# INCENDIARY WARFARE

BY

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*Dedicated to*

MIMI AND ELMARDO
with salutations

# FOREWORD

The incendiary bomb, as developed and supplied by the Chemical Warfare Service to the Air Forces of the Army, Navy, and our Allies, was one of the most effective and spectacular munitions of World War II. As the war came to a close, incendiaries led explosives in amounts rained on Japan, and today the fire bomb is recognized as an outstanding weapon.

American superiority in this field in all the more remarkable because the United States entered the war with no standard fire missile of its own. At that time there was general Army belief that demolition agents were sufficient and, in fact, were better fire producers than bombs designed solely for incendiary effect. Consequently, our bomb program was initially concerned only with explosives.

The Chemical Warfare Service for many years had argued that fire would cause more destruction than high explosives, and a number of its officers continued to urge the adoption of incendiaries. The German fire raids on London in 1940 and 1941 supported this view. The result was that the Army Air Forces called for incendiaries, and the War Department directed the Chemical Warfare Service to supply them. Production of these bombs ultimately became the major class activity of this service as measured by dollar volume.

When we first entered the war, in the absence of American fire bombs, our first effort was to duplicate British and German incendiaries. However, we were short of magnesium, and for the famous Doolittle raid on Tokyo in April, 1942, the Chemical Warfare Service had to produce a makeshift thermate bomb. This was the first large-scale use of incendiaries by our air force. I talked with

General Doolittle shortly afterwards, and he praised the little bombs for their highly successful action.

Magnesium was soon available in quantity, and this type of incendiary ultimately took its place as the chief bomb of the war on the basis of number used. Of nearly 50,000,000 incendiary bombs dropped in all theaters, more than 37,000,000 were of magnesium varieties.

Japan offered an ideal target for incendiary attack. Long before we were able to bomb her home islands the Chemical Warfare Service began looking for the best means of destroying Japanese industrial centers with fire. In cooperation with American science and research groups, the thickened gasoline fillings were evolved. These proved so highly effective that the enemy made peace overtures even before the first atomic bomb was used.

Sixty-six of Nippon's war centers with an aggregate 20,000,000 population received more than 100,000 tons of incendiaries in 15,000 sorties. More than 100 square miles were burned out in five major cities, while incendiary destruction amounted to about 40 per cent in the urban areas involved. "Never in the history of aerial warfare has such destruction been achieved at such moderate cost," declared an Army Air Forces report.

If Japan had prolonged the inevitable, its fire drenching would have taken on astronomical proportions. By the time the war ended, the Chemical Warfare Service had produced more than a quarter of a billion incendiary bombs, of which number 65,000,000 were supplied to the British.

In Europe, according to the United States Strategic Bombing Survey, fires started by our incendiaries did more damage to the Reich's major municipalities than did high explosives. Destruction in some German metropolitan districts amounted to 70 to 80 per cent, largely due to "fire storms" created by this rain of fire.

Only about 6 per cent of our bomb loads in Europe were incendiary, whereas the ratio in the Pacific amounted to nearly 20 per cent, and all-incendiary missions became



commonplace. Before V-J Day, incendiaries predominated in aerial attack on this remaining enemy.

Of all fire bombs dropped by our airmen in the war, more than 28,000,000 fell on Axis targets in Europe and the Mediterranean, and more than 19,000,000 on Japanese targets. It is significant, though, that the fire tonnage in the Pacific exceeded that which fell on the other side of the world—about 123,000 tons for Japan as compared with 120,000 tons for Europe.

Records of the late conflict prove conclusively that aerial incendiaries, per unit of weight, achieved higher damage to industrial and other structures than did high explosives. It is my conviction that incendiary attacks broke the Japanese will to resist before the advent of the atomic bomb.

No one weapon wins a war. The contribution to victory by incendiaries, however, was a tremendous one. Colonel Fisher's book is important in understanding this. It tells the story of a decisive war munition—one about which we must know more so that we may use it to the greatest advantage when necessary and, at the same time, be able to protect ourselves if it is used against us.

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*May*, 1946.

# ACKNOWLEDGMENTS

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# INCENDIARY WARFARE

## CHAPTER I

### THE EXPLOSIVE AND THE INCENDIARY

The two outstanding implements of military force today are the *explosive* and the *incendiary*. Some of the characteristics of each are combined in the atomic bomb. Yet the destructive agencies of explosion and fire each provides its own contribution to modern war fare, and for the most part does so by means of quite distinctive weapons.

Of the two, the incendiary is much the older. The explosive grew out of the incendiary and still retains some of its essential characteristics. Yet as to methods of functioning, the differences between the two are as great as are the differences between their principal end products—rubble and ashes.

**Differences between the Two Weapons.** Explosives and incendiaries both include (*a*) an agent *containing* oxygen and (*b*) an agent that will *combine* with oxygen, the reaction in each instance being essentially one of oxidation. The important distinction between the two reactions is in the speeds with which they take place.

In high-explosive nitrocompounds, the oxidizing agent and the oxidizable agent are represented by different atoms bound into the same molecule. This fact permits the closest possible contact between the reacting atoms and accounts for the extreme speed with which decomposition from detonation spreads through the mass.

In the low-order explosive gunpowder (which actually is a high-order incendiary), we have a mixture of separate substances instead of a chemical compound. Potassium nitrate provides the necessary oxygen, while charcoal represents the oxidizable material, sulphur serving merely to hasten the decomposition. The cycle is essentially that followed by all incendiaries, only flame being needed to initiate the chemical reaction, which is prompted throughout by heat rather than by molecular disintegration.

In action, the explosive is an instrument of physical force, whereas the incendiary is an instrument of chemical force. One type of force is exerted instantaneously, the other gradually. The specific function of the incendiary is to heat an object until it attains a temperature at which it can support its own combustion; this takes time.

Again, thermochemical force is modest compared with explosive force—largely because it is spread out over an appreciable period. The real power of the incendiary, wherein it particularly differs from the high-explosive weapon, lies in a unique capacity for radiating to other objects the type of force it represents. This is something the explosive can scarcely do. The force of the explosive is contained within itself. The force of fire destruction is contained within the target; the incendiary merely invokes that force.[1]

**The Explosive as a Fire Producer.** Explosive shell and explosive bombs do of course produce fires, both directly and indirectly. Yet such fires, even though they are occasionally of some magnitude, are incidental and cannot compare in scope with those produced by intensive incendiary attack.

The detonation of a high-explosive bomb is accompanied by release of high-temperature flame.[2] Once the case ruptures, this flame front moves rapidly in all directions. Yet it normally dies at a distance of probably not more than fifty times the diameter of the projectile. And, what is more important from the viewpoint of incendiary effectiveness, its duration is extremely brief. Unless wider combustible gases are present within the area covered by the flame front, the flash quickly expires; and the high pressures of both phases of the blast wave serve to deter ignition, even where conditions of combustibility are otherwise favorable.



Many more fires result indirectly from the earth shock and blast effects of bomb detonation than are caused by ignition from the momentary flash of burning gases that accompanies the initial burst. Ruptures of gas mains, sympathetic detonation of sensitive explosives, shattering of structures, all conduce to fire incidents so that an HE attack in strength against the average urban target is almost certain to produce a number of primary fires. When fortune favors the attacker, these fires sometimes attain serious proportions.

However, such fires are mere by-products of the principal objective of bombing with high explosives, which is to shatter and demolish matériel targets by physical force. For thorough fire destruction, fire-raising or incendiary bombs must be used according to well-defined tactical methods. Where principal reliance is placed on incendiaries, the explosive then becomes a supporting weapon and its employment is determined by the extent to which it can contribute to the primary mission of fire destruction.

**Incendiary Mission vs. Explosive Mission.** The deficiencies of the explosive as a fire producer coupled with the effectiveness of modern incendiaries for this purpose have led to the definite groupment of bombing operations into either IB missions or HE missions.[3]

Where combustibility of the target is limited or nil, incendiary bombs are excluded. By dropping 100 per cent HE, there is a better chance of accomplishing thorough destruction by demolition and at the same time starting some fires that may or may not reach serious proportions. In the HE mission, fire is at best an incidental contributor to the main objective rather than an outright support weapon. Where there is an even or better chance for destroying by fire, emphasis is shifted to the incendiary, which then becomes the keynote of the attack.

Differentiation between explosive and incendiary missions did not appear in the World War. It is to be noted first in connection with early Luftwaffe attacks (1940) against British targets. In RAF and, later, AAF operations over Europe, this tactical concept was considerably clarified.

The incendiary weapon early proved itself to be particularly suited to RAF methods, which stressed night bombing of area targets. In a London suburb the British maintained an elaborate, scientifically objective establishment for analyzing bombardment results and for comparing HE and IB damage. On the basis of these evaluations, it became clear that in area bombing a ton of incendiaries caused three times as much damage as a ton of explosives.

When the systematic reduction of Ruhr industrial cities began in March, 1943, as a joint RAF-AAF undertaking, American high-altitude precision bombing by day came in to supplement British area bombing at night. The British continued to attack industrial *districts* (cities), while the Americans took on specific industrial *units*, including installations that had escaped fire destruction.

Because of the continued good comparative showing made by incendiaries under British damage evaluations, the incendiary mission became the standard bombing operation against German area targets. The AAF, on the other hand, considered HE bombing more appropriate to the high-altitude precision methods in which the Americans specialized.

It was not until October, 1943, that the Bomber Command of the Eighth Air Force began flying frequent incendiary missions and commenced accumulating data as to the comparative effectiveness of IB and HE in precision bombing.

The tactical theories developed from European experience



during 1944–1945 and which were, in turn, applied by the UNAF against Japan were essentially

*a.* Area bombing is incendiary bombing—only such explosive bombs being used as are needed to further fire destruction.

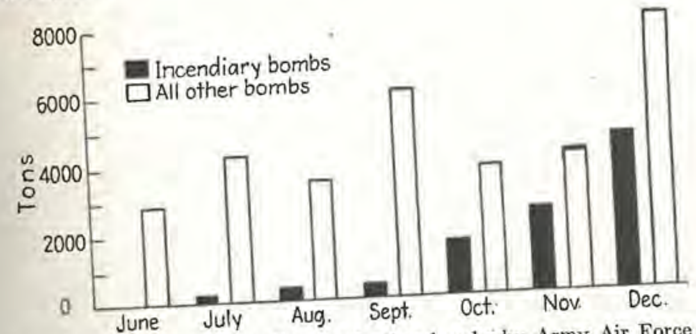



FIG. 1.—Expenditure of incendiary and other bombs by Army Air Force over Europe during last half of 1943.

*b.* In precision bombing, IB missions should be limited to targets or sections of targets known to be inflammable; all others being attacked with HE.

**Comparison of HE and IB Effectiveness.** An inherent limitation of the explosive weapon is the fact that, although the force of its effect may be tremendously powerful, the radius of its effectiveness is always narrowly restricted. Thus in attacking certain types of targets it is necessary to place bomb impacts so close as practically to overlap in order to ensure positive results. This procedure involves a tremendous expenditure of ammunition where a considerable area is under attack, an expenditure that has been ruled out in the light of the known effectiveness of area incendiary bombing.

In the fire destruction of an industrial community, the primary motive is the elimination of the industrial war production contained therein. It has been reliably estimated that Germany's loss in industrial war potential was two to possibly three times as great from area (principally incendiary) bombing as it was from precision (part IB and part HE) bombing.

In addition to the elimination of production facilities located in burned-over areas, wide fire destruction of housing it usually entailed, leading to absenteeism and lowering of worker morale. Loss of stocks of raw materials and end products within the area also must frequently be added to the sum total of incendiary damage.

Although the urban industrial area can usually be eliminated by incendiary bombing, the isolated industrial unit (precision target) is not always vulnerable to fire damage. Against such targets, the explosive bomb makes probably its most important contribution to strategic aerial operations, although even here the effectiveness of explosive action may be indecisive.

The bombings of the Renault Works near Paris affords an interesting case history of the action of explosive bombs against an industrial point target, especially since, for reasons probably of political nature, no incendiaries were ever used in attacking this plant.

The initial attack by the RAF in March, 1942, put the main Renault Works out of production. Yet within less than a month production was resumed and the rate climbed steadily until in about four months the plant had been rebuilt and was operating at full capacity.

In April, 1943, Renault was attacked again, this time by the Eighth (U.S.) Air Force, dropping 250 tons of heavy HE bombs. Again production was suspended, only to be resumed once more in less than a month. Subsequent attacks resulted in the same succession of shutdown, followed by gradual resumption, until finally the plant fell into Allied hands. From the AAF saturation attack in April, 1943, it is reported that 20 per cent of Renault's shops were wrecked, 500 machines destroyed, 1,000 machines badly and 2,000 slightly damaged. This proved to be a serious *yet not an irreparable* blow to production.

Plants destroyed by fire, on the other hand, are plants



gutted and left usually beyond recuperation. The intense heat generated by combustible materials burning within a building is sufficient to destroy machinery that would escape anything but a direct hit with an explosive bomb.

Thus in planning direct aerial attack of an isolated industrial facility, the combustibility of structures and their contents is carefully studied. Where burning can be sup-

FIG. 2.—Iron and steel in the wake of fire. (*Courtesy of National Fire Protection Association.*)

ported, it is cheaper and more effective to resort to fire destruction. Where, as often appears, no part of the target is burnable, the employment of incendiaries is futile. In many instances, the target will require selective bombing for maximum effect, striking at noninflammable sections with explosives and at other sections with fire bombs. Where the target as a whole is partly combustible and partly noncombustible, the preferable order of attack is to lead off with an incendiary mission followed later with explosive bomb missions to reduce sections that have withstood fire damage.

**Contribution of HE to Incendiary Missions.** The principal use of explosive munitions in the furtherance of incendiary attack is to prevent the extinguishment of fires. For this purpose, the antipersonnel effectiveness of explosives finds important usage.[4]

Before the science of incendiary warfare had become well defined, preliminary bombing of an area for demolition prior to incendiary attack was favored as a means of increasing the combustibility of structures.

It is now evident, from considerable experience, that standing structures are ignited more readily than are demolished structures. As a rule, where areas are first bombed over with HE, good results are not obtainable with incendiaries. An exception is the special situation where fire-resistant coverings must be demolished in order to disclose a fire-vulnerable target. But in most cases the undisturbed building or group of buildings is much the better incendiary target. Some shattering of glass does serve to make fresh oxygen available and thus stimulates burning; yet this slight advantage is more than offset by the disadvantage of a preponderance of horizontal rather than vertical combustible surfaces, which so often results from heavy bombing with explosives.

However, disruption of water supply or distribution systems is important to the success of the incendiary attack and, in fact, points to the proper role of the explosive bomb as a supporting weapon when the primary objective is destruction by fire. Where water installations can be selectively bombed, their early destruction is worth while.

When the intensive bombing of German cities was in progress, it became standard practice for fire-fighting appliances to be withdrawn to the perimeter of the metropolitan area at the first air-raid warning as a means of avoiding exposure of apparatus and crews to explosive bombs. Thus the threat of explosive bombing proved sufficient to deny the defenders the use of their most important fire defense until after the all-clear had sounded. Meanwhile



streets had been blown up, increasing the difficulties of fire apparatus in reaching scenes of conflagration.

The bombing of an already burning area with HE serves to impede the efforts of local fire fighters, but heavy demolition bombs are also effective means for extinguishing fires. Fragmentation bombs have been found to be reasonably satisfactory in restraining firemen without impeding the progress of the fires. These of course must be detonated while fire fighting is in progress, that is, some time after the incendiary bombs have been dropped. Delayed-action bombs dropped at random throughout the area also add to the uncertainty and confusion of the defense.

The white phosphorus bomb, although not strictly an explosive munition, was widely used during incendiary bombing of European cities. White phosphorus has but negligible value as a fire starter; yet it proved most effective in restraining fire fighting.

**Proportionate Employment of Incendiary Bombs.** Both explosive and incendiary bombs were carried on the earliest strategical bombing missions (1915). Experience during ensuing years has enabled better evaluation of the respective contributions of the two types of bombs to the objectives of specific operations and has led to more accurate determinations of proper rations for each category.

During World War II the proportion of incendiary to explosive bombs, in terms of total bomb weight carried on strategic missions, increased steadily following the introduction of incendiary warfare in September, 1940. In early RAF missions, not more than 30 per cent incendiaries to 70 per cent HE was used. Two years later these proportions had been reversed; bombers were carrying 70 to 80 per cent incendiary loads. A record was set in the AAF operation against Hankow (Dec. 12, 1944) when for the first time the use of explosive bombs was entirely eliminated.[5]

These figures do not reflect any predilection on the part of bomber crews for carrying incendiaries. In fact, airmen today, like their predecessors in the World War, have been generally partial to high-explosive bombs. Only the demonstrated effectiveness of incendiary bombing when properly conducted with the right munitions has induced air commands to order the loading of so many bomb bays with incendiaries.

The proportion of explosive bombs appropriate to any incendiary mission is largely dependent on the fire vulnerability of the target. Where structures are inclined to fire resistance, it is most important to the success of the incendiary attack that fire fighting be impeded in order that fires may have time to develop and spread. Where structures are readily inflammable, explosives are more sparingly used or even eliminated altogether, the theory being that in such situations bomber capacities can be more efficiently utilized for all-incendiary loads.

The practical difficulties always experienced in properly coordinating antipersonnel bombing with incendiary attack have led to increasing reliance being placed on incendiary bombs with built-in explosive elements designed to detonate with killing force while fires are being kindled, thus effectively deterring the approach of fire fighters.

**Typical Attack Plan.** The typical incendiary attack may be initiated by demolition of water supplies, where this can be accomplished without impairing the combustibility of the target, or it may be preceded by other HE missions that promise to further the principal objective. Incendiaries are then laid on the target, in types and quantities calculated to accomplish appropriate fire destruction. Finally, fire-prevention efforts are voided insofar as practicable by fragmentation bombing, delayed-action munitions, or by other means, which may even extend to machine-gunning. In any event, aircraft are usually kept over the target area long enough to prevent the all-clear signal from being sounded before fires have gotten well under way.



Later, when fire destruction is complete, any remaining objects that have withstood burning may be bombed for demolition if their reduction is considered necessary.

FOOTNOTES

[1] Atomic energy is not considered in this discussion because of uncertainties as to its future employment. The atomic bomb may be classed broadly as a weapon of physical rather than of chemical force.

[2] The heat generated by the detonation of a high explosive is theoretically calculated as the difference between the heat required to break the explosive material into its elements and the heat developed on recombining of these elements. In the case of TNT, this amounts to about 3740°F., which is about the upper limit for explosives permissible for use in mines in the United States. By expanding and doing work, the hot gases produced by explosives commence to cool themselves so quickly as to allow insufficient time for even the slight induction period required in most cases for ignition of combustible gases.

[3] The concept of the incendiary mission per se is inapplicable to artillery fire. Although incendiary projectiles were at one time important artillery weapons, they became obsolescent with the introduction of rifled cannon and high explosives. This interesting development in military technique is discussed in Chap. VIII.

[4] As early as 1827, Major Gen. Sir William Congreve pointed out that the "great use of (explosive) shells is to prevent the people from extinguishing the conflagration."

[5] Despite the fact that in the early stages of World War II few incendiary bombs were used, of the total of 2 million tons of bombs dropped by the USAAF up to July 1, 1945, 9 per cent were incendiaries. In June, 1945, 25,000 tons of fire bombs were dropped, against 5,000 tons of explosive bombs.

## CHAPTER II

## PROPAGATION OF FIRE

Fire is normally man's powerful servant. It can also be his fiercely destructive enemy. Incendiary warfare seeks to exploit the destructive potentialities of fire in such fashion as to influence military operations.

The extensive literature relating to combustion deals either with the economic utilization of heat in the service of society or with the prevention of losses from fire destruction. The deliberate propagation of fire as an agency of destruction has scarcely been considered in scientific publications. However, the well-established principles governing the thermal properties of matter, on which are based the constructive employment of fire, apply equally to the utilization of fire as a weapon of military force.

**The Nature of Fire.** Fire is a chemical reaction characterized by the evolution of intense heat accompanied by flames. The reaction produces a radical transformation of the materials involved, wholly altering their original structures. The result, when fire is on the loose, is *de*struction of the substances actually burned.

Fire, as the chemist sees it, is a bright flame caused by combustion. It is a manifestation of the release of energy in forms of both heat and light, which is a characteristic phenomenon of combustion. When fire is burning, there is certain indication that chemical *combination* (a change in the molecular arrangement of atoms) is taking place. In the process, energy is being released while solids and/or liquids are being transformed largely into gases. In controlled burning, the products of combustion are useful. In uncontrolled burning, the end product is destruction.

Combustion, then, is the generator of fire. Combustion is simply the rapid combining of oxygen with certain other elements, especially carbon, for which it has particular affinity.

**The Role of Oxygen.** Although oxygen is the indispensable supporter of combustion, the gas itself does not burn. It represents about 21 per cent of the volume of the atmosphere, the remainder being almost all nitrogen (which is also noncombustible). These two gases appear together in air, not as a compound but as a simple mixture of gases. Thus ready stores of oxygen are constantly available to combine with any materials with which air comes in contact, so that oxidation is a constant and universal reaction in the laboratory of nature.

The leisurely union of oxygen with other elements, which is continuously in process, is closely akin to combustion, although this latter term refers more particularly to the highly accelerated oxidation of certain materials whose heats have been abnormally increased.

The heat of a material determines the speed with which it will react with the free oxygen present in air. When the material is cool, the molecules of which it is composed are relatively quiescent and only those at the surface have an opportunity to unite with near-by atoms of oxygen. As the temperature of the material rises, however, movement of the molecules is increased and more and more of them reach the surface so that the rate of their union with oxygen is accordingly accelerated. This is particularly true with liquids, in which the movement of molecules is characteristically freer than is the case with solids. Yet with both liquids and solids the reaction of oxidation is accomplished with increasing speed as temperature rises, until finally combustible gases begin to escape and their burning gives visual evidence of combustion.

The rate of the reaction of any combustible material with oxygen doubles with each 18°F. increase in its temperature.



This means that coal, for example, when heated by the sun's rays from 68 to 86°F. will oxidize twice as fast at the latter as at the former temperature. It also means that the same material when heated to 400°F. will react with oxygen *one-half million times* as fast as it will at ordinary summer temperature. This fact is of considerable importance in incendiary warfare, for the propagation of fire is largely a matter of increasing the heat of solid and liquid substances to temperatures at which they will combine most speedily with oxygen.

Once the heat throughout the material to be burned reaches a point where combustible gases are emerging steadily from it, burning will continue until the whole body is consumed, provided an adequate volume of oxygen atoms is present to unite with appropriate atoms presented by molecules of the oncoming gases.[1] However, a slight reduction of the normal oxygen content of air is sufficient to interrupt the process. At least 16 per cent of oxygen must be present in the atmosphere in which burning is taking place (or not less than 5 points below the 21 per cent normally present) in order to support combustion. On the other hand, as the proportion of oxygen is increased beyond 21 per cent, oxidation is accelerated because more oxygen atoms are available to unite with molecules of the combustible material while less nitrogen atoms are present to impede their union.

