MEDICAL ASPECTS OF ATOMIC WARFARE*

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In future wars we face the certainty of unconventional methods of warfare, including attack with nuclear weapons. Basically a nuclear explosion is a chain reaction in which matter is converted into energy. The energy which is released creates immediate and residual hazards to life on an unprecedented scale and has consequently given rise to a series of new concepts concerning the medical aspects of nuclear warfare.

Despite the fantastic powers of destruction of nuclear weapons a great deal can nevertheless be done about surviving such an attack provided the population in general and the organized medical services in particular are well informed on what to expect and how to deal with the threat of the various effects of an atomic or thermonuclear bomb attack. In a military sense the hydrogen bomb is just another and bigger weapon designed primarily for its blast effects. Despite its awesome power, its immediate effects are essentially localized, in the sense that it initially effects only a few square miles around the point of detonation. Survival on an individual level is in fact possible, even very close to the bomb's point of detonation, provided reasonable precautions are taken beforehand. A realistic appreciation and knowledge of what the bomb can do and what it cannot do is in fact the first step to survival.

From the strictly medical point of view the injuries sustained by casualties in such an attack are mainly conventional in nature, but are overwhelming in numbers. Injuries are conventional in the sense that like any blast weapon the atomic detonation will occasion a certain energy release, which if inflicted on unprotected human beings will cause the multiple lacerations, haemorrhages, fractures, burns, etc. with which the medical services have become familiar in previous wars. The only additional casualty-producing factor of importance in attacks with nuclear weapons is the matter of ionizing-radiation injuries, but it must be remembered that in the attacks on the Japanese cities of Hiroshima and Nagasaki only approximately 15% of the total casualties were due to this factor.

* A paper presented at the South African Medical Congress, Durban, September 1957.

The critical problem for the medical organization in nuclear warfare will be the fantastic number of casualties which by sheer weight of numbers will totally disrupt even the most extensive medical organization created to deal with such an emergency. Added to this is the unpleasant fact that when a strategic megaton weapon is delivered on any important population centre it may at the moment of explosion eliminate existing medical facilities, like hospitals and treatment centres, in addition to destroying the transport system. The massive size of the problem is emphasized by the fact that even the relatively small 20-kiloton atom bombs exploded over the Japanese cities were each responsible for between 60,000 and 80,000 casualties. The so-called nominal atomic bombs of 20 kilotons are equivalent in energy but not in effect to 20,000 tons of TNT. They pale into insignificance beside today's 20-megaton hydrogen bomb, where 1 megaton is equal in energy to 1,000,000 tons of TNT. In other words if the equivalent of 20,000 tons of TNT can cause 60,000 to 80,000 casualties, imagine what the equivalent of 20,000,000 tons of TNT will do to any high-density population centre!

In military terms the problem can be stated quite simply. In World War II it took thousands of bomber aircraft 4 years to deliver an estimated 2·3 million tons of TNT. In the next war a single aircraft on one sortie could deliver the equivalent of 10 million tons of TNT. Hence the formula for World War III—one bomb plus one aircraft equals one city.

In medical terms the answer to the problem, at least in part, is the employment of sub-professional personnel—sub-professional in the sense that it includes anybody and everybody inside the medical and allied professions or in any organization outside, or any private individual whatever who has some knowledge or prior training in the principles and practice of life-saving, first-aid techniques or elementary nursing. It is conceivable that in a city demolished by an H-bomb, qualified medical personnel may be eliminated, together with most, if not all, existing medical facilities, so that the casualties cannot depend on being rescued and given conventional medical treatment by doctors in hospitals. Treatment of mass casualties will for the most part have to be given on the spot by whoever is able to give any treatment whatsoever and not be deferred by hopefully waiting for medical assistance which may not be forthcoming. Great reliance will consequently have to be placed on the services of such sub-professional personnel. The adequate instruction of volunteer aid detachments during peace-time in the special techniques of mass casualty treatment therefore becomes the best possible insurance against a catastrophic fatality rate.

