SOME MEDICAL ASPECTS OF ATOMIC WARFARE

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WHILE recent newspaper articles have stressed various possibilities of Atomic Warfare, there is still a widely held belief that nearly all aspects of this subject are shrouded in secrecy. Some of the unclassified material which is now available is to be found in the references at the end of this article and it is hoped that this may be of some use to those who wish to study the subject further.

Atomic warfare of the future may involve the use of much more powerful weapons than have so far been demonstrated [28]; but the information collected in Japan and obtained by experiment and clinical study will help to guide the preparations which must be made for such a disaster. The various effects which may be met in atomic warfare can all be studied in peacetime although on a somewhat reduced scale. Burns of all types are only too much with us and wounds of all types had been encountered for a long time before 1945. Many years separate the first radiation burns from those reported by Knowlton and others at Eniwetok [34]. Acute effects of total body ionizing radiation are discussed by Tsuzuki [48] in a paper which appeared some twenty years before his report on the Hiroshima cases.

The explosion of an atomic bomb can liberate an enormous amount of energy in an extremely short period of time [47]. The final effect will depend on the efficiency of the weapon and the conditions under which it operates; but in all cases the injuries produced can be grouped under the following three headings:

(1) *Mechanical Injuries.*—Due to blast, wounding by secondary missiles and crushing by falling debris.

(2) *Thermal Injuries.*—Flash burns, scorch burns, contact burns and burns due to secondary fires.

(3) *Radiation Injuries.*—(*a*) Produced by penetrating radiations and neutrons from the bomb or

(*b*) By radiation from radioactive substances. These substances may be fission products, unexpended fissionable material or substances made radioactive by neutron bombardment. Unlike the radiation associated with the explosion, that from radioactive substances (including those used as "poisons" in a manner similar to C.W. agents [35]), continues to be effective for an appreciable period of time. Besides penetrating gamma radiation, the effects of α and β particles must also be considered, especially when radioactive substances enter the body.

Mechanical Injuries.—These caused the bulk of the Japanese casualties. They did not present any unusual features although, in certain cases where radiation sickness developed, slight wounds were said to break down and there was an increased tendency to gangrene. Among the survivors it was rare to find ruptured ear drums or other evidence of blast injury [30, 54]. Those subjected to very severe blast effects were usually "killed thrice over" [53]. Collapse of buildings caused the highest proportion of indirect injuries and indeed of all injuries. Fractures and the usual sequelæ of crushing were frequently met. Injuries from shattered glass were, according to the Japanese, too many to be counted. Windows were broken up to 12½ miles from the bomb [53].

In one series of Japanese cases where burns and trauma accounted for 85 per cent of the casualties, it was found that 34·7 per cent of the traumatic cases were lacerations, 53·8 per cent contusion and 11·5 per cent more serious trauma —fractures, etc. [6]. Outside a three-mile radius there was a rapid falling off in mechanical injuries.

Burns.—In the case of an atomic explosion an enormous amount of energy is released as heat and radiated over a wide area. Where the bomb bursts at a sufficiently low altitude the heat may be sufficient to fuse tile surfaces [54].

People who were directly under the explosion were said to have had the exposed skin charred [53]. In some cases there were what Tsuzuki described as blast heat effects where corpses were found with charred skin ripped and hanging in fragments.

Most cases of burns surviving long enough to receive medical attention were relatively superficial flash burns. In such cases light shielding from clothing, etc., gave adequate protection and only directly exposed surfaces were burned [9]. Shadow effects were commonly encountered. Depigmentation and hyperpigmentation as in the "mask of Hiroshima" were among the heat effects [6]. In the Japanese cases poor and inadequate treatment intensified the plight of the casualties and keloids following the burns were common. Keloids were also found after non-atomic burns in Japanese [16].

Charring and ignition of clothing caused further burns. Where the hot cloth was tightly stretched and in close contact with the skin contact burns resulted. Dark cloth absorbed more heat than lightly coloured fabric and patterns were sometimes burned into the skin.

