FOREST-FIRE FIGHTING

by

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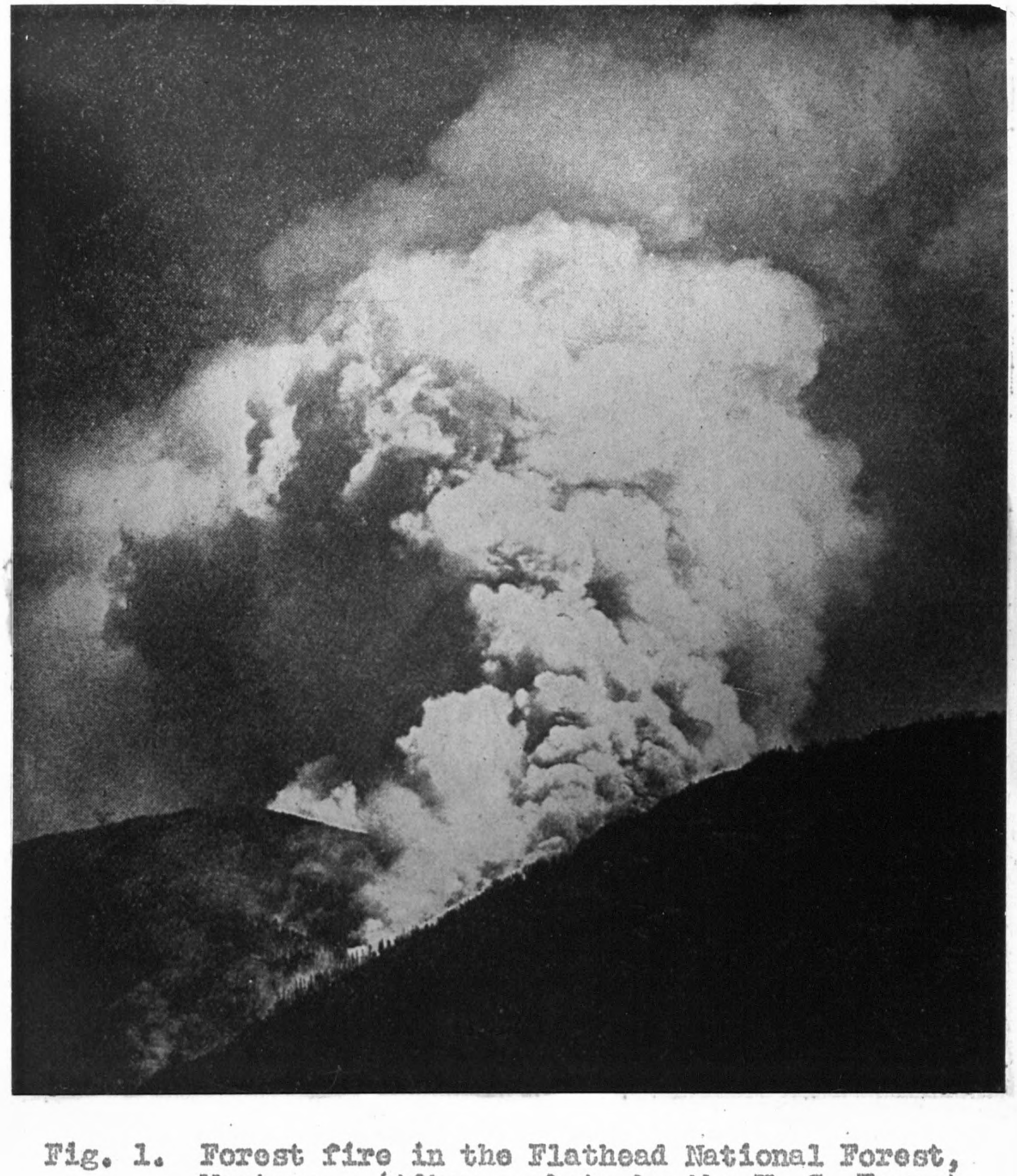

Fig. 1. Forest fire in the Flathead National Forest, Montana. (After a photo by the U. S. Forest Service).

C O N T E N T S

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INTRODUCTION

"Fire fighting is the acid test of protective organization and men. It is an emergency job where success or failure hinges not only on experience and skill, but also to a very large extent on the speed with which various phases of the work are successfully completed" (108). This paper deals with a review of the literature on all these phases of forest-fire fighting from the discovery of the smoke to the suppression of the last spark. Since, however, a complete understanding of fire behavior is essential to a reliable planning of fire-suppression a ctivities, a detailed study is made of the elements of fire behavior. Special emphasis is also given to the discussion of the various methods of fire fighting, and of the numerous methods of man-power organization for fire-suppression purposes. Then, a review is made of the equipment, tools and supplies used in connection with forest-fire fighting.

FOREST-FIRE BEHAVIOR

An adequate fire suppression policy calls for a thorough understanding of fire behavior, or "the action of fire as a result of the complex of variable factors tha t influence it"

(12). Appraisal of fire behavior is the only basis for planning the strategy of attack, the man-power needs, the placing of crews and camps, etc. The question of fire behavior involves widely varying conditions of cover, topography and weather, and no exact formula or rule exists to solve this problem. But, an intelligent estimate, based on the fundamental laws of combustion, the inflammability of the forest fuels, the effect of the physical factors, etc., is far better than a wild guess of the probable burning conditions to be expected. "Success in fire fighting hinges to a very large extent upon one's ability to size up not only what the burning conditions are now, but also what they will be as the day advances, or under probable changes of inflammability, wind, slope or type" (108). The knowledge of fire behavior also enables the fire fighter to profit from every natural law which he can turn to his advantage, and to prepare against the adverse factors. Success in fire suppression is largely dependent upon the fireman's ability to identify and measure the factors, elements and influences of fire behavior. According to Gisborne (69), forest pyrology or the science of forest fire behavior "is rapidly supplanting rule-of-thumb fire control".

A) <u>Combustion</u>

Forest fire is the result of the combustion or the rapid chemical combination of the oxygen of the air with the carbon of the material, which occurs when the fuel is raised to an abnormally high temperature of 600 to 800 degrees F. (108). This temperature, called the kindling point, varies slightly with the different fuels and the length of time during which the heat is applied to the material. Unless these three elements - air, fuel and heat - are present, there cannot be any fire, and the rapid spread of fire requires that these three essentials be present in optimum quantities. If an entire piece of wood is uniformly heated to the kindling temperature, the whole stick bursts in flame spontaneously and burns as rapidly as oxygen is supplied. Usually, however, the fire creeps along the surface because only the particles immediately adjacent to or above the source of heat are raised to the kindling point and are ignited.

The moisture content of the fuels is of prime importance in combustion since the materials cannot be ignited until they have been dried out; a large portion of the available heat applied to damp material is dissipated in driving off the moisture before it can raise the fuel to kindling temperature. This explains why damp fuels are hard to ignite, burn slowly and give off a relatively small amount of heat.

Oxygen, an essential element of combustion, is contained in the air to the extent of 21 per cent of the total volume of the atmospheric gases, so that only one fifth of the volume of the air is utilized as the oxidizing agent in the process of combustion. About 130 cubic feet of air are needed to supply the oxygen necessary for the burning of one pound of wood. This supply is carried to the fire by the draft which is set by the fire itself. Fuels cannot burn any faster than the necessary oxygen is supplied.

The maximum temperature produced by burning wood ranges from 800 to 1,200 degrees F., but the amount of heat given off at any time varies directly with the rate of combustion. For instance, two fuels may produce the same total amount of heat, but the one burns up in one hour and the other in one minute; the total amount of heat produced by the latter will be given off in one minute, whereas the same amount of heat will be given off by the former in one hour, resulting in a production of heat per minute 60 times greater in the latter case than in the former.

Highly inflammable materials are those easily ignited or with a low kindling point, whereas highly combustible fuels are those burning rapidly and likely to give off a great amount of heat per unit of time. "Both the inflammability and the combustibility of forest fuels are governed not only by their moisture content, but also by their size and arrangement" (108). In other words, the ratio of the surface to the volume of the fuels and their disposal with reference to both a free circulation of air and the heat rising from the burning materials, are, with the weather conditions, the major factors influencing the inflammability and combustibility of forest fuels. But, since the size and arrangement are not likely to undergo obvious modifications, changes in the moisture content of the fuels remain almost alone responsible for the changes in their inflammability and combustibility.

The heat from a fire passes off in two ways: a) as a column of heated air which tends to rise straight up, and b) as radiating heat which travels in straight line in all directions. The upward flow of heated air develops into drafts and whirlwinds, and tends to retain its heat as long as the air current retains its strength. The heat radiation, however, is inversely proportional to the square of the distance from the fire, materials ten feet away receiving only one hundredth as much heat as fuels within one foot. Except for materials directly above the fire and reached by the column of heated air, only the fuels lying close to the fire may be raised to the kindling point and be ignited. The drier the material the more rapid the spread and the greater the resulting heat. The amount of heat given off by a fire may be so great that the radiant energy is sufficient to transmit the ignition temperature to fuels separated from the fire by the width of constructed fire trenches (65).

The volume of heat from a fire may be tremendous and cause strong convectional currents, whirlwinds and drafts. These air currents or drafts are set in motion by the fire itself and are governed by the fact that hot air is lighter than cold air, the heated air tending to rise straight up. To replace the rising air an inrush of cold air towards the base of the burning material provides the fire with a new supply of oxygen. The hotter the fire the stronger the resulting currents, occasionally resulting in whirlwinds of sufficient strength to break off and uproot large trees. Flying sparks and embers carried by these hot air currents are responsible for setting so-called spot fires. The inrush movement of cold air towards the base of the fire to replace the flow of rising hot air is used to particular advantage in checking fires at the top of sharp ridges working as natural firebreaks.

B) Forest Fuels

The amount and character of fuel have an important bearing upon the rate of spread of forest fires. Forest fuels have been divided into three groups: critical, slow-burning and green fuels. The critical fuels are "those which under natural conditions may become susceptible to easy ignition and rapid combustion" (108). They consist of dead vegetative materials including the top layer of forest duff, the light litter of twigs, small branches, needles, leaves, ferns, grasses, etc., the outer shell of heavy limbs, logs, snags, etc. These fuels are usually somewhat jack-strawed, loosely arranged, and constitute the tinder and kindling wood in which fires are first established and spread rapidly; burning fast they give off a tremendous amount of heat which dries out and ignites the adjacent materials. The slow-burning fuels are the remaining dead materials which are incapable of burning rapidly because of their structure, arrangement and lack of exposure. They include the lower strata of the forest duff, the humus, the interior portions of heavy limbs, logs or snags, etc. Burning slowly behind the advance of the fire edge, they hence have comparatively little or no influence on the rate of spread. The green fuels are made up of all the forest growth, including the foliage of trees, the brushes, grasses, weeds, ferns, etc. Under natural condition they are charactetized by a high moisture content, and are considered as non-inflammable. But, they may be very quickly dried out by the heat rising or radiating from burning materials and burn with great rapidity and intense heat, joining with the critical fuels in carrying forward any rapidly advancing fire.

Another classification divides the forest fuels into flash fuels and heavy fuels. The flash fuels are those "light fuels such as grasses, ferns, tree moss, etc., which ignite readily and are consumed very rapidly, and thus contribute to very rapid rate of spread" (12). The heavy fuels are those "fuels such as snags, windfalls, branchwood, etc., which, while they usually burn more slowly than flash fuels, liberate a greater amount of heat and burn more fiercely, thus materially increasing the difficulty of suppression" (12).

Show and Kotok (123) have studied forest-cover types from the fire-control standpoint, as a basis to determine "an index of the difference in fire control between the major cover types", and have established a correlation between the cover type and the rate of spread. Hornby (84, 85) has developed a system of fuel-type classification in which the forest areas are divided "into units according to both the normal rate of spread of fire on an average bad day, and the resistance to control-line construction offered by the fuels, topography and soil".

Fine fuels cause faster spread and burn more rapidly because they are more quickly dried out and heated to the kindling point, and have a greater proportion of their volume in free contact with the oxygen of the air. The percentage of fine materials, therefore, has an important bearing on the inflammability of the forest. These light, loose fuels, such as the top duff or litter, the herbaceous vegetation, the dry moss, the outer bark of dead timber, etc., are the materials which are most likely to make possible the start and rapid spread of forest fires. The severity of forest fires is directly dependent upon the amount of available fuel, and large accumulations of dry fuels may cause serious conflagations. Once a fire has created a large volume of heat, it gains momentum and progressively dries out the fuels before its own advance. "This explains why slash-covered areas with a large accumulation of dry fuel may be a menace to adjoining green timber" (77).

In discussing the laws of combustion, mention was made that the arrangement of the fuels influences their inflammability and combustibility and, therefore, the frequency and severity of forest fires. This is due to the fact that the disposition of the fuels in reference to both a free circulation of air and the heat rising or radiating from the burning materials provides for a rapid drying out of the fuels and an optimum supply of oxygen, and facilitates the raising of the fuels to the kindling temperature. Old burns in which snags and killed trees have broken and fallen in a tangle of dead limbs and logs are an example of fuel arrangement with optimum conditions for the rapid spread of fire.

Likewise, the moisture content of the fuels has already been shown to have an important bearing upon their inflammability and combustibility, and, therefore, the inception, spread and gravity of forest fires. Materials cannot be ignited until they have been dried out; the amount of heat necessary to drive off moisture from damp material before it is raised to the kindling point explains why it is hard to ignite, burns slowly and gives off little heat. So much heat is necessary to dry out wet material that the chances of wet fuel getting ignited are negligible, there not being enough remaining heat to keep the temperature above the kindling point.

Show (120), Gisborne (63,64,67,68) and Wright (145, 146,147) have demonstrated the correlation between the moisture content of the fuels and their inflammability and combustibility. Gisborne (64,66,68) and Wright (145,146) have applied this principle in the development of a fire-danger rating system based on the moisture content of the top litter as measured by means of duff hygrometers or wood cylinders. Wright (145,146) found in mixed red and white pine forest "that fire could not be started by any ordinary means when the top half-inch of needles or duff on the forest floor contained more than 23 per cent of its oven-dry weight of moisture" (145). He established five zones of inflammability based on the moisture content of the top layer of duff or litter, which is the material in which fires generally start. One region of the U.S. Forest Service has also adopted a scale of current danger rating based on the moisture content of the fuels (124).

Students of fire behavior have recognized the influence of seasonal vegetation on forest fire hazard. Wright and Beall (149) mention that the month of May is "a particularly dangerous period from the standpoint of fire hazard", largely due to the fact that the inflammable remains of previous year's growth are then in that critical stage between the melting of snow and the development of the seasonal vegetation, a somewhat similar situation being encountered in the late fall after the death of the seasonal vegetation.

C) Physical Factors

The influence of the physical factors on the behavior of forest fires has already been inferred in discussing the moisture content of the fuels. Indeed, the physical environment is of primary importance in governing a) the moisture content of the fuels and hence their inflammability and combustibility, and b) the direction and rate of spread of the fire. The principal physical factors affecting the behavior of forest fires are: a) the weather, including such elements as relative humidity, precipitation, temperature, evaporation, vapor pressure, barometric pressure, solar radiation, and wind; b) the topography.

a) <u>Weather</u>

The relative humidity is by far the most important weather element affecting forest fires. Hofmann and Osborne (82) claim that the atmospheric humidity is the most important single weather element controlling the fluctuations of forest inflammability. The relative humidity or atmospheric water vapor is "the ratio of the quantity of moisture contained in a unit of space to the maximum quantity of moisture that could be contained in that space at the existing temperature and pressure" (67). The effect of relative atmospheric humidity on fire behavior is due principally to its influence on the moisture content of the forest fuels. Forest fuels being hygroscopic, they take on or give off moisture until they come into equilibrium with the air. When relative humidity is low and forest fuels are wet, moisture evaporates from the fuels rapidly, whereas the materials tend to absorb moisture from the atmosphere when the humidity is high. The finer the fuels the closer the correlation between fuel moisture and atmospheric humidity. The moisture-holding capacity of the air varies with its temperature, warm air being able to hold much more moisture than cool air, and the relative humidity likewise being lower at warmer temperatures and higher on cool days. Extremely low relative humidities are likely to result in high inflammability of forest fuels, the danger becoming greater and greater as the low-humidity period goes on.

Precipitation may be regarded as the chief weather factor influencing the moisture content of forest fuels over protracted periods. Like the relative humidity, but to a much greater extent, precipitation or rainfall influences the inflammability and combustibility of forest fuels by increasing their moisture content. According to Gisborne (64, 67), precipitation alone, of all the weather elements, makes fuels non-inflammable and obliterates forest-fire danger. Important considerations in connection with the effect of rainfall on forest fire are: a) the amount of precipitation; b) its duration; c) its distribution; d) the evaporation rate in the periods between rainstorms; e) the moisture content of the fuels before the rainfall; f) the kind of fuel; g) the nature of the site; h) the topography; i) the season of the year (64, 102, 117, 147).

Temperature has already been shown as exerting an influence upon the relative humidity and hence affecting the inflammability and combustibility of the fuels. High temperatures increase the rate of evaporation and are also important in raising the temperature of the fuels and creating a condition in which less additional heat is required both to ignite and consume the materials (64). Differences between the temperature at different stations affect forest fires by influencing the velocity and direction of the wind, occasioning rainfalls, etc. High temperatures are generally accompanied by very dry atmosphere and a critical fire period.

Evaporation is the result of at least four weather elements: relative humidity, temperature, wind and sunlight. All of these factors combine for removing moisture from the fuels. Munns (105) has demonstrated the direct correlation between the size and occurrence of forest fires and the rate of evaporation. Stickel (135) also found the rate of evaporation to be an accurate and satisfactory integration of the influences of its components, i. e. temperature, relative humidity, solar radiation and wind velocity, on the moisture content of the forest fuels.

Vapor pressure also has an influence on forest fires. "As high vapor pressure indicates a large amount of absolute moisture per unit volume of atmospheric space, it also implies that less cooling will be required to condense or precipitate that moisture than if the vapor pressure was low" (64). Munns (105) found that the occurrence and spread of large forest fires are coincident with a decrease in vapor pressure. When considered in conjunction with temperature, vapor pressure is a reliable indicator of future relative humidity and precipitation and hence provides a valuable forecast of fire danger.

Barometric pressure has a correlation with fuel moisture and hence forest fires, in that high barometers are nearly always indicative of high temperatures and low humidities, consequently of a high rate of evaporation. Air pressure being recognized as the most reliable indicator of weather conditions, it is natural that it must have some influence on the inflammability of forest fuels. Air pressure, however, is essentially a forecast of future weather conditions rather than a picture of the current fire hazard.

The amount of sunshine or the intensity of solar radiation influences forest fires by affecting the rate of drying of fuels exposed to the sun's rays (37, 38), and the rate of evaporation in general. Insolation is also of importance to forest-fire hazard because of its heating effects.