**Mechanism of Combustion.** It was Lavoisier (1743–1794) who first explained that combustion is a union of a combustible substance with oxygen; by virtue of which dictum this French scientist is regarded as the founder of modern chemistry. All earlier and erroneous conceptions of combustion gave way before this theory. Today much more is known about the mechanism of combustion than when its theory was announced by Lavoisier, even though some aspects of the phenomenon still remain obscure.

The combining of carbon (a combustible element) with oxygen is represented by the chemist with the formula

$$C + O_2 = CO_2$$

This simply accounts for the units of matter that are transformed in the course of the reaction without telling the whole story of what has happened. A transference of energy has also taken place, unaccounted for by the formula, yet of significant importance in the spreading of fire.

When the product of the reaction (indicated to the right of the equation) is so constituted that it cannot contain all the heat held by the materials entering the reaction, then the excess heat represents kinetic energy that must be *released* before the equilibrium indicated by the equation can be attained. Since there is always some disparity in heat content between the substances entering and those remaining after a chemical reaction, there must always be either a discharge or an absorption of heat before the reaction can be completed.

When heat is liberated, as in the combining of carbon with oxygen, the reaction is "exothermic." When the products to the right of the equation are deficient in heat, this must be supplied; and the reaction becomes "endothermic."

These terms, however, are indicative of the preponderant effect: in most cases both exothermic and endothermic reactions proceed simultaneously, the net result of the reaction being determined by the side that must finally be balanced. Even with carbon burning in oxygen, some heat must be *supplied* to break up the respective molecules before they can re-form.

Although the endothermic phase has the lesser value in an over-all exothermic reaction, the heat requirement must be satisfied first. Once this requisite heat has been supplied from outside sources, the reaction becomes self-supporting; enough heat is provided by the exothermic phase to meet the further needs of the reaction, and the



excess heat developed as the reaction then proceeds is released as surplusage.

It will thus be seen that the essential function of an incendiary is to provide the heat required by the initial endothermic phase of an exothermic reaction—after which a great deal more heat is produced than was supplied. This is much the same as pouring water down a pump to prime it.

**Carbon and Oxygen.** Carbon compounds are essentially the fuels consumed in all types of fires. The union of carbon with oxygen is therefore of considerable interest in incendiary warfare.

Carbon is unique in that it is capable of forming an almost infinite number of compounds with other elements. The product of its union with oxygen is a *gas*, carbon dioxide, a compound whose molecules each contain two oxygen atoms joined to one carbon atom. A small amount of this gas is constantly present in air (0.03 per cent). It is indispensable to life. Plants in sunlight produce sugars and starches by utilizing carbon dioxide (photosynthesis) and thus is stored into woody fibers the energy that is later released as excess heat when, during combustion, carbon dioxide again escapes back into the atmosphere.

The energy resident in all combustible materials was absorbed principally from radiant sunlight and is so held until conditions become suitable for its release. The providing of such suitable conditions is then the task of incendiaries.

**Radiation of Heat.** Combustion is thus characterized by a transference of energy in the form of heat (which can be felt) and, at higher temperature, of light (which can be seen).[2] Low-temperature nonvisible heat radiation is of little consequence in incendiary warfare, which is concerned principally with the heats in the flame brackets of temperature.

The dazzling spectacle of flame indicates to the naked eye that heat is being given off very rapidly, so fast that part of it is *burning*, although the remainder (and much larger volume) is being transmitted invisibly to surrounding bodies.

Heat is transmitted in three ways: by conduction, by convection, and by radiation. Only the latter two modes are of interest in incendiary warfare.

In theory, heat radiates in all directions, although its intensity diminishes as the square of the distance increases. In practice, it is transmitted most directly to the material on which the burning takes place, regardless of the plane of the surface. Next in order of directness, it is transmitted upward, under the influence of convection. Lastly, it is transmitted in horizontal directions.

Heat radiated to an object is either absorbed or reflected by that body. Heat will be absorbed until the temperature of the absorbing body attains that of the heat being radiated, after which the excess is not received. If in the process of absorption enough heat is taken in to raise the absorbing body to its ignition temperature, the latter commences to burn and becomes in turn a transmitter rather than a receiver of heat.

**Temperature.** The temperature of a body is a measurement of its thermal condition at a given instant. Since heat is always fluid, tending to move from a warmer to a cooler body, temperatures are constantly changing. The thermal condition of a body may be elevated by absorption of heat from a near-by warmer body or by an exothermic reaction in which it is participating.

In the latter case, starting from a relatively low point, temperature increases steadily until it reaches the plateau characterized by the combustion of the particular substance, where it levels off and remains approximately constant until the reaction is completed—after which in most cases the temperature of the ash or other residue soon



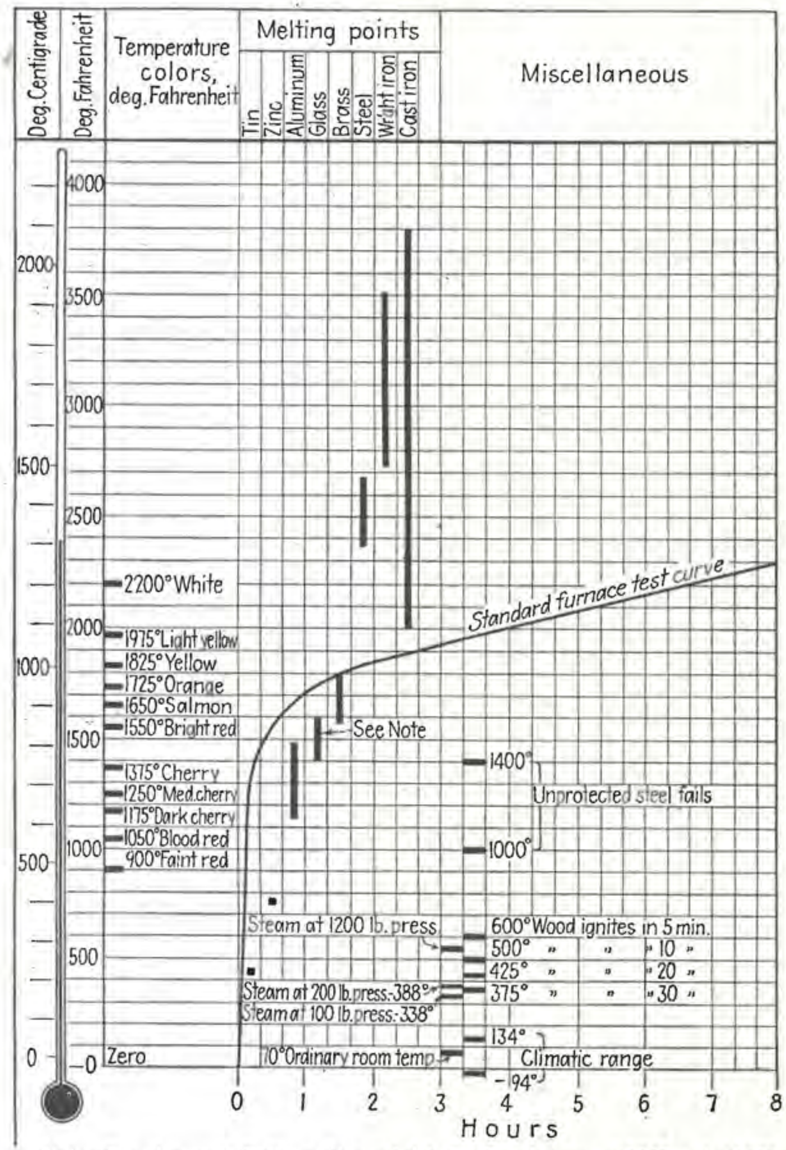
lowers to that of the surrounding atmosphere. Thus temperature indicates the varying heat effects to which a material may be exposed. The constancy with which the temperature of the human body is maintained stands as a marked exception to the fluctuations of temperature that are characteristic of inert objects.

The first thermometer for measuring temperature was devised by Fahrenheit, a German physicist, in 1714. The range between the freezing point of water and the boiling point of water he conceived as a semicircle, to which he ascribed a value of 180 degrees. The term "degree" thus became the accepted designation for the unit of temperature measurement. The Fahrenheit scale values the freezing point of water at 32 degrees and the boiling point of water at 212 degrees. Since it is the most common scale and the one generally employed in fire-prevention work, it is used throughout this book.

In the centigrade scale (introduced in 1742), the range between the freezing and boiling points of water is divided into 100 degrees, 0 designating the freezing point of water. The Fahrenheit degree therefore equals 1.8 times the value of the centigrade degree. Centigrade degrees are converted to Fahrenheit by multiplying by 1.8 and adding 32.

TABLE 1.—MAGNITUDE OF TEMPERATURE, DEG. F.

| | |
|---|---|
| Sun surface | 10,000 |
| Atomic hydrogen torch | 7,600 |
| Oxyhydrogen torch | 3,600 |
| Incendiaries (average) | 3,000 |
| White heat | 2,200 |
| Steel fails | 1,200 |
| Wood ignites | 500 |
| Water boils | 212 |
| Hottest climate | 136.4 |
| Body temperature | 98.6 |
| Ocean water | 78.6 |
| Water freezes | 32 |
| Coldest climate | −82 |
| Liquid air | −319 |
| Lowest experimental | −458 |




Note:- Glass has no definite melting point but softens between 1400°F. and 1600°F.

FIG. 3.—Temperature ranges and effects. (*Courtesy of National Fire Protection Association.*)



**Heat Measurement.** Temperature is a measure of the intensity of heat, but it affords no indication of the *quantity* of heat that a given reaction may be expected to release. For measuring heat quantity, other units must be employed, such as the British thermal unit or the calorie.

Each unit represents the amount of heat required to raise a specified quantity of water through a definite temperature range. The B.t.u. is the quantity of heat that must be utilized to raise one pound of water from 39 to 40°F. The calorie expresses a similar value under the metric system: the quantity of heat required to raise one gram of water one degree centigrade.

In measuring calorific value, we can then say that one pound of oak wood will produce 7180 B.t.u. of heat; the same heat unit can be applied to a cord, a ton, or any other measure. For convenience in comparing the heat-producing capacities of various substances, another unit is used: the heat of combustion. This indicates the number of heat units that will be produced when one gram-molecular weight of a given substance is completely burned.

This quantity of heat may be released slowly or quickly, depending on the conditions under which the reaction takes place. In slow oxidation, the heat may be given off over a period of months. In the more rapid reaction of burning, it may be released in a few minutes. In either case, the total quantity of heat released is theoretically identical. The temperature of the reaction merely indicates the rapidity with which oxidation is taking place and, incidentally, the speed with which it will be completed.

**Ignition.** Fires are started and spread in an incendiary attack according to the same familiar pattern that applies in starting a hearth fire. An ignited match kindles readily combustible materials; heat is radiated to other materials that take fire less easily than the match but that, once started, burn more intensely; finally, heat of sufficient duration and intensity is available to ensure the ignition of coal.

The fire destruction aimed at in incendiary attack follows the culmination of this same three-phase pattern. The first step is the *ignition* of the incendiary; the incendiary in turn *kindles* the lightly combustible intermediate; this then *fires* high-ignition-point materials whose burning produces circumambient heat.

In the hearth fire, the incendiary is the common match. In incendiary attack, the fire bomb has a function identical with that of the match, even though the design of the bomb is more complicated. With the match, the head and the stick together comprise the incendiary unit. The heat generated by slight friction is sufficient to induce burning of the match head, which is composed of material having a conveniently low ignition point. The head being in direct contact with the stick, the excess heat given off by the burning head quickly brings the stick to its ignition temperature. In the incendiary bomb (described in Chap. IV), there is a quick-firing element corresponding to the readily ignitable head of the common match. The first fire it produces serves to ignite the longer burning primary incendiary, which corresponds to the stick of the match.

Although the term "ignition" is here narrowly used to designate the first step in the progressive sequence of events leading to wide-scale combustion, actually a series of ignitions are involved as, in each step, another group of material is heated to its ignition temperature and in turn commences to burn. Strictly speaking igniters are materials characterized by unusually low ignition points or materials whose composition is such that combustion can be readily induced by friction or shock. More broadly, the ignition point of any substance is the temperature at which it begins to burn. It is reached when the rate of gain of heat by a volume of vapor balances the rate of loss of heat.



**Kindling.** The caloric value of the match is very low, yet it suffices for the kindling of intermediate combustibles because these can be deliberately arranged to facilitate progressive burning and because the flaming match can be carried directly to them. In the dropping of incendiary bombs, no such convenient arrangement can be expected. Consequently, a much higher caloric value must be provided for the fire bomb.

The kindling of any material is simplified when the surface exposed is large in relation to the total mass. Loose paper is a most readily ignitable solid because the thinness of the paper permits it to heat so fast that the ignition point of the material is reached almost immediately. The same paper piled in stacks would ignite much more slowly.

Light structural wood and the inflammable matter contained within structures are the materials usually kindled by incendiary bombs and those which serve as intermediate combustibles to ensure the spread of fire. The fire bomb, to achieve its purpose, must reach an object having a low ignition point or one whose dimensions are such that the entire body can be quickly heated to its ignition temperature. The trend in the design of incendiary munitions is constantly toward greater heat of combustion and longer burning periods, looking to a wider range of materials that incendiaries may ignite. However, the function of the incendiary remains that of kindling materials that will ignite with relative ease.

Wood is the most important combustible kindled by incendiaries and the one that gives most body to spreading fires. Dry wood ignites at temperatures between 470 and 515°F. When heat of this magnitude is applied to a small piece, such as a matchstick, its substance is rapidly oxidized, and heat is liberated so quickly that the ignition temperature reached at one point is carried along as the exothermic reaction progresses, until, the entire stick is consumed in combustion.

Where a larger body of wood is involved, however, the reaction is more complex. The temperature rises much more slowly, depending on the thickness of the wood and its consequent ability to absorb and diffuse additional quantities of heat. Decomposition of the structure begins well before the ignition point is reached.

At about 200°F. the water, which even dry wood retains, is driven off together with some volatile esters. At 330°F. the cellular structure begins to decompose with evolution of carbon dioxide. As the ignition point is approached, destructive distillation commences, volatile vapors are produced and given off, and these are ignited by the heat liberated through oxidation. When wood is directly exposed to the high temperatures generated by incendiaries, all three stages of decomposition may be proceeding simultaneously, the part nearest the incendiary bomb actually burning while other sections of the mass are merely moving toward the combustion stage. This is in fact the critical point in the kindling of wood. The incendiary must burn long enough and give off a sufficient volume of heat to ensure that burning extends to a sizable section of the wood, after which enough heat is liberated by the wood itself to sustain its own combustion.

**Spread of Fire.** The purpose of incendiary attack is to initiate fire of a magnitude sufficient to destroy a given target. Where the target is compact, large incendiary units are customarily used, with the expectation that a major fire (or deflagration) will quickly get under way before extinguishing apparatus can be brought up. Where extension of fire over a considerable area is intended, a large number of scattered small fires are started, with the expectation that they will join to produce a conflagration of such proportions that extinguishment is impossible. In either situation, the *spread* of fire must be depended upon to produce the results desired.



There are then two situations to be considered in tracing the manner in which fire spreads: first is the extension of fire through a single structure; second is the sweep of fire across an area.

A fire is most likely to be started by incendiaries kindling the combustible contents of a building, these in turn setting fire to the structure.[3] The spread of fire from building to building, however, is effected in most cases by ignition of exterior surfaces, particularly roofs.

A fire tends to extend first upward through a building in which it starts. This vertical movement is impelled by convection, or the rise of heated gases. Small incendiary bombs that do not penetrate to ground levels are less effective in starting inside fires than large bombs that may pass through several floors.

Early types of incendiaries frequently burnt out on floor surfaces without kindling combustible materials, or, if they scattered, their fire was so diffused that it could ignite only the most inflammable materials. Later types eject masses of a flaming incendiary agent capable of reaching any burnable objects at hand or of becoming affixed to wall surfaces along which fire is likely to travel.

Once fire has gotten well under way at ground level, it will move to floors above through any unprotected openings, such as stairways; or it may burn through floors; or concentrations of smoke and volatile vapors may filter through to upper chambers and there explode.

Movement of fire horizontally follows somewhat later after the initial fire has developed to a point where heat is intense and some fire pressure has been developed. In passing to an adjoining building, fire will first seek an unprotected vertical opening; or it will burn through combustible interior walls; or it may pass along cornices and roof coverings.

When buildings are not closely adjoining, fire spreads with much more difficulty. The principal method is by ignition of inflammable roofs and combustible cornices, or through easily ignitable debris, small structures, etc. Heat radiated from an intense fire can ignite combustible trim of buildings as much as 500 ft. away.

**Conflagration.** Once a fire burning in a single building has extended through the roof and outer walls, it may be considered as a *primary* fire, or one that is about to spread to adjacent structures.[4]

When fire has actually spread into an area and is gaining ground, it becomes a *secondary* fire. At this stage, it can be stopped only by a number of fire-fighter companies working together—a battalion or even a division.

When, as frequently happens under incendiary attack, several secondary fires are burning simultaneously, these are likely to join to produce a *tertiary* fire or conflagration, which can be defined as a fire of such magnitude that all available fire-fighting equipment is unable to cope with it. Well over 100 conflagrations, or out-of-control fires, have occurred in the United States during the present century, most of them growing out of single fires that were not deliberately kindled. These peacetime conflagrations usually developed out of single secondary fires, rather than from a combination of several secondary fires as is frequent under area bombing with incendiaries.

A secondary or tertiary fire will attain and sustain temperatures of 500°F. and upward throughout the area in which it is burning. Where large stores of combustible materials—oils, chemicals, etc.—are engulfed, much higher temperatures are produced in spots. The intense heats developed by these fires are sufficient to bring all types of combustible materials within the fire zone to their ignition temperatures almost without delay.

The conflagration exhibits, in large dimensions, much the general characteristics of a primary fire burning in a single building. The upward movement is much more pronounced than is lateral radiatory spread. Great volumes of



hot air and gases rise rapidly, creating terrific air currents. To replace them, fresh air is drawn in from all sides so that high winds moving toward the fire may be noticed several miles away. These supply the large amounts of fresh oxygen needed to sustain combustion on such a large scale. Meanwhile, hot gases billowing high into the air may burst into flame aloft, and pieces of burning solid materials are often carried along to fall far downwind.

The phenomenon of "fire storm" was frequently experienced by German cities following saturation bombing. The tremendous updraft of air over burning areas drew in air at hurricane speed, which in Hamburg was reported as snapping down trees 2 and 3 ft. in diameter and forcing firemen to lash themselves to their engines.

The lateral spread of fire in conflagrations, resulting in limited degree from heat radiation, is caused primarily by prevailing winds that drive the fire forward, combining with radiation to set up a strong pressure front along the down-wind edge of the conflagration. It is wind that counteracts the natural tendency of heat to rise, bending much of it instead to the horizontal where it can contribute in bringing whole buildings into the range of ignition temperatures. High wind, more than any other one factor, will develop a secondary fire into a conflagration and will spread the conflagration as long as combustible structures stand in its path.

FOOTNOTES

[1] With light wood and certain metals (*e.g.*, thermit), requisite heat need only be applied in one area to ensure ignition of the entire mass.

[2] Heat as radiant energy is given off in the form of electromagnetic vibrations, transmitted at a velocity equaling that of light (186,000 miles per second). Cosmic rays stand at one end of the electromagnetic wave spectrum, radio waves at the other end, with radiant heat waves somewhere between.

[3] An exception to the general rule that contents are more easily kindled than structures appears in the case of the typical Japanese house, which is sparsely furnished and has smoothly plastered interior walls. The

combustible nature of exteriors and the closeness with which houses were spaced in congested areas accounted for the rapid spread of fire in Japanese cities.

[4] From the fire-protection viewpoint, a primary fire is a fire that has reached a stage where it can be brought under control only by a company of professional fire fighters. It is thus referred to as an "appliance fire."

# CHAPTER III

## INCENDIARY AGENTS

An incendiary agent may be defined simply as a material that can be used in a bomb or shell and is readily capable of starting fires. It must meet certain technical requirements as a heat producer, and it must at the same time satisfy the exceedingly practical demands of military usage.

The *primary* incendiary agent is a material that transmits fire directly to a burnable object. Secondary incendiary agents are used to ignite primary incendiaries.

**Important Characteristics.** The task of the incendiary agent is to heat an object until it reaches its ignition temperature, which is the minimum temperature required to maintain self-combustion. This, for various types of wood and for many flammable liquids, will range between 400 and 800°F. Some light materials ignite at lower temperatures, but these are too infrequently encountered in modern warfare to justify serious consideration.

In order to raise an object to its ignition point, the incendiary agent must necessarily develop a burning temperature that is well above that point. Incendiaries cannot be efficient heat radiators, as much of their thermal energy is dissipated before it can reach the object being heated. To compensate for heat losses and to ensure functioning under varied conditions, the agent must generate four to five times the value of the ignition temperature. This may be averaged empirically at 500°F. Thus a combustion temperature of not less than 2000°F. is an essential characteristic of a generally effective incendiary agent.

It is also important, from the viewpoint of military economy, that a large volume of latent heat energy be included in a low unit of weight. This heat of combustion is expressed in terms of British thermal units (or of calories) that the material is capable of developing.

Materials characterized by high heats of combustion are well known. The most important are the gaseous element hydrogen; the solid elements aluminum, magnesium, phosphorus, and sodium; and the petroleum derivatives, notably gasoline, fuel oils, and paraffin. These constitute essentially the arsenal of incendiary warfare.

TABLE 2.—COMBUSTION HEATS OF INCENDIARY MATERIALS

| Material | B.t.u. per Pound |
|---|---|
| Sodium | 4,000 |
| Phosphorus (white) | 10,400 |
| Magnesium | 10,800 |
| Aluminum | 13,300 |
| Paraffin | 19,035 (av.) |
| Fuel oils | 19,160 (av.) |
| Gasoline | 20,160 (av.) |
| Hydrogen | 61,060 |

The skilled incendiary technologist must induce his materials not only to release the extremely high temperatures they are capable of producing, but also to maintain heat generation without replenishment of fuel. The heat must continue to radiate for an appreciable time, and, when the heated object is ready to burn, there must still be fire present to ignite it. The two factors, intensity of heat and duration of burning, are complementary and must be brought into satisfactory relationship.

In theory, a low-intensity flame, held against a burnable object for a long time, will induce combustion as well as a hotter flame maintained for a shorter period. However, an agent that is a slow fire starter allows more time for fire extinguishment. On the other hand, the chemical reaction involved in kindling fires cannot be hastened beyond a given point, even by stepping up the heats produced, because of the practical conditions under which incendiary attack must be staged.