Another new concept in nuclear warfare is that of *triage*, whereby available medical officers will in the first instance be employed in casualty selection, rather than for casualty treatment. With the overwhelming number of casualties expected and the certainty of inadequate facilities and medical supplies, the task of categorizing the casualties into priority groups falls very heavily on the professional personnel. Not only must the doctor distinguish the obviously moribund, but he has to modify normal treatment priorities for other groups of injured by devoting the most of his limited facilities and help to those groups where it will do the most good. These groups may not, however, be the most seriously injured, because in general the prognosis for such cases is uniformly poor. A harsh reality may thus force him to turn from cases which he would otherwise have treated first. This responsibility of deciding who is to fall into this unfortunate group of the 'living dead' and forego other than strictly palliative treatment so that others may live can obviously only be vested in responsible qualified medical personnel. Their task is further complicated by the fact that many of the casualties who may have apparently minor injuries may in fact have absorbed a fatal dose of radiation and are doomed to die days or weeks later.

Whilst the collection and classification of casualties is proceeding under the direction of the medical officer, preliminary treatment must be initiated by the sub-professional personnel to the best of their ability. Only afterwards will the doctor turn to his secondary task of actively treating the casualties. This revolutionary new medical concept is forced on us by the grim realities of nuclear warfare, because when one is faced with anything up to 200,000 casualties in a large city a handful of doctors with limited facilities cannot do very much by themselves, particularly if it is borne in mind that a single surgeon is limited to no more than 12 serious cases per day.

Military medical units are being reorganized to meet the threat of nuclear warfare. In such warfare, no longer would fighting be limited to more or less clearly defined front lines, but nuclear-weapon attacks on strategic areas would involve large sections of the general population. The established evacuation sequence from the regimental aid post at the front lines to the base hospital at the rear will be something of the past and so will the medical field-ambulance units of recent wars. The emphasis will be on highly mobile self-contained casualty collecting and staging units who can be flown into disaster areas in large transport aircraft from the unaffected regions where they are held in reserve. These airborne units are completely self-dependent and are equipped with and capable of erecting and operating thousand-bedded tented hospitals within a matter of 4 hours after their arrival on the scene. These mobile hospitals represent the only practical solution to the problem of providing adequate treatment facilities in disaster areas for the mass casualties of nuclear warfare.

EFFECTS ON MAN OF NUCLEAR EXPLOSIONS

The main characteristics of nuclear explosions may conveniently be dealt with under the headings: (1) flash blindness, (2) thermal effects, (3) blast effects, and (4) ionizing-radiation effects.

1. *Flash Blindness*

The bomb explodes in the shape of a fireball emitting a flash of light of fantastic intensity. An inadvertent glance at the flash will result in a temporary blindness lasting up to 15 minutes. This temporary blindness, although not in itself a serious medical problem, may cause undesirable psychological reactions, particularly if its temporary character and the completeness of recovery have not previously been explained to those affected by it. This temporary blindness may have military significance because the affected men will be unable to defend themselves or move about safely whilst it lasts. Flash blindness cannot be avoided by wearing dark glasses such as would permit daylight vision. Individuals unwise enough to gaze steadily at the fireball may suffer permanent blindness as a result of retinal burns.

2. *Thermal Effects*

The glowing ball of fire emits radiations in the entire electro-magnetic spectrum, including ultra-violet and infra-red. Because of its instantaneous transmission and considerable range, this emission of heat is by far the most potent casualty producing factor; in Japan it was responsible for at least 50% of the total casualties.

Thermal radiation effects are classified according to the mode of production into primary, or flash, and secondary or flame, burn. The clinical manifestations of these burns, however, are in all respects, similar to those caused by conventional high-explosive weapons and do not demand other than conventional treatment. The severity of the flash burns are directly related to the distance from the explosion and to the existing atmospheric conditions, but they are modified by shielding and shading of interposed structures and by the angle of incidence. It has been determined that for a nominal 20-kiloton weapon exposure of the skin to 3 calories per sq. cm. at approximately 4,000 yards will result in second-degree burns, whilst an increase in incident thermal energy to 5½ calories per sq. cm. at 3,000 yards will result in third-degree burns. The thermal energy varies with the total weapon yield, so that with a 1-megaton weapon, for instance, third-degree burns will be sustained up to 14,700 yards from ground zero. In other words, the H-bomb has a scaling factor of approximately 11 in relation to the A-bomb.