Burns sustained in burning buildings and other secondary fires were the same as those produced by fires of less spectacular origin.

Histological examination of the skin in cases of flash burn showed that depigmentation could occur even if the epithelium was not completely destroyed. There was marginal pigmentation and deep to the burns œdema fluid and myxomatous material were observed. Proliferation of fibroblasts and infiltration by macrophages occurred. At a later stage the picture was often complicated by radiation effects resulting in anæmia and leucopenia with subsequent infective and hæmorrhagic changes. In these cases the absence of a normal cellular reaction was striking.

Radiation Effects.—Prior to July 16, 1945, radiation illness was not of serious military importance. It is not the main cause of casualties from atomic warfare, but it produces large numbers by ordinary standards and presents some unique features.

Acute Ionizing Radiation Illness has been caused by atomic bombs and by powerful sources of X and gamma rays [52] and its effects have been studied both in humans and experimental animals [2, 10, 12, 13, 20, 32, 36, 37, 43, 44, 48, 50]. Unfortunately the different species vary in their response to the same dose of radiation [14]. The hard X-rays and gamma rays are very penetrating and within their effective range cause marked damage to unshielded sensitive tissues. Clothing is not an effective shield although a steel helmet has been known to prevent epilation. Neutrons have a less wide effective range than gamma rays from a bomb but within that range they may effectively penetrate shielding which is adequate against the gamma rays.

Acute total body radiation produces simultaneously in all tissues varying degrees of injury, the following [20] being a grouping in increasing order of radio-resistance.

(1) Lymphocytes
(2) Erythroblasts
(3) Germinal epithelium of the testis
(4) Myeloblasts
(5) Epithelium lining the base of the gastro-intestinal crypts
(6) Germinal cells of the ovary
(7) Basal layer of the skin
(8) Connective tissue
(9) Bone
(10) Liver
(11) Pancreas
(12) Kidney
(13) Nerve
(14) Brain
(15) Muscle

The first eight are the most likely to show changes. In the more easily damaged organs and tissues there are more resistant cells [51] from which, if the patient lives long enough, regeneration may occur.

After exposure to massive doses of penetrating radiation vomiting and malaise usually appear within a few hours [20]. Fever and diarrhœa follow: in the most severe cases without remission. Within twenty-four hours leukocytes practically disappear, there are scattered petechiæ and rapid deterioration sets in with increasingly severe diarrhœa. Among the Japanese death in this group usually occurred suddenly from four to ten days after exposure.

In the intermediate dose range nausea, vomiting, diarrhœa and malaise usually come on a few hours after exposure. The initial symptoms subside till, after a latent period of between seven to twenty-eight days there may be gastro-intestinal disturbances with intractable and often bloody diarrhœa in most cases. Purpura, fever and pancytopenia become progressively worse, and secondary effects of the leucopenia are laryngitis, stomatitis, pharyngitis, tonsillitis, gingivitis and ulcerative lesions of the skin and genitalia.

Death may be of the pan-leukopenic or hæmorrhagic type. In the Japanese cases hæmorrhagic deaths were most common from the third to fifth week after irradiation.

Hæmorrhagic phenomena are first seen in the skin and mucosa and are later manifested as epistaxis, melæna, hæmaturia and menorrhagia.

In this group epilation, beginning on the crown of the head, was common but was seldom complete.

In the sub-lethal dose range similar but less severe effects are met. By definition there will be no radiation deaths. The latent period is longer and those symptoms which develop are less severe. Hæmorrhagic phenomena are minimal, leukopenia and anæmia are less marked. With doses below 50 r symptoms may be absent. The only detectable hæmatological change may be a fleeting lymphopenia.

A sub-lethal dose of radiation lowers resistance to trauma and infection and prolonged avoidance of physical effort may be necessary in the more seriously damaged but non-fatal cases.