Actually a heat range of between 2000 and 3000°F., maintained for approximately 10 minutes, represents a satisfactory working compromise. Here both duration and intensity of heat are more than adequate for ignition of many materials. Yet a substantial lessening of the value of either factor would seriously diminish the effectiveness of the agent when in contact with ignitable objects whose nature or dimensions render them inherently more fire-resistant. Average rather than optimum conditions of combustibility are aimed at in incendiary attack.

If an agent will burn for about 10 minutes at a temperature in the neighborhood of 2500°F. and if the material meets requirements for military munitions, it has the makings of a satisfactory incendiary agent. Other characteristics may be desirable, but they are of lesser importance.

It is desirable that an incendiary agent be difficult to extinguish. It does not follow, however, that the agent that resists extinguishment is always the better incendiary. Thermit continues to burn even under water, yet it is unsatisfactory as a general-purpose incendiary.

Good radiating qualities are an asset to an incendiary agent. Extension of luminous flame for good distances, both laterally and vertically, greatly increases the probabilities for fire raising.

The agent should burn freely without exhausting too much oxygen from the air, or it will defeat its purpose as an incendiary. It must also burn completely without leaving a residue to insulate and thus prevent the surface on which it burns from catching fire. In burning it should not cool surrounding materials.

An incendiary agent ideal from every technical viewpoint is still impracticable unless it can be adapted to requirements of field use. This means that the agent will be inert and perfectly safe in storage and shipment, that it can be loaded readily into projectiles, and that it will ignite at the proper time, when released on hostile territory. The material must be one that can be brought to the enemy without danger to the friend.

**Intensive Agents.** Incendiary materials are conveniently classified as either "intensive" or "scatter" type. These terms, adopted by American technicians in the World War, were soon generally accepted. The classifications still apply, even though radical changes in incendiary munitions have since been introduced.

An intensive agent is one that is merely ignited (not detonated) and that while burning holds its fire in one compact mass. Certain agents are more effective when permitted to burn intensively; magnesium is a notable example.

The intensive agent burns long and intensely, but its action is confined to a small area. It is to be preferred against targets of low combustibility. The disadvantage of intensive munitions lies in the fact that they frequently fall on surfaces that are not ignitable, where they burn out harmlessly even though inflammable materials may be located just a few feet away.

**Scatter Agents.** A material that can be dispersed or scattered through considerable space in all directions from the point of burst is a scatter agent. Usually these agents are liquids, although solid phosphorus is customarily dispersed as a scatter incendiary.

By scattering the incendiary, the probabilities of starting fires are greatly improved in situations where inflammables are prevalent. Moreover, vertical surfaces can be reached; here convection aids the burning agent in firing the structure so that fires get under way much quicker than is the case when the burning agent remains on a floor surface.

The breaking up of the incendiary filling of a bomb into globules or fragments and their dispersal for appreciable distances involves heat loss, with corresponding decrease in incendiary efficiency. Duration of burning is somewhat



shorter, and intensity of heat is lower with scatter agents than with intensive agents. This is not a serious disadvantage when readily combustible objects are at hand. For light structures built of ignitable materials, scatter agents are ideal.

**Magnesium.** Although several metals can be made to burn at high temperatures and are otherwise acceptable as incendiary agents, magnesium has proved to be the most generally satisfactory.

Development of the magnesium-type fire bomb represented a turning point in the history of incendiary warfare; since this was the first generally adequate incendiary munition, it immediately replaced earlier makeshift devices, which had always been more promising in theory than in practice.

German technology must be credited with the successful introduction of magnesium as an incendiary agent. The German magnesium bomb was perfected in the spring of 1918, and although available for use before the termination of the World War, it was not actually employed in military operations until after the resumption of hostilities in 1939.

Magnesium is customarily strengthened with alloys when employed in incendiary bombs. German scientists had developed in 1909 such a light metal substitute for structural steel, the material containing 86 per cent magnesium, 13 per cent aluminum, and some copper. This alloy carried the trade name of Electron.[1] A similar American product, Dowmetal, contains a slightly higher proportion of magnesium. Aluminum is less efficient than magnesium as an incendiary agent but otherwise proves most satisfactory as an alloying agent.

Magnesium reacts rapidly with oxygen and begins to burn vigorously when heated above its melting point (1204°F.). Once ignited, the metal quickly rises to its boiling point (2012°F.) and magnesium vapor is rapidly produced. This vapor, mixing with air, produces an extremely hot flame with a temperature of approximately 3630°F. In burning, 1 lb. of magnesium consumes but 0.9 lb. of oxygen, which means that it has less tendency than many other incendiaries to exhaust available oxygen below the 16 per cent minimum that must be present in air in order to sustain combustion of surrounding materials.

Although magnesium ribbon can be ignited with a match flame, the solid metal must be subjected to more intense heat. This is readily supplied by thermit, which burns at a temperature of 4330°F. Customary practice is to shape magnesium alloy into a thick-walled tube, loading the core with thermit, which when ignited quickly precipitates the burning of the entire mass of metal.

The light weight of magnesium (density, 1.8) plus the fact that practically the entire weight of the magnesium bomb contributes to the exothermic reaction make this material a highly efficient fire producer when it can be brought *into contact* with ignitable objects. However, magnesium bombs frequently burn themselves out fairly close to such objects, say 3 ft. away, without starting fires. Although magnesium cannot be used as a scatter agent, a similar effect is sought by distributing large numbers of small magnesium bombs over an area.

**Petroleum Derivatives.** Flammable oils have long been used as military incendiaries. The fact that such materials will themselves burn readily under favorable conditions has often obscured the more important fact that they do not so readily transmit fire.

Earliest efforts of technicians to employ oils as incendiary agents may be described simply as a search for the most suitable petroleum products that nature happened to offer for man's use. Next, in order to improve such natural agents for military purposes, mechanical combinations of oils with various absorbents were undertaken. Finally, as knowledge of chemical science extended, success has been achieved in changing the chemical characteristics of oils to provide compounds with physical states more suitable for employment as incendiaries.



The efficiency of petroleum products as heat generators is evidenced from the fact that 1 gram of kerosene, in burning, gives off 11,000 calories of heat, or enough to raise by one centigrade degree the temperature of 11,000 grams of water. The problem in incendiary warfare is to harness such stupendous energy and direct it to effective work.

Oils find two distinct uses as incendiary agents. They are employed as fuels for flame throwers and as fillers for incendiary bombs. The ends sought with the two weapons are quite different, however. The flame thrower is designed for use against personnel and so is expected to produce only a short blast of hot flame. The agent used in the oil bomb must generate fire long enough to induce burning of inert objects.

Flammable liquids, like solids, will burn only when they have been heated (either naturally or artificially) to a proper temperature. Vapors that will "flash" are produced at temperatures considerably below actual ignition points. Heating of liquids must be continued well beyond their flash points until a suitable concentration of their vapor in air is available to sustain combustion. The liquid incendiary must be brought to its ignition temperature and its vapor ignited before it can function.

TABLE 3.—IGNITION TEMPERATURES OF LIQUIDS

| Liquid | Temperature, °F. |
|---|---|
| Cylinder oil | 783 |
| Fuel oil, No. 6 | 765 |
| Lubricating oil, turbine | 700 |
| Gasoline | 522 (av.) |
| Kerosene | 490 |
| Paraffin | 473 |

The volatile oils (such as gasoline) release their heat much more quickly than do the heavier oils. Their exothermic reaction is actually too rapid for most incendiary purposes. It is therefore preferable to combine gasoline with a slower burning (higher ignition temperature) liquid, relying on the heat generated by the former to ensure ignition of the latter, thus substantially extending the burning period of the mixture.

Even such a combination of slow- and fast-burning oils has never been quite satisfactory for general incendiary purposes. However, it has value for use as flame-thrower fuel.

The flame thrower is designed to throw a stream of liquid for a considerable distance, the stream to be burning *when it strikes the target.* The fact that the liquid must be ignited at the point of emission is actually a handicap, for it means that much of the liquid will have burned itself out along the trajectory. The flame-thrower fuel must have a fairly high specific gravity to avoid wasteful spraying and to ensure good range. It must at the same time be readily ignitable.

Oils used in flame throwers must therefore be both heavy and volatile—heavy to ensure a ranging stream that will generate highest heats away from the operator, resist wind pressures along the trajectory, and preferably enable carrying of some unburned material to ignite at the target; and volatile for quick lighting as the material is ejected and then for positive ignition of the entire mixture.

A satisfactory oil mixture for this purpose is one having a specific gravity of about 1.0 (at 32°F.), composed of about 60 per cent heavy oil and 40 per cent gasoline, the percentage of the latter being reduced in hot climates.

**Incendiary Gels.** Despite the high heat-generating characteristics of many petroleum derivatives, their liquid physical state has always militated against their efficiency as fillers for incendiary bombs. A fast-burning oil tends to vaporize rapidly and thus keeps cooled down the wood on which it may be burning. Slow-burning liquids often leave residues that actually fireproof the fire hearth, or they may drain away before they become ignited. Pitches, rosins, heavy and light oils, saturated absorbents, and even solidified oils have all failed in some respect to meet the requirements of ideal incendiary agents.



Many of the disadvantages inherent in the oil incendiary have been overcome by the simple expedient of transforming a light volatile liquid into a colloidal gel by the introduction of such a material as sodium stearate. The result is a homogeneous thickened fuel that burns readily but slowly and completely, generating temperatures averaging 3270°F., and possessing a physical structure that permits it to be scattered and attached in a burning mass to any exposed surface. Such incendiary gels, although most useful as fillers for aerial bombs, also have advantages as flame-thrower fuels, enabling greater ranges, a cleaner fire rod, and longer burning of the fuel at the target.

For scattering from bombs, the physical state of incendiary gels is ideal. These materials, however, burn at rather low temperatures for a relatively short time, and they can be extinguished without difficulty. To overcome these disadvantages, incendiary gels are sometimes reinforced with various absorbents or with incendiaries from the solids group.

A composite material combining features of both scatter and intensive type agents is a standard fill for small U.S. incendiaries. It includes magnesium powder coated with asphalt particles to which are added gasoline, white phosphorus, and oxidizing agents. The mixture is kneaded into a tough rubbery mass that burns at approximately 3500°F. and resists extinguishment.

**White Phosphorus.** Because it possesses the property of igniting spontaneously when exposed to air, white (and yellow) phosphorus will always find a role as an incendiary agent even though that role may be strictly limited.

Phosphorus is most effective in igniting gases where momentary exposure to a small flame will suffice. Phosphorus-loaded bullets spelled the doom of hydrogen-filled airships. Yet this agent can be depended upon to ignite only readily combustible materials. It burns with a good temperature (2730°F.), but, as burning proceeds, phosphoric oxides accumulate[2] to provide fire-resistant insulation for the surfaces covered. Phosphorus is an effective incendiary only where fires can be started quickly, before these products of combustion have had time to form.

Phosphorus is troublesome to handle, for the pure substance must be kept constantly immersed in water or otherwise protected from air to prevent its reacting spontaneously with oxygen. Ordinarily, phosphorus is a waxy solid that melts at 111°F. and boils at 538°F. Its primary military use is as a smoke producer. On burning, a dense white smoke is given off, consisting of particles of oxide of phosphorus and of phosphoric acid formed by the action of moisture of the air on the oxide. When scattered against personnel, painful burns are produced.

Thus the incendiary use of phosphorus is in a sense a by-product of its more important military values as an obscurant and as an antipersonnel munition. When employed for these latter purposes, it sometimes starts fires, but since it cannot compete with more efficient incendiaries, it is seldom used as a primary agent where fire-raising is the principal objective. However, phosphorus is employed as an important ingredient in incendiary and pyrotechnic mixtures. As both igniter and obscurant the ease with which it ignites (and reignites after extinguishment) ensures its continued use for special incendiary purposes.

Phosphorus dissolves readily in carbon disulfide. In this form it was favored by the Japanese for use in incendiary bombs and shell. The usual practice is to saturate rubber globules or other porous objects with phosphorus disulfide solution. After the bomb or shell bursts the carbon disulfide evaporates very quickly, the residue of phosphorus bursts into flame, carbon disulfide gas is ignited, and the



rubber pellet continues for several minutes to emit fire as the particles of phosphorus with which it is impregnated ignite. The advantage of such an arrangement is the certainty of spontaneous ignition. The fire is shortlived, however.

**Thermit.** The mixture of metallic aluminum and oxide of iron, when exposed to a high-temperature flame, burns to produce extraordinarily high heat that will melt any iron or steel with which it comes in contact.[3] In industry, this readily developed heat is utilized in thermit welding.

Because of its high heat of combustion, ease of production, and nonhazardous nature, thermit is an important incendiary agent despite the fact that, in comparison with magnesium, it does not rate high as a primary fire starter.

An intimate mixture of an iron oxide (such as hammer scalings) with powdered aluminum in proportions of three to one produces a satisfactory thermit. A priming mixture that ignites easily and will burn at a very high temperature is required to fire the thermit. Once the reaction starts at one point, it quickly spreads throughout the mass. The aluminum contained in the mixture burns in the oxygen provided by the oxide of iron, the intensity of the heat of the reaction being largely a result of the speed with which the aluminum combines with the readily available oxygen. The solid mass of thermit is transformed in a matter of seconds to a white-hot liquid which, when it finally cools, consists of iron and aluminum slag.

What rules out thermit as a primary incendiary, despite the high (4330°F.) temperature it develops, is the speed with which it burns. If thermit's high rate of combustion could be maintained for minutes instead of seconds, thus allowing time for surrounding objects to be heated to ignition temperatures, this material would find more general employment for incendiary purposes.

As a secondary agent for starting the burning of magnesium, thermit is ideal. For this purpose it is essential that extremely high temperature be produced, although it is necessary to maintain this temperature only momentarily.

**Miscellaneous Secondary Agents.** Sodium is a soft light metal that is commonly isolated by electrolysis of sodium chloride (common salt). When in contact with water, this element reacts vigorously, releasing gaseous hydrogen from the water and developing sufficient heat to set the flammable hydrogen afire.[4] By this unique characteristic, sodium may be classed as a self-inflammable incendiary. However, the fact that this exothermic reaction takes place only in contact with moisture narrowly limits the value of sodium for starting fires. Its most important use is in igniting oils that have been dispersed on water.

Potassium is a metallic element resembling sodium. It reacts even more violently than sodium in contact with water. As it is a much rarer metal, the cost of its manufacture is so great as to limit its use even as a secondary incendiary agent.

For firing incendiary agents, both detonators and igniters are sometimes used. The initiating impulse may be supplied by either shock or flame; a combination of the two is frequently required. Shock initiators, including such materials as tetryl and fulminate mixtures, are fully described in textbooks of explosives.

Flame initiation may be supplied by hydrogen (for igniting flame-thrower fuels) or by fuze (for conveying fire from point of ignition to the agent); even electric current may be utilized to generate heat through a loose igniting mixture, thus producing initial flame. Ordinary black powder (composed of sulphur, charcoal, and potassium nitrate) is a convenient and frequently used initiating agent because of the ease with which it ignites and the high temperature at which it burns.

The burning of incendiary agents is facilitated by the presence in the incendiary mixture of some substance rich



in oxygen. The accelerated burning of modern incendiaries draws so rapidly on the oxygen available in that air that unless some reserve supply is available combustion would soon be retarded.

Important oxidizing agents used in incendiary warfare are the oxides of iron, barium, and lead and nitrates of barium, potassium, and strontium. Without incorporation of such materials, it would be impossible to maintain combustion of masses of intensively burning primary agents.

FOOTNOTES

1 The term "electron bomb" is properly applicable only to the German magnesium bomb in which this particular alloy is used.

2 $$\underset{\text{Phosphorus}}{4P} + \underset{\text{Oxygen}}{5O_2} = \underset{\text{Phosphorous pentoxide}}{2P_2O_5}$$

3 $$\underset{\text{Aluminum}}{2A_1} + \underset{\text{Oxide of iron}}{Fe_2O_3} = \underset{\text{Aluminum oxide}}{Al_2O_3} + \underset{\text{Iron}}{2F_2} + \text{heat}$$

4 $$\underset{\text{Sodium}}{2Na} + \underset{\text{Water}}{2H_2O} \rightarrow \underset{\text{Soda lye}}{2NaOH} + \underset{\text{Hydrogen gas}}{H_2}$$

CHAPTER IV

## INCENDIARY MUNITIONS

Incendiary munitions include devices employed to convey or project incendiary materials (described in Chap. III) to appropriate targets. They are provided for weapons used by both air and ground forces and are used to some extent by the navy as well as by the army.

**Light Bombs.** Aerial incendiary bombs fall into two general classifications: light and heavy.

In American practice, the light incendiary bomb is dropped in a bundle or cluster. The individual bomb may weigh from about 4 lb. for the intensive type to 10 lb., when filled with a scatter-type agent.

The magnesium bomb is typical of the light intensive-burning incendiary. In this bomb the body rather than the filler constitutes the primary incendiary agent. The body is made of magnesium alloy cored to receive an igniting charge of thermit. A nose of iron is usually affixed to enable penetration of light to medium roofs. A tailpiece is also added to ensure perpendicular flight after the bomb is released from the cluster.

On impact, a firing pin explodes a sensitive primer that communicates flame to a first-fire charge; this in turn ignites the thermit filler, which burns at such high temperature as shortly to cause fusing of the magnesium body.[1] This type of bomb will normally burn for about 10 minutes in one compact mass, releasing about 13,000 B.t.u.

The scatter-type light incendiary bomb consists essentially of a body of thin rolled steel with a nose and tail attached, the body being filled with gasoline gel or other viscous incendiary mixture that scatters for distances up

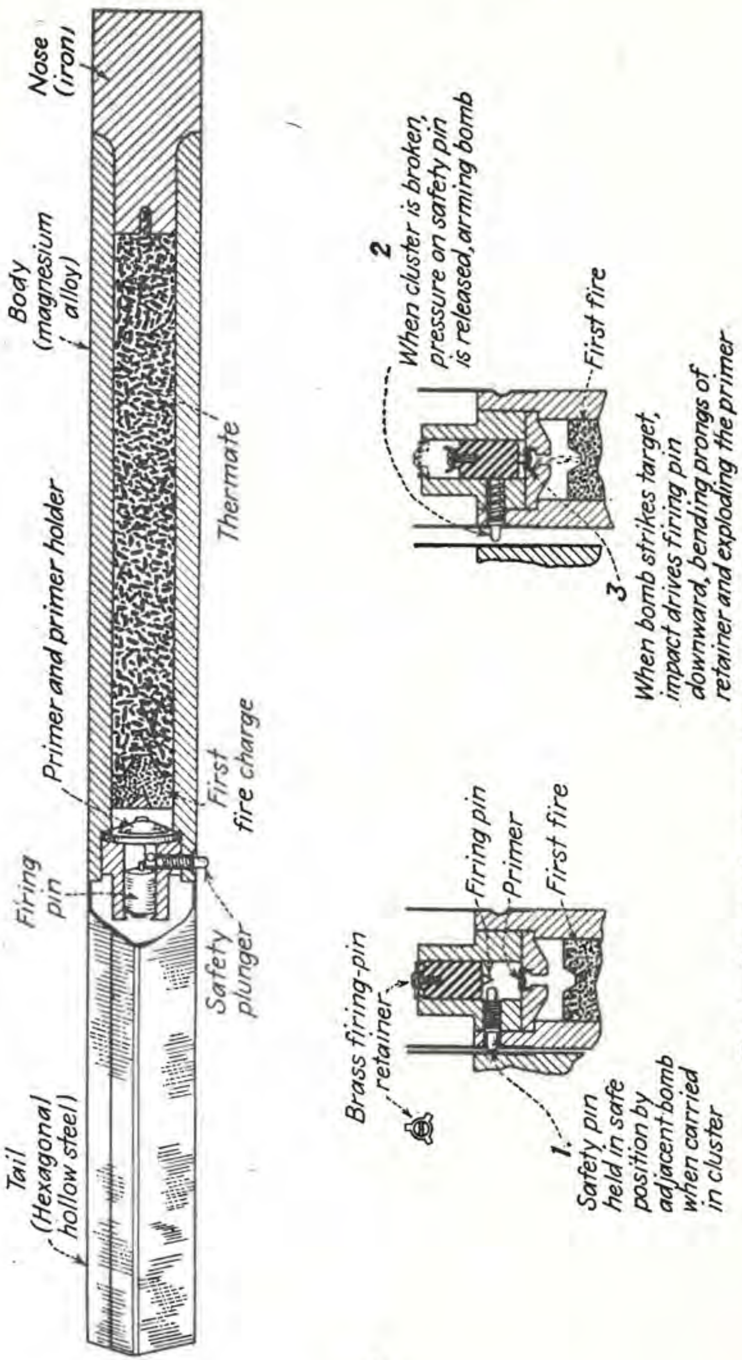



Fig. 4.—Diagram of magnesium incendiary bomb and its firing mechanism.





to 200 ft. This type of bomb is designed to eject its contents from the tail by means of a charge placed in its nose, which simultaneously expels and ignites the incendiary filling. White phosphorus is sometimes added to produce smoke and thus prevent firemen from locating scenes of fire.

The bomb may be fuzed for delayed action so as to permit penetration into structures before functioning or for superquick action so as to scatter flaming materials over roof surfaces. The heat content of such bombs will run as high as 40,000 B.t.u.

Light bombs are frequently provided with powerful antipersonnel explosive charges so as to constitute in effect combined fragmentation-incendiary bombs. Such charges, which may be set to explode at any time while the bomb is burning, throw fragments that are lethal to a distance of 150 ft. They are effective in preventing fire fighters from approaching burning incendiaries.

Japanese equivalents of light American clustered incendiary bombs were

*a*. Small rubber pellets impregnated with phosphorus in carbon disulfide solution (loaded in 100-lb. bombs).

*b*. Magnesium containers with thermit igniters (loaded in 156-lb. bombs).

*c*. Open-end iron cylinders made of 1-in. tubing 2¾ in. long and filled with special thermit mix (loaded in 560-lb. bomb).

**Clusters.** Both intensive and scatter-type light incendiary bombs of American design are bundled into clusters that may approximate the weight and dimensions of either 100- or 500-lb. explosive-type bombs. To facilitate clustering, light bombs are designed with hexagonal-shaped bodies. Twenty-five to 100 bombs may be packaged in one cluster.

The aimable cluster of incendiary bombs may be directed at a target from high altitude by the same precision-bombing methods as followed in releasing an HE bomb of corresponding size. The cluster normally opens at a predetermined elevation to scatter the individual bombs in an elliptical pattern across the target, the release mechanism being set before loading by the adjustment of a delay fuze. The aimable cluster can also be kept intact during flight so as to burst on impact, thus holding the entire bundle of bombs to a tight pattern.

