VIETNAM WAR

Forest Fire as a Military Weapon

A June 1970 Report of study commissioned by the Department of Defense.

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FOREST FIRE AS A MILITARY WEAPON

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FINAL REPORT
JUNE 1970

U.S. DEPARTMENT
of
AGRICULTURE
Forest Service

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REMOTE AREA CONFLICT
ARPA Order No. 818

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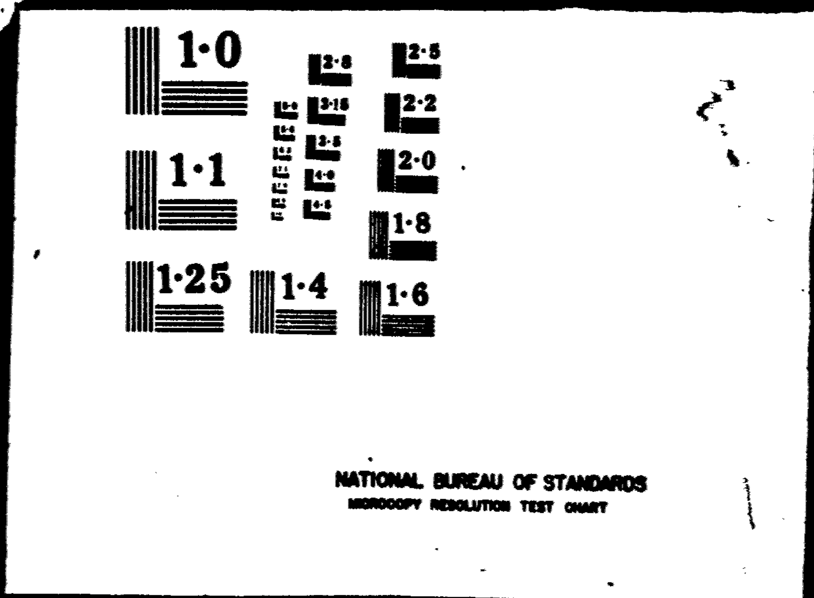
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FOREST FIRE AS A MILITARY WEAPON

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June 1970

U. S. Department of Agriculture – Forest Service

Sponsored by

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Overseas Defense Research
ARPA Order No. 818

INDEX

INDEX (Continued)

SUMMARY

In 1965, the Joint Chiefs of Staff requested that the Secretary of Defense initiate research to determine the feasibility of measuring the flammability characteristics of forests and jungle growth, modifying flammability so that vegetation would readily support combustion, and developing measures to destroy large areas of forest or jungle growth by fire. This research has been conducted by the Forest Service of the Department of Agriculture, under sponsorship of the Advanced Research Projects Agency through ARPA Order 818.

Primary research attention has been given to the flammability characteristics of jungle growth in tropical and monsoonal climates where forest fires seldom occur naturally. Major consideration has been given to developing operational guidelines that utilize input data readily available to military commanders under field conditions. The following conclusions are directly pertinent to the JCS request:

Forest flammability depends on the amount of dead vegetation on or near the ground surface, the moisture content of this ground level material, and the weather at the time of burning.

Forest flammability can be greatly increased by killing all shrub vegetation, selecting optimum weather conditions for burning, and igniting fires in a preselected pattern.

Removal of overhead tree canopy requires the initiation of high intensity crown fires. In many climates, crown fires are unlikely to be achieved by any environmental modification technique. However, significant military damage can be produced by forest fires of lesser intensity.

FOREST FIRE AS A MILITARY WEAPON

> The battle was fought
> in the forest of E'phraim;
> and the forest devoured
> more people that day
> than the sword.
>
> II Samuel 18: 6, 8

Forests were a haven and refuge for bandits, insurgents, and rebel bands long before Absalom took up arms against King David in the forest of E'phraim. Leaders as diverse as Robin Hood, Marshall Tito, Chief Croatan of the Seminoles, and Fidel Castro, learned to conduct successful military operations from forest havens. The Vietnamese insurgency has placed heavy reliance on forest bases since the first stirrings of rebellion during the Japanese occupation. The Viet Cong is not really Chairman Mao's "fish who swims in the sea of peasants"; he more closely resembles a jungle cat who lives hidden in the forest but preys on the surrounding villages. Large forest havens along the border, such as Dong Thapmuoi, U Minh and War Zone C, serve as training and supply bases for the VC and North Vietnamese Main Force, as well as secure infiltration and escape routes (Fig. 1). Forests in the interior such as War Zone D, Do Xa, and Chu Pong contain major supply depots and operational base complexes. Innumerable small forests, like Boi Loi Forest, the Iron Traingle, and Ho Bo Woods, all lying between Tay Ninh City and Saigon, are used as temporary staging areas. 1/

Although considerations of communications, food supply, strategic location and availability of support all enter into the selection of a particular area as an insurgent base or safe haven, the major requirement is dictated by the need for concealment from above. Dense forest growth offers the best possible overhead concealment for base operations of company size or larger.

A recent study of VC bases showed that 83 percent were located in dense forest and only 1 percent were further than one-half kilometer from dense forest (Cambodian R and R areas excluded). 2/ An Australian study of changes in VC installations over a 9-year period showed that when selecting a new base site, the VC chose areas in which vegetative cover offered the most effective concealment at that time. 3/

One additional characteristic of a forest haven is so obvious that it has gone unmentioned in most studies of the problem. The forested area must be large enough that it cannot be surrounded nor effectively swept by conventional forces. Consequently, any successful counterinsurgency effort against such bases must depend on extremely accurate,

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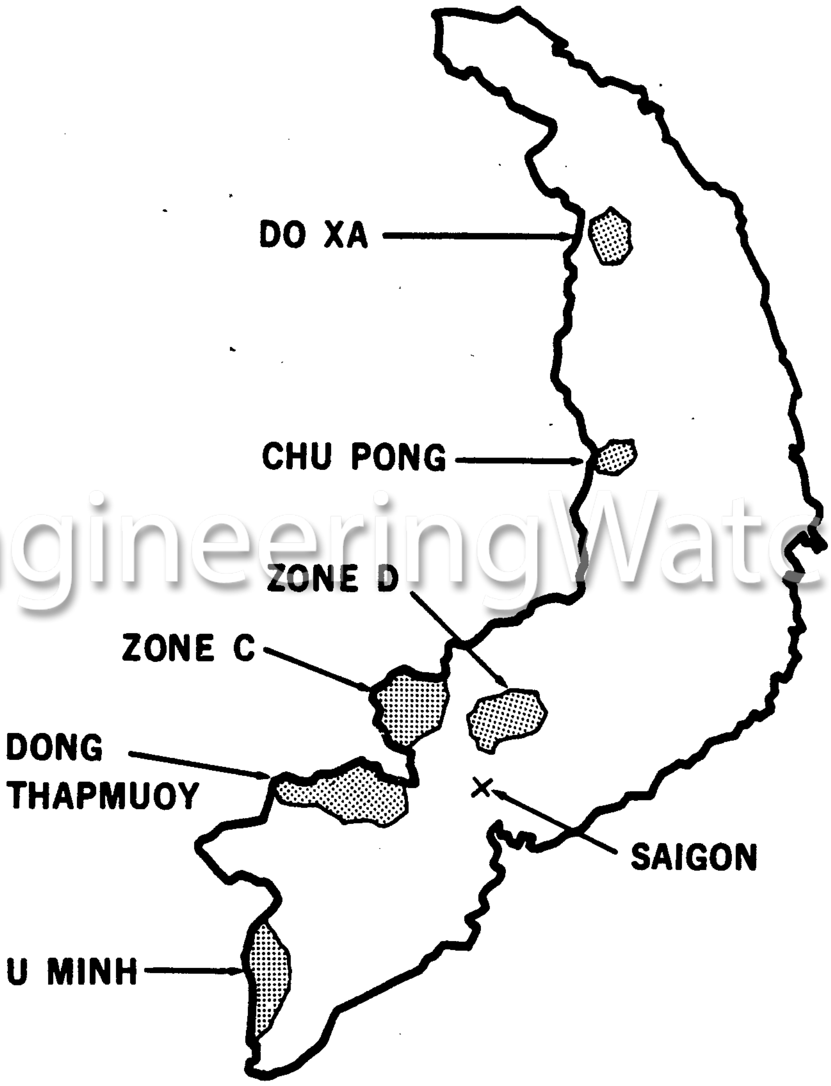
1/ Breit, J. M. and others. Neutralization of Viet Cong Safe Havens. Research Analysis Corp. Technical Paper RAC–TP–191. September 1965, 74 pp., illus. SECRET.

2/ Narten, P. F. and E. E. Kraus. Area analysis techniques in insurgent base location. CIRADS III Proc. Vol. 2, pp. 1–59. December 1968. CONFIDENTIAL.

3/ Holt, E. S. Prediction of the location of insurgent installations. CIRADS III Proc. Vol. 2, pp. 59–76. December 1968. CONFIDENTIAL.

FIG. 1

VIET CONG FOREST BASES



detailed and timely intelligence, or upon the use of weapons and tactics capable of affecting very large areas almost simultaneously. Forest fires have the potential both to remove concealing vegetation, thus assisting in intelligence operations, and to destroy stores and facilities over a wide area within a short time.

In late March, 1965, the 315th Air Commando Group initiated a fire bombing raid, code-named Operation SHERWOOD FOREST, against the Boi Loi Forest, 25 miles west of Saigon. Although the raid was conducted in the rain and did not result in any appreciable destruction of forest cover, the concept evoked considerable interest. 4/

In September 1965, CINCPAC requested that the Joint Chiefs of Staff take action to expedite the development of a device capable of destroying large areas of jungle or forest growth by fire.

In December 1965, the Joint Chiefs of Staff by JCSM-862-65, requested that the Secretary of Defense initiate programs to determine the feasibility of dehydrating jungle growth to the point where such material would support combustion, and to initiate development of operational means for determining the specific conditions under which there is the greatest probability of destroying jungle or forest growth by fire.

On December 20, 1965, the Advanced Research Projects Agency initiated ARPA Order 818 with the Division of Fire and Atmospheric Sciences Research of the Forest Service to conduct a research program of environmental modification techniques (Project EMOTE). The program was concerned with basic flammability problems of the major vegetation types of the world; although specific emphasis was given to humid forests, particularly the jungles of Southeast Asia. The major objectives were to develop the knowledge and technology needed to:

1. Describe, measure, and express quantitatively the flammability characteristics of forests and associated vegetation.
2. Modify flammability of vegetation types so that the fuel masses will readily support combustion.
3. Achieve rapid mass ignition and burning as required to remove each kind of canopy.

The initial Forest Service effort was devoted to assisting the Commander in Chief, Pacific with a second operational test of forest burning, code-named Operation HOT TIP. This raid was conducted in March 1966 against Chu Pong Mountain in Pleiku Province. The results were sufficiently successful that an expanded program of research to develop operational criteria was pursued. Guidelined for future incendiary operations were published in June 1966. 5/ At the same time laboratory studies were undertaken to develop flammability criteria for Southeast Asian fuels similar to those already developed for forest fuel types in the United States, and climatic analyses of Southeast Asia were initiated in order to define the weather conditions most likely to contribute to successful incendiary operations.

In January through April, 1967, a series of three full scale operational tests, code-named Operation PINK ROSE, were conducted by the 7th Air Force against targets in War Zones C and D. The results were no better than those of Operation HOT TIP, and the Forest Service advised against further operational testing in Vietnam. 6/

Further research was conducted in 1968 and 1969 to determine the specific limiting factors for forest fire initiation in humid tropical forests. Both test fires and naturally occurring forest fires were observed and analyzed in Malaysia, Vietnam, Thailand, Bougainville, Australia, Puerto Rico, Hawaii, and the southeastern United States.

4/ Breit, J. M., et al, op. cit.

5/ Bentley, J. R. and others. Forest Fire Research, Vols. I and II. USDA–Forest Service. 279 pp., illus. SECRET.

6/ Mutch, R. W. and others. Operation PINK ROSE. USDA–Forest Service. 121 pp., illus. SECRET.

This report contains the findings and conclusions of Project EMOTE and is presented in final fulfillment of ARPA Order 818.

FOREST FIRE EFFECTS

When considering forest fires as a potential weapon, certain advantages and limitations must be kept clearly in mind. The greatest single superiority factor of fire as opposed to other damage-causing agents, is that under the proper circumstances fire is self-propagating. A relatively large area can be covered with a minimum expenditure of ordnance. The burning of the U Minh Forest in March and April 1968 resulted in a burned-over area of more than 1000 square miles from an expenditure of 20 aircraft sorties and 36 naval gunfire support missions (see Appendix A). The damage caused by this fire was equivalent to that of a 20 megaton nuclear device. On the other hand, the greatest single disadvantage to the use of forest fires as military weapons is that they are totally weather dependent. Thus their use against troops on the move must be opportunistic rather than planned, and successful forest incendiary operations are most likely when directed at fixed bases, or at least semi-permanent targets such as potential ambush sites.

The overwhelmingly important result of forest fires from a military point of view is visibility enhancement and cover denial. Despite the use of an array of sophisticated sensors for improving aerial intelligence capability, an analysis of tactical air strikes in South Vietnam during fall of 1966 showed that there were 35 strikes on "suspected" troop locations for every strike on a "known" troop location.[7/] Equally revealing is an analysis of Australian/UK ground engagements in Borneo, Malaya, and Vietnam which showed that over 75 percent of all enemy targets were encountered in forest cover regardless of whether the attack was initiated by enemy or friendly forces.[8/]

In addition to removing vegetative cover, all forest fires can be expected to destroy some supplies. Intense fires will also produce some casualties. The extent of damage will depend on the type of forest fire. There are four generally recognized forest fire types:

1. Creeping ground fire. The creeping ground fire is the least intense and least damaging of the four fire types. As the name implies, ground fires burn in the leaves and litter of the forest floor without consuming standing trees of shrubs. Ground fires spread at rates varying from a few inches per minute to a maximum of about 4 feet per minute with flames less than 2-3 feet high. Although these fires do not consume trees or bushes, they do heat their stems at the groundline and can kill the smaller and thinner barked species. Within a day or two the leaves wilt on affected plants. Thus horizontal visibility is enhanced at eye level by a factor of 2-3 in situations where brush or vines normally limit visibility. Since the larger trees that make up the top layer of cover generally have larger, more fire-resistant stems, they are relatively unaffected by ground fires. Consequently, vertical visibility is not changed after ground fires.

Even the lightest ground fires will cause some damage, particularly to munitions, unless precautions have been taken to protect loose stores by raking the area around them clean of all leaves and debris. Three of the six Vietnamese forest fire raids studied by Project EMOTE resulted in initiation of light ground fires (Sherwood Forest, Pink Rose I, Pink Rose III). Despite the fact that none of these fires burned any appreciable amount of foliage, and that the initial incendiary

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7/ Zwemer, H. A. Tactical Air Strikes in South Vietnam – Fall 1966. CIRADS II Proc. Vol II, Part 1 pp. 109–119. June 1967. CONFIDENTIAL.

8/ The ABA Firepower Study Group. Some statistics of counterinsurgency operations. CIRADA II Proc. Vol. II, Part 2, pp. 3–31. June 1967. SECRET.

FIG. 2
TYPICAL GROUND FIRE

FIG. 3
HORIZONTAL VISIBILITY
BEFORE FIRE

FIG. 4
HORIZONTAL VISIBILITY
AFTER FIRE

sets did not even burn together on the first two fires, several seconday explosions were observed on each of the fires. [9/] The timing of the secondaries was such that they could not have been caused by the incendiaries themselves, but could only have been touched off by ground fires burning into unprotected munitions caches.

2. Running surface fire. The running surface fire burns both the debris on the forest floor and any shrubs and other undergrowth that may be present beneath the main forest canopy. Rates of spread vary from 3 to 12 feet per minute. Flame heights range from 3-4 feet up to 15-20 feet. Grass fires in clearings are a special case of running surface fire. Fire intensity is about the same as that of running surface fires in the forest, but rates of spread and flame heights are about two and one-half times those of forest fires of the same intensity.

Running surface fires will burn off 75 to 90 percent of the leaves, twigs, and dead stems up to one-half inch in diameter from the undergrowth. Horizontal visibility will be increased by one to two orders of magnitude depending on the number of large stems left to block the view. Running surface fires in the forest do not burn the upper tree canopy, but they are usually hot enough to kill leaves at heights 5 to 6 times the flame length. Within a few days, these dead leaves will turn brown and begin to drop off. Vertical visibility will be improved if the average height of the forest canopy is low enough for the topmost layer of leaves to be killed. The effect of heat kill on opening up the forest canopy for aerial observation is practically identical to that achieved by spraying the forest with defoliant chemicals: The leaves fall off, given time, but the twigs and limbs remain. These residual twigs are often sufficiently dense to seriously hinder photographic interpretation. They offer practically no hinderance to infrared scanning, laser scanning or other fixed-point, line-of-sight remote sensing techniques.

Running surface fires are a much greater threat to unprotected stores than are low intensity ground fires. A total of 15 secondary explosions were confirmed in the 50 square kilometer area burned by running surface fire during Operation Pink Rose II, compared to three confirmed secondaries caused by the ground fires of Pink Rose I. For the U Minh fire, which burned as a running surface fire during many of the afternoons in mid-April, the report of the 96th Advisory Team notes that secondary explosions were occurring at the rate of one every 20 minutes during these periods.

3. Forest crown fire. Intense fires within the tree crowns require simultaneous intense running surface fires. Without adequate fire at the ground surface, a crown fire will not be propagated and sustained. Crown fires ordinarily spread at rates of 20 to 100 feet per minute, although runs of 200 to 400 feet per minute are possible for short periods. In flat country, crown fires will seldom persist in the absence of a moderate to strong breeze, since wind is necessary to tilt the flames into unburned foliage at the fire front.

Since a crown fire removes not only the leaves, but also the smaller twigs and branches, vertical visibility is sufficiently enhanced for accurate identification of ground features by aerial observers or from conventional aerial photography. Crown fires will destroy or seriously damage all equipment and supplies not stored underground or in clearings at least one-half tree height from the edge of the forest. Crown fires can also be expected to produce casualties, particularly to troops who are unfamiliar with forest fire behavior. Intelligence reports following Operation Hot Tip in 1965 listed two hundred VC casualties out of an estimated population of two thousand VC in the 21 square kilometer target area. Since only 17 percent of the target area burned as a crown fire, this seems to substantiate the thesis that casualties will be limited to, and closely correlated with, the areas burned by crown fires.

9/ Mutch, R. W. et al. Operation Pink Rose. USDA – Forest service. May 1967, 121 pp. SECRET.

FIG. 5
TYPICAL RUNNING SURFACE FIRE

FIG. 6
BEFORE FIRE

FIG. 7
AFTER FIRE

4. Firestorm. Under exceptional circumstances, forest fires may develop into the phenomenon known as "Firestorm." Although the term was first used by the Police Commissioner of Hamburg to describe the effects of the RAF raids of 24-25 July, 1943, the phenomenon has been noted in forest fires in America as far back as the great Peshtigo Fire of Wisconsin in 1871. A firestorm occurs when a large area (generally greater than 2 1/2 square kilometers) is burning at one time under meteorological conditions such that the entrainment of air to the fire is confined to a relatively shallow layer near the surface, and air enters the fire area with an appreciable tendency to rotate. This combination results in the development of strong surface winds which act to fan the fire and increase its burning rate. The increased burning rate causes more rapid air entrainment with a consequent further increase in wind speed, which increases burning rate still further which increases etc., etc. until all available fuel has been burned. Wind velocities exceeding 100 miles per hour are often attained during peak firestorm development. [10/]

Experts are not in full agreement on the conditions necessary for firestorm formation. In general, any factor contributing to a rapid vertical heat release rate, or to marked surface wind vorticity will be favorable. Such factors include:

1. Heavy fuel loadings of unusually dry material.
2. Many simultaneous ignitions.
3. Intense solar insolation.
4. An unstable atmospheric lapse rate.
5. Marked vertical and/or horizontal wind shear.

Since the winds are blowing into a firestorm area from all sides, the firestorm has no rate of spread in the conventional sense—the entire firestorm area burns up as a unit. However, a firestorm almost always occurs on only a portion of a large forest fire. Consequently, the fire may be spreading actively at one location while a firestorm is keeping the fire stationary at another. Flame heights usually reach 100-150 feet in firestorms, and flashes of flame as high as 500-600 feet are not uncommon.

Because of the intense heat and high winds, firestorms are extremely destructive. All dead material, regardless of size, and all living stems and branches smaller than 1-2 inches in diameter are consumed. Firestorms can be expected to cause extensive casualties to troops in the field. The mortality rate can be high, even among experienced firefighters, when even a part of a forest fire reaches firestorm conditions.

10/ Anderson, H. E. Sundance Fire: An analysis of fire phenomena. USDA – Forest Service Research Paper INT – 56, 37 pp., illus. 1968.