The pathology of the Japanese cases has been well described by Liebow, Warren and De Coursey [37]. The main lesions in most cases of fatal total body radiation examined may be associated with hæmorrhage, necrosis and secondary infection [49]. In the production of the hæmorrhagic state there may be a circulating anti-coagulant [2, 3, 4, 25, 18] which will add to the effects of capillary damage, and at the time that hæmorrhages are most marked there is usually a fall of platelets [18]. Anæmia results from hæmorrhage into the tissues, into the hollow viscera and from damaged surfaces, as well as from destruction of the erythropoietic elements of the bone-marrow. Erythrophagocytosis and hæmolysis probably play a part too.

Leukopenia is produced by destruction of the myelopoietic and lymphopoietic elements. The fall of lymphocytes is early [21].

Toxæmia is likely from products of tissue breakdown and absorption of intestinal toxins.

Infection is serious in these cases where the normal defence mechanism of the body is destroyed or seriously impaired [19]. A marked feature of many lesions is the absence of any cellular reaction.

Histological Appearance in Atom Bomb Casualties

(1) Skin: Pigmentation and burns occurred as thermal radiation effect. Ionizing ray burns were not seen in the Japanese cases. Damaged hair follicles associated with epilation were commonest in the scalp. Vascular changes were minimal although these may be an important sequel to intense radiation.

(2) Pituitary: In some cases dying several weeks after irradiation "castration cells" were found.

(3) Adrenals: Loss of lipoid, later thinning of cortex.

(4) Heart: Epicardial petechiæ within the first two weeks—this is also seen in animals.

(5) Lungs: Only slight evidence of a primary radiation effect. Later a necrotizing pneumonia of the aplastic type was found.

(6) G.U. system: No primary effects of radiation seen in kidney or uterus. In the hæmorrhagic stage mucosal hæmorrhages might lead to ulceration with no leucocytic response.

Changes in the testes were striking and illustrate the mechanism of production of the temporary sterility common in survivors. Interstitial cells were not damaged hence loss of libido or potency would not be expected where the dose received had caused severe malaise or general debility. Atrophy was more marked in cases surviving for more than two weeks.

In the ovary the changes were less striking and primary ova were usually still present.

(7) G.I. tract: Animal work has shown that the lymphoid tissues and certain of the epithelial cells show evidence of radiosensitivity at an early stage [13] and in the Japanese cases some of the earliest gross lesions occurred here. Greenish ulcers and petechial hæmorrhages were common post-mortem findings. An important part in the production of ulcers was probably lowered ability of the intestinal mucosa to cope with bacteria together with lowered antibiotic capabilities of the blood.

(8) Lymph nodes: In cases examined from the third day onward atrophy was marked and by the second week there was disappearance of germinal centres. Later enlargement and softening of nodes was associated with hæmorrhage. This has been well shown in animals. The tonsils and other lymphoid tissue were similarly affected. Breakdown with ulceration was a secondary effect.

(9) Spleen: The lymphoid elements reacted as in the lymph nodes. The loss of white pulp was prominent, lymphocytes completely disappeared, other features were erythrophagocytosis and formation of hæmosiderin deposits.

(10) Bone marrow: By the end of the first week extreme hypoplasia was common—gelatinous marrow. Islets of reticulum cells were found and damage was usually less severe in the shaft than at the metaphysis.

From the second to sixth week hypoplasia was the rule in those cases which died, but some showed marked reticulum hyperplasia and focal myeloid regeneration was sometimes met. In some cases marked myeloid hyperplasia occurred.

In those surviving for more than six weeks reaction and attempted recovery were the rule although there were still cases where the marrow remained hypoplastic.

(11) Liver: In cases dying in the first week some giant nuclei were seen

and there was congestion and œdema of central veins. Later fatty changes —probably associated with infection and toxæmia—were observed.

(12) Other organs: No striking changes were seen. There are no reports of the thymus but here one would expect destruction of thymocytes as is seen in animals. Loss of adipose tissue became more marked in the cases dying after a prolonged illness. Recently cataracts have been observed in Japanese children [8].

Those dying in the first three weeks usually showed severe pan-leukopenic manifestations. Where death occurred in the third to fifth week hæmorrhagic lesions predominated and were associated with low leukocyte and platelet levels and possibly a circulating anti-coagulant. At this stage, ulcers, hæmorrhages and necrotizing pneumonia were common. The oral and buccal ulcers were sometimes nomatous.

