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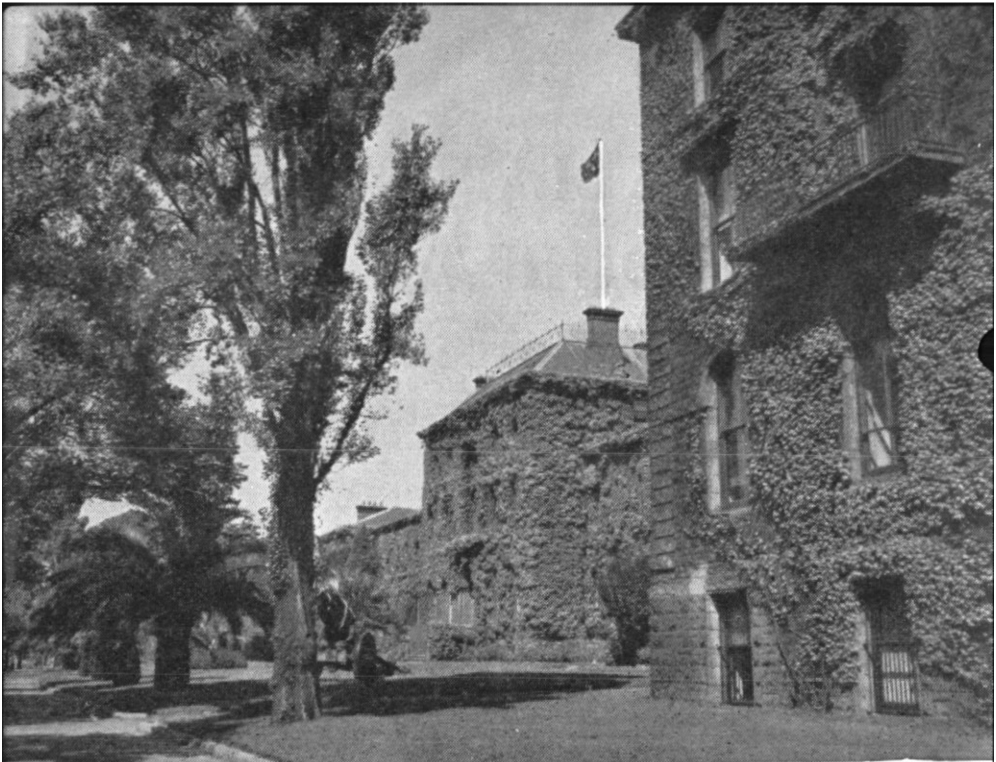

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INTRODUCTION

RECENTLY many articles of a factual and a speculative nature relating to atomic warfare have been written by Australian authors and published in the Australian Army Journal. The scope of the articles has varied from expositions of indisputable scientific knowledge to provocative papers dealing with the application of atomic energy to tactical operations.

In the absence of a proven doctrine on the subject the articles have been helpful in stimulating local military thought and discussion. Some fairly firm principles are beginning to emerge. Additional stimulus to thought is given by the increasing frequency of atomic explosions in and close to Australia.

The Directorate of Military Training considers that some consolidation of data and opinions in a convenient form will assist officers in the study of this new facet of warfare, and will provide a basis on which further ideas may be founded. Consequently this Issue of the Journal has been enlarged and devoted entirely to material which may be used as the basis for further thought, discussion and development.

The evolution of a firm tactical doctrine may take some time. Meanwhile, it is important that as much elementary training as possible should be undertaken. The Army must become accustomed to thinking in terms of atomic warfare. To assist officers preparing indoctrination training of this nature a catalogue of the material available is given in Appendix "A."

M. F. BROGAN, Colonel,

Director of Military Training.

1 November, 1955.

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TACTICS and ATOMICS

Colonel M. F. Brogan, OBE, BE, Australian Staff Corps

The views expressed in this article do not necessarily represent AHQ policy.—Editor.

Introduction

ONE could be forgiven for believing that the advent of atomic weapons in the form of atomic artillery, guided weapons and the aerial bomb into the tactical field has in one bludgeoning stroke removed the finesse, the nicety of moves and counter-moves and the necessity for high proficiency in individual training and detailed staff work called for in the past. The awful power of these devices vis à vis conventional weapons, together with the absence of any international convention governing their use (as is the case with gas warfare), portends World War III as a short succession of rapid holocausts in which all the tactical principles we have learned hitherto will be subjugated to the object of getting in first with the only blow required. One atomic device exploded somewhere near the centre of gravity of the enemy's field forces would appear to resolve each operation.

Closer reflection, however, indicates that the foregoing conception is rather absolute and needs to be tempered with factual considerations. Some of these considerations are associated with the atomic devices themselves, for example, the time taken to deliver one at the right time and place. Others relate to the well-established principles of preservation learned in earlier warfare but to some extent overlooked since 1918, e.g., the protection afforded by solid earth and the vulnerability of mass attacks to fire power.

There is no doubt that whilst either side has an atomic weapon the "good old days" of warfare are gone forever, but, on the other hand, *this does not mean that the whole* of our current tactical doctrine must be scrapped. Indeed, without trying to oversimplify the issue, a theoretical investigation (and the price per A-bomb permits only this at present) will show that the old principles, varied in application in degree only, will still prove sound. The degree will be in terms of such factors as ground, size of forces, mobility, protective works, time and space. After all, the physical effects of an atomic explosion are heat, blast and radiation, the two former of which are not new to war (albeit in a less efficient degree weight for weight) and the latter of which now shown as not the inexorable killer it was first believed to be.

The rational approach to the use of atomic weapons would, therefore, seem to be somewhere on a line between resigning ourselves to hopelessness of combating them on the one hand and regarding them as just a new series of explosive devices on the other. Admittedly, no sane person subscribes to either of these philosophies, but let us examine some tactical concepts to determine the weighting due to each with a view to establishing a more realistic picture of the influence of atomic weapons on the battlefield. For the sake of simplicity it is proposed to devote the rest of this submission to five parts, covering each phase of war, i.e., advance, attack, defence and withdrawal, plus a final summary. It is assumed that the following vehicles are available for the delivery of atomic devices:

(a) Aerial bomb (ground and air burst);
(b) Guided missiles:
  (i) Air to ground;
  (ii) Ground to ground;
  (iii) Ground to air;
(c) Atomic artillery;
(d) Land mine;

and that both sides have overall parity in devices and the means of delivering them. This postulation is an unlikely one, but is chosen here for simplicity's sake. Variation of these conditions or of other relevant factors, e.g., ground or morale, would materially influence any conclusions drawn here.

The Advance

In recapitulating some of the more important principles involved in a successful advance (including the advance to contact, the follow-up and the pursuit), we are reminded of the importance of:

(a) The necessity to reconnoitre on a wide front;
(b) Tactical surprise;
(c) The early capture of tactical features (firm bases);
(d) The maintenance of momentum;
(e) Good control;
(f) Passing of intelligence;
(g) Tactical grouping and local protection;
(h) Sound logistics; and
(j) The inherent fillip to morale.

As in other phases, the object might well be to force the enemy into a position where he will become vulnerable to atomic attack whilst ensuring we do not present him with a similar target. This emphasises perhaps more than hitherto the early passage of information, particularly relating to enemy dispositions, lines of withdrawal, defiles, check points and administrative installations where suitable targets are likely to eventuate. The laying on of an air strike or the deployment of ground-to-ground missile units, on present indications, take considerably longer than that involved in using conventional projectiles. This, and the fleeting nature of a target presented by a mechanised column, underlines the importance of a streamlined reporting system based on, say, a combination of reconnaissance aircraft, radar, agents and armoured vehicles. This system would also be required to report on enemy atomic preparations, such as the fabrication of launching ramps, which might be engaged by our offensive air support or CB organizations. On our part, the need for dispersion consistent with control and the requirements of local protection arises more forcibly. A concentration of a certain number of men to the square mile will constitute a density sufficient to warrant the use of an A-bomb. Axes of advance should be chosen where ground, defiles, groupings and speed do not combine adversely to produce a banking up to the degree indicated. The concomitant requirement of a reliable intercommunication system covering the dispersion necessary is a vital factor to the control of this type of advance.

Our selection of tactical bounds could conceivably be modified by the enemy's possession of atomic weapons in the field. In the past the high topographical features astride the axes which, if necessary, could be held against a turning enemy, have been the desiderata from the advancer's point of view. It is now well known that atomic blast from the air burst of a nominal (20 KT) bomb will kill at 1,000 yards by either heat flash or an overdose (2,500 Roentgens) of gamma rays. This lethality may not be possible from tactical weapons at this range, but the possibility remains that those exposed on high features are liable to become casualties from heat flash and/or radiation alone, as well as blast. Bounds may therefore be selected where the ground offers good reverse slope positions and where personnel may gain a certain amount of protection from the "atomic shadow" provided by the figuration of the ground and its relationship to ground zero.

Where it is necessary that close contact is maintained regardless of the possible exposure to atomic explosions, the need to protect fighting personnel from the effects of such explosions stresses the importance of the maximum numbers of tanks, armoured personnel carriers and self-propelled guns well forward. In addition to the mobility necessary for this type of operation, such equipments afford an acceptable degree of protection to crews against all three products of fission. The crossing of radio-active ground or the concentration of forces for a quick tactical decision would appear to be directly related to the numbers of such equipments which are available. This, balanced against the offering of a suitable atomic target when forming up, may well call for a nicety of tactical judgment on the commander's part.

The air aspect is a dominating factor. It is most likely that in an advance, at least a favourable local air situation will prevail. In addition to providing tactical reconnaissance this situation could be exploited (subject always to the efficacy of the enemy's ground-to-air missiles) in such roles as:

(a) By-passing of radio-active ground to seize tactical features with airborne troops;
(b) Denying enemy air observation over our concentrations, installations or movement; and
(c) Resupplying field units where maintenance areas are liable to atomic attack.

The Attack

Again, let us refresh ourselves on some of the basic considerations in planning the classical attacks. The following points warrant attention:

(a) The launching of the attack from a firm base and the gaining of firm bases for subsequent phases;

(b) The penetrative power of the attack in depth on a narrow front (except across wide obstacles);

(c) The security of start lines;

(d) The early movement forward of supporting weapons;

(e) The maintaining of momentum; and

(f) The need to widen the gap of penetration, to get behind and to outflank the enemy positions.

Of the above requirements, probably the most telling is that of momentum. If the attack is slowed down or stopped, and the enemy given the chance to regroup and hit back, the chances of our attack succeeding become slimmer. It is after the break in and during the dog fight that this critical stage will probably occur, i.e., when the enemy recovered from his initial shock and has had time to get his defence plan (including his counter-attack) into operation. At such a stage all our resources of close support, tanks, artillery and offensive air are called into play. It is now that the extra punch is required. Atomic weapons used indiscriminately in such a melee may clear the battlefield, but probably of both sides, with resultant indecision. Suitable targets would appear to be on the outskirts of the area and include HQs, command posts, signal centres, artillery positions, tank assembly areas and reinforcement routes. Thus interdiction on a tactical scale may be achieved, leaving the mopping up to be done by the attackers using conventional weapons.

The preparatory stage of the attack will require somewhat more caution than hitherto. The massing of men and material in preliminary positions, such as concentration areas, assembly areas and forming-up places has always been fraught with a certain amount of risk, but now the vulnerability of such concentrations is even less acceptable. This may involve more such areas, smaller forces or more limited objectives, or some combination of these factors. If our requirement of attacking with a maximum of momentum on a narrow front is not to be upset we must face up to smaller, harder-hitting, mobile, protected forces extended in considerable depth in "get set" positions behind a secure Start Line. These, in turn, must be supported by adequate atomic fire power and backed up, if necessary, by tactically grouped reserves ready to by-pass dog fights and maintain the initial impact of the break in.

A cover plan to mask preparatory activity is indicated in the above atomic setting. Any deception or simulations possible, e.g., dummy signal traffic, sonic devices, mock-up guns, vehicles and tanks should repay effort. Resupply of expensive and complex atomic devices to either side is hardly likely to approach the same scale as for conventional ammunition, and every enemy abortive round fired is a contribution to the unbalancing of his logistics.

Routes to Start Lines will require careful consideration to ensure that "man density" is not increased by reason of banking up at obstacles, defiles, minefields and enemy fields of fire. The arrival of a well-placed atomic missile amongst the attacking force during this opening gambit could involve the abandonment or postponement of the operation. This consideration may have to be balanced with the narrow front complex and force the use of more axes on a wider front, followed by convergence after contact.

Once battle is joined, close contact as well as momentum will need to be maintained right through the pursuit stage. Thus the enemy becomes, in effect, an atomic shield whose proximity to our forces will lessen the likelihood of enemy atomic missiles being launched against the interlocked combatants. It should not, however, be discounted that the enemy's philosophy and reinforcement position may be such that the simultaneous liquidation of both friend and foe will, in certain circumstances, be justifiable.

Because of the need already mentioned, to husband our resources of atomic missiles, the decision to use them will remain at a high level. For the immediate future and until all commanders are experienced in the use of these devices, some form of specially trained atomic adviser to the commander would appear justified to advise on the probable effects of atomic requests before acceptance is given. Such an adviser would require to be kept continuously informed of the tactical situation by means of a reporting and control organization possibly superimposed on the air support signal system.

As before, success will be materially affected by the local air situation, the availability of tanks, armoured personnel carriers and self-propelled guns. These factors, if favourable, will enhance our ability to deploy and to take quick advantage of the targets presented by enemy concentrations.

The Defence

In this phase of warfare, we have been taught conventionally to give emphasis to:

(a) Depth;

(b) Concealment;

(c) All-round defence;

(d) Mutual support;

(e) A co-ordinated plan, including counter attack;

(f) The need to sustain morale;

(g) Domination of ground between opposing forces;

(h) Centralized control of artillery;

(j) Protection of obstacles; and

(k) Good communications.

Probably the greatest influence of atomic attack will be to increase the depth of defence, and this means depth in two planes, deep in distance and deep down. The emphasis is on digging. Here the human element enters and, regardless of the latest scientific developments, the fighting soldier can be expected only to remove average spoil at the old standard rate of 1 cubic yard an hour, using hand tools. Hasty defences, therefore, to be effective against atomic attack, will require the application of mechanised equipment on a large scale. To meet this situation, it is considered a case exists for the formation of special earth-moving units with the primary role of construction of field works. (An empirical figure determined for Australian troops in World War II was that 1 brake horse power was on an average the equivalent in output of 2½ men. Assuming that one item of plant can work twice as many shifts as a soldier, one 35 bhp excavator is the approximate equivalent of 175 men. The indication is clear—more horse power in the defence.)

The requirements of all-round defence, mutual support, protection of obstacles, control and good communications militate against the need to disperse to avoid mass casualties from the one blast. This points to small self-contained bastions of defence supported by more self-propelled artillery. The risk of penetration and defeat in detail must be countered by thicker minefields, probably laid mechanically, and mobile, hard-hitting counter-attack forces, kept on the move or ready to concentrate for a quick decision. The need to disperse will reduce the effectiveness of control to a degree which will demand a high order of initiative in, and a granting of freedom of action to, junior commanders and leaders.

Whilst avoiding concentrating ourselves, it will obviously be to our advantage if we can force the enemy into a worthwhile mass formation in an area where he is exposed to our atomic weapons. In a defensive sector this may well be achieved by large-scale use of tactical and defensive wire and minefields, thickened up possibly with radio-active material to render certain ground untenable. This presupposes a very deliberate defence, but may be possible in a modified form in a hasty operation.

A prerequisite to a successful defence against enemy atomic attack will be a high state of training and morale. Apart from the physical havoc to be seen immediately on detonation, it is going to demand a high state of morale and efficiency to keep a participant fighting with the knowledge that he has absorbed a lethal amount of gamma radiation and his remaining life can be measured in hours.

The selection of the ground to be defended in relation to vital ground will, in future, be influenced to some degree by its relative exposure to atomic blast, either ground or air burst. Here again, reverse slope positions seem to offer a certain attraction, but a lot will depend on technical developments, particularly in fuses and the accuracy of their control.

Concealment, camouflage and deception will demand considerable attention. The combination of hiding targets and diverting enemy atomic ammunition to non-existent concentrations is a tactical advantage and, in the long-term view, a dissipation of valuable enemy resources.

It is probable that the enemy will be aware of the atomic potential against him, and will be wary in massing large numbers for attack. Should he do so, however, it is imperative that he be seen off before he effects close contact. This will entail the pre-positioning and registration on our part of launching devices and/or atomic artillery, together with an efficient warning system.

Unless the defence has been organized on a deliberate basis and defenders are well protected, it seems unlikely that any close support in the nature of Defensive Fire or Defensive Fire (SOS) will be practicable from atomic sources. It is more likely that such support will be reserved for Harassing Fire or softening up prior to a deliberate counter-attack.

In the field of resupply, our present system of road or rail bound convoys feeding static formation maintenance areas is relatively inflexible and liable to neutralization by a few atomic missiles. An overhauling seems necessary to reduce the amounts and types of stores brought up, and the means of bringing them is indicated to be by aircraft requiring no elaborate forward airfield, i.e., helicopters, usually, and fixed-wing aircraft in appropriate situations.

The Withdrawal

In this temporary phase of warfare, planning is usually directed to:

(a) The withdrawal of tactical groups from, through and to firm bases;

(b) Simplicity commensurate with flexibility;

(c) Strict timings and centralised control;

(d) Secrecy; and

(e) The achievement of a clean break, together with the avoidance of a running fight.

Usually the adverse factor is time. The operation is more often than not started without much warning and is executed in a hasty manner. These circumstances react against the completion of reconnaissances, detailed staff work and, most importantly, the completion of intermediate or main positions, i.e., the firm bases on which we can stand and fight back. The time taken to complete effective protective works against atomic blast, even with an increased scaling of engineer plant, is going to be protracted. The decision to hold intermediate positions must be carefully considered in the light of the amount of excavation possible in the time available, and whether it would be more prudent to divert this effort into preparation of the main position. Similarly, covering positions, being even less effective in stopping power, cannot be relied on against atomic assault.

A likely pattern of withdrawal, then, might be to move rearwards in longer bounds, or one bound only, to a main position prepared with the extensive use of earth-moving equipment and mechanical mine layers. To enable the retreating force to gain its quick break and unmolested occupation of the new position, something drastic in the way of staving off the enemy may have to be done. This might take the form of an atomic barrage whilst the getaway is achieved or if this is considered too prodigal, to attack in force with a grouping which is capable of changing to a rearguard role when the main body is well clear of the action.

Really spectacular results should be possible with atomic devices in the demolition aspects of the withdrawal, but the tendency to crack nuts with sledge hammers by enthusiastic vandals will have to be watched. The time and manpower involved in preparing demolition belts has given rise to two types of demolition, viz., "preliminary," which are blown when ready, and "tactical," which are blown when tactically necessary. It is obvious that any large-scale preliminary demolition activity prejudices secrecy and militates against the clean break. The absolute destructive effect of atomic charges should reduce the work involved in preparing structures for demolition and eliminate the necessity for preliminary neutralization, thereby completely reducing the chances of disclosing our retrogressive intentions.

Once the rearward movement is apparent to the enemy and his follow-up commences, there will probably be scope for our inflicting delay by the detonation of carefully sited atomic land mines. Apart from the casualties inflicted by heat and blast, there will remain the persistent hazard of gamma radiation. Such deterrents located between primary demolition belts and supplemented by nuisance minefields should slow the pursuer down to the degree necessary for our disengagement and redeployment in the new position.

In common with the other phases discussed above, the requirement will exist here to avoid concentrations of men and equipment, to provide a large degree of mobility and armoured protection for personnel, to operate under a favourable air situation and to ensure the provision of adequate earth-moving equipment.

Summary

The introduction of atomic weapons into the tactical fields has brought new problems into the conduct of operations. These problems are determinate, using accepted tactical doctrine, and modifying it to the degree imposed by the physical effects of atomic detonation in specific field conditions.

The major unit reorganisation necessary is in artillery units to undertake the offensive use of atomic missiles. In addition, a real need exists to ensure that engineer support is of such a scale and so equipped that the provision of protective works against atomic assault is feasible in most field situations. Intercommunication and control systems now operative should be extended or duplicated to provide facilities for rapidly reporting, requesting or granting atomic action.

In the circumstances of atomic activity the need is emphasised to provide adequate resources of tanks, self-propelled guns and armoured personnel carriers to exploit or withdraw from atomic explosions.

Control of atomic missile expenditure should be vested in the most senior commander practicable and he should be assisted by a specialist trained in the technicalities of such missiles.

Some of the prime requirements in training for and conduct of field operations involving the use of atomic weapons are:

(a) Move mechanised, protected and self-contained;

(b) Grant freedom of tactical action to junior commanders and leaders — encourage initiative and stimulate leadership qualities;

(c) Avoid concentrations of men, material and maintenance areas and aim at forcing the enemy into such concentrations;

(d) Avoid road bound lines of communication; seek flexibility in resupply by the use of aircraft, both fixed and rotating winged; reduce the quantities of stores brought forward, particularly creature comforts;

(e) Gain maximum mobility, range, arcs and coming into action of artillery weapons;

(f) Provide maximum resources of manpower-saving devices, including a high proportion of earth-moving and mine-laying equipments;

(g) Move in big bounds between well-dug, firm bases;

(h) Local air superiority is essential to successful ground operation;

(j) Disperse, dig, disappear and deceive.

To gain full advantage of the immense fire power that nuclear weapons have provided, and avoid destruction by enemy nuclear attack, armies must develop a more lively and opportunist type of battle leader than exists at present, in both junior and senior ranks. Such a leader must have the imagination, the daring, and the resources to seize fleeting local opportunities; he must be trained to act independently and immediately within the framework of a general plan, rather than on precise and detailed orders or only after reference to a superior.

—*Field-Marshal Montgomery.*

PROPERTIES of NUCLEAR EXPLOSIONS

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I INTEND to restrict myself in this paper to describing nuclear weapons and giving information about their mode of operation only to the extent to which these things have been published openly in various American publications. This presents certain elements of difficulty to me, and it may be that I shall err on the cautious side; on the other hand, I may assume that things are known and discuss them freely when, strictly, I should not do so.

I wish, firstly, to show the differences between nuclear and other explosions, and then to discuss some of the physical effects of the atom bomb. I do not propose to discuss in detail the effects on the ground of a nuclear explosion, because that subject has been left to a subsequent paper.

1. The Difference Between Nuclear and Other Explosions

An explosive is a device for releasing suddenly a large amount of energy in a relatively small volume. This energy is always released in matter, which is raised to a very high temperature and generates an enormous local pressure. Until recently, explosive energy was released by chemical action, either by rapid burning, e.g., of carbon and sulphur, in black gunpowder, or by the rapid breakdown of unstable chemical substances such as nitroglycerine, trinitrotoluene, mercury fulminate or lead azide.

Black gunpowder was developed about 2000 years ago by the Chinese. It is set off by heating portion of it to a temperature such that the carbon and sulphur combine rapidly with the oxygen of the potassium nitrate with which they are intimately mixed, yielding energy in the same way as when coal is burnt, but far more rapidly. Explosives such as mercury fulminate and lead azide decompose with extreme rapidity into their components when subjected to friction or compression, while T.N.T. and such "high" explosives can be stimulated by detonators to undergo similar decomposition into simpler substances. In such cases energy is, as it were, built into the explosive chemical

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—From Proceedings of the Institute of Defence Science, No. 6.

compounds when they are manufactured, and is released when they decompose. This decomposition takes place more rapidly than the chemical combination in black gunpowder, giving a steeper wavefront to the explosion which yields a greater blast. However, the actual energy released per pound of high explosive is not greater by an order of magnitude than that of the most primitive of explosives.

Nuclear explosives represent a complete revolution in this development: they do not release chemical energy at all. Perhaps I had better say something about atoms and atomic nuclei; not that these are not well known to you, but to recall to your minds the salient facts needed in this discussion. We all know that the atom is a small object; it is about one hundred millionth of an inch in diameter. In the centre is the nucleus, discovered by Rutherford, which is one million millionth of an inch in diameter and carries all the positive charge and almost all the mass. Around this is the soft exterior of electrons, which carry negative charges. The nucleus itself is composite, containing protons, the smallest positively charged particles but 2,000 times as massive as the electrons, and neutrons, which carry no charge and are slightly greater in mass than the protons. A single proton forms the core of the lightest hydrogen atom: helium, which has atomic weight 4, has two protons and two neutrons in the nucleus. Uranium 238, which is element 92 in the periodic atomic table, has 92 protons and 146 neutrons in its nucleus.

The protons and neutrons which constitute nuclei are bound together by enormous forces. It is convenient to measure nuclear forces and atomic energies in electron-volts. The fundamental difference between chemical and nuclear binding forces then become apparent: the binding energy between carbon and oxygen in an ordinary chemical compound like carbon dioxide is of the order of one to five electron-volts; that between protons and neutrons in a nucleus must be measured in millions of electron-volts. Some idea of the quantity of energy liberated in a nuclear explosion can be gathered by this fundamental difference. The nature of nuclear forces is not well known: it is thought that protons exchange charge with neutrons and the reverse, and that the newly-discovered particles, mesons, play some part. If a proton or neutron is added to a nucleus, then a new atom is formed; for instance, if a proton is added to carbon of mass 13 we get nitrogen of mass 14 and in the process eight million electron-volts of energy are set free. This energy lost is a measure of the binding energy of the proton. Rutherford, in 1919, first fired particles at atoms and effected transmutation of the elements in this way.

It is found that the protons and neutrons in nuclei are most tightly bound for elements of intermediate atomic mass. This means that heavier and lighter nuclei tend to transform to these intermediate species with release of energy. This energy release can be depicted graphically as in Figure 1. It will be seen that hydrogen is a great source of energy and, at the other end of the curve, uranium is also a reasonable source. The elements between oxygen and mass about 160, in the

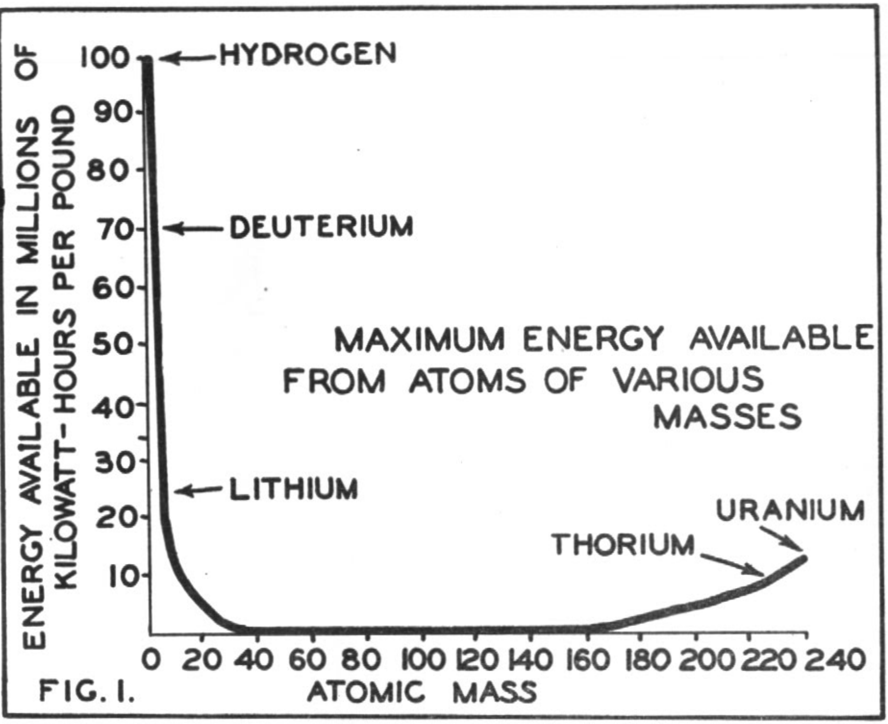


FIG. 1.

The graph shows the energy which could be extracted from various nuclei on the assumption that suitable chain processes can be developed. It will be seen that the fusion processes with hydrogen or deuterium yield weight for weight about 10 times the deuteron energy obtainable from uranium.

centre of the curve, cannot liberate energy. This is interesting, because about 90 per cent. of the earth's surface consists of these elements. When hydrogen nuclei are combined to give heavier elements much energy is evolved; this is called energy of "fusion." When uranium is broken down into elements of intermediate mass, energy again is evolved; this is called energy of "fission." All nuclear explosions depend on these two processes of fusion or fission.

Fission Process

The first process to be realized successfully was fission, produced by introducing a neutron into uranium 235. This divided into two simpler elements, yielding about 200 million electron-volts as kinetic energy of two fission particles, together with two or three neutrons. To achieve an explosion, fission must be maintained in a chain reaction: thus there must be a release of neutrons as well as the division into simpler elements.