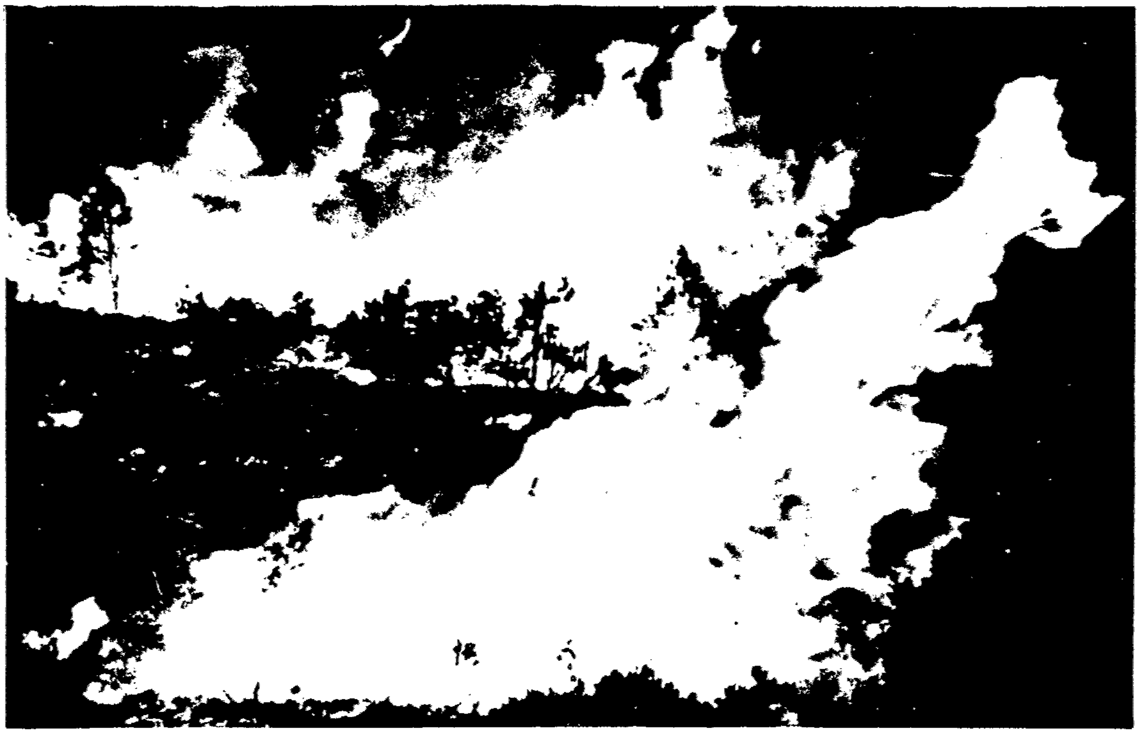


FIG. 8
TYPICAL CROWN FIRE

FIG. 9
BEFORE FIRE

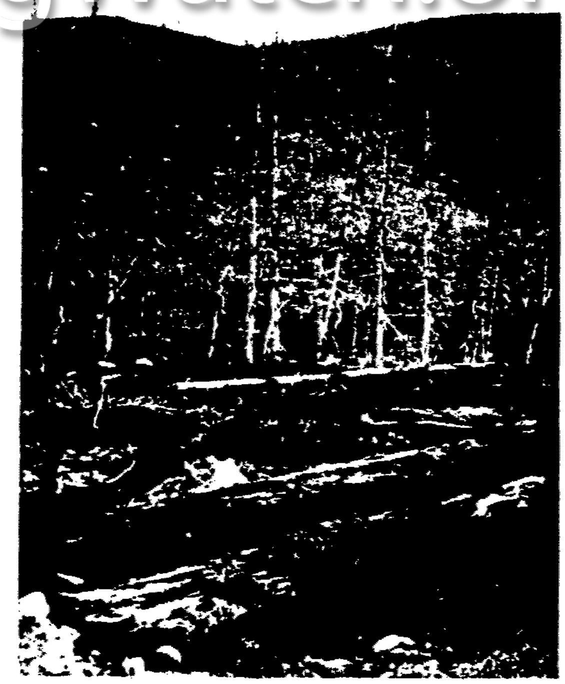


FIG. 10
AFTER FIRE

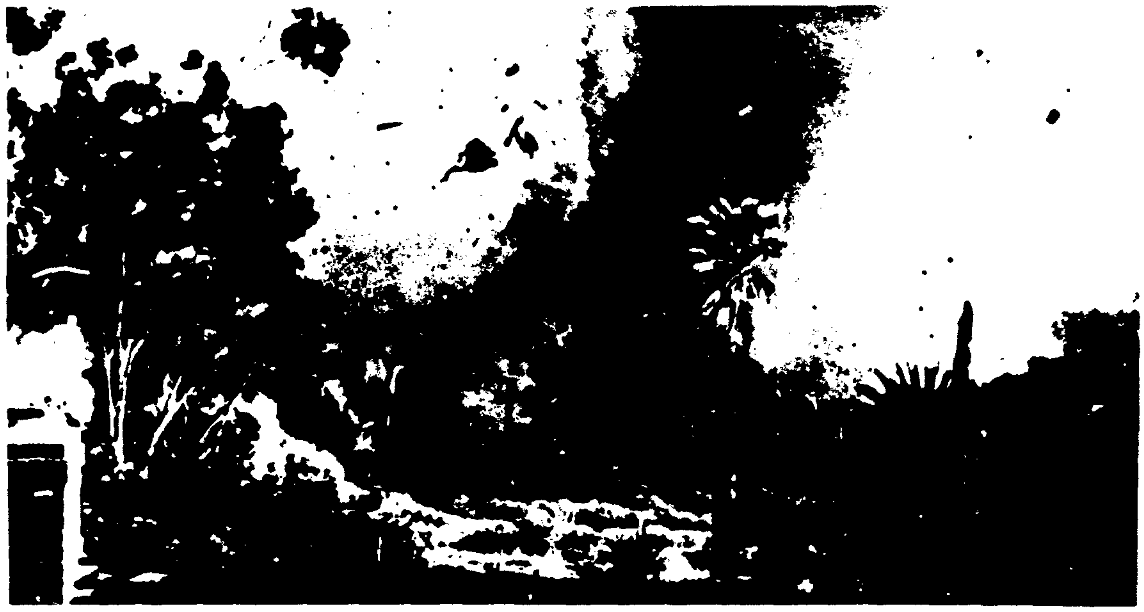


FIG. 11
FIRESTORM

FIG. 12
AFTER A FIRESTORM

REQUIREMENTS FOR SUCCESSFUL FOREST BURNING

Forest flammability depends on the amount and arrangement of dead vegetation at ground level, the moisture content of this fuel, and the weather at the time of burning. A technique for successful forest burning must involve feasible procedures for developing adequate fuels, for bringing the fuels to proper moisture content, and for burning under satisfactory weather conditions.

The major problems center around developing adequate dry fuel at the ground surface. A limited amount of litter can be supplied as leaves dropped from tree canopies killed by a desiccation treatment. Otherwise, the fuel needed for a running ground fire–the required objective–must be furnished by the dead and living woody vegetation already present at ground level. To serve as fuel, all living vegetation at ground level must be killed by a desiccation treatment. The moisture content of this material must be reduced to a low level–to a point where the heat produced by combustion and transferred to new fuels will exceed the heat absorbed by water remaining in the fuel.

The dry weight of forest vegetation–potential burnable fuel–ranges from 1/10 pound, or less, per square foot in an opening of light grass up to 5 pounds per square foot in the densest triple canopy jungle. This potential fuel has a high heat value–about 9,000 Btu. per pound for oven-dry wood–about half that of gasoline, and only slightly less than that of white phosphorous. Thus, it is not feasible to replace, or materially supplement, the natural vegetation with additives such as gasoline, oxidizing agents, or other fuel boosters. Such additives have been suggested by people unfamiliar with the subject, as a means for supplementing natural fuels or overcoming wet conditions. Logistic considerations totally preclude this approach over an area of any appreciable size.

An example will point out the problem of replacing natural woody fuels with additives. For a typical forest situation with a loading of potential fuel equal to 1.5 pounds per square foot, the incendiary equivalent is 950,000 gallons of gasoline, or 770 tons of white phosphorous per square kilometer. In Pink Rose I–the least effective of the Vietnamese forest fire raids–1 ton per square kilometer of PT-1 jellied hydrocarbon ignited a light ground fire that burned 22 tons of ground litter per square kilometer. In the most successful raid–Operation Hot Tip–1,850 tons of forest fuel per square kilometer were burned with an ordnance expenditure of only 1/2 ton of PT-1.

The use of fuel additives or oxidizers to extend the upper limit of moisture conditions for successful burning also is precluded by logistics. For example, 600 gallons of gasoline per square kilometer would be needed to vaporize the water added to the forest by a 1 percent increase in relative humidity. An increase from 40 up to 80 percent relative humidity, without any precipitation, can add almost a quarter million gallons of water to a square kilometer. A light rain of 1/10 inch would amount to more than a half million gallons on the same area.

Obviously, a successful burning technique must rely heavily on natural evaporation of water from the fuels to bring their moisture content down to a satisfactory level at the time of burning. Fuel moisture content is critical in determining forest fire behavior. During burning, heat is required to drive out the remaining water as steam, which displaces oxygen and nitrogen in the air around the fuel, and reduces the oxygen supply available for combustion. The water vapor also lowers flame temperature which contributes further to lower combustion efficiency.

Combustion is never 100 percent efficient in a forest fire. If woody materials were to burn at this ideal efficiency, they could burn even if they contained water equal to seven times their own weight (700 percent moisture content). But radiative efficiency is only 22 percent in ground fires which, on flat terrain, are spread by radiation from burning material

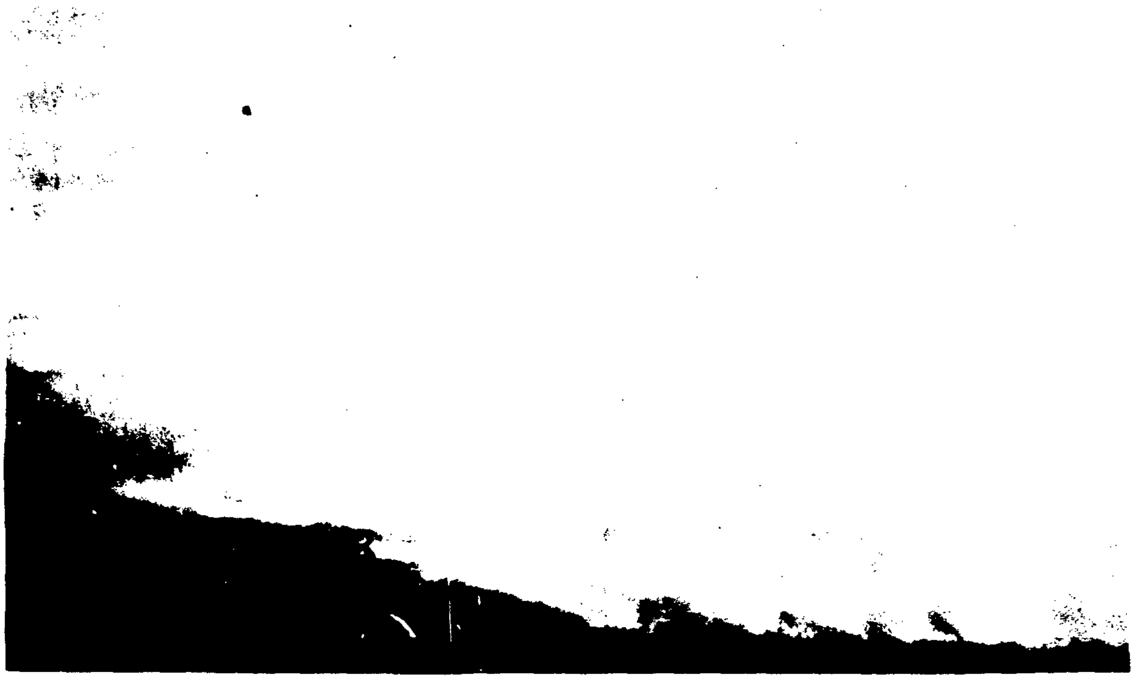


FIG. 13
OPERATION PINK ROSE I. T+9 MIN.

FIG. 14
OPERATION HOT TIP. T+9 MIN.

heating adjacent unburned litter. Consequently, ground fires will not spread if moisture content of the litter is greater than 25 percent. In crown fires the combustion efficiency averages 55-60 percent because both radiation and convective heat act on the vegetation above the burning ground surface fuels. Crown fires are possible whenever the aerial fuels have moisture contents below 120 percent. Even in firestorms the burning efficiency seldom exceed 70-80 percent.

Since all forest fires must be started as ground fires, 25 percent moisture in the ground litter is an absolute upper limit for incendiary operations of military value. A more realistic moisture content level for successful operations is 16 percent in the ground litter as well as the leaves, twigs, and small stems of shrubby vegetation needed to produce a running fire. A relative humidity below 50 percent at the time of ignition also is required for successful incendiary opeartions.

For a given fuel moisture content and specified weather conditions at time of burning, the importance of the ground fuel amount and arrangement on the intensity of ground fire that can be obtained is illustrated in Figures 15 and 16. Moisture content is assumed to be 15 percent for the leaves, twigs and small stems of all plants at ground level. Two weather conditions are specified: 1) Air temperature 70°F. and relative humidity 60 percent—a situation borderline for developing a running ground fire in the best of fuels: and 2) 90°F. and 40 percent—near the best burning situation to be expected in tropical hardwood forests, and slightly more favorable than commonly prescribed for burning the best of fuels in the U.S.

Two extreme degrees of woody plant fuel at ground levels are illustrated in the figures. Figure 15 shows the poorest of woody plant understories for burning. It typifies a common situation under dense hardwood forest canopy. The ground level plants mainly are seedlings of overstory trees, with occasional shrubby plants and vines. Few, if any, leaves and twigs are within 2 feet of the ground surface. When alive, the leaves and stems obscure horizontal vision and give a false sense of plant volumes. When dead and dry, the widely spaced small stems supply scant fuel. Dry weight of fine woody material, including stems under 1/2-inch diameter, is as low as 0.03 pounds per square foot and practically never exceeds 0.5 pounds per square foot. Volume of woody material per cubic foot of air space is quite low.

Figure 16 represents an ideal arrangement and amount of dead woody fuel for developing a running ground fire. It occurs in dense brushfields and can be found under open forest canopies. Leaves, twigs, and small stems are uniformly distributed from near the ground surface to the top of the shrubs. Horizontal visibility is obscured below the height of the shrubs, even when they are dead and dry. The dense ground cover is almost impenetrable. Dry weight of upright small fuels ranges from 0.2 pounds per square foot for semi-dense low shrubs up to 1 pound, or more, per square foot for dense shrub cover over 5 feet tall. Ratio of fuel volume to air volume is near ideal.

The tables above Figures 15 and 16 illustrate a range in depth of litter that may occur under each of these two classes of upright woody fuel. For fuel class A this litter must be supplied by overstory canopy. The range, from left to right is from 0 to 2 inch depth—.01 to .40 pounds per square foot. For example, in Figure 15 the symbol A0.5 represents the light upright woody fuel situation with a 1/2-inch litter depth. Thus 10 fuel situations—A0, A0.5, A1, A1.5, A2, and B0, B1, B2, B3, B4—are illustrated in the tables.

Relative fire intensities that can be expected for each of the 10 fuel situations under each of the two specified weather conditions are shown in the tables. These intensities are calculated for a no-wind situation and a spacing of 125 feet between ignition points over a 1-square mile area.

FUEL TYPE	AO	AO.5	A1	A1.5	A2
SHRUB WEIGHT (LB/FT²)					
STEMS < ½ IN.	.05	.05	.05	.05	.05
LEAVES	.01	.01	.01	.01	.01
LITTER	.01	.01	.20	.30	.40
T°70 RH60					
INTENSITY	0	0.5	1	2	3
FIRE TYPE	NO FIRE	CREEPING	CREEPING	CREEPING	CREEPING
T°90 RH40					
INTENSITY	0.3	1	3	5	9-10
FIRE TYPE	CREEPING	CREEPING	CREEPING	CREEPING	CREEPING OR RUNNING

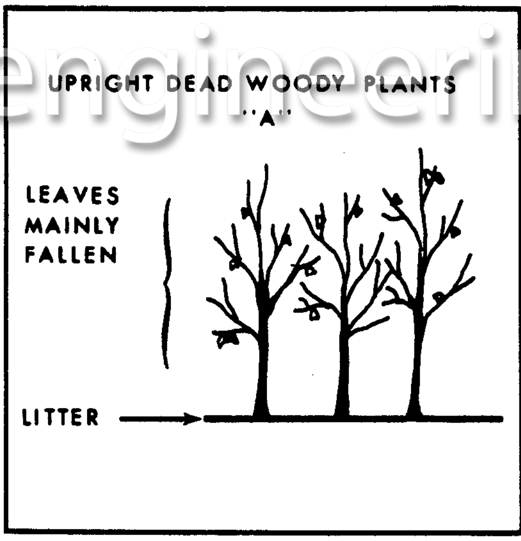


FIG. 15

MARGINAL UNDERSTORY FUELS

FUEL TYPE	B0	B1	B2	B3	B4
SHRUB WEIGHT (LB/FT²)					
TWIGS < ½ IN.	.25	.25	.25	.25	.25
LEAVES	.15	.15	.15	.15	.15
LITTER	.01	.20	.40	.60	.80
T°70 RH60					
INTENSITY	2	5	9	13	28
FIRE TYPE	CREEPING	CREEPING	CREEPING	RUNNING	RUNNING
T°90 RH40					
INTENSITY	7	17	35	70	120
FIRETYPE	CREEPING	RUNNING	RUNNING	CROWNING	CROWNING

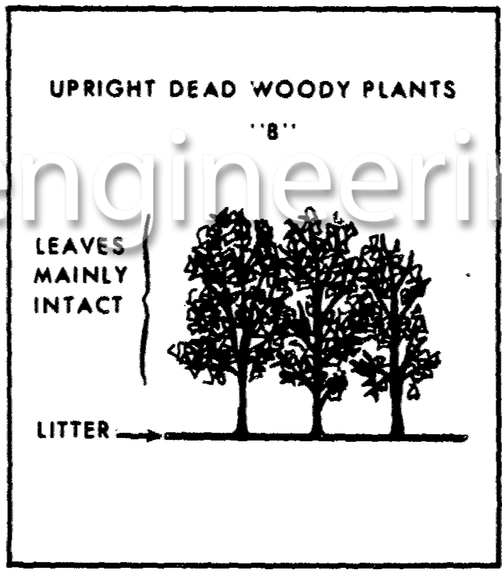


FIG. 16

OPTIMUM UNDERSTORY FUELS

The figures illustrate the fuel and weather situations under which a creeping ground fire will be generated, the point at which the fire can develop into a running ground fire, and the point at which fire intensity is sufficiently great to develop a crown fire. The lightest fuel loading will not burn at all under marginal conditions, and crown fires can only be obtained under near optimum conditions of fuel and weather.

Only two classes of ground level woody fuels have been shown, each with a full range of ground litter. Hundreds of intermediate classes occur—with various arrangements of dead shrubby plants having different sizes and shapes. Fuel moisture content at the time of burning can be expected to vary on either side of the 15 percent level assumed here. Numerous other combinations of air temperature and relative humidity will be encountered, and their effects on fire intensity will be modified by wind and terrain. Obviously, the thousands of different combinations of fuel moisture content and weather can not be illustrated. Instead, the expected fire intensity for a specific situation must be determined from data on fuel and climatic conditions and knowledge of how these conditions affect fire behavior. The remainder of this report discusses forest fire behavior as determined by specific fuel, weather and ignition system factors, and shows how these factors can be utilized in considering and planning forest incendiary operations.

VEGETATION TYPES

The most obvious requirement for forest burning is the presence of fuel to burn. The amount and arrangement of potential forest fire fuels depends on the type of vegetation and the climate. In considering susceptibility to forest fires, we can distinguish four primary vegetation types and four subtypes:

I. Grass
II. Shrub
III. Conifer Forest
  A. Pine
  B. Other conifers
IV. Hardwood Forest
  A. Deciduous
  B. Evergreen

Grass

The grass type includes all areas where more than 50 percent of the ground surface, as viewed from the air, is covered with grasses, forbs, sedges, reeds, canes or mosses. This includes such vegetative cover as tundra, steppe, savanna, prairie, meadow, marsh, bamboo, and open woodland.

The grass type varies from cover a few inches high with a fuel weight less than 0.04 pounds per square foot in the tundra to 20 foot tall stands of elephant grass that weight over 1 pound per square foot in parts of the Congo. Yet all grass type fuels have certain characteristics in common that produce a profound effect on fire behavior.

1. Individual plants with very thin leaves provide an extremely fast burning fuel that ignities easily when dry.
2. A moisture content that is well indicated by color. Green grass won't burn, yellow grass will.
3. A uniform distribution of fuel, both horizontally and vertically, produces fires that stabilize quickly and spread evenly and predictable.
4. Fuel surfaces that are completely exposed to rain, sunshine and the full sweep of the wind.

FIG. 17

GRASS STAND IN A FOREST CLEARING

AVERAGE HEIGHT 24 INCHES,
AVERAGE WEIGHT 0.10 LB./FT.^{2}

Consequently, fire behavior in grass types is particularly affected by the weather of the moment. A pasture that cannot be made to burn at dawn may nearly explode from a single spark at 3 p.m., and this fire once started may go out by itself shortly after sundown.

Some exceptions to normal fire behavior have been noted in some grass fuels. For example, many species of bamboo contain an abnormally high proportion of inorganic salts, particularly silicates, and burn much more slowly than would be predicted from considerations of weight and form alone. Several species of elephant grass (Neyraudia) and sword grass (Imperata) retain their green color when curing, and burn well even though they would be considered nonflammable on the basis of color. About the only way to predict fire behavior in these special fuels is to set test fires in representative stands and observe the results.

Shrub

The shrub type includes all areas where more than 50 percent of the ground surface, as viewed from the air, is covered with perennial woody vegetation whose lower leafy branches are within 2 feet of the ground (within the flame zone of the average ground fire). Locally, shrub types are known by such names as brushlands, scrub, chaparral, and bush, although scrub and bush are also used occasionally to refer to non-commercial forests and woodlands, and to savanna types with short trees. For forest fire rating purposes a stand of young trees whose lowest branches are still close to the ground would be classed as shrub rather than forest—the governing criteria is the availability of foliage within the ground fire flame zone.

Shrub types vary widely in height, form, and fuel weight. Semi-desert species (sagebrush, for example) are usually fine stemmed, and either low growing or thinly foliaged in order to reduce transpirational water losses. Fuel weights are usually less than 0.7 pounds per square foot. At the other extreme, brush thickets in cooler temperate climates may stand over 30 feet high and have more than 2-1/2 pounds of burnable material per square foot.

Evergreen shrubs—those that have green leaves yearlong—usually have a hard waxy leaf surface which serves to reduce moisture loss during dry periods. These leaf coatings are especially heavy in arid climates or those with long dry seasons. Since the coatings contain gums and resins they burn readily. The effects of such coatings on fuel flammability are least under climates with adequate yearlong precipitation.

Leaves of deciduous shrubs are newly formed each year; they lack a protective coating, and tend to drop from the branches during periods of moisture stress. Their normal flammability is low compared to evergreen leaves.

Despite this diversity, shrub fuels all have the following common characteristics:

1. Foliage extending into the surface fire flame zone so that the shrub will be automatically ignitied if foliage moisture is sufficiently low.
2. A large proportion of leaves and small twigs in comparison with stemwood and larger branches. Since burning rate varies inversely with fuel size, shrub fuels burn rapidly.