Wind is of outstanding importance in gaging the rate of spread and the direction of spread of fires, and in affecting the moisture content and hence the inflammability of fuels. According to Show (120), "the rate of spread, as governed by wind velocity, may be stated to vary as the square of the wind velocity". Osborne (108) also indicates that wind pressure varies with the square of its velocity. The effect of wind on the moisture content of fuels varies greatly depending whether the incoming air is moist and cool or dry and warm. Byram and Jemison (38), studying the influence of sun and wind on fuel moisture, found that, "in bright sunlight, contrary to popular belief, wind maintains levels of fuel moisture higher than those in calm air", the wind's action more than offsetting the sun's drying action. Byram's study of the effects of sun and wind (37) also indicates that "wind partially offsets the drying effect of sunshine" on fuel moisture. The effect of wind on the rate of evaporation has an important bearing upon the moisture content of fuels. In Gisborne's scheme of fire-danger rating, "wind is given almost as much weight as fuel moisture" (68). Show and Kotok (122) indicate that "from the standpoint of organized fire protection, obviously the most critical combination of factors is in the coincidence of very low relative humidity and very high wind". Another influence of wind on forest fire is its "effect on combustion by furnishing fresh supplies of oxygen" (135). According to Wright (147), "wind is also an important factor in the development of crown fires", due to the fact that the combined heat from the ground fuel and the burning foliage, when levelled by a high wind, causes the fire to run rapidly in the tree tops. Another way in which wind affects forest fires is by carrying sparks and burning embers ahead of the fire and thus setting spot fires (108). The direction of winds is very likely to be affected by local topographical features. Likewise, wind velocity undergoes daily cycles, wind going down at night and coming up again in the morning.

Because of daily variations in the weather factors influencing the inflammability and combustibility of forest fuels, consistent changes may be expected in the burning conditions which normally occur with more or less regularity during the twenty-four hours of the day. According to Osborne (108), a) fires are generally at their lowest ebb at about 4 A. M.; b) they then usually smolder until 7 or 8 A.M.; c) they then begin to gradually pick up until 12 or 1 P. M.; d) from then until 5 or 6 P. M. they usually burn most fiercely and spread with maximum rapidity; e) at about 6 P. M. their intensity begins to decrease; f) after 10 P. M. fires seldom make much advance and their intensity is always reduced; g) a very large percentage of the fire edge goes out as the night advances. Local winds or extreme humidity conditions may, however, completely upset this schedule.

The interpretation of fire weather has brought about the design of fire-danger meters which express the exceedingly complex relationships of the fire elements into simple indices which the confused administrators could use to determine the intensity of fire organization. This idea of fire-danger meters has been applied throughout the United States and Canada "with the many variations and adaptations required by local conditions and needs, and a bewildering array of fire-danger meters has arisen each with some new and valuable feature" (70).

b) Topography

The topographical features have a great deal to do with the fire behaviors and particularly the rate and direction of spread of forest fires. The ways through which topography may affect fires include: a) elevation or altitude; b) aspect or exposure; c) slope; d) surface conditions. The elevation and aspect influence forest fires in as much as both factors affect the atmospheric conditions which determine the moisture content of the fuels. Hayes (78) experimenting forest fire behavior at variable altitudes throughout the day, found that during the night most dangerous burning conditions occur between 3,000 and 4,000 feet, mid-dangerous conditions occurring above 4,000 feet, and least dangerous ones below 3,000 feet elevation, whereas during the day fire behaviors on south slopes are slightly more dangerous between 3,000 and 4,000 feet elevation than above or below, while on north slopes the greater danger is in the high zone above 4,000 feet elevation. Hayes' findings reveal the importance of exposure or aspect on the occurrence and spread of fires, slopes with southern or western aspects suffering more severely than those with northern or eastern exposures. This is explained by the dryer conditions of the fuels due to their greater degree of exposure to the weather on the southwestern slopes.

Fires spread more rapidly and more fiercely on the uphill side of slopes than on the downhill side, due to the fact that the heated air draws the flames upward. The steeper the hill the greater the speed.

The different fire behaviors in rugged country may also be explained by the different vegetation conditions encountered at various levels on the differently exposed slopes and on the varying steepness of the surface.

Slopes may cause burning embers to slide and roll downhill into unignited fuels and thereby increase the spread of the fires. Osborne (108) mentions that in many regions and types, slopes are of even greater importance than winds in influencing the spread of fires.

The condition of the surface effects forest fires by bringing about changes of fuel types and fuel moisture due to different exposure. "A smooth surface on which the inflammable material occurs uniformly distributed tends to make the fire burn more evenly and intensely" (77). Breaks in topography, such as ridges, canyons, etc., also influence fire behavior by causing changes in the air currents.

Topography has a marked influence on the shape of forest fires. In level country, fires tends to spread in an elongated ellipse, whereas on a steep slope they normally run uphill in the form of a diverging or converging wedge. On both level and rugged country, the flanks usually spread slowly and are comparatively easy to control.

KINDS OF FIRES

A crude fire classification distinguishes between small fires and large fires depending upon the relative size of the burning areas and whether the total area can be comprehended at a glance or not.

Firemen also distinguish between the main fire and the spot fires "set in advance of or away from the main fire by flying sparks or embers" (12). Spot fires, which are the result of the tremendous convectional currents generated by the main fire, may be set as far as several miles from the main fire, and it occasionally happens that they produce serious conflagations.

The term extra-period fires has been applied to fires not controlled or coralled within the first work period, i. e. by 10 A. M. of the day following discovery, whereas a hangover fire is " a fire started by lightning which remains dormant until a later period when it becomes active" (12).

For the purpose of analysis, forest fires are divided into the major sets of causative agencies responsible for the origin of the fire. The eight standard specific causes of forest fires recognized by most protective units are: camp fire, debris burning, incendiary, lightning, lumbering, railroad, smoker and miscellaneous. Some organizations use a ninth class for unknown causes, i. e. when the exact cause cannot be definitely determined.

Also for the purpose of analysis and statistical comparison, forest fires have been grouped into five classes according to the size of the burned area (12), as follows: a) class A fire, one-fourth acre or less; b) class B fire, more than one-fourth acre but less than 10 acres; c) class C fire, 10 acres or more but less than 100 acres; d) class D fire, 100 acres or more but less than 300 acres; e) class E fire, 300 acres or more.

The comparative spread and intensity of forest fires have given rise to the six following characters of burning conditions (12): a) smoldering fires "making no appreciable spread and burning without flame"; b) creeping fires "spreading slowly, usually with low flame"; c) running fires "spreading rapidly and with a well-defined head but without spotting or crowning"; d) spotting fires, already referred to as spot fires, "spreading as a result of sparks or embers falling ahead and starting new fires"; e) crowning fires, also known as running crown fires, "advancing primarily from crown to crown rather than from ground to crown"; f) dependent crown fires progressing mostly from ground to crown rather than from crown to crown.

TYPES OF FIRES

The three following types of fires are generally recognized depending primarily upon the forest layer in which they spread and cause the most damage: a) surface fires; b) ground fires; c) crown fires.

A) Surface Fires

A surface fire is "a fire that runs over the forest floor, burning only the surface litter, the loose debris, and the smaller vegetation or ground cover" (12). Surface fires burn and spread rapidly, with abundant flame and heat, but they burn out quickly. They are the commonest fires and fortunately the most easily controlled. Fires in old burns, grass types, fern types, pine needles, etc. are typical examples of surface fires. Feeding on the top layer of dry loose needles, litter, grass, weeds, low brush, the outer surface of logs, etc., they burn only the leaves, the top layer, the loose debris and the smaller vegetation. Surface fires injure only the lower part of the trunks of trees beyond the reproduction stage, but they may kill them by applying heat to the surface of the trunks. Most fires start as surface fires, the fuel upon which they feed being of a light, loose nature and likely to be very inflammable. But, they develop into ground or crown fires as soon as the requisite conditions are fulfilled.

B) Ground Fires

A ground fire is "a fire confined to the materials composing the forest floor or beneath the surface" (12). Ground fires may be further subdivided into peat fires and duff fires, depending upon the nature of the fuel. Peat fires are those ground fires which occur on ill-drained areas, such as swamps and bogs, where layers of duff and peat several feet in thickness have accumulated. Peat fires are sometimes referred to as underground fires, because they burn in deep organic material several feet below the surface (91). This is especially true when the surface is wet and the lower layer is dry. The exact location of such underground fires is difficult to determine, and records sometimes show peat fires which have burned for several months in swamps. The smoke and odor from burning swampy areas is very pungent.

Duff fires are "those ground fires which occur on upland areas where thick deposits of litter, duff and humus have accumulated" (77). They generally burn and spread more rapidly, give more heat, and produce less smoke than the peat fires, but they give off a comparatively small amount of heat, spread rather slowly and require a long time to burn out.

Ground fires are distinguished from surface fires by the fact that the entire accumulation of duff is burned. They are very hard to control or extinguish, on account of their capacity to smolder beneath the surface. They may destroy completely the organic materials of the soil, and create barren areas which may require centuries to restock.

C) Crown Fires

Crown fires are those which burn in the crowns of the trees, or in which the spread takes place in the crown as well as on the surface of the forest floor, comsuming all or a large part of the foliage. Crown fires are typical of coniferous forests. They spread and burn rapidly, and generate a tremendous heat. Burning brands and embers from crown fires may be carried by the wind and set spot fires, thus complicating the fire fighters' job.

As already mentioned, crown fires may be of two types: a) running crown fires, or b) dependent crown fires, contingent upon whether the crown fires progress through the crowns of the trees and independently of surface fires, or are maintained by the heat and flames rising from surface fires which furnish the heat necessary to ignite the crowns. Crown fires are sometimes set by lightning strikes.

PARTS OF A FIRE

To facilitate the study of forest fires, their different parts have been defined and designated as follows (12): a) the edge, sometimes referred to as the front, "the line, usually irregular, to which a fire has burned at a given moment"; b) the perimeter, "the entire outer edge of the fire", or "the length of the outer line or edge of the fire";
c) the head, sometimes also referred to as the front, "the portion of the edge of a fire on which rate of spread is most rapid". It is that part of the fire that is spreading most rapidly, being driven forward by the wind. In level country, this is the lee side or the side in which direction the wind is blowing; in rugged terrain, it is the uphill side as opposed to the downhill side.
d) the rear, also known as the tail, "the portion of the edge of a fire on the windward or downhill side". Being opposed to the head and driven by the wind toward the portion already

attacked by the head, the rear is very likely to suffer of starvation and to die out of its own accord.

e) the flanks, sometimes called the sides, "the portions of the edge of a fire between the head and the rear", or the sides or edge connecting the head and the rear. They tend to extend the fire at right angles with the direction of the head, but at a much less rapid rate than at the head.

f) the fingers, "the long narrow tongues of a fire projecting from the main body". They are the results of changes in the character of the fuels and in the level of the country, fires spreading more rapidly in certain fuel types and on steep slopes and upward as opposed to level terrain or downward.

OBJECTIVES OF FIRE SUPPRESSION

The first and most standard objective of fire suppression is to corral the fire, stop its spread and make it reasonably safe before the heat of the day or not later than 10 A. M. of the day following discovery. When this objective is not reached, plans of attack will contemplate control before 10 A.M. of the next day or each succeeding day. To reach this objective, every organization must be prepared to meet the most severe fire situation under prevailing or predicted conditions. When the fire is corelled or the control line has been completed, the next objective is to keep it under control and to prevent its possibilities of escape through negligence. The final objective is then to mop it up and to put it out completely.

Other objectives of fire suppression are to confine the fire to the smallest possible area, maintain the number of class C fires to a minimum, and keep the damage below an arbitrary percentage of allowable burn set up for each given area or fuel type. To reach these objectives, the fire must be handled with such speed and trained competence that it is quickly put out, such immediate control being made possible for all fires in all locations with any kind of weather.

FIRE DETECTION

Suppression activities of a protective organization start with the discovery and location of the fire once it has been set. Fire detection requires concentration, vigilance, alertness, precision and good eyesight, for promptness in discovery and accuracy in location. Adequate and effective detection is also contingent upon a complete supply of dependable fire-finding equipment, including detailed and accurately oriented maps, precise fire finders or alidades, binoculars, colored glasses, and panoramic pictures indicating ridges, drainages, false smokes and other landmarks. Dependable detection system also calls for adequate coverage of the whole territory, involving ground or airplane patrol to supplement the lookout stations, in blind areas or during intervals of low visibility due to haze, fog or smoke.

Speed of discovery is one of the main objectives of fire detection, and may be considered the efficiency test of the lookout system. Several protective units have set an elapsed time standard of detection, known as discovery time, which is "the elapsed time from start of a fire until the time of the first discovery which results directly in subsequent suppression action" (12). Several regions of the U. S. Forest Service have set a maximum elapsed time standard of fifteen minutes for discovery (4, 6, 7, 8). One region has set another time standard objective requiring that all fires be detected before reaching a size larger than one-eight acre (7). Another region requires as elapsed time standard of discovery that it be "possible to discover 90 per cent of all fires within fifteen minutes after smoke arises above the cover, for areas of high hazard and with lookouts on duty during periods of normal visibility" (6).

An important phase of fire detection deals with its accurate location. Accuracy in location assumes the use of dependable and precisely oriented maps and fire-finding apparatus, and requires from the lookout man a thorough knowledge of his territory, adequate training in the details of his job, and sufficient education and intelligence to make accurate observations. One region of the U. S. Forest Service has set a location standard of not over ¼ mile from the actual location at any point within a circle 10 miles in radius from the lookout station, in not more than 2 minutes from the time of discovery (7). Whenever possible, the location should be checked from other lookout stations in the neighbourood with overlapping visibility distances.

The various methods used in locating forest fires involve the use of: a) local landmarks, b) land survey maps, c) panoramic photographs, and d) oblique aerial photographs. The method of locating fires by local landmarks is the simplest and also the least accurate. It requires that both the lookout man and the dispatcher be thoroughly familiar with the country. However, the location through landmarks provides a valuable supplement to the other methods. The method of location by means of land surveying maps, commonly known as the map method, consists in locating fires according to the public land survey system, referring to such subdivisions as townships, ranges, sections, quarter sections or sixteenth sections. The determination of the location on the map may be obtained either by the plane table method, or by platting the intersection of the horizontal angles from two or more lookout stations. The application of the plane table method is limited to fires sighted from only one lookout station, although its use may provide a valuable check when the fire can be seen and located from two or more stations. Its application presupposes the use of a fire finder; when the sights are trained on the fire, the platted position of the fire is somewhere on the line defined on the instrument map by the direction of the sights; then "the observer can usually determine very closely where on the defined line of sight the fire should be platted" (107). The location of fires from two or more lookout stations is determined by graphically platting on the map by means of a protractor the intersection of the azimuths or horizontal angles obtained from the various stations. This may also be determined trigonometrically, by computing the distance from the stations by trigonometry and then platting the bearing and distance by latitude and departure, making allowance for any shrinkage or expansion of the map (107). This is the most precise way of platting a fire sighted from two or more stations, but it is not recommended for general use, because it is slow and subject to errors in computation. The panoramic photograph method (110), also known as photo survey method, presupposes the use of a fire finder and consists simply in sighting on the fire and platting on a graduated panoramic picture the azimuth and the vertical angle read from the lookout station. These graduated pictures are taken from the lookout stations by means of a photo-transit camera, also referred to as a photo-recording transit (107) or a panoramic photo-survey camera (13), "a special type of panoramic camera that records the vertical angle and the true azimuth of objects photographed on the landscape in relation to the photographic station" (12). According to Osborne (107), anyone using this method can determine in a few seconds and to the accuracy of a needlepoint the exact location of any fire. Sparks (128) has described a method using oblique aerial photographs and "celluloid grids the size of the photographs and divided into inch squares, numbered along the top and lettered down the sides". The fire location is given with reference to the photograph number and the cross-reading of the grid. By means of a especially designed stereoscope the changes of elevation can be studied and even the differences in the fuel types may be noted on the photographs.

REPORTING THE FIRE

As soon as the location of the fire has been ascertained, the next action of the lookout man is to report the fire to the dispatching officer. Speed in initial report is of prime importance, so that the suppression forces could start and reach the fire in the shortest elapsed time after its inception. Standards of report time or "elapsed time from discovery of a fire until the first man who goes to the fire is notified of the existence and location of the fire" (12), have been set as a way to maintain this period to a minimum. Several regions of the U. S. Forest Service have set an objective of five minutes for the report of fires directly from the lookout man to the dispatching officer (4, 6, 7, 10). Some regions make an allowance of fifteen minutes, especially when all or a part of the telephone line is commercially owned (7, 8, 10). When several fires are sighted at once, not over two minutes are allowed for each additional fire (7, 10). Likewise, when the report must be relayed or supplemental reports are necessary, an additional period of five minutes is allowed for each relay or supplemental report (7, 10). This interval of time is affected by several factors which are not readily avoidable, such as difficulty of obtaining cross shots from other lookout stations, poor visibility due to haze, delays in communication over private telephone lines, relays, etc. After **the initial notification, subsequent reports should promptly follow**, providing more details, as available, on the exact location, size, burning conditions, etc. When several fires are sighted at once, they should be reported in the order of their relative importance.

When reporting a fire, the lookout man should provide the dispatching officer with all the information necessary for determining the exact location of the fire by means of the methods of location already described. Such information should include landmarks, land survey subdivisions, azimuth or horizontal angle, vertical angle, distance, etc. Additional information pertaining to the size of the fire, the burning conditions, the wind direction, the rapidity of spread, etc. are also important for the estimation of the strength of the attack.

Speed in reporting fires is largely dependent upon the adequacy of the communication system. The lookout stations must be connected with the dispatching headquarters. The telephone is the most adequate means of communication for this purpose. The radio provides a very satisfactory supplement to the telephone, giving a more flexible service and likely to prove less expensive than the telephone. Where the airplane is utilized for forest protection, then the radio may prove invaluable and necessary even in areas covered by telephone lines.

Whenever possible, arrangements should be made to provide the dispatching crews on their way to the fire, with further information secured from the lookout man as to the definite location of the fire, the burning conditions, the direction of the spread, etc.

In order to shorten the time taken for reporting fires, protective organizations have set regular procedures calling for a description of the information concerning the fires in a definite order. Standard forms are utilized, so that each party of the conversation is aware of what is coming next.