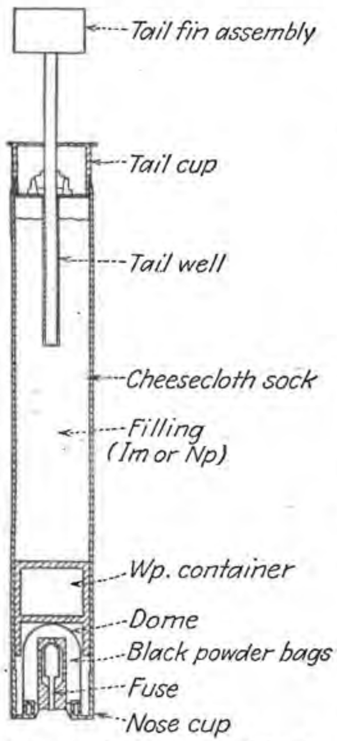


FIG. 5.—Scatter type light incendiary bomb.

Aimable clusters are usually opened at heights up to 5,000 ft. In such cases the elevation from which the cluster is dropped does not affect the dispersion of the bombs, the dispersion pattern being determined primarily by the distance at which the cluster opens above the target. In a typical pattern, small fire bombs released from a single aimable cluster will spread over an area 1,200 ft. long by 400 ft. wide.

The aimable cluster provides the only practicable means for dropping small incendiary bombs from close formations of bombers flying at high altitudes with due regard to the safety of accompanying aircraft and the accurate placement of bombs. However, on individual or open-formation bombing missions where low-altitude attack is feasible, a quick-opening type of cluster is preferable.

The quick-opening cluster releases its bomb as soon as the bomb bay has been safely cleared, the separate bombs then falling in a somewhat dispersed pattern. This method of clustering has definite advantages in bombing



at altitudes under 5,000 ft. and where accuracy of aim is not important. More bombs can be carried in quick-

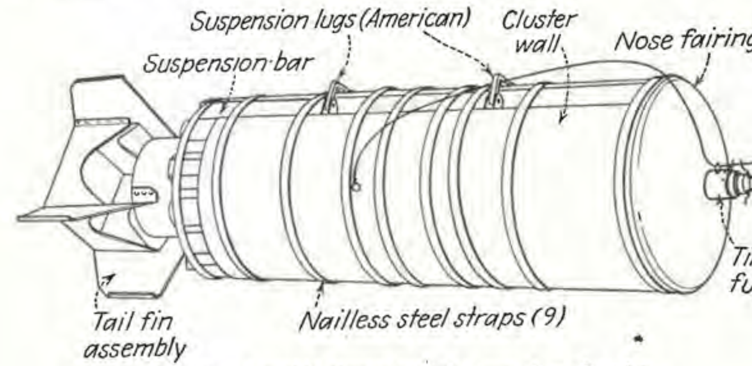


FIG. 6.—Aimable cluster of light incendiary bombs.

opening clusters, and the slanting angle of fall characteristic of this type of attack generally results in more bombs impacting on burnable structures.

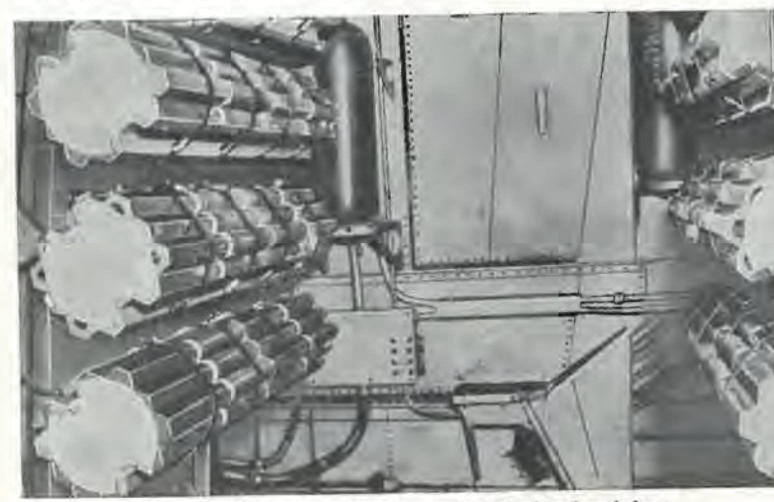


FIG. 7.—Quick-opening clusters installed in bomb bay.

**Heavy Bombs.** For precision bombing, incendiary units ranging in weight from 100 to 500 lb. are used. Although these large bombs are sometimes employed in area attack, they are used principally against point targets.

Heavy bombs are released individually. A particular advantage is their ability to penetrate heavily roofed structures that would resist the impact of light bombs. When dropped from high altitudes, these heavy bombs develop terminal velocities of 1,000 ft. per second and up and will pass through reinforced concrete 5 in. up to 15 in. thick for the heavier sizes.

The incendiary filling of heavy bombs varies between 35 and 55 per cent of the total bomb weight, the larger and better penetrating bombs showing lower efficiency ratios because of the heavier casings used. For this reason, use of the largest incendiary bombs is favored only against special targets.

The heavy bomb must be provided with an explosive burster charge for opening the bomb case in addition to an igniter charge or train. The case may be filled with a homogeneous incendiary mix, this arrangement being generally preferred in the design of heavy incendiary bombs for U.S. forces. Upon burst, flaming incendiary material is scattered for distances of 150 to 500 ft. When impacting close to inflammable objects, such bombs can be depended upon to start primary fires too serious to be extinguished by fire squads.

The large German (240-lb.) incendiary-mix bombs superseded earlier oil-filled bombs that had been used by the Luftwaffe without satisfactory results. The newer mixtures that were standard when Germany surrendered were never widely used.

The 132-lb. bomb was the largest incendiary mix bomb used by the Japanese. Larger Japanese bombs (156 and 560 lb.) were actually containers of small incendiary units that scattered over the target following air burst. These bombs also carried powerful explosive charges that produced considerable antipersonnel effect.

A variation of the heavy incendiary bomb is sometimes improvised by the expedient of dropping ordinary 55-gal. drums filled with inflammable oil and equipped with a



suitable igniter. Such drums were used, with poor results, due probably to imperfect ignition, by the German air force in attacks against British targets. When filled with thickened gasoline and dropped by bombers flying in formation, they provide an inexpensive means for burning of canopies of jungle foliage.

TABLE 4.—COMPARISON OF GERMAN AND JAPANESE INCENDIARY BOMBS

| Nominal weight, lb. | Incendiary filling | Nationality |
|---|---|---|
| 2 | Magnesium body, thermit igniter | German* |
| 25 | Thermit | German-Japanese |
| 70 | Phosphorus with steel pellets embedded | Japanese† |
| 75 | 67, 2.4-oz. thermit pots | German |
| 90 | 30-lb. incendiary mix, per cent:<br>Benzene . . . . . 86<br>Rubber . . . . . 10<br>Phosphorus . . . . . 4 | German |
| 100 | 35 lb. charge of from 400 to 450 small rubber pellets impregnated with phosphorus, in carbon disulfide solution | Japanese‡ |
| 132 | 80 lb. incendiary mix containing paraffin wax and kerosene | Japanese |
| 156 | Magnesium containers filled with thermit | Japanese |
| 240 | 19 gal. incendiary mix, per cent<br>Petroleum solvent . . . . . 87.7<br>Polystyrene . . . . . 11.7<br>Phosphorus . . . . . 0.5 | German |
| 240 | 110 lb. incendiary mix, per cent<br>Phosphorus . . . . . 86.5<br>Benzene . . . . . 13.1<br>Polystyrene . . . . . 0.4 | German |
| 560 | 756 open-end iron cylinders filled with thermit (300 lb.) | Japanese§ |

* When provided with an explosive head, this bomb weighed about 4 lb.

† Pellets (1⅛ by 15/16 in.) have a circumferential cavity in which phosphorus is held. Designed for air burst.

‡ Upon air burst, pellets are scattered up to 150 ft. They ignite immediately, burn 5 to 7 minutes with a flame 4 to 6 in. high. Most common incendiary used by Japanese army.

§ Normally air bursts at 150 to 200 ft. scattering cylinders over a radius of 500 ft. Thermit burns about 1 minute, with flames 6 to 9 in. long shooting from both ends of cylinder.

A much more effective improvisation in incendiary bombing was developed later in the war by adaptation of the jettisonable airplane fuel tank. This type of bomb has been widely used by low-flying fighter planes in direct attack against personnel. It is usually filled with ordinary gasoline mixed with a thickening agent. A large burst of intense flame is spread over a wide area, the general effect being that of a huge flame thrower. Burning is of such short duration that continuing fires are seldom started, although decisive tactical results have frequently been obtained in action against entrenched troops.

Incendiary bombs have been continuously improved since their first use in 1915. Types of American design are now capable of producing greater property damage than any other known weapon. Further developments are to be expected, not so much in fundamental design as in adaptation to specific types of targets. The small intensively burning bomb, for example, has never fully met expectations; probably a medium-size unit of this type will prove more effective in igniting semi-fire-resistant structures. Incorporation of improved antipersonnel features will make increasingly difficult the extinguishment of fires from all incendiary bombs.

**Flame Throwers.** One of the oldest uses of an incendiary weapon is the throwing of burning oil on an enemy. The flame thrower is merely a modern device for streamlining this ancient practice.

Three types of flame throwers are currently in use: the portable, the tank-mounted, and the stationary. They are all identical in principle. An inflammable liquid is held in a metal container, to be ejected by expanding pressure of a heavily compressed gas and ignited as it leaves a discharge pipe.

Characteristics of liquid agents used in flame projectors have been discussed in Chap. III.

Although the Japanese are said to be the first to use compressed gas to project inflammable liquid, during the Russo-Japanese War, the portable flame thrower did not come



into use until 1912, when it was standardized as equipment for siege trains of the German army.

The portable unit is carried and fired by one man, usually under protection of other soldiers who cover the enemy with small-arms fire while the flame thrower is being brought into action. The weight of the modern U.S. model is 70 lb.; Japanese units (of lesser capacity) were lighter.

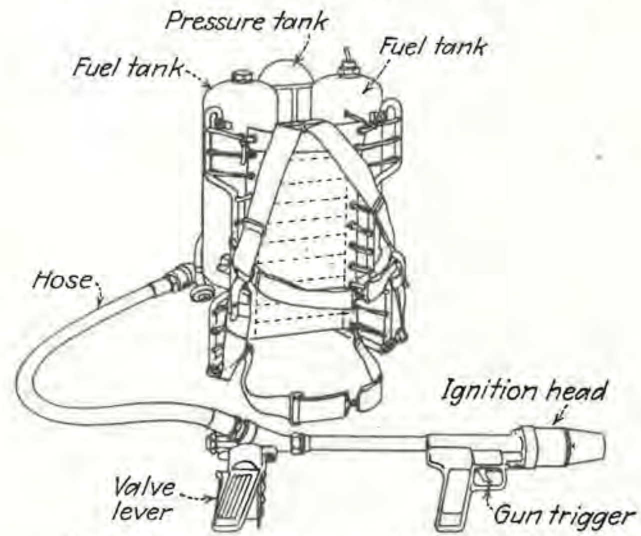



FIG. 8.—Portable flame thrower, United States Army.

Components of the portable flame thrower are grouped around (*a*) the tanks and (*b*) the gun.

The tank system includes two fuel tanks and a pressure tank. The fuel tanks are joined by a connector to form a single fuel reservoir with a capacity of 4 gal. The pressure tank may contain either nitrogen or air compressed so as to eject the fuel under a pressure of 2,000 lb. per square inch. The gun system includes a hose to convey fuel from the tank and the gun assembly that ignites the stream of fuel and directs it to the target. Fuel passes through the gun as the valve lever is gripped. Pressure on the gun trigger flashes a spark or incendiary charge that ignites the fuel as it emerges from the ignition head.

The contents of the fuel tank are ordinarily ejected within 10 seconds. In practice, the flame thrower is fired in a series of short bursts of 2 or 3 seconds each. Under satisfactory wind conditions, the effective range of the flame projected by the portable device is about 125 ft. After the unit has been emptied it must be moved back for refilling.

At the close of the war in 1945, there were promising developments of very light portable flame throwers, "one-shot" types intended to be discarded after use.

In the tank-mounted flame thrower, two of the limitations inherent in the portable unit are overcome. Larger fuel and pressure tanks can be carried, enabling flame to be projected longer and for greater distances. More security can at the same time be provided for the operator. The combination of ready mobility with fire power to cover the projection of flame in sizable volume as incorporated in the mechanized flame thrower represents an important development in military technique.

Although best results are obtained when the tank-mounted flame thrower is operated at extremely close range, the weapon can be fired effectively at a target over 200 ft. distant, discharging flame for a total period of about 60 seconds. However, the particular advantage of the mechanized flame thrower lies not in its range but in the fact that armored protection is provided so as to enable the flame to be projected close to the embrasure, thus greatly enhancing its effective uses.

The striking value of flame from both portable and mechanized projectors is in penetrating openings such as embrasures and gun ports. By filling the fortification with flame and smoke, enemy personnel is burned, blinded, or shocked.

In a stationary design, the same essential components as are employed in portable or mechanized flame throwers can be provided on a more elaborate scale. This type, however, is more promising in theory than in practice, since its use is limited to situations of static defense.



**Shell.** Two factors tend to lessen the importance in modern warfare of the incendiary-loaded artillery shell. Good incendiary targets are today seldom found within range of artillery. When such targets are found, usually they can be destroyed by incendiary bombing. Thus the effective worth of the incendiary shell is narrowed to certain specialized targets and to situations where tactical air force cannot be utilized.

For these reasons, many types of incendiary shell that were standard during the World War have since been discarded. The United States retains only the white phosphorus shell, which is not officially listed as an incendiary munition. White phosphorus here serves as a smoke and antipersonnel agent with only incidental incendiary value; yet it will set fire to light combustible materials and can be used in burning away camouflage.

The 81-mm. mortar shell is typical of this type of munition. This projectile weighs 11½ lb. and has a range of slightly under 2,000 yd. It carries a charge of 4 lb. of solid phosphorus. A burster well of thin-walled tubing filled with tetryl extends about three-quarters the length of the cavity. On impact, the nose fuze detonates the burster charge, which bursts the shell and simultaneously ignites and scatters the burning phosphorus.

Japanese divisional artillery was provided with incendiary shell loaded with rubber pellets impregnated with a solution of 88 per cent phosphorus and 12 per cent carbon disulfide. These were issued for 75-mm. guns and 90-mm. mortars. A burster charge of picric acid scattered the incendiary pellets, which ignited on exposure to air and burned for about 5 minutes. This type of incendiary is effective against readily ignitable materials.

The use of incendiaries against aircraft has engaged considerable attention. Although incendiary projectiles made the hydrogen-filled airship obsolete, the problems of attacking airplanes with fire have not been wholly solved.

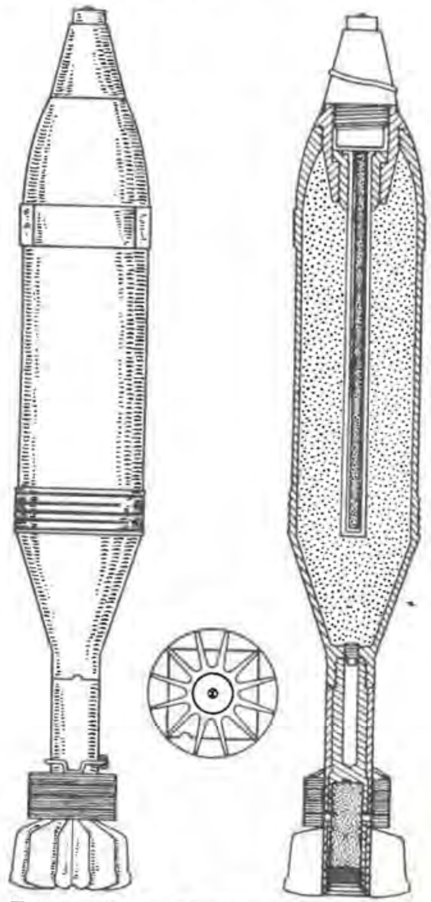


FIG. 9.—81-mm. phosphorus-loaded shell.

The 20-mm. explosive-incendiary shell has proved an effective munition for aircraft cannon for use against airplane targets. Functioning of this projectile is similar to that of the .50-caliber incendiary cartridge. The Japanese 20-mm. shell carried a small incendiary charge of barium nitrate 50 per cent, magnesium 40 per cent, and aluminum



10 per cent. German projectiles of this type carried phosphorus, thermit, and sometimes other incendiary materials.

The German 32-cm. rocket projectile incendiary, which may have been used in antiaircraft fire, carried a charge of 13 gal. of incendiary oil. The phosphorus-loaded AA shell was a standard Japanese munition. These projectiles produced large and spectacular aerial bursts, but their value was probably more psychological than destructive to aircraft.

The Japanese 120-mm. incendiary projectile, sometimes used in antiaircraft fire, contained 48 steel pellets similar to those used in the Japanese 70-lb. air-bursting incendiary bomb. The pellets were embedded in a canister filled with phosphorus, some of which was retained in an annular cavity extending around each pellet.

Application of incendiary-filled rocket projectiles to conditions of modern warfare is still somewhat uncertain despite the increasing importance of the rocket itself. At extreme ranges the rocket cannot compete with the bomber in attacking incendiary targets because of the diffuse pattern of rocket impacts. At shorter ranges (5,000 yd.), the 5-in. rocket is an effective incendiary weapon. For example, when fired from landing craft in amphibious operations, rocket heads loaded with thermit or oil incendiaries are useful against personnel or for igniting inflammable materials on or close to the beach.

**Grenades.** Although uses for incendiary grenades are limited, these portable weapons are valuable whenever fire can be employed for destroying materials or munitions or for attacking personnel at close range.

Incendiary grenades are of two types: standard items regularly produced and supplied, and improvised frangible grenades made from materials readily obtainable in the field. Standard grenades, although normally thrown by hand, can also be fired from rifles or grenade launchers.

The thermit type grenade is the most satisfactory for general incendiary purposes. The agent (approximately 26 oz.) is held in a steel container 2½ in. in diameter by 4¾ in. high, the complete grenade weighing 2 lb. In the top is a Bouchon-type fuze with a lever held in unarmed position by a safety pin, the fuze being positioned over a starter mixture contained in a plastic cup. When the grenade is thrown or laid in position, release of pressure against the fuze lever permits the firing pin to strike after a short delay, igniting the starter, which in turn initiates burning of the thermit filler. Vent holes are provided in the top of the grenade. The munition burns intensely for about half a minute with sufficient heat to melt and fuse metal parts, thus providing means for destruction of guns, airplanes, or other equipment about to be abandoned. By the use of an exterior Primacord detonator, the burning thermit grenade can also be made to scatter particles of molten iron for a distance of 75 ft.

The phosphorus hand grenade is constructed in the same manner as the thermit grenade but functions as a bursting rather than as a burning munition. On exploding, solid pieces of phosphorus are thrown a distance of 75 ft. and burn for about 30 seconds. This grenade is useful in setting fire to gasoline that has been projected against bunkers or into pillboxes or caves.

Japanese incendiary hand grenades carried either phosphorus or rubber pellets impregnated with phosphorus–carbon disulfide solution. The latter type was provided with a wooden handle to facilitate throwing.

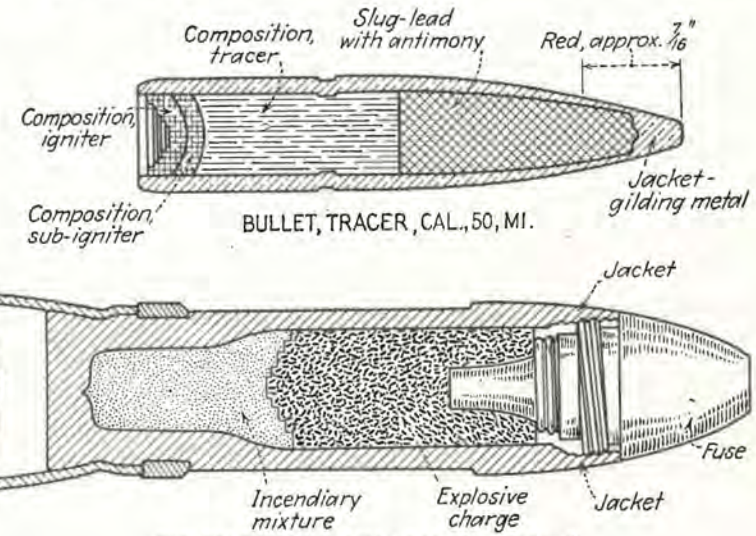
Incendiary grenades can be thrown by hand about 100 ft. They can also be adapted for firing from rifles or special grenade launchers to distances of 750 ft. When projected by rifle, using a special cartridge, the incendiary grenade is a valuable weapon for attacking tanks and other vehicles.

The frangible incendiary grenade is an ordinary small glass bottle filled with gasoline (preferably thickened), with some type of igniter tied or taped on the outside. The bottle breaks when thrown against a tank or other hard-



surfaced object, then the igniter sets fire to the liquid incendiary.

**Small-arms Ammunition.** Special rifle and machine-gun cartridges containing incendiary materials are used by both ground and air forces. The most common projectile of this type is the tracer bullet, supplied primarily to serve as a guide in aiming automatic weapons but also used




BULLET, TRACER, CAL. .50, M1.

EXPLOSIVE-INCENDIARY BULLET (20-MM. GUN)

Fig. 10.

occasionally for incendiary purposes. The head of the tracer-bullet jacket contains a lead slug, the rear half of the jacket being filled with incendiary material complete with igniter. As the cartridge is fired, the propelling charge lights the igniter, which in turn ignites the incendiary composition shortly after the projectile leaves the barrel. The incendiary material burns along the trajectory with a bright flame (red or sometimes green) that enables the course of the bullet to be seen by the gunner.

As the tracer flame is quite hot and is not easily extinguished, this type of projectile can be used for setting fire to gasoline or other inflammable materials. For this purpose, however, the usual range must be considerably shortened, because the incendiary composition burns for only a few seconds and is extinguished before the bullet has covered its normal trajectory. Incendiary fillers weigh from about 20 grains for .30-caliber projectiles to 75 grains for .50-caliber projectiles.

The tracer bullet is used only occasionally for incendiary purposes, whereas the explosive-incendiary bullet is designed to normally function with combined explosive and incendiary effect. This type of projectile is supplied for weapons up to 50-mm. caliber for use with ground and air armament against aircraft and other light matériel targets.

The explosive-incendiary bullet differs from the tracer bullet in that it ignites on impact instead of on discharge. It is provided with a point-detonating fuze and a charge of high explosive, with an incendiary filler placed behind the explosive charge. After the projectile penetrates the target, the explosive filler is detonated, the jacket or shell is shattered, and the incendiary composition is ignited.

Typical incendiary filler for Japanese .50-caliber explosive-incendiary bullet included the following

| | Per Cent |
|---|---|
| Barium nitrate | 38 |
| Sodium nitrate | 20 |
| Magnesium | 36 |
| Aluminum | 6 |

FOOTNOTES

[1] Each incendiary bomb must be provided with a means of igniting itself after it has been dropped from the bomber. Materials employed for this purpose vary according to the type of bomb and the primary incendiary agent used. They constitute the "ignition train" of the bomb. (An ignition train is also built into an incendiary shell.)