In shrub fuels—as with all woody vegetation—the moisture content of dead material responds to changes in atmospheric moisture, while that of living material is governed more by soil moisture. Depending on the climate, moisture contents of living plant parts also are governed by changes in the life processes within the plant. Consequently, moisture contents of green leaves, twigs, and small stems vary slowly over time, and during the year they fit orderly patterns within each climate.

FIG. 18
SHRUB TYPE

FIG. 19
TYPICAL ARID ZONE SHRUB

FIG. 20
TYPICAL TEMPERATE ZONE SHRUB

Flammability of shrub types depends on the amount of litter plus dead stems, twigs and leaves, as well as on flammability of the green leaves and twigs. In a mature stand of shrubs, the amount of dead material is largely a function of the climate. Shrub types are most flammable in climates where periodic droughts or extreme cold kills many branches, or entire plants, and where a layer of litter has developed under the shrubs. In this situation evergreen shrub types will burn naturally after 3–5 consecutive weeks of low rainfall averaging less than 1/4 inch per week. In most situations, however, burning of shrub types is not successful unless the amount of dead material has been increased by killing and desiccating the plants, through treatments such as mechanical crushing of the shrubs or spraying them with herbicides.

Simple systems relating fire behavior characteristics to fuel weight and weather cannot be prepared for shrub types as a whole. The types vary too widely in their physical characteristics, and in their yearly moisture trends as related to soil moisture and physical processes.

The manner in which air temperature, relative humidity, and windspeed affect the approximate relative rate of fire intensity is shown in Tables 1, 2, and 3 for a single situation. This is an evergreen shrub type–with sufficient litter and other dead material to be flammable without desiccation treatment–2 months into the dry season. The numbers are relative index values; that is, a fire will burn twice as intensely at an index of 40 as it will at an index of 20.

Table 1

Shrub Burning Index

Wind 0 – 10 miles per hour

Relative Humidity	Temperature (^{o}F)							
(%)	40	50	60	70	80	90	100	110
10	9	11	12	14	15	17	18	20
20	3	5	7	9	10	12	14	15
30	2	3	5	6	7	9	11	12
40	1	2	3	4	6	7	9	10
50	0	1	2	2	3	5	7	8
60	0	0	0	1	1	2	3	6
70	0	0	0	0	1	1	2	5
80	0	0	0	0	0	1	2	4

Table 2

Shrub Burning Index

Wind 11 – 25 miles per hour

Relative Humidity (%)	Temperature (°F) 40	50	60	70	80	90	100	110
10	28	35	40	45	50	54	58	72
20	12	20	26	33	37	41	45	50
30	7	10	15	20	25	30	35	40
40	3	7	10	14	19	24	29	33
50	1	3	5	8	12	18	23	28
60	0	1	2	3	6	11	19	25
70	0	0	1	1	3	6	12	22
80	0	0	0	0	1	3	6	20

Table 3

Shrub Burning Index

Wind 25 Miles per hour or more

Relative Humidity (%)	Temperature (°F) 40	50	60	70	80	90	100	110
10	49	58	66	74	82	89	95	100
20	26	37	46	53	59	66	74	81
30	13	19	26	33	41	47	56	66
40	7	12	18	25	33	41	49	57
50	4	7	11	18	25	34	43	50
60	2	2	3	8	13	22	33	44
70	0	1	2	3	6	12	23	39
80	0	0	0	1	2	5	13	36

Conifer Forest

The conifer forest type includes all areas where more than 50 percent of the ground surface, as viewed from the air, is covered by tree canopies, and more than half the trees are needle-bearing species such as pine, fir or spruce—with lowest foliage bearing branches more than 2 feet above the ground.

Conifer stands vary in height from 20 feet to more than 200 feet, and in fuel weight from 0.7 pounds per square foot to 3 pounds per square foot of burnable material under one-half inch in diameter. Conifer species are more flammable than are hardwoods, both because the shape and arrangement of conifer foliage is more conducive to effective heat transfer than is that of hardwood leaves, and because conifers contain a higher proportion of aromatic hydrocarbons than do most hardwoods.

In all forests–both conifer and hardwood–fires start and buildup in the ground level fuels. They then develop into one of the forest fire types from a creeping ground fire to a crown fire or a firestorm. For a given weather condition, fire intensity will depend to a large extent on the amount and arrangement of litter and woody material on the ground–as in shrub types. In contrast to both grass types and most shrub types, ground fuel temperatures and moisture contents in forests depend on the microclimates developed under the tree canopies. Kind and amount of ground fuel and its moisture content differ greatly among the various forest types.

Crown fire behavior, and firestorm potential are more directly related to the trees themselves, as distinct from the forest litter and undergrowth, and the four forest types are largely distinguishable on the basis of their ability to achieve and sustain crown fires. On this basis, the conifer type can be subdivided into two subtypes: Pines, and Other Conifers.

Conifer Forest – Pine

Pine types have two distinctive characteristics when compared to other conifers: they generally grow on drier sites and their crowns are more open (less space is occupied by foliage and branches). Consequently, soil moistures are lower, and the forest floor is more exposed to sunshine and wind. Both litter fuels and shrubs have lower moisture contents under pine stands than under stands of other conifers given the same weather conditions. Both ground and running surface fires burn more fiercely, and spread more rapidly in pine forests.

Pine forests will also sustain crown fires when conditions are still too damp for them to occur in forests of other species. However, pine forests have less total fuel near the ground than do most conifers. Thus, crown fires in pine are not as intense or destructive as those in other conifers.

Conifer Forest – Other Than Pine

In addition to growing in dense stands on comparatively moist sites, other conifers have branches and foliage on a greater proportion of the tree trunk than do pines of the same height and age. As a result, crown fuel weights are heavier and, equally important, small sized crown fuels are closer to the surface litter and underbrush which provides the heat to initiate crown fires. When the litter and underbrush have dried sufficiently to burn well (which usually takes at least 6 to 8 weeks of drought) all conifers will crown easily and burn extremely hot. Because of their heavier fuel weights, firestorms are more common in conifers other than pine, than in any other fuel type.

Hardwood Forest

The hardwood forest type includes all areas where more than half the ground surface, as viewed from the air, is tree covered, and more than half the trees are broadleaf species such as oak and beech–with lowest foliage-bearing branches more than 2 feet above the ground.

Hardwood types are extremely variable, and there are about as many exceptions as there are rules governing fire behavior in hardwoods. In spite of this, the following generalization is important: With the sole exception of Eucalyptus, [11/] pure stands of hardwoods will not support sustained crown fires. If sufficient litter and dry undergorwth is

11/ Fire behavior in Eucalyptus has been the subject of several monographs, the best of which is McArthur, A. G. Fire Behavior in Eucalypt Forests. Commonwealth of Australia, Department of National Development, Forestry and Timber Bureau Leaflet No. 107, 36 pp., illus. 1967.

FIG. 21
CONIFER FOREST - PINE

FIG. 22

SHRUB GROWTH BENEATH PINE STAND

FIG. 23

CONIFER FOREST
(SPRUCE-FIR-HEMLOCK)

A. IN LEAF

B. OUT OF LEAF

FIG. 24

HARDWOOD FOREST

present, individual trees, of even groups of trees may burn. However, fires in the tree crowns damp out very rapidly because living hardwood foliage requires more heat for ignition than it liberates in combustion.

The achievement of a crown fire or a firestorm in any hardwood forest requires external measures which will lower the moisture content of the crown foliage and branches and/or increase the amount of dead surface fuels that can transfer heat into the tree crowns.

Ground fires and running surface fires do occur naturally in hardwood forests, and we can distinguish between two hardwood subtypes.

Deciduous Hardwood Forest

Hardwoods that periodically lose all their leaves are much more subject to forest fires during the season when the leaves are off the trees. The dead leaves themselves add considerable fuel to the normal ground litter (a single large oak tree will drop about 900 pounds of leaves in the fall). The bare branches expose the fallen leaves to the full drying effects of sun and wind. In temperate climates, such as the Northern US and USSR, where leaf fall occurs in the autumn, surface fires burn the deciduous hardwood forests before the winter precipitation begins, and again in early spring. Later, new plant growth adds too much moisture to the ground fuels, and new tree foliage provides too much shade. In climates where leaf fall is brought on by drought rather than cold, surface fires burn during the entire dry period.

Surface fire behavior in deciduous hardwood types not in leaf is fairly well represented by the shrub burning indexes (Tables 1, 2, and 3).

Evergreen Hardwood Forests

Evergreen hardwoods forests retain green leaves yearlong. Virtually all the tropical forests loosely classed as "jungle" belong to this subclass. Such forests are generally found on moist sites to begin with, and the perpetual canopy of foliage serves to retain ground moisture through occasional short dry spells. Consequently, fires of any kind are rare in evergreen hardwoods (Eucalyptus excepted). Extensive fires occur only after unusual and prolonged periods of drought. Under normal circumstances, artificial defoliation is required to expose the surface litter to sun and wind before even the lightest ground fire will spread. To achieve a crown fire requires both partial defoliation and desiccation of the smaller twigs and branches in the tree and shrub canopy. After defoliation, evergreen hardwoods burn almost as well as deciduous hardwoods not in leaf. Without defoliation, evergreen hardwoods do not burn at all.

CLIMATE

Climate, or the normal annual weather pattern, has a profound influence on planning forest incendiary operations. The kind of vegetation at any location, and the ease with which it can be ignited and burned at any time of year is largely the result of interacting climatic and vegetative factors. Specifically, climate governs:

1. The rate of accumulation and amount of litter and ground fuels needed for forest fire initiation.
2. The moisture content of both dead and living vegetation.
3. The physiological processes that determine when, or whether, herbicide applications can be used to desiccate living fuels.

FIG. 25

EVERGREEN HARDWOOD FOREST

The most critical aspect of climate is its influence on development and accumulation of plant litter on the soil surface. This fuel layer–required for ignition and buildup of fire–is present under many dry or cold climates. It is virtually absent, except for current year leaf drop, in hot, humid climates where there is a continuous breakdown of woody material by chemical and biological agents.

Within any given fuel type, the profound local effects of climatic factors must be recognized and evaluated. The climate, modified by other factors such as geology, topography, soil type and drainage, determines density and total biomass of the existing vegetative cover that serves as fuel for burning. The yearly weather pattern also determines which species are present and how they grow and mature seasonally–whether or not they ever become dry fuels that can be burned without desiccation treatment.

The moisture content of living plants changes relatively slowly in response to weather. Just as each climate has a characteristic annual cycle of temperature, humidity and precipitation, so each type of vegetation has a fixed seasonal pattern of moisture content.

Grasses, being shallow rooted, respond rapidly to climatic change. Annual grasses mature rapidly and dry soon after the onset of moisture stress in the upper soil layers. Perennial grasses stay green longer, but are usually dead and dry by the end of summer. In climates with cold winter's dry grass is burnable from late summer or early fall until new growth appears in the spring. In mild winter climates, new growth begins early, and the grassburning season is restricted to summer and early fall.

Perennial shrubs and trees follow a more complex seasonal pattern of growth, maturity and drying. The flush of new growth, and high moisture content, always occurs at a time when adequate soil moisture coincides with daily mean temperatures above 60 degrees Fahrenheit. The new leaves of shrubs and hardwoods have moisture contents above 200 percent at this time, and even the persistent leaves of evergreen species contain 120–150 percent moisture. Within a few weeks, moisture contents begin to drop–very rapidly for the succulent new foliage, and more slowly for evergreen leaves–and reach levels of 100–120 percent after about a month. Foliage moisture will stabilize at about this level in warm, humid climates. In climates with dry summers or cold winters, moisture contents will continue to decline. The minimum moisture will depend on the length and severity of cold or drought, but 50–70 percent is the absolute minimum that plants can reach and still recover. Since dead fuel moisture is invariably lower than that of living plants even under the most extreme drought conditions, external measures that kill forest vegetation will always result in increased flammability.

Systemic herbicides aimed at killing and drying vegetation before burning must be applied during seasons favorable for entry and movement of the herbicides within the plants. Consequently, yearly weather patterns have great importance in planning desiccation treatments. The seasonal influence is of less importance in applying contact desiccants aimed at drying only the foliage. Desiccation treatments such as slashing or crushing of vegetation can be done at any time of year, but must be timed to prevent regrowth of succulent vegetation before burning.

Thus, climate to a large extent determines fuel characteristics of the natural vegetation, and it dictates the planning and execution of the various phases of the burning operation–from prefire desiccation treatment to the final ignition and burning. The first step in planning an incendiary operation is to study climatic records and decide whether odds are favorable for successful burning of dry vegetation during a certain month, or months. The next step is to plan the date for fuel desiccation treatment to provide the necessary quantity of dead, dry vegetation.

In developing recommended practices for burning, we have used rules of thumb and simple classifications and descriptions of world climates. The descriptions include those weather elements most important in predicting probability of good burning weather and in selecting dates for desiccation treatments.

Probability of Incendiary Success

When considering forest incendiary operations for any area of the world, the first climatic determination should be whether the locality will support fires in nearby forests at any time of year. This can be judged quite quickly from the climatic records. Find the driest month and the warmest month. Then calculate whether either month meets both of the following conditions:

1. The mean monthly precipitation (inches) is less than the mean daily temperature for the month (^{o}F.) times 0.03.
2. The number of rainy days (0.1 inches or more) is less than the mean daily temperature divided by 10.

If both conditions are not met for either the warmest or the driest month, then the location should not be seriously considered as a suitable target for forest incendiary operations. This does not mean that suitable weather for burning may not occur occasionally, and such occasions should be taken advantage of on an opportunistic basis. But the opportunities for successful burning will be too infrequent for inclusion in planned operations. For example: The driest month in Washington, D.C. is November, with a mean temperature of 47 degrees and 2.6 inches of precipitation occurring on 5.9 rainy days. The warmest month is August, with a mean temperature of 75 and 4.3 inches of rain on 7.5 days. Neither month meets our criteria (November would have to have less than 1.4 inches and fewer than 4.7 days; August has few enough rainy days, but must have less than 2.25 inches of rain). Consequently, any guerrilla forces in the woods surrounding the Pentagon will have to be routed by some other means than fire.

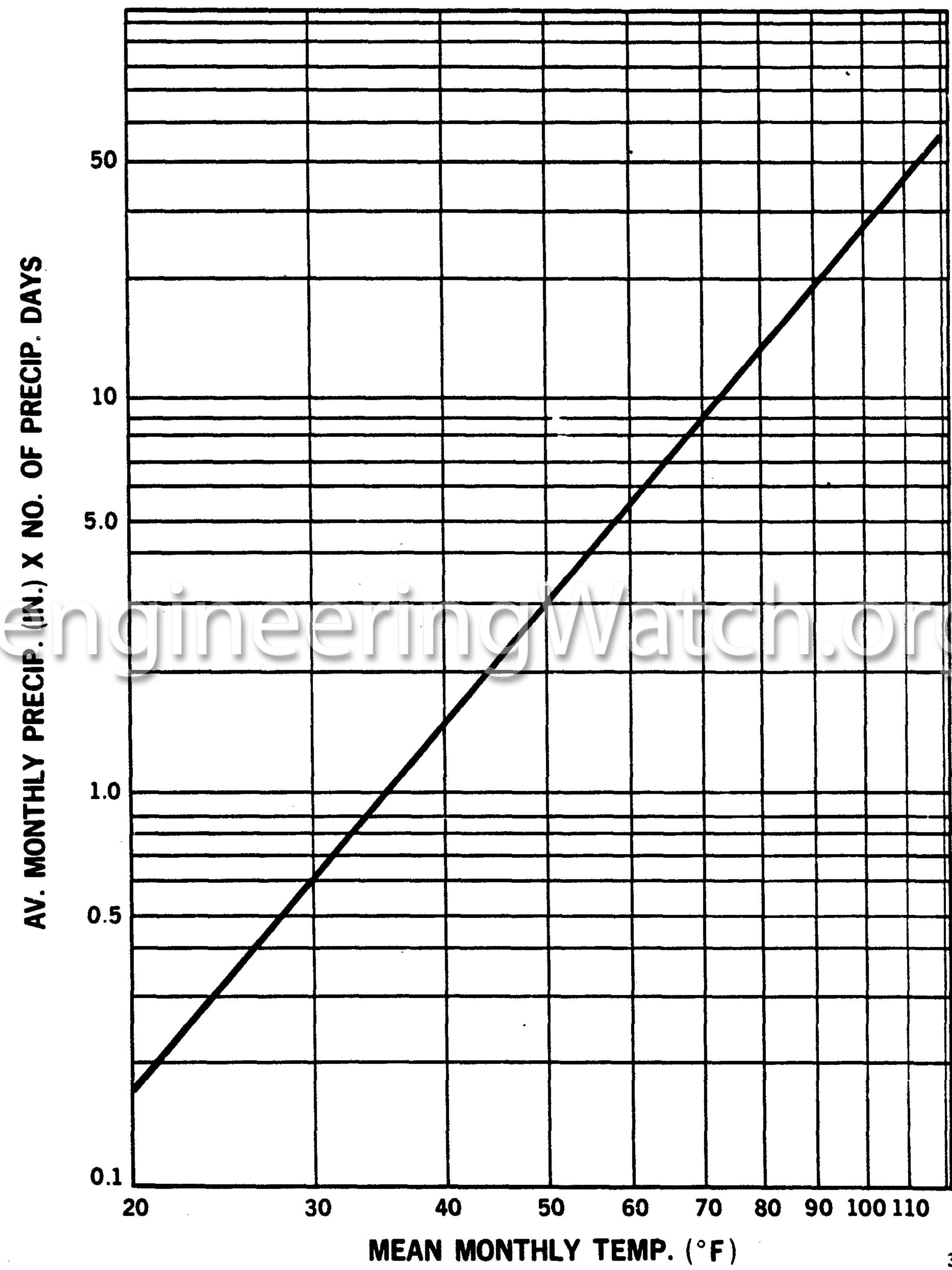
On the other hand, Missoula, Montana, has its driest month in February, with a mean temperature of 27, and 0.9 inches of precipitation on 4.4 days. Its warmest month is July: mean temperature 68, precipitation 1.0 inches on 3.7 days. February does not fit the criteria, but July does; so if military operations were being conducted in the vicinity of Missoula, the use of fire should be explored more carefully.

Once it is decided that an area can support planned incendiary operations over forests, the next step is to determine the frequency and extent of periods when successful burning is likely. Figure 26 is a plot of mean monthly temperature versus the PD value (mean monthly precipitation times the number of days with precipitation $\geq$ 0.1 inch). The diagonal line represents the 50/50 probability that a day chosen at random during the month will have weather suitable for forest burning. A point above the line means the chances are less than 50 percent—the greater the plus (+) value between the point and the line the poorer the odds. Likewise, the greater the negative (-) value below the line the better the odds for occurrence of a suitable burning day. When all 12 months of climatic data are calculated for a location, the result is a good picture of the forest fire possibilities during the year.

The climatic data for Missoula are in Table 4 and Figure 27. The plotted points show a better than even chance of weather favorable for incendiary operations from early July through early September—and little chance the rest of the year. The data show (-) humidity values of -4.0 and -3.9 for the two months of good burning weather—July and August. They also show that weather most favorable for growth of green vegetation occurs during May through June—when (+) values are highest. The decision as to whether 2 months of summer burning weather will justify the planned use of forest incendiaries will depend on the projected military situation, and on the possibilities for drying the green vegetation ahead of burning.

FIG. 26

PROBABILITY OF SUCCESSFUL BURNING



The yearly sums of (+) values and (-) values describe the yearly precipitation regime at a location, as illustrated for Missoula in Table 4. The sum of (+) values does not include any month when mean temperature is less than 40° F—the approximate lower limit for plant growth activity. At lower temperatures the level of soil moisture content is not considered as a major factor limiting plant growth. Also, in calculating the yearly sum of (+) values the maximum value used for any month is +40. This value represents a rather humid month—equal to an average monthly precipitation of 4.51 inches occurring on 10 rain days for a month having an average daily mean temperature of 60° F. The highest possible humidity value for a location is 12 times 40, or +480. The (-) values for all burn months—designated as "B" months—are totaled, regardless of monthly mean temperature, in calculating their yearly sum.