DISPATCHING ACTION

The dispatcher or "the member of the fire-control organization who receives reports of discovery and status of fires, determines the location of fires, and sends men, supplies and equipment to suppress fires" (12), may be either a clerk at the headquarters or an experienced ranger at a district station. The first duty of the dispatcher when a fire is reported is to determine or check the location of the fire. By means of the information secured from the lookout man, such as landmarks, land survey description, azimuth or horizontal angle, vertical angle, distance, etc., the exact location of the fire is ascertained and platted on a map. The platting map, which may be mounted either on a table or on the wall, must be as complete as compatible with its accuracy and neatness, including all the land survey lines, topographical features, travelling facilities, fire-control improvements, etc. After the location of the fire has been determined and platted, it is checked with the location described by the lookout man. When the same fire is reported from several stations, it often happens that the platting of each described location results in a so-called triangle of error, giving as many locations as observers. If this triangle is large, an hypothetical location must be figured, taking into consideration such factors as the distance of each lookout station from the fire, the direction of the smoke drift, the comparative dependability of the lookout men, and whether the source of the smoke is sighted or not. Then the direction to the location of the fire is oriented with reference to the dispatching headquarters, and the distance is computed.

Reference is made to the transportation map, travel-time map, topographic map, fuel-type map, and water-supply map, to ascertain respectively the travelling facilities, the computed time required to reach the fire, the physical characteristics of the area, the type of fuel, and the availability and location of water supplies.

The number of men to dispatch to a fire depends primarily upon a) the size of the fire when detected, b) the travel-time, c) the fuel type, d) the topography, e) the weather, f) the time of the day, g) the season. This number may vary very widely from day to day, and from place to place. The man power dispatched to a fire should be provided with competent leadership and adequate equipment and food ration. Arrangements should be made, whenever possible, to keep in touch with the dispatched crew and to send supplementary man power, if necessary.

The dispatcher should be thoroughly acquainted with his territory, i. e. its topographical features, the direction of local winds, the distribution of its fuel types, its implements, including roads, trails, camps, lookout stations, and other facilities. The more familiar he is with these details, the faster he can dispatch suppression crews to reported fires, start for a fire not being made before its exact location has been ascertained and the travel to the fire and its probable location has been figured. Speed in dispatching action is of prime importance, a few men on the job at an early moment being more effective than a large crew later. Crews should be ready to leave at any time of the day or night, and the best men promptly available should be dispatched first.

As a way to hasten the dispatching action, fire-control planners have set a get-away time standard, which is the elapsed time from the receipt of the report of a fire until the actual departure of the dispatched crew for the fire. Five minutes constitute the most common standard get-away time, especially when the crew travels on foot or in automobile (4, 6, 7, 8, 108, 124). The standard of get-away time is extended to 15 minutes when the crew travels with horse (4, 6), and even

25 minutes when the crew travels with saddle and pack horses (4). One region of the U. S. Forest Service contemplates an objective of 8-minute get-away time when the crew travels on saddle horse, and 13-minute get-away time when the travel to the fire is made with saddle and pack horses (124).

As already mentioned, when the location of a fire is doubtful, it is considered preferable to delay the get-away until the definite location is ascertained or a cross reading is secured from another lookout station, more time being saved in the travel than lost in the get-away. But, when the dispatcher can get in touch with the crew on the way to the fire, the get-away should not be delayed, and the more specific information should be reported to the crew as soon as secured from the detection forces.

TRAVELLING TO THE FIRE

The main objective of the crew is to get quickly to the fire, and the best transportation facilities should be used in order to save a very valuable time. The expense involved in furnishing the transportation is generally offset by the saving of time and the fact that men arrive and start to work in better condition. As already mentioned, reference should always be made to the transportation and travel-time maps, to ascertain the travelling facilities and the time required to reach the fire. Fire control planners also have set a standard objective of travel time or elapsed time from the departure until the arrival to the fire. This elapsed time standard varies with the means of transportation, the quality of the roads or trails, and whether the travelling is done during daylight or at night. For most organizations, the minimum requirement for day travel is 10 miles per hour by automobile, 3 miles per hour on horse, and 2 miles per hour on foot (6, 7, 10), whereas for night travel the objective is set at 2 miles per hour on horse and 1½ miles per hour on foot (7, 10). The most common means of travel include: a) on foot, b) on horse, c) in passenger car, d) in pick-up, e) in truck, f) in trailer, g) in bus, h) in boat or canoe. The travelling facilities also include: a) paved highways, b) dirt or gravel highways, c) one-way dirt roads, d) trails, e) lakes or rivers. Important considerations in connection with the road systems are the roadbed, the gradient and the turnouts.

Crews should be ready to start immediately either in daytime or at night, and willing to travel continously regardless whether with daylight or at night. Travel by road or trail is often quicker, although sometimes involving a greater distance.

When the crew approaches to the vicinity of the reported location of the fire, frequent observations are advisable, using lookout trees, open slopes or any other point from which a far-reaching view could be obtained over the territory. It often happens that after getting to the vicinity of the fire a dense and wild forested area has to be travelled before the firemen reach the edge of the fire. Considerable difficulty may, indeed, be encountered in this last phase of the travel before the fire is sighted and firemen could start effective suppression work.

The simplest procedure for finding a fire is to plat on a map the line of sight from the lookout station to the fire, as reported by the observer, find out where the lookout line of sight to the fire crosses the road or trail leading to the fire, and locate a landmark from which the magnetic direction and the distance to the fire can be computed. When the crew reaches this landmark on its way to the fire, the firemen then take out their compass, turn to the direction corresponding to the lookout line of sight to the fire, and travel the distance already computed between the landmark and the fire. A check of the direction can be obtained by backsighting on the lookout station. The presence of obstacles on the way between the landmark and the fire may necessitate detours and offsets to avoid such obstructions as cliffs, canyons, impassable streams or creeks, impenetrable brush fields, etc.

When only the lookout line of sight to the fire is known, the firemen travel to the vicinity of the fire and then keep going back and forth until the line of sight to the lookout station, as indicated by the compass, coincides with the lookout line of sight to the fire already reported by the observer. Since the fire is on this line of sight, the firemen travel in this direction until the fire is reached.

Another method of reaching a fire is to plat the reported location on a map, and travel on the road or trail up to the section line which is closest to the fire. Then, the crew travels along this section line again up to the point laying closest to the fire. Finally the men leave the section line and proceed straight to the marked location of the fire.

If a firemen cannot find a fire which was located on a map by the intersection of the line of sight from two lookout stations, it may be possible to ascertain this location on the area by means of the compass. The procedure is as follows: a) backsight onto one station and move back and forth until the back azimuth checks with the reported line of sight; b) keeping on this line of sight, proceed similarly with the other station until the correct back azimuth is read; c) the reported fire is at the intersection of the two lines of sight. The topography of the area may prevent a back vision to one of the lookout stations. This difficulty may be overcome by sighting onto the lookout station which can be seen, and moving along this line of sight until the other station cab be seen. Knowing the distance from the latter station to the reported location of the fire, and the azimuths from this station to both the fire and the location of the smokechaser, the distance from the smokechaser to the fire along the line of sight from the former station can be computed trigonometrically. Trigonometrical calculations may also ascertain the location of a fire reported from a single lookout station, which cannot be backsighted. This procedure, known as the Tangent Offset method is "a method used by firemen to get on line of sight from a lookout to a fire, where a compass shot on the lookout point cannot be obtained except from a point to one side of the line of sight" (12). Knowing the distance from the station to the fire, and the angle between the observer's line of sight to the fire and the smokechaser's line of sight to the lookout station, the distance from the smokechaser to the fire can be calculated trigonometrically, the fire being approximately at right angle to the smokechaser's line of sight to the station, at a distance equal to the product of the reported distance by the tangent of the angle between the observer's line of sight onto the fire and the smokechaser's line of sight onto the station.

Another method of locating a fire, known as the Gridiron method, is used when "the fireman paces a certain distance at right angle to the line of sight from lookout station, then runs a compass line parallel to the line of sight, repeating the process if necessary, to cover a considerable area on each side of the line of sight" (12). This method is especially used when dealing with small fires hard to locate or large fires concealed by a dense smoke drift. The fireman, after reaching close to the fire along the line of sight from the station, paces the area in a gridiron pattern on both sides of the line of sight until he finds the fire.

Other ways of finding a fire include: a) sighting the fire before getting to it, from tall trees, open meadows, cliffs, etc., and locating it on the map in reference to well-known landmarks, so that when the smokechaser can no longer see the fire he will have other landmarks to guide him; b) smelling the smoke and checking the wind direction; c) referring to the occurence map and appraising the possibility of fires caused by incendiaries, travellers on roads or trails, campers, sportsmen, lumbermen, railroads, etc. The smokechaser himself may become unable to locate his own position. He must then sight two or more landmarks indicated on his map and plat his own location on the map at the intersection of the lines of sight. Having the platted location of himself and of the fire on the map, he can compute the azimuth and the distance to the fire and travel to it. An important consideration in connection with the travelling to a fire is to record on the map all the details of the trip, indicating take-off points, directions, distances, etc.

COLLECTION OF EVIDENCE AND CLUES

Although the main objective of the fireman is to extinguish or control the reported fire, and while fires should not be allowed to spread because of search for clues, the first men travelling to or reaching a fire should, whenever possible, make provision for determining the cause of the fire before the evidence is obliterated. During the travel and upon arrival, firemen should watch for and record any clue of possible evidence. If the fire demands immediate attention, attempts should be made to preserve all the clues for later follow-up.

Any thing is a clue which may reveal the cause of a fire or identify the agent responsible for setting up the fire. Important points to watch for and record include: a) tracks, camp fires, lunch remains, supply boxes, cigarette butts, gun shells, scraps of paper, or any other physical evidence; b) names and addresses of persons likely to be connected with the setting up of the fire; c) where and when the fire started. Any one clue may lead to others, that will eventually complete the evidence. Every effort should, therefore, be made to preserve possible clues and especially to avoid the possibility of their being purloined, spoiled or obliterated. Only extraordinary emergency should prevent the first firemen at the fire from spending a short time looking for clues and collecting evidence as to its cause or author.

SIZING UP THE FIRE

The first thing to do after reaching a fire is to make a careful review of the situation, and to determine the most critical points both under the present conditions and following expected changes. This reconnaissance should include such items as: a) the size of the fire, b) the present burning conditions, c) the rate of spread, d) the weather conditions, especially the wind direction and velocity, the temperature, the relative humidity; e) the topography, particularly the presence of slopes, lakes, rivers, etc.; f) the type and moisture content of fuels, g) the time of the day and the season of the year; h) the probable future spread of the fire, i) the presence of spot fires, j) as already mentioned, the probable cause and author of the fire.

This quick size-up of the conditions within the fire and in the surrounding area toward which the fire is spreading, should enable the fireman to decide which is the most vital point of attack, and identify all natural barriers or firebraks of possible use in checking the fire. If possible, men should be posted or scouts should be assigned to reconnoiter the fire and report the progress of the fire and the changes of conditions. It is of prime importance that the fire boss be kept informed of everything that is going on. Scouting the fire is the only way to lay out an intelligent plan of suppression work.

TIME OF ATTACK

Suppression action should start as soon as a quick size-up of the fire has revealed the most critical point of attack. The greater proportion of forest fires is made up of small fires, which can be comprehended at a glance, and calling for a very short reconnaissance. Firemen should, therefore, start the attack just at once, i. e. as soon as the crew arrives. In such fires, the time of the day is unimportant, and an attempt should be made immediately upon arrival to extinguish them or to put them under control just as soon as possible. Continuous action will be the rule whenever there is any chance of extinction or control during the first work period.

In larger fires, particularly extra-period fires, no intelligent plan of action is possible until a size-up of the situation has shown where work is most needed and will be most effective. Since the conservation of man-power energy is of prime importance at a fire, it would be unwise to put the fighters at work before this reconnaissance is completed. "It is better to have crew rest while a reconnaissance is made than to waste energy on an unimportant sector" (108).

In such fires, firemen must remember that the most effective work can be performed in the evening, at night or in the early morning, and the campaign of work should be laid out accordingly. As already mentioned, daily changes in weather conditions produce consistent differences in fire behavior at different hours of the day, the active burning period of the day beginning at about 10 A. M., the most intense period raging from noon to 5 or 6 P. M., after which time the intensity is likely to decrease, the quietest period extending from daybreak until 5 A. M., and the fire then smoldering until 8 or 9 A. M. These habits of fires explain why work in the evening, at night or during the early morning may be more effective than during the heat of the day. It is easier to control a fire that is quieting down than when it burns most fiercely and spreads with maximum rapidity. The time of attack should, therefore, be so planned as to take advantage of the periods during the twenty-four hours that are most favorable for fire fighting.

In some forest protective organizations, night work on all fires is the standard practice (8, 14, 15). Night, indeed, is a better time to fight a fire than the hotter half of the day, if adequate lighting facilities are made available. According to Osborne (108), however, night work in Douglas fir and similar timbered types is not advocated as a general practice, after the initial attack, for the following reasons: a) the decrease in quantity and quality of work accomplished, due to poor light conditions, usually more than offsets advantages; b) since fires keep dying down more and more as the night advances, firemen fight fires which are going out of their own accord; c) there is a maximum danger of men being struck by falling snags or otherwise injured; d) in the majority of cases there is opportunity for direct attack and the accomplishment of greater net results during daylight hours, provided that the men start to work at the break of the day. The same author (108) claims that in Yellow pine types night is generally the best time to work, because, the timber being more open, and there being little underbrush, light conditions are normally much better. Because such fires furnish themselves adequate light, and due to the fact that there is little danger from falling snags, and that the reduced inflammability of materials facilitates the control, it may be then possible to accomplish greater results than during the day. Special jobs which may have to be done at night include: a) the burning out of moss-ladened timber inside of the control line, b) the checking of very vital points including critical spot fires; c) backfiring when the conditions are particularly favorable, d) essential patrol.

Evening is a good time to work, but never so good as early morning. However, certain jobs, as backfiring under exceptionally favorable conditions, may be advantageously done in the evening. Likewise, patrol work is essential in the evening as at any other time of the day.

Work at night or in the evening should be the rule whenever by working during the evening or even the whole night there is a possibility of getting a fire under control during the first work period.

According to Osborne (108), the best results are obtained at daybreak, i. e. between 4 and 5 A. M., when fires are at their lowest ebb. At this time, the fuels are damp; the firemen have a minimum amount of smoke, flame, heat, and sparks to content with; the air is cool; and 6 to 8 hours will elapse before the fire burns fiercely again. Early morning work also facilitates control because: a) large stretches of the fire have gone out; b) firemen can get at snags which are burned out or have cooled down; c) smoldering embers go out readily when dug out and exposed to the air. As much work as possible should, therefore, be done before the heat of the day. One hour's work in the early morning is more effective than from 2 to 10 hours' work in the afternoon (106). Accordingly, it is better to make the fight in the morning from daybreak, and simply patrol the line in the afternoon, than to let the fire gain momentum in the morning and then try to fight it when it is at its maximum strength. If firemen cannot control a fire when the conditions are favorable, they surely cannot when it rages most fiercely.

The period after a slight rain offers somewhat the same advantages as the early morning: it is then just the time to work on a fire when it is weak, and to clean it up before it gets a fresh start. Firemen should also take advantage of all lulls in the burning conditions, due to changes in wind, topography, etc. The timing of fire suppression work must be so planned as to take advantage of the prediction of the hourly fluctations of the weather and of their effect on the burning conditions.

One region of the U. S. Forest Service requires that work at a fire continue day and night until it is controlled, mopped up, and entirely safe, and that at no time a fire line be left unmanned until suppression is complete (7).

When it becomes apparent that the crew cannot suppress a fire within the first twenty-four hours, strength of men must be conserved and labor applied when and where it will be most effective. "Only in extreme emergencies should they work over 10 or 12 hours a day after the first day" (108). In order to conserve man-power energy, a part of the crew may rest a part of the day, while the other men are on the fire line, the two groups working in shifts. Osborne (108) suggests that from 60 to 80 per cent of the crew starts to work at daybreak, i. e. between 4 and 5 A. M., and work during 6 or 8 hours, and that a relay then come on to work until 6 or 7 P. M., a few men being reserved for night patrol. One region of the U. S. Forest Service (7) has set a limit of 18 hours for the first work period, and shifts of 12 work hours until control is established, and shifts of 8 work hours for mopping up and patrol after completion of the control line, plans being made to organize the force into regular shifts when it is evident that the job will run beyond the one shift period. Another region of the U. S. Forest Service (3) has set a limit of 12 hours a day for line-construction work, and 10 hours for patrol and mop-up work. Other organizations (8, 14) recommend short shifts of not more than 6 hours for fire-line construction, and standard working periods of from 8 to 10 hours for patrol and mopping up.

"Understanding of timing fire-control operations is a major part of the qualifications possessed by a successful fire boss" (121). The problem of selecting the sector for first attack, deciding on the timing and order of attack on other sectors, and deciding as to the timing and order for back-firing several sectors, illustrates the vital role of timing fire-suppression work.

POINT OF ATTACK

The point of attack is an important consideration in planning fire-suppression work. In small fires, the attack may be made simultaneously on the whole perimeter if the crew is large enough. But, on most fires the initial attack does not comprehend all the sectors at once, and a choice is necessary on the correctness of which usually depends the outcome of the fire. As already mentioned, a reconnaissance of the conditions within the fire and in the surrounding country is necessary to determine the key sectors or the most strategic points of attack, and the sectors which may be temporarily neglected. There generally are vital points of attack which, if handled properly, facilitate, guarantee and hasten the suppression. It is also important that the fire boss be kept informed as to the progress of the fire and the changes of conditions, and that the plan of attack be modified accordingly.

The vital sectors are those where most rapid spread may be expected, or where a small amount of work applied at the right moment will give maximum results in preventing spread (108). They include: a) spot fires which have become established across the fire line; b) points where the fire has worked or may run across some natural firebreaks; c) sectors where the fire threatens an area where the control would become much more difficult; d) sectors which threaten to flank the rear end of the fire line; e) sectors toward which the wind is likely to drive the fire; f) sectors lying on a steep slope above the fire; g) sectors extending through slashings, old burns, or windfalls; h) sectors lying in precipitous slopes below the fire, where rolling embers may result in a rapid spread; i) sectors where the fire would destroy valuable timber or reproduction; j) sectors which have gone out almost completely, but where the remaining spots may get a fresh start as the day advances or following changes of cover, topography or weather.

The sectors which may be temporarily neglected include (108): a) the rear of the fire, or the portion on the windward or downhill side; b) sectors protected by a natural firebreack; c) sectors burning as ground fires as opposed to surface or crown fires; d) sectors where poor burning conditions are indicated by the irregular shape of the fire; e) sectors in green timber as opposed to those in old burns, slashings, or windfalls; f) sectors sheltered from the wind.

As a general rule the head of a fire should be attacked first. The head, indeed, is the most active and dangerous sector, and once it is stopped the flanks and the rear can be suppressed with relative ease. Sometimes, however, there is more than one head, in which case the several leads should also be attacked at once, if enough men are available; but, when the crew is not sufficient to attack all the leads simultaneously, the several leads should be cut off progressively hitting the side leads first (6). The type of fuel, the burning conditions, the number of men, and the kind of available equipment enable to determine whether or not the fire should be hit at the head. The general rule, however, is to hit the head first if it appears to be a chance of stopping it, since if the head can be controlled, the crew can then handle the rest of the fire and mop it up completely. Starting at the head, the crew may divide and work in opposite directions across the head, then down the two sides, and finally meet at the rear of the fire. "Most fires can be attacked right in front, although to inexperienced men it may seem impossible" (77).