Special conditions must be satisfied to realize a chain process. Uranium 238 occurs naturally 140 times as commonly as uranium 235. It absorbs fission neutrons to produce an isotope uranium 239; this then emits two beta particles and becomes plutonium, a chemical element which does not exist on earth. However, fission cannot be propagated in natural uranium. One way of establishing the fission process is to separate out the uranium 235. Neutrons which are emitted in the fission process have an energy of about 1 M.e.V. and a velocity of about 6000 miles per second, one-tenth of the speed of light. Such neutrons penetrate about 4 inches into matter before being absorbed in a nucleus. It was essential therefore to have a thickness of at least about 4 inches of material present for absorption subsequent to fission to take place; otherwise the neutrons escaped from the surface and a chain reaction was impossible. As the size of a spherical mass of uranium 235 is increased, it reaches a critical size where the chain reaction becomes possible because sufficient neutrons are absorbed internally to replace those lost from the external surface. The critical size depends upon the shape and density of the fissionable material.

Materials known to develop a chain reaction by fission are uranium 235 (element number 92), plutonium 239 (element number 94), and uranium 233. This last can be made from thorium 232 (element number 90) by absorption of neutrons when irradiated in an atomic pile. The critical mass is of the same order of magnitude for all these substances, and was quoted in the original Smythe report as 1 to 100 kilograms: this figure has been narrowed down since and is now known to be about 10 kilograms. The density of these substances is very high, about 20. Thus, a 10 kilogram sphere is only about 10 centimetres in diameter.

How do we ensure that an explosion in the 10 kilograms of material will take place? Uranium 235 is subject to slow spontaneous fission with liberation of neutrons, so that any mass bigger than the critical size is sure to explode. It will not do so instantly, but within a few micro-seconds spontaneous fission will establish a chain reaction. To make quite sure that this does happen, a few neutrons can be liberated in the centre of the mass; for instance, a small piece of beryllium bombarded with alpha particles from polonium would be sufficient.

The chain reaction will be established in a time of the order of that taken for a neutron to traverse 4 inches, that is, one hundred millionth of a second. In a large mass of material in one micro-second (10^{-6} seconds) there would occur about 100 generations of neutrons (or fissions), that is, 2^{100} or 10^{30} fissions, which is more than the total number of atoms present, the number being smaller if the mass is only just above the critical size, so that some of the neutrons escape and do not cause further fissions. You will understand, therefore, that the energy builds up at an extraordinarily quick rate, and hence will form some idea of the explosive possibilities of the bomb.

To get the largest and most efficient explosion the mass of fissionable material must be made bigger than the critical size by as much as is possible; otherwise a mere fizz and not an explosion will result, since the material will be blown apart. One method is to take a hollow cylindrical piece of material, smaller than the critical size for that shape, and drive a plug of the same material into it. This must be fired in by some sort of a gun, so that assembly takes place rapidly without shattering the material. A band of irradiated beryllium would provide the neutrons to start the chain process. This was the sort of bomb used on Hiroshima: it consisted of uranium 235 and was very effective.

The bomb dropped on Nagasaki was of a different type, the plutonium bomb, which worked by the implosion process. This was at one time regarded as a secret process, but details have since been released. The principle employed in this is to take a spherical piece of the fission material slightly less than the critical size and compress it suddenly by detonating high velocity explosives around it.

To understand the principle of the implosion process one must realize that the critical size depends not only on the amount of material but on the density: the denser the material is the more particles will be met by the neutron on its passage through the mass. Thus an increase of density will change a given mass of material from below the critical size to something above it. In driving the sphere in to become a denser solid mass of fissionable material, care must be taken that fuzes fire the surrounding explosive simultaneously all round, and that unsymmetrical detonation does not merely blow the mass to pieces.

This has now become the standard atom bomb, but important improvements have been made since

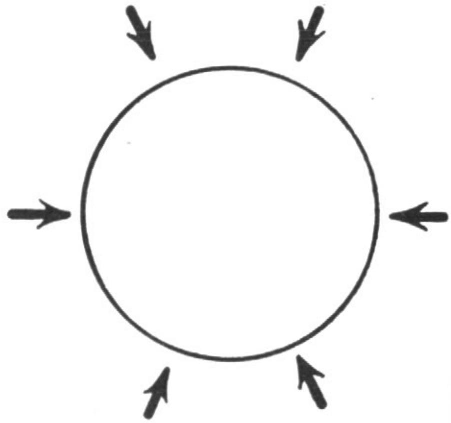


FIG. 2.
THE IMPLOSION PROCESS

it was first exploded. It has been found that plutonium and uranium 235 can be mixed with advantage, and that there are methods of increasing the amount of fissionable material. It can be made, for instance, as a hollow sphere, which when compressed into a solid mass will yield an efficient explosion. The bombs of today are certainly more potent, and release of explosive energy equivalent to that released by 100,000 tons of T.N.T. is within the realm of practical possibility. But it is difficult to see the likelihood of fission bombs being made equivalent to much more than 100,000 tons of T.N.T.

Fusion Process

The fusion process is that by which hydrogen is transformed continually in a star, for instance in our own sun, into helium and heavier elements under the conditions of temperature and pressure which hold at the centre of the star. This release of energy keeps the sun hot at the expense of the hydrogen which it contains. Now, unfortunately, it is not a practicable proposition to take ordinary hydrogen and bring about the fusion process in the laboratory. The probability that two hydrogen atoms will stick together to give a deuterium atom is remote; that is, that they should come together and, while fused, that one should get rid of a positive electric charge, the positron, and leave an isotope of hydrogen with a proton and neutron in its nucleus, is very unlikely. The probability is not zero, but the likelihood of such an event occurring under conditions of temperature and pressure present in the laboratory is remote. The likelihood of three coming together to give tritium is even less probable.

If we take the isotopes of hydrogen, namely, deuterium and tritium, then we find that these will react with one another with great ease, leading to production of helium at surprisingly low temperatures and pressures; in fact, at energies of about 1000 electron-volts. Now 1000 electron-volts is about 10,000,000 degrees centigrade, and the temperature produced by a fission bomb is about four times this. It is thus possible to heat the gases deuterium and tritium to a temperature where fusion takes place by putting them round the outside of a fission bomb. The problem of making a hydrogen bomb is that of keeping these materials there.

The possibility of constructing a hydrogen bomb was discussed in 1943, long before the fission bomb had been completed, under the code name "Super." There is thus nothing new about it, but the difficulties which have delayed its appearance have centred round methods of setting it off. The temperature required is of the order of magnitude of 10 million degrees centigrade, but this temperature cannot be communicated to any significant amount of material. The original American plan was to use liquid deuterium and tritium, making the tritium in a pile at the expense of plutonium production, and using it to detonate the deuterium.

Hans Thirring of Austria first suggested adding to the hydrogen isotope some lithium, in the form of the isotope lithium 6, which would absorb a neutron and break into tritium and helium, with considerable release of energy. The trouble with deuterium is that it is a gas and very transparent to neutrons, many of which escape instead of entering other nuclei. Lithium hydride, lithium deuteride and lithium tritide have the virtue of being solids. Lithium was first used apparently by the Russians, and it has been stated that it was not until the Americans found lithium in the upper atmosphere after the Russian hydrogen explosion that they realized there must be something in Thirring's idea and adopted this process. Lithium deuteride can be used as a solid sheath around the fission bomb.

There is no critical size for the hydrogen bomb; the energy released depends upon the amount of material present. Diagrammatically, it can be represented as an assembly of an implosion type of fission bomb surrounded by a sheath of lithium deuteride around which is a tamping device, so that the dissipation of material will be delayed long enough for a reasonable

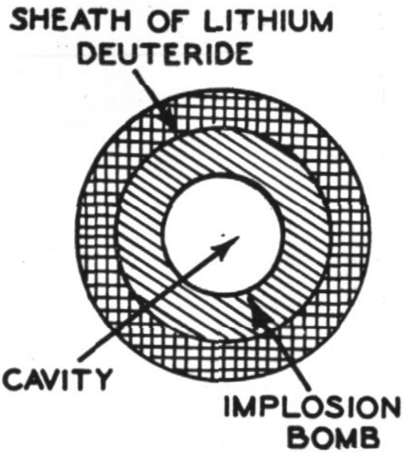


FIG. 3.
SCHEMATIC DIAGRAM OF HYDROGEN BOMB

amount of the lithium deuteride to react. Since the amount of energy released by the fusion of a given weight of deuterium is of the order of seven times that released in the fission of the same mass of uranium, to get an explosion 1,000 times as great as that of the fission bomb (that is, the equivalent of 20,000,000 tons or more of T.N.T.), only a relatively small amount of deuterium would be required. Temperatures involved in the two types of bomb are of the order of 40 million degrees centigrade for the fission bomb and more than 60 million degrees centigrade for the hydrogen bomb.

A further development of atomic weapons appears to have taken place and to have been achieved in the first place by the Russians. This is a weapon in which a fission bomb detonates a relatively small amount of lithium deuteride, the fusion reaction in which releases large numbers of neutrons with energies great enough to produce fission in uranium of mass 238, which is present as a sheath around the whole. The fast neutron fission of the U238, unlike the medium neutron energy fission in the fission bomb, can now take place in a relatively unlimited mass of uranium, so that the total energy released is enormous. It is believed that an example of this fission-fusion-fission weapon was detonated by the United States in the Pacific.

Unfortunately, when the power of a nuclear weapon is boosted in this way, enormous quantities of fission products are produced, the effects of which can be very unpleasant. The fission-fusion-fission bomb appears to be the most compact of the thermonuclear devices and to be capable of liberating virtually unlimited energy.

Dr. Bhabha, of India, has stated that he believes that thermonuclear reactions can be initiated without the fission bomb as a detonator. In that case, these powerful weapons could be made with relative ease, and would be within the reach of all nations.

2. Physical Effects of the Atom Bomb Explosion

I now wish to consider what happens when the energy of the atom bomb is released. Because the release of great energy in a millionth of a second produces a temperature 1,000 times greater than that of the surface of the sun, radiations of energy of all wave lengths spread out in all directions through the air or medium surrounding the bomb, and some heat radiations will travel a long distance. Because of the high temperature, the bulk of the radiations will be in the ultra-violet and will be rapidly absorbed in the air. Similarly, the neutrons and gamma rays will collide with atoms of the air and be rapidly absorbed. Round the system is thus built up a zone of hot air which grows outwards at first more rapidly than the adiabatic wave of compression, and we have the beginnings of the "ball of fire."

The rapid expansion of the ball of fire compresses adiabatically the atmosphere around it and heats it: thus the ball of fire grows rapidly until the energy is not sufficient to heat any more air. Then, as the blast wave goes out, the pressure tends to drop in the centre. The wave of radiation, consisting of X-rays, gamma rays, ultra-violet and heat radiation, is propagated at the speed of light and goes before the ball of fire. The effects of heat radiation fall off more rapidly than inversely as the square of the distance, so that burns rapidly diminish in severity according to distance from the bomb. The neutrons, X-rays, and gamma rays are absorbed in a few thousand feet.

Then follows the blast wave, which gives a destructive effect as in ordinary explosions. The gas in the ball of fire is at very high temperature, but its density is less than that of the surrounding air. It therefore rises and gives a pillar of cloud, as adiabatic expansion produces condensation as the pressure falls. In the absence of rain, fission products are carried high into the upper atmosphere and are dissipated harmlessly in very dilute concentration.

The Nagasaki-type bomb, if exploded at the optimum height, gives a zone of complete destruction of about three-quarters of a mile measured radially from the centre. The radius of destruction falls off according to the cube root of the distance, so that a hydrogen bomb 1,000 times as powerful would have a zone of complete destruction of from five to ten miles from the centre. It has been described as a "city buster" rather than as a "block buster."

Other Effects

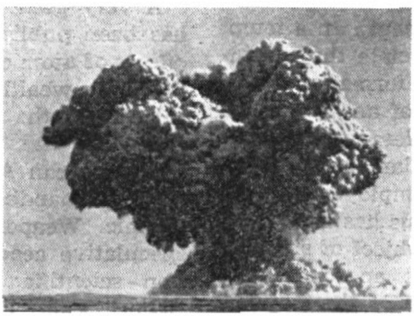
There are other effects produced by atomic weapons. If there is rain during the stage of dissipation of the radioactive products of the explosion, then the fission products will be brought down on to the ground instead of being spread through the upper atmosphere. The seriousness of this will naturally depend on the heaviness of the rainfall and its distribution, but it could be very harmful to all living things. If the bomb goes off on the surface of the ground, then there will be much radioactive material spread round on the surface, partly products of the bomb and partly constituents of the earth rendered radioactive by radiation. This appears to have been responsible for the radiation effects experienced by Japanese fishermen in the Pacific test of the fission-fusion-fission weapon by U.S.A.

If the explosion is underground, or worse still underwater, the most far-reaching result of all follows An enormous fountain of water or of earth containing radioactive substances rises and falls over a wide area of country, rendering it quite uninhabitable.

The products of a hydrogen explosion are not highly radioactive. The neutrons may affect the argon and other constituents of the atmosphere, but, generally, we may say that fusion products are not so deadly as fission products. At the American test explosion a good deal of radioactive coral was carried up with the mushroom cloud because the explosion took place at low level, and very large quantities of fission products were deposited over a large area.

Cobalt Bomb

Finally, it is necessary to mention the "cobalt" bomb. No one in his senses would think of making one of these, but it could be made by surrounding a fission or fusion bomb with a sheath of cobalt. The radioactive isotope cobalt 60 has a long half-life of 50 or so years, and its radiations are very harmful to health. Cobalt incorporated with a hydrogen bomb would lead to very serious radioactive poisoning for many years of a very large area of the earth's surface. It would be hard to imagine any person using such a weapon: it would render a country uninhabitable both by the conqueror and the conquered.



MONTE BELLO, 1952

The PHYSICAL EFFECTS of ATOMIC WEAPONS

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(This paper is to be regarded as RESTRICTED, and is not to be re-published, in whole or in part, without the permission of Army Headquarters.—Editor.)

IN this paper an attempt has been made to relate the considerable amount of information available on the effects of an atomic explosion to the problems of calculating casualties and damage when an atomic weapon is employed in military operations. This has been done with the principal object of showing how a quantitative approach may be made to a study of the employment of atomic weapons against field formations.

This paper surveys the literature and includes a bibliography. The well-known effects of the nominal bomb are given in some detail, and an explanation of the scaling laws is included to permit the extension of these effects to weapons of different power.

On the basis of this evidence, a discussion follows on the calculation of casualties and damage. Some brief remarks on the cost-effectiveness of atomic weapons are included.

Introduction

A very great deal of information has been published on the physical effects of atomic weapons. It ranges from the wealth of authentic detail relating to the Nominal Bomb contained in the Smythe Report and the American Atomic Energy Commission's handbook—"The Effects of Atomic Weapons" — to the many speculative accounts in well-known non-scientific journals such as "Time" and "Post." The former deal with principles of operations and the physical effects, but do not relate them in any specific way to a military situation. In more recent months these latter sources have included accounts of the hydrogen bomb. Between these extremes many articles have appeared in the various British and American services' journals (8, 9, 13), and deal in somewhat general and speculative terms, with the effects of atomic weapons on military operations, tactics and strategy. On the passive defence aspects (11, 15, 16, 17, 18) and on radiac instrumentation (5) the unclassified literature is very complete indeed. The bibliography at the end of this paper gives details of the above sources of information, and its use is strongly recommended for those wishing to pursue the subject further.

This comprehensive body of literature has in fact been largely concerned with the strategic aspects of atomic weapons and the problem of their tactical role and possibilities is only beginning to emerge (3, 10, 12), at least as far as the unclassified and lightly classified literature is concerned.

The object of these two papers is to provide an informed and, where possible, a quantitative basis for the subsequent discussions on the atomic factor in land combat. The first paper—"The Physical Effects of Atomic Weapons"—will seek to relate the known data to the military scene, whilst the second paper—"The Effects of Atomic Weapons on Military Operations"—will extend this relationship to some typical tactical situations.

It may appear somewhat paradoxical that the lack of almost all classified information on this highly classified subject does not appear to place undue limitations on these tasks. The unclassified information on physical effects generally, the various public statements from people in high places, and such comprehensive surveys of the whole field of atomic energy as Gordon Dean's "Report on the Atom" provide sufficient grounds on which to base the main assumptions for these papers. They are:—

(a) The physical effects of the nominal bomb are known in great detail.

(b) Scaling laws have been derived which readily permit these effects being calculated for weapons ranging in power from one-quarter that of the nominal bomb to powers many times as great. With reservation, the scaling laws may even be applied to assessment of some of the effects of the thermo-nuclear weapons.

(c) Atomic weapons will be available in sufficient quantities for use by field forces.

(d) They will be available in a considerable variety and with a very great range of power.

(e) Appropriate means of delivery have been, or will be, developed.

Types of Atomic Weapons

Developments in atomic weapons have made it necessary to be more specific in describing and classifying the various types. Until recently the term atomic bomb was sufficient to describe all such weapons. Now it is necessary to classify atomic weapons in terms of:

(a) Method of operation.

(b) Method of delivery.

Classification in Terms of Method of Operation

(a) Fission or Uranium weapons, or more colloquially atom bombs.

(b) Thermo-nuclear or fusion weapons, or colloquially hydrogen bombs.

The colloquial terms are basically quite incorrect, and although it may appear something of a quibble to differentiate it is wise to remember that as developments continue loose phraseology will become more and more confusing, and may even result in serious misinterpretation at a later stage. The use of the term fusion is deprecated, because of the likelihood of confusion with fission. It is suggested that fission and thermo-nuclear be adopted as standard terms.

In addition to the above, reference is often made to a "cobalt bomb." Such a description is not fundamental to the mechanics of operation, but is intended to describe some type of nuclear weapon which is "loaded" with cobalt or some other substance that can be made highly radio-active. The purpose of such a bomb would be to increase the effect of radio-active contamination from such a weapon. Whilst there is little doubt that such a bomb could readily be constructed it is not generally regarded as likely —especially for weapons for employment in a tactical role. It will therefore not be considered further in this paper.

Classification in terms of method of delivery

(a) Bombs.

(b) Mines.

(c) Shells.

(d) Warheads of guided missiles.

With the exception of a thermo-nuclear shell, the remaining seven varieties, derivable from this 2 x 4 classification, appear likely.

On a first consideration one would be inclined to eliminate from a discussion of tactical weapons the thermo-nuclear varieties. More careful examination shows, however, that this may not be justified. It has been estimated that the size of a thermo-nuclear bomb may be 100-1000 times that of the nominal fission bomb. However, a major tactical and certainly an L of C situation which would warrant the delivery of a destructive weapon of this order is not beyond the bounds of possibility. This possibility, taken together with the fact that one thermo-nuclear bomb would be vastly less costly than the equivalent number of fission bombs, would suggest that the use of thermo-nuclear weapons is possible in military operations.

Having outlined the possible range of an atomic arsenal, it is not intended to consider thermo-nuclear bombs as such in this paper, for there is little doubt that the smaller fission bombs will provide the main atomic fire power in field operations.

It may be inferred from the discussion so far, that atomic weapons are available in a considerable range of sizes, and in the further development of this paper it will be sufficient to refer only to a given weight of attack.

The question of weight of atomic attack makes it necessary to define a basic unit of atomic explosive power.

Because of the great deal of information published on the effect of the fission bombs which were dropped on Hiroshima and Nagasaki, and which were tested at Los Alamos and Bikini, together with the fact that these weapons were similar in size, it is convenient indeed to accept such weapons as a standard for calculating physical effects. In fact, weapons of this type have become known as Nominal Bombs.

The Nominal Fission Bomb

The explosive element of such a

bomb is 235 isotope of Uranium or Plutonium, a synthetically manufactured element of atomic weight 239. Such materials undergo "fission" when the nuclei of individual atoms are struck by neutrons. The result of this fission process is to split the uranium or plutonium nucleus into two fragments of approximately equal size, and release at the same time two or three more neutrons. However, the mass of all these separate products does not add up to the mass of the original nucleus. This mass defect is transformed into energy at a conversion rate given by Einstein's equation—

$$E = MC^2$$

where E is the energy equivalent in ergs

M is the mass defect in grams

C is the velocity of light (3×10^{10} cms/sec).

If, as in the nominal bomb, 1 kilogram of uranium 235 undergoes fission, the mass defect is very nearly 1 gram, and the energy release is thus approximately equal to—

2×10^{13} calories
2.3×10^{7} kilowatt hours
6.2×10^{13} foot-pounds.

In addition to this, another 12½% additional energy is set free in the course of time as energy of the beta and gamma rays produced by the decay of the fission products.

The figure of 6.2×10^{13} foot-pounds is equivalent to lifting 30 million tons of matter through one thousand feet, i.e., half a million Centurion tanks blown 1000 feet high. In addition to these basic units of energy, the energy release of a nominal bomb has been estimated as equivalent to that released by the detonation of 20,000 tons of T.N.T. Although the energy released by fission is very impressive, it is relatively small compared with the energies involved in the forces of nature. For example, it is about the same as the energy of the sun's rays falling on 2 square miles of ground on a normal day, or to that released by a moderate shower producing a ¼ inch of rain, say, over the greater Melbourne area. A strong earthquake dissipates as much energy as about one million nominal bombs. These various comparisons are given in an attempt to give some kind of balance to the mind in comprehending orders of magnitude that are represented when 10 is raised to powers of the same order.

The explosive effects and physical damage are not, of course, a function of the total energy release only, but are also functions of time. It is the rate of release of a given quantity of energy that determines the destructive consequences, and in the case of the atomic weapons it is necessary to take into account the form in which the energy manifests itself—blast, heat and nuclear radiations. More will be said of this in the next section of the paper.

The Physical Effects Resulting from the Detonation of a Nominal Bomb

The actual effect on troops and military installations of an explosion of an atomic weapon depends on a very large number of parameters. For a bomb of given size delivered against troops in a specified geographical disposition there are more than twenty likely cases to be considered, depending on the nature of the burst, the passive defence condition of the troops, the

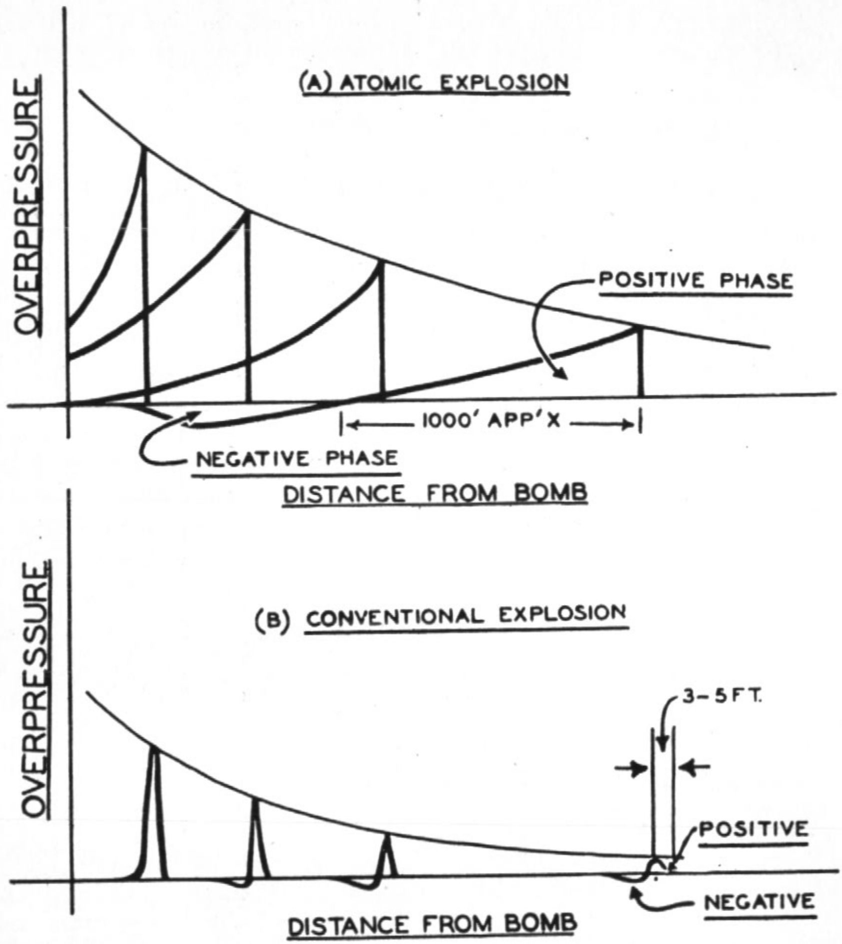


FIG. 1.

BLAST WAVES FROM ATOMIC & CONVENTIONAL BOMBS.

atmospheric conditions, their geographical disposition and the accuracy of delivery of the weapon. These various factors will be considered in more detail in the section dealing with lethality of atomic weapons. In this section the principal known effects of the nominal or standard fission bomb will be considered. Then, after considering the problem of scaling, it will be possible to make some attempt to analyze the problem of lethality. This, taken together with the logistic cost-effectiveness of atomic weapons, should provide the foundation for consideration of their tactical employment.

The detonation of a nominal fission bomb in the air (say 2000 ft. above ground) produces four major effects—

(a) Blast,

(b) Heat,

(c) Initial nuclear radiations — neutrons, gamma rays,

(d) Residual nuclear radiations.

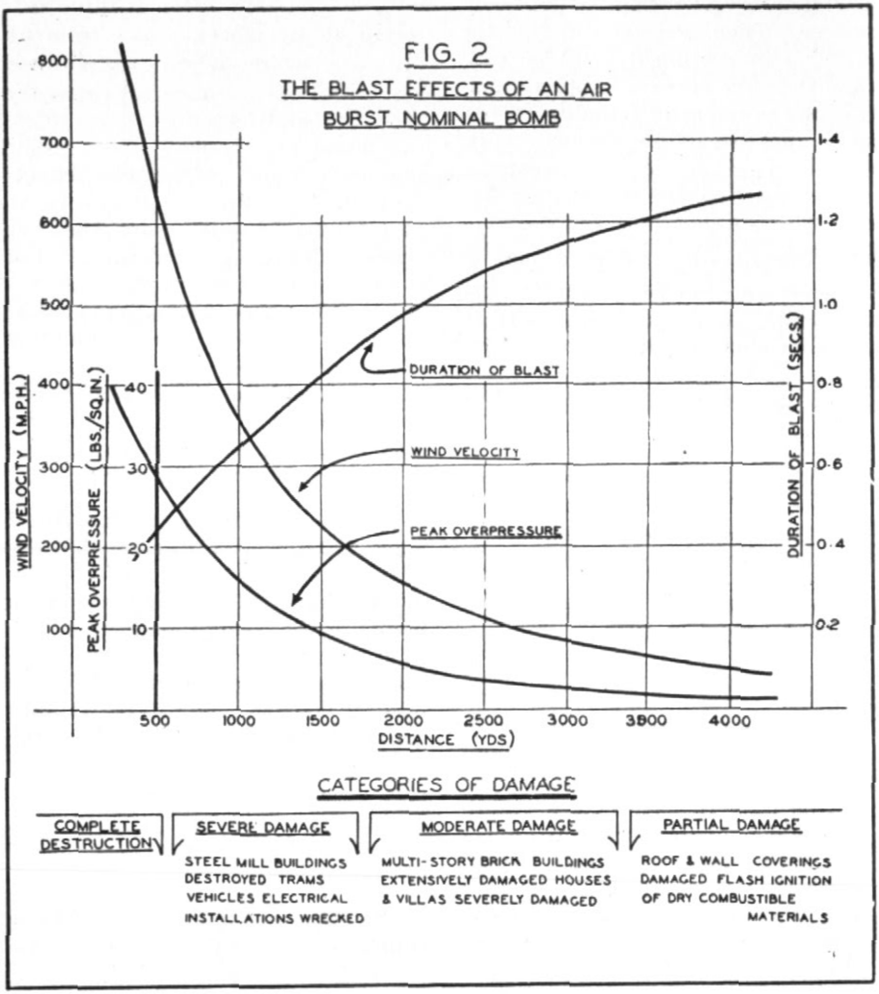
It will be desirable to consider briefly the principal features of each of these effects in turn.

Blast

When a great quantity of energy is released in a very short time there is considerable rise in temperature (in this case 10^{6}° K). As a result, the products of the fission are almost completely vaporised, and consequently a very high pressure is set up in the immediate vicinity of the explosion. This pressure is transmitted through the surrounding medium with the speed of sound. The pressure front in such an explosion as this becomes very steep indeed, and builds up into a shock wave. This is due to the fact that the initial disturbance heats up and pressurises the medium through which it has passed. As the speed of sound increases with temperature and pressure, the trailing portion of the pressure blast catches up on the initial disturbance, producing a shock front with a long tail. This is quite different to the shock wave from an ordinary bomb, where the limited amount of energy does not cause the same integrating effect. An ordinary bomb blast is more like a single impulsive blow. The two effects are shown in Fig. 1. It results in quite different effects for the two types of blast on structures. For a given amount of energy the impulsive blast would cause the greater damage. A detailed understanding of the difference between the conventional and the atomic blast is important to military engineers who may be concerned with the design of field works and structures.