Principal steps leading to full ignition of the bomb are

*a.* Activation of the firing pin, by impact or time fuze.

*b.* Explosion of sensitive primer to produce flame.

*c.* Ignition of secondary (booster) incendiary.

*d.* Firing of primary incendiary.

# CHAPTER V

## TACTICS OF INCENDIARY BOMBING

Incendiary tactics involve determination of military methods to be followed in applying fire to a given target. The heat is dormant in the bombs. The tactician's job is to see that the bombs are conveyed to the proper place and that their heat is released under favorable conditions.

The timing of the attack, the bombing procedure, and the density and pattern for placement of incendiaries are all tactical decisions that can be made only after close study of the target.

**The Target Determines the Tactics.** The starting point in considering incendiary tactics is therefore the target.

Incendiaries have become more important as the distances at which war is waged have increased. The rise of military air power has vastly enlarged the horizons of battle. The airplane also permitted the development of modern incendiary warfare, one reason being that air force can seek out appropriate incendiary targets located at considerable distances from the immediate scene of ground operations.

As this striking distance is extended, incendiary warfare tends to fall into the sphere of strategical rather than tactical operations. Yet certain tactical principles are involved in any aerial incendiary attack, even though the military mission of the attack may be broadly strategical in nature.

The targets sought in incendiary bombing are *matériel* targets. The essential purpose of military fire-raising is to destroy inanimate objects so that the enemy will be denied their use. Diversion of the enemy's war effort to the replacing of indispensable fire losses is the toll exacted by successful incendiary attack. Injury to personnel is merely incidental—and actually has proved to be surprisingly small.

The first question to be asked regarding the target is: Will it burn readily? If the whole or any appreciable part of the target is combustible, destruction by fire is invited. If this is not the case, then the use of incendiaries is a mere waste of ammunition.

Given a satisfactory incendiary target, its layout determines whether aimed (precision) bombing or area (pattern) bombing procedure is applicable. This is primarily a question of aerial tactics. So also are decisions as to bombing elevation to evade antiaircraft fire and organization of the attack in strength sufficient to overcome fighter opposition.

But as to incendiary considerations, certain features of the target must be carefully studied in the light of intelligence information and reconnaissance photos in order to determine the pattern, density, and location of impacts best calculated to produce an appropriate volume of fire.

**Innate Combustibility of the Target.** There is in most targets an inherent element of potential self-destructibility, which may be called the *fire potential.* To fully exploit this vulnerability of the target is profitable because fire-raising has become relatively cheap in terms of military effort and because fire destruction is, in the main, thorough.

It is this invisible fire potential of the target that is aimed at in incendiary bombing. It must be envisaged just as clearly in operational planning as a point target must be seen during the bombing run.

In industry as in community life, the threat of fire destruction is constant. Normally this threat is held in check, principally by rigid control of fire-spreading agencies. Density of population, whether industrial or communital,



is feasible only insofar as fire can be made to serve its users and at the same time can be prevented from destroying them.

The implicit fire potential of a lived-in area tends normally to increase with the passage of time. Years may be required to develop naturally what can be regarded as a prime target for area incendiary attack. This accumulated susceptibility to fire can be seriously attenuated by a partial attack, whether with incendiaries or with explosives.

The military principle of the mass is here directly applicable. Within the clearly delineated confines of the target designated for a given operation, preferably a virgin target, complete fire destruction is attempted by bringing to bear in one continuous attack an adequate volume of fire bombs. This involves the generation of heat energy ample not only to kindle the target itself, but also to override the fire-protection resources available.

**Firebrakes.** A fire front driven by a strong wind will move steadily as long as there are ignitable materials within easy reach. However, when the front reaches an open space, such as a parkway or canal, say 300 ft. wide, the heat radiated down-wind will be diminished to such an extent that buildings beyond the fire check are unlikely to ignite.[1] Even though sparks and flaming embers may be blown into the down-wind area, the spreading fire is substantially checked and can be effectively combated by fire fighters.[2]

Such fire barriers may appear adventitiously, as in the case of Canal Street in New Orleans, or they may be laid as a measure of protection against incendiary attack, as for example the fire lanes cut through Tokyo and other Japanese cities after the bombing of Japan by United States planes was begun. In any case, the fire check is a static defense measure that influences the tactics of incendiary bombing.

Since the firebrake marks the down-wind boundary of an area fire, it becomes in effect a limiting dimension of a given target. It must therefore be located, and it must be considered in the tactical plan. Whether firing of the area beyong the fire lane is undertaken at the same time or later will depend on the bombing force available and on the general objectives of the attack.

Similar in effect is the barrier or fire division frequently encountered in point targets. Long, narrow warehouses, for example, are usually constructed with fire walls to confine a blaze to one section of the premises. Complete fire destruction of such a structure is possible only by impacting incendiaries between each fire division.

**Fire Fighters.** Incendiary attack differs from attack with explosive bombs in that, where fire is involved, energetic and usually effective resistance on the ground is to be expected.

Although fire fighters are unable to oppose the *dropping* of incendiaries, they are able to limit, sometimes materially, the results that incendiaries would otherwise produce. Thus the attack must not only set the target afire; it must at the same time overwhelm the efforts of the defenders to extinguish the fires. The power of fire-fighting resistance is therefore an important consideration in planning an incendiary attack.

Countercontrols are those active measures employed by the attacker to prevent the defender from controlling incendiaries or extinguishing fires they have started. A simple countercontrol is the "howler" built into the fin of the 1-kg. electron bomb to simulate the sound of a falling explosive bomb and thus frighten people away from the area.

A more positive deterrent to fire fighting is the explosive-type incendiary bomb, armed with a powerful explosive charge designed to detonate with killing force some time after the incendiary element has ignited.

Scattering of small fragmentation bombs while fires are



in progress is another method of hampering fire fighting without interfering with the progress of fires that have gotten under way. Other countercontrol measures are the destruction of water reservoirs and distribution systems and the immobilization of fire apparatus.

Besides the interposition of such positive measures to protect incendiary fires from extinguishment, it is usually necessary for the attacker to produce a volume of fire that will overtax the fire-fighting resources of the defender. This is a matter first of timing, or concentration of the entire attack into the shortest lapse of time that is operationally feasible, and second of use of saturation quantities of incendiary bombs.

One of the desired characteristics of an incendiary agent is that it be unextinguishable. This ideal has never been attained. Instead of depending on technical means to provide one agent that is intrinsically more difficult than another to subdue, the more promising procedure is to rely on tactical methods that will outmaneuver the defense.

Thus, to overcome fire resistance on the ground, the incendiary attack must be implemented with a certain force over and above that theoretically required to fire the target. This force acts directly to impede fire fighting and/or production of fire volume too great to be handled.

**Influence of Weather.** Four of the six weather elements have bearing on the success of incendiary attack. They influence area-bombing operations more than the attack of point targets.

It is difficult to imagine an area being bombed effectively with incendiaries in a driving rain. Precipitation retards burning of the incendiary and, more important, lessens the ignitibility of matériel. Thus record of rain or snow preceding the attack must be taken into account in rating the fire potential of the target.

Wind is an important contributor to the success of an area-bombing operation. Fresh winds supply additional oxygen to accelerate combustion. Strong wind drives fire ahead and spreads it over wide areas. Wind direction is to be considered in determining the axis of attack.

Major fires occur more readily when there is a deficiency of moisture in the air. A relative humidity of even 50 to 60 per cent serves to dampen exterior surfaces and so exerts a retarding influence during the initial stages of combustion. Records of peacetime conflagrations indicate that these almost always occur on days of low humidity.

Extremes of temperature in either direction may favor incendiary attack. Warm weather, especially if accompanied by low humidity, provides the more promising natural conditions for fires. On the other hand, extremely cold weather hampers fire protection, as was evidenced during the incendiary attacks against London in the winter of 1940–1941. Low temperature alone does not materially influence the combustibility of matériel.

As between precipitation, wind, humidity, and temperature, only the first two elements are of real importance tactically. Fire cannot be expected to spread during or immediately following heavy rain. Steady winds are needed to cause the separate fires generated by incendiary bombs to coalesce; where such winds are present, their direction must be known in order that the successive impact centers of the bombing pattern may be placed upwind in order to avoid interference from wind-blown smoke.

**Concentrated or Spreading Fire.** A primary consideration in planning an incendiary attack is whether the fire can be made to spread over an area. If not, then a concentrated fire must be set up at one point.

This decision is dictated largely by the layout of the facilities under attack. Given a sprawling target, where a hit in one spot is as effective as a hit in another, refinement in aiming is superfluous. On the other hand, a warehouse located on a pier must be hit directly, any bombs falling over or short being altogether useless.



Whether to attack by precision- or pattern-bombing tactics is essentially an airman's decision. Yet the decision is influenced by the incendiary mission, which may be either to burn out a single objective or to induce the spread of fire throughout a wide area.

**Point Target.** Operationally, the pin-point target is one that is aimed at directly and with precision. From an incendiary viewpoint, it is a combustible target of relatively narrow dimensions, *surrounded by an area devoid of inflammables*. Perfectly fitting this definition is a ship at sea; an incendiary near miss is no good. Thus the distinguishing feature of an incendiary point target is the fact that it is an isolated target; were it not, then technically it would be simpler to fire the environs and depend on the spread of fire to destroy the target.

Penetrability is more likely to be a factor with a point target than in situations where area tactics are permissible. Frequently the contents are more inflammable than the containing structure. Combustibles stored under strong sheltering structures can be reached only by heavily cased bombs. In many instances, preliminary bombing with explosives is necessary to lay the target open for incendiary bombing.

Bombing efficiency demands, where precision methods apply, that the bomb unit be as large as is technically feasible. This operational requirement generally dictates the selection of a large incendiary bomb. Twofold effects follow: the larger bomb penetrates better, and it produces a heavy mass of fire at one point. The latter is particularly important since it represents the only means for offsetting fire protection within the narrow confines of a typical point target.

**Area Target.** The area target differs from the point target just as radically in the technique of fire-raising as it does in bombing procedure.

The objective in incendiary bombing of an area is to destroy all the structures within that area. This destruction is accomplished by laying incendiaries on the area with such density as to initiate a fire front that will sweep across the area and either consume or destroy by heat warpage substantially everything therein. Obviously this can be accomplished only in an area containing structures which are of at least medium combustibility and which are compactly grouped. The combustibility of the structures in any given area may be rated as high, medium, or low.

A principal criterion as to combustibility is the proportion of wood used in building construction. This, in turn, is largely a matter of the availability and cheapness of lumber in the locality. Dearth of wood in North Africa leads to a type of construction that is highly fire-resistant and therefore unattractive as a target for incendiary attack. In arid regions where timber is scarce, combustibility may in general be rated as low and the prospects for spreading fires as extremely limited.

In regions where wood is more generally used, differentiation must still be made in the matter of combustibility between one locality and another. Even in one city, wide variations are to be noted between local districts as to fire susceptibility. National building characteristics thus afford only a broad gage to fire potential; the specific area in a given community must be rated according to the prevailing type of structure and the density of groupment.

Thus two principal factors determine the limits of an area over which fires initiated by incendiary bombs may be expected to spread. First is the innate combustibility of the structures located within the area. Second is the density with which these structures are grouped. When high to medium combustibility throughout and ground coverage of at least 30 per cent are taken together, it is possible to delineate with considerable accuracy the specific area to be covered by spreading fire.



**Zoning of Areas.** The average community may thus be zoned for incendiary attack. There will usually be found a central compactly built high fire-risk area, which can be designated as zone *A*. The boundaries of this zone may be a river or, more usually, a line where density of construction falls off to where fire will cease to spread.

Zone *A* may in some cases be attacked as a single target, although more frequently it will have to be divided into a number of subtargets. The entire zone often includes a core of modern fire-resistant buildings against which direct incendiary attack will prove ineffective. Surrounding them are generally located the types of structures more suitable for incendiary bombing. Yet careful study of the latter will usually disclose fire lanes deliberately designed to prevent the spread of fires over an area that the defenders have recognized as particularly susceptible to incendiary attack. Careful preliminary study of zone *A* and its division into subtargets (target sectors) where necessary is therefore requisite in order that the entire operation may be exactly planned to best meet ever-varying local situations.

From an operational viewpoint, an area of 1 million sq. yd. offers a convenient target unit to be attacked with one formation of bombers loaded with one type of incendiary bomb. Where zone *A* is of greater expanse, it is usually desirable to divide it into component sections.

Zone *B* may be described as the area, frequently surrounding zone *A*, where buildings are more widely dispersed and into which a conflagration will not penetrate. There may be located in zone *B* islands of clustered structures extending over sufficient ground to justify pattern bombing. Where such secondary *B* targets are of military importance, they can be attacked independently, whereas it is preferable to attack simultaneously all subtargets in zone *A*.

Located in many instances on the outskirts of a metropolis are to be found centers of highly industrialized activity, the destruction of which will prove of immediate military importance. Such areas may be designated as *C* zones. Normally they contain both area targets and point targets. Shipyards, docks, arsenals, refineries, and similar industrial facilities are characteristic *C* targets. Their destruction usually necessitates attack with both explosive bombs and incendiaries.

**Incendiary-bombing Map.** Modern incendiary bombing is no hit-or-miss proposition. Before the field order for an attack is written, the vulnerability aspects of the target are thoroughly analyzed. Technical intelligence is obtained by interrogation of architects and other specialists who may be found to have intimate knowledge of construction practice, areas of special fire risk, and other pertinent information. From such sources there is assembled an intelligence summary including data regarding

*a.* Fire defense (and air-raid protection in general).

*b.* Water supply.

*c.* Prevailing types of structures.

*d.* Average height of structures.

*e.* Important industrial installations.

The city will also be completely photographed from observation aircraft so that a full mosaic of the entire area can be developed. From this mosaic a special incendiary bombing map of the city is drawn.

On the bombing map will be designated (*a*) districts seen to be susceptible to area bombing, (*b*) districts *not* susceptible to area bombing, and (*c*) important isolated industrial targets to be attacked by precision-bombing methods.

Two simple rules are followed in preparing such a blueprint for bombing. They are

*a.* For areas: *The 30 Per Cent Rule.* Roof coverage of at least 30 per cent is required to sustain spreading fire over an area; where structures are less compactly grouped, pattern bombing of the area is not justified.

*b.* For isolated targets: *The 25 Per Cent Rule.* Incendiary attack is preferable to explosive bombing of any single building if at least 25 per cent of structures and/or contents are inflammable.



With the essential data as to vulnerability graphically indicated on the incendiary map, preparation of the operations order for the attack is greatly simplified. The order will be influenced by two important considerations:

*a. Areas will be bombed with incendiaries.*

1. Explosive bombs may be employed in limited quantities as needed to hamper fire fighting.

2. Clustered small incendiary bombs or larger individually released units, or both, may be employed, depending on relative combustibility and on penetrability of roofs.

3. Two hundred tons of bombs per square mile, more or less, will be dropped.

4. An appropriate segment of the target area is assigned to each tactical formation of aircraft.

*b. Isolated industrial plants will be bombed with explosives and/or incendiaries.*

1. Vulnerability of each important unit composing the plant will be analyzed.

2. Use of incendiaries will be limited to units reasonably vulnerable to fire.

3. Precision bombing with 100- or 500-lb. incendiaries is normal, although pattern bombing is justified where a sizable area is well covered with fire-vulnerable units.

**The Continuing Fire.** The only incendiary bomb that counts is the one that starts a fire that continues to burn. Of the bombs dropped in pattern bombing, the probabilities are that less than one out of three will start fires; one *continuing* fire from 20 small bombs is good expentancy.[3]

Of 1,000 small bombs scattered over an area, the order of expectancy is somewhat as follows:

100 will malfunction
500 (or more) will strike in open spaces
125 will burn inside buildings without starting fires
725 bombs are wasted so that 275 *may start fires*

Of the 275 incendiary fires thus started, many will be extinguished by fire fighters. Intelligence data should permit a fair estimate of how many incendiary fires will be put out before developing into more serious fires (see Chap. VII). If it be assumed that fire squads will handle 200 and appliance units 25 of these 275 fires, then 50 fires will continue to burn despite all efforts of the defense. The success of the operation will depend on these 50 continuing fires, resulting from 5 per cent of the clustered incendiaries dropped on the target.

The values given the above categories are of course mere approximations. However, it is important that similar factors be correctly evaluated in the tactical planning of an incendiary mission. The area incendiary attack is largely a race between the placement of bombs by the attacker and the extinguishment of the bombs by the defender. The margin by which the bombs burning exceeds the bombs extinguished is the measure of effectiveness of the attack.

It is this remainder of continuing fires, each expanding and spreading by pressure of winds and of the fires themselves, that coalesces into a solid area fire.

To produce a thoroughly destructive area fire, continuing fires must appear simultaneously throughout the area in which bombs are impacted. Where the target combustibility is rated as *medium*, spacing of continuing fires at distances of about 50 yd. gives good results; where combustibility rating is higher, a smaller number of continuing fires will suffice. This assumes of course that density of buildings in either case is sufficient to support spreading fires.

The concept of the continuing fire is helpful in planning bombing patterns and in estimating quantities of munitions required for specific missions. Dependence must be placed on the law of probabilities for ensuring enough continuing fires in an area to meet the arbitrary standard of fires 50 yd. or further apart as discussed above.




FIG. 11.—Incendiary attack and defense of a Japanese urban area.
Boundary of target sectors
Natural firebrake

The plan evidently contemplated starting six secondary fires at points marked (*2F*) with expectation that they would join to produce a conflagration that would sweep the entire area.

It will be noted that the boundaries of target sectors follow existing firebrakes wherever possible.

Fire No. 1 was kept from spreading laterally and was driven into pocket formed by firebrakes in the upper corner of the sector, about half of which was destroyed.

Fire No. 2 was stopped along the line of rail trackage, although the remainder of the sector was burned out. This was the most destructive fire, yet it did not spread into the next sector.

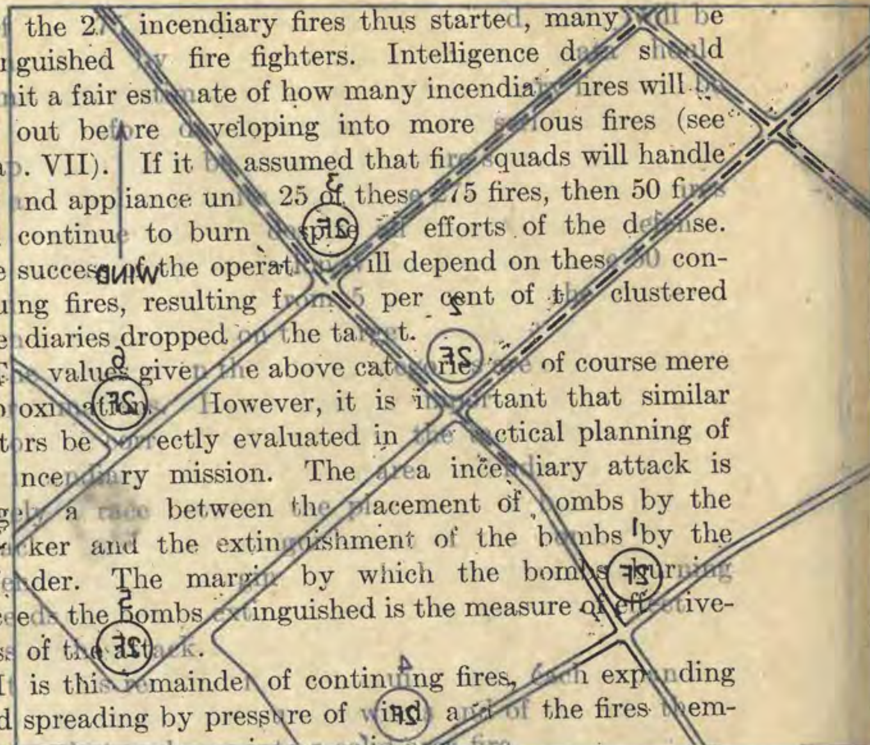
Stopping of fire No. 3 along an air gap was no doubt facilitated by the diagonal direction of the wind. Six blocks of houses were destroyed, but the remainder of the sector was saved.

For fire No. 4 the same tactics were used as for fire No. 1; lateral spread was stopped and the fire died out against firebrakes without spreading to adjoining sectors.

Fire No. 5 was pinched out along a fairly wide diagonal street in what appears to have been a good example of fire fighting.

Fire No. 6 was actually a series of primary fires in a sector where fire susceptibility was only fair. The stopping of fire No. 5 probably saved this sector from more serious damage.

Obviously, the attack was handicapped in this situation by the direction of the wind. On the other hand, the fire defense took full advantage of this fact. In subsequent attacks of this area, the chances of starting a conflagration would be slight.



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For point targets, the expectancy for continuing fires is higher than is the case where area bombing tactics are employed.

The larger bombs used in aimed bombing are obviously designed to start much larger fires of a type that cannot be handled by individuals or fire squads. The numbers falling in open spaces are attributable to bombing errors; the value of this factor can be determined on the basis of bombing experience. Misfires are fairly constant, regardless of the size of bomb.

The essential consideration, then, in attacking a point target is whether more continuing fires can be started than can be handled by available fire-fighting equipment. Reasonable expectancies may be allocated as follows for 10 incendiary bombs dropped against a point target:

2 will miss the target
1 will malfunction
1 will burn inside the target without starting fires
3 will be extinguished by fire companies
3 will continue burning

**The Tactical Decision.** The choice of bombs to be employed in an incendiary attack depends on (*a*) the combustibility and penetrability of structures and (*b*) whether concentrated or spreading fires are to be started. Characteristics of incendiary bombs have been discussed in Chap. IV.

The primary tactical decision concerns the massing of continuing fires that can be achieved with the type of incendiary selected as most appropriate. Timing of the attack is important, as is also the location of impact centers so as to take advantage of favoring winds. Of greater significance, however, is the volume of fire that should be produced with respect to the extent of fire destruction attempted. In short, the ultimate tactical decision is made by properly reconciling the means available and the ends sought.



This of course applies in principle to any military operation. For incendiary attack it involves appraisal first of the heat energy required to kindly the target, plus the volume that must be added to surpass the fire-fighting capacity of the defenders. Operational experience will dictate the proportions by which the requirements thus adduced should be increased to account for hostile interference with the attack, bombing errors, and other losses.

The target should, in turn, be carefully studied in the light of this adjusted computation of requirements. *It is usually easier to limit the objective than it is to increase the force.* This limiting should be done without hesitancy whenever necessary to ensure adequate concentration of fire. Although it is desirable to burn out all fire-vulnerable areas in one massive strike, thorough fire destruction in a single sector is preferable to the partial burning over of large areas.

FOOTNOTES

[1] Theoretically, the intensity of radiated heat decreases as the square of the distance increases.

[2] Van Ness Avenue served as a check to the San Francisco fire of 1906.

[3] The discussion of incendiary-bomb expectancies is based on the number of bombs placed on the target, not on the number leaving the bomber base. Of the latter total, a certain proportion may never be released over the objective; of the bombs dropped, some may miss the target.