Deaths after six weeks were usually associated with a severe wasting condition.

Delayed Radiation.—The fission products which are created by the explosion of an atomic bomb continue to decay and give rise to radiation as they are carried up in the mushroom cloud. In a high air burst the effect of this radiation on personnel is negligible although the question of fall out at a distance has to be considered. Where, as a result of an underwater burst, a base surge has been produced the delayed radiation effect will be greatly enhanced. Personnel engulfed in the radioactive cloud, which in the Bikini trials moved over an area of five square miles [6], will be subjected to beta and gamma radiation from all directions and will in most cases receive a lethal dose of external radiation. Such personnel and their clothing will, like everything in the area, be contaminated by radioactive substances.

Radioactive contamination.—In an area which has become heavily contaminated there is a significant but not necessarily lethal external radiation hazard. This hazard is due to beta and gamma radiation; in the case of the former suitable clothing will protect the skin and superficial tissues from damage. A recent report in the J.A.M.A. [34] described some of the lesions produced at Eniwetok; chronic ulceration of the skin and sloughing of tendons resulted from "breakdown in protective measures." Against the more penetrating gamma radiation no adequate shielding can be worn by those working in a contaminated area, and thus it is important that the level of radiation should be known in order to avoid excessive exposure. "Burns" due to radiation from an external source have been reported since shortly after the discovery of radium [26].

In connexion with radioactive contamination, internal radiation is a serious delayed hazard. The radioactive material may enter the body by inhalation or ingestion or through open wounds. It is mostly in particulate form and protection from inhalation may be obtained by wearing a suitable respirator. Working in a contaminated area is likely to stir up dust and increase the inhalation hazard.

As certain fission products and plutonium are predisposed to become localized in bone [11] where they remain fixed and decay over a long period, serious results, such as have already been observed in radium dial painters are to be expected [39]. Bone-marrow damage may result in aplastic anæmia and late effects may include pathological fractures, and sarcoma of bones. Displacement of bone-seeking substances has been tried [41]. The localization of a radioactive substance is utilized in the investigation [40] and treatment of thyroid disorders by I^{131} and in obtaining radio-autographs [27] or to study the circulation time, etc. [45]. Other radio-isotopes are used to produce more general internal radiation [38, 40].

Chronic effects of prolonged exposure to low levels of radiation have been studied for a long time in X-ray and radium workers [15]. These include ulceration and malignant changes in the skin, anæmia, severe or fatal aplastic anæmia and leukæmia. Chronic low level radiation in female mice has caused sterility.

Genetic effects of radiation have been studied in drosophila and neurospora; studies are proceeding on mice.[1] A survey of the Japanese survivors is being conducted in order to follow up any possible genetic effects—this will require years of patient work and careful vital statistics. Haldane [29] has stated that the total number of deaths from recessive mutations to be expected as the result of an atomic bomb explosion is a small fraction of the number immediately killed and is spread out over thousands of generations.

Collection and Treatment of Atomic Casualties

After an atomic explosion efficient rescues will be required if casualties who could be saved are not to perish in secondary fires. An adequate Defence Plan must be prepared in advance [33]. In rescue operations it will be important to conduct a survey for residual radioactivity and to take precautions against over-exposure [31]. For this suitably trained personnel will be required.

Priority in evacuation should be given to major surgical casualties. It should be remembered that those who have received more than 600 r total body radiation are unlikely to survive even where radiation effects are uncomplicated by burns and wounds [31].

It will be several days before symptoms of less severe radiation illness become apparent, the longer the latent period, the better will be the prognosis. In borderline cases the therapeutic challenge will be greatest. While it must be remembered that all forms of treatment tried up to the present have failed to prevent the ultimate death of animals given a fatal dose of total body irradiation, in some cases life has been prolonged. At slightly lower doses the possibility of death becomes a certainty unless adequate medical, surgical and nursing facilities are available.

