EFFECTS

Radiation casualties in a nuclear war

from Patricia Lindop, Joseph Rotblat & Philip Webber

Calculations of the effects of nuclear explosions over London suggest that the proportion and absolute number of radiation fatalities are higher than previously estimated. They are sensitive to the value of LD_{50} assumed for people, but the number of total casualties, deaths plus injuries, is practically independent of the LD_{50}.

THE several recent calculations of the numbers of casualties likely in a nuclear war differ widely in their estimates of casualties caused by radiation, both absolutely and relative to other major causes of death or injury, the blast wave and the heat pulse. The ratio of radiation to blast deaths has been variously estimated as 6 per cent[1] or 86 per cent[2]. Part of the discrepancy arises from the different assumptions made about the protection afforded by buildings, part from the relationship assumed between the radiation exposure of individuals and the risk of mortality.

In calculations of the consequences of nuclear war, the choice of a value for LD_{50}, the radiation dose causing 50 per cent mortality in human beings, seems to be somewhat arbitrary. Indeed, there are very few data on which to base accurate estimates. Such information as there is derives from radiation accidents in peacetime, with victims receiving first-rate medical care. The experience in Hiroshima and Nagasaki has not so far been used in this respect, but clearly in the aftermath of a nuclear war the radiation mortality would be much greater than in peacetime.

Here we consider two cases — a single one-megaton bomb in a ground-burst on a major city (we have chosen London so as to work with a known population distribution) and the explosion of several thermonuclear weapons on the periphery of a major city. The first case is probably an unrealistic representation of nuclear war, but is simple to calculate and easily translated to other circumstances. The second is the London component of the 1980 'Square Leg' exercise of the British Home Office. We also consider the effect of sublethal exposures in the two cases.

Single bomb

We first assume that a one-megaton bomb (half-fission, half-fusion) is exploded 580 metres above the centre of London. For such a detonation, the fireball would touch the ground, giving rise to local fall-out. Before calculating the effects of the latter, the deaths due to the heat and blast waves in a given area have to be subtracted. Those due to the initial neutrons and γ rays can be ignored, since they occur within the lethal area of the blast effect. Using a procedure suggested by the US Office of Technology Assessment[3], we have calculated that the total number of fatalities from heat and blast would amount to 560,000 out of a London population of 7 million.

For the estimate of fall-out casualties, we have assumed a steady southerly wind blowing at 24 kilometres per hour, and zero wind shear. We have ignored the effects from the inhalation and ingestion of radioactive materials, but have considered only the γ rays from the fission products after their deposition on the ground. A terrain shielding factor of 0.7 was applied to allow for roughness of the surface. Under the postulated idealized atmospheric conditions, the contours for constant dose-rate could be assumed to be ellipses with dimensions deduced from the formulae given by Glasstone and Dolan[4]. In combination with the population densities in the individual London boroughs, we were thus able to calculate the numbers of people receiving a given dose in a specified time under stipulated exposure conditions. From the sigmoid-shaped curves relating mortality to radiation dose, we then calculated the number of fatalities for the various parameters in our scenario.

We have chosen four values of the LD_{50}, to cover the likely range, namely 3,4,6 and 8 gray, these being tissue doses at the surface of the body. For each LD_{50} value we calculated the casualties for four values of the protection factor (PF) — 1, 5, 10 and 20. The first of these refers to the case in which people remain in the open during the whole period of exposure. In war scenarios described in the literature, a protection factor of 5 is often used as an average value for city populations. We have also calculated the effect of receiving the exposure in one day and over 7 days. The latter is the period during which the accumulated dose is nearly equal to the infinity dose, although if people in shelters with a high PF emerged after 7 days, they could still accumulate a large dose if they subsequently remained in the open. A one-day exposure is of relevance in conjunction with a PF of 1; if the bomb were part of a surprise attack, many survivors of the heat and blast effects would be disoriented — some would try to get home, others would try to leave the city, but it might take a day to find an uncontaminated area or a shelter.

