

Medicine and the Bomb

Radiation injury and effects of early fallout

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This is the second of four articles on the medical aspects of nuclear explosions. Last week described the blast and heat effects and explained that with modern large bombs significant radiation injury was likely to be due to fallout rather than to the radiation emitted by the explosion itself because most people subjected to the extremely short-lived initial radiation would be killed or fatally injured by blast or fire.

Fallout has acquired a sinister reputation as a long-lived poison. In fact, the earth's surface is exposed to natural radiation from cosmic rays (with a higher dose the higher the altitude, since the atmosphere acts as a shield), from radioactive materials in the soil and air, and from fallout from past nuclear explosions—and this fallout now forms under 1% of total natural background radiation.

In any future conflict one or more nuclear explosions will expose people in the target zone to an immediate surge of nuclear radiation and, if bombs of several megatons have been detonated close to the earth's surface, will threaten people up to 200 miles or more downwind of the explosion with radiation emitted from particles that descend as local fallout. Radioactivity in these particles will decay according to the $t^{-1.2}$ formula (see last week's article). In addition the explosions will deposit some fission products in the atmosphere and residual radiation from this source will add to background radioactivity. It is the radiation emitted at the point of explosion and from local fallout that is important in producing potentially lethal radiation damage to man in the short term; and acute radiation sickness will be discussed here. The long-term effects of radiation in those who survive the acute phase and the effects of the residual radiation deposited world wide will be discussed next week.

Radiation damage

Whatever the kind of radiation— x or gamma-rays, alpha-particles or beta-particles, or neutrons—the final injury to biological tissue is produced by electrons already in the tissue absorbing energy from the incoming radiation. The cellular consequences depend on the actual energy deposited on the sensitive targets in the cell—the nucleus and its genetic material, the chromosomes and genes. Any dose may cause chromosomal damage in a cell; the number of cells damaged increases with the dose. Thus all radiation can cause genetic and chromosomal mutations and all radiation can impair the cell's ability to divide, or even kill the cell outright. The amount of each of these kinds of damage depends on the amount of radiation absorbed in a unit mass of tissue—that is, on the dose. Mutations can never

Measuring radiation

In the immediate surge of initial radiation from the explosion neutrons and gamma-rays are particularly important. Neutrons travel a relatively short distance compared with gamma-rays and quickly disappear after the initial surge of radiation. In the local fallout, too, penetrating gamma-rays account for all practical purposes for the damage caused by whole-body irradiation for people under cover. Those in the open may suffer surface damage from isotopes emitting beta-particles—hence the beta-burns caused to the skin of Rongelap natives after the Bikini explosion. For these articles we shall therefore concentrate on gamma-rays and express radiation in roentgens—a measure suitable for x -rays and gamma-rays. The effect on the human body is related to the amount of energy absorbed in tissue as a result of exposure to radiation, and this is measured in rads. In tissue near to or at the surface of the body an exposure to one roentgen results in an absorption of about one rad—equivalent to 100 ergs/gram.

express themselves unless the cell not only survives but also retains the ability to divide.

The initial radiation from an explosion produces massive amounts of both gamma-rays and neutrons. A one-megaton air burst with half of its yield from fission, for example, produces a dose of 10 000 rads from gamma-rays for anyone on the ground in the open about 2000 yards from the centre of the explosion, which falls off rapidly (according to the inverse square law and attenuation by absorption and scattering of gamma-rays in the atmosphere) to a dose of about 100 rads to anyone about 3300 yards away. For neutrons released from a one-megaton explosion the distance for equivalent doses are 1600 and 2500 yards. Anyone within a mile could, therefore, expect a fatal dose, whereas anyone more than two miles away from the centre of the explosion need not be fatally injured.