In the case of the atomic blast wave it is the peak pressure that determines the destructive effects. An overpressure of 5-6 lb./sq. inch would cause severe damage in a built-up area, cause severe structural damage to steel frame buildings, B-vehicles and the most substantial of camp buildings. In the case of the nominal bomb this pressure occurs at about 2000 yds. Fig. 2 gives an annotated graphical picture of the blast effects of a nominal bomb.

The effect of blast on personnel is rather more difficult to assess. The human body is capable of withstanding peak overpressures of up to 35 lb./sq. in. or more. At distances closer than 400 yds., therefore, a human being is almost certain to die as a direct result of blast. However, by far the greater danger from blast arises from secondary effects. As indicated above, a peak pressure of 5 or 6 lb./sq. in. causes severe damage to structures — troops in the vicinity are likely to suffer heavy casualties. This would apply par-



Categories of Blast Damage

Classification of Damage	Distance in Miles		Area of Damage Sq. miles
	Min.	Max.	
Complete destruction	0	5	.75
Severe damage	.5	1.0	1.00
Moderate damage	1.0	2.0	9.5
Partial damage	2.0	4.0	40.0
Light damage	4.0	8.0	150.0

TABLE 1

ticularly to troops either in or close to B-vehicles.

The various categories of blast damage are set out in Table 1.

Thermal Radiation

Because of the very high temperatures attained in an atomic explosion—initially approaching that of the sun's interior—there is a large amount of thermal radiation. In fact, about one-third of the energy of the nominal bomb is released in this manner, i.e., about 8 x 10^6 kilowatt hours. At 0.1 milliseconds after detonation the ball of fire consists of an isothermal sphere of 50 ft. radius at a temperature of 300,000° K. The proportion of the radiation at various distances from this high temperature source depends on the clarity of the atmosphere and the distance from the burst. Because of the absorption by various components of the atmosphere, this radiation will be in the spectral region of wavelength exceeding 1860 Angstrom units (1 Ang-

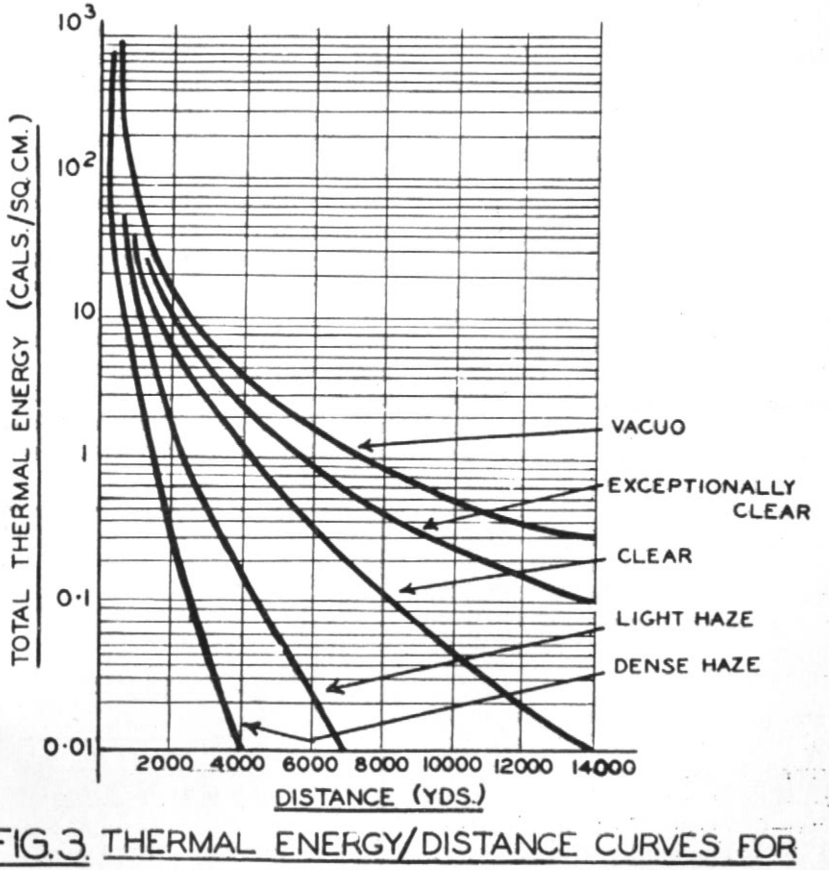


FIG. 3. THERMAL ENERGY/DISTANCE CURVES FOR VARIOUS ATMOSPHERIC CONDITIONS

Attenuation Factors for Various Atmospheric Conditions

Atmospheric Conditions	Attenuation Factor Km^{-1}	Attenuation Factor/1000 yards
In vacuo	0	0
Exceptionally Clear	0.1	0.09
Clear	0.2-0.4	0.18-0.36
Light Haze	0.8-1.2	0.73-1.09
Dense Haze	1.6-2.0	1.45-1.82

TABLE 2

strom Unit = 10^{-8} cm.), i.e., it will consist of—

Ultra violet radiation (1860A-3850A),

Visible light (3850A-7600A),

Infra red rays (greater than 7600A).

One of the principal factors relating to the radiation of thermal energy is the absorption and scattering it experiences in passing through the atmosphere. Many factors influence this, and it is not proposed to discuss them here. However, the physical effects are markedly influenced by the atmospheric conditions, and they are thus of great importance in estimating casualties and other effects caused by the heat flash. Table 2 and Fig. 3 summarise the situation in this regard. Table 2 shows the approximate attenuation factors for various atmospheric conditions, whilst Fig. 3 gives the total thermal energy delivered at varying distances for a range of attenuation factors.

An important feature so far as the resultant physical effects are concerned is that the whole of this radiation is emitted in a very short time—3 seconds from the initiation of the explosion. The time intensity is thus high, and as a result the radiation falling on any combustible object has little time to dissipate by conduction. The temperature of such objects thus rises rapidly, and ignition takes place much more readily than it would if the same quantity of heat were applied over a longer period. Fig. 4 shows the nature of the relationship between total energy and its rate of supply in the case of ignition of wood.

From the considerations described above it is clear then that the principal criteria for determining the effect of the heat flash in combustible materials and skin is the total energy received per unit area. A great amount of experimental work has been carried out on the determination of the critical energies (expressed in calories/sq. cm.) required

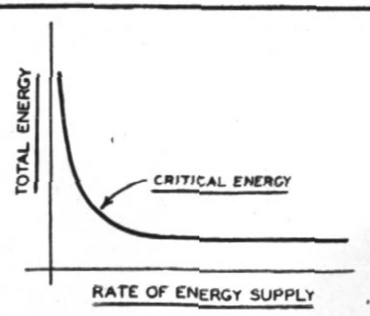


FIG. 4. CRITICAL ENERGY FOR IGNITION OF WOOD

to cause ignition of various materials. The results of this work are summarised in Table 3. In addition, the effective distances from ground zero of a nominal bomb at which the given critical energies will occur are given. These distances are given for attenuation factors K = 0.2 km^{-1} and 0.4 km^{-1}. These factors represent the limits of attenuation on what would normally be described as a clear day.

It has been assumed, so far, that the damaging effects of the thermal radiations have been due to the high temperatures resulting from the

Critical Energies and Distances from Ground Zero for an Air Burst Nominal Bomb

(Reprinted from "Effects of Atomic Weapons")

Material		Critical Energy	Effective Distance	
			K=0.2Km⁻¹	K=0.4Km⁻¹
		cal/cm²	feet	feet
Skin	Moderate burns	3	10,000	8,000
	Slight burns	2	12,000	9,600
White paper	Chars	8	7,000	6,000
	Burns	10	6,300	5,400
Black paper	Burns	3	10,000	8,400
Douglas fir	Burns	11	5,900	5,200
	Chars	8	7,000	6,000
Douglas fir (stained dark)	Burns	3	10,000	8,400
Philippine mahogany	Chars	7	7,300	6,300
	Burns	9	7,150	6,150
Maple (black)	Chars	8	7,000	6,000
	Burns	25	4,300	3,800
Cotton shirting (grey)	Scorches	8	7,000	6,000
	Burns	10	6,300	5,400
Cotton twill	Scorches	10	6,300	5,400
	Burns	17	5,100	4,400
Gabardine (green)	Brittle	7	7,300	6,300
	Burns	10	6,300	5,400
Nylon (olive drab)	Melts	3	10,000	8,400
Rayon lining	Scorches	3	10,000	8,400
	Burns	8	7,000	6,000
Wool serge (dark blue)	Nap gone	2	12,000	9,600
	Loose fibres burn	7	7,300	6,300
Worsted (tropical khaki)	Nap melts	4	9,100	7,600
	Burns	15	5,400	4,700
Rubber (synthetic)	Burns	8	7,000	6,000
Lucite	Softens	72	2,400	2,300
Bakelite	Chars	75	2,400	2,300

TABLE 3

rapid absorption of the heat energy. Damage to skin tissue can be caused by the direct chemical effects resulting from the ultra-violet radiations. The symptoms of this effect are known as erythema.

A considerable amount of work has been done to determine what percentage of burn casualties are likely to fall into this class. The results of this work show casualties from ultra-violet radiations are not likely to occur, except to the most sensitive individuals at distances greater than about 2000 yds. At such distances severe burning would occur from infra-red radiations.

These facts are of more than academic interest, as the bulk of the ultra-violet radiation is emitted almost instantaneously when the temperature falls to 10,000° K. Infra red rays are emitted from 0.3 to 3 seconds later, and this means that there is a very good chance of minimising burn casualties if individuals take immediate cover after the initial flash of the explosion.

In addition to the direct effects of thermal radiation, an extremely serious effect will result from the interaction between blast and thermal radiation in built-up areas and above ground base and L of C installations. Blast damage to physical structures is in itself likely to cause many fires, and this, taken together with the intense heat flash, may cause the situation to become extremely critical.

However, on the credit side there is some evidence to show that fires started by the heat flash in certain structures in the absence of inflammable accessories such as gas and electric installations may be extinguished by the blast wave which follows. This is likely to occur under certain conditions in wooded country, and it would minimise the possibility of bush fires.

The Initial Nuclear Radiations

Nuclear radiations from an atomic explosion fall into two classes—

(a) Initial radiations,

(b) Residual radiations.

There is a continuous transition from one type to the other, and so the demarcation between the two kinds is fixed more or less arbitrarily by considering those which occur within one minute of the explosion as initial radiations. The residual radiations may exist for days and even weeks afterwards, but, of course, with diminishing strength. The characteristics of both types of radiation, but more particularly of the residual radiations, depend on the nature of the burst (air burst, ground burst, underwater burst, etc.). As the two types of radiation are characterised by very different properties, they will be discussed separately—initial radiations in this section and residual radiations in the succeeding one.

The detonation of an atomic weapon is accompanied by the release of gamma rays, neutrons, beta and alpha particles. The neutrons and some gamma rays are emitted in the actual fission process, i.e., simultaneously with the explosion, while the remainder of the gamma radiation and the beta particles are liberated as the fission products decay. The alpha particles result from the normal radioactive decay of uranium and plutonium. The range of the alpha and beta particles is small, and for an air burst bomb they will not reach the earth's surface. The initial radiations may therefore be considered to consist of neutrons and gamma rays.

These radiations are very penetrating. For example, at a distance of 1000 yards from the explosion the initial nuclear radiation would probably prove fatal to 50% of human beings, even if protected by 12 inches of concrete.

The properties of neutrons and gamma rays are novel, and lead to many results of interest to soldiers as well as scientists (1, 2, 15, 21). In this paper it will be necessary to limit the discussion to some brief remarks concerning their range in air and their lethal effects. As the properties of the two types of radiation are so different, they will be considered separately.

Neutrons

The neutrons emitted in the fission process carry about 3% of the energy of the explosion. Of this something less than 1% escapes because of the loss of energy to components of the exploding bomb, i.e., the escaping neutrons have about 0.03% of the energy of the explosion. This seems small compared with the 33% of energy appearing in the heat flash. However, the lethal effect of neutrons is considerable, and in addition they will penetrate many inches of shielding material, whereas shielding from the thermal effect is comparatively easy.

The spectrum of the neutron radiation is characterised by fast and slow neutrons, the latter predominating in the ratio of 10 to 1. The intensity of the neutron flux, for fast and slow neutrons, at various distances from the explosion is given in Fig. 5.

The interaction of neutrons with animate and inanimate matter is a complex study. It is sufficient to say here that the principal effects cause transmutation of elements and induce radioactivity. These effects produce serious physiological effects. The lethal number of slow neutrons may be taken as 5×10^{11} per sq.cm., and that of fast neutrons 10^{11} per sq.-cm. Reference to Fig. 5 shows that their lethal range is approximately 600 yds. If allowance is made for neutrons of energies intermediate between the slow and the fast varieties, this figure may be increased to 800 yds. Although these ranges are small compared with those resulting from other causes of lethal effects, it is important to note that at points very close to the explosion (say 400 yds.), where field works may protect personnel from the effects of blast and heat, the penetrating power of the neutrons may cause casualties which would not otherwise occur.

The problems associated with the shielding from neutrons are very complex, as the interaction of neutrons on many shielding materials produces gamma ray photons, which if not absorbed constitute an additional hazard. Concrete is a satisfactory material, as it contains a large amount of hydrogen to slow down the neutrons, and calcium silicon and oxygen to absorb the gamma photons. Addition of scrap iron improves the properties of concrete as a shield.

Gamma Rays

The energy associated with the gamma rays is of the same order as that carried by the neutrons, i.e.,

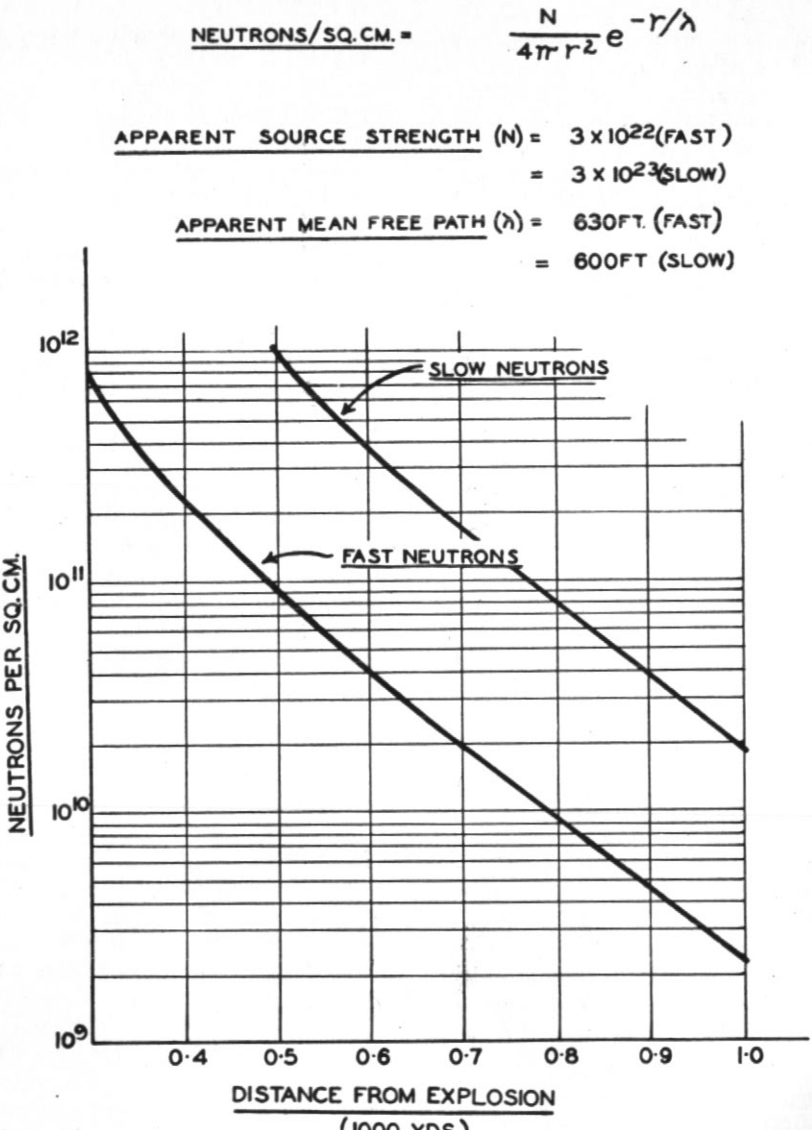


FIG. 5.

FAST & SLOW NEUTRONS AS FUNCTIONS OF DISTANCE FROM EXPLOSION

3% of total bomb energy. As with neutrons, only about 1% of this amount penetrates to any distances from the source of the explosion.

The gamma rays are of two kinds—prompt and delayed. The prompt gamma radiations are produced within a few millionths of a second of the detonation. However, associated with the explosion are various fission fragments, many of which are radioactive. As these decay, gamma rays are emitted. There will be appreciable liberation in the first minute from this decay activity; after this, the decay continues, and the accompanying radiation merges into the residual category.

Although gamma rays may induce some radioactivity in other substances, the amount is negligible. On the other hand, they have very strong ionizing effects on matter, and this may have profound physiological consequences. For this reason the radiation dosage is a measure of their ionizing capacity. The unit dosage is the roentgen, which is the amount of gamma radiation which will produce electrically charged particles carrying 1 electrostatic unit of charge in 1 c.c. of dry air at 0° C. and 1 atmosphere pressure.

The dosage (in roentgens) of gamma rays which occurs at various distances from a nominal bomb is given in Fig. 6. This graph, taken in conjunction with Table 4, which relates the dosage to its resultant physiological effects, will permit the determination of the lethal effects on human beings. If we take 400 roentgens as a median lethal dose (one causing a 50% likelihood of death), then reference to Fig. 6 indicates that this would occur at 1400 yards from the explosion.

The intensity of gamma radiation is reduced by shielding. Figs. 7 and 8 show the thicknesses of concrete and steel required to reduce the radiation to given levels at various distances from the explosion. Compacted earth produces about the same shielding effect as concrete. Examination of these graphs shows that the armour of an A.F.V. will

Probable Effects of Single Exposure. (Ref. 5)

Single Dose R.	Mortality at 24 hrs.	Mortality at 6 weeks	Number incap. within 24 hrs.	Probable time of unfitness for duty
0.25	0	0	Negligible	2-3 days
25-75	0	0	A few	2-3 days
75-100	0	0.1%	Half	1-2 weeks
100-150	0	0.5%	Half	3 weeks
150-200	0	5%	Three-quarters	Not less than 3 weeks Some very ill
200-400	Not likely	About ⅓	Prob. all	3 months
400-600	A few	About ½	Prob. all	3 months
Over 800	Some	Almost all	Prob. all	

TABLE 4

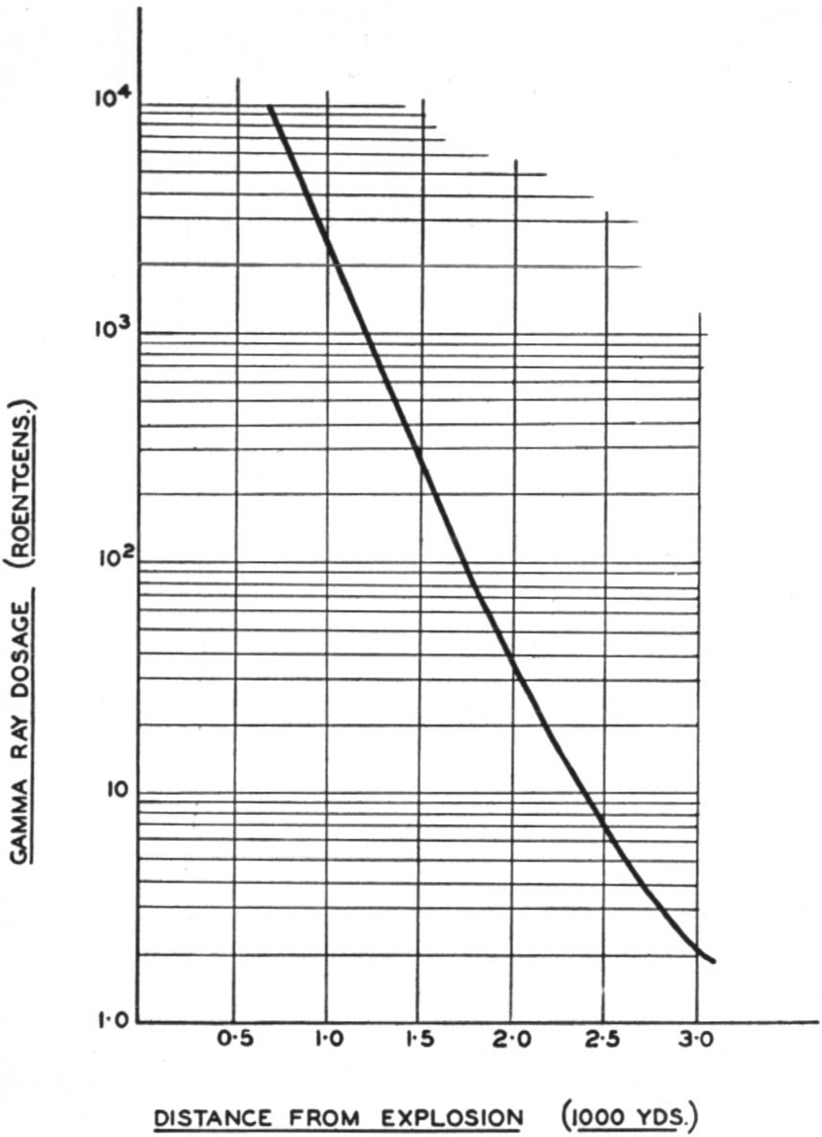


FIG. 6. DOSAGE OF INITIAL GAMMA RADIATION

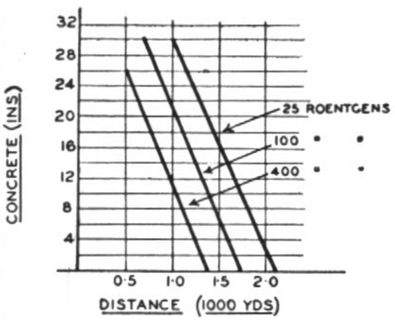


FIG. 7

SHIELDING THICKNESS OF CONCRETE

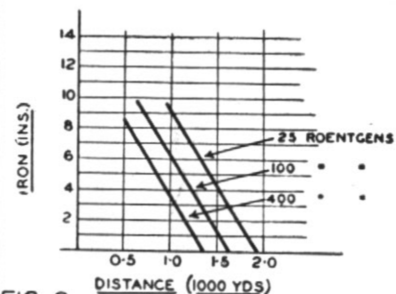


FIG. 8.

SHIELDING THICKNESS OF FERROUS METALS

produce a worthwhile radiation shield, e.g., 3 inches of armour plate will reduce the dosage to 25% of its original value.

Residual Radiations

Consideration of the effects of the residual radiation from an atomic explosion is a subject to which several papers should be devoted in their entirety. The residual radiations will not cause large numbers of fatal casualties. If proper attention is given to passive defence measures, such casualties would be extremely small. In large scale operations the effect of certain areas being uninhabitable for varying periods will need to be taken into account in tactical plans. More important, however, will be the medical problems. resulting from non-lethal dosages to troops; and the multitude of administrative problems arising from contamination of food, other supplies and equipment. Procedures associated with "mapping" contamination intensities, inspection and decontamination will produce many new training problems. It is not intended to do more than mention these problems here. The remaining part of this brief discussion of residual radiations will be devoted to an explanation of the principal characteristics of the residual radiations.

The residual radiations, as has been indicated already, are emitted after a minute from the instant of the atomic explosion. They arise from—

(a) Fission products,

(b) Uranium 235 and plutonium that have escaped fission.

(c) Activity induced by neutrons in various elements present in the earth and sea.

The major portion of the residual radioactivity is due to the decay of the fission products. The induced activity is important only in the case of ground, underground and underwater explosions. Confining the discussion once again to the air burst nominal bomb, it will be seen that the residual radioactivity hazard is due to (a) and (b) above.

The radioactive fission products and the uranium and plutonium being heavier than air, eventually fall to the ground. The intensity of the radiations they produce and the area over which they occur are determined mainly by the meteorological conditions at the time of the explosion. This precipitation of radioactive materials has become known as "fall-out" and the area over which they spread is the "fall-out area." It would appear that field meteorology will become an important service to a field commander.

The residual radioactive effects are due to gamma rays and alpha and beta particles. Brief mention has already been made concerning the interaction of gamma rays with matter. Although the properties and the mechanics of interaction of the alpha and beta particles are different, the overall effect is the same —i.e., they cause ionization, and hence are a physiological hazard. The range of the alpha particles is such that it would produce no harmful effects unless the material emitting it is ingested or finds its way into an open wound. Beta particles, on the other hand, would cause harmful effects if deposited on the skin or even on clothing.

Consideration of the lethality of residual radiation leads to the question of the effects on the body of small doses which continue over a period of time as distinct from the flash dose received from the initial radiations. It has been stated that 400 roentgens "one-shot" dose would result in a 50% chance of survival However, if 400 roentgens were received over a period of one month (12-14 roentgens/day) the chance of death would be considerably less Not very much is known of the detailed effects of small continuous doses of ionizing radiations on the human body, and as a result the standards employed in industrial environments are conservative. The figure generally employed for people continuously subject to such radiations is 0.1 roentgens per day, with an over-riding provision that it shall not exceed 0.3 roentgens per week. There is no doubt that soldiers, civilians and civil defence workers in a future war will be called upon to endure continuous doses much greater than those accepted for peace-time industrial purposes.

The Scaling Laws

The value of the great amount of quantitative information on the nominal bomb is very much enhanced by the facility with which scaling laws may be applied to derive similar quantitative information for atomic explosions in general. In spite of the complex conditions that exist in the immediate vicinity of an atomic explosion, the justification for applying simple scaling laws to explosions of different power rests on the following foundations:—

(a) The energy source resulting from the explosion is concentrated.

(b) The distances at which the results of the scaling are required are large compared with the radius of the sphere in which the initial build-up of the explosion takes place.

(c) The attenuation of the various radiations in the atmosphere obeys an exponential law.

Different atomic explosions may thus be considered, with reasonable precision, to have originated from a point source or more correctly a small isothermal sphere. On the foregoing premises the various state variables — pressure, temperature, radiation intensity, etc., may be considered as functions of distance from the explosion. The results for any explosion may be obtained from those of the reference explosion multiplied by a function of the initial energy release and where appropriate an exponential decay function.

The variables of greatest interest in assessing military effects are—

(a) Blast overpressure,

(b) Intensity of thermal radiation,

(c) Intensities of nuclear radiations.

Blast Overpressure

If E_n is the energy release of the nominal bomb and r_n is the distance from the explosion, it may be proved that—

$$\frac{r}{r_n} = \left\{\frac{E}{E_n}\right\}^{1/3}$$

This means that the peak overpressure is a universal function of $r/E^{1/3}$. Reference to Fig. 2 shows that a nominal bomb produces a peak overpressure of 5.2 lb./sq. inch at a distance of 2000 yards from ground zero. If a bomb with an energy release of 8 times that of the nominal bomb were exploded, this same overpressure would occur at a distance given by—

$$r = r_n \left\{\frac{E}{E_n}\right\}^{1/3} = 2000 \times \left\{\frac{8}{1}\right\}^{1/3}$$
$$= 4000 \text{ yards}$$

A thermo-nuclear bomb one thousand times as powerful as a nominal bomb would cause severe damage (i.e., 5.2 lb./sq. inch overpressure) up to a distance of 20,000 yards—perhaps not as far as one would expect!! One thousand nominal bombs appropriately distributed would devastate an area ten times as great.

Thermal Effects

If e_n is the total thermal energy associated with the explosion of a nominal bomb having a total energy E_n, then at distance r_n the quantity of heat energy Q_n per unit area is—

$$Q_n = \frac{e_n}{4\pi r_n} 2 \,.\, e^{-kr_n}$$

where k is the atmospheric attenuation factor.

For a second atomic weapon liberating an amount of heat energy e, the distance at which it will produce a heating effect similar to that of the nominal bomb is given by

$$Q_n = \frac{e}{4\pi r} 2\, e^{-kr} = \frac{e_n}{4\pi r_n} 2\, e^{-kr_n}$$

$$\frac{r^2}{r_n^2} = \frac{E}{E_n} e^{-k(r-r_n)}$$

In considering two bombs whose energy release does not differ by more than a factor of (say) 2 the exponential term may be ignored, and radii at which equal heat effects are produced are approximately proportional to the square root of their respective energy release. When the energy ratio is considerable, and when the attenuation is high, the more accurate result may be obtained graphically by reference to Fig. 3. The ordinates are scaled in the inverse ratio of the energy release, and corresponding abscissae measure the respective distances at which equal radiation intensities are received.