CHAPTER VI

## WARTIME FIRE DEFENSE

The threat of serial attack is no longer the vague but disturbing possibility that plagued the civilized world following the publication in 1921 of Giulio Douhet's ambitious "Command of the Air." It is today a much more definitely known quantity. The prospect of aerial bombardment was once a field for speculation by a few "experts"; now the future presents a grim reality, the dimensions of which can be measured with certainty by the vivid experience of many peoples.

**Fire Defense and National Defense.** Although it is to be hoped that the atomic bomb may be shelved by general concurrence, as was gas warfare, any such action with respect to the incendiary bomb has not been seriously considered. The incendiary weapon, having been forged and tempered in the past conflict, is certain to be a leading instrumentality of future warfare. The pattern of future operations can be seen definitely outlined in the military campaigns against Germany and Japan. Softening of the defense by prolonged aerial attack will be the prelude to invasion. This aerial offensive will depend heavily on the incendiary bomb for its initial effectiveness. The incendiary will spearhead the attack and will continue to support it as long as fire affords promise of laying waste the material resources of the enemy.

Since the civil community, regardless of its location, must hereafter be regarded as an early target for incendiary attack, measures for its protection become an integral feature of national defense. This is a local problem only insofar as the measures adopted must be locally imple-





mented. The exigencies of modern warfare burden the state with responsibility that the community shall in every practicable way lessen its susceptibility to incendiary bombing. This requires progressive long-range planning as well as intensive short-term preparation.

The survival of London and other British communities under the vicious incendiary attacks of 1940 and 1941 was due not alone to the indomitable spirit displayed by fire fighters of all ranks. It was due also in large measure to the foresight of British authorities in preparing for these attacks during the years immediately preceding the war.

Since the tactics of incendiary bombing have now been, if not formalized, at least considerably clarified, preparations for incendiary defense can now be undertaken with certainly clearer understanding of the problem and, consequently, with firmer expectancy as to results than was possible before 1939.

From the viewpoint of the defense, protection against incendiary bombing is liberally promising of results. Purely passive defense can of course never completely eliminate fire damage from a well-organized attack in force. It can eventually be overpowered by a preponderance of air force in the hands of the attacker, as was the case in Germany. The incendiary defense scheme can remain continuously effective only in conjunction with aggressive aerial defense with which it is actually allied. Where active and passive defense are coordinated, however, the latter can deny the attacker the full benefit of such blows as he may be able to deliver. Refused the advantage of widespread fire destruction, he must fall back on less effective methods of attack. Thus well-ordered defense measures on the community level, besides minimizing local losses, contribute directly to national security.

**Fire Defense in Action.** During the past war, civilian defense organizations in Great Britain, Germany, and Japan were in turn called on to withstand the impact of incendiary bombing. In each country fire protection was expanded well in advance in preparation for impending attack. As to importance of accomplishment, the British fire service may be rated first, the German second, and the Japanese a poor third.

This, however, does not indicate the relative efficiency of fire protection in these three countries. This could be determined only if it were possible to apply a common denominator to the widely different problems that had to be met in each instance. Susceptibility to fire attack is one variable; the preponderance of force with which attack could be delivered is another. Each of these factors must be taken into consideration in evaluating the contribution of local defense measures to the ultimate military decision.

In order of fire vulnerability, Japan can be rated first, Britain second, Germany third. As to intensity of attack, it is now apparent that the fire raids against London and other English cities, although seemingly heavy, were actually moderate compared with the overpowering assaults made on German and later on Japanese cities.

**Fire Defense in Great Britain.** British wartime fire defense was built up around the sound core of local professional fire brigades, of which there were some 1,400 throughout the British Isles at the outset of the war. Directly supporting these permanent fire brigades was the Auxiliary Fire Service. In addition, there was a large army of fire watchers and fire squads to handle minor incendiary incidents.

The British Auxiliary Fire Service was formally organized in April, 1938, nearly a year and a half before the beginning of the war in Europe. Its rapid expansion began in the fall of 1938, immediately following the Munich Conference, when the strength of the A.F.S. rose to 100,000 men. Failure of incendiary attack to materialize during the early months of the war led to a falling off of interest in this



organization so that the enrollment had dropped to something like 50,000 when the Battle of Britain began.

The principal equipment of the A.F.S. was the trailer pump, large numbers of which were provided before the outset of hostilities. These pumps were designed to be towed by any automobile commandeered on the street. Three sizes were eventually standardized: the smallest with a capacity of 120 to 220 gal. of water per minute, the intermediate with a capacity of 250 to 350 gal. per minute, and the large trailer pump capable of delivering 350 to 500 gal. per minute. About 500 units of each type were manned by London auxiliaries during the heaviest German attacks.

For each member of the A.F.S., 60 hours of training in pump operation and in fire-fighting tactics were prescribed. Eventually, British practice provided for training of 10 auxiliaries for every professional fireman.

Fire watching and the handling of minor incidents became duties of air-raid wardens according to fire-precaution schemes set up by local authorities under the Air Raid Precautions Act of 1937. Wardens were eventually available in proportions up to 1,200 men and women per 100,000 population, all trained to spot handle small incendiary fires with portable appliances.

Performance of British incendiary defense can be summarized from experience in dealing with fire raids against the city of London. After failure of the Luftwaffe to destroy British port facilities and airfields by bombing, which had been undertaken as a preliminary to the invasion of England, the Germans next attempted to destroy the British capital by fire. Since daylight bombing operations had proved so costly, night attacks were resorted to, and the bomber strength of the German air force was concentrated on a series of incendiary missions that proved to be the final phase of the Battle of Britain.

Beginning Sept. 8, 1940, London was attacked for 22 successive nights with fire bombs. During this period, an average of *over* 700 *serious fires were combated each night* by the regular Fire Brigade and auxiliary fire units of London. On the night of December 8 a more intensive attack was delivered, resulting in some 2,000 appliance fires. These figures do not include the countless small fires that were put out night after night by air-raid wardens and volunteer firemen.

Throughout this entire period, the London services were learning the techniques of handling large-scale incendiary fires and were becoming more proficient in operation under aerial attack. They were thus seasoned to meet the climactic raid of December 29. On this date the old City, the same area that had been devastated by the historic fire of 1666, was deluged with incendiaries. Although this attack resulted in the greatest single area of destruction produced in Great Britain during the entire war, the London fire services were able to bring the situation under control after about 8 hours of heroic work. Later attacks, although frequent, were never staged in sufficient force seriously to challenge British fire-protection organization.

It is a historic fact that British fire defense succeeded in turning back the incendiary offensive with which the German High Command had expected to produce decisive results.[1] Yet without detracting from this splendid accomplishment, the following facts must be considered:

*a.* The Royal Air Force never relinquished substantial control of the air over Britain.

*b.* The Luftwaffe could scarcely muster as many as 400 bombers for a single operation—aircraft that would not be judged first-rate according to present standards.

*c.* The magnesium and oil bombs used by the Germans did not prove so effective as the incendiaries later used by the British and American air forces.

Although fire protection was at the outset primarily a local problem, the necessity for reinforcing fire-fighting facilities from near-by communities became increasingly urgent as German attacks continued. This led eventually (Aug. 18, 1941) to the organization of the National Fire



Service, under which all local fire brigades and auxiliary units were pooled and employed as circumstances required under over-all direction of the national government. This wartime development will no doubt be retained as a permanent feature of British fire defense.

**German Fire Protection.** Defense of German cities against wartime fires was deeply rooted in experience. At the siege of Kolberg (1807), the essential features of modern fire protection were put into effect to save the city from being destroyed by incendiary shell. Preparations for combating incendiary bombs were begun in the era following the World War and were continued under the Nazis. More attention was paid to reducing fire hazards than to reinforcing permanent fire services. However, even Goering's promise that Germany would never be bombed had little effect on the thoroughness with which local authorities throughout the Reich carried forward preparations to withstand incendiary attack.

Functioning of all civil-defense organizations in Germany varied with the rise and fall of Germany's military fortunes. This can be noted by examining fire-protection measures for the city of Cologne, as they existed before saturation raiding began in June, 1943, and as they progressively deteriorated under obliteration bombing.

Fire equipment included 118 large appliances manned by professional fire fighters (although occasionally auxiliaries or temporary personnel were called on to man certain vehicles). The city was divided into four fire districts, a three-company fire battalion being assigned to each. In addition, five fireboats were available for fighting waterfront fires.

Trailer pumps were handled by the Nazi Party Fire Service, which limited its operations to certain selected industrial plants and utilities.

Fire parties provided with hand appliances were available in each of the 32 sectors of the city to assist householders in dealing with local fires. These fire parties, along with other civilian defense groups, were under police control and responded only on call.

Because of the general fire resistance of structures and the small divisions through which fire could spread in Cologne, this organization proved effective in handling light to medium attacks. This was one fact that influenced the decision to undertake 1,000-plane attacks against Cologne. Much the same situation applied in most German cities. For effective incendiary attack, fires had to be started simultaneously in many fire divisions, and sufficient explosive bombs had to be used to keep people under cover until fires were well started.[2]

With the beginning of heavy aerial attacks, it became standard practice to move fire apparatus to the outskirts of the city. After 1943, fire personnel refused to reenter the city until bombing had ceased. This meant a lapse of 1 to 2 hours after incendiaries had landed before appliance units could arrive at the scene of serious fires.

During the height of later attacks against Cologne and other German cities, the population simply concentrated on remaining alive in shelters. As the attack lessened or ended, fire parties emerged from shelters to take care of small incidents. From the main control center, appliance units were directed to the scene of more serious fires. These were usually delayed in arriving by obstructions, particularly the melting of asphalt pavements.

As continued attacks took their toll of fire destruction, the city was gradually reduced to a waste of rubble and charred ashes, until eventually there remained little for fire fighting to protect. At last on Mar. 2, 1945, a direct bomb hit destroyed the main control center, after which organized fire protection, as well as all other civilian-defense agencies, ceased to exist.

It can scarcely be said that the fire defense of German cities was found wanting—it was simply overwhelmed. Its failure to function more effectively can be traced to the



failure of German antiaircraft and fighter protection to ward off more of the force of Allied bombing attack.

**Japan under Incendiary Attack.** The Japanese were able to put up even less effective military opposition to bombing attack than were the Germans. Both lost control of the air, so in neither instance could fire protection have been expected to avert eventual fire destruction; yet here the parallel ends.

Susceptibility of Japanese cities to spreading fires proved to be high. Buildings were not so inflammable as was popularly supposed; yet congested districts did burn much more readily than was the case in Europe. Another important consideration was the fact that U.S. air forces had acquired extensive experience in incendiary warfare by the time the aerial assault of Japan was begun. Bombing was concentrated and was scientifically carried out after careful study of each target. And the munitions used were properly designed. As a result of this combination of circumstances, fires quickly reached out-of-control proportions which defied all fire-fighting efforts.

The Japanese populace had long lived under the threat of fire destruction, and fire fighting was accordingly well developed throughout Japan. However, the problems of fire fighting under incendiary attack were found to be very different from those normally encountered, even in a country where earth tremors are of nearly daily occurrence.

As far back as 1935, the Japanese government had prepared and distributed elaborate folders depicting organized and volunteer fire-fighting units handling simulated incendiary incidents. The motive was ostensibly to discourage incendiary attack by conveying the idea that fire protection of Japanese cities was thoroughly organized. The effect of this gesture was of course negligible except in that it served to invite attention to an inherent weakness that was recognized even in Japan. When the strategical situation permitted incendiary attacks to be made in force, these were not dissuaded by knowledge that organized protection was at hand. The attacks were made with due regard to the estimated capabilities of the defense, and the results of each attack were studied in the cold light of reconnaissance photographs. The use of explosive bombs was omitted, as it was rightly estimated that fire and more fire was the answer to the problem.

Thus the efficacy of Japanese fire protection was tested and was found wanting. However, failure to prevent devastating fire damage to Japanese cities is scarcely chargeable to inefficient organization or to lack of courage or spirit on the part of fire fighters. Failure resulted primarily because the problem was one too great to be solved by fire fighting alone.

The reaction within Japan to the fire destruction of great cities is here illuminating. From the Tokyo radio came such comments as: "Our buildings have been placed too close together. . . . Community life has been too congested. . . . In the future we must follow more dispersed patterns in social and industrial groupments."

Here is a keynote to future community planning outside as well as within Japan. Full reliance cannot be placed on fire fighting to ward off destruction from incendiary bombing. The fire fighter is indispensable, yet he must be given a fair chance. The layout of the community or the industrial facility he is protecting must be such as to work with him instead of against him.

From the experience of England, Germany, and Japan under incendiary attack, it becomes clear that

*a.* A well-developed scheme of fire protection is an essential feature of civilian defense against enemy bombing.

*b.* The fire-protection organization cannot be expected to function for long once control of the air is lost by the defender.

*c.* Elimination of excessive fire hazard is necessary.



FOOTNOTES

[1] The high hopes of the Germans for the electron bomb, which was the principal incendiary used in the Luftwaffe against England in 1940 and 1941, are expressed in the following quotation from Hans Rumpf, "Brandbomben," E. S. Mittler & Sohn, Berlin, 1932:

"Electron bombs cannot be extinguished with water; on the contrary, the more they come in contact with water, the stronger is the incendiary action. It could therefore almost certainly be assumed, on the basis of many experiments proving the reliability and effectiveness of electron bombs, that their proper use would probably lead to the catastrophic destruction by fire of raided cities. In the unanimous judgment of experts, the German army high command now possessed a military incendiary agent of the first order, one that was capable of exercising such a demoralizing effect on the population of big cities of the enemy that a weakening of the will to fight seemed possible."

[2] Records of the Chief of Police of Cologne contained the following statistics of the attack of Oct. 30, 1944. The small number of people killed out of shelters is evidence that almost everyone went underground at the first warning and stayed there until the all clear.

| | | |
|---|---|---|
| *Date and Time* | | |
| Oct. 30, 1944 | 1st warning | 2035 |
| | Sirens | 2045 |
| | Enemy planes arrive | 2055 |
| | Enemy planes leave | 2125 |
| | All clear | 2218 |
| *Attack* | | |
| Approximate number of enemy aircraft | | 1,000 |
| Approximate number of bombs 4,000 lb. and over | | 170 |
| Approximate number of bombs less than 4,000 lb. | | 4,000 (delayed action, 105) |
| Approximate number of phosphorus bombs | | 635 |
| Approximate number of incendiary bombs | | 200,000 |
| *Casualties* | | |
| Killed in shelters | | 490 |
| Wounded in shelters | | 177 |
| Killed out of shelters | | 5 |
| Wounded out of shelters | | 26 |
| Foreign labor killed | | 2 |
| Homeless | | 26,000 |

*Fires*

| | |
|---|---|
| Large fires | 5 |
| Medium fires | 1,281 |
| Small fires | 246 |

*Material Damage*

| | Total destruction | Heavy damage | Light damage |
|---|---|---|---|
| Houses | 1,200 | 800 | 2,500 |
| Official buildings | 1 | 2 | 0 |
| Army buildings | 1 | 1 | 0 |
| Hospitals | 1 | 5 | 0 |
| Churches | 1 | 4 | 0 |
| Schools | 1 | 3 | 2 |
| Postal buildings | 1 | 2 | 0 |
| Railway installations | 3 | 4 | 1 |
| Industrial plants | 14 | 11 | 0 |
| Police buildings | 4 | 6 | 0 |

## CHAPTER VII

## PREPAREDNESS AGAINST INCENDIARY ATTACK

Survival of communities under future bombing attack must depend largely on the extent to which the threat of incendiary warfare is understood and on the preparations made to meet this threat.

**Basis for Bombing Attack.** Tactical factors influencing incendiary-bomb missions are outlined in Chap. V. These same factors that govern the offensive use of incendiaries also point the way to the preparation of a realistic plan of incendiary defense.

Although each community presents a distinct problem to the attacker, the problem will be approached in each case according to what are now fairly well-established principles. The same approach can be followed by municipal authorities charged with protection against incendiary bombing, and the groundwork can thus be laid for a working solution to include the more important defense measures that should be instituted.

In planning an attack, the first step is to study the prospective target. Much of the success of the operation depends on the thoroughness with which this initial survey is made.

The operational order for the bombing mission is developed directly from an air incendiary-bombing map, preparation of which is discussed in Chap. V. This map designates (*a*) districts seen to be susceptible to area (pattern) bombing, (*b*) districts not susceptible to area bombing, and (*c*) important industrial targets located outside districts susceptible to area bombing.

By applying the 30 per cent rule and the 25 per cent rule (Chap. V), the problem confronting the attacker is materially simplified. The sizable areas that do not justify incendiary bombing are marked off and eliminated from consideration.[1] The zones through which fire can be expected to spread are carefully delineated. The locations of those more important industrial clusters that warrant special bombing operations are clearly designated. In this manner a scientific basis is developed for preparation of the detailed plan of attack, which provides for setting fire, first, to areas, and, second, to individual targets that cannot be reached by spreading fires.

**First Principle of Incendiary Defense.** Defense against incendiary attack, if it is to be realistic and of maximum effectiveness, must be predicated on an objective analysis of fire vulnerability paralleling that to which the target will be subjected by a hostile air force.

Even though the incendiary-bombing map prepared as a prelude to attack may be astonishingly accurate, similar data can be assembled more authentically and certainly more easily for defensive than for offensive ends. Judgment may differ in establishing lines of demarcation between districts suitable and unsuitable for area bombing. Estimates may vary as to the combustibility of individual structures and their contents. Yet in each instance information available to the defensive must actually be the more dependable.

Planning for defense against incendiary attack should therefore begin with mapping of the community to indicate (*a*) all the area through which fire may spread and (*b*) all the separate installations outside such an area which may be thought of sufficient importance to attract a precision-bombing attack.

Thus the defense problem can be divided into its two essential elements: protection of *areas* against spreading fire and protection of *isolated targets* from fire destruction.



Although each of these two aspects of the over-all problem of incendiary defense requires distinctive consideration, they are both subject to the same basic principle that applies to fire protection generally: *first, lessen fire susceptibility; then, prepare to fight fire.*

Protection against incendiary attack may thus be summed up as a matter of applying this basic principle to the particular conditions encountered in (*a*) the area targets and (*b*) the precision targets that have been indicated on the community defense map.

**Lessening Susceptibility to Area Bombing.** The real answer to area bombing is *dispersion*. The threat of area incendiary attack can be substantially lessened, if not entirely eliminated, whenever the groupment of structures can be spread out so that occupancy represents less than 30 per cent of the ground covered. This fact must hereafter be given full consideration in connection with long-range planning for future community development. The social objective of a pattern for more healthy community living corresponds to the defense objective of an area reasonably immune from incendiary attack.

European and Asiatic cities that already have been devastated by fire will certainly be rebuilt in well-dispersed patterns so as materially to lessen fire susceptibility. Much more complicated is the problem encountered in cities that have so far escaped the ordeal of incendiary bombing, especially older communities of some size and commercial importance.

In the heart of such cities are often to be found congested groupments of structures erected in the nineteenth century or earlier—old buildings located on narrow streets and alleys but which are important in the industrial and commercial life of the community.

Clearance of such districts is a certain (and often the only) means of avoiding destruction by incendiary attack. Yet even under the immediate threat of war the obstacles to such action are great. A foreign technical adviser who visited London in the summer of 1940 recommended razing of a number of structures in the City of London to facilitate action against aerial bombing. His recommendations were rejected as being too drastic. On his return a year later, these buildings and many more had disappeared, having been destroyed by German fire bombs. The choice in such cases is always a hard one; yet at the same time the realities of modern incendiary warfare are too obvious to be ignored.

Although elimination of congestion is the most certain means of offsetting the threat of area destruction by incendiary bombing, the extent to which this can be accomplished must necessarily vary. If dispersal of existing groupment patterns is impracticable, some easement of a bad situation is still possible. Any or all of the following measures may be adopted:

*a.* Cut air gaps (fire lanes) through the area.

*b.* As buildings are torn down, use land for parks or parking purposes.

*c.* Eliminate bulk storage of highly inflammable materials in the area.

*d.* Require fireproof roofing.

The problem of reducing the fire susceptibility of areas to incendiary attack is essentially the same as the ever-present problem of reducing vulnerability to accidental fire. The newer threat of incendiary attack combining with the older normal fire risk should be taken to justify considerable expenditures where needed to provide wide fire divisions and similar precautionary measures. In most communities, such measures have been repeatedly advocated by fire-prevention experts; today they deserve renewed consideration as an essential feature of the incendiary-defense program.

**Fire Protection of Areas.** After every feasible measure has been adopted to lessen susceptibility to area bombing, there remains the problem of fire protection in zones where the risk of spreading fires must be accepted.



The order for the attack is drawn up after careful study of the incendiary-bombing map has determined the most favorable prospects for initiating spreading fires. Here the attacker enjoys considerable latitude within the limitations of the over-all strategical situation. However, his choice of methods is influenced by certain well-defined tactical considerations, understanding of which is of assistance in planning the details of area fire protection.

Given sufficient air power, the attack will undertake in one continuous operation fire destruction in *all* the built-up area over which fires may be expected to spread. If air force is limited, as was the case with early United States bomber operations against Japan, operations will be concentrated against what is considered to be the most vulnerable section of the area target zone, in the hope that fire protection will be unable to check the spread of fire throughout the entire area.[2]

In either situation, whether the entire area or only part of it is to be brought under direct attack, the tactical plan is based on division of the closely built zone into a suitable number of *target sectors* or attack units. Examination of the photograph (see Fig. 11) will show how these target sectors suggest themselves naturally from an aerial view of the city.

Once suitable sectors for the area-attack zone have been selected, they are marked off on the incendiary-bombing map according to relative fire susceptibility, and aiming points are picked in each sector for the guidance of formation leaders.

A similar division of the community into target sectors for purposes of protective planning can readily be accomplished. Such mapping is needed to work out the tactical aspects of fire fighting. It is also needed to enable an intelligent estimate of the resources required to withstand the full force of incendiary attack. The defense plan, like the attack plan, should be developed from aerial observation.

The size of any target sector may range from 30,000 to 3,000,000 sq. ft. or larger. From an operational viewpoint, the ideal sector is one that can be attacked by a single formation of bombers carrying one type of incendiary bomb.

The most important factor in determining the boundaries of a target sector are the natural fire divisions provided by existing air gaps or obstacles that will prevent the spread of fire. The attack plan will designate (*a*) the force to be directed against each sector and (*b*) the number of sectors to be engaged in the over-all operation. The objective with regard to fire protection is to start more secondary or sector fires than can be coped with by available fire equipment with the expectation that overlapping secondary fires will develop into a sweeping conflagration.

The scheme for protection against area fires is therefore based essentially on fighting a series of sector fires and holding them to the limits of existing fire divisions.

There is obviously a place in this scheme for the individual or squad of fire fighters with portable equipment to extinguish small fires inside buildings. There is also a place for single pumper units in handling appliance fires. Yet these have become quite secondary in view of the weight and type of incendiaries now being employed in bombing operations.