Table 4
Missoula, Montana

Month	Av. mean temp. (°F.)	Av. monthly prec. (Ins.)	Av. rain days, ≥ 0.1 in. (No.)	PD value	Humidity values from Figure 26 1/ (+) value	(-) value
Jan.	22	1.3	5.9	7.7	(7.4)	
Feb.	27	0.9	4.4	4.0	(3.5)	
Mar.	36	1.0	5.2	5.2	(4.0)	
Apr.	45	1.0	5.2	5.2	+3.0	
May	54	2.0	5.9	11.8	+7.9	
June	60	2.1	6.7	14.1	+9.0	
July	68	1.0	3.7	3.7		-4.0
Aug.	66	0.9	3.7	3.3		-3.9
Sept.	56	1.3	4.4	5.7	+1.4	
Oct.	46	1.2	4.4	5.3	+2.9	
Nov.	33	1.2	5.9	7.1	(6.2)	
Dec.	25	1.3	5.9	7.7	(7.3)	
Yearly sum 2/					+24.2	-7.9
No. of "B" mos. 3/						2

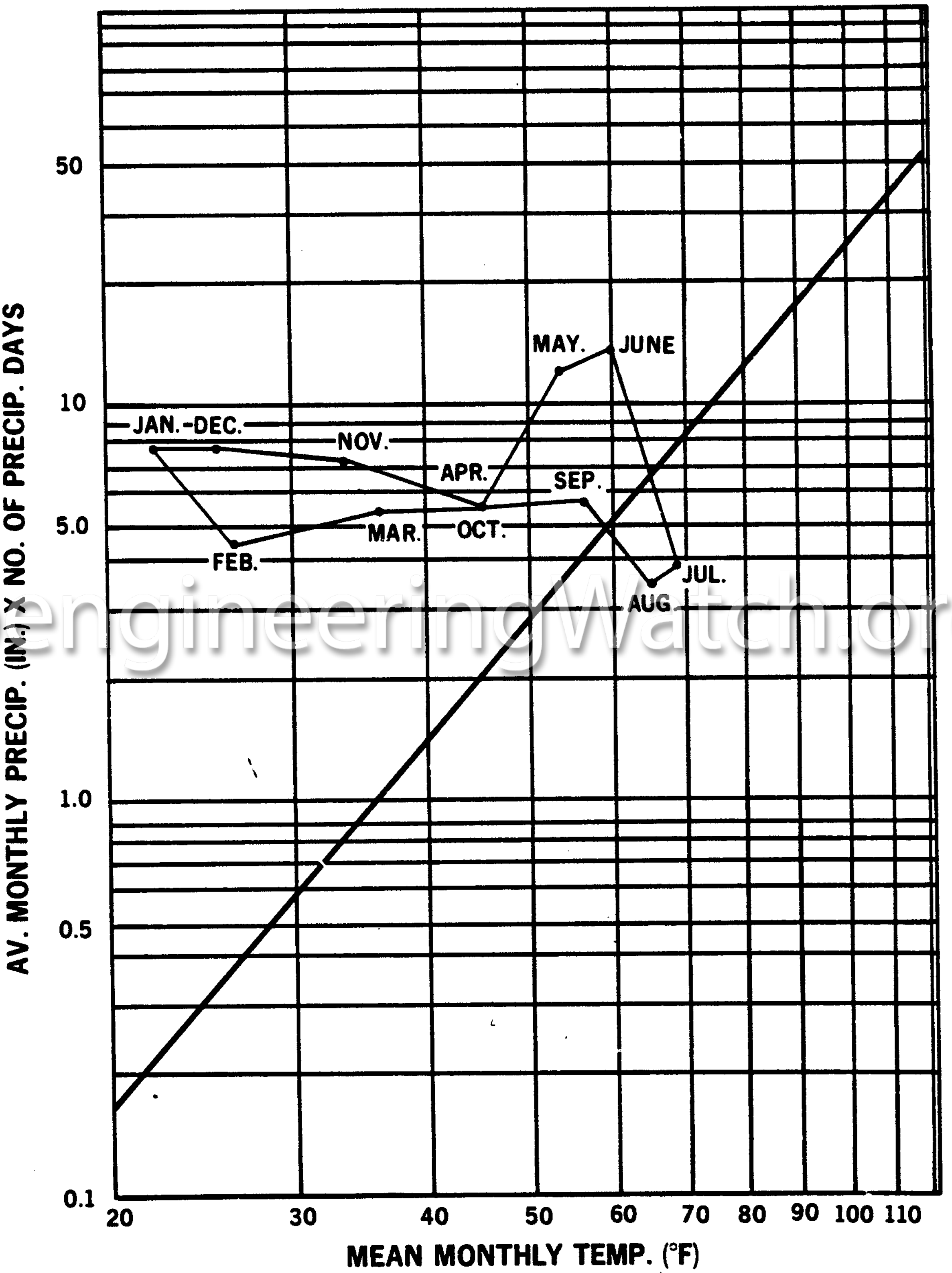
1/ A (+) or (-) value for any month is its PD value less the value of the 50/50 line for the mean temperature of that month. For example, in this table the PD value for January is 7.7, the 50/50 line value from Figure 26 for 22° mean temperature is 0.3, and the (+) value for January is 7.4.

2/ Yearly sum of (+) values does not include months with mean temperature less than 40°F.

3/ A "B" month is any one having a (-) value.

FIG. 27

PROBABILITY OF SUCCESSFUL BURNING MISSOULA, MONTANA



Fireclimate Classification

If the decision is reached to include forest fire operations as part of the planned military strategy, then a full-scale climatic analysis should be made in order to determine the probable ground fuel accumulations by forest types and define the need and timing requirements for special desiccation treatments. Climatologists have divided the climates of the world into natural groups that describe the airmasses responsible for the various climates. The major climate groups are subdivided, almost without limit, as needed to describe more precisely each local situation. The classifications presented by the different authors are rather complex. They are useful for many purposes, as in studies of natural vegetation and soil formation, and in determining potential use of crop plants. But none are directly applicable in planning the use of fire in forests. A fireclimate classification must distinguish among the myriad temperature-precipitation combinations for their effects on forest burning conditions and on plant growth.

Temperature Regimes:

The fireclimate temperature classification is based on severity of winter weather as a means of showing the season when air temperature restricts plant growth regardless of soil moisture conditions, and to show the seasons when plants grow and mature. Drying of natural fuels is geared to these seasons; and treatments aimed at desiccating green vegetation must be timed to fit the seasons.

Winter weather is defined by average monthly mean temperature (one half the sum of average maximum and average minimum daily temperatures for the month) and by average monthly lowest temperature (sum of lowest temperature recorded each year for the month divided by number of years of record). Both the mean temperature and the monthly lowest are averages for the 3 coldest months. This procedure eliminates consideration of occasional extremely low temperatures which are relatively unimportant in growth of native forest vegetation.

The six winter temperature regimes are:

Winter severity	Average temperature for coldest 3 months: Daily means (°F)	Average temperature for coldest 3 months: Monthly lowest (°F)
Frostfree (FF)	61, or higher	48, or higher
Mild (MI)	51-60	26-46
Cool (CL)	41-50	16-25
Short, cold (SC)	31-40	1-15
Long, cold (LC)	21-30	-15-0
Very cold (VC)	20, or lower	-16, or lower

NOTE: If a borderline location fits into 2 different temperature classes (For example, mean = 50° and lowest = 27°) the classification is set by the coldest class (above example = cool winter, CL).

Precipitation Regimes:

The fireclimate precipitation classes show: (1) the relative length and intensity of the dry season having weather suitable for burning, and (2) the relative amount and frequency of rainfall during that portion of the non-burn season having temperatures favorable for plant growth. Four lengths of burn season are recognized: none, short, long, and yearlong. The non-burn portion of the year is classed as either humid or nonhumid.

The distinction between a humid and a nonhumid month commonly is made by comparing average precipitation of the month with the potential evapotranspiration for the month. Potential evapotranspiration—a concept introduced by Thornthwaite [12/]—is the estimated amount of water needed for both evaporation losses and plant transpiration losses from a vegetation-covered land surface, assuming that plant growth is not inhibited by water shortage. Papadakis has published monthly potential evapotranspirational losses for 2400 locations over the world. [13/] The monthly loss can be approximated from average maximum daily temperature and average afternoon relative humidity as shown by the curves in Figure 28, which were adapted from the Papadakis data.

Months with average precipitation equal to or greater than estimated potential evapotranspiration are considered humid, designated as "H". Papadakis has described a dry month, designated as "D", as one in which water stored in the soil during previous humid months plus average precipitation of the month together equal less than one half of the estimated potential evapotranspiration for the month. Maximum water storage capacity of the soil is assumed to be 3.9 inches of water. At most locations a few months of the year are intermediate between humid and dry.

The data obtained during calculation of the burning odds at any location—as illustrated in Table 4—also can be used to designate months of adequate precipitation and months of moisture stress. For example, "H" months always show positive (+) values from Figure 27; and "D" months, with few exceptions, are also burn months, designated as "B", which have negative (-) values. In addition, the driest of the intermediate months are apparent because they have negative (-) values, which usually are small.

By combining length of burn season and adequacy of precipitation during the non-burn season, the 7 fireclimate precipitation regimes are:

Humid yearlong (HUYL)—No "B" months and no (-) values; yearly (+) values from a minimum of 200 down to 50, depending on temperature regimes as shown in Table 5. These locations have no "D" months, and usually have 6 to 12 "H" months.

Nonhumid, no burn season (NHYL)—No "B" months and no "D" months; but otherwise not in the humid class (see Table 5).

Humid, short burn season (HUSB)—1-4 "B" months, with yearly (-) values of 1-25; (for yearly (+) values see Table 5). Most locations have 4 to 10 "H" months 0 to 4 "D" months.

Nonhumid, short burn season (NHSB)— 1-4 "B" months, with yearly (-) values of 1-25; yearly (+) values too low for humid (see Table 5).

12/ Thornthwaite, C. W. An approach towards a rational classification of climate. Geogr. Rev. XXXVIII, pp. 55-94. 1948.
13/ Papadakis, J. Climatic tables for the world. Published by the author Cordoba 4564, Buenos Aires, Argentine. 1961.

TABLE 5

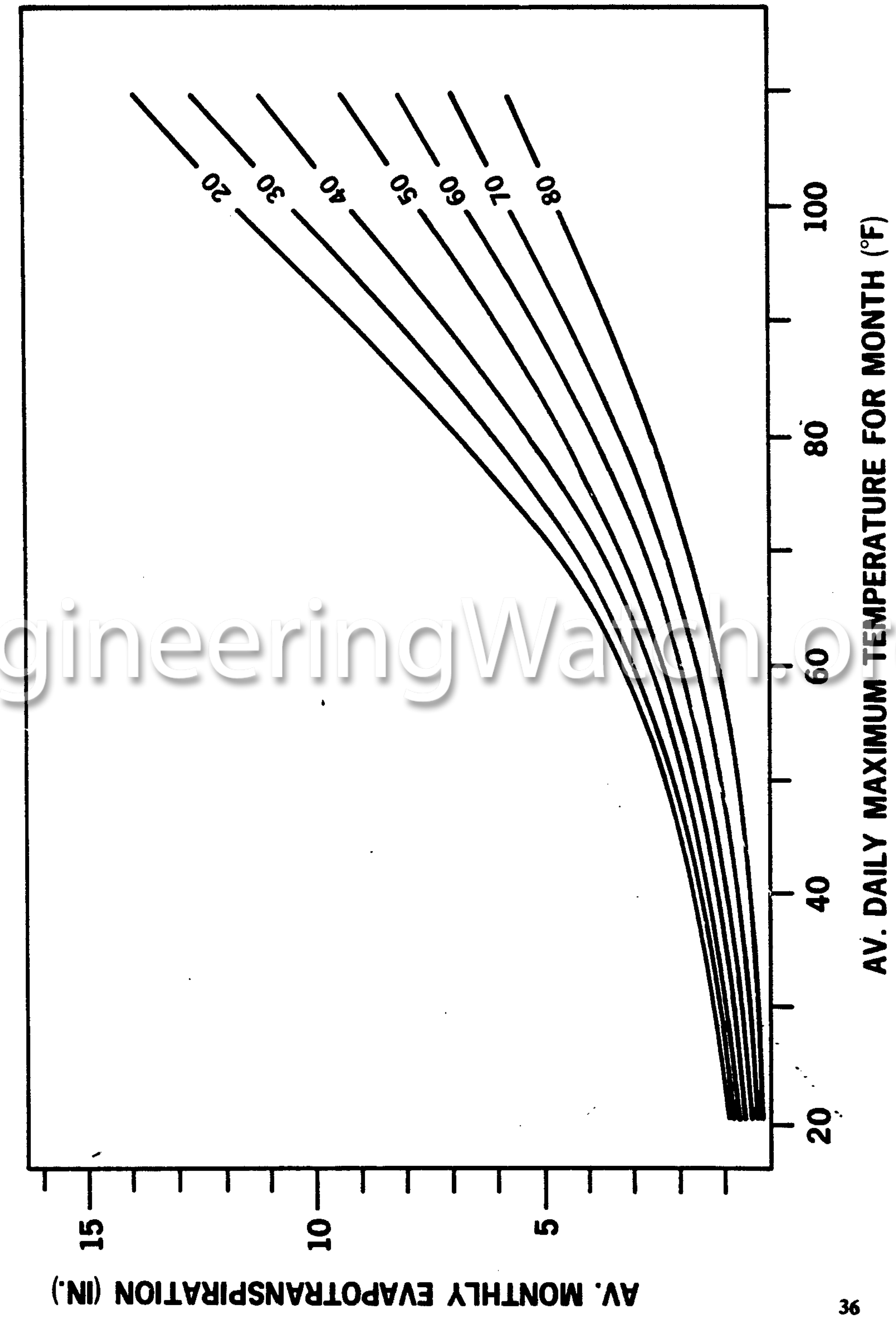
KEY TO IDENTIFICATION OF FIRE CLIMATES

TEMPERATURES: AVERAGES FOR 3 COLDEST MONTHS — DAILY MEAN (°F)	MONTHLY LOWEST (°F)	HUMIDITY VALUES: MONTHS HAVING (-) VALUES (NO. OF MONTHS)	TOTAL YEARLY (-) VALUES (SUM)	TOTAL YEARLY (+) VALUES (SUM)	CLIMATE SYMBOL
61 OR HIGHER	48 OR HIGHER	0	0	200-480	FF-HUYL
				0-199	FF-NHYL
		1-4	1-25	100-480	FF-HUSB
				0-99	FF-NHSB
			26-200	100-480	FF-HULB
				0-99	FF-NHLB
		5-12	1-200	100-480	FF-HULB
				1-99	FF-NHLB
				0	FF-DRYL
51-60 OR HIGHER	26 TO 47	0	0	125-480	MI-HUYL
				0-124	MI-NHYL
		1-4	1-25	100-480	MI-HUSB
				0-99	MI-NHSB
			26-200	100-480	MI-HULB
				0-99	MI-NHLB
		5-12	1-200	100-480	MI-HULB
				1-99	MI-NHLB
				0	MI-DRYL
41-50 OR HIGHER	16 TO 25	0	0	125-480	CL-HUYL
				0-124	CL-NHYL
		1-4	1-25	75-480	CL-HUSB
				0-74	CL-NHSB
			26-200	75-480	CL-HULB
				0-74	CL-NHLB
		5-12	1-200	75-480	CL-HULB
				1-74	CL-NHLB
				0	CL-DRYL
31-40 OR HIGHER	1 TO 15	0	0	100-400	SC-HUYL
				0-99	SC-NHYL
		1-4	1-25	50-480	SC-HUSB
				0-49	SC-NHSB
			26-200	50-480	SC-HULB
				0-49	SC-NHLB
		5-12	1-200	50-480	SC-HULB
				1-49	SC-NHLB
				0	SC-DRYL
21-30 OR HIGHER	0 TO -15	0	0	75-480	LC-HUYL
				0-74	LC-NHYL
		1-4	1-25	50-480	LC-HUSB
				0-49	LC-NHSB
			26-100	50-480	LC-HULB
				0-49	LC-NHLB
		5-12	1-200	50-480	LC-HULB
				1-49	LC-NHLB
				0	LC-DRYL
10-30 OR LOWER	-16 OR LOWER	0	0	75-480	VC-HUYL
				0-74	VC-NHYL
		1-4	1-25	50-480	VC-HUSB
				0-49	VC-NHSB
			26-100	50-480	VC-HULB
				0-49	VC-NHLB
		5-12	1-200	50-480	VC-HULB
				1-49	VC-NHLB
				0	VC-DRYL

FIG. 28

POTENTIAL EVAPOTRANSPIRATION -- FOR AFTERNOON RELATIVE HUMIDITIES OF 20 TO 80 PERCENT

(APPROXIMATIONS FROM PAPADAKIS DATA)



Humid, long burn season (HULB)—5, or more, "B" months, or yearly (-) value of 26, or more; (for yearly (+) values see Table 5). Most locations have 3 to 9 "H" months and 1 to 7 "D" months.

Nonhumid, long dry season (NHLB)—5, or more, "B" months, or yearly (-) values of 26, or more; yearly (+) value at least 1 but too low for humid (see Table 5).

Dry yearlong (DRYL)—Most months designated as "B"; no yearly (+) value (see Table 5). No months are "H"; all, or most, are "D".

The climate at any location can be readily classified by use of the identification key in Table 5. For example, the coldest 3 months at Missoula have an average mean temperature of 25°F and an average monthly lowest of -2°F. This puts the location in the long cold (LC) winter. From Table 4, 2 months have (-) values with a yearly total of -7.9, and yearly (+) values total +24.2—the climate is LC-NHSB (Long cold winter; nonhumid, short burn season).

The climate at any location will fall into one of the 42 possible climatic situations shown in Table 5. A number of these situations seldom occur at locations for which climatic records are available, or they will occupy only limited geographic area. Appendix B lists for the most important climates—or combinations of climates—the typical vegetative cover, litter weights, desiccation requirements, burning conditions, and representative locations.

Fuel Characteristics

Fuel and air are the two factors that determine whether and how a forest fire will burn. In the two preceding sections, we have discussed forest fire behavior in terms of vegetation and climatic types. But these are merely convenient descriptors for generalizing a large number of more basic fuel and atmospheric factors. In order to have a real understanding of forest fire behavior, it is necessary to examine forest combustion, not in terms of biology or geography, but as a physical-chemical process.

To oversimplify only slightly, combustion of wood is a chemical chain raction that is the exact reverse of the process of photosynthesis which originally produced the wood. In the combustion of wood, cellulose ($C_6H_{10}O_5$) and oxygen combine to produce carbon dioxide, water and excess energy in the form of heat. This process takes place in three distinct phases: charring, flaming, and glowing. To examine the process more closely, lets look at what happens when we put a lighted candle underneath the Christmas tree, too close to one of the branches.

First, heat from the burning candle is absorbed at the surface of nearby needles and twigs. This absorbed heat is transfered by conduction into the interior of the needle or twig, and heats the woody material beneath the surface. The rate of heat conduction varies inversely with the density of this material and directly with its moisture content. The temperature of the wood rises as heat moves from the surface inwards. Once a layer begins heating, the moisture in that layer starts to vaporize and is driven off into the air as steam. When the temperature has risen further, the wood itself begins to decompose into carbon charcoal and a complex mixture of flammable gaseous hydrocarbons which are also driven off, together with the steam coming from the deeper, cooler layers of the needle or twig. Soon the surface layer consists of nearly pure charcoal. This is the charring phase of combustion.

Once the charring process has reached deeply enough into the twig so that the vapors driven off contain more hydrocarbon than steam, then the vapors themselves will burn as they mix with oxygen in the air around the twig. This flaming, or burning of evolved gases, will continue so long as the needle or twig is producing hydrocarbons at a sufficient rate. This is the flaming phase of combustion.

Meanwhile, the charcoal surface of the twig is also burning—in a very simple pair of reactions where solid carbon changes to carbon monoxide right at the charcoal surface, and the monoxide is further oxidized to carbon dioxide as soon as additional oxygen becomes available. The latter reaction takes place very close to the surface: the blue flame right next to the logs in the fireplace is the CO -CO_2 zone. This is the glowing phase of combustion. Since the initial reaction requires the direct contact of oxygen at the solid charcoal surface, glowing is a slower process than flaming and continues long after the flames have died out.

From the preceding discussion, several fuel characteristics are obviously important:

1. Moisture content. Fuel moisture is far and away the most important factor in determining whether or not a piece of wood will burn. Moisture absorbs heat, increases conductivity, dilutes flame gases and generally reduces flammability for all three phases of combustion. Fuel moisture relationships will be discussed in detail later.

2. Thickness. The thinner the fuel, the sooner heat is conducted all the way through, and the more rapidly surface layers will reach the decomposition temperature. Thin fuels burn sooner and more rapidly than do thick fuels because they require less energy to reach the temperature where flammable gases are emitted.

3. Surface – Volume Ratio. Since all heat is originally received at the fuel surface, the surface area of the fuel determines the heat input. Since this heat is eventually distributed through the whole mass of fuel, the volume of fuel determines how fast the temperature will rise in the surface layer. If all fuels were the same shape, the effect would be adequately determined by fuel thickness. But forest fuels vary in shape from smooth cyclinders to rough plates, so thickness alone is not an adequate guide to ignitibility or heat content. The higher the ratio of fuel surface to fuel volume, the higher the rate of combustion, once the fuel particle is ignited. Table 6 lists the surface volume ratios of some common forest fuels and fuel mixtures.

Table 6

Surface/Volume Ratios of Some
Common Forest Fuels and Fuel Mixture

Fuel	Surface/Volume (ft.$^{-1}$)
Fuel Particles	
Wiregrass blade	8,700
Beech leaf	6,770
Maple leaf	4,690
Sedge grass blade	3,590
Oak leaf	3,500
Scotch Pine needle	2,770
Rhododendron leaf	2,440
Ponderosa Pine needle	1,850
Norway Spruce needle	1,450
1/4 inch twig	190
1/2 inch twig	95
Fuel Mixtures	
Grass	3,500
Shrub	1,700
Pine	
Aerial fuel	825
Litter	1,890
Other Conifer	
Aerial fuel	830
Litter	1,380
Hardwoods	
In leaf	
Aerial fuel	1,370
Litter	2,490
Out of leaf	
Aerial fuel	230
Litter	2,630

4. Chemistry. Forest fuels are not pure cellulose. They contain varying amounts of lignin (less flammable than cellulose), fats, oils, add other higher hydrocarbons (much more flammable than cellulose), and inorganic trace elements which catalyze various combustion reactions and may affect flammability either way. 14/ Short of laboratory analysis, the only way to determine whether an unfamiliary species has an unusual chemical makeup is to conduct test fires and observe such features as flame height, amount of residual ash, etc.

14/ Two widely separated investigators have found a strong inverse correlation between combustion rate and inorganic ash content of the fuel.

Philpot, C. W. Mineral content and pyrolysis of selected plant species. USDA – Forest Service Research Note INT-84, 4 pp. 1968.

King, N. K. and R. G. Vines. Variation in the flammability of the leaves of some Australian forest species. CSIRO Div. of Applied Chem. Unnumbered Report, 14 pp. July 1969.

5. Full Bed Characteristics. In the previous example, the combustion process was started by exposing a few twigs and needles to the heat from a burning candle. This may result in a few burned twigs and needles—or it may result in a totally destroyed house. The outcome depends not so much on the properties of the individual fuel particles as it does on how those particles are arranged together to form an overall accumulation of fuel, or fuel bed. For once fire has burned a short distance from the external heat source (in this case the Christmas candle), the forest fuels themselves become both heat source and heat receiver. The important properties of the fuel bed are those that affect heat transmission. These are

a. Amount. The total weight of fuel available for burning determines the total potential heat output of the fire. Since not all of the vegetation is burnable (living stems and branches larger than an inch or so in diameter never burn completely under any circumstances, for example), fuel weight is not the same thing as biomass, a term frequently used in forestry and ecology to express the total weight of organic material. Although the weight of available fire fuels actually varies with weather conditions, the term is commonly used to mean the weight of living and dead material one-half inch in diameter or less. Under average forest fire conditions in the United States, this is the fuel that contributes to fire spread. Figure 29 shows the weight of available fuel for several common tree species of the United States. The values refer to foliage and branches of the trees themselves. Weights of ground litter and understory shrubs or grass are not included.

b. Vertical Distribution. Given an adequate amount of available fuel, the vertical distribution of particles has the greatest influence on fire spread through a fuel bed. Figure 30 illustrates various natural distributions. In a typical forest or brushfield, 60-80 precent of the potentially available fuel is aerial, above the surface litter. If there is an empty space greater than about twice the flame length between the surface litter and these aerial fuels, they will not ignite. This means that if the average height of the lowest branches in a forest is 10 feet above the ground, a crown fire will not occur until burning conditions are such that the understory litter and shrubs will burn with flames at least 5 feet high. Figure 31 shows the relationship between flame height, fuel weight, and the shrub burning index (Tables 1, 2, and 3, page 20).