Scaling of Effects of Nuclear Radiations

The problem of scaling the effects of nuclear radiations is more complicated than for blast and heat. This is due to the fact that the neutron and gamma ray intensity depends on the geometry and other design details of the bomb, as well as the actual energy release. In other words, these radiations do not carry a *fixed percentage of the energy* of different bombs, for example, the neutron energy that escapes from a nominal bomb has been stated as approximately 0.03% of total energy—this is not necessarily the case for thermo-nuclear weapons. However, for two fission weapons which are not too dissimilar in construction and size it is reasonable to suppose that the energy associated with neutrons and gamma rays is proportional to the total energy. In such circumstances the ordinates of Figs. 5 and 6 may be scaled in the inverse ratio of the energy release, and the corresponding abscissae will measure the radii at which similar intensities of radiation will occur.

As an example, consider the gamma radiation for a bomb with energy double that of the nominal bomb. From Fig. 6 it will be seen that a median lethal dose of 400 roentgens will occur at 1400 yards. If the ordinate is now multiplied by ½ to give a dosage of 200 roentgens, the corresponding abscissae is approximately 1600 yards.

Lethality of Atomic Weapons and the Estimation of Casualties and Damage

The considerable amount of data on the physical effects of the nominal bomb, together with a knowledge of the scaling laws, provides a quantitative basis for—

(a) The estimation of casualties,

(b) Calculation of damage to military installations and equipment.

Careful and painstaking study of these problems is most important, as the results of such study provide the starting point for all subsequent work on the effect of atomic weapons on military operations. A further point of importance is that this work must of necessity be mainly theoretical, for it is clear that in future wars experience of the effects of atomic weapons will not be gained *in sufficiently small* steps to permit the build up of knowledge by trial and error methods.

Estimation of Casualties

The estimation of casualties depends on a large number of factors, the more important of which are—

(a) Power of the atomic weapon,

(b) Nature of the burst, i.e., air burst, underwater burst, etc.,

(c) Passive defence condition of the troops (this factor is influenced by warning time),

(d) Atmospheric conditions,

(e) *Geographical (including topographical)* distribution of troops,

(f) Accuracy of delivery.

The first four factors may be taken together to define a **lethality function for the weapon.** The remaining factors define a **distribution function** for the troops in the area. It is reasonable to assume radial symmetry for the lethal effects of an exploding bomb, *i.e., same effects* take place in all radial directions. The lethality function, therefore, may be considered as a function of distance only from the explosion, provided that the passive defence condition of the troops is uniform over the entire area. If this is not the case, it would be neeessary to introduce a passive defence function which depends on both distance and bearing. Alternatively the lethality function could be described as a function of both variables. For the purpose of this discussion, however, a uniform passive defence condition will be assumed, and the lethality function will be dependent on r, the distance from the explosion.

The troop distribution function may in general be considered as a function of distance and bearing, i.e., G (r, θ).

It is easy to prove, then, that the total casualties over a given area is given by—

$$C = \iint L(r)\ G(r, \theta)\ r dr . d\theta$$

and the limits of integration are defined by the particular area under consideration.

This expression for the casualties cannot be evaluated analytically in all cases. A number of simple ones may readily be solved, and the answer to more complicated cases can always be obtained by resorting to graphical or numerical integration.

Solutions have already been obtained in cases characterized by the following conditions:—

(a) Power of bomb—nominal or standard,

(b) Type of burst—air burst,

(c) Passive defence situation,
  (i) Troops in open,
  (ii) Troops "well dug in."

(d) Atmospheric conditions—very clear,

(e) Troop distributions,
  (i) Uniform two-dimensional or area distribution,
  (ii) Linear distributions.

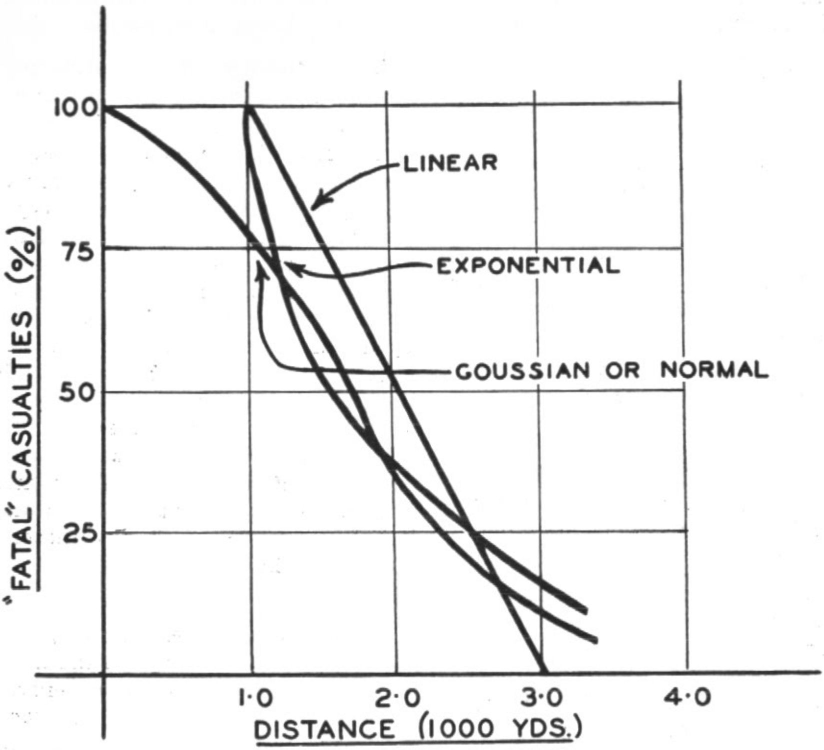
(f) Accuracy of delivery — miss distances of 500, 1000, 1500, 2000 yards from centre line of the linear distribution.

Under these conditions it is possible to determine the lethality functions for the two passive defence conditions. There is a number of types of curves that may be used to represent the function. Three types are shown in Fig. 9. The results given below are based on the linear approximation. The lethality function for the case of troops in the open has been obtained from the data given in Figs. 2, 3, 5 and 6. It is approximate, and admittedly is a "worst" case. However, as the main purpose is to compare casualties for different distributions and miss distances, the exact form of the lethality function will not materially affect this.

The question of troop distributions demands that consideration be given to the intensity of troops in the field. A study of conventional defensive layouts indicates that in a brigade group the intensity of troops is approximately one per 2500 sq. yards. If this figure is halved to make an initial allowance for the atomic situation, then a concentration of 1/5000 tps./sq. yd. would be obtained. This is approximately one man per acre, and such dispersion is considered to be the maximum that would permit effective tactical and administrative handling of troops without considerable reorganization of field forces.

In dealing with linear distributions the same figure for the concentration has been used. The linear distribution is further assumed to be 500 yards wide.

The results of the calculations are given in Table 5.



LINEAR APPROX'N. $L(r) = 1 \qquad 0 < r < 1000$

$= \frac{1}{2}\left(3 - \frac{r}{1000}\right) \qquad 1000 < r < 3000$

EXPONENTIAL $L(r) = 1 \qquad 0 < r < 1000$

$= e^{-\left(\frac{r}{1000} - 1\right)} \qquad r > 1000$

GOUSSIAN $L(r) = e^{-\left(\frac{r}{2000}\right)^2} \qquad \text{ALL } r.$

FIG. 9.

METHODS OF APPROXIMATING THE LETHALITY FUNCTION

Linear distributions suggest a lattice system of field formations—the bars of that lattice giving depth and the uprights providing for support.

The large ratio in casualties for the area and the linear distribution must not be taken as an indication of the merit of the two systems with-

Fatal Casualties from Atomic Attack on Troops in the Open

Type of Distribution	Miss Distance (yards)	Casualties
Area	—	3000
Linear	0	400
	500	380
	1000	280
	1500	195
	2000	110

TABLE 5

out further qualification. The casualties in the 500-yard strip are low, mainly because there are many less troops in the strip in the first place. If a given number of troops is to be deployed in a given area, the density of troops in the lattice would need to be increased, and hence the casualties would increase also. If the area is not fixed, then the lattice arrangement automatically gives greater depth for a given number of troops. This is most desirable, provided it does not result in individual lattice members becoming too weak. Certain other attractive features of the lattice layout depend on the following considerations:—

(a) Reference to Table 5 shows that the casualties for an area distribution, even with a troop concentration of one per acre, could not be tolerated — in other words, the dispersion would need to be much greater, and as a result problems of tactical and logistic control would become serious. On the other hand, one or even more per acre could be permitted along the members of the lattice.

(b) The lattice distribution can be designed to set a top limit to the number of casualties any one atomic weapon can inflict.

(c) As the casualties fall with miss distance, the enemy is faced with an additional factor in ensuring the cost-effectiveness of his atomic strike is sufficient to warrant its employment.

(d) The linear distribution leads naturally to the "strong-point" method of deployment if the distribution along a lattice is contracted until the troops are concentrated at centre points of its members.

These remarks have been based on a lethality function which has been constructed to deal with a "worst" case. If instead a "best" case is taken, i.e., a maximum of digging-in and other passive defence preparations, the lethality function may be modified to give—

(a) 100% casualties from G.Z. to 500 yards.

(b) A linear regression from 100% casualties at 500 yards to nil at 1500 yards.

If this is applied to the calculation of casualties, then the results given in Table 5 are altered to those given in Table 6. Table 6 also shows casualties if the concentration is in-

Fatal Casualties from Atomic Attack on Troops "Well-Dug-In"

Type of Distribution	Miss Dist. (yards)	Casualties	
		1 per 5000 sq. yds.	4 per 5000 sq. yds.
Area	—	680	2720
Linear	0	200	800
	500	150	600
	1000	55	220
	1500	0	0

TABLE 6

creased to four soldiers per 5000 sq. yards, as it is felt that elaborate passive defence works would demand a somewhat greater concentration of troops than one per acre.

In applying these figures to the design of a lattice system of troop distributions, the tactical and logistic problems are reduced in complexity as size of the lattice mesh is reduced from something of the order of 6000 yards to 3000 yards. This means that with an intensity of four men per acre there are approximately 1200 men for deployment on a 3000-yard front.

Damage to Military Installations

An estimate of damage likely to be caused to military installations, such as ordnance depots, base camps, port facilities, can be made from the data assembled in the foregoing sections of this paper. Space will not permit any very full investigation being recorded here. However, the following observations are of interest:—

(a) Assuming a peak overpressure of 5-6 lb. per sq. inch will cause severe damage to steel mill buildings, ordnance sheds, workshop buildings, and all kinds of camp buildings, then the area over which such damage would occur is of the order of 1.5 square miles.

(b) Over the same area the intensity of the heat flash would be such that it would contribute materially to initiation of fires. In conjunction with the blast effects, the fire hazard would extend the area of severe and permanent damage to something like 3 to 4 square miles.

(c) A perusal has been made of the ground plans of certain ordnance and R.A.E.M.E. base installations, and it is at once obvious that some depots would be totally and completely destroyed. Others would not fare much better.

(d) A typical training camp would also be destroyed, and most of its occupants would be fatal casualties. (Concentration of troops at such a camp is about 12 per acre.)

(e) Much of the heavy equipment (guns, trucks, etc.) at the ordnance installations could be salvaged, but there would be a serious decontamination and repair problem associated with making it suitable for issue.

These observations indicate that the damage problem to existing type installations would be very serious indeed. The analysis given in the previous section of the paper may have even greater application to the problem of layout of military installations — a linear layout would certainly minimise the damage. A study should be made of the problem of "phasing" stocks in various depots to ensure that the complete stocks of no essential store were located in one depot.

There is no doubt that the greatest contribution to the reduction of physical damage to installations, stores and equipment will result from going underground.

The Cost-Effectiveness of Atomic Weapons

In this brief review it will not be possible to carry out a complete analysis of the cost-effectiveness of atomic weapons. Furthermore, any valid conclusion would depend on authentic information of the design details and the manufacturing processes of atomic weapons. However, there are certain factors which bring light to bear on this problem, and it is proposed to discuss them here.

In considering the cost of an atomic weapon both the cost of the weapon itself and the cost of delivery must be taken into account. In fact, by doing this the lack of information on the actual cost of the weapons can to some extent be eliminated from the problem.

The basis for an estimation of cost of delivery of an atomic weapon is a comparative one. The most spectacular case is that of their strategic or tactical/strategic employment. It has been variously estimated that the effect of a single nominal bomb is comparable to that of a "thousand bomber" conventional raid. If this estimate is seriously in error, then it can readily be corrected by substituting a bigger bomb—up to say four times the power of a nominal bomb. On the basis of this equivalence there is little need to extend the argument further. A nominal or a 4 x N-bomb could be delivered by a single bomber. On the other hand, a thousand bomber raid represents a capital investment of something of the order of £500 million. Assuming a 5% loss of aircraft in such a raid, and a 15% maintenance and operating overhead, it would appear that such a raid would cost something of the order of £100 million. It would seem, therefore, to matter little if the atomic weapon itself cost £1,000,000 or £10,000,000.

A typical tactical comparison cannot be made in such general terms. In the case of troops deployed in the open there is some evidence to support the claim that 100,000 25-pdr. shells may produce the same order of casualties as a nominal bomb. However, unless they were delivered almost instantaneously (and that would require a prohibitive number of guns), the casualties would drop very rapidly as troops took cover. However, if it is further assumed that the artillery attack is spread over 10 minutes, then it would require something like 2000 field pieces to carry out the job. Such a number of 25-pdr. guns would represent a capital of £20,000,000. Such a concentration of artillery is roughly equivalent to the total resources of an Army. The total overhead associated with such a deployment (vehicles, fire control gear, personal equipment) would be of the order of £100 million. Assuming a figure of 20% for the maintenance and operating costs, then the cost of delivery is of the order of £20,000,000. Although this comparison is not so spectacular as the former, it does nevertheless draw attention to the fact that the cost of delivery is more important than the actual cost of the lethal part of the weapon.

It is not fair to leave this aspect of the discussion without mentioning that the mass fire support envisaged in this context is only one of the roles of artillery. In addition, an effective neutralising barrage of an area equivalent to that destroyed by a nominal bomb is often all that is required, and such fire support could be given by the normal resources of a divisional artillery.

The "effectiveness" factor in the cost-effectiveness equation has been implied in adopting the comparative method. In other words, to achieve a given result the relative costs of atomic and conventional fire power have been assessed. Furthermore the cost of the weapon—which is unknown—has been eliminated.

Before concluding this section mention is made, however, of the actual values that the effectiveness term may embrace. It was stated earlier that one atomic weapon (nominal) would be sufficient to destroy a major ordnance depot. The capital cost of such a depot (including its associated R.A.E.M.E. workshop installations) may be taken to be something in excess of £5,000,000. The stores contained in such a depot could have value of upwards of ten times this figure, i.e., £50,000,000.

From this brief and not too rigorous analysis, it would be safe to conclude that the cost-effectiveness of atomic weapons is likely to be high in comparison with standard weapons, especially against military installations and base facilities, such as ports and depots. So far as their use in the field is concerned, the situation is more obscure. If the discrimination of targets is adequate, a major tactical success may be achieved. However, to compare atomic and conventional artillery only in the case of "massed" fire support is not fair, as the conventional weapons have a wide variety of other functions.

Conclusion

In setting down the conclusions resulting from the foregoing discussion it is important to emphasise that they are based on information which is in the main unclassified. Some of the "real" secrets may alter such conclusions drastically. However, even if they do, no real harm will have been done, for the main object of the paper has been to show how basic data on the effect of an atomic explosion may be applied to a military situation. If new data are supplied, new calculations may be carried out and fresh results obtained.

With this in mind, it is felt, then, that within the limitations of the available information the following conclusions may be warranted:—

(a) There is considerable literature available on the subject.

(b) The known effects of the nominal bomb and the scaling laws permit determination of the effects of atomic weapons of all sizes likely to be employed in military situations.

(c) Determination of casualties resulting from use of atomic weapons is difficult. It is, however, important that work should proceed on this task in order to provide quantitative data for new planning. Work on estimation of casualties already carried out reveals—

(i) Casualties fall very rapidly as the passive defence measures are improved,

(ii) Linear distributions of troops reduce casualties to a marked extent, and it appears that consideration should be given to the tactical and organizational problems involved in a "lattice" distribution of field forces,

(iii) Casualties and damage in built-up and congested base areas, ports, L of C installations will be heavy.

(d) The pollution of large areas by residual radiations will influence large-scale tactical planning, and will introduce a whole series of administrative problems relating to contamination of personnel, food and equipment.

(e) Cost-effectiveness should be high, provided there is adequate discrimination of targets, and that accuracy of delivery is sufficiently high.

(f) It will be necessary to provide on the various formation headquarters a senior staff officer, who is basically qualified in physics and mathematics, and who has been trained and experienced in the many specialised problems relating to the employment of atomic weapons. Such an officer may require his own small staff of scientists at G.I. and G.II. level.

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The EFFECTS of ATOMIC WEAPONS on MILITARY OPERATIONS

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This paper is to be regarded as RESTRICTED and is not to be republished, in whole or in part, without the permission of Army Headquarters.—Editor.

THE aim of this paper is:

(a) To discuss the tactical employment of A-weapons in the field, with particular reference to the defence, and

(b) As a result of some quantitative estimates of the effects of A-weapons in various tactical situations to bring out some of the more important lessons which will determine the most effective measures, both active and passive, which can turn the introduction of A-weapons to our own advantage.

Introduction

As the effects of A-weapons represent an increase of weapon effectiveness by an order of magnitude, we must be prepared to examine tactics and organization from first principles to decide whether basic changes in either or both may be necessary.

Throughout our discussion, we must keep constantly in mind the twofold problem:

(a) The adaptation of the field force to suit atomic conditions, and

(b) The best use of our resources to obtain the maximum effectiveness with conventional weapons. (For example, in dispersing our force in a defensive position we must ensure that we do not leave ourselves open to defeat by conventional means.)

Probably no previous single change in the materials for waging war has provided such a scope for detailed analysis. We have seen a few of the early attempts to provide the answer in a number of articles already published. No doubt further solutions will be forthcoming and will be widely divergent, and are likely to range from the notion that A-weapons are merely a natural extension of conventional support weapons to be taken in our stride (just as a tactical air force has come to be accepted as a normal means of support), to the opposite extreme view that A-weapons will entirely change the nature of the battle-field and lead to a push-button war.

I believe that the results of careful and deliberate study which is going on at present will find a solution which will not be extreme, but which will indicate the need for changes in organization and methods, both in tactics and administration, and which will probably lay new and greater emphasis on some of the well-established factors and principles. We should not expect changes in principles because, if they are true principles, they are not likely to alter. It is the changes in methods and in the possible changes of emphasis on the several factors which contribute to success in battle in which we will find the most profitable field of study.

Types of Weapons to be Considered

The physical effects of atomic weapons are now well known. Most of the details of their effects on men and material in a wide range of conditions are well known and may be found in the unclassified literature. The most valuable publication to date is "Effects of Atomic Weapons," produced by the Los Alamos Scientific Laboratory in USA. Practically all the information on which this paper has been based has been drawn from this source. I do not know whether the so-called Hydrogen bombs — or more correctly thermo-nuclear bombs — are likely to be used in the field. Their primary use appears naturally to be for employment against major strategic targets rather than for tactical use. Large ports, vital industrial areas, beach-heads such as the one developed in OVERLORD, major river crossings, and large civilian targets such as big cities seem to be the natural and primary targets for thermo-nuclear weapons. However, the appearance of thermo-nuclear weapons in the battle-field is not out of the question.

The use of either type of atomic weapon in the field, and the scale of their availability, will depend quite naturally on the strategic appreciation by the combatant nation. We may assume that each of the likely combatants will have both types of atomic weapons available in finite but considerable numbers. It seems probable that superiority in numbers of atomic weapons may be the Allies' only initial advantage. Naturally, strategic targets, which may be attacked by long-range bombers or guided missiles or possibly by seaborne weapons, will have first call on a nation's atomic potential. If the supply of either or both types of weapon can be extended to provide for their tactical use, the scale of provision for use in the field will *be determined by an appreciation* designed to obtain the maximum effectiveness of the total supply of atomic weapons. For example, if in the last war, high explosive were in critically short supply, it would have been quite a nice problem to decide whether the greatest effectiveness were to be achieved by putting it into 10-ton bombers to demolish cities, or by using it in large numbers of shells in the field, or to determine what combination of the two would produce the optimum solution. From such a consideration, it seems reasonable to suppose that atomic weapons will be available for field use and that the scale of provision will, at least in the early stages of a war, be somewhat limited.

For the purpose of the present discussion, the case is built on fission weapons, although the possibility of the use of thermo-nuclear weapons must not be excluded. Two considerations point to the possibility of more liberal use of thermo-nuclear bombs.

(a) They are now, I believe, much simpler and compact in construction.

(b) The development of a fusion bomb which does not require Uranium or Plutonium as a primer should always be regarded as technically feasible.

Initially, let us concentrate on the weapons which we now expect to find in the field, but be conscious of the fact that we have limited the scope of the discussion, and remain aware that there are in the background other possibilities which, if introduced, will bring changes of a further order of magnitude and a new set of far-reaching implications.

In addition, there is the next regular step in the problem—the extension of our tactical methods to provide for the day when atomic weapons in the field are plentiful.

As a basis for our problem, therefore, and to keep it to manageable proportions, let us start with some reasonable assumptions and apply to some typical situations the well-known physical effects of atomic weapons, and leave the discussion of the problem of tactics in the presence of thermo-nuclear weapons or of atomic plenty until another day.

As a starting point for our discussions, let us begin by assuming:

(a) That atomic weapons of energy capacity one-quarter to about four times that of the nominal (20 KT) bombs will be available in the field in small numbers for a given tactical event on a divisional scale or larger, and

(b) That these weapons may be delivered by bomb, shell or guided missile with a degree of accuracy of the same order as that of a heavy gun.

Tactical Effects of A-Weapons

Before trying to evaluate the changes in tactical employment of field forces, let us apply the effects of a nominal (20 KT) bomb to a reasonably typical divisional area.

Let us examine three cases:

(a) The worst extreme—with all troops and equipment in the open.

(b) The best case — all troops under cover, with 18 inches or more of head-cover and equipment and vehicles dug in as far as would be practicable.

(c) An intermediate case — say four-feet trenches for all personnel but no overhead cover except in command posts and with vehicles and weapons only partly dug in.

Now let us study the divisional picture under these conditions and see what results might be expected from one nominal bomb. The area is shaded to show the areas in which a

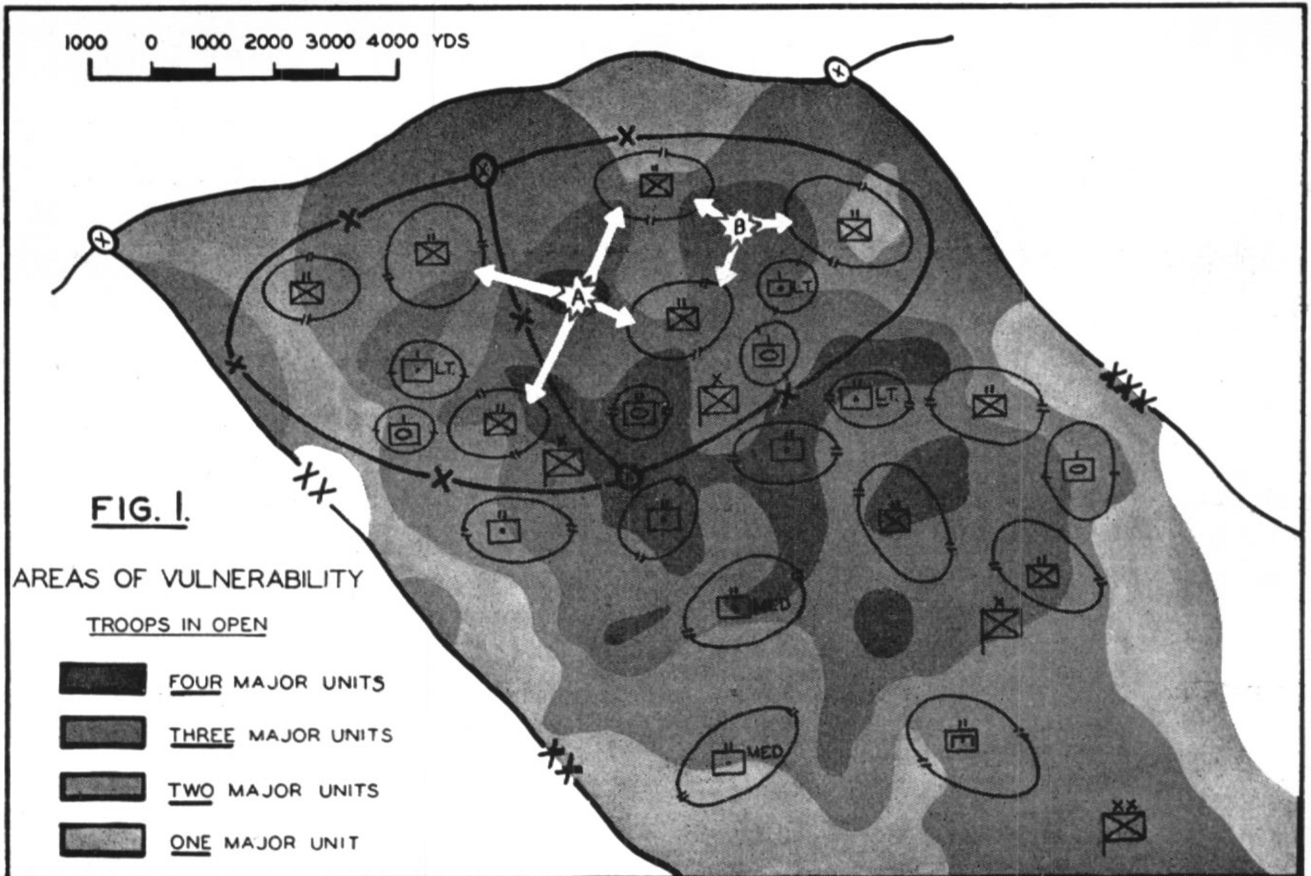

FIG. 1.

AREAS OF VULNERABILITY

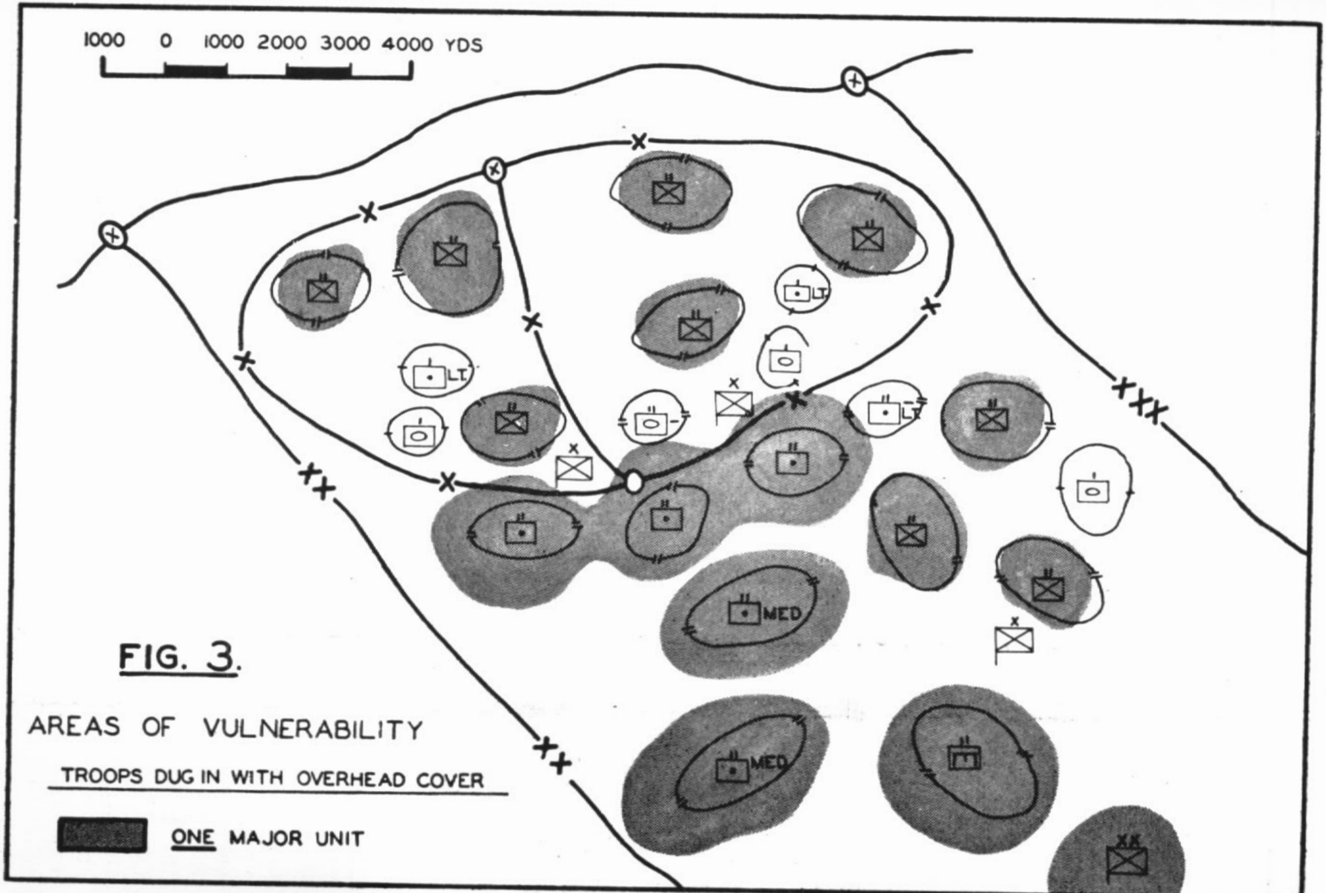

FIG. 3.