If the head of a fire cannot be attacked directly with success, then the flanks on both sides of the head should be attacked, and the attempt made to work toward the head, gradually pinching it out. This is expecially the case: a) when the head of the fire is too hot to work; b) when the fire is advancing too rapidly; c) when a small crew has to work against a fire with a large head. Since, however, the spread will not be checked until the head is under control, an attempt should be made to work as close to the head as can be done with safety to the men.

When a fire on level ground with similar fuel on all sides and no wind spreads with approximately the same rapidity and intensity in all directions, the attack should start on the side toward which the wind may be expected to blow (108), or, on large fires, at the point first reached by the crew (121).

If one flank of the fire is parallel to a natural barrier, such as a lake, a stream, a road, or a fuel type in which the fire will not spread rapidly, a wet swamp for example, in this case only one flank would need to be protected, and the other flank along the firebreak would only have to be watched so that thefire will not get across. Other cases are likely to be encountered where good strategy will attack at some special point other than the head or the flanks toward the head. Where, for example, a valuable stand is threatened by the advance of one of the flanks, or when a portion of the perimeter advances toward an old burn in which the fire will gain strength, the attack should vary to fit the circumstances. Advantage should be taken of such natural features as lakes, streams, cliffs, wet swamps, etc., toward which the fire may be directed by properly selecting the point of attack.

Other considerations of importance in planning the attack may be summarized as follows (9, 121, 124): a) cut fires off from the most dangerous fuels; b) confine fires to one major area rather than to let them develop two heads; c) prevent fires from getting from lower-value to higher-value country; d) tie the fire line into something definite, leaving no loose end behind or openning through which the fire may slip; e) make the most effective use of the available mechanical equipment; f) be sure that the men are properly safeguarded; g) take advantage of the knowledge of fire behavior; h) utilize existing barriers to the fullest extent.

It must be remembered that these are only general rules, and that every fire is likely to be different. The primary consideration is to check the rate of spread as quickly as possible, and then to methodically and systematically suppress the whole fire. Aircraft is of great assistance in reconnoitering large fires, and autogiros, because of their capacity of hovering at low altitudes and their ability to land and take off in very restricted areas, are particularly valuable in planning the attack and directing the suppression work. Weather forecasts and the anticipation of their effect upon the burning conditions are also important in planning fire suppression.

STRENGTH OF ATTACK

As already referred to in connection with the dispatching section, the amount of man power needed to suppress a fire is dependent upon the fire danger, and varies with the time and the locality. The size of the crew should be ample enough for rapid progress and quick and effective control, but not so large as to entail unnecessary expenses. Enough men should be dispatched to cope with the situation as calculated from the report of the lookout man and other available information. The strength of the attack on a fire is also correlated with the existence of barriers and the probable direction of disastrous runs.

"The initial attack is usually conducted by one man, a few men or a small crew of seven to ten" (56). A small fire is easily put out by 1 to 5 men, whereas several hundred men may be required to suppress large fires (19). The size of the initial crew is generally predetermined by the fire plan of the forest protective unit. In western United States, a single fireman is usually dispatched for the initial attack, whereas in southern United States, where flash fuels and young coniferous stands are likely to produce crown fires quickly, between 6 and 10 men may compose the initial crew (56).

The appraisal of the size of the crew is largely a matter of individual judgment, and is widely dependent upon such factors as size of the fire, topography, ground cover, accessibility, value of the threatened timber, weather conditions, season of the year, distance, fire danger, and availability of man power and competent leadership. Appraising the forces needed is relatively simple when the fire danger is low or in easily accessible areas. Hawley (77) mentions that, in regions like Connecticut with excellent transportation systems and fairly fast fire spread, a crew unit of several men is ordinarily sent to every fire with the idea of controlling it quickly and getting back to headquarters. When man power is plentiful and transportation adequate, the hiring of a sufficient crew is not only the safest, but in the long run the cheapest method. The fire-suppression objective of controlling fires within the first work period also guides the dispatcher in deciding on the number of men necessary to handle a fire.

Follow up, or "the art of supporting the first man or men who go to a fire by sending additional man power to facilitate either suppression or mop-up work" (12), should be provided for at any time, and made available if and when necessary. No more follow up, however, should be sent to a fire than can be adequately supervised, equipped and subsisted. Most fires can be extinguished by the smokechasers, and no follow up is usually needed (6).

On large fires, particularly extra-period fires, follow up is necessary, and a method of determining the man power needed is almost essential. This is especially true under difficult conditions of fire suppression afforded by a heavy accumulation of highly inflammable fuels and a slow hour control. One region of the U. S. Forest Service (6) has developed such a method of appraising man-power requirements on the basis of the probable perimeter of the fire by noon following the first full work period after the arrival of the men at the fire, the number of men needed being indicated by the length of the line to be built divided by the amount that one man can build in the time available.

Another region of the U. S. Forest Service (9) has prepared dispatcher's guide charts for calculating the man-power needs. The method is based on the calculation of probabilities, and includes four steps, as follows: a) ascertain the danger class from the spread-danger meter; b) ascertain the rate-of-spread factor from Chart 1, by selecting the proper danger class and referring to the proper fuel-type class; c) ascertain the perimeter-increase factor from Chart 2, by selecting the hour of discovery, referring to the time objective and figuring the anticipated perimeter; d) ascertain the man-power needs from Chart 3, by figuring the number of smokechaser's hours of work to be done, selecting the number of hours of work, and referring to the number of hours of smokechaser's work, which gives the number of men required to do the job.

The California region of the U. S. Forest Service (121) also has elaborated a method of appraising the man power needed on large fires. Tables and charts were prepared indicating: a) the normal work rate per man-hour of line construction in different cover types; b) the percentage of efficiency or the line-construction output per work period; c) the man-power requirements for line holding per cover types; d) the number of men required for combined line-construction and line-holding work per cover types; e) the ratio of mechanical equipment to man power for line construction.

Hornby (85) has devised a system for determining the strength of the initial attack, the size of light reinforcements and the number of men dispatched as heavy reinforcements, in the Northern Rocky Mountain Region of the U. S. Forest Service, on the basis of the past fire history. Charts, tables and formulae were prepared, taking into account such factors as the fuel resistance to control, the rate of held-line construction, the rate of perimeter increase, and the travel time. On the basis of these considerations, Hornby suggests crews ranging from 2 to 5 men for the initial attack, 5 to 50 men for light reinforcements, and 100 or more men for heavy reinforcements. Hornby's analytical study of fires of the 10-year period of 1920-1930, indicates that 6 per cent of the fires required heavy reinforcements, 16 per cent needed light reinforcements, and 84 per cent could be handled by the initial crew.

Stephenson (130) has developed a man-power meter applicable to the U. S. Southern Coastal Plain, on the basis of Mississippi fire records. The number of men needed being determined by the perimeter of the fire divided by the rate of line construction per man, tables were computed to ascertain the man-power requirements, based upon the relationships between the fuel type, the wind velocity, the relative humidity, the time of the day, the hour control, the rate of

Fig. 2. Forest-fire fighting. (After a photo by the U. S. Civilian Conservation Corps).

spread, and the size of the fire.

METHODS OF ATTACK

The choice of the proper method of suppression is one of the highest tests of fire-fighting skill. This selection is largely dependent upon such factors as: a) the type of fire; b) the character of the fire; c) the expected changes in the burning conditions; d) the probable effectiveness of the various methods available; e) the topography and the presence of natural barriers; f) the amount of man power available; g) the weather conditions; h) the type of fuels, etc. A single method may not be found applicable on the whole suppression job of a fire, but proper methods may have to be resorted to in order to meet existing conditions on diverse sectors. Even the same sector may require different methods at various hours of the day. The diverse methods of fire suppression are based on the study of the fundamental laws of combustion. The application of water, chemicals, or dirt to the fuels reduces their supply of oxygen and prevent their being raised to the kindling temperatures, whereas by raking, by building a fire line, or by backfiring, the fire is robbed of new fuel.

Fire suppression practices may be classified in two classes, namely: a) methods of extinction, and b) methods of control. Theoretically, the extinction methods are those in which materials or practices are applied as a direct attack on all the portions of a fire as a way to put it out completely, whereas the control methods contemplate only the surrounding of the fire with a control line in an attempt to check its spread and make it absolutely safe.

A) Methods of Extinction

The term extinction is very widely used in fire suppression, but as a matter of facts only small fires are actually extinguished. To extinguish a fire requires that the work of putting out the fire be carried out over the whole burning area, that combustion be stopped on all the portions of the fire, and that every spark or ember be literally put out. Complete extinction is generally performed on fires covering only a few square feet of area (108), or less than one or two acres (14, 15). Thorough extinction may also be achieved on spot fires. But, such treatment is too time-consuming to be practicable on forest fires, except those of small size. Extinguishment of the outer edge of the fire is, however, put in practice on larger fires, especially in the so-called Direct method and in mop-up work.

There are four ways of extinguishing fires, namely: a) by means of water; b) by means of chemicals; c) with dirt; d) by beating out or raking. Combinations of these methods may be used on the same fire, and even in the same sector.

a) Use of Water

Foresters for some time did not employ water for fire suppression. "Absence of water supply within reasonable distance and non-existence of suitable water-throwing devices probably account for the early reluctance to use this great means of suppression. Today the story is quite different. Beginning in the early twenties, study, invention and experimentation made a good start. Year after year practically every means of water application was given a tryout in an effort to apply it to our peculiar needs and the process continues" (72). The use of water in fire suppression results in a very definite economic advantage in man power (60). Extensive use of water in fire fighting on a forest property is in relation with the natural water resources of the region and the development of the transportation system and the water equipment.

The application of water to the burning materials is one of the best methods of extinguishing a fire. When applied with hose lines under high pressure, it is the quickest and, in many cases, the only way of knocking down an extremely hot blaze, checking rapidly-running surface, brush, or low crown fires, extinguishing fire in standing snags, and putting out any hot ember. Water is used to great advantage in both direct suppression and mop-up work, and as a safety factor in the back-firing of regularly constructed lines. The back-pack can with a trombone-type pump is a most effective piece of water equipment. When using this device, it should be remembered that a relatively fine spray of water is much more effective in knocking down a blazing fire than a solid stream of water. Firemen applying water should always get as close to the fire as possible, and direct the water at the base of the fire. When mopping up a fire, a very small amount of water will go a long way if the nozzle is placed just as close to the burning embers as possible. Water is most economically applied to the burning materials by means of hand spray pumps, which conserve the water and permit its application at the exact spots and in the minimum quantities needed.

The application of water in forest-fire suppression was greatly facilitated by the use of portable power pumps capable of delivering large quantities of water through a half-mile or more of hose to elevations of 300 feet or more, and especially by their use in relays for raising water to 500 or 1000 feet (20). Gravity systems are also utilized to excellent advantage for carrying water from the water supply to the fire, by simply tapping streams at a point above the fire (20, 108). As a fact, with a head of 100 feet or more, gravity systems are preferable to a pump line, delivering a continuous flow without shut down or chance of failure. The Michigan Forest Fire Experiment Station (131, 132, 133) has demonstrated the practicability of quickly developing an abundant water supply where the water table is within 22 feet from the surface in a pervious soil layer, by sinking temporary wells by the hydraulic pressure secured from the ordinary portable power pumps used in fire fighting.

The use of water is particularly valuable for the following purposes: a) quieting or cooling down hot spots, so that men can work close to the fire and use either the Direct or the Two-foot methods where otherwise it would be necessary to rely upon the Parallel method; b) slowing down the rate of spread; c) extinguishing spot fires; d) disposing of spark-throwing snags; e) holding the fire line; f) mopping up the fire after completion of the fire line.

b) Use of Chemicals

The use of chemicals for extinguishing forest fires is still in the experimental stage. Tests have been carried for years on various chemical solutions or dusts, but the results as yet have not been enough satisfactory to advocate their widespread use. "The idea that chemistry has something to contribute to forest-fire control has always gripped the imagination. But from the first experiment in 1911 until the present time, nothing has been found which is definitely superior in practice to an equal weight of water, except the foam-producing combinations" (79). Fire foams are "the product of various chemicals which, when mixed with water, cause a great increase of volume by forming froth or bubbles, which may or may not be filled with noninflammable gas" (12). The bubbles adhere to the burning fuel and reduce the combustion by excluding the oxygen as well as by cooling down and moistening. Most fire foams are produced when a mixture of sodium bicarbonate and aluminum sulphate, plus a stabilizer or bubble former, are brought into contact with water. Godwin (71) mentions that "the volume of foam produced is about eight times the volume of water used", and that "a gallon of water mixed with a pound of foam is more fire suppressive than a gallon of water".

Barrett (32), studying the fire-extinguishing properties of the water-soluble salts of the alkali metals, found that potassium carbonate in solution is more effective than water alone in extinguishing fires in dense grass and weed cover, requiring less time and less spraying solution or water to obtain complete extinguishment. Davis and Benson (49) concluded from a series of tests on the effectiveness and practicability of various chemical compounds in forest-fire control, that certain combinations of dry materials added to water increase its fire extinguishing properties in the ratio of 25 to 1. They claim that the use of chemical compounds can and will be developed to the point where their efficiency "will preclude the possibility of major conflagations". The U. S. Forest Products Laboratory has conducted an investigation of the whole chemical field to determine "whether any chemicals, in addition to the foam producers, will have a value for fire fighting especially greater than that of an equal weight of water" (79). Truax (139, 140), reporting on the field tests conducted in connection with this investigation, claims that the extinguishing capacity of water can be increased materially by the addition of certain chemicals, "the increase depending upon both the kind of chemical and its concentration in the solution". He admits, however, that miraculous results with chemicals are not to be expected, and that where an abundant supply of water is available, chemicals are not considered to have any worth-while application. Godwin (72) suggests that, with further development of aircraft, the dropping foams, liquid chemicals, or dusts from airplanes may become an effective means of fire suppression in the future.

Stickel (136) concluded from his experiments with calcium chloride as a fire retardant, that the value of this chemical "is practically nil on actual fires". But, further studies by Mitchell (103) indicate that calcium chloride provided an effective fire retardant on going fires. Wright's (148) experiments on the use of chemicals in fire suppression show that a 20 per cent solution of ammonium in water was most effective as a fire retardant, and that calcium chloride was most efficient in serving as both fire retardent and fireguard. Godwin (71) mentions the pre-treatment of fuels with fire foams ahead of fires "to check the advance and permit line building", foams permeating and clinging, while water alone vaporizes.

c) <u>Use of Dirt</u>

On a large proportion of fires, dirt is the sole or the most important means of extinction. It is more readily available than water, and its use may means a saving of time in suppressing a fire. Clean, fresh, cool and damp sand or dirt, obtained by throwing aside the mat of needles and digging in the ground, is very effective in smothering a fire or slowing the rate of combustion by reducing the supply of oxygen, and in acting as an absobent for drawing out the heat and so lowering the temperature of the fuel below the kindling point. The real art in using dirt efficiently is to change it frequently, finally leaving the materials comoletely exposed, so that any lurking spot of fire can be easily detected. Dirt is best applied with a shovel, and can be employed with efficiency both for arresting the advancing edge of a surface fire, or for extinguishing burning materials within the fire. In applying earth or dirt, it should be thrown at the base of the fire with an energetic swinging motion, so as to scatter out the dirt in a thin layer over the burning embers or surface fuels, and to make the sand or dirt particles to penetrate the crevices and stick to the surface of the fuels.

For knocking down or temporarily checking a hot blaze, a few shovelfuls of fine, cool dirt are nearly as effective as a bucketful of water. Dirt free from undecomposed organic matter is particularly efficacious in estinguishing flash fuels, cooling down hot spots, putting out blazes in snags or crown fires in young growth, suppressing burning embers, etc.

But, fire extinguishment with sand or dirt is a rather slow and tedious procedure, which is most extensively used in mop-up work. The use of sand is, therefore, restricted to small fires, because of the difficulty of its application in large quantities. The Michigan Forest Fire Esperiment Station has recently developed a power-driven sand-throwing machine which may prove highly valuable in applying sand on surface fires in sandy soils.

d) Beating Out and Raking

Occasionally, grass, weed or light-brush fires can be entirely extinguished by whipping out with fir boughs or pine tops, wet gunny sacks or burlap sacks, brooms of all types, swatters, rakes, shovels, etc. The method consists in striking glancing blows, separating the materials, sweeping or pushing sparks and embers onto the fire, or raking the surface litter and cleaning the soil of inflammable material. In such fires, the fuel is so light that it can only hold the fire for a few seconds. The results obtained by this method are through smothering the flame and separating it from new fuel, cooling it down, breaking up embers into tiny particles, and sweeping in light litter (108). Embers broken up into tiny particles go out quickly and do not give off enough heat to ignite nearby materials. In many surface fires in the hardwood types, the fuels consist almost entirely of dead leaves, and complete control may be accomplished merely by raking a clean path through the leaves at the edge of the fire (8, 14, 15). Similarly, in fir types, when a scum of dry, loose needles on the top of the compact mat carries a light flare of fire ahead very rapidly, the advance of the fire may frequently be effectively checked merely by sweeping the loose needles with a fir or pine bough, or another tool. One advantage of this beating-out or raking method is that it can be applied with any available or improvised tool. It is best suited to fires which are feeding on a light surface litter, and cannot be used effectively in dense brush. Beating-out and raking methods are resorted to when water or dirt are not available or other appropriate tools are lacking. They are also used for extinguishing tiny spot fires established across the fire line, or for whipping out the flame and reducing the heat, so as to temporarily check the advance until a permanent line can be constructed (108). Beating out and raking are most extensively used in mop-up work, and in extinguishing flash fuels by stopping the supply of oxygen and preventing continued combustion, or by robbing the fire of new fuel.

B) Methods of Control

By control is meant "to surround a fire and any spot fires therefrom, with control lines and complete the backfiring of any unburned surface adjacent to the inner edge of the control lines" (12). On large fires, when complete extinguishment is not possible, the fire is controlled by holding it within constructed or natural barriers, the extinction work being carried on only over the outer edge of the burning zone, instead of over the whole area. The purpose is to establish a break in the forest fuel and thus rob the fire of new material. The center portion of the fire may remain ignited, but eventually dies out on exhaustion of the available fuels. "This may occur immediately after the edge of the fire is suppressed or it may require weeks, dependent upon the forest conditions and the weather" (77). Osborne (108) mentions that control methods are used when a fire covers more than ¼ acre or so, suppression being then at first confined to a narrow strip around its outer margin.