Appendix B lists typical litter and shrub fuel weights by climatic and vegetation type. These values should be used when no other data is available. If direct observations of the target area are possible, fuel weight can be calculated by assuming that each inch of conifer litter depth represents 0.2 pounds per square foot, each inch of hardwood litter represents 0.07 pounds per square foot, and dead shrub cover represents an additional 0.125 pounds per square foot for each foot of shrub height when the ground is completely shrub covered. Thus a forest with 1 inch of dry conifer litter and a 30 percent cover of dead shrubs 4 feet high will have about 0.35 pounds of ground fuels per square foot

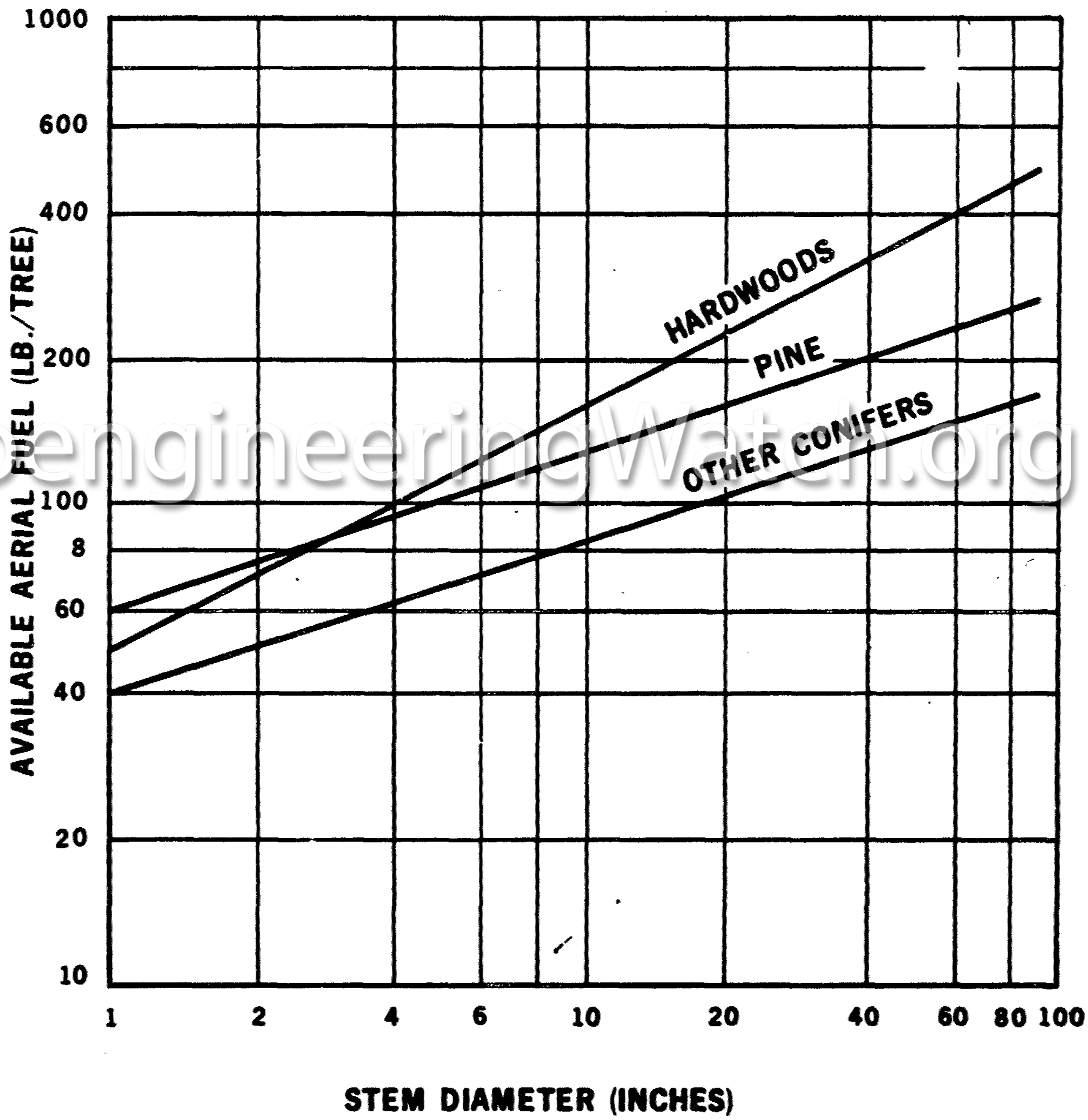
$$\left[(1 \times 0.2) + (0.125 \times 4 \times 0.3)\right]$$

Flames will be 6 feet high when the burning index is 16

Knowledge of understory shrub cover is vital to the prediction of fire behavior in forest. When ground access to the target area is denied, shrub estimates must be made from aerial observations or interpretation of aerial photographs.

FIG. 29

AVAILABLE FUEL WEIGHT



A. POOR

NO AVAILABLE FUEL BETWEEN LITTER AND CROWN FOLIAGE

B. MARGINAL

LARGE GAP BETWEEN SHRUBS AND TREE CROWNS

C. GOOD

FUEL AVAILABLE FROM GROUND TO TOP OF CANOPY

D. IDEAL

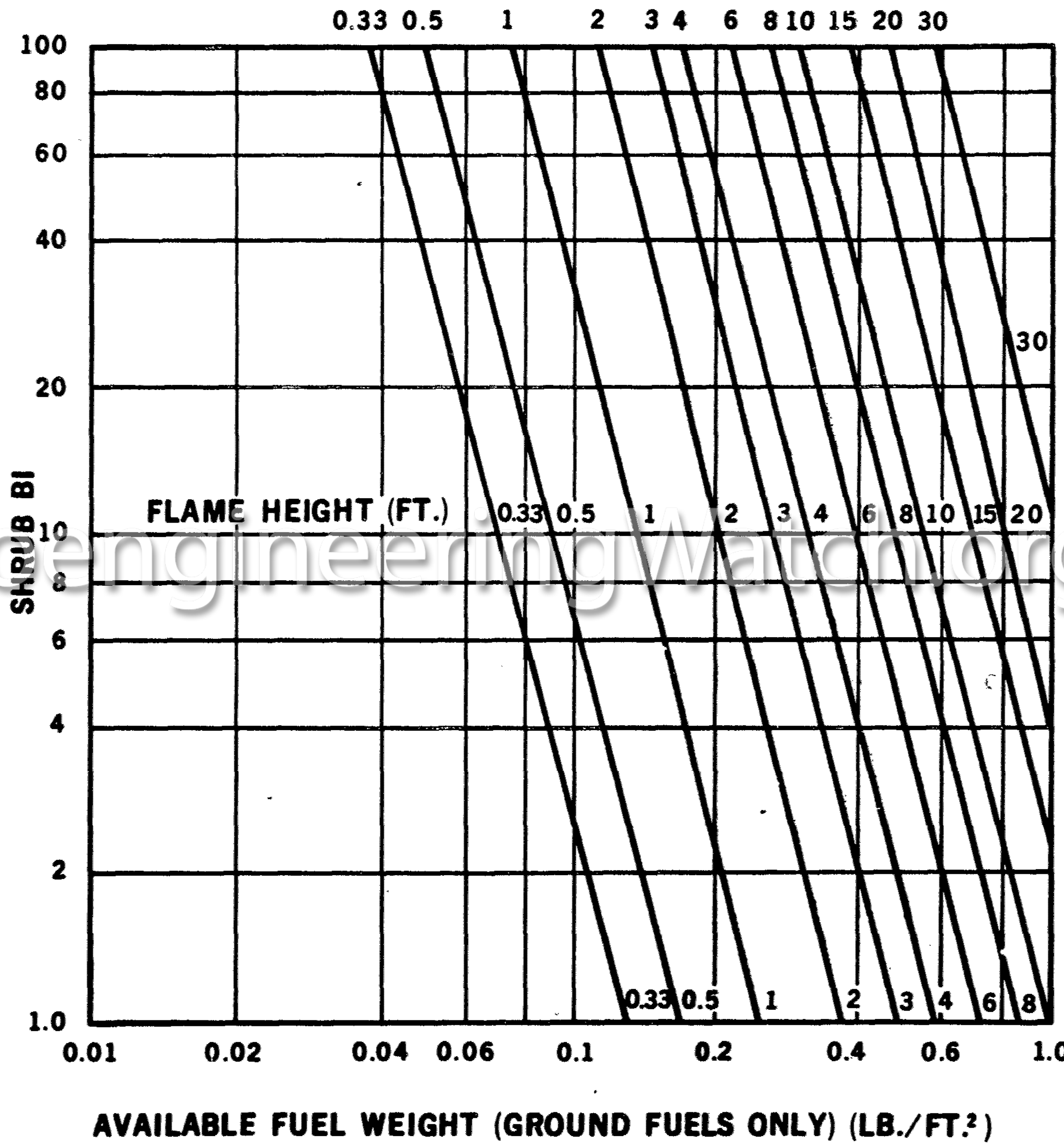
CONTINUOUS FUEL FROM GROUND TO TOP OF CANOPY

FIG. 30

VERTICAL FUEL DISTRIBUTION

FIG. 31

FLAME HEIGHTS IN LITTER AND SHRUB FUELS BENEATH FOREST STANDS



Aerial observers have a natural tendency to overestimate shrub cover because they are misled by looking at conditions along the edges of roads and clearings where shrubs are always unusally dense. Observers should be instructed to try to look through small gaps in the tree crowns to check the portion of the ground occupied by low-growing vegetation. Pilots should fly into the shadows (generally north to south), and keep ground speeds as low as practical. An altitude of about 1500 feet is optimum unless aircraft speeds are so high that altitude must be increased to allow the observer enough time to scan each spot. The maximum altitude from which accurate understory determinations can be made without binoculars is about 3500 feet.

For aerial photographic interpretation of understory shrub density, Ektachrome film Type 2448 at a scale of 1:8000 and flown at right angles to the shadows (generally east to west) is optimum, but photos at any scale between 1:2500 and 1:18,000 are usable. When using aerial photos, the interpreter should pick out the shrub color and texture characteristics by looking at clearing edges, and then estimate understory shrub density by slowly moving his view into the tree stand. 15/

WEATHER CHARACTERISTICS

Since the moisture content of the fuel is the overriding determinant of forest fire behavior, it is not surprising that weather variables are primarily important for the manner in which they affect fuel moisture. Temperature, humidity, wind and precipitation all affect the moisture content of woody materials—acting directly on dead wood, and indirectly on living plants by influencing the physiological moisture regulating processes. 16/ The moisture content of living plants changes relatively slowly. The effect of weather on living fuel moisture has already been discussed in the section on climate. But dead twigs, leaves and other litter depends more on the weather of the moment than it does on the seasonal climate. The following weather variables have a direct effect on the drying of dead forest fuels.

Precipitation: Obviously, rain or snowfall will greatly increase the moisture content of forest litter. Since water holding capacity differs among various forest fuels, the amount of rainfall required to saturate forest litter varies with both the amount and type of litter. Table 7 shows the rainfall requirements for each of the standard vegetation types.

Not all rainfall reaches the forest floor. A substantial amount is caught on the twigs and foliage of the upper canopy, and evaporates without ever reaching the ground. The amount thus lost depends on the amount of surface area in the foliage and on the amount of rain in the storm. Table 7 also shows the interception losses that can be expected in each of the vegetation types, and the amount of rain needed to saturate both light and heavy litter accumulations. As shown in the last column, it takes nearly twice as much rain to saturate a dense accumulation of shrub or hardwood litter as it does for an equal weight of grass or conifers.

15/ More complete guidelines and photo interpreter's keys can be found in Lund, H. G. and G. R. Fahnestock. Color aerial photography for interpreting understory vegetation. USDA-Forest Service. Final Progress Report PNW-2103: FA-2.2. /9 pp., illus. July 1968

16/ The detailed mechanics of wood-moisture relations are beyond the scope of this paper. Three excellent references are available:

For dead wood, see Simard, A. J., The moisture content of forest fuels – I: A review of basic concepts. Forest Fire Research Institute, Ottawa, Ontario. Information Report FF-X-14. 47 pp. July 1968.

For living vegetation, see Kozlowski, T. T., Water metabolism in plants. Harper and Row, N. Y. 227 pp. 1964

For living plants under drought stress, see Zgurovskaya, L. N. and Yu. L. Tsel'niker., The influence of irrigation after a prolonged drought on transpiration and on the condition of the absorbing roots of arboreal species in the Derkul' Steppe. (Translated from Russian). Office of Tech. Svcs., U.S. Department of Commerce., PST Cat. No. 311. 10 pp. 1961.

Table 7

Precipitation Effects on Forest Litter Moisture

Fuel Type	Saturation Moisture Content (% dry weight)	Interception Loss: Initial Storage (inches)	Interception Loss: Evaporation Loss (% of storm total)	Inches of rainfall required to saturate litter: 0.1 lb/ft^2	Inches of rainfall required to saturate litter: 1 lb/ft^2
Grass	280	0.000	0	0.054	0.54
Shrub	365	0.01	10	0.088	0.79
Pine	170	0.03	20	0.071	0.44
Other Conifer	165	0.05	35	0.099	0.54
Hardwood					
Inleaf	350	0.03	25	0.120	0.93
Out of Leaf	350	0.02	10	0.095	0.77

The time required for forest litter to dry out after a rain depends on the ensuring weather. The drying rate also varies with the amount and kind of litter, and on the type and density of overstory vegetation. The concept of "drying days" has proven useful in simplifying all these factors for planning forest burning operations. A drying day is defined as one on which:

1. No rain has fallen in the preceding 24 hours.
2. Minimum relative humidity drops below a value equal to one-half the maximum temperatures + 25 percent. For example, if the maximum temperature is 90^0 the humidity must be below 70 percent ($90/_2$ + 25); if the maximum temperature is 50 degrees, the humidity must be below 50 percent.
3. Afternoon cloud cover is less than 3/8.

A day which satisfies one, but not both, of criteria 2 and 3 is counted as 3/4 of a drying day. A day which satisfies neither criteria 2 nor 3 is counted as 1/2 day. The countdown starts on the first day following precipitation. Table 8 lists the number of drying days required to bring surface fuels to under 25 percent moisture content, the point at which they will barely sustain combustion. If the preceding rain was sufficient to fully saturate the litter (see Table 7, above) then the "Fully Saturated" column applies. If the preceding rain was less than that shown in Table 8, the "Partially Saturated" column should be used

Table 8

Drying Days Required to Reach Flammable Limit

Vegetation Type	Fully Saturated	Partially Saturated
Grass	2	1.5
Shrub	3	2
Pine	5	3
Other Conifer	8	5
Hardwoods		
In leaf	4	3
Out of leaf	3	2

Relative Humidity: Once the excess water added by rain or dew has evaporated, a different mechanism begins to control fuel moisture. Forest fuels are hygroscopic; at moisture contents below 25–30 percent they gain or lose moisture directly to the surrounding air without any free moisture such as rain or dew being present. The water exchanged between air and wood at moisture contents below 25 percent is known as bound water because it is chemically bonded to the cell walls of the fuel. The amount of bound water in forest fuels is controlled primarily by the relative humidity of the surrounding air, with air temperature having a strong influence. Because of chemical and physical differences in the structure of various forest fuels, each fuel type has a different relationship between its moisture content and the air's relative humidity. Figure 32 shows the relationships between fuel moisture content and relative humidity for several common forest fuels. The curves in Figure 32 represent the moisture content that the fuel would reach if exposed for an indefinite period of 70°F. and the specified relative humidity. The curves can be corrected for temperature by multiplying the fuel moisture by $1 - (\frac{7 - 70}{100})$. For example, the curve shows pine needles to have a fuel moisture of 9 percent when the relative humidity is 60 percent and the temperature is 70 degrees Fahrenheit. The fuel moisture at 60 percent humidity and 100 degrees would be $9 \times 1 - {}^{30}/100$ or $9 \times 0.7 = 6.3$ percent.

Because bound water is chemically bonded to the fuel, energy is required to remove it from the fuel surface and energy is released when water is absorbed from the air into the fuel. For this reason, the relationship between fuel moisture and relative humidity for a particular fuel is different when the humidity is rising (late afternoon, for instance) than it is when it is falling (in the morning). Figure 33 shows a typical set of curves.

Forest fuels do not react instantaneously to changes in temperature or humidity. Their rate of change in moisture content depends on the chemical and physical properties of the fuel particle, particularly its thickness, on the magnitude of the change in humidity, and on whether the fuel is adsorbing or desorbing moisture. Table 9 shows the time required for common forest fuels to reach approximate equilibrium when the relative humidity is varied between 20 percent and 80 percent.

Table 9

Timelags of Common Forest Fuels

Fuel	Timelag (hours) Adsorption (20% - 80% RH)	Timelag (hours) Desorption (80% - 20% RH)
Grass	3/4	1/2
Shrub or Hardwood leaves	5	4
Conifer Needles	7	5
1/2-inch Twigs	30	25

Because of the important, but complex, relationship between fuel moisture and changes in atmospheric humidity, accurate prediction of forest flammability requires knowledge of the daily humidity pattern, not just a single mean or instantaneous value. If a single value must be used for planning purposes, the daily minimum humidity is the most useful; it gives a good indication of whether or not fuel moisture will drop low enough to permit fires to spread. Incendiary success is virtually impossible unless the minimum humidity is below 70 percent, and conditions are marginal unless minimum humidity drops below 50 percent. The minimum humidity value alone given no information on how long fires will continue to spread, once ignited.

FIG. 32

EQUILIBRIUM MOISTURE CONTENT

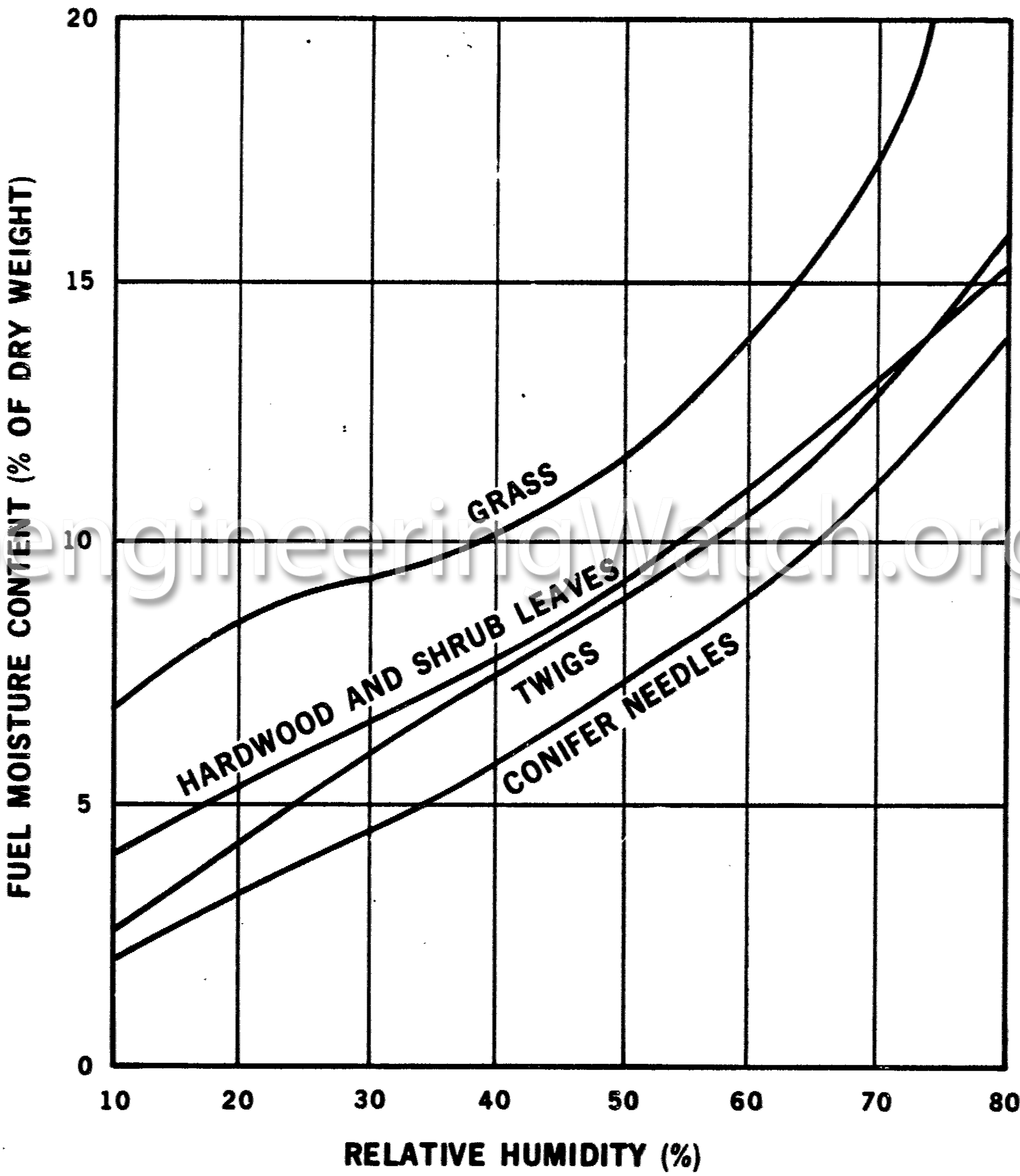
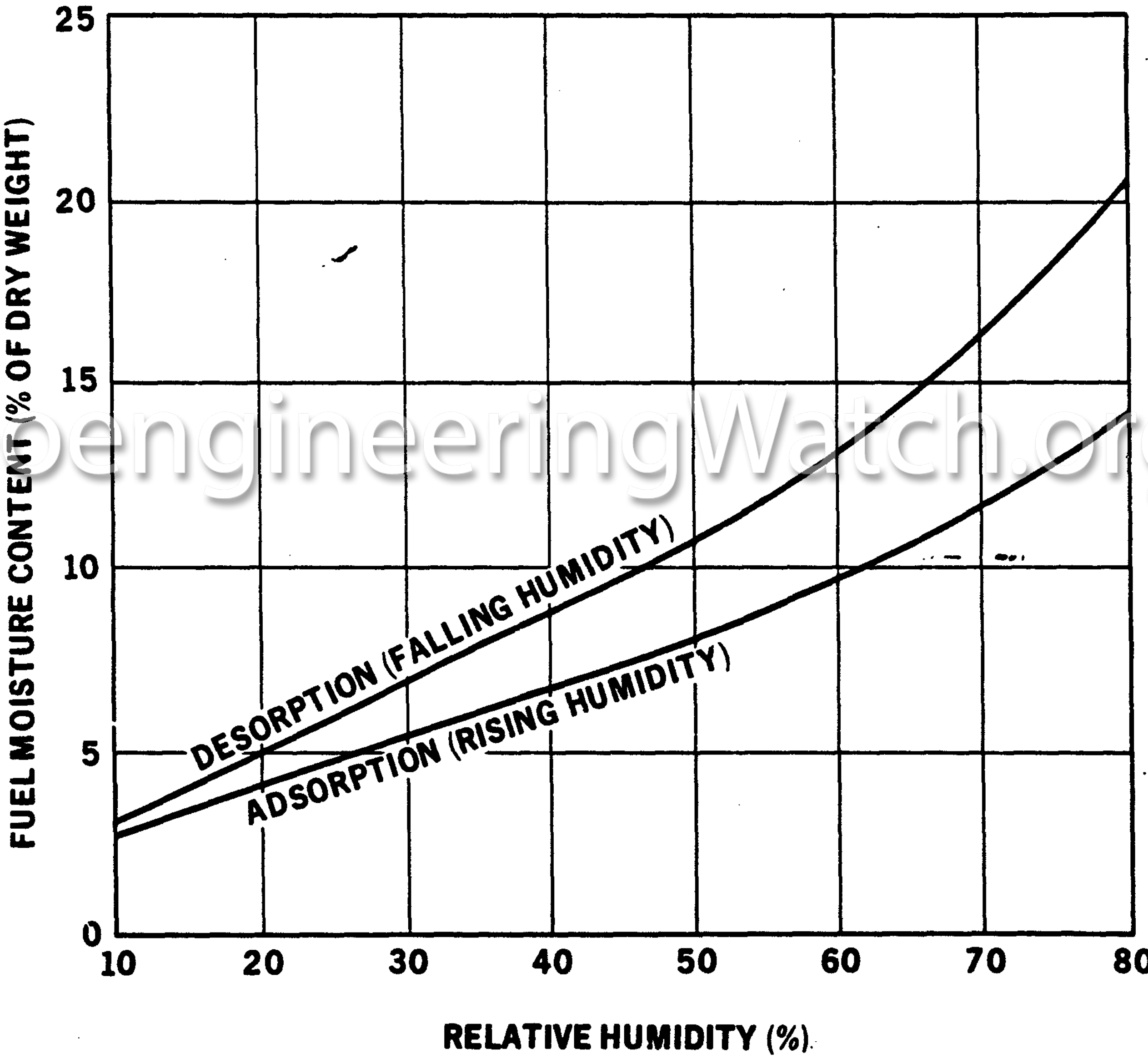