The larger and heavier radioactive particles produced by the explosion will fall near to ground zero fairly soon as local fallout. Smaller particles require longer to fall to earth and are taken by winds further away from the point of explosion. The longer particles remain in the air the lower their activity when they reach the ground, but with megaton weapons with a high fission yield the amount of contaminated material is so large that fallout can continue to arrive in hazardous concentrations up to 24 hours. At any given distance from a surface burst there will be an interval before fallout begins to arrive—depending on

distance from ground zero and the wind speed. When fallout first starts to arrive the dose rate is small, but radiation increases as more fallout descends. Once fallout is complete the radioactive decay of the material will reduce the dose rate. For example, at a point in the open 20 miles downwind of a two-megaton explosion with 15 mph winds, the dose rate at one hour is three rads an hour, rising rapidly to over 500 rads an hour between one and two hours. Then it will decrease to 200 rads an hour at six hours and 50 rads an hour at 18 hours. By 18 hours anyone who remains in the open throughout will have accumulated a total dose of 2000 rads—well in excess of the fatal dose for man.

Effects of irradiation

The tissues most sensitive to radiation are lymphoid tissue, bone marrow, spleen, the male reproductive organs, and the gastrointestinal tract. Survival from large brief radiation exposures depends on the damage done to the haematopoietic system. The higher the dose the greater the damage, but if the dose of radiation is spread over weeks or months rather than hours or days the body can tolerate higher doses of radiation, because cellular recovery processes have time to take place while irradiation continues.

The body's responses to radiation delivered over 48 hours or less are shown in the table. Doses of 5000 rads and more cause rapid incapacitation with delirium, ataxia, and respiratory distress and death within a few hours.

Lower doses cause nausea, vomiting, and malaise within a few hours with apparent recovery within 24 to 48 hours. A latent interval of up to two weeks then supervenes, only for symptoms to recur. The higher the dose of radiation the shorter the latent interval and the more severe the recurrent symptoms. Damage to the gastrointestinal tract produces diarrhoea. Damage to the bone marrow causes thrombocytopenia, with bleeding from mucosal surfaces, while the neutropenia increases susceptibility to infection. Even doses well below the lethal range cause alopecia and sterility.

The body's responses to whole-body irradiation in brief doses

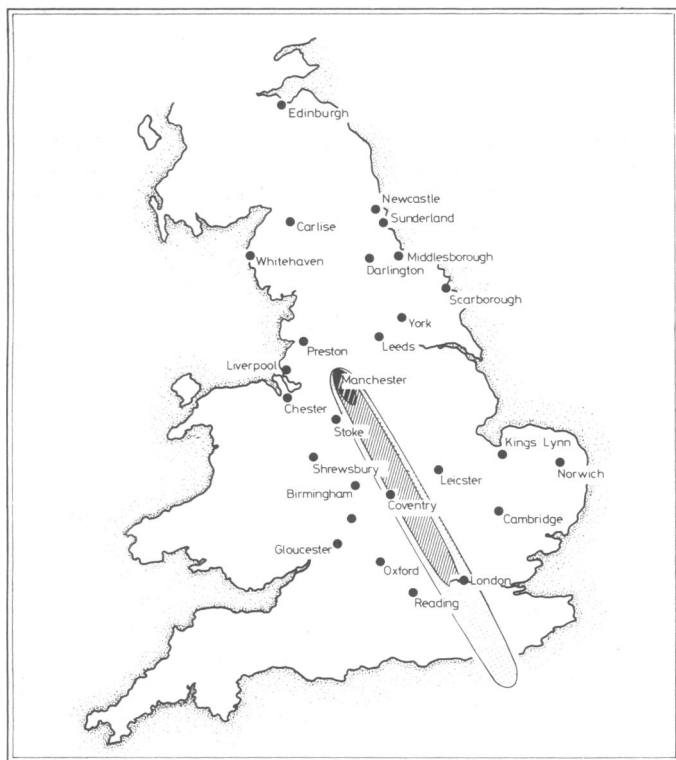
Dose (rads)	Symptoms	Deaths
0-100	Loss of fertility in men at 20-50 rads	0
100-200	Nausea and vomiting in 3-6 hours for less than 1 day. Latent period of up to 2 weeks, followed by recurrence of symptoms for 4 weeks. Leucopenia	0
200-600	Nausea and vomiting lasting 1-2 days. Latent period of 1-4 weeks followed by recurrence of symptoms for up to 8 weeks. Severe leucopenia, purpura, haemorrhage, ? infection; loss of hair above 300 rads	0-90% in 2-12 weeks from haemorrhage or infection
600-1000	Nausea and vomiting starting within 1 hour and lasting 2 days. Latent phase of 5-10 days followed by final phase (same symptoms as at 200-600 rads) of 1-4 weeks	90-100% in 6 weeks from haemorrhage or infection
1000-5000	Nausea and vomiting within 1 hour lasting under 1 day. Latent phase of under 7 days followed by gastrointestinal syndrome with diarrhoea, fever, and disturbed electrolyte balance lasting 2-14 days	100% within 14 days from circulatory collapse
> 5000	Nausea and vomiting almost immediately followed by convulsions, tremor, ataxia, and lethargy	100% in 48 hours from respiratory failure or brain oedema