Secondary, or flame, burns are caused by actual burning of the clothing. Dark-coloured clothing absorbs heat and transmits it to the body, or bursts into flame. It is to be noted that 9 calories per sq. cm. is required to ignite cotton and 14 calories per sq. cm. to ignite wool. In Japan these secondary burns were responsible for many fatalities, especially in casualties who were so injured by secondary blast effects that they could not escape.

The treatment of burns will undoubtedly be the biggest problem for the medical services immediately after a nuclear attack, because burn treatment requires a high level of surgical and nursing skill and because it necessitates the extravagant use of sterile and other dressings, which will most certainly be in desperately short supply. Unshielded persons will sustain a large number of burns, involving exposed body surfaces, particularly the hands and the face. This is particularly significant from a military point of view as such troops so affected will be unable to handle their weapons for periods from days to weeks. Initial treatment should consist of occlusive sterile dressings and sedation as required and available. The important life-saving consideration is the evacuation to medical facilities like the thousand-bedded emergency hospital mentioned above where surgical techniques and extensive supportive fluid replacement treatment is available. Treatment in such medical units will be required for burns involving more than 18% of the total body surface in adults or more than 5% in children or more than 9% in the aged. For lesser burns treatment will of necessity have to be on a self-help or mutual-aid basis. Extensive research is in fact being conducted for the development of such self-treatment methods and materials which will lead to efficient mass therapy.

In Japan, lack of adequate treatment led to improper healing of burns, and common sequelae were contractures and keloid formation. Such contractures are, however, by no means a particular feature of atomic burns, and keloid formation is more likely a function of pigmentation than exposure to atomic flash.

3. *Blast Effects*

Blast effects are also divided into primary, or direct, blast effects and secondary, or indirect, effects which are mainly due to flying debris behaving like dangerous, secondary missiles. In Japan, blast effects were responsible for an estimated 35% of the casualties but, contrary to expectation, the primary blast effects have but little significance as a casualty-producing factor. It has been determined that the primary shock wave lasts for approximately one second, which is much longer than with conventional high-explosive weapons. The shock wave thus becomes in effect an extremely violent wind, having an initial velocity in excess of 700 miles per hour. A nominal atomic bomb explosion will produce peak overpressures in excess of 3 p.s.i. up to 1½ miles from ground zero, which is enough to demolish all ordinary residential constructions. However, pressures in excess of 100 p.s.i. are required to cause significant internal blast damage to the human body but, with a nominal atomic bomb such primary blast pressures are not attained even at ground zero.

The secondary blast effects, however, are prodigious casualty-producing factors, particularly in built-up areas where masonry, glass, and virtually every displaceable object, will be blasted to speeds of 700 miles per hour, so causing multiple contusions, lacerations and fractures. Once more, the injuries are conventional and the treatment is largely conventional, but the fantastic number of casualties and the number of such injuries to individual casualties are on a scale seen only in this type of disaster. The only additional points for consideration are the possibility of concurrent radiation injury and its effects on priorities and prognosis and the possibility of contamination of wounds with radio-active material, which must first be detected and then removed by excision.

4. *Ionizing-Radiation Effects*

The only factor not present in the high explosive weapon is that of radiation. The effects of ionizing-radiation injury in the attacks on Hiroshima and Nagasaki were directly responsible for less than 10% of the total casualties. Despite its statistically minor role, radiation effects nevertheless warrant extensive investigation, both because of the fact that ionizing radiation complicates an estimated 25% of blast and heat injuries, and because of the profound reaction, both mental and physical, of casualties to the immediate and the residual effects of radiation.

Various types of ionizing radiation are given off at the moment of detonation of a nuclear weapon and continue to be emitted by the radio-active substances inside the characteristic mushroom cloud. Of these electro-magnetic emissions, gamma rays with their very short wave-length and high penetrative power, plus the shower of spare neutrons travelling at high speed, are the most important in causing ionizing-radiation injury.