It is a fact that the attack is seldom delivered exactly as planned because of operational difficulties, adverse weather, aerial opposition, and personnel errors. Such deviations from plan generally favor the defense and offer opportunities for supplementary fire-control agencies to contribute to the fire fight along, say, secondary lines of resistance. However, the protection scheme must contemplate meeting the main effort of the attack under conditions most favorable to the offense. This means fire fighting at a high professional level of both organization and equipment. It requires a broad base of permanent personnel and



matériel, butressed by local auxiliaries, with arrangements for reinforcement from other communities within reasonable distance. Fighting fires resulting from area bombing according to best tactical procedure is a job that can be entrusted only to experienced professional fire-fighting leadership.

**Fire Protection of Isolated Targets.** The shipyard, power house, oil refinery, or other industrial installation standing outside the reach of spreading fires is often so important as to draw attack even before bombing of the congested urban district is undertaken.

Incendiary attack of such a target is to some extent conventionalized. If the installation includes a number of buildings clustered close enough so as to sustain spreading fire throughout the plant, pattern bombing is indicated. In this case the mission will be similar to the attack of one target sector in an area-bombing operation. If less than 30 per cent of the plant area is covered with structures or stores, precision-bombing methods will be followed.

Dispersion of plant buildings discourages pattern bombing. Where efficiency of plant operation necessitates clustering of buildings to such an extent as to invite area bombing, a limited use of camouflage is desirable in order to conceal the number of buildings actually present.

Where the situation is such that precision-bombing methods must be followed, the fire vulnerability of each structure is in turn examined. It can be considered that the enemy air force will be supplied such intelligence data by his government and that it will be in reasonable agreement with aerial-reconnaissance data.

If the fire vulnerability of the structure or of the materials it shelters can be rated as at least 25 per cent, the probabilities are that attack will be made with incendiary bombs. From the viewpoint of plant protection, if combustibility of the structure and its contents can be kept below this figure, there is good expectancy that the incendiary attack will fail. If it is a practical impossibility to so narrow the fire risk, it still follows that the lower the combustibility rating, the better the prospects for effective fire fighting.

It is thus apparent that incendiary protection of industrial installations commences, as does protection of urban communities, with *fire prevention* intelligently planned to meet conditions of incendiary warfare. Dispersion of buildings, dispersion of inflammables within buildings, fireproofing, installation of fire walls, and elimination of unneeded combustible materials are all measures that require careful study followed by positive action.

It is a relatively simple matter for the plant-protection authority to develop an outline of probable attack by considering the following questions:

*a. Will attack aim at demolition or fire destruction?* A heavy industrial plant (*e.g.*, locomotive assembly) would be hit with explosive bombs; incendiaries would be used against light industries such as rubber fabrication. However, a combination of explosive and incendiary bombs may be expected in the majority of instances, each type being directed against the most appropriate objective.

*b. Will incendiary attack be by pattern bombing or by precision bombing?* Pattern bombing is feasible only where the target complex shows closely grouped structures or large single structures with easily penetrable roofs.

*c. What points within the plant area would be selected for precision bombing with incendiaries?* Stocks of combustible materials and structures that target analysis indicates to be inflammable. (The precision-aimed bomb is large, penetrates well, and produces a large incendiary fire.)

By referring these questions to the particular installation for which protection is being planned, considerable light can be thrown on proper fire-prevention procedures and on suitable organization for fire control.

The isolated target must in most cases depend principally on its own fire-fighting organization, even though arrangements are made for reinforcement from near-by municipal fire departments. Although individual fire fighting with hand appliances should complement fire defense, this is of secondary importance in combating a heavy incendiary attack; principal reliance must be placed, at least in protecting points of high fire risk, on pumper units manned by well-trained crews.



**Control of Wartime Fires.** Five distinct types of fires grow out of incendiary attack.

*a. Incendiary fire:* burning of the incendiary material from the time the bomb is ignited until combustible objects have been kindled.

*b. Squad fire:* burning of combustible materials to which fire has been directly communicated by the incendiary. At this stage, the incident can still be handled with portable equipment—water buckets, hand pumps, sand.

*c. Primary fire:* situation has gotten beyond control of amateur fire fighters. Appliances are needed, although the fire is still contained, that is, has not begun to spread.

*d. Secondary fire:* burning is spreading over an area so that a number of appliance units are required to handle the situation.

*e. Tertiary fire:* spreading fire has accumulated so much force that there is no longer the possibility of bringing it under control—the *conflagration* stage.

In handling each type of fire, standard fire-fighting procedure applies: first, prevent the fire from spreading; then, extinguish the fire.

There is an appreciable time lag in most instances between the ignition of the incendiary and the kindling of a free fire. Except in the case of very inflammable materials, as much as 10 minutes may be required to bring intermediate combustibles to proper ignition temperatures. However, this much time is often required to reach the scene of the incident, so that in many cases the incendiary fire stage has actually passed before control can be attempted.

In this connection it is to be noted that fires generated by incendiary bombs are most likely to occur on roofs or in upper floors, whereas normal fires more often start nearer ground level.

In handling any incendiary fire, first thought should be given to containing the fire by wetting and thus cooling near-by materials. Where this can be done effectively, it usually follows that the incendiary itself can be left to burn out without serious damage.

The incendiary fire may represent the combustion of the contents of either a large or a small bomb. A large bomb will contain 50 to 200 lb. of active incendiary material. A small bomb will carry 2 to 5 lb. of fire-producing agent. In any case, the ignited agent may burn intensively in one compact mass, or it may be scattered widely. Large bombs will usually impact at some distance from each other. Small bombs will fall much closer together; many clusters are dropped in train, the pattern of any one cluster placing as many as 100 individual bombs within a rectangle measuring possibly 400 by 1,200 ft. When it is considered that some small incendiary bombs disperse a dozen or more fist-sized globs of burning viscid material, many of which will become affixed to walls and ceilings, it becomes evident that the most amateur fire personnel can hope to accomplish is to prevent a large number of simultaneously burning incendiary fires from developing into more advanced fires.

The real difficulty in handling incendiary fires is that modern methods of aerial attack result in producing such a volume of either large or small fires within a very restricted area that efforts at spot control are apt to be ineffective. One modern bomber can carry 5 tons or more of incendiary bombs.[3]

The question of whether the incendiary itself can be extinguished is therefore somewhat academic. The real problem is whether the personnel at hand can hold in check a considerable number of incendiary fires burning at the



same time without calling on organizational units for assistance.

There is in fact no known incendiary agent that cannot be extinguished if enough time and effort can be spared for the purpose. The materials most resistant to extinguishment are pyrotechnic mixtures containing such ingredients as magnesium and sodium. Inflammable oils, even when gelled, can be attacked with either sand or water. Burning magnesium can be brought under control with a heavy stream of water. White phosphorus is easily extinguished by water, although this material will resume burning as soon as it has dried out.

For extinguishing any burning incendiary, water is the best all-round medium, serving the dual purpose of lowering the temperature of the fire itself and of cooling surrounding objects. If sufficient pressure is available, any incendiary fire can be knocked out by a stream of water; but pressure streams are seldom at hand during the incendiary fire stage.

Fighting of incendiary fires is made more complicated by the countercontrols discussed in Chap. V—explosive charges attached to incendiary bombs as well as smoke charges intended to obscure the burning incendiary.

Development of the incendiary fire into a squad fire may be so rapid as to make artificial a distinction between the two types of fires. This is particularly true where incendiary bombs ignite near very combustible stores and where a number of bombs are burning in close proximity to each other. On the other hand, it frequently happens that only a few bombs released actually impact where they can cause serious damage, in which case the handling of squad fires is much easier. In fighting such fires with hand pumps and other portable equipment, nice judgment must be exercised in deciding which are the most dangerous and in handling these in such a manner as to prevent their spreading.

Control of primary and secondary fires requires highly selective apportionment of facilities, which in turn necessitates centralized command of all available appliance units. Against a heavy incendiary attack there will never be enough pumpers available in the area sustaining the heaviest bombing. This means that equipment must be reinforced from other districts and even from other communities under mutual-aid arrangements. It also means that, unlike peacetime fires, all wartime fire calls cannot be responded to. Responsible authority must decide on the strategy to be followed in meeting the situation, concentrating reserves where they may be most urgently needed.

The handling of spreading fires following incendiary attack therefore involves a technique differing from that set by tradition and training in combatting ordinary fires. Under peace conditions, every fire is alarmed and attended even though it may be brought under control by hand extinguishers before pumper units arrive. During aerial attack, only the most serious fires are reported. Of possibly 750 to 1,000 calls actually coming in to control stations during or following a raid, some difficult decisions must be taken. Even primary fires will have to be ignored in order to make sufficient apparatus available for bringing secondary fires under control. The question in fighting wartime fires is not so much "where" the fires are as it is "which" of many fires are the most urgent in view of the over-all situation.

**Fire Defense of Military Installations.** Isolated military (and naval) installations are logical objects of incendiary attack, especially when they include stores of hazardous materials such as fuel and ammunition. Such depots when located in combat zones are subject to attack with artillery shell as well as with aerial bombs. The jettisonable airplane fuel tank (described in Chap. IV) is frequently used by tactical aircraft to ignite combustible stocks in open storage.

Protection of advance depots, airfields, and supply columns against incendiary attack is rendered more difficult



by the fact that such installations seldom have the advantage of dependence on organized appliance units such as are ordinarily available for protection of urban areas and industrial facilities. As a result, it has been necessary, under the constant threat of incendiary attack, to organize military units along professional fire-fighting lines for defense of more important field facilities. In the many instances where fire-appliance troops are lacking, reliance must be placed on organization of other troops for emergency fire-defense duties.

A fire-defense plan for the protection of military installations is an important feature of the air-raid protection scheme which must be drawn up for all facilities located in combat zones. This involves division of the military area into sectors, each with a commander designated as responsible for fire protection therein. Personnel detailed as fire guards must be trained in the use of available equipment such as fire extinguishers, water buckets and barrels, sand, and similar materials.

Serious fires of course cannot be controlled by means of portable equipment. Even pumper units are of little immediate value when large stocks of ammunition or fuel oils are under incendiary attack. Such materials must be stored in dispersed groupments, far enough apart so that fire from one will not spread to another. Fire prevention, or at least the minimizing of fire hazards, is a priority consideration in planning for fire defense on military facilities.

FOOTNOTES

[1] During the hectic days of 1942 and 1943 when civilian defense fervor was high in the United States, much effort was devoted to training fire wardens for duty in suburban and rural districts which would never have attracted incendiary bombing.

[2] In the incendiary attack against Nagoya, Jan. 3, 1945, it was necessary because of operational limitations to concentrate fire in only one section of the city. An area of 2½ million sq. ft. was burned over, but the Japanese were able to concentrate fire-fighting equipment so as to bring this secondary fire under control. Actually, this early operation

was a handicap when later attacks were staged with much greater force because the burned area provided an excellent fire check.

[3] The actual amount of incendiary *material* laid down always runs much less than the weight of incendiary *bombs* released. A ton of thin-cased 100-lb. bombs will carry 1,200 lb. of incendiary agent. A ton of small clustered bombs will include only 850 lb. of incendiary material.

# CHAPTER VIII

## EVOLUTION OF INCENDIARY WARFARE

Military technique has been radically influenced by two inventions: the powder gun and the airplane. Their effects proved to be so far-reaching that the introduction of each in turn marked the beginning of a new era in the implementation of armed forces.

The military employment of fire, like everything else pertaining to the science of war, had to be readjusted for accommodation to each of these devices. It is therefore convenient to consider the evolution of incendiary warfare under three headings: (*a*) before the invention of the gun, (*b*) after the invention of the gun, and (*c*) after the introduction of the airplane.

From its nature, fire has always been a difficult weapon to handle. Its successful employment is dependent as much on satisfactory means for projecting incendiaries as on the development of adequate heat-generating units. For this reason, the propelling potentialities of the gun and the airplane have been of particular significance to incendiary warfare.

**Era of Manually Propelled Missiles.** Prior to the introduction of powder-propelled shot during the fourteenth century, chief reliance had to be placed on human brawn for projecting missiles against an enemy. True, other means were employed, as for example Sampson's use of foxes with firebrands affixed to their tails to burn the cornfields of the Philistines (Judges 15:3–5). Again, engines capable of hurling large stones, such as those designed by Archimedes for use in the defense of Syracuse, were not uncommon. Yet hand-wielded and muscle-propelled weapons were principally relied on in early military operations—and fire weapons were generally included in the latter group.

It may be that the introduction of fire as a weapon coincided with the transition from primitive to "civilized" warfare. This at least can be read into the lines of Lucretius (*ca.* 60 B.C.).

> Weapons of ancient times were hands and nails
> and teeth,
> Then axes hewn from trees of the forests,
> *Flame and fire* as soon as men knew them.

Certainly the formalizing of war and the massing of fighting men into armies gave rise to tactics and new techniques; fortifications were devised to protect rich communities, and so siege operations had to be undertaken; fighting extended onto the sea, and naval forces came into being. In all these martial activities, from the earliest epochs of recorded history, fire was a spectacular and formidable weapon.

The value of fire in military operations before the invention of the cannon was emphasized by the inherent weakness of other early weapons. By burning his enemies' protective structures, the ancient warrior could accomplish with relative ease much more effective destruction than was possible with any other means at his disposal. The fact that this early importance of incendiaries was eclipsed to some extent once the power of the offensive was so greatly enhanced by the introduction of gunpowder does not diminish from the once heroic role of fire.

**Early Incendiary Agents.** The ancients employed pitch, sulphur, oakum, incense, straw, wood coals, old wine (alcohol), resinous chips, bitumen, and crude oil as incendiary agents. Other ingredients were added to incendiary mixtures, sometimes in an attempt to accelerate burning, often because they were thought to possess mystical powers to confound the enemy.



The earliest reliable record of an incendiary mixture is contained in the writings of the Greek tactician Aeneas, who compiled about 350 B.C. the first European treatise on the art of war. Aeneas lists sulphur, pitch, pine wood, incense, and tow as the essential incendiary materials.

Seven centuries later (A.D. 350), Vegetius, a foremost Roman military authority, listed sulphur, bitumen, resin, and naphtha as incendiary agents. The essential difference between the two lists is the addition of a petroleum oil, which represented a significant advance in incendiary technique.

There remain depicted on Assyrian bas-reliefs of the eighth century B.C. images of warriors projecting burning oils and extinguishing fires. Probably knowledge of oil incendiaries reached Europe during the Persian invasions of Greece. At least the Greeks early recognized the value of oils as incendiary agents, despite the fact that Aeneas fails to list them. The Greeks had access to the Baku fields; they were acquainted with surface deposits present there, and their scientific knowledge was sufficient to permit them to capitalize on these natural resources.

Oil incendiaries were carried abroad during Alexander's Eastern campaigns. The Romans, in turn, took over from the Greeks the oil-incendiary agent and employed it from time to time in their military operations. After the fall of Rome, interest in petroleum oils for incendiary purposes was limited to the Mediterranean basin, where these materials were available.

**Incendiary Missiles.** One of the earliest incendiary munitions of some military importance was the "fire club." This device was simply a wooden club with sharp iron prongs affixed to each end, the center being wrapped with incendiary materials such as tarred rope. When lighted and slung with force against a wooden structure, the pointed prongs held the fire-bearing club in place against the wall or roof of the building until fire spread. This primitive weapon was effectively used against improvised shelters in earliest seige operations. Although its range was extremely limited, it is interesting as the forerunner of many later and improved incendiary munitions. The fire club was described by Aeneas, although it was probably in use much before his time.

The incendiary hand grenade was also used early in the history of warfare, probably soon after the making of pottery became established. From fragments that have been excavated, it appears that a hollow clay vessel having a narrow open throat was used to contain incendiary materials; once ignited, it was quickly thrown so that, in striking, the vessel broke, exposing a flaming fireball to ignite near-by combustible materials. Glass was also used for such early frangible grenades.

Once catapult machines were devised and were adapted to siege warfare, larger and more effective incendiary missiles were developed. At the siege of Heraclea (A.D. 805), stone shot proved so ineffective that these were coated with incendiary mixtures and ignited, the flaming projectiles quickly forcing the collapse of the defense. Metal containers (fire pots) perforated or latticed so as to permit emission of flames from hotly burning charges of pitch, sulphur, bitumen, and similar materials were projected by catapult. Other "shells" were designed to burst on impact and scatter burning mixtures. Such iron fire bombs used by the Romans ran to 2 ft. in diameter.

**Fire Arrows.** The arrow, one of man's first offensive weapons, greatly multiplied chances for killing from a safe distance either animal or human enemies. But the piercing arrow, although deadly against the living, was useless against protective structures until someone conceived the idea of attaching fire to the shaft.

Vegetius lists the materials commonly used in incendiary arrows by the Romans during the fourth century A.D. as oakum, resin, sulphur, bitumen, and crude oil. However,



the fire arrow, probably much cruder, had already been in use many centuries. It has always been a favorite weapon of primitive peoples, *e.g.*, the American Indians.

A particular disadvantage of the fire arrow was the tendency of the fire to be extinguished during rapid flight. For this reason the arrow had to be shot slowly, limiting its already short range. Even with this precaution, the fire arrow could not be rated a very reliable weapon.

It seems probably that what came later to be known as "gunpowder" was first devised in an effort to overcome the disadvantages of a bow-shot arrow carrying fire. At least it is now fairly well established that the combination of charcoal, sulphur, and saltpeter was first devised as an improved incendiary mixture. The incendiary arrow, on the other hand, survived well into the age of gunpowder and, as Hime states, "died a lingering death."

**Flame Projectors.** The modern flame thrower can trace its origin to an ingenious incendiary device employed, according to Thucydides, in the fifth century B.C. A hollowed tree trunk mounted on wheels conveyed at one end a cauldron bearing ignited coals reinforced with sulphur and pitch. At the rear of the trunk was attached a bellows made of skins, which was used to force air across the fire and project flames against wooden structures.

As knowledge of incendiary materials increased, this crude flame thrower was replaced by an improved blowpipe which was used by Roman armies. Incendiary balls made of resin and sulphur were forced through the tube, being ignited as they left by flame held at the muzzle.

Much later, the Moslems employed a fire tube filled with materials (probably including black powder) which in burning clogged the muzzle until sufficient pressure had been built up inside the tube to project flaming masses a distance of about 100 yd. This device preceded the cannon, which it resembled in principle.

**Greek Fire.** References to many interesting and ingenious incendiary devices appear throughout ancient and medieval history; yet it is difficult accurately to estimate the real influence of many of them on military operations. In most instances, accounts were written from the viewpoint of the attacker rather than of the attacked and were influenced more by the spectacle presented than by the results produced. An exception is Greek fire, which was unquestionably the most important incendiary agent known before the era of modern science.

Greek fire was produced solely for use against ships. It had little or no value in land warfare.[1] It did, however, provide the defenders of Constantinople and the Eastern Roman Empire with a technical weapon, the exclusive possession of which enabled them successfully to withstand the naval attacks which in 673 and again in 717 the Moslems launched against this outpost of European civilization. This incendiary continued to be a powerful defensive weapon until the end of the Byzantine military system.

The value of Greek fire thus made its composition a military secret of highest importance to the state. The secret was so closely guarded that even today the formula is not certainly known. It was a liquid that was ignited when spread onto the sea from siphons or thrown in pots. Its principal ingredients may have been petroleum and quicklime, the reaction of the lime with water serving to raise the oil to its ignition temperature and to ignite the oil vapors with explosive force.[2]

Where especially combustible targets are offered, the soldier's reaction has always been to set them afire as quickly as he can lay his hands on fire-raising weapons. The wooden ships that plied the Mediterranean in the days of the Roman Empire were most inviting incendiary targets. The wood above the water line was usually tinder-dry, the rigging inflammable, and the oakum, pitch, and similar materials used about the ship were themselves incendiary agents.



To take advantage of this inherent susceptibility of naval craft to fire attack, even glasses were sometimes used to focus the sun's rays on sails. One of Homer's heroes, Hector, tried valiantly but without success to fire the ships of the Greeks. Many schemes were tried, but none ever equaled the success attained with Greek fire.

**The Discovery of Saltpeter.** The Greeks early held that salt added to an incendiary mixture would make it burn more intensely. (Actually salt made only a more vigorous flame.) The substitution of saltpeter for sodium chloride has been attributed to the Chinese. Although this is disputed, it is at least certain that the innovation represented a significant advance and provided the key to later developments that were of high importance to civilization.

Potassium nitrate (saltpeter) happened to be the one accessible material that possessed the desirable characteristic of *releasing* instead of consuming oxygen at ordinary burning temperatures—a characteristic that made it valuable first in incendiary and later in explosive mixtures.

The ancients were accustomed to the use of sulphur in incendiary mixtures. They were also acquainted with charcoal. Combining these two with saltpeter provided an incendiary mix that was superior to anything that had previously been used as a fire starter. A slightly different combination of these materials, when burned in a confined space, reacted with explosive violence; but the full significance of this fact was not appreciated until some time after the utility of "black powder" as an incendiary material had been discovered.

Although pure potassium nitrate is today produced cheaply from potassium chloride or from sodium nitrate, its earliest production in medieval times was crude and probably came about accidentally. It appears as a white film of niter where humus is saturated with animal excreta, particularly in humid regions. Use of the terms "snow of India" and "China snow" in early chronicles suggests that saltpeter was first gathered and used in the East.

**Black Powder.** From the compilation of recipes included in the "Fire Book" of Marcus Graecus (*ca.* A.D. 1300), it is evident that the combination of six parts saltpeter, two parts charcoal, and one part sulphur was used in two munitions, a "thunder" bomb and an incendiary rocket, before the invention of the gun.

For the rocket, the slow-burning saltpeter-sulphur-charcoal combination acted as both propellant and incendiary. Sulphur served as the inflammable agent, catching fire and transmitting it to the combustible charcoal. Oxygen provided by the saltpeter completed the essential requirements for reliable burning.

The pressure of the gases produced by the *burning* powder was utilized to drive the lance according to the now well-recognized rocket principle.[3] The charge of powder was ample so that, after the rocket had impacted, enough remained to continue burning and ignite near-by combustibles. Thus was developed a flying arrow much improved over the original incendiary arrows shot from bows; its range was greater, and there was no chance of extinguishing the fire during flight.

This method of propelling incendiaries is presumed to have been discovered by the Chinese.[4] It continued to be an important use of saltpeter-charcoal-sulphur until the gun was invented to employ the *explosive* force of black powder. Meanwhile, knowledge of potassium nitrate and its unusual reaction with charcoal and sulphur spread (possibly through the Arabs) into Europe, paving the way for the general adoption of black powder first as a primary and eventually as a secondary incendiary agent.

**Rise of the Powder-propelled Incendiary.** More than five and a half centuries elapsed between the invention of the gun and the introduction of the military airplane (1350–1910). During this period, the powder-propelled missle was constantly in the ascendency as a military weapon.