Early surgical treatment is important, as the development of radiation illness

[1] Catcheside has recently reviewed these effects.

with lowered resistance to infection and an increased tendency to bleed will make surgical intervention at a later period more difficult. General measures should include complete physical and mental rest; mild sedation will probably be required. The diet should be low in residue and easily digestible. In the early stages there should be a low fat content with sufficient protein to meet basal requirements, carbohydrates should be sufficient for resting caloric requirements. In the later stages, as recovery begins, the diet should be rich in easily digested proteins and of high caloric value. Careful nursing will be required; the mouth, bowel and skin will require special attention. Bed-sores or infected wounds must be avoided at all costs and chilling prevented by careful control of ward temperatures. All hypodermic and intravenous techniques must be absolutely aseptic [20].

Other measures will probably require the use of penicillin and other antibiotics. Sulphonamides and other preparations likely to cause leukocyte depletion should be avoided. Controlled transfusions of whole blood and the use of plasma and substitutes will be required on a large scale. An adequate fluid intake must be maintained, intravenously if necessary. Specific anti-irradiation drugs may be available [1, 7, 22, 23, 24]—those tested up to the present time have been disappointing when given after irradiation in the lethal dose range.

Besides the two groups of those whose treatment can only be palliative and those who can and should be saved by adequate treatment of their burns, trauma and radiation there will be a third group who will need reassurance and can then be returned to useful work.

In evacuation plans air transport for radiation casualties is not contra-indicated [46].

Hygiene and Atomic Warfare

Besides the problems associated with large-scale destruction of buildings and interference with public services, which an atomic explosion would cause, the question of radioactive contamination is important. Personnel engaged in rescue operations must be protected by efficient monitoring and the spread of contamination prevented when an area is discovered. No authorized personnel should enter a contaminated area. Those who must do so should not be retained in the area long enough to receive more than "military tolerance" dose of radiation. When in a contaminated area, eating, drinking and smoking must be prohibited, the wearing of protective clothing and respirators will be ordered whenever necessary and personnel will be monitored on leaving the area to check for removal of contamination [6].

No food suspected of containing radioactive material should be consumed until it has been proved to be safe. Similarly suspected water supplies should be cut off and alternative safe sources used. Decontamination of radioactive water may be necessary [5].

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NUCLEAR PHYSICS DEFINITIONS

The Atom

Consists of:

(i) *A nucleus* containing
 (*a*) protons which have a positive electrical charge, and are equal in number to the atomic number of the particular element.
 (*b*) a variable number of neutrons.

(ii) *Electrons* which are negatively charged particles, equal in number to the protons in any neutral (uncharged) atom, and which circulate around the nucleus[1]. Chemical properties depend on the number of electrons. The number of neutrons in the nucleus can be altered, thereby altering the atomic weight without affecting the chemical properties.

The Hydrogen Atom

The smallest atom consists of one proton (the nucleus) and one electron circulating round it. (Thus a proton is simply a hydrogen nucleus.) The nucleus is indicated by the symbol ${}_1H^1$

"Heavy Hydrogen"

Consists of hydrogen to the nuclei of whose atoms one neutron has been added. Its symbol is then, ${}_1H^2$. In such a symbol the first number, or *subscript* is the *atomic number*, or *charge*, and equals the number of protons; the second number, or *superscript*, is called the *mass number* and equals the protons *plus* the neutrons. (Thus the radium nucleus is indicated by ${}_{88}Ra$, the charge, or number of protons, being 88, and the mass number, or protons plus neutrons, being 226, i.e. 88 protons + 138 neutrons.

A deuteron is a proton plus a neutron, and thus is simply a nucleus of heavy hydrogen.

Isotopes are atoms with the same charge but different mass number (owing to different number of neutrons).

Ionization consists of the removal of one or more electron from the outer shell, thus leaving a positively charged atom. This can be done by shooting high-speed electrons at the atom, the missiles knocking electrons out of their orbit.

X-rays.—By bombarding an atom with very high energy electrons, one of the electrons

[1] In "shells," or concentric orbits, at different distances from the nucleus.

in a "K," or inner, shell may be knocked out and replaced by one of the outer shell electrons. In this process energy is liberated in the form of an X-ray.