When fires are controlled in contrast to being extinguished, a control line is used to stop the fire. Roads, streams, lakes, bare rocks, wet swamps, etc. constitute natural or constructed barriers that should be used whenever possible, to hold the fire in check until it is completely mopped up. But, where natural or permanent firebreaks are not available, control lines must be constructed. Four principal classes of control-line methods are quite generally recognized with respect to the distance of the control line from the edge of the fire. The four methods defined by this standard control-line classification are known as: a) the Direct method; b) the Two-foot method; c) the Parallel method; d) the Indirect method. The Two-foot and the Parallel methods are modifications of either the Direct or the Indirect methods, and are not recognized as distinct methods of control by several organizations or authors (4, 5, 6, 7, 10, 56), but the Direct and the Indirect methods are well differentiated. Other methods of control-line construction are the Oblique, the Frontal, and the Point and Cut-off methods. There are other methods of less common usage, and combinations of the various above methods may be used on some fires to meet existing conditions in different sectors or at different hours of the day. The choice of a method of control-line construction is largely dependent upon (8, 9, 14, 15, 108): a) the conditions of the fire at the time of attack; b) the probable changes in the burning conditions as the day advances; c) the probable effectiveness of backfiring; d) the topography and the presence of permanent barriers; e) the menace from snags and crown fires; f) the relative amount of labor required and available.

a) <u>Direct Method</u>

The Direct method is "a method of suppression that applies work immediately at the edge of the fire" (12). As the name implies, it involves direct action on the fire itself. It consist in digging out every spark along the burning edge, which may be done by scraping in, shoveling in, or digging out and throwing onto the burning zone, and includes building a control line, beating out, cooling down or extinguishing with water or dirt, digging out and shoveling in burning material, cutting off and throwing in the burning ends of poles and logs, etc. The fire line coincides with the advancing edge of the fire. A shovel is generally the best tool to use with this method as all material must be thrown in (108). It is absolutely necessary to dig down to the mineral soil and to throw the burning material back onto the fire.

The advantages of the Direct method are (4, 6, 9, 108, 117): a) it takes advantage of the stretches which have gone out through lack of fuel or changes of burning conditions; b) it maintains the size of the fire to a mimimum and minimizes the chances of escape; c) it gives no opportunity to the fire to gain momentum and develop into major conflagations; d) it saves the time and expenses of backfiring; e) it eliminates the uncertain element involved in backfiring.

But, the Direct method also presents the following disadvantages (9, 108, 117): a) it is not applicable on intensely hot fires, as the heat and smoke make work impossible; b) it usually results in a more irregular and, therefore, longer fire line than with either the Parallel or the Indirect methods; c) there is a great danger that smoldering spots on the outer margin of the fire line may be overlooked, thus making patrol work more difficult; d) fire-line construction is more difficult to supervise; e) there is a real danger of firemen being injured by falling snags.

The Direct method can be used only on fires where the rate of spread is slow and the heat not too intense for the men to work on the burning edge. It is generally used whenever the fire can be caught in the smoldering stage, and it is especially recommended (2, 6, 8, 9, 14, 15, 19, 77, 108): a) on fires in light fuels, such as grass, leaves, or duff, where the heat is not too intense for working close to the flame; b) when considerable stretches of the fire are extinct, so that the digging out of a few smoldering spots would result in gaining advantage of long stretches of dead line (this condition often prevails in the early morning); c) where there is a danger for the fire to develop into a crown fire later in the day; d) on steep hillsides above the fire, so as not to let it gain momentum; e) wherever it would be particularly hard to control backfires on account of adverse winds, large head, or excessive amount of debris and snags; f) when a fire is burning against the wind; g) on surface and ground fires, as opposed to crown fires; h) whenever it is possible to use the method safely.

b) Two-Foot Method

The Two-foot method is "a method of suppression in which a fire line is constructed not over two feet from the edge of the fire" (12). The object is to leave just as little material as possible to smolder out. It contemplates no back-firing, and aims to leave a minimum strip of unburned material. It differs from the Direct method in that it leaves an edge of duff two feet wide to smolder out. The distance from the burning edge permits safer use of hand tools. A narrow trench from 12 to 14 inches is dug down to the mineral soil, not more than two feet ahead of the fire, the material being thrown onto the outer edge of the fire line, and the fire is allowed to burn out to the trench. The method is particularly useful if mattocks, grub hoes, adz hoes, rakes, or plows are the tools available for digging, since there is a danger of scattering the burning material with these tools if the actual edge of the fire is dug out (6, 77, 108). It is a substitute for the Direct method in those situations where there is a large amount of fuel at the edge of the fire, as in the case of deep duff or peat bog, and when there is a real danger of some unseen burning embers being left outside the fire line, if the Direct method were used. Special care should be given to removing small roots and pockets of rotted wood, since these are apt to carry smoldering fires across the fire line. There is no need to employ this method, which is a variation of the Direct method, if the edge of the fire can be extinguished without digging a trench. If the fire does not burn to the control line, it becomes necessary to shovel all intervening combustible material onto the burned area, or to dig out intervening smoldering spots, as in the Direct method.

The advantages of the Two-foot method are (4, 77, 108, 117): a) it allows the firemen to utilize pulling tools and to work away from the fire at the distance that they can reach with their tools, thus permitting to avoid excessive heat and to build the fire line much faster than shoveling close to the fire edge; b) it simplifies supervision, eliminates the danger of overlooking burning spots on the outer edge of the line, and facilitates the patrol work; c) it insures more safety and comfort to the men; d) it permits the crew to switch instantly to the Direct method whenever the edge is extinct or to work around trees and avoid rocks and other resistances to line construction; e) in digging the edge of a smoldering fire, burning portions may possibly be overlooked, which is not likely to happen if the fire line is dug a little ahead of the fire; f) it allows a straightening of the fire line where irregularities occur in the edge of the fire.

The following disadvantages are, however, characteristic of the Two-foot method (9, 108): a) it fails to immediately rob the fire of new fuel, leaving a strip of duff which may hold the fire and endanger the control; b) the increased duration of the patrol and increased amount of mop-up work often results in more work than the Direct method would have involved; c) there is the danger of the fire line giving a false sense of security to over-confident firemen; d) there is the danger that the men may throw some embers outside the fire line.

The Two-foot method is particularly advisable in sectors where the fire is smoldering in heavy duff. It is also used when the edge of the fire cannot be dug out with hoes or mattocks, or when backfiring is difficult or impossible.

c) Parallel Method

The Parallel method is "the method used in suppression when a continuous fire line is constructed parallel to, but withind 100 feet from the edge of the fire, and the intervening strip is immediately burned out" (12). The object is to keep just far enough away from the fire to enable men to work most efficiently. A fire line 5- to 10-foot wide is constructed roughly parallel to the fire edge and at any distance from the fire edge within a radius of 100 feet, and the inflammable material between the advancing fire and the newly constructed fire line is burned out at once. There are, however, some disagreements as to the distance between the control line and the edge of the fire: some authors mention 100 feet (12, 19, 56), whereas others specify 50 feet (2, 8, 9, 14, 15, 108, 117), or even 30 feet (77).

The basic principles are to stay relatively close to the edge of the fire to allow latitude for dropping back far enough to avoid intense heat and smoke, and to cut across deep fingers of the fire edge, thus decreasing the length of the line to be constructed. The Parallel method enable one to work somewhat away from the heat and smoke, and yet to construct a fire line close enough, so that the area intervening between the fire and the control line can be quickly burned out.

The Parallel method differs from the Direct method and the Two-foot method in that a continuous fire line is built and interior burning is done, and from the Indirect method in that the fire line is constructed close to the fire regardless of the topography and the presence of natural or permanent barriers.

The advantages of the Parallel method, as compared to the Direct and Two-foot methods, include (4, 77, 108, 117): a) it can be used with hot fires and allows the men to work out of the zone of intense heat; b) it simplifies the supervision, eliminates the danger of overlooking burning spots outside the fire line, and facilitates the patrol work; c) it allows the use of plows, scrapers, hoes, Pulaski tools, mattocks, etc., and permits cutting across indentations and encompassing logs, thus facilitating and accelerating the construction of the fire line; d) the control line may embrace several scattered spot fires.

In comparison with the Indirect method, the Parallel method presents the following advantages (9, 108): a) the burning out of the intervening strip is easier than the backfiring involved in the Indirect method; b) the firemen can easily change to the Direct or the Two-foot methods if the fire dies down; c) the burned area is held to a smaller acreage.

But, the Parallel method also presents the following disadvantages (9, 108, 117): a) it fails to take advantage of the portions of the fire edge which may have gone out, and calls for the re-establishment of a complete fire edge; b) it is subject to the danger that the firemen fail in trying to burn out the intervening strip between the control line and the edge of the fire, or that the burning gets beyond control or develops into a crown fire; c) it delays the issue of the fire, thus involving more labor and expenses.

The use of the Parallel method is advisable when the heat of the fire prevents the use of the Direct or the Two-foot methods, but when the heat is not so excessive as to necessitate the use of the Indirect method. It is particularly recommended (2, 6, 8, 9, 14, 15, 19, 77, 108): a) on fast-running surface fires; b) on the flanks of crown fires, or on weak crown fires that quiet down at night; c) when using plows and tractors; d) on sectors where the litter is such as it can be ignited easily and is likely to burn out without special danger; e) on sectors where the control line can be shortened by making cut-offs; f) on steep slopes below the fire. The Parallel method is best for holding a fire down to a small size, but should not be depended on in a heavy wind or with large fires. It should also never be used when there is any danger of inability to burn out the intervening strip and making the fire burn clean to the edge of the control line.

d) Indirect Method

The Indirect method, also referred to as the Backfiring method, is the one in which "the control line is located along favorable breaks in topography or natural firebreaks, and the intervening strip is backfired" (12). By implication, any control line more than 100 feet from the edge of the fire represents an application of the Indirect method, even if the line is not located along a break in the topography (12). In this method, the fire fighters drop back from the advancing fire to a firebreak or to some good natural control line or fire line built as a part of the suppression work, where they set backfires which are allowed to run toward the main fire. It consists, therefore, in completing a continuous control line quite a distance in advance of the fire, taking advantage of permanent firebreaks, such as roads, streams, lakes, open ridge tops, etc., and then backfiring as soon as it is safe to do so. Backfires are usually not set until the line across the entire edge of the fire is completed.

Extremely good judgment and an unusual amount of skill are required in setting backfires in such a way that they will not get out of control. This method should not be used unless the control line can be completed and backfired in the early morning, before the heat of the day. The purpose of the Indirect method is to starve the main fire, by burning out a wide strip of area ahead of the fire. Backfires are, however, risky because they may get across the control line and develop into uncontrolled fires. The method is, therefore, an emergency one, and should not be employed if any of the other methods described can be successfully applied. Even running crown fires frequently come to the ground, and nearly always do at night, and can then be fought by the other methods.

Success in using this method is largely dependent upon taking advantage of the indraft of the main fire, or of slopes, changes in wind direction, etc., to carry the backfire in against the advancing edge of the fire. The backfires should be set close to the control line, so that the fire will have no opportunity to gain momentum in running toward the fire line. If a fire is running uphill, the backfire should be set just over the highest ridge and allowed to spread toward the main fire. The setting of backfires on slopes above an advancing fire should be avoided. The two most important points in the application of the Indirect method are: a) when the backfire first blazes up along the fire line; b) when the backfire meets the main fire. Firemen must be on the watch at these times for break-overs or spot fires. It is also recommended that the fire line be constructed as close as practicable to the main fire, and that the backfires be set from three to six feet inside the control line, rather than directly at the edge of the fire line.

The Indirect method differs from the Parallel method by the width of the intervening strip between the control line and the edge of the fire, and by the fact that the backfiring is not generally started before the line is completed across the entire edge of the fire. The advantages of the Indirect method are (9, 108, 117): a) it permits taking advantage of favorable breaks in topography and natural or constructed firebreaks; b) firemen are not troubled by excessive heat or smoke from the main fire, resulting in a much faster line-construction work; c) it often calls for a much shorter control line, thus speeding the construction of the control line; d) it allows one to select more open country for easier and faster line construction; e) it procures more safety to the men.

But, the following disadvantages are also encountered with the Indirect method (9, 108, 117): a) it fails to take advantage of the portions of the fire edge which may have gone out, and calls for the re-establishment of a new fire edge; b) it is subject to the danger that the backfires cannot be made to burn after the completion of the control line; c) there is also the danger that the backfires fail to starve the main fire, and cause disastrous conflagations by adding its heat and momentum to that of the main fire; d) it involves the burning out of a wide strip of area ahead of the main fire; e) it sometimes throws too much confidence upon the judgment, strategy and skill of tacticians.

As already mentioned, the Indirect method is a last resort when the use of the other methods has proved a failure or would be futile. Being an emergency method it should seldom be necessary. The conditions which warrant the use of the Indirect method are produced by extreme fuel dryness and high wind velocities, which have caused the fires to crown, or may cause them to crown at any time, or which make it possible for the fires to generate such a terrific heat that the use of other methods is humanly impossible or would jeopardize the lives of the men working on the fires. Cases when this method could be advantageously utilized include (2, 6, 9, 10, 14, 15, 108): a) on hot, fast-spreading fires requiring attack at a distance to provide the necessary workable conditions and time to set a control line around the fire; b) when very low humidities, exceedingly dry and combustible fuels, high winds, precipitous slopes result in running crown fires; c) when fires are travelling fast in old slashings or windfalls, where control-line construction is a very slow process; d) when spot fires are so numerous and increase in size so rapidly that the only practical method of control is to fall back for a safe distance as to include the spot fires with the main fire, construct a control line, and then back fire the whole area; e) when natural or constructed firebreaks are available close to the edge of the fire; f) when control lines can be completed in a relatively short time, and conditions are especially favorable for backfiring; g) when fires have to be fought in rocky areas or on steep hillsides.

e) Other Control Methods

The other methods of control are modifications of the

Indirect method, in which the location of the control line is adapted to fit special conditions encountered on different fires (7, 10). They all provide, as in the Indirect method, for the construction of a fire line at critical points and the backfiring of the intervening strip between this control line and the main fire.

The Oblique method is used when a good-sized fire is advancing with a fairly uniform front, thus presenting no district points or tongues which may be attacked separately. Under such circumstances it would be decidedly dangerous if the main fire would strike all points of the fire line or the backfire at the same time. Using an oblique control line, the main fire comes up to the fire line or meets the backfire successively at different points instead of simultaneously over the whole head of the fire, and is more easily handled. Otherwise, there would be the danger that the simultaneous meeting of the wide head of the fire with the whole backfire may develop a tremendous heat resulting in whirling drafts, and set spot fires across the control line.

The Frontal method is a square-front method involving the construction of a fire line square across the head of the fire, at right angle with the direction of the spread, and eventually surrounding the whole fire. It is particularly useful in the case of long, narrow fires with no pronounced points or fingers.

The Point and Cut-Off method is used on irregularlyshaped fires with several advancing points or fingers. Fire lines are built in front of each point to cut off these fingers. The scheme is to emphasize the concentration of the attack at the most critical points, with provision for later line construction to cut off the flanks.

CONTROL-LINE SPECIFICATIONS

Success in controlling fires is largely dependent upon the location, size and other characteristics of the fire line. Line location, one of the most important considerations in controlling fires, was already referred to in describing the various methods of control-line construction with reference to the distance of the fire line from the edge of the fire. The designation of the most advantageous location is an art requiring nice judgment on the part of the fire boss in considering the values at stake, the method of attack, The rapidity of construction, the presence of barriers, etc. (7). Important points to keep in mind in connection with line location include (6, 7, 9, 10, 77, 108, 117, 121, 124): a) stay as close to the fire as heat permits; b) avoid areas of dense underbrush and heavy fuels where fire-line construction is a slow and costly process, and where control lines are hard to hold; c) run lines around stumps, logs, snags, etc., which are hard to remove and may be a source of danger; d) make no sharp angles in the fire line; e) avoid extreme slopes, lines on level ground being far easier to hold than those on slopes;

f) avoid lines running straight up and down a hill; g) avoid hillsides where rolling cones and burs are a source of danger; h) catch fires on the downhill side of slopes, and do not let them cross the bottom of a hill and get a start on the uphill opposite slope; i) before dropping back to a natural firebreak, be sure that there is no chance of constructing a safe control line nearer the fire; j) be sure that the line is sufficiently away from the fire to allow enough time to construct the line and backfire before the main fire comes in; k) the lee side of a ridge is preferable to the windward side; l) take advantage of all available features; m) make the most efficient use of all available machinery; n) locate the fire line so that rolling embers cannot cross; o) make fires lines as short as possible and as free as practicable from tortuous windings; p) take advantage of all dead sectors on the fire edge; q) give an uphill start to the backfires; r) eliminate high-hazard types where possible; s) locate fires lines far enough to enclose falling snags and catch sparks; t) select the most open locations; u) provide for safety to the men; v) encircle areas where spot fires are so numerous as to make impracticable to handle them as individual fires.

The width of the fire line has a direct bearing upon both its effectiveness in controlling fires and the ease, rapidity and cost of its construction. Since the object is to get the most efficient line in the shortest time and at the least cost, the size of the control line should be as small as contingent with the conditions to be encountered and the values at stake. The width of the control line varies with (7, 10, 117): a) the type of fuel and cover; b) the wind velocity; c) the character of the slopes; d) the condition of the fuels; e) the actual and expected burning conditions. As a general rule, the tendency is to build strips 6 to 12 feet wide with bare soil over practically the entire width (77). One region of the U. S. Forest Service (9) has published a table of specifications for line construction, in which it is shown that, for different fuel types, the total width of the fire line may vary from 1 to 8 feet, and that the width of the area cleaned to mineral soil ranges from ½ to 2 feet. Another region of the U. S. Forest Service (124) has also published a table indicating, for different fuel types, the total width to be cleared, which ranges from 1 to 60 feet, and the width to be cleaned to the mineral soil, which varies from 1 to 10 feet. Most control lines involve the clearing of a strip of from a few feet up to 15 or 20 feet through the fuels, the digging of a narrow trench through the duff, humus and other vegetable matter, down to the mineral soil, and the removal of any such threat as snags inside the fire line, which may fall across the line (19).

Other considerations of importance in connection with line construction include (6, 8, 9, 14, 15, 117, 124): a) clean all lines to mineral soil for all or a part of the width; b) dispose of the material so as to facilitate backfiring and not to interfere with the mopping up; c) protect undercut lines against rolling embers; d) scrape or throw all burning or charred fuel into the line; e) the effectiveness of a given width of line can be increased by using dirt or water to cool down adjacent fire and cover fuels on the outside of the control line; f) use temporary lines to slow down the fire when additional time is needed for the construction of the main control line; g) as little fuel as possible should be left inside the fire line; h) the debris removed in digging the fire line may be thrown either inside or outside the line, depending on whether it will be useful in the burning-out process or will form a menace by smoldering or throwing sparks; i) the fire line cannot be considered safe until it has been burned out clean to the edge of the fire.