Treatment

Symptomatic treatment of patients who have received sublethal doses of radiation include fluid replacement until vomiting and diarrhoea cease. If treatment facilities were available transfusions of blood and blood fractions might fend off death for long enough to allow recovery. When only a few individuals need treatment the optimum management includes nursing in a pathogen-free environment until the bone marrow recovers.

Continued exposure

If the dose of radiation is spread over weeks or months rather than hours or days the body can tolerate higher doses of radiation because the cells start to recover while irradiation is continuing. The factor that the British Home Office works on is one of 10 rads a day. Thus if a person has been exposed to radiation for seven days 70 rads (10 a day for seven days) should be deducted from his accumulated dose over that period to determine his



London or Edinburgh? Alternative patterns of fallout from a one-megaton surface burst on Manchester depending on wind direction. Both examples assume a steady wind of 15 mph. The contours indicate seven-day accumulated doses of 3000, 900, 300, and 90 rads to unprotected people. A dose of 450-500 rads will kill about half those exposed to it.

equivalent dose had he received it all in one brief exposure.

Studies on animals show that recovery is enhanced when part of the body is shielded from radiation. A dose of 500 rads confined to the legs is not fatal for man—but there is no practical possibility of an antinuclear breast plate that would protect the vital organs and some bone marrow in an individual exposed to an otherwise fatal dose of radiation.

Other hazards of fallout

Fallout particles are intensely radioactive in the first few hours after a nuclear explosion, and if these particles stay in contact with the skin they can cause burns—so-called beta-burns. These fallout particles would be visible as dust, and people caught in fallout can reduce the risk of burns and lower the amount of radiation received by brushing their clothes or taking them off, combing their hair, and washing any exposed skin.

Apart from external radiation another source of danger would be internal radiation—ingestion of radioactive isotopes in food and drink. Some of these isotopes tend to concentrate in organs where they or elements with similar properties are found normally—examples are iodine concentrating in the thyroid and strontium in the bone. Nevertheless, short-term radiation injury from internal fallout seems likely to be minor compared with the threat from external radiation. There may, however, be delayed effects from internal radiation.

Environmental contamination

Apart from the initial surge of nuclear radiation released by the explosion, which may damage electronic components, in general radiation does not affect inanimate objects; its dangers are to living things. Most domestic animals—irrespective of size—are susceptible to radiation, with dose-response relations similar to those of man. For some reason, donkeys are sometimes unusually sensitive, with a lower lethal dose. In general, therefore, animals—like humans—will either have died or recovered within four to six weeks. Grazing animals caught in fallout will develop multiple beta-burns in their hides and may ingest fallout from eating contaminated grass. Like man, survival of animals is favoured if they are under cover.

Crops that have completed their growth but have not been harvested can generally be made safe to eat, provided any fallout particles are removed. Their ability to germinate if planted, however, may have been destroyed. Sensitivity to radiation is greater in the early stages of growth; even if the plants do not

die, their yield may be substantially reduced. Crops grown on contaminated soil may also have taken up some of the longer lived isotopes such as strontium-90 and caesium-137.