AREAS OF VULNERABILITY

ground zero may be located with the result that the explosion would effectively destroy the tactical effectiveness of one or more major units.

From an examination of the effects in the worst case, shown in Figure 1, it is clear that one or two nominal bombs suitably placed could effectively destroy the defensive position. For example, a bomb exploding over a ground zero at point "A" would eliminate the four battalions as shown in Figure 1, while one with ground zero at point "B" would eliminate the three units indicated. In this case, the large area of destruction is predominantly due to the flash of thermal radiation.

Now let us turn to the other extreme, where everyone is provided with at least 18 inches of overhead cover, and there has been some warning of the approach of the weapon, so that everyone has had the opportunity of availing himself of the protection available. In this case, shown in Figure 3, the effect of heat is practically eliminated, unless troops are unlucky enough to be trapped in burning buildings or forest and suffer secondary effects of heat radiation.

The primary effects of blast would produce few casualties but the secondary effects of blast are quite unpredictable; injuries are likely to be caused by flying debris, or by collapse of overhead cover, rather than by the direct effect of blast on the body. The major causes of casualties in this case will be radiation with some casualties caused by the secondary effects of blast. An examination of the percentage of casualties to be expected from all causes, as a function of distance from ground zero shows how considerably the danger area has been reduced.

The interesting feature of the comparison between these two cases is the fact that whereas the most effective positions for ground zero in the first case were near the centre of mass of a group of units, in the second case, a ground zero needs to be practically inside a unit's perimeter for the weapon to be completely effective.

These are the worst and the best cases, and neither is likely to be realised in the majority of situations. An intermediate case is shown in Figure 2, where everyone has the opportunity of being four feet below the surface of the ground, but without overhead cover. It has been assumed that everyone is making the best use of his cover, although not all will be protected from direct line of sight to the point of burst.

In this case, there will be a wide range of casualty incidence, depending as it does on the length of straight portions of trench, the orientation of the trench with respect to ground zero and the exact height of the point of burst above ground level, as well as each man's position in the trench at the time of burst. The casualty estimate has been based on the expected or mean values of the probability distribution. A fairly wide range of better or worse cases must be expected, depending on the true distribution of the several factors which influence the result.

It is mentioned that physical features of ground will not have much shielding effect, as 2000 feet — the optimum height of burst for a nomi-

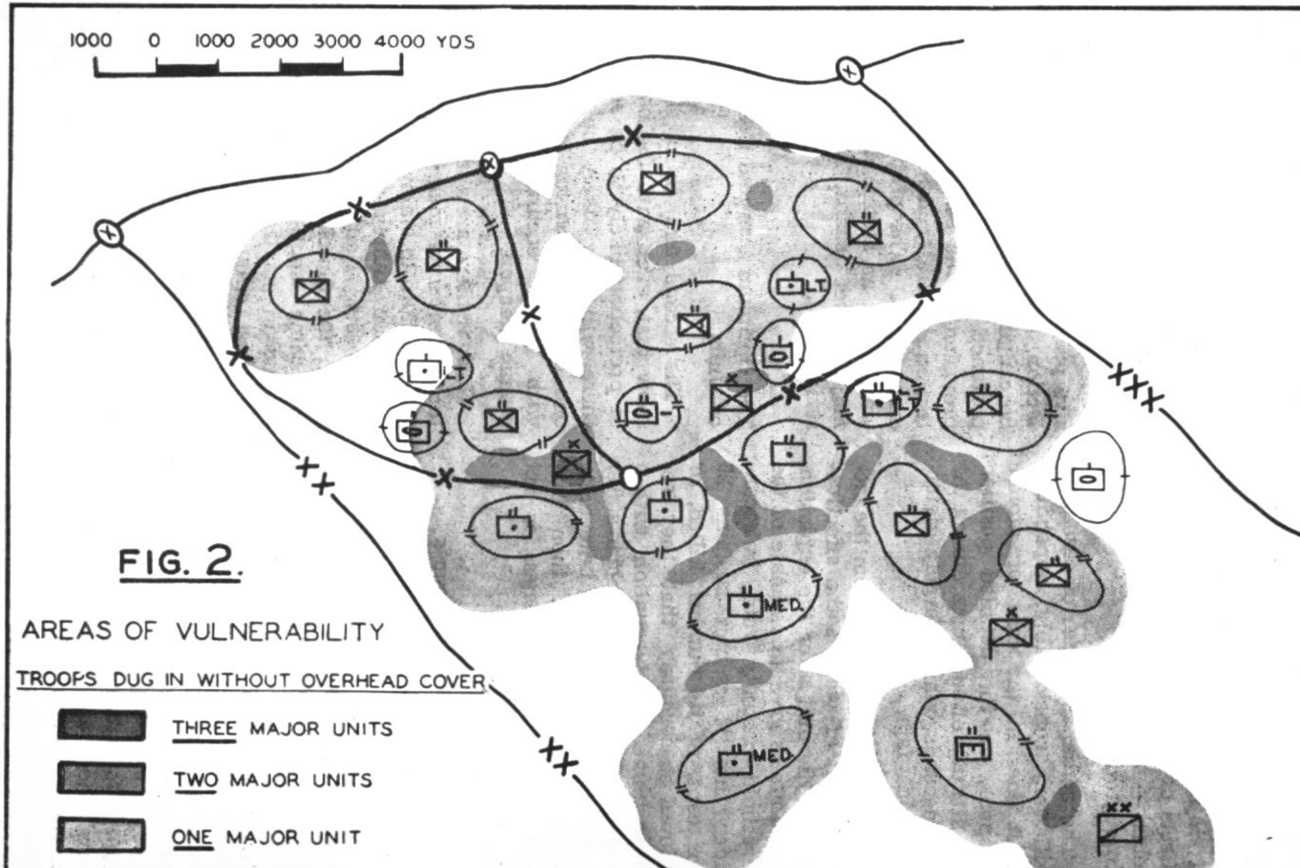
1000 0 1000 2000 3000 4000 YDS
AREAS OF VULNERABILITY
TROOPS DUG IN WITHOUT OVERHEAD COVER
THREE MAJOR UNITS
TWO MAJOR UNITS
ONE MAJOR UNIT
LT.
MED.
XX
XXX

FIG. 2.

nal bomb — subtends 37½ degrees at 880 yards. The presence of timber, however, presents a serious hazard, as it will greatly increase the risk of injuries from the secondary effects of blast—flying branches and debris — up to 2500 yards or more from ground zero.

The actual incidence of casualties will vary considerably, depending, as it does in the case of atomic weapons, on the detailed position and attitude of each man during the two seconds which largely determine his fate.

The important result from the tactical point of view is the effectiveness of the unit after the explosion. I hesitate to give an estimate of the threshold casualty rate, but consider that if a unit sustains 25 per cent. of its number killed, or injured so seriously that they require immediate evacuation, with a proportionate number liable to suffer delayed effects, or with immediate but less severe effects, then that unit's fighting effectiveness is set down at zero.

Tactical Consequences

The Value of Cover

It is neither a new nor a surprising result that overhead protection makes a very material contribution to the safety of troops in the presence of an atomic threat. The principle is well appreciated; the degree of protection may not have been quite as obvious. When troops are exposed it does not appear to matter quite so materially how they are arranged on the ground in units and sub-units; the effect is much the same, as shown by the large areas of vulnerability in Figure 1. Not all troops can expect the same degree of overhead cover at all times. The artillery units will be particularly vulnerable when the guns are manned. The results can be minimised by even a few seconds' warning of the approach of an atomic weapon, provided that each man has nearby some form of defensive preparation with overhead protection. Inevitably, some men will be caught in the open, but the importance of early warning and the provision of the best available protection generally cannot be overemphasised. The problem of early warning of an atomic threat, which may include shells, is indeed a serious one.

The Optimum Size and Composition of Units

The second and third situations show that, even with the best form of protection likely to be achieved, there will very likely be at least one major unit virtually destroyed with each accurately delivered atomic weapon.

Now, if there are a strictly limited total number of men available, we cannot afford to maintain a balanced disposition simply by stacking in more units. Neither can we go too far in the direction of distributing the same man-power over the ground in smaller groups, because we must still maintain the maximum effectiveness in the conventional battle.

I suggest that we need to look for the optimum arrangement with a larger number of self-contained organic units within a formation. From a study of the effects of the atomic threat alone, I should say that the smaller each unit can be made the better the result will be. Balancing this against the conflicting consideration of strength in the conventional battle, I should think that the optimum will be reached by determining the maximum workable number of the smallest practicable self-contained, mutually supporting organic units possible within a formation. Moreover, the unit so determined must represent the optimum solution and the one most suitable for all phases of war.

Disposition of Major Units

I am not going to be rash enough to propose a blue-print for this new streamlined Army. If the result is based primarily on technical considerations, I suggest that it will require a very material alteration in the organization of the field force as we know it. Possible solutions may include the reduction in size of the infantry battalion, with a greater proportion of automatic weapons and an improvement in its own support weapons to make up for loss of manpower by increased fire-power. This should not be regarded as an easy solution as each new automatic weapon means an increase in the administrative "tail." We will probably be obliged to seek means of increasing fire-power and to find drastic methods of reducing the administrative load, which is already great. As it is now possible to destroy completely the effectiveness of a major unit in a matter of seconds, it becomes apparent that, in siting units on the ground, it will be necessary to think in terms of more than three units as the tactical group, and to site them in sets of more than three. It is clear that it is not possible to arrange a group of three positions in such a way that, when any one is removed, the other two may present a balanced organization. In order to achieve this result, at least four and preferably more should be grouped. As grouping means co-ordination of mutual defence, including the fire plan, the group should be under a single command.

Now there is a limit to the number of subordinate units which a headquarters can command, control and administer. An optimum number of units should therefore be determined, greater than three, but not too numerous to be manageable. Whatever the formation next above the battalion should be it is suggested that it ought to contain not less than five battalions, so that balance can be maintained despite the loss of one or possibly two complete unts.

The Counter-Attack Force

It is normal for a commander to have at his disposal a mobile force which may be launched in a deliberate counter-attack when the momentum of the enemy's attack has been lost. It is an advantage to have this force reasonably concentrated and, of course, usually above ground. Such a force would make an attractive atomic target, so that it will be necessary to keep it either protected by overhead cover or dispersed. Dispersion would appear to be the more feasible alternative, so that the problem then is to achieve the desired degree of dispersion up to the time of launching the counter-attack and then to concentrate rapidly just before the delivery of the attack. This will call for very careful co-ordination and rehearsal, a high degree of control and leadership at all levels and an efficient communication system.

The Optimum Size of A-Weapons

If we set aside for the present the possibility of the use of megaton class weapons, it would appear that the best size of A-weapon to use in the field would be one which, delivered with a given degree of accuracy, could cover one major unit in a well-prepared position with its zone of total destruction. If it were larger than this, but not sufficiently large to cover two units, the additional energy would be wasted. Within this maximum limit, an optimum size will be found such that the greatest tactical effectiveness may be achieved from the use of limited resources of fissionable material and of the means of delivering the weapons in the field. An approximate estimate of this value indicates that the most effective practical size is about 5 to 10 kilo tons, i.e., a quarter to half the size of a nominal bomb.

If thermo-nuclear weapons were available at a total cost of production and delivery of not more than a few times that of a fission bomb, it would be an economical proposition to use them in the field, because the thermo-nuclear vulnerability pattern would probably be worse against prepared positions than the one for fission weapons used against troops in the open.

The Artillery Problem

As I see it, the artillery problem is made worse than ever. Already, we are likely to be outnumbered and outranged by enemy artillery. In order to fulfil our task of providing shells on the ground where and when they are required and the complementary task of preventing the enemy from doing the same to us, we are compelled to push guns further forward and closer together than they ought to be.

We will probably still have to accept the loss of one major unit with each atomic weapon directed at it, as in most situations there are simply not enough battery positions to site our artillery by batteries so arranged that no single explosion will take out more than one battery. In any case, with the limited range of our present equipment, our guns would be out of range, and unable to carry out the CB requirement, quite apart from the certain disability of being unable to provide the depth and density of covering fire where it is required. The medium and heavy guns will therefore have to be put further forward than we would like them.

I do not expect to find the need for drastic reorganization of the artillery. We may find it an advantage to have slightly smaller regiments and more of them, but the problem of limited range and difficulty of finding enough gun positions puts a severe restriction on changes in artillery organization and employment.

The use of the super heavy (atomic) guns is a problem in itself. If we look at the converse of our defensive problem we will see some of the leading considerations. The time factor in atomic support will be vital because, in the defence, our most profitable targets are likely to be the opportunity targets, when the attacker is caught concentrated in the open. A glance at the first diagram will suggest the type of position into which we hope to force the enemy.

We do not know at present the technical considerations which will limit the time factor. I gather that it may take from 15 minutes to two hours from the appearance of a target to the delivery of a half nominal (10 KT) shell over it. It should not be more, and certainly less if we can make it. Control for the launching of A-weapons on opportunity targets will, therefore, need to be so delegated that the commander who is best situated to determine the most effective targets should be able to call for the timely delivery of atomic weapons on them.

Protection of the means of launching atomic missiles (guided missile platforms or S Hy (A) guns) will be one of the most important local defence problems. Such an attractive prize makes it appear to be one of the most vulnerable VPs. The weapons themselves are not able to contribute to their own local protection. Concealment alone will be difficult, but alternative and dummy positions will help. Ground protection should be provided against airborne attacks. The AA defence of these locations will probably be one of the highest priority AA tasks. These positions will be few in number, but I suggest that they should ideally be provided on a scale of about 100 per cent. in excess of the number required to ensure atomic support when it is needed.

The Selection of A-Targets by the Defender

The advantage of the defender is that, while he is likely to be well stage be exposed and, to a certain protected, the attacker must at some degree, concentrated, just how long he may remain concentrated preparatory to an attack will depend upon the speed and accuracy with which an atomic weapon can be delivered after a target is observed. How to achieve the degree of concentration required to ensure success by ground forces against a defensive position without presenting an atomic target is a subject for study in itself.

A suggested list of priority A-targets from the defender's point of view might be:

(a) "Atomic CB" if it is possible to use A-weapons to knock out those of the enemy, always provided that we have atomic superiority.

(b) Opportunity targets including enemy concentration areas where concentrations of troops in sufficient density are detected, for example at bridgeheads or physical features where he may be forced to concentrate temporarily.

(c) CB fire against his gun areas which are beyond the range of our own heavy guns.

(d) Covering an obstacle. — A-weapons should be particularly effective when the attacker is astride an obstacle — provided that our own FDLs are not too close to it. (This raises a question of how to locate our FDLs in relation to an obstacle.)

(e) Enemy headquarters, if accurately located.

(f) Targets located in his administrative area.

Although our gun areas are possibly one of our most vulnerable spots, this does not apply in the same degree to the enemy. This is principally so because, with his superior range, he can stand further back, as he probably will, to be outside the range of our CB fire. In addition, the greater range of his guns permits a higher degree of dispersion and, as he is believed to give less attention to CB than we do, he is less constrained to deploy his artillery forward.

Observation and Intelligence

The need for good observation of the enemy's position is paramount. With the imminence of very long range and accurate weapons in the field, the early detection of atomically attractive targets and the prompt delivery of a missile on them is vital. This range could be as great as 50 miles for a ground-launched weapon. Conversely, it is equally important to deny to the enemy observation of temporary concentrations or appearance of vulnerable points in our own area. Concealment and deception will be more important than ever.

The Role of Atomic Advisers

There would appear to be a vital necessity to study the atomic implications of every proposed tactical move. The problems will include:

(a) An assessment of the vulnerability of each part of our field force at any stage of the battle, and steps which may be taken to reduce this vulnerability.

(b) The choice of atomic targets and the allocation of priorities.

(c) The most efficient use of limited resources to gain the greatest effect from the atomic fire plan.

(d) The detection, marking and assessment of any radioactive areas.

(e) Casualty forecasts and provision of advice on special arrangements necessary for evacuation of casualties and provision of reinforcements.

There needs to be provision on each formation headquarters of a properly trained scientific staff. Whether this staff is to be a small central group to advise on all implications of the atomic problem or whether there should be a scientific officer in each of the existing branches of the staff to advise the staff on atomic aspects of their specific problems is a debatable matter. As there are unique problems confronting each branch of the staff as well as each Arm and Service, I believe that the most effective method of providing this service is to have a small group — probably one or two at Division with slightly larger groups at higher formations — to advise the Commander and his staff on all aspects of the atomic problem. Such a group would not only maintain a close scrutiny of the possible effect of A-weapons on the current position, on which they would work in close co-operation with the Operations staff, but they would act as an information centre on every aspect of atomic problems.

Camouflage

It will be at least as important in the atomic as in the conventional battle to practise camouflage and deception. It will be particularly important if well prepared positions are possible, especially if enemy weapons are liable to be aimed with a high degree of accuracy, as in this case it could make the difference between the effects of aimed and random fire, with the benefits to the defender which are illustrated by a study of Figure 3.

Training and Morale

There is likely to be a considerably increased necessity for greater mobility and greater speed of movement, in concentration and dispersion, with a consequent need for a high standard of control and efficient leadership at all levels of a command. The rapid reorganization of a unit after an atomic explosion may make the difference between an effective resistance and a debacle.

There are two important new factors which are introduced by the presence of atomic weapons.

Firstly, there will very likely be large numbers of delayed casualties among troops protected by armour or overhead cover from the effects of heat and blast. They may be comparatively unaffected, apart from the effects of shock, for some time after the explosion, but may be aware of the fact that they will in time become casualties from the effects of radiation. Just what the effect of this condition will have on the men themselves and on those nearby who may have escaped a dangerous dose of radiation is difficult to predict. There appears to be a moral issue involved in that, if immediate evacuation will enhance a man's chances of survival, he should not be require to fight on. Conversely, the moral fibre of those who have not had a dangerous dose, but think they have, will be severely tested. This new prospect demands a high standard of training and morale.

Secondly, there is the practical certainty that, virtually instantaneously, large numbers of men in a unit will become casualties while the remainder are almost unaffected. The level of incidence of casualties which a unit can suffer and still remain an effective force will also depend critically on the quality, including morale and leadership, of the men in that unit.

For a time, too, there will be a natural fear of the unknown, when nobody will know where or when an atomic explosion might occur, nor what to expect when it does occur. The development of passive defence measures, including an efficient warning system and experience in combat, will go a long way to solving this problem.

Conclusion

In the absence of experience in atomic combat, most of our preparation has to be based on predictions and on theoretical estimates.

The size and numbers of weapons employed will have a critical effect on the organization and employment of a field force. As the introduction of fission weapons even in limited numbers will have a considerable effect on military operations, there appears to be a prima facie case for a review of the organization and employment of a field force to find the optimum solution which will be most effective in both the atomic and the conventional situations.

The best use of cover, concealment and deception in a defensive situation is vital; in other phases of war, dispersion will be of the first importance.

The introduction of atomic weapons brings with it a fresh set of problems to determine the best methods of their control and employment. It is essential that the atomic aspect of all tactical problems should be examined and atomic advisers should be available at each formation.

There is an even greater need for a high standard of command, control, leadership and morale at all levels of command.

Experience cannot be accumulated gradually as has been possible in the past; it will be imperative to examine tactical doctrine for all phases of war to find the best means of turning the advent of atomic weapons of all types to our own advantage. This appears to be the most important contribution which research can make at the present time, because upon the atomic factor alone could well depend our very survival in a future major conflict.

The skilful employment and accurate application of superior nuclear fire power in combination with the operations of streamlined land forces can be a decisive factor in the land/air battle. The problem will be, how to force the enemy to concentrate his forces sufficiently to offer a worth-while nuclear target, without exposing our own forces to destruction by the enemy's nuclear attack.

In our forward thinking we must put the emphasis on organization, on tactical conceptions, and on the weapons and equipment that are necessary to enable us to fight in the way we want.

All our future depends on getting the right answers to the problems we now have to face.

—*Field-Marshal Montgomery.*

SIMPLE CALCULATIONS for TACTICIANS in NUCLEAR WAR

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Introduction

THE purpose of this article is to show how the basic data on the physical effects of nuclear weapons may be used to clarify many of the new situations that will result from their employment in the field. To do this a number of typical (though hypothetical) tactical situations have been taken and the effects of an atomic explosion in each context have been calculated. Whilst it is not the intention of the authors to draw tactical deductions it is hoped that the results of these calculations will provide a framework in which the tactician can move systematically in his study of the impact of atomic weapons on tactics.

The basic data on which the calculations depend are taken from "The Effects of Atomic Weapons," 1950, by Glastone and others, and a sufficient summary of these data is given in "The Physical Effects of Atomic Weapons."

It is somewhat surprising that a weapon so revolutionary as the atomic bomb should provide scope for the application of simple quantitative methods in the study of its impact on tactics. Deeper consideration shows, however, that this is not so astonishing as one might at first suppose, for the very magnitude of the effect of an atomic explosion smooths out or eliminates many of indefinable variables that would otherwise need to be considered. In addition, the heat flash and nuclear radiation are the main lethal agents in tactical situations, and the effect of these may be determined by the application of comparatively simple geometry.

In the examples which follow it will be noted that no account has been taken of the errors that will occur in the delivery of the bomb. This has been done in order that the particularly "atomic" aspect of the calculations may be emphasized. Aiming and delivery errors are well understood, and the problem of superimposing their effects on the results given below is left to the reader. It is also pointed out that little, if any, precise information is at present available on the actual magnitude of such errors for atomic weapons, and this is a further reason for not including them in the discussion.

Criteria for Assessment of Tactical Effects

The tactical significance of an atomic explosion depends on a variety of factors, such as resulting casualties, damage to equipment, effect on morale, radioactive contamination, and so on. In tactical situations the damage to equipment is of secondary importance. The morale effect may be very great indeed, but at this stage insufficient is known to make use of it for quantitative assessment. On the other hand, casualties resulting from an atomic explosion may be determined with considerable facility and precision, and so may be used as the basis for establishing the following criteria for assessing tactical effects, i.e.:

(a) The Limit of Effect—the radius of a circle, with centre at ground zero, and outside which the casualties from the explosion are negligible;

(b) The Radius of Neutralization—the radius of the circle, centre at GZ, inside which the proportion of casualties will be something in excess of 50%.

The application of these criteria permits ready computation of the vulnerability of various distributions of units and formations and also shows in the clear light the possible juxtapositions of our own and enemy troops.

It is well known that the lethal effects of an atomic explosion are fourfold, viz:—

(a) Blast.

(b) Thermal radiation.

(c) Nuclear radiations.

(d) Residual radiations.

The first three produce instantaneous tactical consequences, whilst the last mentioned places limitations on the use that may be made of the area in the vicinity of the explosion for some time afterwards.

The way in which the tactical criteria given above may be defined in terms of the physical effects is shown in Tables I and II.

Table I deals with the instantaneous effects. The limit of effect is determined by values of blast pressure, heat intensity and gamma radiation dosage which may safely be assumed to cause no casualties of any

Instantaneous Effects

Effect	Limit of Effect	Neutralization
Blast	1.5 lb./sq. in.	10 lb./sq. in.
Heat	2 cals/sq. cm.	5 cals/sq. cm.
Nuclear Rad.	75 Roentgens	500 Roentgens

TABLE 1

consequence. The values which define the radius of neutralization are such as to cause approximately 50% casualties on the circle of neutralization.

There is some interaction between the three effects and, close to Ground Zero, one would be killed thrice. However, at the edge of the neutralization zone, and more particularly at the limit of effect, one or other of the lethal effects takes precedence as indicated below—

(a) Troops in the open—Heat flash.

(b) Troops in slit trenches—Gamma radiation and some heat flash.

(c) Troops in AFV's—Gamma radiation and some blast.

(d) Troops dug in with overhead cover—Gamma radiation.

(e) Troops in camp buildings, workshops and soft-skinned vehicles—Blast and some heat flash and some gamma radiation.

The radioactive contamination that occurs after the initial effects of the explosion is only of tactical significance when the bomb is detonated so close to the ground that the fire-ball itself touches the ground. For a nominal bomb this means the height of explosion must be less than 400 ft. Bombs bursting higher than this may be regarded as "air-burst," and tactical operations may proceed in the vicinity of the burst within a few minutes of the explosion. It should be noted that there will be radioactive fall-out from an airburst, and it will result in many administrative problems, but this must not be confused with the intense induced activity that occurs when the bomb is burst on the ground. Table II gives some

Radiation Rate in Vicinity of Ground Burst
Nominal Bomb

Distance from Ground Zero (yds.)	Radiation Rate at 1 hour after Burst Roentgens/hour
0	8000
100	5000
200	600
300	150
400	30
500	10
750	5
1000	0.3

TABLE II

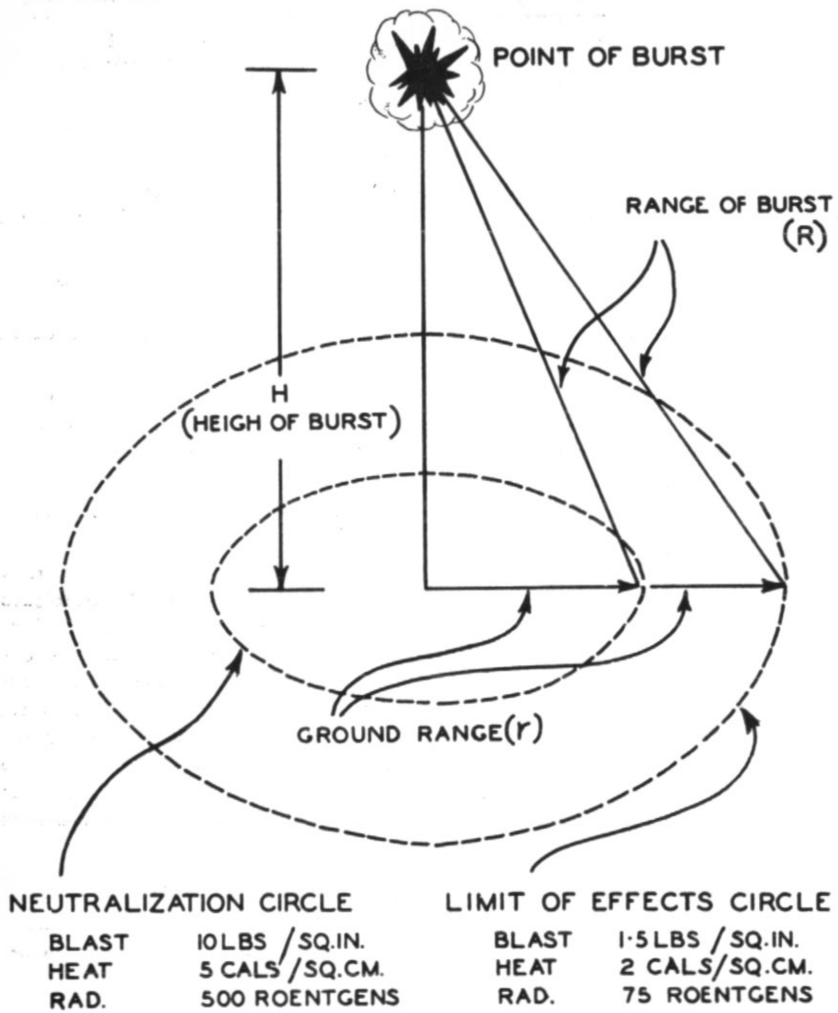

FIG. 1. RADII OF EFFECTS

idea of the rate at which this radioactivity is being produced at various distances from GZ one hour after the explosion. These data will permit calculations to be made to ascertain how long troops may remain in an area so affected.