FIG. 33

MOISTURE CONTENT: ADSORPTION VS DESORPTION (PINE TWIGS)



Sunshine: Solar radiation is an important factor in determining the moisture content of forest fuels. The effect is primarily indirect. Forest litter lying in the sunshine is heated to temperatures as much as 70 degrees higher than that of the surrounding air. Consequently, the equilibrium moisture content is much lower than one would calculate from the temperature and humidity of the air aone. The difference between the actual and the calculated fuel moisture depends on the duration of exposure to sunshine, and on the intensity of solar radiation. A good rule of thumb for middle latitudes is that fuel moistures of fully exposed materials at midafternoon on a clear day will be one-half those calculated from atmospheric temperature and relative humidity. The pine needles of the example on page 80 would have a moisture content below 3-1/2 percent if they were out in the open on a calm, sunny afternoon. They would be even drier at the end of a long summer day at high latitudes, or exposed to the intense sunlight of the tropics. Whenever possible, incendiary operations should be limited to days when cloud cover is 3/8 or less.

Except in forest openings, litter is seldom exposed to full sunlight for prolonged periods. The very overstory trees and shrubs that provided the litter act to shade it. One of the primary reasons for partially defoliating shrub and hardwood stands prior to burning is to remove the shade provided by the foliage and let solar radiation down to the ground litter.

Solar radiation also has a slight direct effect on fire behavior. The intensity of solar radiation on a sunny afternoon in the tropics adds about 20 percent to the radiation received 2 feet from a ground fire in pine needles. This effect, although too slight to produce a statistically significant difference in rates of spread, is sufficient to make a visually noticeable difference in fire intensity if a cloud passes in front of the sun when a small ground fire is burning.

Wind: Wind also affects forest fuel moisture, although its greatest influence on forest fire behavior is a direct one. Wind serves to mix the air in the layer immediately around the fuel, removing moisture when fuels are drying and bringing in fresh moisture when fuels are absorbing water vapor. Wind also reduces the difference between the reported air temperature and the temperature at the fuel surface when fuels are exposed to sunlight. Fuels in the shade dry faster on windy days. Fuels in full sunlight dry more slowly when the wind is blowing.

In addition to its effect on fuel moisture, wind has a major effect on heat transfer within the fuel bed. Wind increases flame length and tilts the flames forward into unburned fuel thus greatly increasing the rate of radiation transfer between flame and fuel. At the same time, wind also moves hot gases into the fuel downwind of the fire. By increasing the amount of energy transferred directly to the fuel, wind effectively increases combustion efficiency. Rate of spread varies exponentially with the velocity of the wind at flame height. When the wind at flame height is 7 knots, a fire moves about 5 times as fast as it does when the wind is 2 knots. Sloping ground has the same effect as wind; the flames are tilted up the slope. For a fire spreading up a slope, the rate of spread will approximately double for each 15 degree increase in slope. 17/ 18/

17/ Slopes and other topographic features also affect surface wind patterns. This subject is well covered by Buck, C. C., Winds over wildlands – A guide over forest management. USDA–Forest Service. Agric. Handbook No. 272, 33 pp., illus. November 1964.

18/ The entire preceding discussion of weather variables is primarily applicable to surface fires in their initial stages. Weather effects on large, intense fires are much more complicated. An excellent reference is Countryman, C. M. Project Flambeau... An investigation of Mass Fire (1964-1967). USFS Pacific Southwest Forest and Range Experiment Station 118 pp., illus. June 1969.

Even though winds plays an extemely important role in forest fire behavior, it is a factor best ignored when planning incendiary operations. There are several reasons for this:

1. If operations are planned assuming calm conditions, any wind that may occur provides a margin of safety—or bonus effect. On the other hand, an operation planned around an expected 20–knot wind may be a total failure if the wind fails to materialize. Accurate spot forecasting of wind velocity is the most difficult job in meteorology

2. Winds within the forest are not the same as those measured at airports or other meteorological data collection stations. Studies in Canada have shown that the wind velocity 20 feet above the top of the forest canopy averaged only two-thirds of the velocities measured 20 feet above the runway at adjacent airports. [19/] And on the ground beneath the canopy, where all forest fires originate, windspeeds are much lower still. As an extreme example, the windspeed measured 1 foot above the ground in a dense fir forest never exceeded 2 miles per hour over any 10-minute period during the course of an entire year of continuous record.

3. In many situations, high wind velocities are associated with precipitation, high humidities, and sudden changes in weather. Planning a large incendiary operation to take advantage of high winds preceding the passage of a cold front is a long-shot gamble that seldom pays off. The planner should look for stable periods of clear, dry weather—and these are usually associated with high pressures and light surface winds.

4. One exception to the rule that high winds mean high humidity is the foehn wind, called a Santa Ana in California a Mistral in France, a Bora in Yugoslavia, etc. This is a dry wind blowing down slope, which often shows humidities of a few percent and which dries all exposed fuel rapidly.

Because weather is such a critical factor to the conduct of a successful forest incendiary operation, and because logistical considerations usually require that a TOT be fixed some days in advance, it is vital that a trained meteorologist be incorporated into the planning staff once a look at the climatic records make it apparent that incendiary operations are feasible. The meteorologist should make a thorough study of dry period weather patterns, and prepare objective forecasting aids that will assist in early identification of unfavorable weather situations. [20/]

In areas where local cumulus shower activity is likely, it is necessary to establish a positive weather watch on the target area for a least a week preceding incendiary operations to insure that the target is not hit by an undetected rain shower. If there are ground patrols in the target area for any reason, they should be instructed to report any evidence of recent rain. If the target is within range of normal radar operations, the exact location should be pinpointed for the radar operator and provisions made to report shower activity. If neither ground patrols nor radar are available, early morning and evening observation flights can pick up shower lines and puddles in roads or clearings.

19/ Simard, A. J. Variability in wind speed measurement and its effect on fire danger rating. Forest Fire Research Institute, Ottawa, Ontario. Information Report FF-X-19. 39 pp. June 1969.

20/ Two good examples of hindsight analyses that would have been extremely useful had they been done in advance are:

O'Dell, C. A. Climatological and meteorological analysis of Operation Pink Rose (U). USDA–Forest Service, 89 pp., illus. 1968 SECRET.

McCutchan, M. H., and B. Taylor. Synoptic-scale weather disturbances that influence the fire climate in Southeast Asia during the normally dry period. USDA–Forest Service Pacific Southwest Forest and Range Experiment Station, 149 pp., illus. 1969.

FIG. 34

AIR DROPPABLE,
TELEMETERING WEATHER STATION

Ideally, a weather station should be established within the target area. A relatively inexpensive station has been designed to be airdropped into forested areas and hang up on the top of the forest canopy. The station makes hourly measurements of relative humidity, the presence or absence of sunshine, and the presence or absence of free moisture. These data are stored on magnetic tape and transmitted on command to an aircraft receiving unit. The station has an unattended operating life of two weeks. 21/

DESICCATION TECHNIQUES

The desiccation process—converting live, green vegetation into dead, dry fuel—benefits burning in several ways: 22/

1. Adds to the available litter fuels in which fires ignite and spread. Adding fuel weight is the primary benefit in in hot, humid climates where plant material does not accumulate naturally at the soil surface. The addition is less important in regions where a substantial litter layer has accumulated naturally.

2. Kills and drys twigs and stems up to one-half inch in diameter, or larger. Burning of these fuels adds to the fire intensity and to effective removal of the total vegetative cover.

3. Kills and drys succulent green leaves in the understory. Reducing the dampening effect of live deciduous shrub leaves is always needed to promote rapid fire buildup.

4. Exposes the ground surface fuels to sun and wind. Opening of overstory and understory canopies speeds drying of fuels, allows preheating of the fuel bed before burning, and aids air movements which increase fire spread.

Desiccation of living shrubs and trees involves killing the woody tissue and then drying it to the point where it serves as fuel. After the tissue is killed it gradually loses water until its moisture content approaches equilibrium with the atmosphere. Once dead, leaves—which have a high ratio of surface to volume—lose moisture rapidly, within hours or days. Twigs and branches die and dry over a period of weeks or months. The desiccation process is especially slow if the stems remain attached to a living root system; the entire process requiring six to twelve months.

Desiccation treatments are aimed at drying the woody material already present in the fuel bed. The most effective treatments also add additional fuels to the ground surface. Dead leaves are shed from upper canopy layers. Killing of upper canopy leaves that remain attached to the branches also increases the possibility of fire spreading upward and moving as a crown fire. Certain treatment drop branches or entire plants to supply essential woody fuels.

A wide variety of methods have been used to prepare vegetation as fuel, ahead of planned burning. All methods involve two basic approaches: (1) Kill the vegetation and mechanically compact it into the fuel bed, or (2) Kill the vegetation and leave it in place.

21/ Specifications and blueprints are available from U.S. Forest Service Division of Fire and Atmospheric Sciences Research. Washington, D.C. 20250.

22/ For incendiary purposes "desiccation" means losing moisture from the plant tissues. In much of the literature on defoliation, the term "desiccation" refers only to the leaves affected by the defoliation treatment. This means that affected leaves have died and turned brown—but the twigs and stems may or may not retain a high moisture content. The reader must remember that "desiccation," as used in context with defoliation, doesn't necessarily mean drying.

Techniques for Killing, Drying, and Compacting Fuels

Slashing: "Slash and burn" is the classic approach to preparing and burning vegetation as practiced by native peoples in tropical regions. 23/ Their shifting agriculture depends on recycling of elements from the lower soil layers. This is accomplished by growing crops on an area for only one or two years, allowing deep-rooted native hardwood vegetation to regrow for several years, and then felling and burning it to return the essential elements to the surface soil.

Fuel preparation involves cutting and dropping the brambles, shrubby plants, and many of the trees. This fallen material makes an excellent fuel bed of fine particles, branches, and larger stems. The severed plants lose moisture as rapidly as weather conditions permit. The slashing is done at least four months ahead of the period when driest weather is expected for burning.

In Southeast Asia, burning of slashed areas in mixed hardwood forest types is done near the end of the dry season, mainly in late February and early March just before the monsoonal transition. The native tribesmen may select the actual day of burning by ritualistic procedures but you can depend on it being done in clear weather with humidity near the minimum for the year. We have observed and evaluated the burning of many small patches in Vietnam and Thailand, where the fuel had been prepared by slashing. The vegetation burned readily and all but the largest tree trunks were consumed. Fire did not spread from the small cleared patches into the dense forest. However, ground fires did creep through surrounding open vegetation that was in an early stage of secondary plant succession.

In tropical regions with yearlong rainfall, prediction of favorable weather and final selection of the day for burning are more difficult. But, slashed dry vegetation can be burned successful in any climate after a few days of clear weather.

Crushing or Chaining: These are more modern versions of the old slashing technique for severing or uprooting woody vegetation and compacting it on the ground. They involve use of heavy equipment to crush or uproot plants with a bulldozer blade, with a roller or cutter drawn by a tractor, or with a heavy chain pulled between two tractors. These methods are useful in shrub types or younger forests, but they are not suitable for clearing mature forests where the trees are too large to be readily knocked down.

Success depends on the vegetation having rigid stems that can be broken off or pulled out by the roots. Fuel preparation generally is not successful in vegetation with limber stems, unless the plants are chopped with a heavy cutter or scraped loose at the soil surface with a bulldozer blade.

A drying period of a few months to a year is usually needed after crushing or chaining, although some shrub types with unusually small stems can be burned within a week or so. If plants are scattered rather then continuous, the preparation treatment should be done early so that a stand of grass to carry fire can grow within the felled vegetation. If new growth is mainly shrub sprouts instead of grass, an additional treatment with herbicides to kill this vegetation is advisable before burning.

Combinations of felling, logging, and slashing have been used to prepare jungle or other forest types for burning, Bulldozer crushing can be used along with hand felling of trees or uprooting of trees with the bulldozer in both woodland and forest types. All of the various combinations kill and compact the woody fuels, and they promote easy burning

23/ This subject is very well covered in Batchelder, R. B. and H. F. Hirt. Fire in Tropical Forests and Grasslands. U.S. Army, Natick Lab. Tech. Rpt 67-41-ES. 380 pp., illus. June 1966.

Techniques for Killing and Drying Fuels in Place

Stem Treatment: This method involves killing larger trees for burning by injecting herbicide into the stem or by girdling the stem. Additional treatment of understory vegetation is needed to prepare a forest for burning. The purpose of stem treatment is to kill both the tree trunk and crown, and allow adequate time for drying ahead of burning. This method will add fuel on the ground eventually, after tree tops have broken off or entire trees have fallen. This requires one or two years in drier climates.

Stem injection of herbicides has the advantage of requiring simple equipment and small amounts of material. It is a more positive method of killing hardwood trees than is aerial herbicide applications. Our observations indicate that a major problem connected with the stem treatment approach is the rapid increase in moist understory vegetation after tree canopies have been killed. The problems of follow-up desiccation treatment will be compounded if both grass and broad-leaved vegetation have increased.

Aerial Applications: Spreading of herbicides from aircraft to kill and dry woody vegetation can overcome certain limitations of other desiccation techniques. Aerial application does not require the use of manpower and equipment on the ground. Thus, it is less limited by terrain, rocky or marshy soil, enemy activity, and other factors that may prohibit the efficient and safe use of ground-based desiccation methods.

The major limitation of aerial herbicide applications is the need to modify the technique to fit specific situations. Success depends on applying the proper herbicide in adequate amounts at the correct time. Applications must be made by experienced operations using proper equipment, with safeguards against damage to "friendly" areas.

Because aerial application of desiccants is the most generally suitable technique for military applications, we have concentrated our research on herbicide treatments that can be applied from the air.

Reduction of Canopy Interception

Aerial application of herbicides will be of little benefit to incendiary operations unless the material is effective in desiccating the ground level vegetation. In dense forests, the primary problem is that aerial sprays are trapped in the upper tree crowns and never reach the ground.

Penetration of spray droplets through forest canopy is inversely related to canopy density (the proportion of the ground surface covered by a canopy when viewed from above.)[24] However, the effectiveness of aerial sprays in desiccation of understory vegetation does not follow a straight-line relationship with canopy density. Instead, spray effectiveness remains about the same over a range of low canopy densities, but drops sharply under higher canopy densities, (Fig. 37). This may occur for either or both of two reasons:

1. The amount of herbicide (chemical does) reaching the understory plants may be too low for effective desiccation.

2. The dose may be sufficient, but the volume of material (chemical plus water on other carrier) may be too low. Plant parts must receive at least 75-100 droplets per square inch.

[24] Studies of this subject by the Agricultural Research Service, USDA, under ARPA Order No. 424, have been summarized by Fred H. Tschirley in report CR-13-67, "Research report—Response of tropical and subtropical woody plants to chemical treatments". 197 pp., illus. 1968.

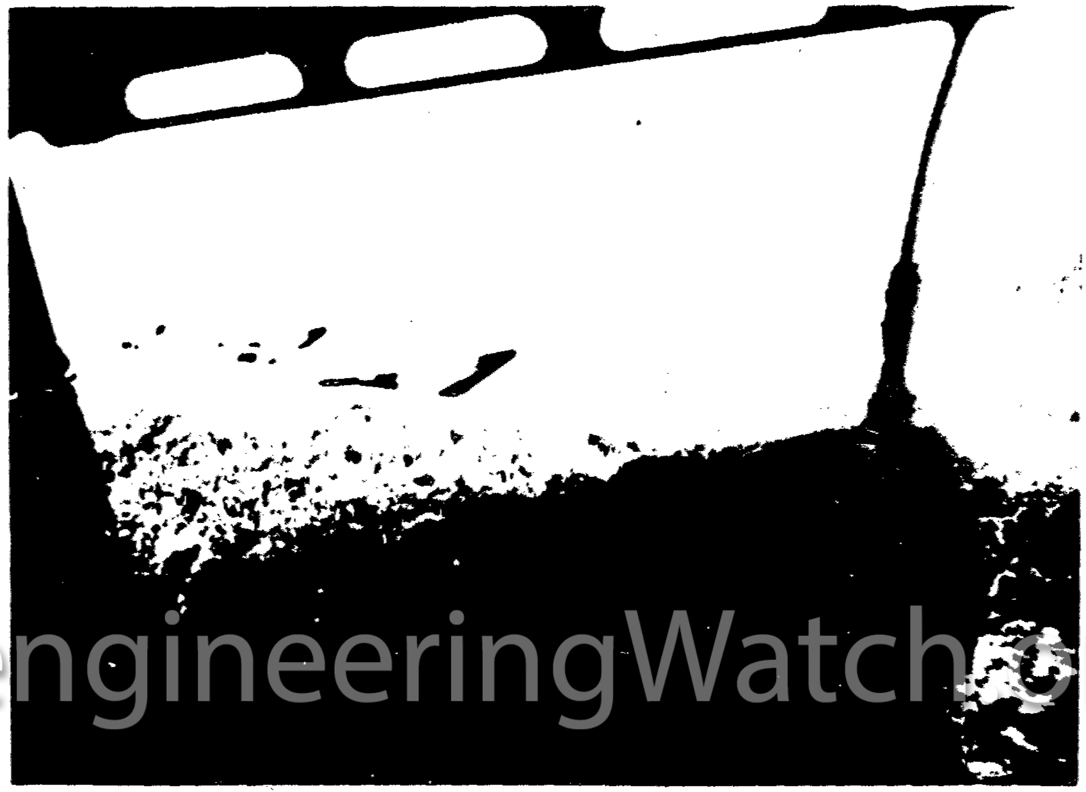


FIG. 35

AERIAL APPLICATION OF HERBICIDE
(OPERATIONAL RANCH HAND
OVER WAR ZONE C)

The effectiveness curve stays relatively flat at low canopy densities because most herbicide applications involve an excess, or "overkill," factor. Consequently, a certain amount of interception by the upper canopy can be tolerated. The point at which a further increase in tree canopy will result in a sharply reduced kill of understory vegetation will depend on the kind and amount of herbicide, and the number of droplets applied per acre over the canopy. The particular data in Figure 36 were obtained from applications of 2,4-D:2,4,5-T mixtures at does rates ranging from 4.0 to 8.4 pounds, acid equivalent, per acre and at volumes of 10 gallons per acre.

The importance of applying an adequate number of droplets in order to overcome the effects of canopy interception cannot be overemphasized. We have observed the benefits from adequate droplet coverage in many situations, even in spraying shrub types. For example, spraying dense stands of an easily killed shrub species in Hawaii produced good kill of overstory vegetation about 15 feet in height regardless of spray volume applied. But small understory plants of the same species were not effectively desiccated when low volumes were applied. The range in percent effectiveness for three different volumes were:

Volume applied (gal./acre)	Desiccation Effectiveness: Overstory (percent)	Desiccation Effectiveness: Understory (percent)	Ratio of understory to overstory
5	100	97	.97
3	91	75	.82
1	86	32	.37

Herbicide dose was the same for the 5-gallon and 1-gallon applications. The 1-gallon volume delivered about 100 droplets per square inch on the overstory plants, but coverage of understory plants was inadequate. The herbicide dose was tripled in the 3-gallon application, but this did not overcome canopy interception to the degree obtained by the greater number of droplets in the 5-gallon application at one-third the dose rate.