Protection

Protection against fallout is relatively easy to achieve. The two factors that attenuate doses of radiation are distance from the source of the radiation and absorption. The intensity of radiation falls off with distance from the source according to the inverse square law—the dose of radiation received is inversely proportional to the square of the distance from the source of radiation. If fallout particles settle on the roof of the house people downstairs, or, better still, in the basement, obtain a substantial degree of protection simply by virtue of their distance from these particles. They are also given further protection by the degree to which the radiation is absorbed by the materials between them and the fallout particles.

A multistorey block of flats would reduce the dose of gamma rays to its inhabitants progressively from the upper storeys, with 99% protection in the basement. A wooden frame house would reduce the radiation by about half. An ordinary basement would reduce the radiation dose to its inhabitants to a tenth of that on the unshielded surface and if earth was piled against the windows and walls to a thickness of 18 inches the inhabitants could further reduce the radiation to a further tenth (see final article). The shelter would need to contain enough food and water for a fortnight, sanitary facilities, and a simple ventilation system that would prevent fallout particles from entering the basement shelter and allow the air to circulate. To gain maximum protection a family would need to enter such a shelter before any amount of fallout descended.

In practical terms survivors cannot be expected to calculate the radiation dose in the fallout that lands on their homes when they may not know the force, the time, or the place their nearest bomb exploded, the wind force or direction, or the fission materials. (A 10-megaton bomb could deposit fallout with maximum radiation intensity 60 to 70 miles from the detonation.) They will need to be told what dose levels they are exposed to and when it is safe to emerge from under cover, and these instructions will have to be based on actual measurements.

Evacuation is the other possibility—provided the low risk areas can be identified reliably. In regions with consistent winds a position upwind of any nuclear target would be ideal. In countries with multiple potential targets, a high population density, and changeable winds evacuation may not be a sensible option owing to the difficulty of identifying safe retreats and the dangers of populations on the move being affected by fallout.

What is the treatment for bony metastases appearing four years after an adenocarcinoma of the prostate was removed?

In most patients metastatic spread from carcinoma of the prostate responds well to either manipulation with hormones or radiotherapy. Cytotoxic drugs have been tried with some success, but the response is uncertain and they are largely limited to clinical trials. If we assume that initially there was no treatment other than the removal of the adenocarcinomatous gland and that the patient is now suffering symptoms from the bony metastases then a bilateral orchidectomy often rapidly relieves symptoms and apart from the risks of the anaesthetic and the psychological aspects is safe and effective. If the patient had been taking stilboestrol then the effect of orchidectomy may be less helpful or possibly of no benefit. Stilboestrol in doses of 1 mg three times a day remains unsurpassed as the most effective drug in metastatic prostatic disease. Because it tends to produce retention of fluid and cardiovascular problems, such as venous thrombosis and pulmonary embolism, it is now often kept for metastatic problems and not given in the early stages of the disease. Radiotherapy to localised areas of bone pain is well worth while and will give many months of symptomatic relief. If the metastases

are found on routine follow-up and are without symptoms many clinicians would still treat them in the belief that the treatment will increase the period before symptoms occur and that possibly treatment will prolong life.

Can a child catch whooping cough twice? If so is it worth immunising a child who has had pertussis?

It is exceedingly unlikely that a child will develop whooping cough due to *Bordetella pertussis* twice; but the difficulty is that a whooping-cough-like illness may also be due to *B. parapertussis* or *B. bronchiseptica*, or to a wide variety of other organisms (mentioned in a series of *Communicable Disease Reports*); they include *Mycoplasma pneumoniae*, coxsackie virus, echovirus, cytomegalovirus, influenza B virus, rhinovirus, parainfluenza, respiratory syncytial virus, and the adenovirus; the list is ever growing. Possibly therefore a child may get a whooping-cough-like illness twice. The difficulty is that in nearly all cases of clinical whooping cough the organism is not isolated but probably most are due to the *B. pertussis* organism.