MAN-POWER ORGANIZATION

Man power plays an important role in fire suppression, so that the planning of man-power organization has a direct bearing upon the outcome of a fire. The objective in line construction is to accomplish as much effective work as possible per man-hour. The size of the crew and the placement of the men on the fire line has much to do with the output of efficient work.

The size of the suppression crew has already been discussed in connection with the dispatching action and the strength of attack. As in any other production management, fire-control planning requires the highest possible output per man per hour. This point of highest production leads to the most rapid and economical standard of line construction. For each different fire there is a size of crew which shows the most efficient suppression work. This optimum size of crew and its highest output vary primarily with the resistance to line construction, or "the relative difficulty of constructing control line as determined by the character and density of fuels, soil conditions, and topography" (12). The rate of line construction may be expressed in chains of held line per man-hour, or in men-hours per chain of held line. Hornby's (85) study of fire-control planning indicates a range of from 0.2 to 10.8 man-hours per chain of held line. One region of the U. S. Forest Service (9) has published a table indicating the rate of output per number of men, which shows that the output decreases as the number of men increases. The same findings were reported by Matthews (94) and Hanson and Abell (76), who also indicate that the output per man-hour decreases as the size of the crew increases. The latter authors (76) show that a 5- to 6-man crew was most efficient on northern California fires from 1925 to 1937 in extreme dry periods, and that crews of from 3 to 4 men made up the most efficient size for period of lower inflammability.

Experience also reveals that, on normal fire-suppression work, one crew leader cannot give effective supervision to more than 8 to 10 firemen performing a single function, and that crews of from 25 to 30 men under the supervision of a crew boss, and subdivided into three smaller crews under the direction of straw bosses, make very efficient man-power units (8, 14). Likewise, the perimeter of large fires is very often divided by topographical features or fuel types into several sectors, which can be most efficiently managed and supervised as more or less independent units by a sector boss in charge of from 2 to 5 crews totalizing between 50 and 125 firemen (8, 14). Sector bosses are supervised by division bosses having charge of two or more sectors, whereas the fire boss, also referred to as the foreman, is in charge of and responsible for all the operations or activities of the suppression work. The size of crews should not be larger than the boss can supervise adequately.

Such an organization of large crews into small units may have a very worth-while effect in decreasing the non-productive time due to waiting, resting, loafing, and other inefficiencies that tend to increase as the size of the crew increases and supervision is spread thinner and thinner. Several methods of organizing large crews according to special patterns were devised as a way to maintain fire-fighting efficiency to a maximum. They include: a) the Sector method; b) the Squad method; c) the Functional-crew-unit method; d) the Specialized-group method; e) the Individual-assignment method; f) the One-lick method; g) the Variable-lick method; h) the Man-passing-man method; i) the 10- to 15-foot method; j) the Progressive method; k) the Progressive-set-up method; l) the Austin-rotary method; m) the Torch-and-flapper method.

A) Sector Method

The Sector method (77) is the method in which the man power engaged for line construction on large fires is divided into small crews, a short sector being assigned to each. Each unit works under the direction of a straw boss who is himself supervised by the crew boss or the fire boss. When a crew unit has finished its allotment, it steps forward past the rest of the men, and starts another sector.

B) Squad Method

The Squad method is a refinement of the Sector method in which "the men are usually split into groups according to the tools they have, and work at the edge of the fire wherever work is most needed" (4). This method has probably evolved from the time when a crew was assembled with little or no organization or overhead, for combating fires. When a piece of line is completed, the firemen move ahead to another location that appears to need attention.

According to Schroeder (117), this is probably the most common system, allowing for very definite supervision and being very flexible. Each man usually has at least two tools, one for digging and one for cutting, using any of them as the necessity arises. A squad usually consists of from 6 to 10 men under the direction of a straw boss. From 4 to 10 squads may form a crew under the supervision of a crew boss, who may also be the fire boss. Attempts have been made to systematize this method with varying degrees of success.

One advantage of this method is that there is little chance of the fire cutting across between the men and splitting the crew (4). Other advantages of this method include (117): a) the squad leader has such a direct supervision over his small crew that he is able to direct his men efficiently; b) the constant association of the squad members add to their efficiency; c) squad units may be organized beforehand and function as a regular fire-fighting organization; d) the method allows for the relief of individual units and their replacement without disruption of the supervision work.

But, the Squad method presents very serious disadvantages (4, 117): a) it is one of the slowest methods of line construction; b) a great deal of work is entailed in packing extra tools and discarding one tool for another; c) men are continually in each other's way, resulting in a general confusion; d) there is nothing to force the men to exert themselves beyond their ordinary rate of work.

C) Functional-Crew-Unit Method

The Functional-crew-unit method (9) is another application of the Sector method, based on the old crew-unit scheme, by which each crew has but one function to perform. It is the most common method used in the Northern region of the U. S. forest Service. The first crew carries axes or Pulaski tools, and clears the line of the smaller fuels sufficiently to permit trench construction; the next crew is the digging unit, using Pulaski tools, hoes or shovels, and building the trench; next comes the clean-up crew, burning out lines with torches or felling snags and cutting the punky logs from across the line with saws, and the patrol and mopping-up crews with shovels or back-pack pumps. The ratio of men in the various units has to be adjusted to meet the character of line-construction work.

Best use of this method is made where the resistance to line construction is extreme, and where the amount of work involved is so considerable as to permit functionalizing each crew unit without loss of time or energy. The advantages of the method may be summarized as follows: a) each member of the functional crew units is under the constant supervision of his straw boss; b) it permits assigning each man to the tool with which he is most skilled; c) it limits the number of tools to but one per man; d) it makes an entire organized-crew unit available for action on hot spots or break-overs; e) it promotes competition between the units, in that each one tries to keep ahead of the others.

The Functional-crew-unit method also presents disadvantages: a) men are bunched up, and lose much time in crawling around each other when one moves up to a new section of the line; b) greater chance for accidents results from the crowding of men on the fire line; c) constant shifting of men from one functional crew unit to another is necessary as fuel types change; d) it lacks flexibility for pulling out crews for spot fires, etc., the entire unit having to be reorganized each time; e) there is the danger that the fire may get across when one crew unit gets too far ahead of the next unit; f) working in group makes it hard to measure the output of held line construction per individual.

D) Specialized-Group Method

The Specialized-group method (117) is a method of managing man power on line-constructio work, by placing all firemen in their respective class of labor for which they are most proficient. It is also a modification of the Sector method, in which an attempt is made to take advantage of special ability in handling tools, by allowing the firemen to use the tool with which they are most familiar, and by grouping together in special units all men most skilful in handling any particular tool. There may be as many groups as needed for performing such functions as felling timber, bucking logs, clearing the way, digging the trench, polishing up and regularizing the fire line, etc. The number of men in each group varies according to the difficulty of the particular assignment. Each unit is under the direction of a leader, who is answerable to the crew boss or the fire boss.

The advantages of the Specialized-group method include: a) the total work done may be increased by allowing each man to do the work for which he is best fitted; b) firemen are stimulated in their work by their pride of their ability; c) the method eliminates the confusion which results from crowding a whole crew in the same sector.

Disadvantages are also encountered: a) the difficulty of adapting the men to a change in routine after they have been maintained at a particular job for which they were most fitted; b) the difficulty of reorganizing the groups along different lines, to take over other duties which may need to be performed.

E) Individual-Assignment Method

The Individual-assignment method, also referred to as the Station method (4), is a system of man-power organization in which "men are assigned individually to designated lengths of fire edge, the task of each man being to hot spot the fire as needed, construct control line, and procees with backfiring and mop up" (12). This method was developed for use in lighter-type fuels or on slow-spreading fires (9). The underlying principle is the assignment, to each individual man, of a specific piece of line, the limits of which are definitely determined. Other men are appointed as sawyers, as in the Squad method, or for such special jobs as scouting for spot fires or hot spotting ahead of the control line. The objective of the method is to obtain maximum output of held-line construction through "the emotional stimulus from a sense of individual responsibility for a specified piece of line and for measurable accomplishment in control-line construction" (12). The men are assembled at the beginning of the control line and shown the type of line-construction work to be done. Each man is assigned a definite strip, the length of which varies according to the size of both the fire and the crew. Each man is provided with a shovel, a mattock, an axe or a Pulaski tool. When a man has completed his section of line, he may either proceed with backfiring or mop-up work, or help his neighbors on line-construction work. After completion of the line portion assigned to a crew, the main crew is moved ahead to a new sector, leaving just a few men for backfiring and mopping up. In order to place individual responsibility on each man, the same length of line will be assigned to every one, thus preventing the men from interfering with each other, and stimulating effort and pride of accomplishment. The Individual-assignment method is especially suited to the Direct method of attack, but it is also practicable on any other method of control.

The chief advantages of this method are (4, 9): a) it takes advantage of one's pride of accomplishment, by placing responsability on each individual for output; b) it permits the simultaneous attack on a larger portion of the fire edge than any other known method; c) men are not in each other's way, and much confusion and waste of time is eliminated in moving men forward to a new sector; d) it decreases the chances of injury by spacing the men.

But, it also presents the following disadvantages (4, 9): a) it requires the individual training of each crew member in all phases of line construction and holding; b) most members of the crew are a part of the time out of the sight of their boss; c) it scatters man power to the extent that temporary concentration of forces to strike a hot spot is difficult, and that there is a possibility of the fire cutting across between the individuals; d) the men being scattered, more tools are needed to provide them with the necessary equipment; e) it does not provide an avenue of escape as a safety factor for the men.

F) One-Lick Method

The One-lick method, also referred to as the Progressive method, is a system of man-power organization in which "an entire crew of line-construction men moves forward without changing their relative positions in line" (12). It was devised for typical brush fires, but variations and adaptations have been applied in various locations and fuel types. This method is directly the opposite in principle to the Individual-assignment method, no fireman being responsible for any one piece of line. The crew is lined up and moves forward, each man contributing a part to the finished line as he goes (4). The whole crew moves forward progressively, leaving a finished fire line in its wake. No single member of the crew does a complete job of fire-line construction, but each member performs a single operation and moves on quickly, leaving the next man behind to perform another strip in the process, and so on until the last man in the crew has performed the last act necessary to complete that portion of the line (8). There is no stop in the forward motion. The leader merely marks the line of progress; the succeeding men with saws or axes open up the line and clean it out, no man stopping in an attempt to complete an operation, but contributing only as much as he can without holding up the crew (4). The method requires that the leader be very proficient in laying out the line, and very energetic in speeding the work. As men move forward, they do one lick of the work, then advance one or more steps, the number of steps being controlled primarily by the number of men and the consequent proper spacing of licks in order that the control line may be completed when the last man has passed over it (12).

The One-lick method is merely an adaptation of mass-production industrial methods to the fire-suppression job. "The principle is that a fire line should be built about as fast as a man can advance through thick brush, occasionally hacking off limbs in his way, and should be improved a little by each succeeding man" (77). The emotional stimulus which comes from rhythm, continuous forward movement, and feeling of great accomplishment, largely contributes to obtain maximum output of line-construction work.

The kind of tools needed, the spacing of men, and the rapidity of the forward motion depend on the number of men in the crew, the fuel type, etc., whereas the kind of tool assign-

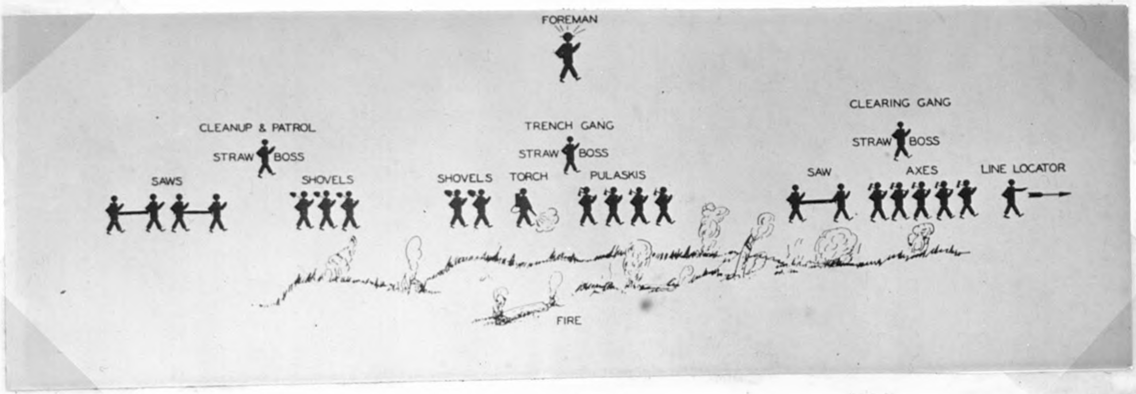

Fig. 9. Functional-crew-unit method of man-power organization. (After a diagram by the U. S. Forest Service).

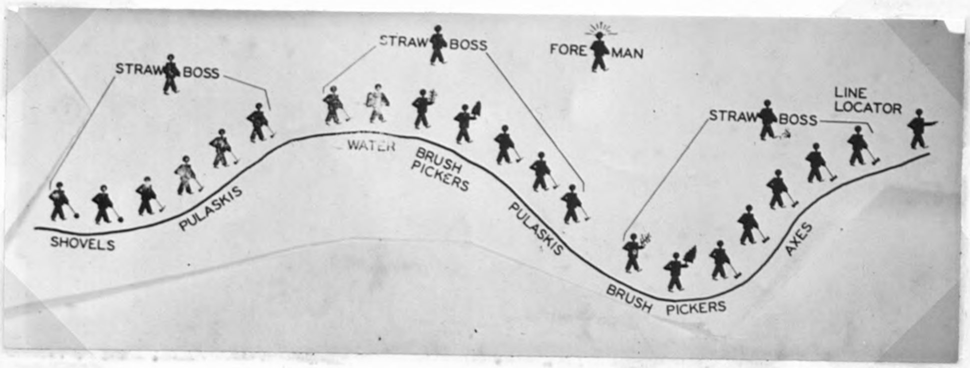

Fig. 10. One-lick method of man-power organization. (After a diagram by the U. S. Forest Service).

ed to the members of the crew depends on their relative position in the line, the axes coming first, followed by the hoes, then the snag-fellers, the shovels, the torches, etc. One region of the U. S. Forest Service (9) describes the One-lick method as made up of standard 25-man crews, including one crew boss, three straw bosses and twenty-one firemen distributed into three units and equipped as follows for medium-fuel type: a) first unit: 5 axes and 2 Pulaski tools; b) second unit: 1 water bag, 4 Pulaski tools, (and 2 brush throwers without equipment); c) third unit: 2 saws, 1 axe and 2 shovels. The principles involved can be applied to any size of crew from 5 to 100 men. Important features in connection with the use of this method include (4) the class of labor available and the selection of the right tools for the job at hand. Provision has to be done for burning out, backfiring, patrolling and mopping up.

McReynolds (97) and Campbell (39) report a significant increase of almost 200 per cent in the amount of fire line built per man-hour under the One-lick method as contrasted to the Sector method or other conventional methods. The advantages of the method may be summarized as follows (39, 97, 117): a) a decided increase in speed of line construction per man-hour; b) a noticeable decrease in the amount of time used in shifting men; c) a reduction in the number of accidents caused by tools, due to the elimination of the crew members passing each other while working; d) there is no opportunity for the members of the crew to feel that they yield more than they receive, and to lean or sit down, every one being lined up and compelled to keep up with the rest of the crew; f) individual training of the crew members is not so important as with the Individual-assignment method.

The disadvantages of the method include (4, 31, 97, 117): a) crews must be trained more thoroughly than for some other method, although reports (106) indicate that the method was used to advantage with untrained civilian fire fighters; b) it is difficult to keep the men moving and working at the same time; c) it is hard on the men. But, the latter difficulty could be obviated by working in shorter shifts. Indeed, it is believed that 4-hour work is the maximum a crew can efficiently produce by this method (31, 39, 117).

G) Variable-Lick Method

The Variable-lick method (96) is another progressive method of managing men through regimentation to obtain maximum output of control line per man engaged. Its essential features are described as follows: a) the entire crew of firemen moves forward along the fire line without changing the relative position of the men in the line; b) a fixed percentage of the available man power is assigned to a particular job and is equipped for that purpose; c) the spacing of men within each unit is a variable which must be kept above a minimum as a safety measure and below a maximum for the sake of efficiency; d) the clearing crew of exmen works as individuals in a progressive line, but not by the Individual-assignment method, under the direction of a straw boss; e) a Puleski-tool crew directed by a straw boss acts as an emergency unit which functions in both clearing and digging as the need arises; f) the digging crew of hazel-hoe men headed by a straw boss works as a unit, step by step, blow by blow, regimented by a count spoken aloud which results in a step forward or a digging blow performed simultaneously by all the members of the crew.

Field tests show that the method can be used efficiently with crews ranging from 8 to 48 men. Every man of a crew is a worker contributing his bit to the finished job. Provisions must be made for bucking out, burning out, backfiring, patrolling, holding and mopping up after completion of the control line. The variable-lick method is not applicable to the Direct method of attack, but may well be applied with the Two-foot, Parallel and Indirect methods of control.

The Variable-lick method presents the following advantages: a) the maximum output in the minimum time and with the least effort is obtained from the digging crew by using the counting system; b) the stimulus and thrill produced by the feeling of great accomplishment resulting from cooperative effort builds up a high morale and zest for the obstacles ahead; c) the accident rate per man engaged is maintained to a minimum by the rigid spacing.

The disadvantages of this method are: a) since it is a highly technical method, it cannot be successfully used by inexperienced fire bosses; b) certain people adapt themselves rather poorly to this method, feeling that their production is above the rate of pay received; c) inexperienced crews soon become leg and tool weary (which can be obviated by shortening the shift duration); d) the method may affect seriously the physical condition of crew members.

H) Man-Passing-Man Method

The Man-passing-man method (12) is a system of managing man power on a fire, in which "after completing a stretch of clearing or fire-line-construction work, a man passes by other men in moving to his next task". As compared with the Individual-assignment and One-lick methods, the Man-passing-man method provides, in certain infrequent but important situations, a better chance for a fast retreat, and must, therefore, be used as a safety measure.

This method is not designed with any particular reference to the emotional response by the members of the crew, or to the speed of line construction. It can be used with less advanced planning and training than in the case of the Individual-assignment and One-lick methods, and under certain conditions it must be resorted to in clearing with the One-lick method.

I) 10- to 15-foot Method

The 10- to 15-foot method (86) was devised for managing large crews of fire fighters for fire-line construction in tangled heavy fuels. It differs only slightly from the One-lick method. It was developed to cope with the extremely heavy fuels encountered in a blowdown area. The presence of tangled heavy fuels made it necessary for the men to work in place and take several licks rather than just one, and then to step ahead as in the One-lick method. To regulate the forward speed of the crew, the men were instructed to work continuously as they proceeded taking as many licks as possible, but never getting closer or farther than from 10 to 15 feet to or from the next man. A space of at least 5 feet was thus provided for each man to work intensively whenever a hold-up prevented forward progress.