In summary, dense overstory canopies must be reduced in order to obtain adequate desiccation of understory vegetation with foliar sprays. The canopy can be reduced by a defoliation spray, followed by a desiccation spray as soon as most leaves have dropped from the upper canopy. The desiccation spray, should be applied at a volume of at least 5 gallons per acre even though upper canopy density has been reduced ahead of desiccation spraying.

An alternate to foliar spraying is aerial application of the herbicide in a solid form that will penetrate dense canopy. Herbicides in a granular or pellet form will reach the soil surface with little canopy interception.

Types of Desiccants

Desiccants suitable for aerial application are of two kinds:

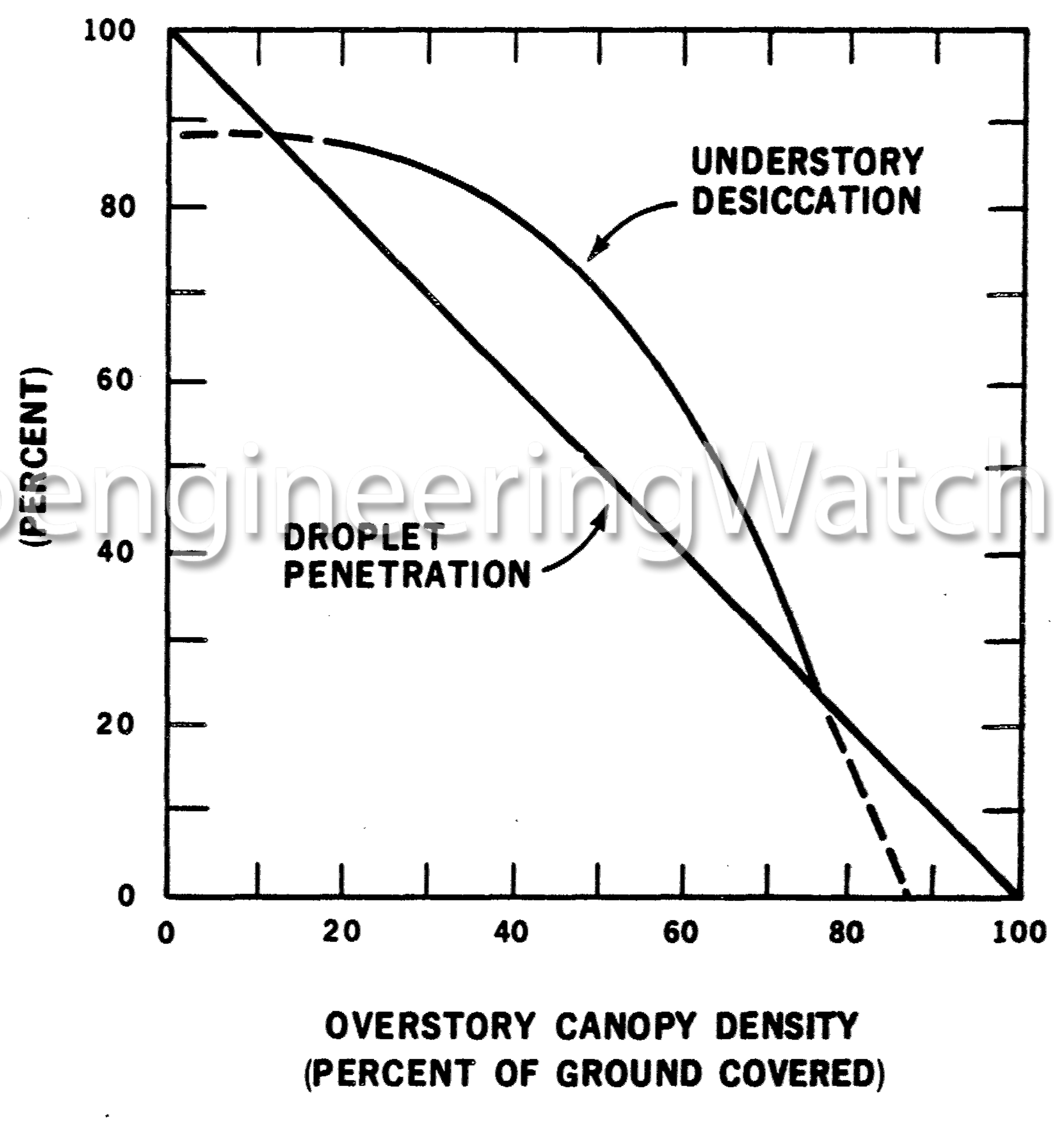
1. Systemic herbicides which enter the plant, move through the vascular system, and kill tissue away from the point of contact.

2. Contact herbicides which kill only the living tissue that is directly contacted.

Contact herbicides are applied as sprays which usually dry leaves within a few days or weeks, depending on the plant species and the weather. The contact sprays are particularly effective on leafy herbaceous plants, such as grass and weeds.

FIG.36

EFFECTS OF OVERSTORY FOREST CANOPY ON PENETRATION OF AERIAL SPRAY DROPLETS AND ON DESICCATION OF UNDERSTORY VEGETATION



Applied to woody vegetation, the contact sprays affect both the leaves and small twigs. These plant parts—with high surface-volume ratios can be killed because a large proportion of the tissue is exposed to contact with the chemical. Larger branches, stems, and buds commonly are protected with resinous or waxy coverings, or by corky bark.

Typical drying of leaves and twigs after application of contact desiccants is shown in Figure 37. Most leaves die within 2-4 weeks, but additional leaves and twigs continue to die and dry for as long as two months. A few succulent stems may die. But most stem tissue remains alive, capable of producing new foliage when weather becomes favorable.

Under humid tropical climate, as with guava in Puerto Rico, the regrowth starts on most stems soon after the original leaves have dried. After a few months the plants show little or no effect from the desiccant spray. In a tropical climate with a long dry season the plants recover during the next wet season after the leaves have been desiccated. Under climates with cool or cold winters, the leaves remain dry and brown until replaced by new foliage during the following spring or summer. Most of the desiccated leaves drop quickly from the plants under tropical climates and under humid climates with cool or cold winters. Leaves remain attached for months on evergreen vegetation under climates with a long dry season.

Contact desiccants are effective in making burnable fuel out of the leaves and a small proportion of the twigs. But since understory vegetation is usually small-stemmed, this represents only about 35-40 percent effective desiccation of the potential small fuel (Figure 38). Although contact desiccants are relatively ineffective in increasing the amount of available fuel, they do reduce the dampening effect of green leaves and open shrub crowns to speed drying of litter. This, along with adding dry leaf fuel, is all that is needed in certain situations, and will promote good burning if adequate litter and dead stems already are present. But contact desiccants are not adequate as the only treatment for use in climates where total available fuel weight is less than 0.3 pounds per square foot (see Appendix B). The contacts are recommended as a supplement to systemics in situations where a quick kill of green leaves is essential. One common situation is where new green foliage has regrown shortly before the planned date of burning.

Several different chemicals will serve equally well as contact desiccants.

Paraquat – 1,1'-dimethyl-4,4'-bipyridinium salt
Diquat – 6,7-dihydrodipyrido(1,2-a:2',1'-c) pyrazidiinium salt
Cacodylic acid – hydroxy dimethylarsine oxide
Dinitro – 2' sec butyl-4,6-dinitrophenol

Paraquat and cacodylic acid were used in most trials and produced consistent results. The best dosage for each chemical was not apparent from out trials: in some cases the lowest applied dosage was as effective as the highest. We recommend any one of the following contact desiccants: paraquat at 4 pounds acid equivalent per acre, cacodylic acid at 12 pounds, diquat at 12 pounds, or dinitro at 12 pounds. The dinitro should be mixed with diesel oil, and the others with water, to make 5 gallons per acre total volume of spray mix.

If weather will be sunny and warm (daily mean temperature above approximately 60°F.) the contact desiccant should be applied 3-4 weeks ahead of the planned date of burning. If cloudy, cool weather is expected, the contact desiccant can be applied two months in advance of burning. Longer periods of drying are not advisable because additional regrowth of green vegetation may occur before burning.

FIG. 37

TYPICAL EFFECT OF CONTACT DESICCANTS ON TROPICAL VEGETATION

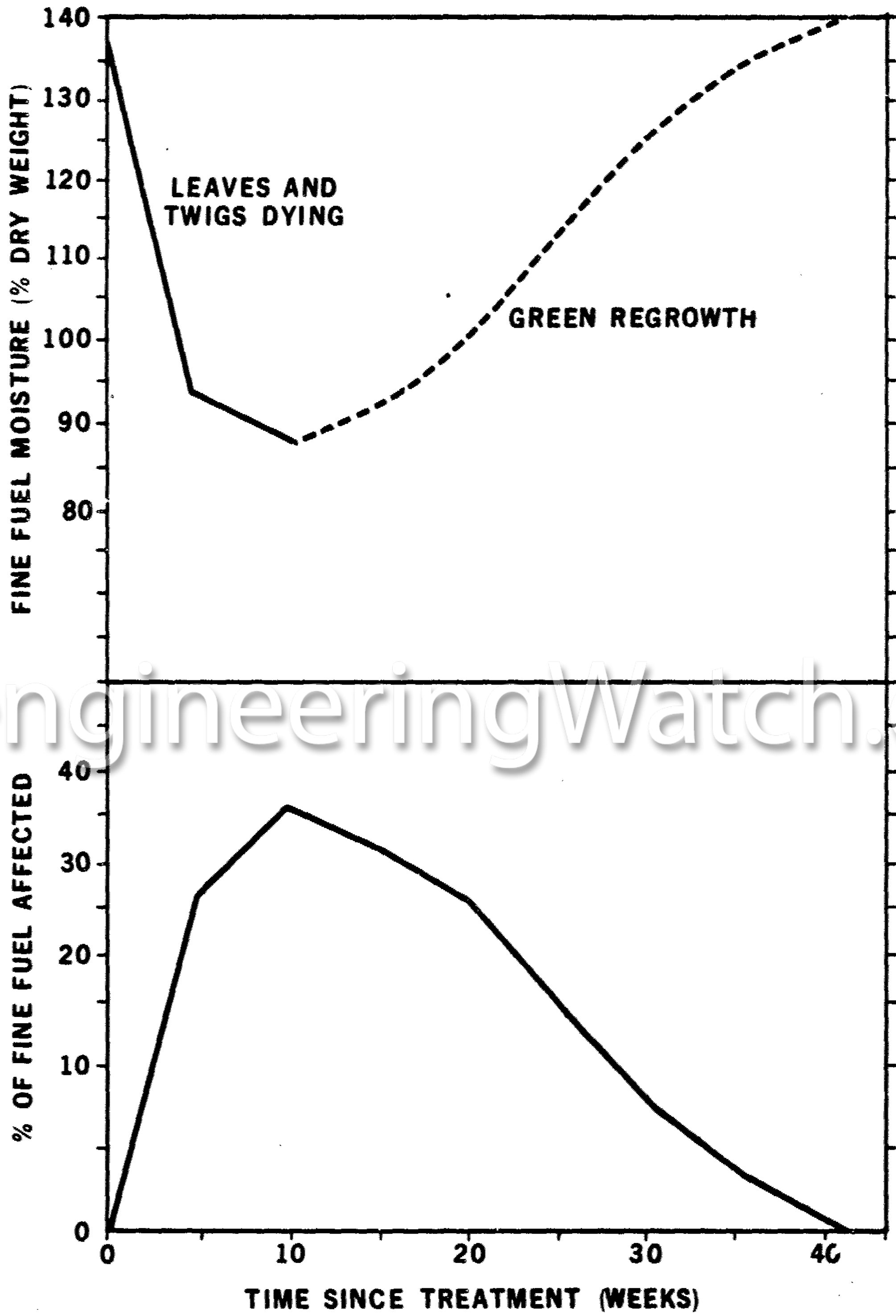
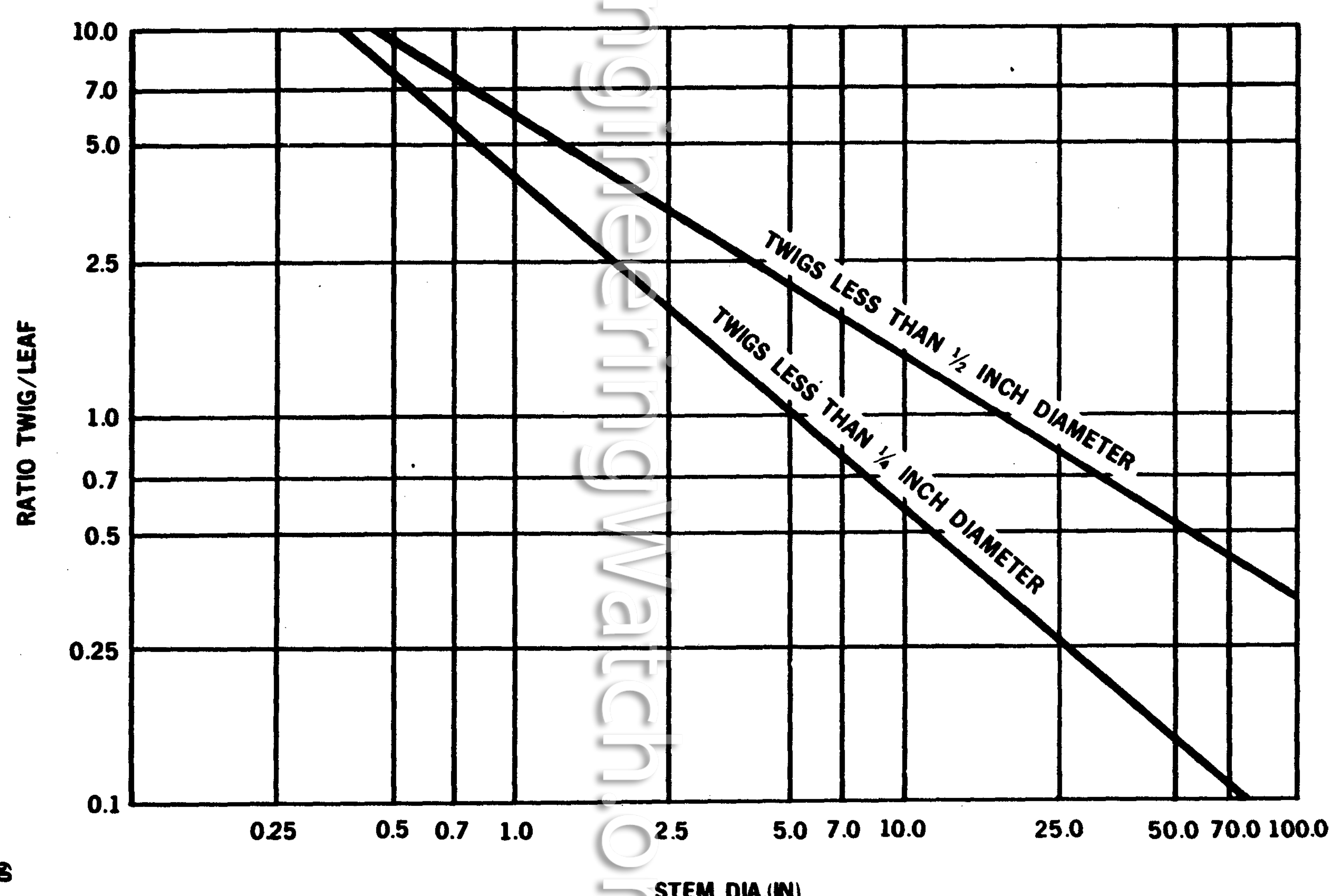


FIG. 38

RELATIVE WEIGHTS OF LEAVES AND TWIGS



Use of Systemic Desiccants

Systemic herbicides can be applied on the foliage as a spray, or on the soil in liquid or dry form. When applied as a foliar spray the chemical is absorbed through the leaves (and the stems to some extent) and is moved downward in the plant through the phloem. When applied to the soil, the chemical is absorbed through the roots and moves upward in the water-conducting tissue.

Systemic herbicides act at a much slower rate than do contacts. The process of dying and drying is somewhat different between foliar sprays and soil applications. In either case, however, leaves and twigs become desiccated before the stems have dried, and several months are required for complete desiccation of all fine fuels (Figure 39). Only three chemicals have shown good promise for widespread use in aerial applications on forest vegetation.

2,4-D – (2,4-dichlorophenoxyacetic acid)
2,4,5-T – (2,4,5-trichlorophenoxyacetic acid)
Picloram – (4-amino-3,5,6-trichloropicolinic acid)

The effects from each systemic herbicide differ between the various climates and vegetation types. Background information is available from worldwide use of these herbicides for plant control, but not as desiccants of woody vegetation Very briefly, our conclusions from hundreds of plot tests are:

1. Application of the systemic herbicide picloram to the soil in pellet form is the most effective single aerial application for desiccation of ground-story vegetation under dense forest canopy. With few exceptions, picloram in pellet form killed a wider range of resistant species than did foliar sprays.

2. Foliar spraying of systemic herbicides will effectively desiccate vegetation if the spray material is not intercepted by overstory canopy. Two aerial sprays will be needed over dense forest canopy—one spray to defoliate the canopy and start the desiccation process, followed 4-6 weeks later by a spray to desiccate understory plants.

3. Either a 1:1 mixture of 2,4-D:2,4,5-T, or picloram alone, or combinations of the two, are effective systemics for foliar application on forest growth under climates with frostfree or mild winters. A mixture of picloram with 2,4-D and 2,4,5-T is preferred for the following reasons: Picloram is known to be effective on a wider range of typical species than is 2,4,-D or 2,4,5-T. Picloram commonly caused quicker kill of 1/2-inch stems in our test plots; and regrowth from large stems often was reduced or eliminated where picloram was applied. Picloram has the disadvantage of being more expensive and much more persistent in the soil or ground water. Each of the herbicides in the mixture should be formulated as a low volatile ester.

4. Picloram was not as effective as 2,4-D and/or 2,4,5-T as a foliar desiccant in climates with cool or cold winters and hot, dry summers. Thus, we recommend adding picloram for stem desiccation only in humid climates with frostfree or mild winters.

5. Foliar sprays should be applied in the largest volume per acre that is practical—to obtain best coverage of leaves with spray droplets. Our tests indicate that 5 gallons total spray volume per acre is the minimum volume that is desired. The herbicide esters should be diluted in diesel oil to make a total volume of 5 gallons per acre.

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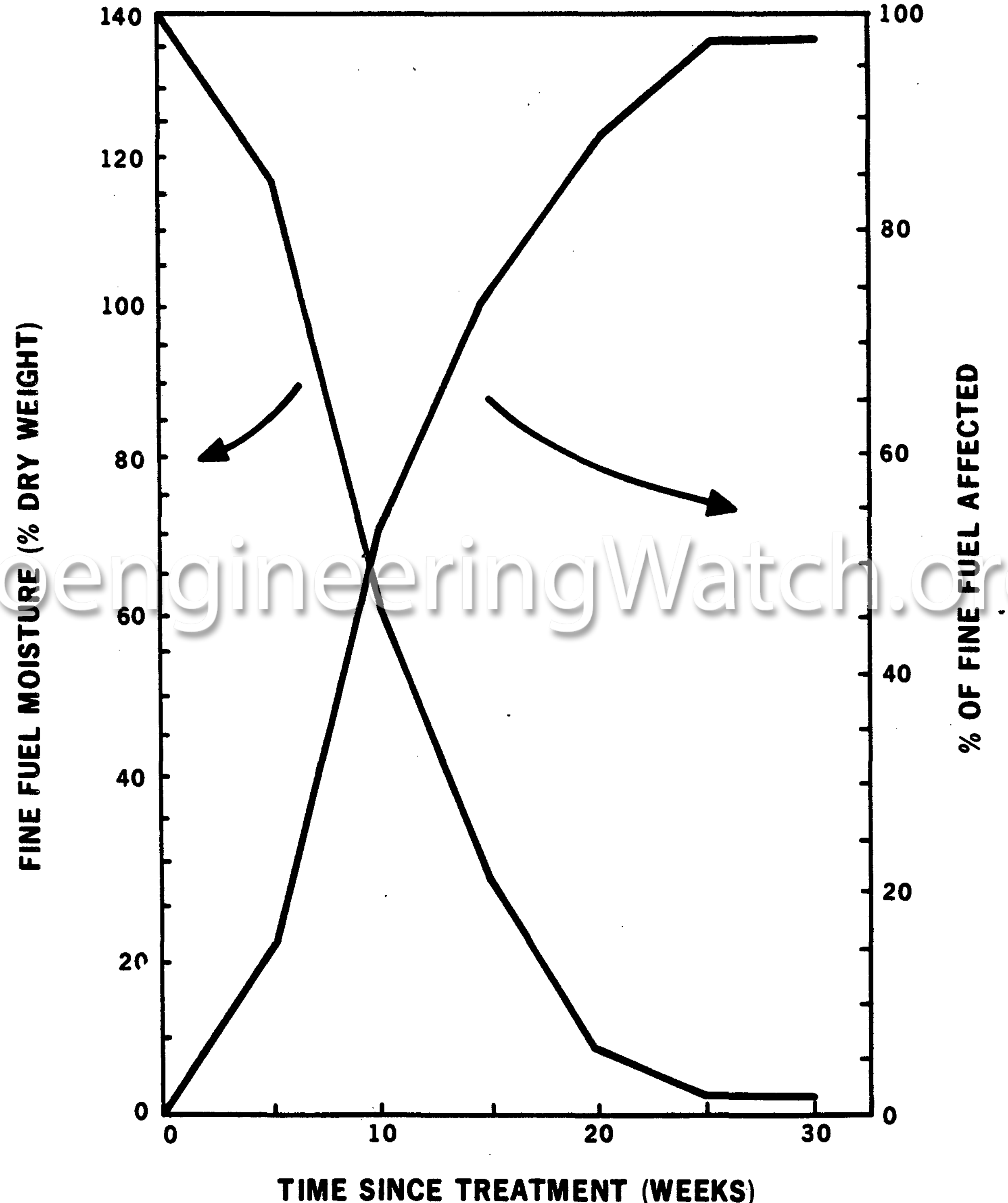
FIG 39

TYPICAL EFFECT OF A SYSTEMIC DESICCANT



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6. Effectiveness of foliar spray is reduced if applied during a dry period when the vegetation is under moisture stress. Effectiveness of a soil-applied herbicide is optimum if applied during a period when it is moved into the soil by moderate rainfall at a time when plants are actively growing.