These initial radiation effects are however strictly localized to the area surrounding the bomb burst. Following a nominal A-bomb explosion no immediate radiation effect is transmitted further than approximately 2,000 yards from ground zero. Although the intensity of radiation will cause 100% fatal casualties up to approximately 1,200 yards, the thermal effects of an A-bomb will cause 100% fatal casualties up to approximately 1,400 yards, so that for the exposed personnel the additional hazard of a fatal dose of radiation at ranges of less than 1,400 yards is of academic interest only. A significant number of initial radiation casualties will thus be caused mainly in a narrow zone between approximately 1,500 and 2,000 yards. The same relation holds good for the larger megaton weapons, where the combined effect of heat and blast will ensure destruction of a target and 100% fatal casualties at ranges far exceeding that attained by immediate nuclear radiation.

The residual radiation effects arising from within the contaminated area of the bomb burst, and as a result of the fall-out phenomenon, constitute a much more formidable hazard. This is not only because it extends further afield, but also because, in addition to gamma rays, the unfissioned weapon material produces alpha particles with a very long half-life, and the fission products, which constitute approximately 200 artificial radio-active isotopes, produce beta particles. The radio-active substances which rush upwards in the atomic cloud may be either dispersed or diluted in the upper atmosphere so that no serious hazard results, or they may be deposited at varying distances down-wind from the site of the explosion, producing a further contamination hazard, mainly from the alpha- and beta-emitting dust. The fall-out dust has a short range and poor powers of penetration and is therefore not an important external hazard, but it is a vitally important internal hazard when it comes into intimate contact with the tissues.

Ionizing-radiation injury to the tissues, whether caused by immediate or residual radiation, depends basically upon the absorption of the energy of the radiation concerned by the tissues exposed. This transfer of energy occurs as a result of ionization, although the exact biophysical and biochemical reactions have not yet been satisfactorily delineated. Although gamma rays, and alpha and beta particles, and neutrons, each produce ionization by different mechanisms and to different degrees, the end result of the energy absorption is destruction of the tissues involved. This is not specific for any given type of radiation, or even for radiation itself. The destructive effect depends on the relative radiosensitivity of the tissues involved. In general a great radiosensitivity is found in tissues which are relatively unspecialized or exhibit rapid multiplication and active reproduction, whilst highly differentiated tissues and those in a quiescent state of development are relatively radio-resistant.

The degree of radiation injury depends not only on the total dose and on the dose rate, but it also involves the spatial relationship between the tissue and the radiation source; in other words, the range, penetration and absorption of the various emissions. For example, alpha particles produce intense ionization, but their range is such that they are stopped by the cornified layer of the skin and they thus present no external hazard. But if they are ingested or inhaled and subsequently deposited near vital tissues, their short-range emissions cause considerable long-term damage. High-energy gamma rays, on the other hand, have far less ionizing power than alpha particles, but their high powers of penetration make gamma emitters the major external hazard.

Clinically, the ionizing radiations give rise to the symptom complex of radiation sickness. Following exposure to acute radiation the symptoms of anorexia, nausea and vomiting usually appear after a variable period of hours, depending on the dosage received. These primary effects last 2-3 days before resolving spontaneously. A second latent period then intervenes and the casualty may feel no apparent ill-effects for a matter of days before the symptoms of the secondary effects supervene. This latent period is inversely proportional to the degree of radiation exposure and is a good clinical yardstick for the ultimate prognosis of the individual concerned. With lethal doses the latent period may become very short or even disappear, and death may occur before the full picture of radiation sickness develops. The secondary effects, which may be delayed for more than 2 weeks, similarly commence with anorexia, general malaise, nausea, vomiting and diarrhoea. Soon epilation starts, followed by mucosal ulceration and the secondary haemorrhages of a profound aplastic anaemia. The blood picture shows a progressive lymphocytopenia, accompanied by a simultaneous granulocytic leucocytosis, a reduction in the platelet count, and diminished erythrocytes.

At this stage the condition either goes into the terminal phase and death follows a period of hyperpyrexia and secondary infection, or a very slow recovery takes place, complicated by a 10% residual effect and a higher susceptibility to pathological changes.

The severity of radiation sickness naturally depends directly on the dosage absorbed. If from 50 to 200 r. are absorbed only mild symptoms will develop, several days afterwards, and it will not kill. Dosage between 200 and 500 r. cause moderate to severe symptoms to develop after a few hours. A dose of 200 r. moreover, is regarded as a critical dose which, if complicated by heat and blast injury, will give the individual a poor prognosis. At 450 r., 50% fatal casualties are to be expected. In the third dose range —from 500 to 700 r.—hyperacute symptoms will develop. In fact, above 600 r., 100% fatal casualties will occur within 10 days.