Table 1 contains the results of the calculation of radiation fatalities following a 7-day exposure. The numbers have been rounded off to the nearest 10,000; greater precision is not warranted. There is more than a 10-fold difference in the number of fatalities between the lowest and highest values of the parameters used. But the main point to note is the large absolute number of deaths. At the conditions most often assumed in the literature, LD_{50} = 4 Gy and PF = 5, the radiation deaths come out to be the same as the total from blast and heat.

Operation Square Leg

In September 1980, several British government departments conducted an exercise, code-named Operation Square Leg, as part of the NATO Crusader exercise, to evaluate the effects of a nuclear attack on Britain. In this exercise, 125 nuclear weapons with a total yield of about 200 megatons were assumed to have been exploded. We analysed the effects of four of these bombs exploded on three targets, all within the Greater London Council (GLC) area but on its periphery. Three of the weapons were assumed to have detonated at ground level, namely at Heathrow (1 Mt), Brentford (2 Mt) and Croydon (3 Mt). Heathrow was also subjected to a 2-Mt weapon detonated at a height of 3.6 km, producing heat and blast casualties, but no local fall-out (Fig. 1).

Out of the initial London population, 1.08 million deaths from blast and 0.27 million from heat were subtracted before calculating the effects of radioactive fall-out. The atmospheric conditions were assumed to be the same as in the case of a single bomb. The calculation of radiation casualties was carried out, using the same methods as described earlier, for LD_{50} values of 4 and 8 Gy, protection factors of 1 and 10 and exposure duration of 7 days.

The calculated numbers of radiation fatalities are: at PF = 1, 3.75 and 3.26 million for LD_{50} values of 4 and 8 Gy. The corresponding values at PF = 10 are 1.91 and 1.09 million. Again, the large absolute number of radiation deaths is noteable. Even though one of the four bombs did not contribute to the fall-out, the interpolated value of radiation fatalities at the typical

Table 1 Radiation fatalities after 7-day exposure (thousands)

LD_{50} (gray)	Protection factor 1	5	10	20
3	1,870	680	420	270
4	1,580	550	340	210
6	1,270	420	270	160
8	1,050	340	210	140

The numbers in this 4 × 4 matrix fit a simple empirical formula: $N = 4 \times 10^6 (PD)^{-2/3}$, where N is the number of radiation deaths, P the protection factor and D the LD_{50} value in gray.