Gamma-rays

The collision between a high energy atomic particle and an atom may "excite" the latter by absorbed energy from the collision and this energy may be got rid of by the emission of a gamma-ray, which differs from an X-ray only in being generally a higher energy "photon."

Alpha Particles, and *Beta Particles*

These are particles which, in addition to gamma rays, are given off by radio-active substances, such as radium and uranium.

Alpha particles are helium nuclei travelling at high speed. They are comparatively massive and therefore comparatively easily stopped.

Beta particles are electrons travelling at high speed and less easily stopped.

Radio-active Decay or *Disintegration*

e.g.

$88Ra^{226}$	$-$	$2He^{4}$ (Alpha particle)	$=$	$86Ra^{222}$
(Radium) parent		(Helium)		(Radon) daughter

But radium and radon are only generations in a parent-daughter series, usually called a radio-active series.

e.g.

$92U^{234} \longrightarrow$	$90Th^{230} \longrightarrow$	$88Ra^{226} \longrightarrow$	$86Ra^{222} \longrightarrow$	$84Po^{218} \longrightarrow$	$82Pb^{214}$
(Uranium)	(Thorium)	(Radium)	(Radon)	(Polonium)	(Lead)

The heaviest "natural" lead, however, is $82\,Pb^{208}$ so that $82\,Pb^{214}$ has six more neutrons than any lead in nature. The further emission of alpha particles would increase this imbalance. It, therefore, emits a beta particle, and, since the emission of a beta particle is accompanied by the conversion of a neutron into a proton, we have:

$82Pb^{214}$	$-$	$1e^{0}$ (beta particle)	$=$	$83Bi^{214}$
(Lead)		(Electron)		(Bismuth)

and by further emission of alpha and beta particles becomes $82Pb^{206}$, which is a stable lead isotope. Eventually all radio-active elements are reduced to lead.

"Half-life"

The half-life of a radio-active element is the time in which half of the atoms of any given quantity of that element will have decayed. Thus the half-life of radium is 1,690 years.

Measurement

Curie is a measurement of activity.

e.g. a millicurie of radium is the amount which gives off 37 million particles per second. I millicurie (mc.) = 1/1000th of a curie.

Roentgen is a measurement of dose.

e.g. 1 r is the quantity of X-radiation which produces 1 electrostatic unit of ions when passing through 1 c.c. of air. 1 milliroentgen (mr.) = 1/1000th of a roentgen.

Measurement is made by means of Geiger counters, ionization chambers, photographic emulsions, etc.

Nuclear Fission

The electrostatic field round the nucleus bars entrance to electrically charged particles, but neutrons can be made to enter. Thus, if a deuteron (proton + neutron, i.e. a nucleus of heavy hydrogen) is fired at great speed, e.g. by a cyclotron, the proton is diverted but the neutron may enter. This "excites" the nucleus and may lead to fission, e.g.

$$\underset{\text{(Uranium)}}{{}_{92}U^{235}} + \underset{\text{(Neutron)}}{{}_{0}n^{1}} = \underset{\text{(Palladium)}}{{}_{46}Pd^{117} + {}_{46}Pd^{117}} + \underset{\text{(Neutrons)}}{{}_{0}n^{1} + {}_{0}n^{1}}$$

The palladium atoms so produced are known as "fission products." Usually the fission products, however, are not equal, and sometimes fission produces more than two products. The neutrons (two in the example above), are emitted at high speed. During the process gamma rays, beta particles, and sometimes alpha particles, may also be omitted.

The fissian products are usually heavy isotopes. Thus the heaviest natural palladium is ${}_{46}Pd^{110}$ (cf. ${}_{46}Pd^{117}$, above). Hence beta particles are emitted at high speed, corresponding to the production of stable lead described previously.

Each fission produces more and more neutrons (see the uranium fission reaction described above), and these neutrons, emitted at high speed, are capable of entering further nuclei, thus setting up a *chain reaction.*