Crews averaged 135 men, but varied from 90 to 175 men. Varying the size of the crews did not materially affect the production per man-hour. The largest crews were approximately constituted as follows: a) 1 fire boss and 1 assistant; b) 1 head scout and 3 assistants; c) 1 clearing-crew boss, 1 assistant, 4 straw bosses and 40 firemen divided into 4 sections; d) 1 digging-crew boss, 1 assistant, 5 straw bosses and 50 men distributed into 5 units; e) 1 patrol-and mop-up-crew boss, 1 assistant, 3 straw bosses and 30 men divided into 3 groups; f) 1 communication boss and 5 men; g) 12 water boys; h) 14 time-keepers, clerks, packers, etc.; i) total: 175 men. The three crews (clearing, digging and patrol and mop-up) worked individually, the clearing crew, for example, advancing as fast as it could and not waiting for the digging crew to keep place. The members of the patrol and mop-up crew served as diggers until each man was assigned to his 3-chain patrol and mop-up beat. The men once on the fire line were spread over a distance varying from 1,200 to 1,800 feet.

Hulett (86) reports that the average time worked on the line varied from 4 hours and a half to 5 hours and two thirds, and that under normal conditions from one third to one half of a chain of line per man-hour, in extremely heavy-fuel type, can be cleared and dug for each hour the crews are actually on the job.

J) Progressive Method

The Progressive method (40, 118) of line construction is another variation of the One-lick method. Besides taking advantage of the merits of the One-lick method with reference to the elimination of the time lost by men passing each other in the line, and the enthusiasm and unity of effort resulting from the rapid progress. The Progressive method is claimed to be "superior to the One-lick method in that men do more effective work by taking a stance and completing a unit of work, and each man can be held accountable for a given segment of line" (40). Each man is assigned to a job according to his aptitude and training. The system was experienced on a 40-man crew organized as follows (40): a) 1 scout; b) 1 line locator; c) 1 clearing-squad straw boss and 8 axmen; d) 1 digging- and clearing-squad straw boss and 10 Pulaski-tool men; e) 1 digging-squad straw boss and 10 hoe men; f) 1 backfiring- and line-holding-squad straw boss and 3 shovel men; g) 2 saw men, for felling and bucking; h) 1 water man. The crew leader controlled the movement of the squads in such a way as to effect the highest rate of held-line construction. Each man of the crew was given a number, which he kept throughout the season. The crew occasionally was split into two units, even-numbered men going one way and odd-numbered men another way. This resulted in a saving of time devoted to walking, and in allowing the crew to start the line at the head of the fire, and to proceed on both sides of the head toward the rear. The disadvantage, however, was the difficulty of giving adequate supervision. Each man is given a segment of line of about 15 feet, and, if one member of the crew completes his section before the men ahead of him, he and the others move up one segment, there being no passing in the line (118).

Cliff and Anderson (40) report an average rate of held-line construction of 1.04 chains per man-hour by the Progressive method, as compared to a standard production of 0.51 chain per man-hour in the North Pacific region of the U. S. Forest Service. For a three-year period, the accomplishments of this Progressive crew indicate a held-line production of 0.34 chain per man-hour, as compared to 0.07 chain per man-hour for other crews in the same region. The

Progressive method develops among the members of the crew a pride of their work which drives them to unusual accomplishments (118).

K) Progressive-Set-Up Method

The Progressive-set-up method (9, 30) is a method of managing man power on line construction, which borrows from the One-lick method, the 10- to 15-foot method, the Individual-assignment method, and the Progressive method. The system differs from the Functional-crew method in that the entire crew progresses forward with each member occupying the same relative position through the work period. The principle is that each member of a unit has a definite assignment of work to accomplish and will work on this section until it is completed, or until some other member of the unit finished the work in his section; then the whole crew moves ahead. Ordinarily the crew consists of three 7-man squads with a straw boss in charge of each squad, and of one or more saw units stationed at the rear of the crew. The first squad is a clearing unit equipped with axes; the second is a loosening unit equipped with grub hoes; the third is a digging unit equipped with shovels. The last two or three men of the clearing squad may be equipped with Pulaski tools instead of axes. The crew members space themselves about 15 feet apart along the fire line. Each man is given a number and is required to complete the work in his section, unless another man behind, number 4, for example, has already completed his section, in which case fireman number 4 and all those before him move up to the point where the man ahead was working, while fireman number 1 in the squad steps 15 feet forward. When, as another example, fireman number 7 completes his section, then fireman number 7 and all those before him move 15 more feet forward, except fireman number 5, who moves 30 feet forward, because the 15 feet of fire line next to his section had been completed before by fireman number 4. The straw boss is the key to a smooth working squad, and it is extremely important that he be alert at all times.

It is believed that the Progressive-set-up method has definitely proved noticeably superior to many other methods. The advantages claimed in its favor are: a) it speeds up the line production; b) it assures a finishes job when the last man passed any point; c) the output of each man is evident at all times; d) there is no opportunity for soldiering or malingering on the job; e) it insures adequate safety to the men, who never pass each other and never get close together.

L) Austin-Rotary Method

The Austin-Rotary method (9, 21, 127), also referred to as the Spinning-Firemen method (89), was developed as a way to speed up line construction on fast-spreading fires in light grass fuels. It was devised for knocking down fires with dirt, and does not work where mineral soil is not readily available. It has proved very effective for small crews on cheat grass fires. It is a progressive method, eliminating any lost motion if properly managed. Four or five men are

Fig. 11. Austin-rotary method of man-power organization. (After a diagram by the U. S. Forest Service).

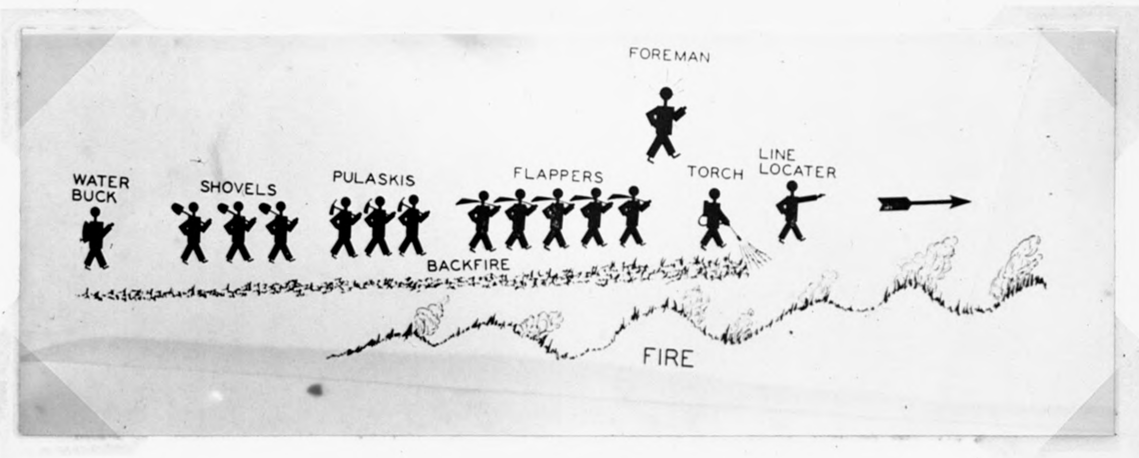

Fig. 12. Torch-and-flapper method of man-power organization. (After a diagram by the U. S. Forest Service).

about the maximum that can perform efficient work on one part of the line at a time (59), four being an adequate number where digging is not too difficult.

The men are equipped with a shovel, and are organized as follows, assuming a four-man crew (9, 21): a) the first man fills his shovel, steps close to the fire and whips his load of dirt as far as possible up the fire edge, throwing the dirt while moving forward; he then moves ahead parallel to the fire edge about three times the distance covered by his shovelful of dirt, and about one or two steps away from the fire, loads his shovel again, and starts the procedure all over again; b) the second man steps to the fire edge where the first man's dirt swath ended, whips his shovelful, and moves quickly ahead of the first man; c) the third man releases his shovelful of dirt where the second man's dirt swath ended, and follows the same pattern as the first and second men; d) the fourth man follows behind, shoveling and extinguishing persistant tufts of matted grass which were not completely knocked out. Each man maintains constant his relative position in the crew. The movement of the crew gives the appearance of a three-man wheel rolling up the edge of the fire (9, 21), each man rotating clockwise when throwing his shovelful of dirt onto the fire, and anticlockwise when stepping aside to fill his shovel with fresh dirt (59). When dirt is plentiful, a four-man crew moves forward about as fast as the men would simply walk.

M) Torch-and-Flapper Method

The Torch-and-Flapper method (9) is an adaptation of the One-lick method to meet the conditions on grass fires. It is also a progressive system in that the entire crew move forward along the line with each member maintaining a constant relative position in the lineup. It is particularly valuable on large grass fires where the Indirect method of attack is applied, but it can be used to excellent advantage with the Direct, Two-foot or Parallel methods of attack. It requires a crew of 15 men or more distributed as follows: a) 1 crew boss; b) 1 line locator; c) 1 torch man, backfiring the line selected by the locator; d) 5 flapper men, knocking out the edge of the backfire on the side opposite from the main fire; e) 3 Pulaski-tool men, using One-lick tactics in cutting off strips of smoldering fuel left by flappers; f) 3 shovel men, shoveling in smoldering material; g) 1 water man, equipped with a back-pack can of drinking water, with a hand pump attached, to put out any spot fire beyond the backfire. The entire crew moves forward continuously, adjusting its speed on the crew boss, who maintains a central position a few feet away from the crew.

The advantages of this method are: a) it eliminates all lost motion, each man working on every step ahead; b) it keeps the whole crew intact for concentration on hot spots, if necessary; c) it provides an assortment of tools adjustable to meet all variety of problems on grass fires;

d) it permits the use of backfire to straighten and shorten the fire line. Its disadvantages are that: a) flappers become almost useless when the fire gets into cliffs, rocks or heavy fuels; b) there is the danger that the backfire "may be swept away from the flappers on steep ground, or when flanking around head of fire counter to wind" (9).

FIRE-FIGHTING EQUIPMENT

"Efficiency in suppression work depends largely upon the adequacy and proper distribution of suitable tools and equipment for the particular job in hand" (108). Firemen work effectively only as they are equipped properly and as their equipment is maintained in a serviceable condition. Fire-suppression equipment. therefore, is a subject in which every man is interested, and one demanding careful attention. Tools and equipment should be ready for immediate use at all times, and upon return from a fire all should be promptly reconditioned, and losses and breakages replaced. Moreover, they should be inspected periodically to assure their usability. Care should also be taken to avoid placing tools and other equipment where they would be endangered by the spread of the fire.

The distribution and storage of fire-fighting equipment are largely dependent upon the source of man power, the transportation facilities, and the relative fire hazard. Firemen travelling in automobiles in forested areas are expected to carry at least a clearing tool, a digging tool, and a back-pack water can provided with a hand pump. Besides, forest protective organizations should always have a reserve supply of fire-fighting equipment to meet emergencies.

The principal items of the fire-fighting equipment may be classified as follows: a) hand tools; b) water equipment; c) mechanical equipment; d) miscellaneous equipment and supplies.

A) Hand Tools

"In spite of our developments in the way of mechanical equipment and use of water, fully 80 to 90 per cent of the work on fires still has to be accomplished with the humble hand tools" (108). No less important than an adequate force of well trained men is a proper supply of the right kind of tools. A wide variety of hand tools has been developed to meet all sorts of conditions on a fire. The objective should be to select the tools that will be most serviceable in the hands of the average crew. It is, therefore, advantageous to have a clear idea of the principal uses to which each tool may be put, and of the conditions under which some other tools may become more effective. Standard tool caches are prepared which contain an assortment of basic fire-fighting tools suited to a wide variety of conditions. The selection of the right kind of tools for the particular fuel type is an important feature of fire-control technique (8). The fuel type and local customs influence to a great extent the choice of the hand tools. Experience in fire suppression is essential to a proper selection of hand tools. It is very important at a fire that there be the right number of each tool needed to equip a well-balanced crew for any method of suppression. The proper condition of the tools is also important, and, if a fire is likely to extend beyond the first work period, arrangements must be made to sharpen and recondition tools which have been dulled or broken on the job. In small crews, each fireman is usually responsible for his own tools and their reconditioning.

For several years, the shovel, axe, hoe and rake, the basic hand tools developed by man through centuries of manual labor, were accepted by fire fighters as they were, wherever they could be picked up, and little thought was given to size, weight and balance. "But, gradually it became apparent that more careful selection was essential to efficient work and labor conservation. Careful study, design and test have resulted in standards of shape, balance and quality which will probably stand for many years to come" (72). Hand tools are classified in three classes on the basis of their used, as follows: a) clearing tools; b) digging tools; c) beating-out and raking tools. But, a wide variety of combination tools have been devised which may serve for the dual purpose of clearing and digging, digging and raking, etc.

a) <u>Clearing Tools</u>

The clearing tools (13, 77, 109) include a wide variety of instruments used for both cutting and felling the materials in clearing a fire line. The axe, the principal clearing tool, is one of the most important hand weapon of the fire fighter. Several types of axes are used in fire suppression, such as: a) western-pattern double-bitted axe; b) Young's-pattern double-bitted axe; c) cruiser-pattern double-bitted axe; d) single-bitted axes; e) belt single-bitted axe; f) standard fireman's axe; etc. Axes may be obtained in different weights. Saws may be important tools in fire fighting. They also present several types, as follows: a) crosscut saw; b) Swedish bucksaw; c) power-driven saw (50), etc. Other clearing tools include: a) brush hook; b) brush knife; c) Brown tool, or J axe, a combination of axe and brush hook (35);d) Pulaski tool, a light combination of axe and grub hoe; e) mattock, or cutter mattock, a heavier combination of axe and grub hoe; f) Rich or Council tool, a combination of a cutting, digging and raking tool; g) sledge hammer; h) steel or hardwood wedges; i) snag-boring machine;(13); j) Holst tool, a combined cutting and digging tool (1).

b) <u>Digging Tool</u>

The digging tools (13, 77, 109), as their name implies, are used for digging control lines in fire suppression. The shovel, the most important digging tool, is also among the outstanding items of fire-fighting equipment. Only round-point shovels are used, with both short handles or long handles. The long-handled shovel is particularly indispensa-

Fig. 3. Various types of hand tools. (After a photo by the Western Forestry and Conservation Ass'n).

Fig. 4. Fire fighting with a back-pack bag and a trombone-type hand pump. (After a photo by the U. S. Forest Service).

ble in using dirt as a fire extinguisher. Shovels are also employed for beating out smothering sparks, spreading and tending backfires, etc. Hoes are next in importance to the shovel for digging out fire lines. They are obtainable in a great variety of types, namely: a) grub hoe; b) hazel hoe; c) adz hoe; d) mattock, or cutter mattock; e) Pulaski tool; f) McLeod tool, a sturdy combination of rake and hoe (46); g) Kortik tool, another combination of rake and hoe; h) Rich or Council tool; i) Koch tool, a combination of shovel and hazel hoe; j) Holst tool; etc.

Hoes are also used for cutting weeds and light brush, scraping off debris, tearing off the humus, small roots, etc., loosening the mineral soil, grading the fire line, etc. Osborne (109) claims that hoes are the best tools for digging any fire line located 2 feet or more away from the fire edge. The hazel hoe, the adz hoe and the Pulaski tool seem to offer particular advantages for digging a fire line.

c) Beating-Out and Raking Tools

The fire swatter (13, 138), a flail designed for beating out fires in grass-type and other similar light fuels, has proved a very effective tool in fire suppression.

Different types of rakes have been devised for use in fire fighting. They include (13, 77, 109): a) asphalt rake; b) Rich or Council tool; c) McLeod tool; d) steel broom; e) Kortik tool; f) potato hook; g) weed cutter; h) garden rake; i) road rake; j) lawn-comb rake; etc. They may be used either for raking, pushing or sweeping, and may be useful on practically all but deep-duff or peat fires (77). They are mostly employed for raking up the thin layer of grass, loose litter and pine needles, to stop or check fires, or for scattering backfires(13).

B) Water Equipment

As already mentioned, the use of water in forest-fire fighting is almost entirely dependent upon the development of the water equipment. A wide variety of water-using devices have been developed in the last twenty years, which have greatly improved the methods used in fire suppression. Tinned steel pails and canvas buckets were among the first water containers used at a fire, and are still employed to a great extent, especially where an ample supply of both water and man power is available, bucket brigades being organized and water brought in by hand. Back-pack water bags or cans of approximately 5-gallon capacity and provided with hand pumps are standard equipment wherever water is employed in fire fighting. They furnish a mobile means of suppression, and prove very successful in direct attack and mop-up work. Hand pumps are obtainable in a wide variety of styles. But, the most satisfactory seems to be the trombone type discharging during both the down and the up stroke, and thus giving off a steadier stream without tendency to drop off between strokes (109). The cans and bags also vary considerably in regard to shape, the best types being those which can be carried comfortably on one's back, leaving his hands free to operate the pump and direct the water spray where it is most needed. Canvas bags are advantageous because of their light weight and their ability to collapse in a very small volume, but otherwise the metal cans are on the whole considered preferable.

When an abundant supply of water is available near a fire, portable power pumps using 1½-inch hose have been brought to carry a strong stream of water on thousands of feet even in rough country. These portable gas-engine pumps, referred to as pumpers, have been one of the outstanding developments in the line of fire suppression. Present-day pumps are proving dependable for long and continuous service, and capable of delivering from 35 to 40 gallons of water per minute under high pressure. Reference was already made to the use of power pumps in relays. The efficiency of these pumps has been greatly increased and the weight appreciably reduced. Buck (36) claims that one portable power pump is worth 75 men at a fire. Models of various capacities of volume and pressure are now available for different conditions, very light pumps for rough, inaccessible regions, and heavier, more powerful units for locations reached by roads (20, 108, 109). Portable power pumps are, indeed, available for use on practically any fire where water itself is available.

Four types of power pumps have been designed for use in forest-fire suppression, namely: a) rotary pumps; b) piston pumps; c) plunger pumps; d) centrifugal pumps. Stewart (131) reports that piston, plunger and centrifugal pumps are to be preferred to rotary pumps, although the latter type is highly efficient and useful where clean water is available, and is adaptable to light-weight units when portability is the desired feature. The same author (131) mentions that, except in the most isolated and inaccessible regions, reliability and sturdiness are more desirable features than portability. Some portable power pumps are light enough for back-packing (20, 98); others can be carried by two or more men, or by pack animals. Heavy-duty units may be mounted on trailers (13, 16, 18), or on a tractor (13). Fan-belt-driven power take-off pumps (13, 20, 56) have been placed on the market, "which are intended to be driven by a V-belt and an auxiliary pulley which is driven by the fan belt of the motor" (13) of automobiles or trucks.