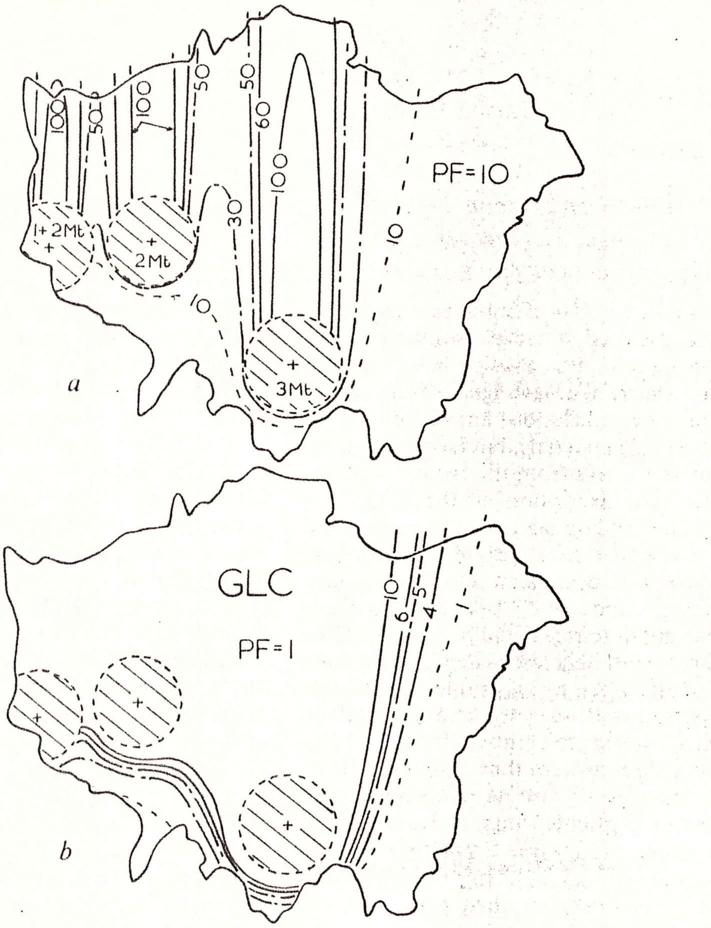

Fig. 1 Dose contours for the GLC area in the Square Leg attack for *a*, PF = 10 and *b*, PF = 1. The numbers on the contours give the total dose, in gray, accumulated in the open after a 7-day exposure. The contours correspond to mortality levels of 90% and 10% for LD_{50} values of 8 Gy (solid lines) and 4 Gy (dash-dotted lines). The contours with dashed lines show the extent of radiation injuries as defined in the text. The shaded circles are the lethal areas for the blast effect.

conditions (LD_{50} = 4 Gy; PF = 5) is twice the number of deaths from the blast effect, although the contribution from blast would have been relatively larger if the centre of London had been a target.

A comparison with the number of fatalities in the one-megaton case shows that, per megaton, the effect of the multiple explosions is less than for a single bomb. This is mainly due to the truncation of the contours at the GLC boundary. With the bombs being exploded near the peripheries, many radiation casualties would occur outside the boundary, particularly at low values of the protection factor. For a PF of 10, when the relevant dose contours occur closer to the epicentre, the number of radiation fatalities approaches the theoretical value (6 times) found in the single bomb case.

Radiation injuries

Apart from radiation fatalities, we have also considered the group of casualties represented by people who received sublethal doses of radiation. Under peacetime conditions, these people would have been expected to survive, by definition. But in wartime there is likely to be a high mortality in the group.

Exposure to sublethal doses gives rise to the prodromal syndrome characterized by a number of gastrointestinal and neuromuscular effects. Some of the symptoms occur even at doses below 1 Gy, in a small proportion of people exposed. On the whole, a dose of 1 Gy may be considered the threshold for the prodromal syndrome.

The main effect of sublethal exposure that may lead to death is the damage to the haemopoietic system. The dramatic reduction in the number of blood cells after such exposures is well documented. Increased susceptibility to respiratory infection has also been reported. In addition to the weakening of local defences, exposure to sublethal doses causes temporary breakdown of an organism's general defences, leading to various types of bacteriocaemia and septicaemia.

In the immediate aftermath of the war, there will be large numbers of people with mechanical injuries, fractures, lacerations and concussions from the blast effect, as well as burns of various degrees of severity from the heat wave and fires. In the absence of adequate medical care and medicaments, these people will depend for survival on their natural resources, and in particular on the effectiveness of their immune responses. But if these have been impaired by exposure to radiation, the chances of survival would be greatly reduced.

Even people who have escaped injury or burns will be much at risk. Confined to indoor living, with little ventilation, extremely poor sanitary conditions and, probably, deprived of adequate food and drink, many people will develop bronchial or gastric disorders. The damage to their immune system, caused by exposure to radiation, would aggravate the situation and in many cases contribute to death.

Conclusions

For the reasons stated, exposure to sublethal doses should be considered as contributing to radiation fatalities, and the number of people exposed to doses above 1 Gy added to the toll of radiation casualties. By our definition, the total number of casualties, or of fatalities plus injuries, is constant for a given PF and independent of the LD_{50} value.

For a single bomb on London, this total comes to nearly 3 million for exposure in the open. Even with a protection factor of 20, the total number of radiation casualties would be more than half a million, whatever the LD_{50} value. In the Square Leg Exercise, total radiation casualties in the London area would be 4.5 and 3.1 million at the two PF values, but the great majority of people receiving sublethal doses in the open would be outside the GLC area.

When extrapolated to an attack on the whole of Britain with 200 megatons, and assuming an average PF of 5, most of the survivors of the heat and blast effects are likely to be radiation casualties.

In a recent article, Teller[5] stated that the effects of fall-out have been overestimated. Our calculations show that this is certainly not the case in relation to local fall-out. It is probably also not true in relation to the intermediate fall-out as appears from recent reports from the Livermore Laboratory[6,7]. With the likely use of nuclear warheads in ground bursts on military targets, and the lower yields of modern weapons, both local and intermediate fall-out become of great consequence. □

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