Examples

The manner in which the criteria set out above may be applied to military situations will be illustrated in the following examples:—

Example 1—Troops in an Assembly Area

The enemy is moving troops into an assembly area in the Goulburn Valley. The Meteororogical forecast indicates that at first light the visibility will be clear, but an hour later when the sun comes up it will improve to exceptionally clear. The commander wishes to know the limit of effect and the radius of the neutralization zone for both atmospheric conditions for a nominal bomb burst at 2100 ft.

As the troops are moving into an assembly area they will presumably be in the open. The lethal effect of the bomb is determined by the heat flash.

At first light when atmospheric conditions are clear reference to Fig. 3 (Physical Effects, Page 33) shows that distance R from explosion for

(a) Limit of effect (2 cals/sq. cm.) is—

$$R = 3300 \text{ yds.}$$

and distance from GZ is—

$$r = \sqrt{R^2—H^2}$$

$$= \sqrt{(3300^2—700^2)} = 3250 \text{ yds.}$$

(ref. Fig. 1).

(b) Radius of neutralization zone is given by the distance at which the heat flash intensity is 5 cals/sq. cm.

i.e., R = 2400 yds.

and r = 2200 yds.

When the sun rises and visibility becomes exceptionally clear, reference to appropriate curve in Fig. 3 (Physical Effects, page 33) gives, for—

(a) Limit of effect—

R = 4300 yds. and

r = 4250 yds.

(b) Radius of zone of neutralization—

R = 3000 yds.

r = 2900 yds.

It is clear from the above results that atmospheric conditions will be of prime importance in assessing vulnerability of troops in the open. In this case the distances of effectiveness are increased by nearly 30% and the consequent lethal area will be about 70% greater.

Example 2. An Armoured Problem

A nominal bomb is burst at a height of 700 yds. What is the diameter *of the circle within which armoured troops in Centurion tanks would be neutralized? The weather conditions are showery.*

What would be the blast pressure and the heat intensity at the edge of this zone? What physical damage is likely to be suffered by the tanks?

In this case the lethal effect is determined by the gamma radiation. The Centurion tank will provide a considerable amount of shielding for the crew. Depending on the aspect of the tank, there may be up to two feet of iron and steel protecting some crew members. However, on the average one could expect not more than about 3" to 4" of gamma ray shielding. The half-thickness of steel is 1¾", so the shielding will be equivalent to 2 half-thicknesses, i.e., the gamma intensity will be reduced by one-quarter.

Assuming 500 roentgens for neutralization, the radiation outside the tank will need to be 2000 roentgens.

This occurs at a range from the burst of 1050 yds. ref. Fig. 6, and the range from GZ is—

r = 780 yds.

The diameter of the circle of neutralization is 1560 yds.

At 780 yds. from GZ the blast pressure and heat intensity are—

Blast—15 lb./sq. in., ref. Fig. 2 (Physical Effects, page 32).

Heat—10 cals/sq. cm., ref. Fig. 3 (Physical Effects, page 33).

Physical damage to the tank will result mainly from the blast pressure. External attachments such as boxes, grenades, dischargers, etc., would be torn off. The BSA gun would be damaged. The turret and main armament may be jammed. The tank itself would in all probability be moved bodily, and tanks showing a side aspect to GZ may be turned over.

The heat flash would ignite anything combustible on the outside of the tank, including tyres of bogey wheels if they faced towards GZ. The blast wave would extinguish such flames, and the net result would be some superficial charring of combustible materials that are too strongly anchored to be ripped away by the blast.

The nuclear radiations at this distance would cause the glass in periscopes to be rendered opaque.

Example 3 (a) and (b). Attack with Nuclear Support

(a) *A commander is preparing to attack a battalion position. He proposes to use a nominal bomb on the enemy prior to moving in. The enemy is well dug-in, with, say, 18" of overhead cover. How high must the bomb be detonated to neutralize the enemy position and how close to the enemy can the attacking troops assemble if—*

(i) *They have adequate protection from heat flash;*

(ii) *No flash protection is possible?*

What will be the nature of the flash protection they require?

Assume the enemy battalion is occupying a 1000-yd. front. The visibility is clear.

The enemy is only vulnerable to the gamma-effect. If the troops

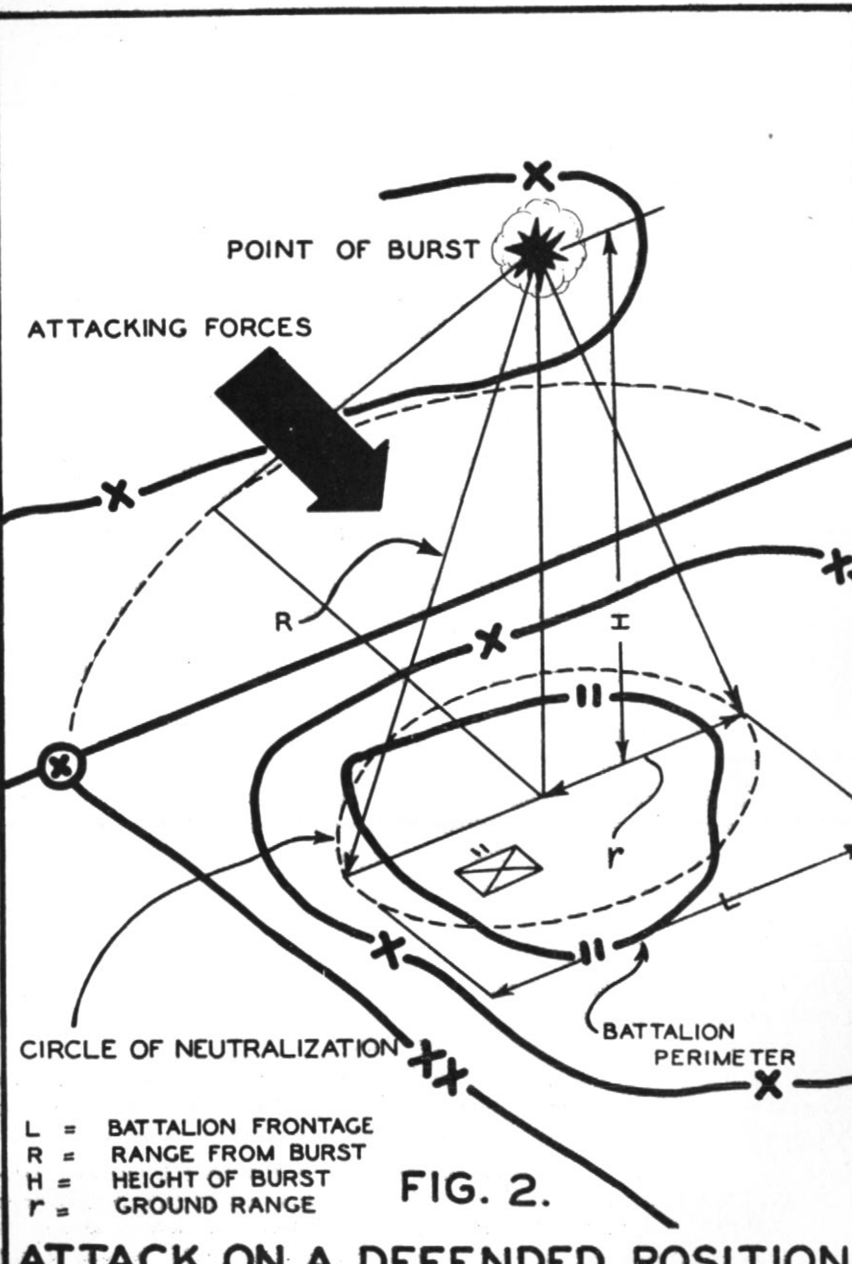

FIG. 2.

ATTACK ON A DEFENDED POSITION

have 18" overhead cover and some protection from the sides of the field works, it is reasonable to assume that they are protected by 3 half-thickness.

Neutralization would therefore require $2^3 \times 500 = 8 \times 500$.

. = 4000 Roentgens at ground level.

This intensity will be obtained at a distance from the explosion given by

R = 850 yds., Fig. 6 (Physical Effects, page 40).

To neutralize the enemy on a front of length L will require a height of burst given by

$$H = \sqrt{R^2 - L^2/4} \text{ (ref. Fig. 2).}$$

$$\therefore H = \sqrt{850^2 - 500^2} = 680 \text{ yds.}$$

For a burst at this height the safe distance of attacking troops can be calculated—

(i) With blast protection they will be vulnerable only to the gamma radiation. Limit of effect dose is 75 Roentgens.
∴ Distance from burst = 1800 yds.
and distance from GZ = 1650 yds.

(ii) With no heat flash protection, the troops will need to be at a distance such that the heat flash intensity has fallen to 2 cals/sq. cm.

If we assume clear atmospheric conditions, the distance from the burst is

R = 3300 yds.
and r = 3200 yds.

To determine the nature of the flash protection equipment, the angle of incidence of the heat flash and the blast pressure must be calculated at 1800 yds. from the burst.

Angle of incidence, θ, is given by

$$\sin \theta = \frac{680}{1800}$$

and $\theta = 22^\circ$ (approx.).
The blast pressure is 6-7 lb./sq. in.
ref. Fig. 2 (Physical Effects, page 32).

With this pressure light, above ground protection would not be adequate. Troops would require to be in slit trenches or behind banks or mounds about 18" high.

(b) *As a result of the conclusions reached in Example 3 (a) the commander decided that heat flash protection would not be possible, and the minimum start line distance of 3200 yds. which would be necessary without adequate flash protection would be too great. Could the enemy position be neutralized by one or two ¼ N bombs, and if so at what distance could the attacking troops assemble.*

Consider first the possibility of using one ¼ N Bomb. To neutralize enemy requires as before 4000 Roentgens at the ground. To find range at which this radiation dose is obtained with ¼ N Bomb it is necessary to apply scaling laws to Fig. 6 (Physical Effects, page 40). This is done by dividing the required dosage by the energy release ratio and reading the range appropriate to this "apparent" dosage.

In this case energy release ratio is 0.25 (i.e., ¼ Nominal Bomb).

$$\therefore \text{Apparent dosage} = \frac{4{,}000}{0.25} = 16{,}000 \text{ R.}$$

Reference to Fig. 6 (page 40) gives range as—

$R = 500$ yds.

For this lethal range to cover a frontage of 1000 yds. would therefore necessitate the bomb being detonated on the ground. As the attack on the enemy position is to follow the atomic attack, a ground burst is not acceptable.

Two ¼ N Bombs will therefore be required. The lethal range is still 500 yds. for each bomb. If an overlap of 200 yds. is allowed, then each bomb will require to cover 600 yds. front, so height of burst will be given by

$$\begin{aligned} H &= \sqrt{R^2 - r^2} \\ &= \sqrt{500^2 - 300^2} \\ &= 400 \text{ yds.} \end{aligned}$$

Using this height, the safe distance of assembly of the attacking force without flash protection may be calculated. Two bombs are being dropped over the enemy position, and assuming they are detonated simultaneously, the permissible heat flash intensity will need to drop to 1 cal/sq. cm. for each bomb.

The scaling of heat flash is effected in the same way as for gamma radiation. The "apparent" heat flash is thus

$$\frac{1}{.25} = 4 \text{ cals./sq. cm.}$$

This gives a range of Fig. 3 (clear curve) (page 33) is 2400 yds. The ground range is thus

$$\begin{aligned} r &= \sqrt{2400^2 - 400^2} \\ &= 2350 \text{ yds.} \end{aligned}$$

It will thus be seen that by employing two ¼ N Bombs the enemy position can be neutralized and the attacking troops can form up for attack at 2350 yds. from the centre of the enemy position. This is approximately half a mile closer than would have been possible if one N Bomb had been used.

Example 4. A Defence Problem

An enemy is attacking on a 300-yd. front. The commander of the de-

fensive position is prepared to attack the enemy with a Nominal Bomb. How close can he allow the enemy to approach and still deliver his attack without causing harm to his own troops? Visibility is exceptionally clear.

Neutralization of the enemy in the open can be effected by exposing him to a heat flash intensity of 5 cals/sq. cm.

Range is thus given Fig. 3 (Physical Effects, page 33) by using the exceptionally clear curve, i.e., R = 3000 yds.

To neutralise the 3000 yds. front would require the bomb to be burst at a height given by

$$H = \sqrt{R^2 - r^2}$$
$$= \sqrt{3000^2 - 1500^2}$$
$$= 2600 \text{ yds.}$$

For a bomb burst at this height the gamma radiation reaching the ground directly below the burst would be ref. Fig. 6 (Physical Effects, page 40), 7 Roentgens.

Provided the defending troops had adequate heat protection, the enemy could advance until contact is made (or even further), and still be attacked by the defending forces' A-weapon.

Discussion

The principal object of this article, as indicated at the start, has been to show how the basic data on the physical effects of atomic explosions may be applied to the military scene. To do this it has been necessary to work from first principles. As time goes on, more and more of the basic data for tactical application will be available in "ready made" form. Even so, it is worth stressing that much value is to be derived from working from first principles, for it is only by so doing that the relative importance of the many new factors entering into atomic warfare may be fully assessed. In addition, it is clear that the scale of an atomic explosion is so great compared with that of conventional weapons that it may be necessary to make an independent assessment of most of the situations in which they will be employed. If this be the case, a blind recourse to rule of thumb formulae would be dangerous.

Although the examples given above are mainly illustrative, the results obtained show up a number of important points. Perhaps the most important is that even weapons of the nominal and one-quarter nominal ratings may be effectively employed in a close support role. Smaller weapons than these are envisaged, and it is clear that a full understanding of their use will be required by commanders down to battalion or company levels.

The examples also illustrate that the dependence of the effect of an atomic explosion on the height of burst permits a considerable flexibility in their employment. Appropriate choice of height can ensure that target systems which are immune from blast and heat (say) will be neutralized by the gamma-radiation. Conversely, heat and blast may be employed to inflict casualties whilst the radiation intensity can be maintained at any predetermined level. In addition to the immediate effects, the ability of a nuclear weapon to contaminate ground provides even more scope for its tactical exploitation.

Finally, an aspect that will require careful study by the tactician stems from the fact that neutralization which results from the gamma effect is in fact a "delayed" neutralization. Reference to Table 4 (Physical Effects) shows the nature of this. For the median lethal dose (500 Roentgens) there may be no incapacity to troops for the first four hours. After that casualties will become apparent until at 24 hours nearly all men exposed to this dose will be incapacitated. Conventional weapons have the reverse effect. Maximum casualties occur during a barrage or concentration, but few, if any, occur after it has ceased. Morale is at its lowest during the height of such an attack, but builds up again afterwards. In the case of an atomic attack it seems likely that morale would deteriorate and reach its peak at the end of the first or second day. From these facts many practical problems will arise in mounting an attack supported by atomic weapons.

It is clear to me that the next world war on land will be very different from the last one; we shall have to fight it in a different way. In particular, we must ensure that our scientific and engineering development is applied in the right way. We must not use it to develop existing weapons to be more efficient for use in conditions which have passed and will not recur.

—Field-Marshal Montgomery.

MEDICAL EFFECTS of RADIOLOGICAL WARFARE

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"Without an equal growth of Mercy, Pity, Peace and Love, Science herself may destroy all that makes human life majestic and tolerable."

—*Sir Winston Churchill.*

I — Introduction

On August 6, 1945, soon after 8 a.m., an American Superfortress bomber released an atomic bomb over the centre of the Japanese city of Hiroshima. More than four square miles of the city were destroyed. The city centre was dominated by a number of reinforced concrete buildings owned by banks, department stores, and other commercial enterprises, while outside the centre lay a densely packed zone of small wooden workshops and lightly constructed wooden dwellings. The destruction was due partly to blast and partly to fire, which took firm hold of the city about an hour after the attack and burned unchecked for days.[1]

1. Medical Aspects of Atomic Welfare, 1948. War Office Official Publication, London.

And so the first atomic bomb was used in war. Earlier in 1945 the prototype weapon was detonated at Los Alamos, New Mexico, and since that time some fifty atomic explosions have taken place in various parts of the world. However, there is very little unclassified information about any except the first five:

(a) Los Alamos. The bomb was exploded on a tower 100 feet high (ground burst).

(b) Japan. Two bombs were exploded, both at 2000 feet (air burst).

(c) Bikini. Two bombs were exploded, one an air burst, the other at a great depth in a tropical lagoon (under water burst).

Now, about 10 years and forty bombs later, we still have to rely on the knowledge gleaned from these five explosions to plan for the future. Because our information comes mainly from such antiquated sources these two articles on the medical aspects of the Atomic weapon will to some extent be obsolete. However, the principles are unchanged. Doubtless the efficiency of atomic weapons has greatly increased since 1945, and the estimates of the destructive power of the hydrogen bomb in particular are too well known to need recapitulation. However, it is doubtful whether the most powerful weapons would be used in any new war. Smaller, though locally more highly destructive, atomic weapons have recently been developed, such as guided missiles and projectiles that can be fired from an 11-inch gun.

It is necessary for clear thinking to have definite beliefs, but it is equally important for us to change them if necessary. These articles are therefore designed to bring before all officers the current beliefs on the medical aspects of Radiological warfare.

Part I of this paper will deal with the causation of atomic injuries and Part II will cover the management of these cases in time of war.

Part I

The Causation of Atomic Injuries

The injuries sustained by the human body following an atomic explosion are due to the sudden release of a great quantity of energy. This energy is released in two main forms:

1. *Mechanical energy,* causing direct damage to the body by blast and falling debris.
2. *Radiant energy,* the thermal radiations causing burns and the ionizing radiations being responsible for the radiation effects on various structures in the body.

Radiation sickness can be caused by instantaneous rays from the ball of fire or from lingering radio activity following the explosion.

Injuries may therefore be classified as follows:

Blast injuries.
Injuries due to *light flash.*
Injuries due to *heat flash.*
Radiation injury.

Of course, many casualties will receive a combination of these injuries. Let us take the example of an unprotected soldier who is less than 800 yards from ground zero. He

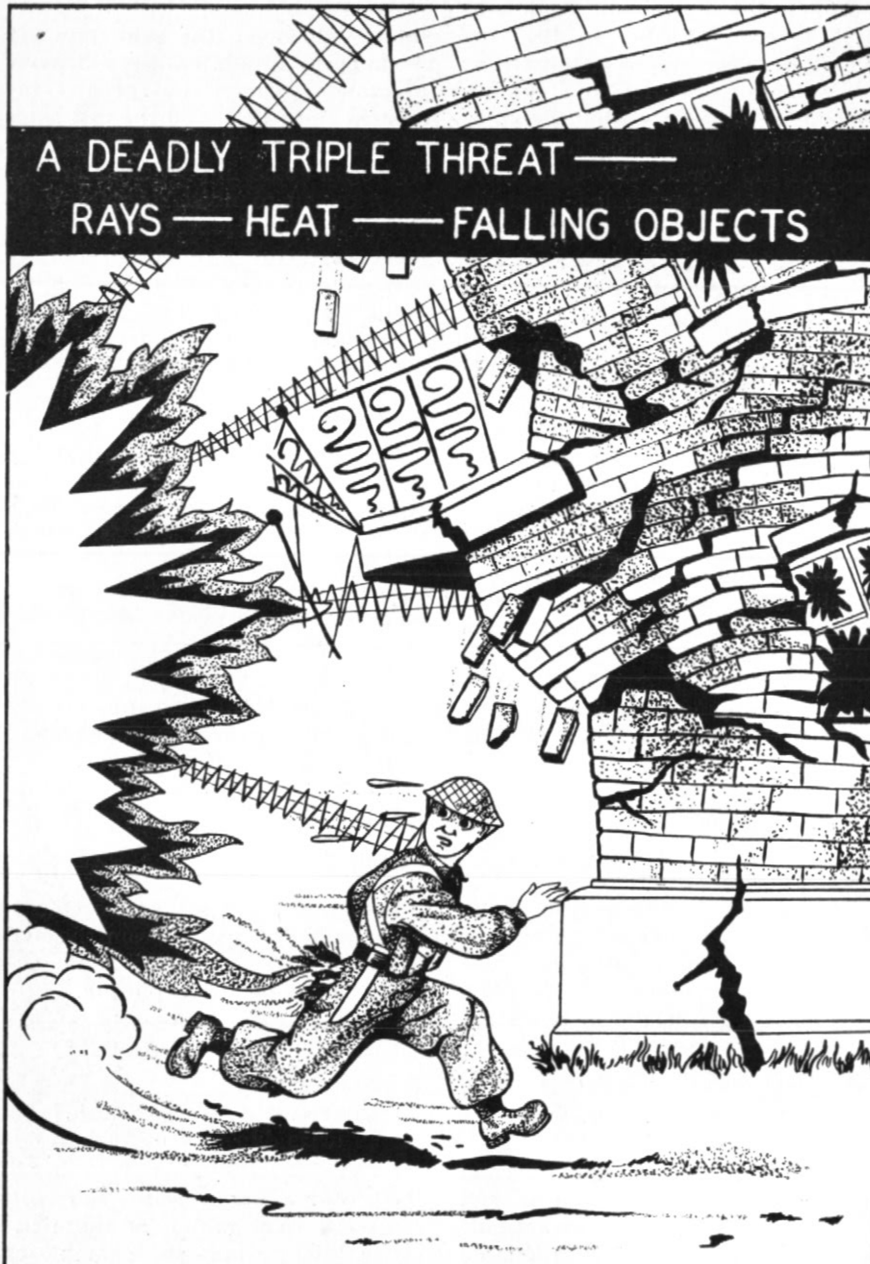


Fig. 1.

may be killed by flying timber, be burned to death or be killed by radiation. Since each of these injuries would be fatal, then which came first makes no difference.

2 — Injuries Due to the Blast

An enormous pressure wave spreads radially from the explosion centre, causing direct injury by blast and indirect injury by hurling masonry and debris through the air. The original positive pressure wave is followed by a negative pressure wave much greater than in an explosion due to TNT—debris is hurled violently TOWARDS the explosion centre, so that a soldier who escapes injury during the original blast may well become a casualty a few seconds later during the second phase. This second phase has been termed the "fire storm," for the winds set up contribute to the spread of secondary fires.

The direct blast is well tolerated by the human body, which can withstand pressures greater than that required to knock down the strongest buildings. Ruptured eardrums are the largest single injury occurring as a result of direct blast, and they occur infrequently. Almost universal damage will occur indirectly from flying debris. In neither case do the injuries differ in essence from those seen after a TNT explosion.

3 — Injuries Due to the Light Flash

The light flash is many times as brilliant as the tropical sun, but lasts for only a fraction of a second. It is not surprising, therefore, that temporary blindness is caused when unprotected eyes are exposed to it. This temporary blindness lasts for about 5 minutes in daylight and up to 1 hour at night. Experience from the Japanese explosions has shown that recovery is complete, and no case of permanent blindness has been recorded from this cause.

4 — Injuries Due to the Heat Flash

The heat flash accompanies the light flash and lasts for a few seconds. However, the highest intensity of heat is only present for a fraction of a second, and therefore causes only comparatively superficial burns. The amount of heat absorbed is governed amongst other things by the colour of the object. The darker the object the greater the heat absorption and the more intense the effect. For example, at Hiroshima, where a casualty had been wearing a light dress with a darker pattern, the part of the skin behind the dark pattern was burned, while that behind the light material was spared (see Fig. 2).

Fig. 2.

Whole thickness burns in exposed skin occurred up to 1000 yards from ground zero in the Japanese incidents, and together with the burns from secondary fires they accounted for about half the casualties.

It must be noted that only those casualties who are able to move themselves or can be speedily evacuated will escape the spread of these secondary fires. This is one reason given for the fact that among the Hiroshima survivors seen two months after the bombing only 4.5% had fractures.

The general line of prevention against burns is therefore clear. Light-coloured protective clothes must cover as much of the body as possible. Loose-fitting garments are better than tight-fitting clothing because of the air-insulation effect. Thus loose trousers are better than tight stockings. Wool is preferred to cotton, which may ignite, and nylon, which melts.

5 — Radiation Injury

This is the type of injury that principally concerns us in this discussion. We are all continually exposed to *background radiation,* which originates from the cosmic radiation of the sun and the radioactive materials in the soil and water. These radiations are of low intensity, and rarely is a dose of 20r exceeded in a lifetime.

Exposure to radiation now occurs commonly from artificial sources. When we have our chest X-rayed, invisible X-rays are sent through the body. Radioactive isotopes are used in many biological experiments to follow the fate of various elements in the body. Radium and its derivatives are used freely in the treatment of cancer, a localised area of the body being exposed to a powerful radiation.

These radiations cannot be detected by any of the senses. For example, when an X-ray of a hand is taken, nothing can be felt, but millions of rays have penetrated the hand and are used to record a shadow on a radio sensitive film. Since the effects are not immediately apparent, special precautions must be taken to protect against these rays when their presence is known or suspected.

At this stage it may be helpful to recapitulate the types of nuclear radiation which are emitted as a result of an atomic explosion.

They are:

(i) Particulate:
- (a) Alpha radiations — Helium nuclei.
- (b) Beta radiations—electrons.
- (c) Neutrons—particles ¼ the weight of Helium.

(ii) Non-particulate:
- (a) Gamma radiations — electro-magnetic radiations.