Development of the gun was slow at first—so slow that fully three centuries elapsed while powder weapons were being technically developed and their military usages fully established. The gunpowder era really began about 1650, after Gustavus Adolphus had demostrated during the Thirty Years' War what firearms could accomplish when properly served. Gunpowder continued as the all-powerful propellant and explosive incendiary until it was finally supplanted by smokeless powder late in the nineteenth century. Through this entire period, incendiaries continued to be widely used, without much change in fire-starting materials but with steady improvement in the munitions employed.

**Era of Transition.** The formula for black powder was widely known in the Near East and throughout the Moslem world before its importance was fully recognized in Western Europe. Roger Bacon mentions it in his "Opus Majus," written in the thirteenth century, from which fact Bacon is sometimes credited with the invention of gunpowder. It is more proper to say that he was the first European scholar to notice black powder.[5]

It was not until the fourteenth century that the gun was invented in order to utilize efficiently for propelling a missile the energy of the expanding gases generated by burning black powder. Yet the development of this interesting internal-combustion engine was very gradual. During the period of transition, black powder continued in use as an effective incendiary agent, although its importance for this purpose was slowly eclipsed as its value as a propellant became increasingly recognized.

Since eventually, however, the employment of black powder as gunpowder became so tremendously important, we have today largely forgotten that initially its primary military value was as an incendiary. The long supremacy of black powder as a fire weapon is still reflected in such common military terms as *fire*arms and *fire* power.

The three centuries that elapsed before the powder gun fully emerged as the arbiter of military tactics saw continued use of most of the incendiary agents and munitions that had been handed down from earlier times. Hand incendiaries, fire arrows, and even catapults were only gradually replaced as appropriate powder-propelled igneous projectiles were devised. The era of transition following the invention of the gun was marked by retention of older fire weapons sometimes long after the technical problems involved in firing incendiaries from cannon had been solved.

**Siege Operations.** Gunpowder found early military employment in siege operations. To understand its importance for this purpose, it is necessary to review briefly the tactics and technique of early siege warfare.

The city was surrounded by a wall of wood or masonry. To get at the defenders, the attackers had to climb over the wall, or break down the wall, or stand off and hurl missiles at the defenders. To climb over the wall, scaling ladders of some type were needed. A most effective means of defense against the scaling of the wall was for the defenders to pour down on the attackers boiling pitch or other flaming incendiaries.

To break down the wall, a manually operated ram (or sometimes a bore) was used. Against this tactic, the defender again could pour incendiaries on the attacker, or if, as was frequently the case, the ramming party could stand at some distance from the wall, missiles were hurled at the rammers. To protect against either incendiary or missile attack from the defense, it became customary to shield the ramming party with a movable shelter built of heavy beams under which the attackers could work with less fear of molestation.

A variation of the battering ram was the flame projector, already described, the purpose of which was to set fire to the walled fortification where this was constructed of wood. The fire arrow was another method of firing the protective



wall and either destroying or weakening it so that it might more easily be breached by the battering ram.

As to weapons with which the wall and its defenders could be attacked from a distance, these included besides arrows and hand-thrown missiles, two important siege engines. These had been gradually perfected in the course of many centuries of warfare, yet they lacked the powerful force that was later supplied by gunpowder. It was these two machines that artillery quickly supplanted.

The first was an elaborate sling device operating on the torsion principle, essentially a high-trajectory weapon for hurling stones or sometimes metal projectiles over the wall. This was more specifically an antimatériel weapon, in connection with which incendiary projectiles were frequently utilized. Many ingenious variations of this principle were employed, all of which may be described as *catapults*. They could hurl projectiles weighing several hundred pounds for distances of 500 yd. or more.

The second type of siege weapon was the *ballista*, which operated on the tension principle and which fired a lancelike projectile along a curved trajectory. It could be aimed much more accurately than was possible with the high-trajectory catapult. Ballista weapons were more particularly employed in open warfare against personnel, although their darts were sometimes armed with incendiaries.

The earliest powder-type siege weapons replaced catapults for hurling projectiles over the walls of fortified cities. The particular advantages of these early bombards were that larger missiles could be employed and that they could be discharged from greater distances. Where incendiaries were involved, a larger and therefore more effective fire unit could be employed.

There was available in ancient times no mechanical device for ramming the walls of besieged cities. This operation prior to the discovery of the powder gun had to be conducted by squads of 30 to 40 men operating by hand a heavy ramming device, usually a massive log slung by ropes from transverse beams. (At Rhodes a battering ram 180 ft. long was used, handled by some 1,000 men.) The application of gunpowder for the purpose of battering walled fortifications came some time after the bombard (*pot de fer*) had been perfected, when a flat trajectory artillery piece had been devised.

Once cannon became available to batter down the walls of cities, types of fortifications that had served fairly well to withstand attack of less powerful weapons became obsolete. Hence incendiaries that had played an important part in the attack and defense of city walls were no longer needed for this particular purpose. Instead, interest shifted to fire destruction of the structures within the city.

**Hot Shot.** The projectile usually employed with sling engines was the stone shot. When the cannon replaced the catapult, a rounded stone became the cannon ball. The effectiveness of the stone shot, however, was limited to the shock produced at the point of its impact. Even after spherical iron shot were introduced, many years elapsed before they could be reinforced with an explosive charge. Thus incendiaries had to be called on to extend the utility of early powder-propelled projectiles.

The first igneous projectile used with cannon was a stone shot smeared with an incendiary mixture that was set afire by the propelling charge. This holdover from the catapult era was superseded by the heated stone shot as soon as the technique of handling hot shot in a cannon was mastered.

The business of heating stone to be hurled by sling machines was widely understood. Caesar recounts how the Britons employed hot balls of clay against Roman camps (54 B.C.). Stone shot could be heated in quicklime or fires. The trick was to get the hot shot home in the cannon without setting off the propellant charge. It was found this could be done by following the load of powder with a wad of wet earth or turf, against which the hot shot could rest until the force of explosion discharged it from the gun.



Iron shot heated red hot for firing into wooden structures were employed in the siege of Cherbourg in 1418 and continued to find important use until modern times. Early military texts (*ca.* 1425) recommend heating of iron shot for small arms when firing into wooden structures sheltering troops. The hot shot was even more effective against naval sailing vessels than against land targets.

Heated cannon balls were good incendiaries when they could be imbedded in inaccessible locations or where their presence went unnoticed until after serious fires had started. In field operations it was always difficult to provide the furnaces for heating them. Their relatively low temperature (well under 1000°F.) was compensated for somewhat by the length of time during which heat was steadily transmitted to the wood in which the hot shot rested.

A variation of the furnace-heated iron shot was the hollow projectile charged with incendiary mixtures intended to bring the shell to red-hot temperature after impact. This device was obviously less satisfactory than burning-type incendiaries such as the flying fire pots which had been used with sling engines and which could transmit fire directly to the target.

**Shell-cased Incendiaries.** Adaptions of burning-type incendiaries to metal projectiles began to appear toward the end of the fifteenth century. Demand for fire weapons was insistent because of the very limited effects that would be achieved with solid shot or even with explosive iron shot.

Henry VIII in about 1515 ordered a portion of his artillery shot charged with black powder which on exploding would shatter the iron shell and scatter fragments, which "hitting any man, would kill or spoil him." But chances were always good for surviving the burst of a shell loaded with black powder, which was tolerated for so many centuries simply because no high-order explosives was available. For demolishing structures, early explosive shell were of little value, so that Henry also provided for a suitable proportion of his hollow shot to be loaded with "wild fyr."

In the typical iron incendiary shell as eventually developed, an explosive charge of black powder was first inserted, and then the remaining cavity was filled with incendiary materials. These usually included pitch, colophony, saltpeter, and both fine and granular powder, the compound being heated to a liquid state and loaded into the shell while warm. Several fire holes were bored so that if the case failed to rupture, flame could still escape following ignition of the incendiary mix.

Such fire bombs in time became standard projectiles for all calibers of artillery. However they were not so generally effective as the "incendiary ball," which was characterized by an exterior surface of burning materials.

**Surface-burning Munitions.** Incendiary balls were built up around a core such as a small iron shot. Customary procedure was first to dip the shot into a vat of liquid sulphur, then wrap the ball in oakum, redip, roll in fine powder, and wrap with wire. This process was repeated until the diameter of the call corresponded to the caliber of the cannon.

A variant of the spherical surface-burning incendiary was the elongated projectile made by kneading a warm incendiary mix over a crossed iron frame which extended to approximately twice the length of the desired diameter. Typical incendiary components were green pitch, fine and corned powder, oakum, tallow, and a small quantity of naphtha. A fuze of fine powder was inserted in the nose to ensure ignition.

A better incendiary munition than either type of fireball was the *carcass*. This important projectile was invented in 1672; it continued for the next two centuries to be widely employed as both a powder-propelled and a hand-thrown missile.



The carcass had an elongated open frame of strap iron, which enclosed a thick cloth sack containing customary incendiary materials such as pitch, oakum, and powder. It combined desirable characteristics of both cased and surface-burning incendiaries. Today the carcass would be classed as an intensive-type incendiary, since the agent quickly burned through the containing sack and then readily transmitted flame in all directions.

Pitch rings and incendiary hoops were also frequently used surface-burning munitions. The incendiary hoop was made from an ordinary barrel hoop on which oakum was first wound and tied. The hoop was then dipped in a boiling incendiary mix of pitch, tar, and priming composition, hung up to dry, and was redipped as many times as necessary to produce a thickness of about 3 in. The incendiary coating was finally bound with wire and the hoop loosely wound with straw. Burning time appears to have been about 30 minutes under favorable conditions, which made the incendiary hoop a very worth-while device, probably superior to any incendiary shell.

**Congreve Rockets.** Although there is record of the very early military employment of rockets by the Chinese, these weapons were first used on a large scale in open warfare by Indian troops against British forces late in the eighteenth century. The Indian rockets were so effective that a British officer, Col. William Congreve, became interested in the subject and eventually developed the improved Congreve rocket.

At the beginning of the nineteenth century, artillery was still comparatively inaccurate and automotive transport was unknown so that heavy concentrations of fire power were practically impossible. Under these conditions, the rocket found for a brief time an important role as an auxiliary to cannon. Its accuracy compared fairly well with that of existing heavy guns, and large numbers could be launched simultaneously, since transport of the launchers presented no great problem. For these reasons, Congreve's ideas were readily adopted, and rockets of various types continued in general use until about 1860, by which time improvements in artillery had resulted in limiting their immediate usefulness.

Congreve's rockets were primarily incendiary weapons; while they were in vogue they succeeded in contributing an important chapter to the story of incendiary warfare. Each size of rocket was provided with either explosive or incendiary charge. The latter type, however, proved to be the more historically important.

Incendiary rockets carried the same open-frame metal carcass that was being used in powder guns. These were produced in sizes ranging from 8 to 18 lb.

The British navy first employed incendiary rockets on a sizable scale against Boulogne in 1806, producing a fire of serious proportions. The following year, Copenhagen was attacked by the British fleet, the greater part of the city being burned to the ground following the firing of some 25,000 incendiary rockets.

Congreve's theory was that fire destruction of the possessions of civilians would bring about more speedy termination of hostilities than would the slaughtering of the military garrison with explosives. His theory was sustained in the action against Copenhagen. This operation is more significant, however, in that it was the first time an adequate mass of fire had been concentrated against a single target in one continuous attack. This was made possible by the use of rockets, large numbers of which could be quickly fired (from ship) in the same direction.

The rocket thus proved to be a forerunner of the more effective employment of incendiary warfare which became possible after the aerial bomber appeared more than a century later.

**Incendiary Technique in the Gunpowder Era.** The incendiary agents used in early igneous projectiles were much the same as those employed before the invention of cannon, except for the more adept utilization of black powder for ignition and to facilitate burning. Many recipes for combustible fillings appear in still extant "Fire Books" published in the Middle Ages. Disregarding such early novelties as fireflies, putrescent organic substances, and plants possessing supposedly mysterious powers, all of which disappeared with the passing of the alchemists, we eventually find more modern chemicals—amber, alcoholic distillates, gum arabic, nitric acid, camphor, and linseed oil—being used in incendiary compositions to intensify combustion or to produce more homogeneous mixtures. The utility of phosphorus as an incendiary was pointed out by Chevalier in France in 1798, although no immediate use was made of this discovery.



It is not easy to evaluate the incendiary materials of the gunpowder era according to the factors (intensity of heat and duration of burning) by which modern agents are rated. Certainly in many instances, artillery munitions failed to meet what seemed reasonable expectations. At the siege of Neisse (1721), 12,000 incendiary bombs and 3,000 rounds of hot shot were fired in a 4-day bombardment with little effect. When combustible targets such as hay magazines could be reached, fires were started and spread to reach sometimes devastating proportions. Much of the accumulated wealth of the German nation was reduced to ashes during the Thirty Years' War by fires started from incendiary shelling. Yet the munitions employed were mostly ineffective against fire-resistant materials, since burning temperatures scarcely exceeded 1500°F. and average burning time for incendiary shell was limited to 2 to 4 minutes.

Gunpowder continued through six centuries to be the principal driving force for propelling incendiaries, until it was finally replaced by smokeless powder about 1890. Progress in incendiary technique during the gunpowder era was slow, one important reason being lack of basic scientific data on incendiary materials. The fundamental achievements being made in the field of general science were therefore of great significance to the ultimate development of incendiary warfare.

Before 1657, when Galileo is reported to have devised the first thermometer, there was no systematic method of determining thermal values. Development of the Fahrenheit (1714) and the centigrade (1742) temperature scales provided the foundations on which such scientists as Rumford and Joule could establish their pioneering researches in heat phenomena. Even the nature of fire could be only guessed at until after Priestley discovered oxygen in 1774. Without benefit of the scientific data that became available during the nineteenth century, incendiary warfare would have continued to rely for its effectiveness on purely empirical rules.

Yet despite their early shortcomings, incendiaries must be rated as important military weapons while gunpowder continued as the principal propellant agent. This was primarily because fire served so well to supplement the limited destructive power of ordnance munitions of the gunpowder era.

**Influence of Modern Artillery.** In the days of spherical shot, the projectile was loaded with the fuze igniting either incendiary or explosive charge carefully pointed toward the muzzle of the piece; the flash that accompanied burning of the propellant passed around the shell and fired the fuze as the projectile left the bore. This practice was necessary before percussion fuzes were devised, but it was possible only as long as close tolerance between the shot and the tube was not insisted upon.

From the wars of Gustavus Adolphus until the middle of the nineteenth century, no substantial improvement was made in the design of artillery pieces. Cannons were smoothbored, muzzle-loading, and fired a bewildering variety of projectiles that never matched perfectly the caliber of the weapon. The modern science of interior ballistics was unborn.



In the latter half of the nineteenth century, three innovations served to usher in the era of modern artillery: the breech block, rifling of cannon, and smokeless powder. Obturation became a new word in the gunner's lexicon, and greater care was necessitated in designing elongated projectiles so that the additional propelling force available in nitrocompounds could be effectively utilized. The newer weapons, characterized by increased muzzle velocity and longer ranges, would not accommodate the flimsy and often makeshift incendiary munitions that had served well enough in the days of the smoothbore muzzle loaders. For example, the incendiary ball, a better fire producer than the incendiary shell, had to be discarded as soon as lands and grooves appeared to impart rotation to projectiles.

Another effect of the newer explosives, which following the discovery of the force harnessed when cellulose and fatty substances are acted on by nitric acid, was to increase the destruction that could be accomplished by the shell when it reached the target. Nitrated coal-tar products such as toluene and phenol, which eventually replaced the low-order black-powder explosive, provided earth shock, blast, and fragmentation effects following detonation of artillery shell which greatly surpassed the capabilities of earlier munitions. So powerful were the new *high* explosives that in comparison with them the value of incendiaries as military weapons appeared to shrink in importance.

The American Civil War ended before the modernization of artillery had fairly begun. Influence of the newer ordnance on incendiary weapons can, however, be seen in the Franco-Prussian War (1870–1871).

At the outset of this war the Prussian artillery was not provided with incendiary shell for its new breech-loading rifled cannon. Demand for fire bombs immediately arose because of the many siege operations that the Germans undertook against French cities. Improvisations of explosive shell that were hastily devised to meet this need failed to provide ideal incendiary weapons, yet they were used with considerable effect.

The typical older French city had a citadel housing the garrison situated usually some distance from the center of the city. Should artillery be used to attack the troops with explosive shell or to fire incendiaries on the city? The troops were well protected, so that the effect of shell burst was likely to be limited. The city, on the other hand, had little protection against fire. By burning the city, or by burning part of it and threatening to burn the rest, it was argued that the civilian population would clamor to the military commandant to surrender and thus avoid destruction of the city's wealth, industrial economy, and cultural monuments.

The Germans favored the incendiary attack, echoing the earlier view of Congreve that destruction of civilian property offered the quicker path to military decision. Or was it that the Prussians preferred the greater destruction of incendiary attack? They fired in turn Toul, Soissons, Verdun, Diedenhofen, Montmédy, Mezières, and Peronne and managed to force the capitulation of these towns principally as a result of the fire damage they instigated.

After the Franco-Prussian war, German technicians undertook the development of more adequate incendiary shell suited to new types of ordnance. Extended experimentation over the next decade failed to provide satisfactory solutions to the problems involved in adapting incendiary fillings to the much heavier projectiles then coming into use. In fact, interest in incendiaries declined as artillerymen became increasingly impressed with the possibilities of the new high-explosive shell.

The fact that incendiary development languished with the advent of nitroexplosives is attributable in part to the opinion widely held that the new explosives were themselves powerful incendiaries. Actually the reverse was true; as explosion is intensified, general incendiary effectiveness



declines. The one working fire munition that remained after the modernization of artillery had been completed was shrapnel, which was capable of starting incidental fires with fair frequency. However, most armies were provided with experimental types of incendiary shell at the outset of the World War.

The principal materials used for loading incendiary shell during 1914–1918 were thermit and white phosphorus. Although incendiaries were employed sporadically throughout the war in artillery bombardments, they proved of little tactical importance. This was due principally to the fact that attractive incendiary targets were seldom found within range of artillery; those that did appear were frequently demolished by explosive shell. The high explosive became artillery's *tour de force*, finally relegating the powder-propelled incendiary missile to comparative obscurity.

**Incendiaries in the Airborne Age.** Just at the time when the powder-propelled incendiary seemed nearing the end of its usefulness, the airplane appeared to lend new significance to fire as an instrument of warfare.

The airplane with its ranging flight was able to select distant targets far beyond the reach of artillery—targets that were ripe for burning. It presented the possibility of transforming the incendiary from a purely tactical weapon to a strategical weapon.

In all the many centuries that fire had been used as a military weapon, its effects were always local and bore directly on the outcome of the immediate action in which it was employed. If fire destruction could be wrought far behind the lines of battle, then the effects of that destruction might influence the outcome of whole campaigns.

The Germans possessed in their Zeppelin airships a means which they thought might enable them to repeat on a larger scale the successes that fire had produced for them in the Franco-Prussian War. The first airship attack against Britain was delivered on the night of Jan. 19–20, 1915, the last attack Aug. 5–6, 1918. The first airplane attack was slightly earlier, Dec. 24, 1914, when a single bomb was dropped.

It has been estimated that a total of 280 tons of aerial bombs were released over the British Isles by the Germans in 51 airship and 52 airplane attacks during the World War.

Attack of British cities was undertaken by the Germans in high hopes of the results to follow the fire destruction they expected to produce by aerial bombing. They had air transport, but they lacked an incendiary bomb. The first was actually an artillery shell that was thrown into the air with a cloth streamer attached to ensure perpendicular descent.

The incendiary bomb, despite crudeness of the early models, was generally preferred by the dirigibles, which carried on the average as many incendiary as explosive bombs. The heavier-than-air service was distrustful of fire bombs, carried them more reluctantly, and started few fires. The most important effects were produced by the something over 3,000 incendiaries dropped by Zeppelins during their two big years, 1915 and 1916.

The face value of these results was scarcely commensurate with the efforts entailed by the Germans. The bombs rarely started continuing fires; the highest loss recorded for any one raid was £225,000. The threat of incendiary warfare sent Lloyd's rates upward but without any correspondingly observable depression of British morale.

One reason for the ineffectiveness of incendiary bombing was of course the inadequacy of the fire bombs used. Another was the inaccuracy of early bomb sighting. Massing of fires was clearly impossible with the small operational groups employed.

The German bombs that replaced the first hastily loaded artillery shell were bucket-shaped affairs containing an inner core of thermit surrounded by tarred cotton waste, with tarred rope tightly coiled around the outside. Ballistic qualities of this device were poor, and incendiary



action was undependable. The Germans were well aware of its defects and eventually replaced it with a torpedo-shaped bomb filled with gasoline paste and paraffin.

This P and W incendiary bomb had better flight than incendiary characteristics. Germany, along with every other military power, was eagerly searching for better incendiary bombs. German technologists came up with the prize solution in the electron (magnesium) bomb, which had satisfactorily passed development tests and was in course of production by August, 1917.

For reasons of state policy, German authorities decided to defer use of the electron bomb until a more favorable military situation presented itself, even though they were supremely confident as to its possibilities. When on Sept. 7, 1940, the Luftwaffe got around to the fire attack of London, the torch was the electron-magnesium bomb.

The results of the ensuing fire raids, although on the whole disappointing to the Germans, at least confirmed the claims of the incendiary-warfare enthusiasts that cities could be more easily damaged by fire than by explosive bombs.

## FOOTNOTES

[1] The term "Greek fire" was applied indiscriminately by the Crusaders to whatever incendiary agents they encountered in the Near East. Here the term is used to identify the sea fire devised by Kallinikos of Heliopolis. Another term, "wildfire," was used in early times to describe an incendiary used in land warfare; the term still survives in the phrase, "spreading like wildfire."

[2] For a summary of modern views as to the composition of Greek fire, see Cheronis, Nicholas D., "Chemical Warfare in the Middle Ages," *Journal of Chemical Education*, vol. 14, pp. 360–365, 1937.

[3] For a complete description of early rockets, see Ley, Willy, "Rockets—The Future of Travel Beyond the Stratosphere," pp. 54–60, The Viking Press, New York, 1944.

[4] For modern incendiaries and pyrotechnics (*fire*works), we are much indebted to the Chinese. The common Chinese firecracker is little changed from the thunder bomb described by Graecus. Knowledge of the incendiary rocket was acquired from the Orient by the Byzantines.

What is today known as the "Roman candle" is merely an adaptation of this Chinese munition.

[5] Roger Bacon evidently regarded black powder as a scientific curiosity. He was impressed with its sound-producing characteristics. "From the force of the salt called saltpeter so horrible a sound is produced at the bursting of so small a thing . . . that we perceive it exceeds the roar of sharp thunder, and the flash exceeds the greatest brilliancy of the lightning accompanying the thunder." However, Bacon was entirely unacquainted with the possibility of using black powder as a propellant.

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