Whilst the genetic effects of immediate radiation have undoubtedly been over-emphasized, the probability of producing a mutation with a single ionizing exposure does nevertheless exist.

Besides these initial radiation effects at the time of the bomb burst, prolonged exposure to the effects of residual radiation may have equally serious and fatal results. The fall-out area of a 10-megaton hydrogen bomb will extend down-wind for approximately 250 miles and anybody exposed continuously for 36 hours in the open will receive a radiation dose varying from 5,000 r. 10 miles from ground zero, to 300 r. at 200 miles. In addition to the obvious danger of exposure in a contaminated area down-wind from the explosion, the undetectable inhalation or ingestion of radioactive particles deposited by the fall-out phenomenon on a world-wide scale following a high yield thermo-nuclear explosion represents a critical problem for virtually everyone on earth.

More than 200 radio-active isotopes are produced in every nuclear explosion, and all are potentially harmful. They range from the short-lived isotopes like iodine-131 and strontium-89, with a half-life of a few days, to caesium-137 and to strontium-90, which has a half-life of 28 years. Although none of these artifically radio-active isotopes existed in the pre-atomic age, it is a disturbing thought that following nuclear test explosions their distribution is today universal, and traces are to be found in the bodies of virtually all human beings.

Long-lived strontium-90, a beta-emitter, is particularly feared, because of its high yield in atomic explosions, its long biological half-life of 7½ years, and the fact that, like calcium, it enters the soil-plant-human cycle and is subsequently deposited in bone. Here its beta-particle emissions may cause bone tumours and sarcomas, as well as leukaemia. A recent American survey by Kulp *et al.* for the U.S. Atomic Energy Commission showed that present-day human beings had an average of 0·12 micromicrocuries per g. of body calcium, and that it was expected to reach an ultimate concentration of approximately 2 micromicrocuries in the foreseeable future if nuclear test explosions proceed at the present rate.

The critical problem facing us is to assess the extent of the hazard represented by any given amount of strontium-90 in the bone. It has been determined that, for people occupationally exposed to radiation from radium sources, the maximum allowable body burden of strontium-90 is 1,000 micromicrocuries, which is 500 times the average dose resulting from the test explosions. If such a dosage holds true for radio-active strontium-90 from the nuclear bomb explosions, there does not appear to be much cause for alarm. But it must be borne in mind that the allowable exposure level must be considerably lower for the foetal, neonatal and adolescent elements, who are far more sensitive to the detrimental effects of radiostrontium than the general population.

Divergent views are at present held by eminent authorities on this problem. Some incline to the view that a threshold value exists for the concentration of strontium-90, giving it a safe latent period, whilst other equally well-known authorities regard the formation of malignancy in bone as a linear function of radiation dosage. If there is such a threshold level for the carcinogenic effect of strontium-90 deposited in bone, then it is reasonably safe to predict that the relatively low levels which will accumulate in bone as the result of current hydrogen-bomb tests will not be deletrious, seeing that it represents approximately only 1/500th of the maximum permissible body burden of radiostrontium. On the other hand, if one takes the worst possible view and regards the dosage and effects as bearing a linear relationship, so that each unit quantity of strontium-90 absorbed will confer a certain probability of bone-tumour formation, the position is indeed serious. It has, for instance, been calculated that if this is the case one high-yield magaton explosion may result in the ultimate formation of 20,000 bone sarcomas throughout the world.

The generally accepted view is that in the present state of knowledge any such theories are to be accepted only with reservation. However, Dr. Masao Tsuzuki, Director of the Red Cross Central Hospital, Tokyo, echoes the views of many medical men when he says: 'I do not believe that strontium-90 will be permanently harmful at its present level, but if experimental explosions continue at the present rate, there will come a time when the human body will be seriously harmed. It will then be too late to do anything about it!'

The author is indebted to Brig. J. H. Rauch, Surgeon General of the U.D.F., for permission to publish this paper.

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