The Alpha Rays

These positively charged particles of matter travel at a very high speed, but have relatively low penetration. They are absorbed in less than 10 centimetres of air, and can be stopped by a thick sheet of paper, clothing or skin. As a result, there is no danger from this type of radiation as a *direct* effect of the explosion. However, as a secondary effect of the explosion radioactive material may be deposited on the skin as a result of the "fall-out" or

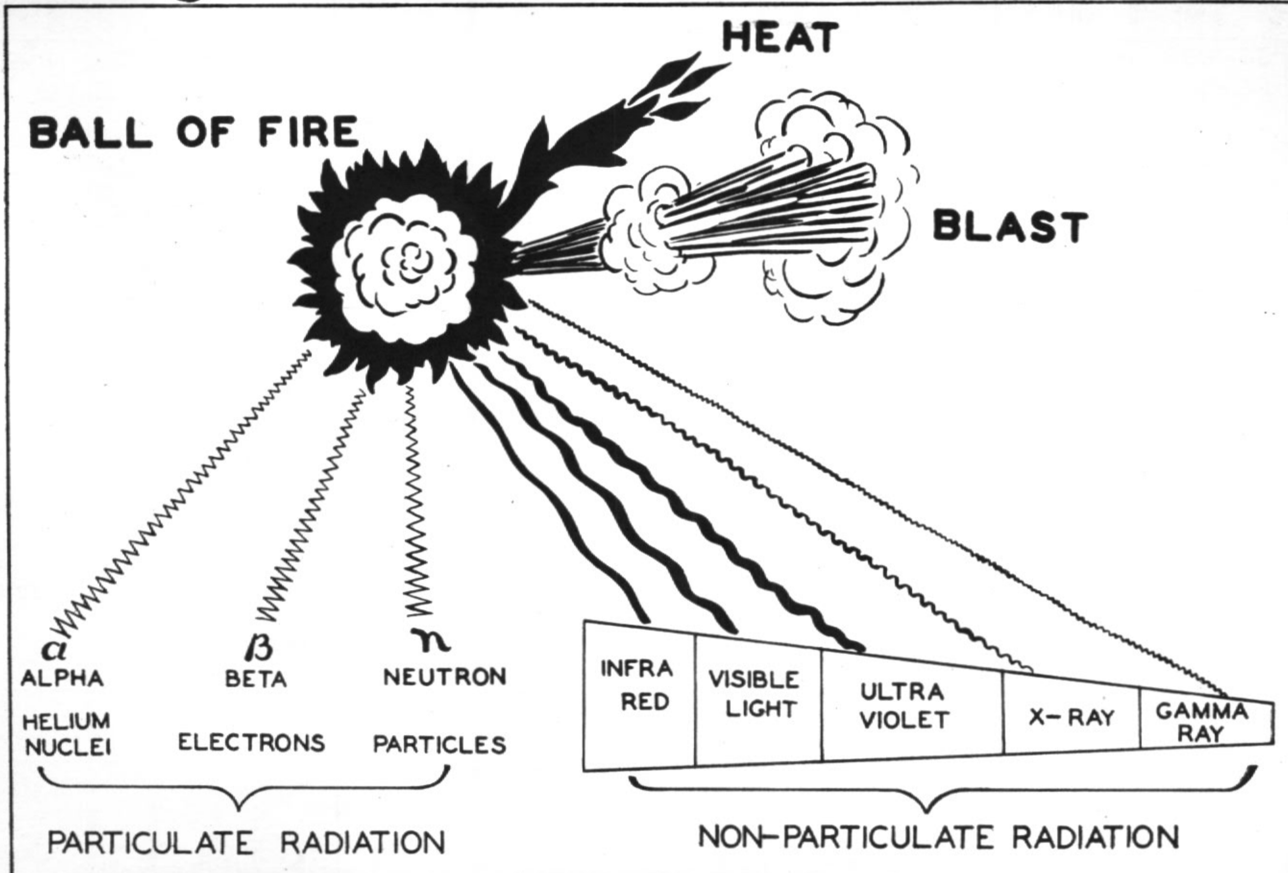
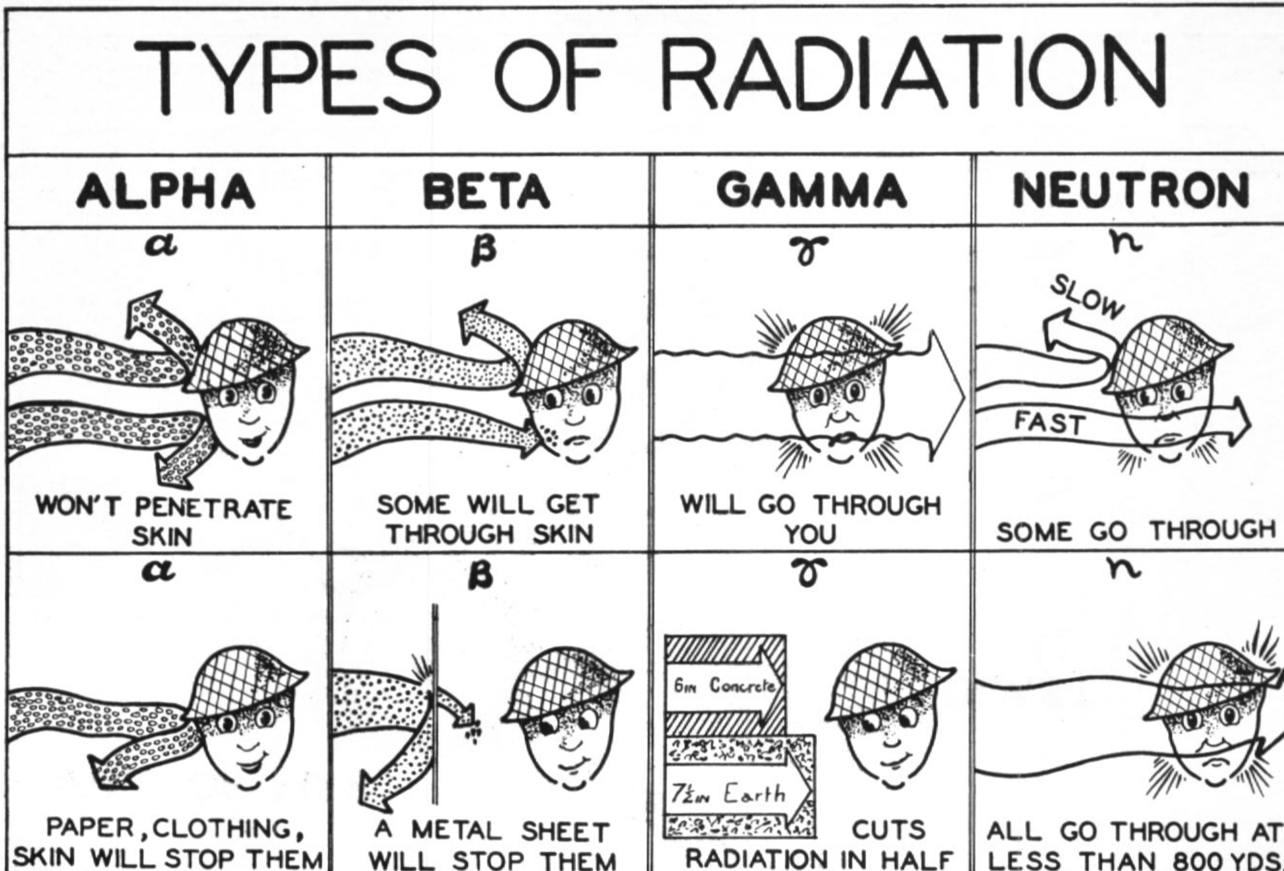


Fig. 3. Types of Energy Released by an Atomic Explosion.



TYPES OF RADIATION
ALPHA
BETA
GAMMA
NEUTRON
α
β
γ
n
SLOW
FAST
WON'T PENETRATE SKIN
SOME WILL GET THROUGH SKIN
WILL GO THROUGH YOU
SOME GO THROUGH
α
β
γ
n
6in Concrete
7½in Earth
PAPER, CLOTHING, SKIN WILL STOP THEM
A METAL SHEET WILL STOP THEM
CUTS RADIATION IN HALF
ALL GO THROUGH AT LESS THAN 800 YDS.

Fig. 4.

from the "base surge" in an underwater explosion, and the alpha particles may then cause serious skin burns.

The Beta Rays

These are negatively charged particles of matter (electrons), more penetrating in effect than the alpha rays, but still readily absorbed. They are only dangerous to the body when deposited on the skin and as a secondary effect of the explosion.

The Gamma Rays

The gamma rays are true electromagnetic radiations, and have tremendous penetrating power. High energy gamma rays can pass through concrete in the same manner as radio waves penetrate the walls of a building to operate a radio receiver. The gamma rays are weakened by passing through concrete and other solid materials. Penetration depends on the thickness of the shielding. The gamma radiations travel in straight lines from the centre of an atomic explosion, falling off in intensity in their course. Their range in air extends to several miles. Fatalities did occur in Japan from gamma radiations up to a distance of one mile. At distances greater than one mile the hazard rapidly decreases. The danger from direct radiation emitted from the explosion centre is over within a few seconds.

The Neutrons

Like the alpha and beta radiations, neutrons are particles of matter travelling through the air. Their damage is only considerable up to half a mile from the centre of the explosion. So that anyone exposed within this range would receive such a high dose of gamma radiation as to prove fatal in any case. However, there are conditions when a person protected from gamma radiation may receive a fatal dose of neutrons. This is due to the fact that light substances are more efficient in slowing down neutrons with consequent absorption, while with gamma radiations the heavier the material the greater the protection.

The Production of Radiation Injuries

Radiation injuries arise due to the whole body receiving a dose of radiation which interferes with the normal function of the cells of the body. When the whole body is radiated the relative sensitivity of the different body cells determine the character of the response. If the radiation is overwhelming, damage will occur to virtually all cells without regard to their individual sensitivities, and death will occur in a matter of hours, possibly days. Usually the dose is not immediately lethal, and there is an opportunity for the varied sensitivities of different body cells to become apparent as radiation sickness develops over days or weeks.

We will now see how these radiation injuries can arise associated with an atomic explosion.

(i) Immediate Radiation

Firstly, exposure may occur with the instantaneous burst of radiation emitted from the explosion centre. The only hazard here is from gamma radiations and perhaps neutrons, the gamma ray hazard being much more important. Fatal gamma ray exposure can occur at greater than one mile from ground zero, while the range of danger from neutrons would be half this distance.

(ii) Delayed Radiation

(a) The first way that delayed exposure can occur is through *"fall-out."* After an explosion radioactive particles ascend to the stratosphere, where they remain until dispersed. They may be carried a long distance in clouds, and eventually fall as radioactive dust or rain.

In March, 1954, a hydrogen bomb was exploded by the American authorities at Bikini Atoll. As a result of that explosion, "fall-out" occurred over a wide area. A Japanese fishing boat, the *Fukuryu Maru,* was 14 miles outside the restricted area about 70 miles east north east of the site of explosion in the direction of the wind, and it was heavily exposed to radioactive material from the "fall-out." A gripping account of this form of exposure to radiation was given by one of the fishermen involved in the mishap. The following account appeared in the American magazine "Life":—

"We saw flashes of light as bright as the sun rising to the sky. . . . The glow lasted several minutes and then faded, leaving a dull red like a piece of iron cooling in the air." After two or three hours Captain Tsu Tsui noticed fine white dust or ash falling. He said that some fell "into my eye and it began to burn. Then ash got into my nostrils." The ash was like talc. "Shortly after, I entered the engine room for my bath after the ash fell, I felt warmer than usual, almost as if I was glowing." The wireless operator described how that night "we were unable to eat our supper. We tried drinking some sake (rice wine), to improve our appetites, but our appetites were not improved and the sake did not make us drunk."

Other members of the crew began to complain of headaches and nausea and then began to itch. "The itch became almost unbearable, and began breaking out with huge irregular blisters. They were terribly painful." The subsequent history of these men is not well known. However, one is known to have died following blood transfusions in Japan.

In contrast with the short-lived primary radiation, radioactivity due to "fall-out" will persist for some time where the material has fallen. This constitutes a grave risk of contamination of food and water, and also in the "fall-out" period radioactive dust may be deposited on unprotected skin, causing severe burning and constitutional upset.

After a low air-burst, radioactive material may be drawn into the ground, which may remain radioactive for some time.

(b) The second method of production of delayed radiation injuries is by the *"base-surge"* which follows an underwater burst. The minute droplets of water in the base-surge contain radioactive materials, and may travel a considerable distance in clouds before falling as *radioactive rain.*

(c) Finally, radiation injuries may be produced as a secondary result of the *neutron emission* from the primary explosion. The neutrons bombarding various materials may produce artificial radioactivity in such items as food, water and drugs or actually within the human body itself. This results in the affected materials or cells emitting alpha, beta or gamma radiations. In addition, the great penetrating power of the neutron renders ordinary reinforced concrete buildings, such as shelters, almost useless as protection against these particles.

Types of Radiation Injury

We have now seen how the various nuclear radiations can produce injury to the living body; it is therefore opportune to briefly consider the types of radiation injury which could result from an atomic explosion. Injuries can occur from (1) external and (2) internal radiation.

(1) Injuries from External Radiation

The injuries may be local or general. Local injuries may be produced in every way similar to radiation burns produced by radium or X-rays. Serious superficial burns may result if the radiation is of sufficient intensity. General external radiation injury occurs when the whole body is subjected to penetrating radiations. The body's reaction depends on the dose of radiation. In mild cases the clinical picture is identical with that observed in radiation sickness, which is sometimes seen when a cancer is treated with radiation. There is nausea with mild vomiting and diarrhoea. The more severe forms are characterised by severe prostration due to loss of body fluid from severe diarrhoea and vomiting, often accompanied by high fever and depression of the blood forming tissues. If the casualty survives the first few days, he may develop ulcers in the mouth, generalised blood poisoning, and bleeding may occur from the lining of his alimentary canal. These general radiation effects may, of course, be seen in association with localised skin burns, but where a large area has been exposed to a sufficiently high dose to produce burns, it is very probable that death will have occurred before the full severity of the skin burn has become apparent.

In illustration, the following facts are noted from the case history of a 26-year-old physicist, who was fatally injured as a result of a temporarily uncontrolled nuclear reaction at the Los Alamos Laboratory. The radiation received was identical with that which occurs in an atomic explosion. Fortunately the reaction was stopped before the blast and heat flash had developed. The physicist had been touching the fissionable material when the reaction took place. It was calculated that his right hand received a dose of 20,000 to 30,000 r. The body dose was of the order of 500 r.

It was reported that after the accident the patient vomited repeatedly for three days. Then from the third to the sixth day he felt reasonably well. However, from the sixth day on he became gradually worse, the nausea, vomiting and diarrhoea returned, and on the tenth day ulcers began to form in his mouth. Death of tissue and severe infection affected the areas burnt on his hands and abdomen. Despite all treatment, death occurred on the twenty-fourth day.

(2) Injury from Radioactivity Within the Body

Radioactive particles may enter the body via the alimentary canal due to the ingestion of contaminated food or water, they may enter the lungs by contamination of the air, or they may enter through damaged skin. This contamination is a secondary effect of the explosion due to the "fall-out" of radioactive material from clouds or from the base-surge. Direct burns may occur in the delicate lining of the lungs and the alimentary canal by inspired or ingested radioactive particles. Fortunately with reasonable precautions this hazard is not great. However, some radioactive material with a comparatively long half life, if absorbed into the body, can lodge in the bone and blood forming organs, causing serious or even fatal effects from its prolonged action on the tissues. The spleen and liver are particularly vulnerable to this type of damage. Cases of malignant tumours of bone due to the consumption of radioactive materials have been recorded.

The types of radiation injury can now be summarised.

External Radiation

(a) Immediate radiation from the explosion centre—effect due to gamma radiations and possibly neutrons.

- (i) Burns to the skin and lining of the alimentary tract; lesser damage occurs to all other cells of the body, depending on their particular sensitivity to irradiation.
- (ii) Generalised constitutional effects.
- (iii) Induced radioactivity in some body cells due to neutron bombardment.

(b) Delayed Radiation — Radioactive fall-out.

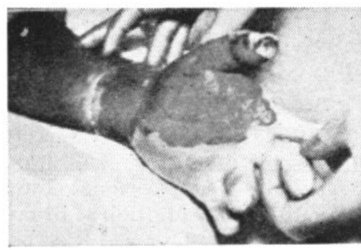
- (i) Skin burns occur due to alpha, beta and gamma radiations from the radioactive material of the fall-out.
- (ii) Generalised constitutional effects, particularly on the blood forming organs, can occur, but are generally of a minor nature.

Internal Radiation

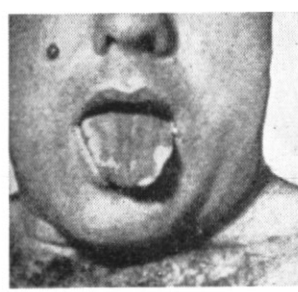
(a) Instantaneous radiation—Nil.

(b) Delayed Radiation.

- (i) Burns can occur to the intestinal tract due to ingestion and to the lining of the lungs due to inhalation.
- (ii) Generalised effects usually mild.
- (iii) Late effects can occur due to deposition of radioactive material in the bones and other tissues of the body.



Local radiation to the hand, causing burns 15 days after exposure.



Cracking of the lips and ulcers on the tongue 12 days after a fatal dose of 500r (a lethal dose).

Radiation and the Body Cell

All the types of nuclear radiation outlined earlier are capable of producing injuries to the cells of the body. The injuries produced are all very similar, notwithstanding the difference in nature of the radiations producing them and the different cells affected. How does this come about? Why are the biological effects of bombardment with alpha or beta particles similar to the effect of gamma radiation, which is an electro-magnetic vibration passing through the atmosphere?

There are many theories on how the rays do the damage, but the facts are few. What matters to us is that the damage is done and that we must be prepared to detect and treat it.

The common factor in the mode of absorption of all these radiations is that in the process of being absorbed they cause a change in the electric equilibrium of the body cells. As a result of this action, the biological change is produced. If the change of equilibrium, or ionisation as it is called, exceeds a certain critical value the cells will die. Cells of different tissues succumb at different values. Actively reproducing cells, such as those of the reproductive organs, the blood forming tissues and the skin are most sensitive.

Effect on Reproduction

It is beyond doubt that some damage is done to hereditary material by radiations. Transient sterility is produced in the male, but permanent sterility is NOT to be expected, because the sterilising dose is so close to the lethal dose in the male and considerably more in the female. A whole body dose, sufficient to cause permanent sterility, will invariably lead to death before such sterility can be manifest.

The casualties recovering from the Japanese incidents have now produced perfectly normal offspring —demonstrating no residual defect. There is some evidence that long-term genetic effects may be produced. However, this is an aspect that must be investigated carefully in the years to come.

The psychological aspect of this reproductive consideration is of the utmost importance. If a soldier fears that he may be rendered sterile by exposure to radiation his morale will suffer. Men must therefore be told the truth, and assured that any effect that does occur is of a temporary nature only, and that recovery will be rapid and complete.

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PART 2

MANAGEMENT OF CASUALTIES

1 — Introduction — Total War

The soldier's morale is based *generally on accurate information* and good training. Therefore, we must put into their hands our present basic knowledge and train them in the special skills of atomic warfare. In Part I we described the causation of atomic casualties and now we will decide how to manage them.

If we accept the present concept of total war we must be prepared to handle many thousands of casualties as a result of an atomic attack. In the past we have taken for granted that there will be adequate facilities for the treatment of all casualties, but this cannot be the case when we have to deal with mass casualties. The very magnitude of the tasks will largely determine the amount and nature of treatment that can be given.

Large-scale treatment can be improved by a certain amount of standardisation. It will be provided to give the best possible care to the greatest number of casualties. Of necessity standardisation in treatment means some compromise between the ideal from the medical point of view, and that which is practical in the face of an atomic attack.

To help with the medical plan every soldier will have to understand his place in the atomic war *and by his knowledge be able to* help reduce casualties, give adequate first aid and prevent panic.

At the present time we do not anticipate any major alteration in the organization of the army medical service as this would invariably reduce the over-all fighting potential. After a bomb had been dropped in the field the war would not be over. The fighting troops on both sides would still have to decide the final issue.

The conclusion to be drawn from this preliminary discussion is that we must train our medical units organized as they are today to deal with the mass casualties that might arise following an atomic attack. Treatment is concerned broadly with mechanical, thermal and radiation injuries and the various combinations of these three general types.

2 — First Aid

General

First aid in the field is based on an equal mixture of basic medical knowledge and common sense. It has been demonstrated often that the efficient care of casualties depends to a very great extent on their rapid evacuation to a place where they can be given definitive surgical or medical treatment. Therefore our first aid must be directed towards prevention of immediate death and the preparation of the casualty for evacuation to a medical unit where he can be fully cared for.

Catastrophic haemorrhage, severe shock and injuries to the respiratory system are conditions which may kill if not treated immediately. Therefore first aid will begin with self help and the assistance of companions in the field. Such emergency care, based on good first aid training, can be life saving. Bleeding must be stopped, severe shock treated, obstructions to breathing removed, and artificial respiration given if necessary by the Holger Nielsen method.

Evacuation will commence as soon as the casualty is fit to walk or stretcher bearers arrive to convey the casualty to the nearest medical post. This is normally the Regimental Aid Post, where the casualty is first seen by a medical officer. The severity of his injuries will be assessed, further first aid given if necessary and evacuation arranged back to the Advanced Dressing Station. While at the RAP further measures to control pain, stop haemorrhage and combat shock are carried out. If morphia is given to control pain in a deeply shocked patient it is more safely given directly into a vein; this drug is best avoided completely in the presence of head injuries, chest wounds, difficult respiration and casualties who are suspected of suffering from moderate to severe radiation.

At the Advanced Dressing Station further first aid treatment is given. The splinting of broken limbs is checked, emergency measures for large wounds and burns are carried out. No large surgical procedures are embarked on but small emergency operations which may be life saving can be performed here. Evacuation priorities are decided and it will become necessary to give priority to those recoverable casualties who are in greatest need of further treatment. During evacuation casualties must be kept comfortable and protected from exposure. No attempt whatsoever should be made to warm patients actively, apart from covering them with blankets, as this defeats the body's own method of combating shock and providing an adequate circulation to the organs essential to life, the brain, the heart, the kidneys and liver.

The correct use of a tourniquet remains a problem. If left on for too long death of a limb may follow. On the other hand even the slightest loosening of a tourniquet may be dangerous in a casualty who has already lost much blood or who is still shocked. Under no circumstances should the limb below the tourniquet be heated.

All treatment given to the casualty should be entered on his Field Medical Card, which is carefully fastened to the casualty. This card remains with the casualty as he is evacuated rearwards through successive medical units.

3 — Treatment of Mechanical Injuries and Shock

The types of injury to be expected have been discussed previously, and except for the modification and standardisation of treatment imposed by the vast numbers to be handled there will be no departures from normal practice. It was recorded in Japan that where the casualty had received any additional radiation injury the complication of infection was very common. Therefore surgical cleanliness to guard against infection becomes even more essential.

Many casualties will require a general anaesthetic for various major and minor procedures and it is doubtful whether there will be sufficient medical officers available to administer the anaesthetics. We will have to train medical orderlies for this task and in the hands of the inexperienced, ether administered by the open drop method is the safest drug by far—despite its explosive qualities.

Shock will be present in all casualties who have been seriously injured and in many who have sustained only minor damage.

Primary Shock which appears immediately after the injury is of nervous origin and is not dangerous. It responds to reassurance, warm drinks and other simple measures.

Secondary Shock on the other hand is of the utmost seriousness and must always be treated energetically. It is caused by any widespread damage to body tissues, loss of blood or severe burns. Severe shock is characterised by two main signs—

(1) Cold pale skin and

(2) Low blood pressure.

The shocked casualty may also have a rapid thin pulse, shallow respiration and be apprehensive. In this type of shock there is loss of circulating blood volume, either due to a massive haemorrhage or due to loss of fluid into the body tissues. The circulation becomes inefficient and the shock worse. Treatment must be commenced before this shock becomes irreversible. Pain should be controlled and haemorrhage stopped. After evacuation to the medical unit where surgery can be performed the shock is further treated with transfusions of whole blood, blood plasma or plasma substitutes and the casualty made ready for operation.

4 — Treatment of Burns

Burns are caused by the heat flash of an atomic explosion and the secondary fires which may follow. The treatment of these burns will present one of the most difficult problems in the management of atomic casualties. The first aid treatment is relatively simple. The burnt area should be lightly covered with any material that is clean. Shell dressings are ideal, but if not available clean sheeting or other material is as satisfactory. The covering prevents further contamination of the raw area with dust which may contain both germs and radioactive elements.

Burns of any magnitude require large amounts of equipment, materials and manpower for their continued management. Many casualties with bad burns will also be suffering from mechanical and radiation injuries. A further problem is that it is often impossible to judge the depth of a burn and hence its severity, until a week or more after the injury—thus early classification is difficult. A standard method of treatment will be absolutely necessary to help simplify management and the supply of materials. It will also be imperative to train many soldiers outside the Medical Corps to care for burnt casualties.

Although no single method of treating burns has been decided upon at present, there is wide agreement on the principles to be followed. The local dressing to the burn should protect, absorb exudate, be non adherent, completely sterile and be applied with moderate pressure. The dressing should be only changed when absolutely necessary—perhaps once a week. Drugs should be given to prevent infection of the burnt area and skin grafts used at a later stage to cover areas that do not heal. Body fluids and blood may have to be replaced by transfusions, and various drugs used to control pain.

In the early stage of treatment of a burned casualty it is necessary to estimate the area of the body that has been involved, as this directly affects the form of treatment and the casualty's outlook. A simple method of estimating the percentage of body area burned is shown in fig. 1, illustrating the "Rule of Nine." Any soldier with more than 15 per cent. of his body area burned will almost certainly require evacuation; if less than 5 per cent. is burned then the area can be dressed and the soldier may well be able to remain on duty if the need is great.

Final care for severely burned casualties is an arduous and difficult task and will be carried out best in a medical unit specially designed for this type of case.

Special Materials in Treatment of Burns

The theme for treatment of mass burns must be standardisation. A dressing suitable for all burns must be decided on. It should be easily produced and not too expensive. The dressing should be designed so that large stocks could be held in forward and rear medical units in the field.

The cellulose pad has been suggested as such a dressing. It has an absorbent fine mesh gauze covering and is not particularly adherent to the burnt area. The pad can be cut into any desired shape and is held in place by a simple roller bandage. When large areas of limbs are involved they can then be immobilised in a splint or in a plaster of Paris cast.

Aluminium powder has been used in the past to provide an artificial coagulum over the burnt area, the affected part then being left exposed to the air. This so-called *"open treatment"* is particularly successful when carried out in a large hospital devoted to this form of treatment. However, it is not applicable to treatment of burns in the field in most circumstances.

Blood and blood substitutes must be available in large quantities for the successful treatment of burns. The supply of blood will always be limited, therefore in the management of mass casualties the answer lies in a substitute. The use of gelatin, dextran and other substances are currently being investigated. The successful substance must meet the requirement of easy manufacture on a large scale and safe stock-piling for extended periods.

Blood transfusion sets must also be readily available in large numbers for emergency use. The sets currently in use are manufactured from glass and polythene tubing, the glass components of which are highly fragile and will not stand up to bulk handling and air dropping

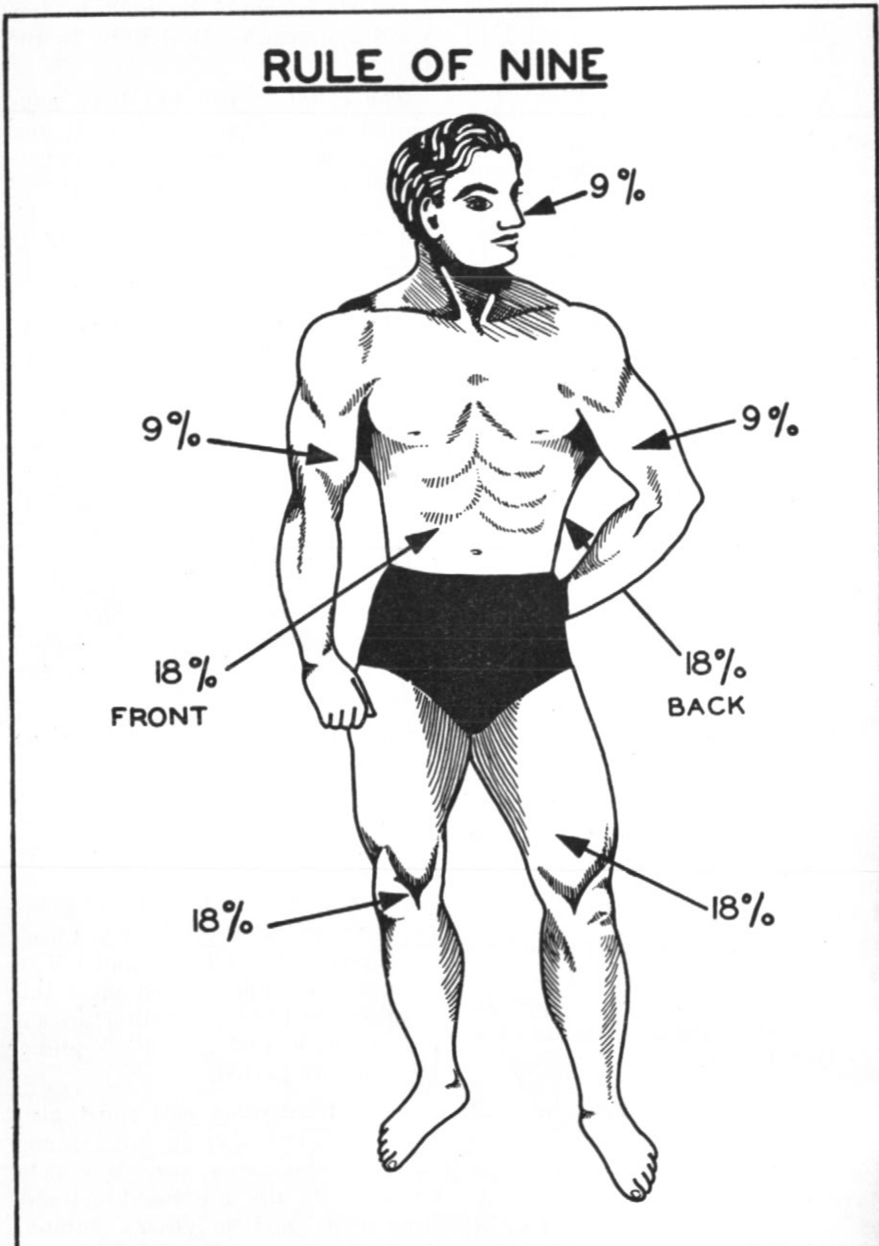

FIG. I. CALCULATION OF BURNT AREA

without very careful packing. A new set manufactured completely from plastic components is now under extensive trial in Australia.

5 — Radiation Casualties

From a practical point of view nearly all the radiation casualties will be caused by gamma rays. The extent of the damage to the human body depends on the distance from the explosion and the shielding between the explosion and the soldier. From the Japanese explosions it has been estimated that troops in the open will sustain practically 100 per cent. casualties up to 1800 yards. Beyond 3000 yards the dose of radiation is virtually harmless. For persons in shelters, trenches and buildings at the time of the explosion the dosage then depends on the shielding. At Hiroshima some escaped with little damage who were in an earth-covered shelter about 300 yards from ground zero!

The Japanese figures allocated only 15 per cent. to casualties from nuclear radiation. However many must have died from severe mechanical and thermal injuries before the radiation injury had become evident. Also it must be remembered that nearly all these radiation casualties will at least have some minor injuries, including burns and wounds from flying debris. These will require normal treatment.

For clinical convenience we can divide our radiation casualties into three grades, minor, moderate and severe. A standard treatment can then be designed for each grade.

