Among pregnant women there was an increase in the number of stillbirths when mothers had been exposed in the last three months of pregnancy; among those infants born alive there was a slight increase in the incidence of mental retardation if they had been irradiated in the first three months of pregnancy.

These conditions, like the whole-body radiation syndrome, have threshold doses; cancers and hereditary damage do not. Much information on induction of cancer by radiation is available from the survivors of Hiroshima and Nagasaki; another source was the Medical Research Council's study of the effect of radiation treatment of ankylosing spondylitis. Many of the 14 000 patients treated by radiation received cumulative doses of over 1000 rads; they proved to have nine times the normal incidence of leukaemia and 26 times the risk of developing aplastic anaemia. Cancers of the lung, thyroid, breast, and skin also occur more frequently in people who have been exposed to radiation.

The rate of induction of malignant disease has been calculated

to be about 100-200 cases per million people exposed to one rad—5-10% in the survivors of an LD₅₀ dose of 450 rads. This represents an increase in the natural frequency of about a quarter to a half.

The risk of induction of genetic handicap is similar to that for malignant disease. About half such cases will occur in the children or grandchildren of someone whose gonads have been irradiated and the remainder in successive generations.

Overall, therefore, survivors of a major nuclear war face in the long term an increased risk of cancer and hereditary damage; men may be sterile for two or three years, and the numbers of stillbirths may be higher than usual. Their main problems, however, will be non-medical—due to destruction of their environment: shortage of food, loss of energy sources, and the collapse of a high-technology society (including high-technology medicine). These ecological consequences are unpredictable because of the vast number of variables. A major war between the United States and the USSR might devastate the northern hemisphere, destroying its industrial and economic basis. How the nations of the southern hemisphere would react is unpredictable.

This memorial in the Peace Park at Hiroshima was built for the girl on the top, who holds an origami crane. She had survived the bomb at Hiroshima but later developed leukaemia and determined to fold 1000 paper cranes. When she died before completing this number her classmates finished them. Today children with leukaemia from all over Japan fold similar cranes, which are hung under the dome. The photograph was reproduced by kind permission of the Hiroshima Peace Memorial Museum.