Automobile trucks provided with water tanks and pumping apparatus, generally known as tankers, do most effective work on fires which can be reached from roads (13, 47, 48, 55, 59, 92, 100, 114, 129, 143). Tank assemblies (16, 51) have been improvised which are made up of four common 55-gallon oil drums mounted on cradles in series, and which can be carried with a power pump in a truck or a trailer. Water tanks or water barrels are also mounted on trailers for fire-fighting uses (13, 16, 134). Large railroad-tank cars usually furnished with steam- or gas-engine pumps are common equipment in most logging camps in the Pacific Northwest. One

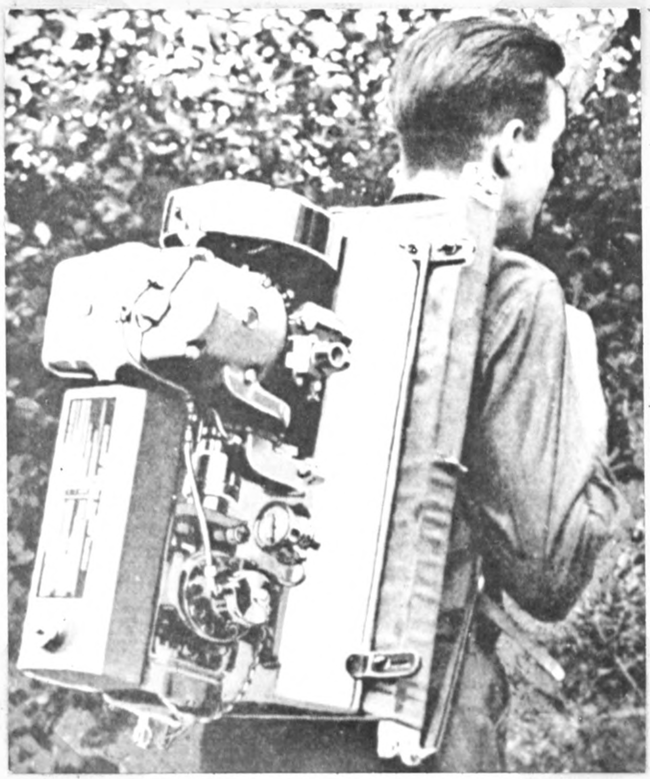

Fig. 5. Back-pack portable power pump. (After a photo by the Pacific Marine Supply Co.).

Fig. 6. Fire truck carrying water and pumping apparatus. (After a photo by the U. S. Forest Service).

of the most outstanding developments in fire fighting has been the equipment of tractors with a water tank, a power pump and a hose reel, resulting in a combined tractor-bulldozer-tanker (74, 93). Stickel (137) describes a brush-breaker fire truck provided with a water tank and pumping equipment. Hand-operated pumps (13, 16, 45) have been adapted to replace power pumps on tankers.

There are two types of hose used in connection with power pumps: a) rubber-lined cotton hose; b) unlined linen hose (13, 20, 109). With linen hoses, the pressure and the volume of water obtained is somewhat reduced on account of the increased friction and seepage loss, but they are much lighter, and, as a result of seepage and sweating, they do not burn so readily as rubber-lined hoses, when used on burned-over areas. Hose back-pack sacks (13, 20, 109) are sold which hold 400 feet of 1½-inch linen hose, and permit the laying out of the hose line as fast as a man can walk.

Other important developments in connection with the water equipment include: a) the use of dry ice as a pressure medium or source of power for use on a water tanker (52, 53); b) the equipment used for sinking shallow wells in pervious soils (13, 18, 131, 132, 133); c) the use of perforated iron nozzles about four or five feet long for extinguishing ground fires by getting the water down to the burning peat underneath the surface (17, 22).

C) Mechanical Equipment

Mechanization of the fire-fighting equipment has made a most important contribution to forest protection. The last twenty-five years have wistnessed the greatest progress in mechanized equipment. The following mechanical devices have already been mentioned in connection with the hand tools and the water equipment: a) power-driven saws; b) snag-boring machines; c) portable power pumps; d) heavy-duty power pumps mounted on trucks, trailers or tractors; e) tank trucks or tankers; etc. Another mechanical aid to forest protection was provided by trucks and cars for the transportation of men, supplies and equipment. Mechanical transport has almost completely supplanted the horse and the mule in fire-fighting organizations, although pack animals are still very important carriers in remote areas. This incorporation, in the fire-control system, of motor-driven carriers for the transportation of men and equipment has revolutionized the effectiveness of forest protection. Thousands of trucks are now at the service of fire control. They include: a) suppression-squad trucks compactly arranged for the accomodation of the firemen and their equipment (13); b) as already referred to, so-called tankers carrying firemen, water, pumping apparatus, small tools and supplies; c) light-weight pick-up trucks; d) heavy-duty stock trucks; e) also mentioned before, brush-breaker trucks carrying men, water, pump, tools and supplies; f) trailmobiles (115), miniature automobiles with a 35-inch tread, adapted to operate on trails with a load capacity of 2,[illegible] pounds.

The transportation of water and pumping apparatus by tractor-tankers has already been referred to. Another development in the use of tractors for fire-fighting transportation is provided by the trail tractor (41, 81, 115), a lightweight tractor with a 36- to 40-inch blade and drawing a special type of trailer of 1- or 2-ton capacity. Light, fast-moving tractors are regularly used in rough roads for fire-fighting transportation.

Other devices developed in connection with mechanical transport for fire-fighting purposes include (13): a) trailers for fire-fighting tools and supplies; b) camp-kitchen trailers convertible for use as a table; c) horse trailers; d) horse and plow trailers; e) water-barrel trailers; f) pump and water-barrel trailers; g) water-barrel and back-pack-outfit trailers; h) water-tank trailers; i) heavy-duty trailers, for carrying tractors, plows,and other heavy equipment; j) tilting-bed trailers especially designed for transporting tractors, trenchers, bulldozers, etc.

Another important group of fire-fighting machines include the various mechanical devices for constructing fire lines with power tools. Numerous machines for clearing, digging or scraping fire lines have been conceived, tested and perfected. "Most designs or tryouts utilize the tractor as the power unit, which either pushes or pulls some heavy attachment that digs, rips, knocks over, or shoves aside the material that must be removed" (72). Reference was already made, in discussing the mechanical transport, of: a) tractor-tankers (74, 90), a combination of tractor, trailbuilder and tanker, equipped with a front blade for building fire lines; b) trail tractors, also equipped with a bulldozer and which may be used for fire-line construction in country which is not too rough. Tractors with trailbuilder, bulldozer, or brushbuster attachments have received wide acceptance, and have proved very efficient (75, 116) on the fire line. New methods of handling them are continually introduced, and the blade attachment and its uses receive important improvements. This technological development has given rise to a variegated array of bulldozers, trailbuilders, brushbusters (13), road graders (95), snag-felling machines (13, 90), etc. Several types of heavy scrapers, drags, plows, ditchers, and trenchers have been designed for fire-line construction with a tractor. They include several models of tractor-drawn plows (13, 23, 24, 56, 104, 108), or tractor-pushed plows (13, 25), of either the rolling-disc type, the middle-buster type, or the combined rolling-disc and middle-buster type. Another type of power-driven fire-line-building machine, known as the Bosworth trencher (34, 43, 144), differs considerably from the other mechanized diggers. "The frame has the appearance of a wheelbarrow with two handles behind and a bicycle wheel in front. The engine, mounted in the center, drives a drum

Fig. 7. Combined tractor, bulldozer and water tanker. (After a photo by the U. S. Forest Service).

Fig. 8. Bosworth trencher. (After a photo by the U. S. Forest Service).

of small, swifty-whirling hammers which, striking the ground, carve out to mineral soil a shallow trench about fourteen inches wide" (72).

As already mentioned in connection with the use of sand as fire extinguisher, the Michigan Forest Fire Experiment Station has developed a power-driven sand-throwing machine, also of wheelbarrow type and operated by one man doing the work of several firemen.

Wershing (143) mentions the use of a chain mesh and an asbestos mat, dragged by a fire truck, for the control of grass fires in the U. S. Western Plains, the drags being hauled directly over the fire line, with the truck on the outside of the fire.

Aircraft has become an important mechanical aid in forest-fire fighting. Besides helping to discover forest fires, airplanes are employed more and more extensively for fire-fighting purposes. They "have become a means of transporting men and supplies with a degree of speed and flexibility quite unattainable by any other means" (79). The transportation of material to be dropped where needed in remote locations seems the major fiels of usefulness of aircraft for fire control. The unloading of supplies and equipment from the air by the use of loose sacking and cheap and easily-made parachutes has proved a very satisfactory means of delivering goods to firemen on going fires in locations difficult of access (13, 26, 61, 62, 80, 83, 101, 113, 119, 141, 142). Reports indicate the successful dropping of such supplies as hot food, fresh water, canned food, fresh meat, dry food, fresh fruits, butter, pickles and preserves in glass jars, eggs, mess equipment, gasoline and oil, shovels, Pulaski tools, saws, back-pack cans, radio sets, portable power pumps, etc. By the use of this technique, hundreds of thousand pounds of cargo have been delivered to remote fire camps.

The practicability of parachuting men to fires was successfully demonstrated (27, 73, 80), and the technique and equipment have been developed for the safe dropping of firemen within a few yards from a land mark in isolated, roadless, forested areas. The potentialities of the use of aircraft for direct attack on a fire from the air by means of chemicals or other extinguishers is still in the experimental stage (71, 72), although the scattering of caustic soda from a plane has proved very successful in fighting steppe fires in Russia (28). The aerial scouting of large fires has proved very valuable in keeping the ground forces informed as to the progress of the fire, either by means of the radio, or by dropping aerial pictures from the plane to the fire boss (44, 72, 80, 99). The autogiro, due to its ability to land and take off in very restricted areas, and its capacity of hovering at low altitudes and at a reduced speed, gives promises of great developments in the use of aircraft for fire-fighting purposes. It is believed that the airplane will eventually be recognized as a tool for the suppression of forest fires, which will be considered as essential as the tractor, the power pump, and even the back-pack can.

The telephone and the radio are two technical instruments of great importance in fire fighting, in that they enable the fire boss to keep in touch with the dispatcher, the lookout men, the fire camp, the division or sector bosses, the scouts, etc. These devices may be of particular assistance: a) in helping the smokechaser to locate a fire on the ground, by contacting the towermen (87); b) in keeping the dispatcher readily informed as to the needs of man power, equipment and supplies (29); c) in coordinating the work of the fire boss, the division or sector bosses, and the scouts (29). Reference was already made of the use of the radio for communication between the fire boss and planes scouting large fires from the air. The use of the telephone, however, is limited to the extent of the wire line, but the radio provides a reliable supplement where telephone communication cannot be utilized. The development of light portable instruments has greatly improved the usefulness of the radio for fire-fighting purposes (13, 125, 126), and it is believed that in a near future radio sets will be taken along to any fire and considered just as important as the regular fire-fighting equipment.

D) Miscellaneous Equipment and Supplies

The use of adequate equipment for backfiring is of prime importance in fire fighting. Skilful thinking and experimentation have greatly improved the technique of this method of control through the achievement of reliable devices and suitable tools. Several types of liquid-gas torches have been developed using either liquified petroleum gas (13), or kerosene oil or gasoline (108, 109) under pressure. The best-known torch, the so-called Hauck torch (108, 109), is equipped with pack straps and hose, and burns either kerosene oil or gasoline. But, the most effective device appears to be the development of a flame thrower using kerosene oil, saw oil, or Diesel oil. This instrument consists in an attachment replacing the nozzle of the trombone-type pump of a standard back-pack can (13, 57). The flame-thrower attachment is a tube terminated by a check valve through which, on the pressure stroke of the pump, a highly aerated stream of the fuel is ejected across a lighted wicking. Larger and more powerful flame throwers using a power pump have been devised to produce a constant stream of an intense flame (58, 112). Other devices used for setting backfires include: a) fused backfiring torches (13); b) fire-starting bombs (13); c) gravity-feed torches (57).

The development of lighting equipment for night fire-fighting work makes it possible to carry on fire-suppression activities at night just as in daytime. Miners' carbide lamps (13) were first employed, but they are rapidly being replaced by electric headlights (13, 109). These individual electric headlights contain a reflector, two 2-cell batteries and a 25-

volt bulb. Osborne (108) claims that they "are considered best for most types of night work". A suitable type of battery floodlight (13, 54, 77, 83) has been developed which uses a regular automobile headlamp mounted on a rod or a tripod. The power is supplied either by a standard 6-volt, 13-plate storage battery, or by eight 6-volt dry cells. Other lighting devices for night work in fire fighting include (13, 109): a) candle lanterns made from tin cans, referred to as palousers or bugs (12); b) electric lanterns using a twin-six battery; c) standard two-cell flashlights; d) gasoline lanterns of the Coleman type; etc.

The equipment and supplies of major importance for fire-fighting purposes also comprise such items as (13, 109): a) fire-camp equipment, including cooking and mess outfits; b) grinding and sharpening tools; c) subsistence supplies; d) medicine kits and first-aid equipment.

MOPPING UP

An important phase of fire suppression is the mop-up work, or "the act of making a fire safe after it is controlled, such as extinguishing or removing burning material along or near the control line, felling snags, etc." (12). After the fire line has been constructed and the advance of the fire stopped, the next step is to make it permanently secure and to put it out completely. The mopping up should progress along with the building of the fire line, or, if all the available men are needed for line construction, it should be started immediately following the completion of the control line.

A fire is not safe as long as there is anything burning, and mopping up consists in completely extinguishing all fire on a zone one to several hundred feet wide along the inside of the control line. The mopping up is the completion of the suppression job, involving the cleaning up of interior hazards after the immediate advance has been stopped, and the fire line has been completed. "In general, by the time lines are completed the duff and light litter inside the lines will have burned themselves out, leaving only scattered fires in the heavier material, such as bark, poles, logs and snags. The objective of the mop up is to hasten the going-out period, or to eliminate hazards until there is little or no possibility of their causing fires to become established across the line as a result of creeping fires, blowing sparks, falling snags, rolling materials, reburns, etc., even under the most adverse condition that might arise" (108).

Mopping up pertains to all work done along the control line to reduce hazard, deaden fire, fell snags, complete the extinction of smoldering fire, prevent further escape and render fire increasingly safe. The practice of mopping up includes not only the extinguishing of fires with water, dirt, etc., but also the act of simply making them go out by separating and scattering materials, shoveling away hot embers, burning out unburned spots between the control line and the edge of the fire, removing snags and other dangerous fuels, etc. Mopping up, therefore, consists in going over the area, systematically felling and suppressing the fire in all burning snags, and putting out completely all smoldering fires. Mopping up also involves extinguishing or quieting down any burning stumps, logs or other material which may threaten the fire line, and extinguishing material burning around the base of moss-covered trunks and under singed, low-hanging branches and reproduction, or removing the latter material through lopping and scattering.

The amount of work to be done for mopping up a fire depends upon a number of factors, including the time of the day, the fuel conditions, the character of the fuel, the quality and width of the fire line, the wind velocity and weather conditions. Power pumps and back-pack cans with hand pumps are particularly adapted for mop-up work, and no opportunity for the use of this equipment should be missed by the firemen. Water, indeed, is the quickest, cheapest and best quenching agent in mop-up work. When correctly used, dirt is also an effective mop-up agent for cooling down dangerous spots, knocking down flames, etc. Likewise, cooling down by scattering the burning fuel is an efficient mopping-up practice.

Important considerations in connection with mopping-up activities may be summarized as follows (4, 9, 124): a) do not leave partially-burned clumps of brush or reproduction close to the fire line; b) separate masses of large fuel to reduce heat and danger of spotting; c) eliminate all snags that could under most adverse conditions throw sparks or fall over the control line; d) on steep slopes, turn logs and chunks so that they lie parallel to the direction of the slope, to eliminate the danger of rolling; e) feel with hands for possibly smoldering spots; f) use water wherever possible; g) employ dirt to reduce heat, retard spotting or smother fire; h) look for and dig out burning roots near the control line; i) spread, rather than bury, smoldering fuel that cannot be put out; j) base the size of the crew on the condition of the fire and the probable rate and direction of spread of any fire which might become established across the line.

PATROL

By patrolling a fire is meant "moving back and forth over a length of control line during or after line construction, to prevent breaks, discover spot fires, and, when times permits, do mop-up work" (12). No matter what method is used, some fires are apt to become established across the control line. Continuous observation is, therefore, necessary to insure the detection and suppression of all breaks in the fire line. All constructed lines should be patrolled even if this means the retention of the entire crew. Since patrol also involves mop-up work, every patrolman should be kept busy cooling down and putting out the fire, strengthening the fire line where needed, looking for the existence of burning or smoldering material within sight or blowing distance from the line, etc.

Patrol is essential at night just as in daytime, but the intensity of the patrol varies greatly during the 24 hours of the day, being lightest at night and heaviest in the afternoon. The size of the patrol crew varies with the length of the line, the weather conditions, etc., and decreases as the danger itself decreases.

Patrol is particularly important (9, 124): a) immediately following the setting of backfires; b) on steep slopes where rolling embers are likely to cross the fire line; c) to search for spot fires outside the control line; d) to guard against breaks where heavy-fuel bodies are burning inside the line; e) on lines adjacent to dangerous snags likely to throw sparks and set spot fires. Patrol is continued after the mopping up to assure a check on the adequacy of the mop-up work, and to add assurance against the possibility of faulty mopping up. On any large fire, where there has been a big volume of heat or dense smoke, close watch for spot fires should be maintained for several days up to two miles or more beyond the control line. At least one man should be kept on patrol for from two to ten days after the last spark of fire was discovered, depending upon the fuel type and the probability of hang-over fires.

ABANDONING THE FIRE

No fire should be abandoned before it is completely out. Only after the fire boss has made a final, careful inspection of the control line, and assumed the responseability of declearing the fire out, will men then be released. As the number of smokes detected decreases, the crew may be gradually laid off. But, only after the last spark or smoke has been seen, and the last vestige of danger has been eliminated, then the fire boss may have satisfied himself that the fire is absolutely safe. Only at this stage the fire should be completely abandoned.

CONCLUSION

Success in forest-fire fighting is dependent upon the degree of preparedness, leadership and aggressive application of the best-known methods of fire suppression and man-power organization. Fire is a chemical action, and a thorough knowledge of fire behavior is essential to understand the principles of the methods used in fire-fighting technique. Success in fire fighting also hinges to a considerable extent upon the rapidity, accuracy and adequacy in fulfilling all the necessary steps from the discovery of the fire to the last spark or smoke. Then, the application of the right method of attack, the use of the best method of man-power organization, and the employment of the most suitable and adequate equipment for the type of fire and the kind of fuel, are necessary to reach the standard objectives of fire suppression.

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