Minor cases have usually received up to 100r. They may complain of non-specific symptoms of nausea, vomiting and loss of appetite coming on within a few hours to three days after the explosion. In most cases these symptoms will pass off in a few days without any specific treatment, and no further effects will be noticed.

Due to quite a marked individual variation in susceptibility to radiation in a few the symptoms will merge with the next group to be described and in some even a dose as low as 100r may prove fatal.

Casualties receiving larger doses say from 100r to 400r fall into the group with moderate damage. Their symptoms are similar initially to the first group, but they tend to be continuous and more severe. Vomiting may continue unrelieved for many days and the bowel actions may become frequent and fluid.

The onset of fever does give some guide to the severity of the damage; in less severe cases fever does not occur for 10 to 14 days or may even be delayed for up to four weeks. If fever is observed in the first week after the explosion the outlook is grave.

During the third and fourth weeks in these moderate cases a rash may occur due to bleeding into the skin —if this occurs earlier, say in the first week, it also indicates a probable fatal outcome. Loss of body hair is also noted in this group and occurs from the second week onwards. Minor ulceration of the lining of the alimentary tract may also be a serious complication.

Finally a casualty who receives a total body dose in excess of 400r will be severely damaged and about 50 per cent. will die in 3 to 10 days as a direct result of gamma radiation. The symptoms are usually severe. They commence early and are progressive—death occurs as a result of disorganisation of the body's internal environment.

In the less severe of these cases there may be a definite interval of up to one week between the initial symptoms and the onset of high fever, rash and severe diarrhoea. Frequent blood transfusions and the use of specific drugs to combat infection will save some of this group.

Injuries from "Fall Out"

Injuries from radioactive fall out will be managed in a like manner to those suffering from the effects of instantaneous radiation. The extent of the radiation injury depends on the area of the body exposed, the dose of radiation contained in the fall out material and the efficiency of decontamination. Symptoms and treatment are essentially the same.

(a) *Assessment of Casualties*

This broad clinical classification can be the basis for allotting treatment. It is considered that however well organized the medical services may be, a planned atomic attack on our forces in the field would cause so many casualties at one time that adequate treatment of all would not be possible. Therefore the main treatment would have to be reserved for those with a hope of recovery while those who were completely hopeless would be made as comfortable as possible.

A medical officer would be best fitted for the assessment. His main task initially would be to diagnose hopeless radiation casualties based on—

(i) Position of the casualty in relation to ground zero.

(ii) Any form of shielding.

(iii) Symptoms.

(iv) Any measure of total body dose.

Doubtful cases would have to be assessed over a few days, watching carefully for such bad signs as—

(i) Early onset of severe vomiting and bloody diarrhoea.

(ii) Rapid rise in body temperature.

(iii) An early fall in the white cell count of the blood.

If a casualty were assessed as hopeless then treatment, except that necessary for comfort, would be withheld in an attempt to conserve resources and avoid the danger of spreading infection from these cases.

(b) *Treatment*

The plan of treatment is comparable with that for burns. A simple routine is again very necessary because of the large number of cases. It is reasonable to recommend administration of drugs to prevent infection in all those who run a fever. It is to be noted that treatment with sulphonamides is to be avoided because of their adverse effect, in some cases, on the blood-forming organs.

Blood transfusions will be required for casualties who lose blood early and for those who become anaemic later on from radiation effects. In any large-scale operation blood substitutes will have to be used.

Fluid intake will have to be maintained. If the casualty is unable to tolerate oral fluid because of vomiting, or the loss of fluid is excessive due to diarrhoea, it will be necessary to feed him through a vein with specially prepared fluids. It is anticipated that there well be insufficient medical officers to set up the large number of transfusions required. Therefore it is considered advisable to train all medical orderlies so that they will be able to carry out transfusion procedures in such an emergency.

The diet is of the utmost importance, due to the damage that may occur to the alimentary canal. Unsuitable hard food may cause death through perforation of the ulcerated bowel. Routine use of a semi-solid diet with little or no residue is therefore recommended. Added vitamin C and B group vitamins will assist the body in its normal repair processes.

An axiom of medical treatment is REST. There is no doubt that a casualty's chance of survival is worsened by all forms of mental and physical stress. Complete rest in the field is nigh impossible, making rapid evacuation and adequate sedation of all serious radiation cases essential.

In summary, treatment is simple and along general lines. The casualty must be put at rest, adequately sedated, given appropriate drugs to prevent the spread of infection and blood transfusions and nourishment by the veins as necessary.

(c) The Psychological Aspect

The manner in which large bodies of troops will react to an atomic attack is not known. The attack on Japan came unexpectedly and without prior consideration. Thus the great fear of radioactivity and tremendous havoc wrought by an atomic explosion had not been ingrained by many months of disquieting publicity. At present our soldiers know a little of the truth about atomic explosions, but they generally fear that which they do not know.

How Will They React?

The extent of their psychological reaction is impossible to predict. Many of the casualties will fear the outcome. This is not new, but many apparently uninjured will suffer apprehension and wonder what is to be their fate.

Where possible they must be examined and reassured. The war will not be over and they must expect to continue their duties. Men fight as they are trained. If we train them now we can expect the best result. A well-organised medical service and a planned training programme will serve as the best treatment for the psychological reaction.

6 — Detection and Measurement of Radiation

As nuclear radiations are invisible it is necessary to use special instruments to detect their presence and intensity. These go by the abbreviation RADIAC instruments (Radiation Detection Identification and Computation). There are two main types in use at present which we can expect to be employed in the field in atomic warfare.

(a) *A Contamination Survey* type of instrument which is accurate but bulky. This will measure the presence and intensity of radiation at any place or time. This instrument is similar to the detector used by uranium prospectors. It consists essentially of two parts—the electrode or probe, which is connected by a short cable to the amplifier and the recording dial from which readings are taken. While this type is both sensitive and accurate it suffers from the weakness of all electronic meters—the liability to mechanical

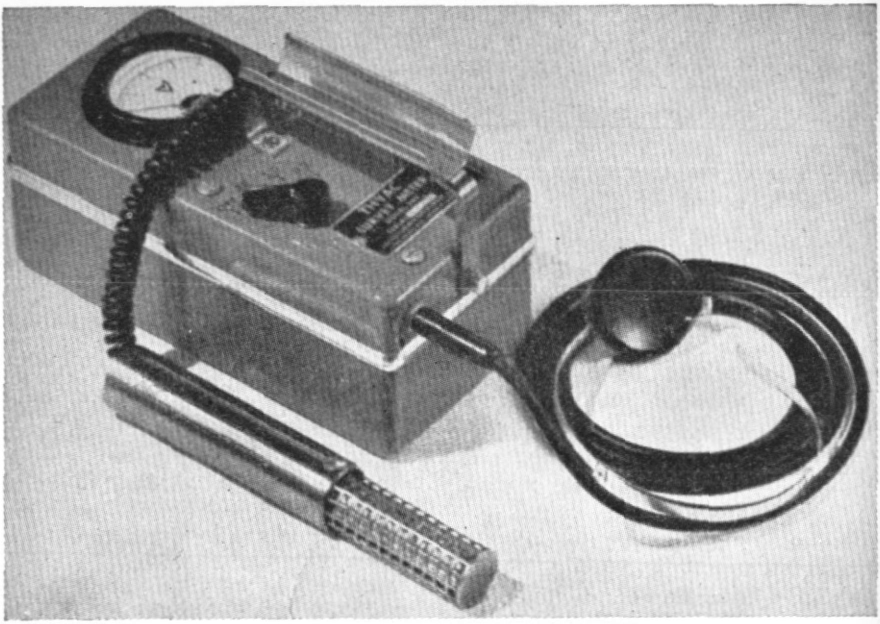

Fig. 2. Contamination Survey Meter

breakdown. However, there is little doubt that this type of instrument would be the mainstay of the ground decontamination squads.

(b) *Personal Detector*

These are small pieces of equipment which can easily be worn on the clothing by each soldier. They vary in type from the simple photographic film badge, which can be developed after wearing — the amount of fogging of the film being proportional to the dose of radiation, to the chemical crystal which changes colour on exposure to radiation. Another instrument which may be used is the "fountain-pen" type of electroscope. This can be slipped into a pocket, and, at a glance, roughly indicates the total body dose received. These personal detectors are small and rugged and will indicate to the medical personnel the total dose of radiation. They do not determine the intensity of radiation at a given time or place.

Estimation of Ground Contamination

After an atomic attack it would be necessary for a number of mobile teams, equipped with decontamination survey meters, wireless, maps and transport, to move into the zone of suspected contamination. They would report the degree of contamination for the benefit of troops who might have to pass through. Recent tests in the United States of America have shown that most radiation injuries are caused by rays at the moment of explosion. Residual radiation from an air burst bomb is now not considered a hazard and troops appropriately clad will be called upon to move through the area guided by the decontamination teams shortly after an explosion.

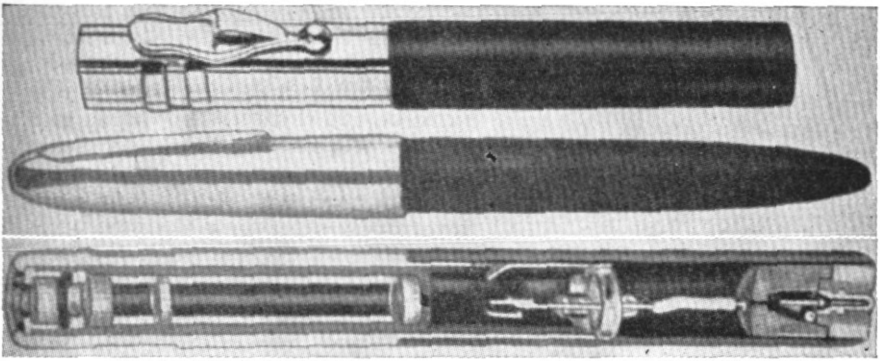

Fig. 3. Pocket Dosimeters

Fig. 4. Film Badges

Personnel Contamination

Medical officers dealing with radiation casualties must be conversant with the following factors—

(a) The fatal dose of radiation. This is variable and can only be quoted in statistical terms as the Lethal Dose 50 (LD50). This is the dose of radiation (or other chemical or physical hazard) which will kill

50 per cent. of a given population—and is of the order of 400 rontgens (400r) total body dose. A fairly even body exposure is implied in this figure. However, with regard to statistics, the statement "So true in general, so false in particular!" applies. Experimentally we know that a number of people will die if they receive 300r, while others will survive 450r. Thus indicating an individual variation response to a given physical dose. *A dose of 600r will be fatal to almost 100 per cent. of those exposed.*

The Fallacies of Dose Detectors

The personal dose detector will be worn on the clothing. Therefore, if, after an attack, the meter showed a fatal dose, then the result would appear obvious.

Suppose, however, that the wearer was protected standing in an open trench with the *detector worn on the greatcoat lapel.* As the rays from the bomb reach the detector in a straight line, it will show a high dose although such vital abdominal organs as the spleen and liver have not been heavily irradiated.

In a second case if the detector is *in the greatcoat pocket* the dose registered with respect to the abdominal organs would be low due to the shielding action of the earth.

The personal dose detector will be a most valuable instrument in the field, but it must be remembered that its reading is to be interpreted with caution.

The effect on the morale of troops, at least some of whom are in possession of radiac instruments, must be considered. Are we to tell those men who have been exposed to a fatal dose of radiation? Should they be assured they are safe after a particular attack, only to find later that a percentage of their number die from radiation sickness, possibly due to high individual susceptibility? These are questions still to be answered. The risk of enemy rumours in relation to fatal radiation dosage must be stressed. Morale will rapidly deteriorate if troops are not reassured regarding their safety—*with a firm scientific basis for such reassurance.* The risk of rumour is great. It must be countered by the truth.

7 — Medical Organization in the Field

As stated previously there will be no major change in organization.

The concept of wider dispersion and adequate digging-in has been accepted. Medical units will conform with this doctrine.

At Divisional level the ADMS will disperse his units in order that one medical unit only will be destroyed by any one atomic missile. One field ambulance might be used to support the forward brigades while the other two field ambulances in the division and the divisional field dressing station are deployed to the rear. These units being kept on wheels ready to act as mobile teams should they be required.

The emphasis is on mobility. A static first aid post of any nature is wasteful of both personnel and equipment. Mobile units such as additional field dressing stations allotted from Army, down to the Corps Casualty Clearing Stations might well provide the added medical potential to deal with mass casualties. An alternative would be to base smaller first aid units on the casualty clearing stations. They could consist of a Captain medical

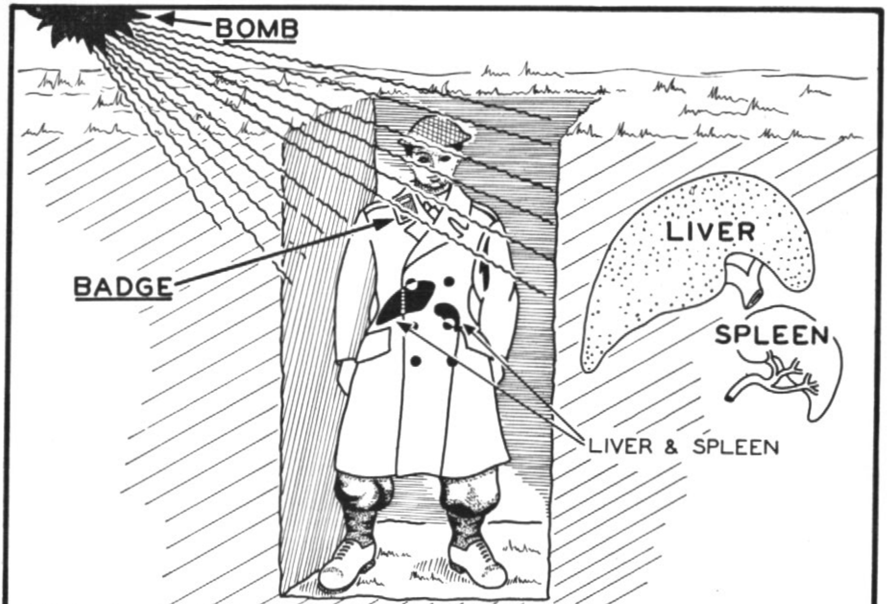

FIG. 5. REGISTERED DOSE TOO HIGH

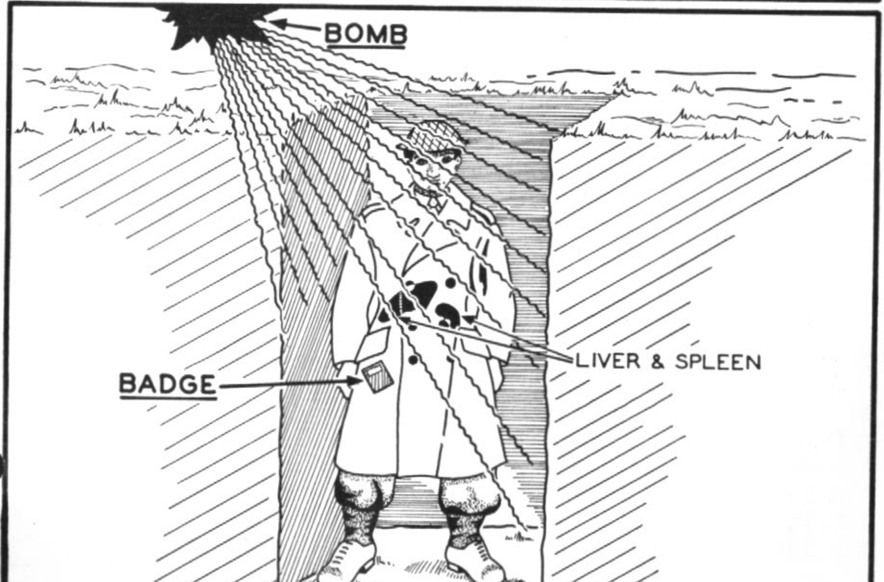

FIG. 6. REGISTERED DOSE TOO LOW

officer and ten nursing orderlies. Such a unit in the field would only give life saving first aid before allowing the normal evacuation to proceed. Minor cases could also be treated in the field and returned direct to their units to prevent overcrowding of advanced dressing stations.

In action after an atomic attack, all available information would be used to assess the actual number and location of casualties. The senior medical officer in the area would then decide on how to use any mobile medical units at his disposal. Normal evacuation would proceed where possible, rapid clearance to the first medical unit being the aim. At the advanced dressing station documentation would be carried out, and any additional simple first aid given.

Early identification of radiation casualties at the ADS would greatly assist in allotting evacuation priorities. This diagnosis would be made by the medical officer after consideration of the soldier's position relative to ground zero, shielding, any measurement of body dose and the soldier's symptoms.

These priorities could be allotted in an attempt to ease the load on the casualty clearing stations.

Priority 1. Casualties with serious wounds requiring urgent resuscitation and/or surgery plus an unknown dose of radiation.

Priority 2. A casualty who is otherwise uninjured presents with definite signs of radiation sickness.

Priority 3. A casualty who from his position in relation to ground zero at the time of evacuation, may have run the risk of receiving a serious dose of radiation, but has no symptoms.

Casualties would be evacuated according to their priority. Priorities 1 and 2 direct to the casualty clearing station. Priority 3, the doubtful group, would be evacuated to a holding unit such as a field dressing station, where the casualty could be observed—evacuated rearwards at a later date if necessary or returned to his unit after fourteen days.

Acknowledgments

It is a pleasure to acknowledge the assistance afforded us during discussions with the Director-General of Medical Services, Major-General W. D. Refshauge, OBE, and the Commonwealth Director of Civil Defence, Brigadier A. W. Wardell, MC.

8 — References for Part 2

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APPENDIX A

MATERIAL AVAILABLE IN THE AMF FOR BASIC ATOMIC TRAINING

Notes on Atomic Warfare

A roneod publication entitled "Notes on Atomic Warfare" has been distributed to Commands and Army Schools. A small pool is held in each Command.

These Notes deal with the principles of atomic warfare and discuss the effects nuclear weapons are likely to have on the conduct of the attack, the defence, and the withdrawal and on administration. They give very useful guidance on the factors which should be taken into account when preparing tactical exercises.

Basic Atomic Training

"Basic Atomic Training" is a roneod document which has been issued to all units of ARA and to National Service Training Units. Copies of the document are held in Command pools.

"Basic Atomic Training" contains 12 lessons designed to bring the facts of atomic warfare to all ranks of the Army. They are suitable for a platoon commander to use as a basis for instructing his men in this aspect of warfare. Each lesson is complete with instructor's notes and illustrations which can easily be reproduced on a blackboard.

Films

The undermentioned films are available in Command Film Libraries. Because of the heavy demand films should be booked well in advance of the date they are required.

MC 38 **Atomic Physics, Parts 1-5.** 85 mins.
An authoritative film on the development of atomic energy.

USC 289 **Medical Effects of the Atomic Bomb, Part 1.** 40 mins.
Nuclear fission and general reaction; thermal energy and mechanical force; nuclear radiation and ionizing effects; physical destruction; casualty effects.

USC 290 **Medical Effects of the Atomic Bomb, Part 2—Medicine (Pathology and the Clinical Problem).** 36 mins.
Mechanics of thermal, traumatic and radiation effects; clinical observations; diagnosis and prognosis; pathological material for illustrative purposes.

USC 315	**Medical Effects of the Atomic Bomb, Part 3—Medical Services in the Atomic Disaster.** Shows the magnitude of the medical problem the bomb would cause.	27 mins.
USC 318	**The Atom Strikes.** The first experimental blast set off in New Mexico, aerial view of the bombing of Hiroshima and Nagasaki; close-ups of devastation in these cities.	31 mins.
USC 320	**Radiological Safety, Operation Crossroads.** A documentary film showing activities of safety teams investigating radioactivity effects at Bikini.	26 mins.
USC 321	**Radiological Safety, Operation Sandstone.** A documentary film showing various aspects and problems of the atomic bomb tests at Eniwetok.	25 mins.
USC 337	**The Effects of Atomic Explosions.** Relative effects of various kinds of atomic explosions as determined at Hiroshima, Nagasaki and the Pacific testing range, as well as the theoretical effects of ground-contact and underwater explosions. Nuclear radiation.	21 mins.
USC 494	**Atomic Support for the Soldier.** Shows the effects of the atomic bomb used in the tactical role. The film is designed for showing to troops to dispel the fear that the attacker as well as the defender will become casualties when the bomb is used tactically. It gives a clear picture of how close troops may be positioned to the target and how soon after the explosion they may assault.	20 mins.
C 1089	**The Effects of Atomic Weapons on Troops in the Field.** Using the nominal 20KT bomb burst at 2000 feet above ground level as a test case throughout, the film shows how casualties to troops in forward positions can be prevented or minimized.	29 mins.
MC 56	**The Atom Bomb — Its Effects and How to Meet Them. 1-5.** Produced by Civil Defence authorities in the United Kingdom. Covers basic detail and is an ABC of atomic warfare. Shows the various effects of atomic bombs on cities.	
AC 72	**Exercise Alphabet.** A film record of an exercise held at the School of Army Health, showing various casualties.	16 mins.

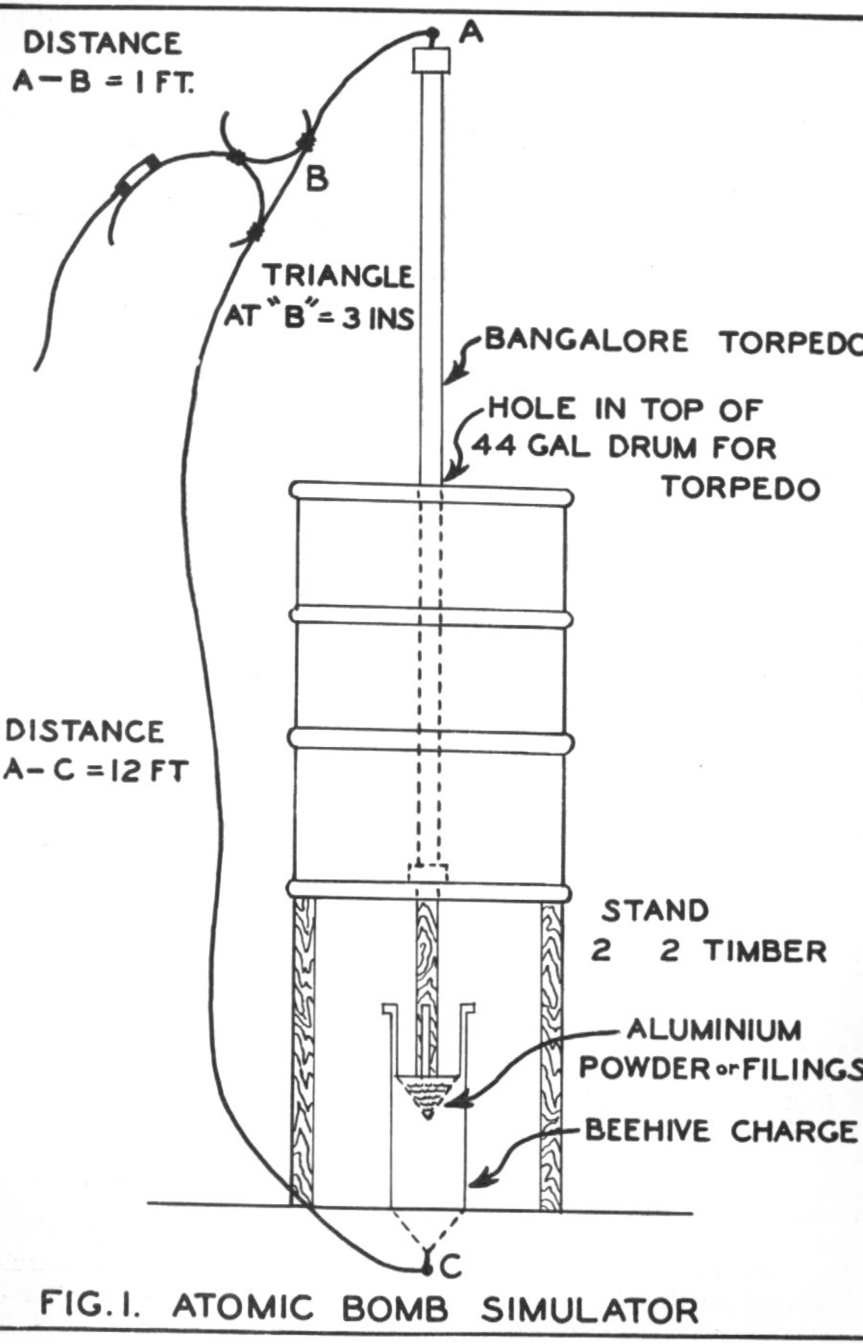

FIG. 1. ATOMIC BOMB SIMULATOR

Simulated Atomic Bomb

Although there is no real substitute for an atomic explosion, an economical training aid which, if properly constructed, will produce the main features of an atomic bomb, may be made by the formula given below. This device should produce—

(a) A satisfactory report.

(b) A "ball of fire" about 70 yards in diameter and 40-50 feet high, and lasting 2-3 seconds.

(c) A grey-black "mushroom" cloud rising to about 250 feet.

When using the device the following conditions will apply—

(a) The device will be prepared and fired by, or under the direct supervision of, those members of the RAE who possess the required knowledge and skills in handling explosives.

(b) The following safety distances will be strictly observed—

(i) An area of 100 yards radius from the bomb will be clear of inflammable material.

(ii) A minimum safety distance of 500 yards will be observed when firing.

Stores

Empty clean 44-gal. drum	1
Dieselene, petrol or 50/50 petrol/dieselene	40 gal.
Napalm or Lux	8 lb.
Bangalore torpedo, MIAI, 5 ft. length	1
Charges, demolition, Beehive, 6 lb.	1
Fuze, detonating, Cordtex	20 ft.
Aluminium powder or filings	2 to 3 oz.
Detonators, No. 27	2
Detonators, electric, No. 33	1

Method

Construct a stand for the drum, from 2 in. x 2 in. timber, with three legs of sufficient length to give a space of 2 ft. between the bottom of the drum and the ground.

In the centre of the top of a clean empty 44-gal. drum cut a hole of sufficient size to admit the Bangalore torpedo and mount the drum on the stand.

In a second drum thicken 40 gal. of petrol, dieselene or petrol/dieselene with 8 lb. of Napalm. If Napalm is not obtainable use a similar quantity of Lux. Ample stirring is necessary to obtain a good gel. When gelling is complete—about the consistency of honey—pour into the prepared drum.

Prepare the initiating Cordtex as shown in Fig. 2, paying strict attention to the dimensions AB and AC. *The sides of the triangle at "B" should* be approximately 3 in. Do not instal the electric detonator at this stage.

Insert detonator "C" in primer of Beehive and mount the Beehive, as

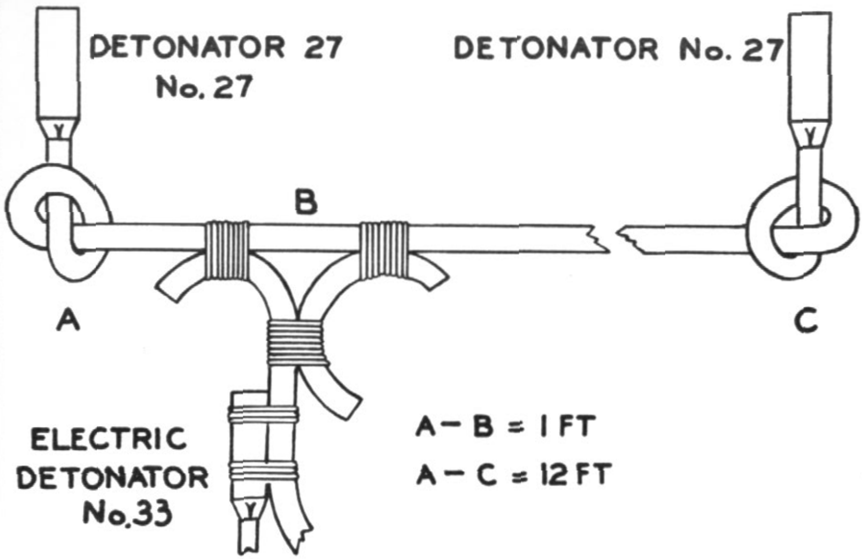

FIG. 2. ATOMIC BOMB SIMULATOR

shown in Fig. 1, centrally under the drum. Place the aluminium powder in the cone.

Pass the Bangalore torpedo through the hole in the top of the drum and, if necessary, wedge it to keep it vertical. Insert detonator "A" in the primer of the Bangalore torpedo.

When ready to fire attach the electric detonator to the long Cordtex lead at "B."

Safety Distances

An area of 100-yd. radius from the bomb should be clear of inflammable material, otherwise serious fires may occur.

A minimum safety distance of 500 yds. must be observed when firing.