7. Many species of trees and shrubs, particularly in tropical regions, are resistent to all commonly used herbicides Such species have been little affected by defoliation or desiccation sprays at the various locations we have observed. In mixed evergreen forests and shrub types, however, the resistant species make up a small proportion of the total vegetative cover and can be ignored in planning desiccation treatments.

8. In general, higher dosages of systemic herbicides were required in humid tropical areas for effective desiccation of groundstory vegetation than in drier areas.

Timing of Desiccation Treatments

Desiccation treatment aims at producing the maximum possible amount of dry ground fuel by the time of burning. Where possible, the time requirements for effective desiccation should be considered before deciding when to burn. However, military considerations and restrictions on choice of weather suitable for burning may leave little latitude in planning the sequence of desiccation and burning operations.

Use of herbicide desiccants must be geared to the yearly patterns of both precipitation and temperature. Consequently, timing of operations will not be exactly the same in any two climates. The following list of requirements for effective herbicide desiccant application will supplement the recommendations listed in Appendix B for each of the climates. Planning of desiccation operations can be based on the readily available records of average monthly precipitation and temperature—the same records used for classifying each climate. Remember, the weather of any year at a location may differ considerably from the average. Consequently, any additional information that can be obtained concerning typical variations for each month at the location will be of benefit in selecting the best month for each treatment. Also, the actual dates of herbicide application should be adjusted slightly from the planned dates if current weather makes such changes advisable.

Following are the requirements to be met, as far as possible, in planning herbicide desiccant treatments (references to months for treatment apply to the Northern Hemisphere):

1. Aerial spraying of systemic herbicides, including both defoliating and desiccating treatments, should be done when woody plants are in their most active growth stage—near the time when new leaves become fully formed. Growth processes for all species are restricted by deficient soil moisture and by low temperatures, acting singly or in combination.

Air temperature: Monthly daily mean should be above 60^{o} F., but spraying can be done when average daily mean is between 50^{o} and 60^{o} if the spray date must be advanced to allow an adequate drying period before burning.

Under climates having most months, or all months, with average daily means above 60^{o} F., the best spray months are from spring (March) through the summer, provided precipitation requirements are met.

Precipitation: The spraying is best done during a humid month when average precipitation exceeds average potential evapotranspiration: with at least one humid month of favorable temperature immediately preceding the spraying, and preferably at least one humid month just after the spray application. In climates with a dry period in the summer, spraying must be done soon after daily mean temperatures have been above 50^{O} F. for at least one month in the spring, but before stored soil moisture has been depleted. This means that potential evapotranspiration may be greater than precipitation during the month of spraying and/or the following month. Avoid spraying during months of high moisture stress, when stored soil moisture has been depleted and the month is classed as "dry." Under climates where most months are classed as dry, spraying must be done in the month that, on the average, has the most favorable combination of precipitation and temperature, but chances will be poor for consistent success.

If operational problems interfere with best timing of spraying, desiccants can be applied to evergreen vegetation with fair success in months that do not fully meet the above requirements for either temperature or precipitation. If applied in an off season, the herbicide dosage should be doubled and the period allowed for dying and drying of vegetation must include months when moisture and temperature are favorable for action of herbicide in the plants (humid months with mean temperature above 50^{O} F.).

2. Application of pellets to the soil should be done at a time when expected precipitation will be adequate (minimum of 2-4 inches) to carry the herbicide into the soil at a stage when plants are actively growing. The objective is to avoid periods of heavy, leaching rainfall that will remove the herbicide before sufficient quantities have entered the plant. In the tropics a good application date is in late spring or early summer (May-June), ahead of the heaviest rains. Under humid climates with cold winters, the best application date is in late winter or early spring. If winter precipitation is relatively low the application can be made during early winter.

3. The plan must allow an adequate period for woody plant stems to die and dry between desiccation treatment and the required date of burning. The minimum period is about four months, and this must include two months of hot, dry weather. At least six months will be needed for full drying of 1/2-inches stems, if the months are humid

If the drying period is cut short, only leaves, twigs, and the smallest stems will be dry at the time of burning–the spray effects will be intermediate between those of a contact herbicide and a systemic. This limited effect will only be adequate for good burning success under climate-vegetation situations with sufficient accumulation of litter and dead stems.

Under climates with cold winters, off-season spraying of evergreen vegetation in the autumn will require a very long period for effective desiccation. The plants will not die until the next summer, and stems will not be thoroughly dry until the following autumn.

4. A major problem develops in timing the use of herbicide desiccants under some climates that are humid yearlong so that hot, humid weather occurs during the period of drying, immediately after applying the desiccant. Under such climates, leaves usually drop from trees and shrubs soon after the desiccant is applied. These leaves, needed as dry ground fuel, will deteriorate from weathering if left too long under warm, moist conditions. Thus the drying period must be cut as short as possible by delaying desiccation treatment so that a minimum of humid weather occurs before burning.

Example of a Desiccation Plan: Saigon, Republic of Vietnam

Figure 40 shows the monthly temperature, precipitation, and probability of successful burning for Saigon. From the definitions given in the section on Climatic Types, there are only 4 "burn" months, but the yearly (-) value is over 26 and the yearly (+) value is over 100. So Saigon falls in Precipitation Class HULB: Humid-long burn season. The average daily mean temperature for the coldest 3 months is 79 degrees, and the average daily minimum for the same months is 65 degrees. So Saigon falls in Temperature Class FF: Frostfree winter.

The vegetation type is dense hardwood forest with relatively continuous ground-story vegetation, but deficient ground litter and dead stems. The best burning period is in late winter (February 15 – March 15).

The first step in planning desiccation treatment is to look at the average weather situation during the months preceeding February 15, as follows:

1. Two months of hot dry weather occur after December 15 – favorable for dying and drying of sprayed vegetation, with minimum deterioration of leaf fuel on the ground.

2. Average precipitation drops rapidly after October 15 – unfavorable for best action of herbicides.

3. Precipitation and temperature in May are favorable for start of active plant growth, and conditions remain favorable through September.

The next step is to decide the best dates of desiccant application and the herbicide to use:

1. The choice of desiccation treatment lies between use of pellets that will penetrate the canopy and act as a soil application, or use of a defoliant spray followed in 4 to 6 weeks by a desiccant spray aimed at the understory.

2. The best period for soil application of herbicide is late April or early May. Later applications stand too much chance of loss from heavy leaching rains. The best spray period is from June through September, whenever clear weather allows spraying to procede.

3. A soil application (before June 1) will drop leaves to the ground and leave them under hot, moist conditions for 4 to 5 months. A defoliant spray (August 1) and a desiccant spray (September 15) will cut the period when leaves are on the ground by at least 2 to 3 months.

4. The best choice is the foliar spray, to reduce loss of leaf litter. At each spray date apply a mixture of 2,4-D and 2,4,5-T (8 pounds, a.e. per acre) and picloram (2 pounds, a.e., per acre) in diesel oil to make a total volume of 5 gallons per acre.

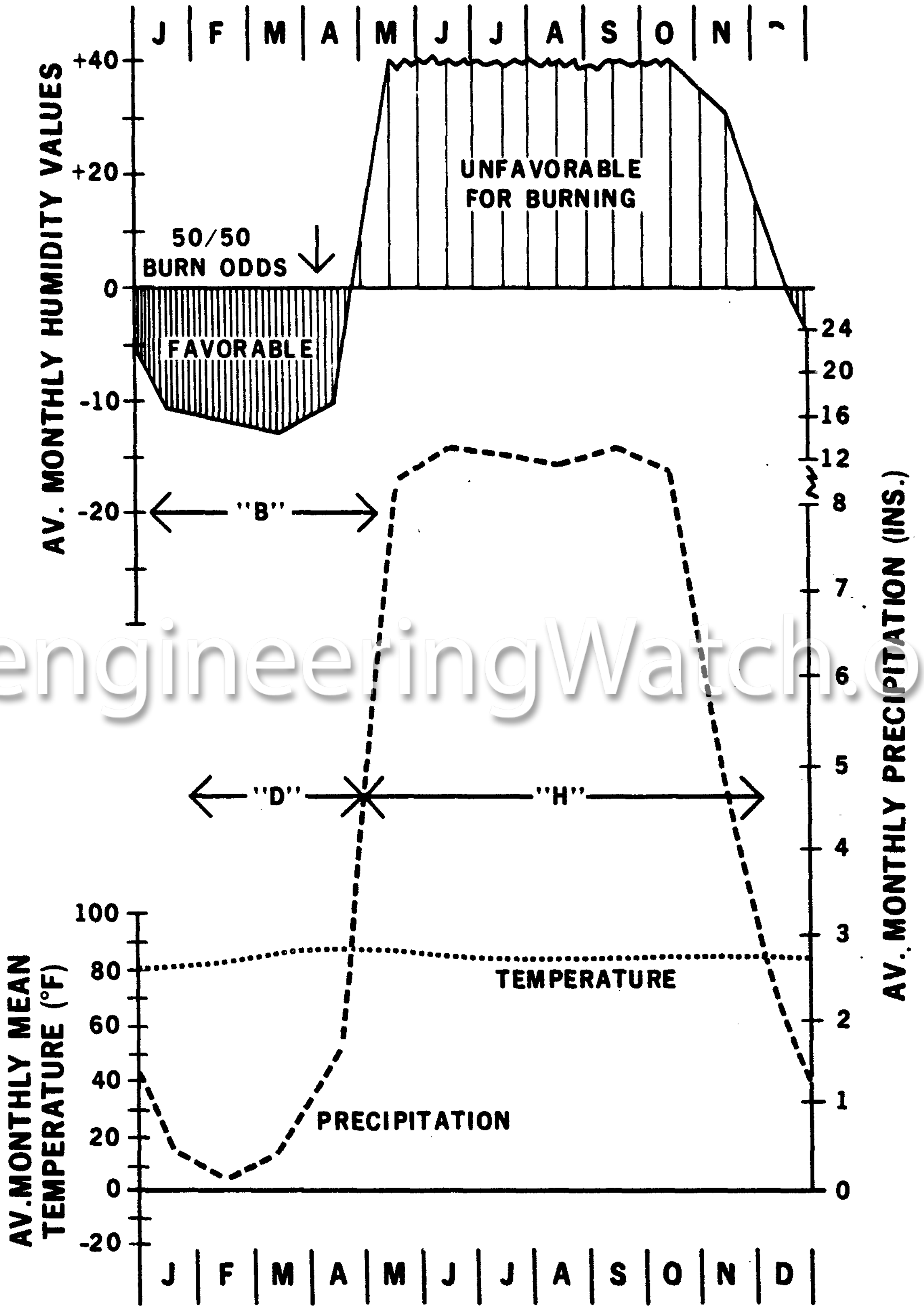
IGNITION TECHNIQUES

In addition to treating live vegetation with desiccant chemicals, and timing incendiary operations to take every possible advantage of the weather, forest fires can be made to spread more rapidly and burn more intensely by igniting many small fires in a predetermined pattern. This technique, known as multiple ignition, utilizes the fact that two approaching flame fronts will interact and reinforce each other. To see how multiple ignition works, let's look first at a fire as it develops from a single ignition, and then at what happens when we set two fires properly spaced.

FIG. 40.

FIRECLIMATE OF SAIGON, RVN

CLIMATE--FF-HULB FROST FREE WINTER; HUMID, LONG BURN SEASON.



If a lighted match is dropped on a bed of forest litter, the fire catches first in the topmost leaves or needles and then spreads slowly outward over the surface and down into the fuel bed. Soon the fire has grown to an appreciable size and resembles a rough circle, all aflame. Eventually, the originally ignited fuels burn out, and the fire looks more like a doughnut with ashes in the center and unburned fuel on the outside. Since the heat ouput of the fire depends on the amount of fuel burning at any time and since the area on fire is continually increasing the heat output increases over time until the burned out central area becomes so large that the fire no longer behaves as a single unit. Because the rate of spread, flame height, and other fire characteristics are largely determined by the fire's heat output, the fire will accelerate its rate of spread and develop continually higher flames from the time of ignition until the central area burns out. Then the rate of spread and flame height stabilize and the fire acts as a continuous line of fire rather than as a solid area or a doughnut.

What happens when two lines of fire come together? Each has its own column of hot gasses above it rising up through a cooler, denser atmosphere. As the two fires approach, the columns of hot gas mingle, resulting in a marked increase in convective activity above the space between the fires. The single convective chimney above the two fires causes the flames to tilt towards each other, and to accelerate their spread. These effects are measurable when the fires are a distance equal to 10 flame lengths apart. They become pronounced when the fires are 3 flame lengths apart, and the intervening distance is bridged in a rush.

How can we achieve the maximum burning rate over any given area, or, to put it another way, how can we get the maximum amount of fuel burning at one time? If fires are started too far apart, much area will have already burned out by the time they meet. If fires are spaced too closely, they will join before they have reached their maximum "normal" heat output. Ignition spacing is optimum when all fires are exactly 3 flame heights apart at the exact moment they reach maximum normal flame height. Three variables are involved: rate of spread, weight of available fuel, and the size of the area to be burned. Figures 41 and 42 can be used to determine a nominal ignition spacing and a correction factor for area. The two values, when multiplied, give the ignition spacing required to achieve maximum burning rate on any sized target area.

Actually, it is seldom logistically possible to actually set incendiaries at the optimum spacing. The number of incendiaries varies as the reciprocal of the square of the spacing (it takes four times the number of sets to cut the spacing in half). Figure 43 shows the increase in burning rate that can be achieved when the incendiary spacing actually used varies from that required by the formula. Table 10 shows the calculations for three incendiary operations in Vietnam. Even on Operation Pink Rose II, when incendiaries were spaced at nearly six times the optimum distance, the overall burning rate was increased by 20 percent.

Table 10

Fire Name	Hot Tip	Pink Rose II	U. Minh (Maximum day)
Available fuel weight (lb./ft.^{2})	0.34	0.095	0.30
Shrub burning index	7	6	28
Target area (acres)	5,200	10,000	Not applicable
Nominal spacing (Fig. 41)	14	1.5	24
Area correction (Fig. 42)	8.5	10.0	Not applicable
Required spacing (ft.)	119	15	Not applicable
Actual spacing (ft.)	125	85	∞ (single Ignition)
Actual/Required	1.05	5.7	∞
Intensity Factor (Fig. 43)	4.7	1.2	1.0

FIG. 41

NOMINAL INCENDIARY SPACING (FEET)

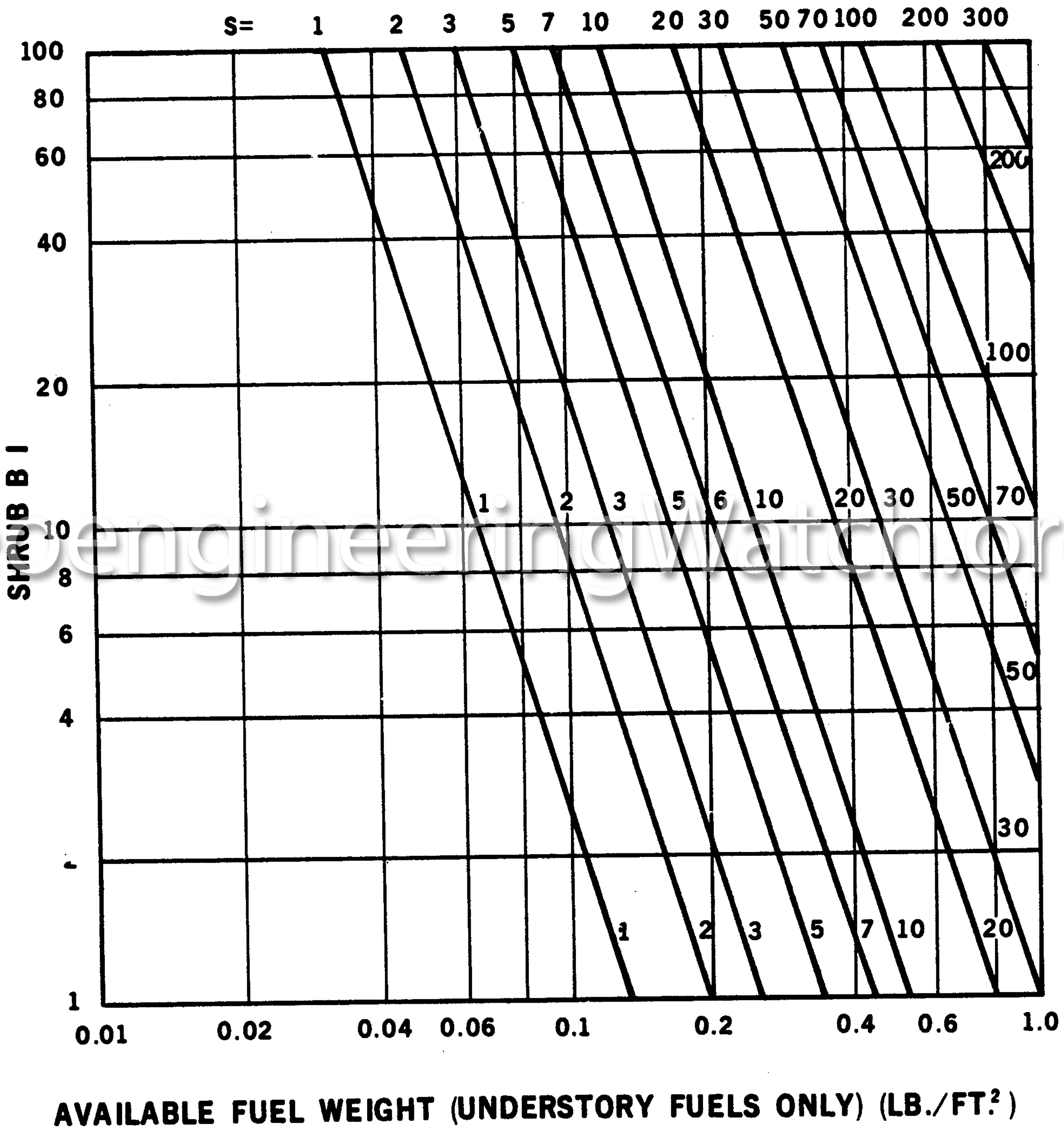


FIG.42

INCENDIARY SPACING-AREA CORRECTION FACTOR

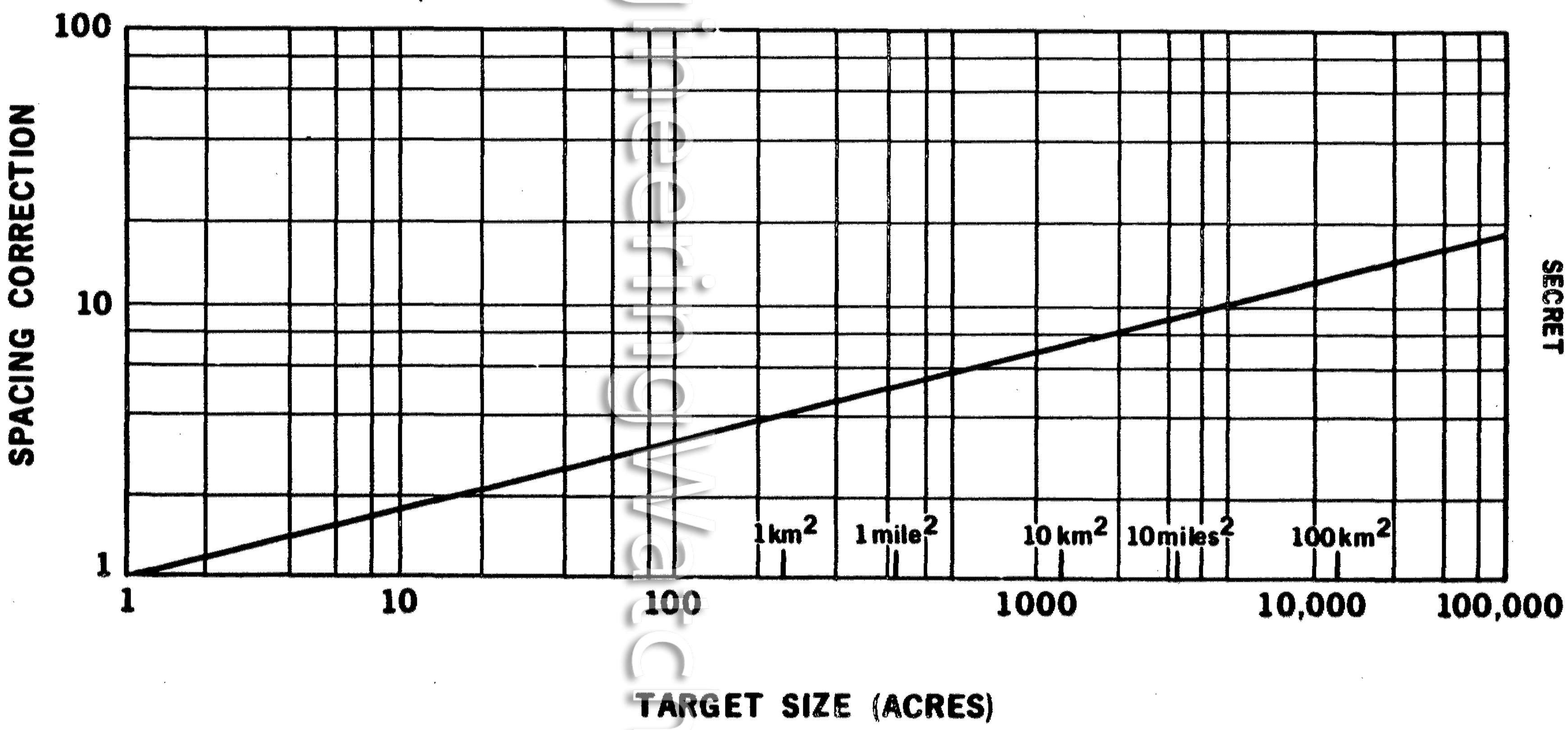
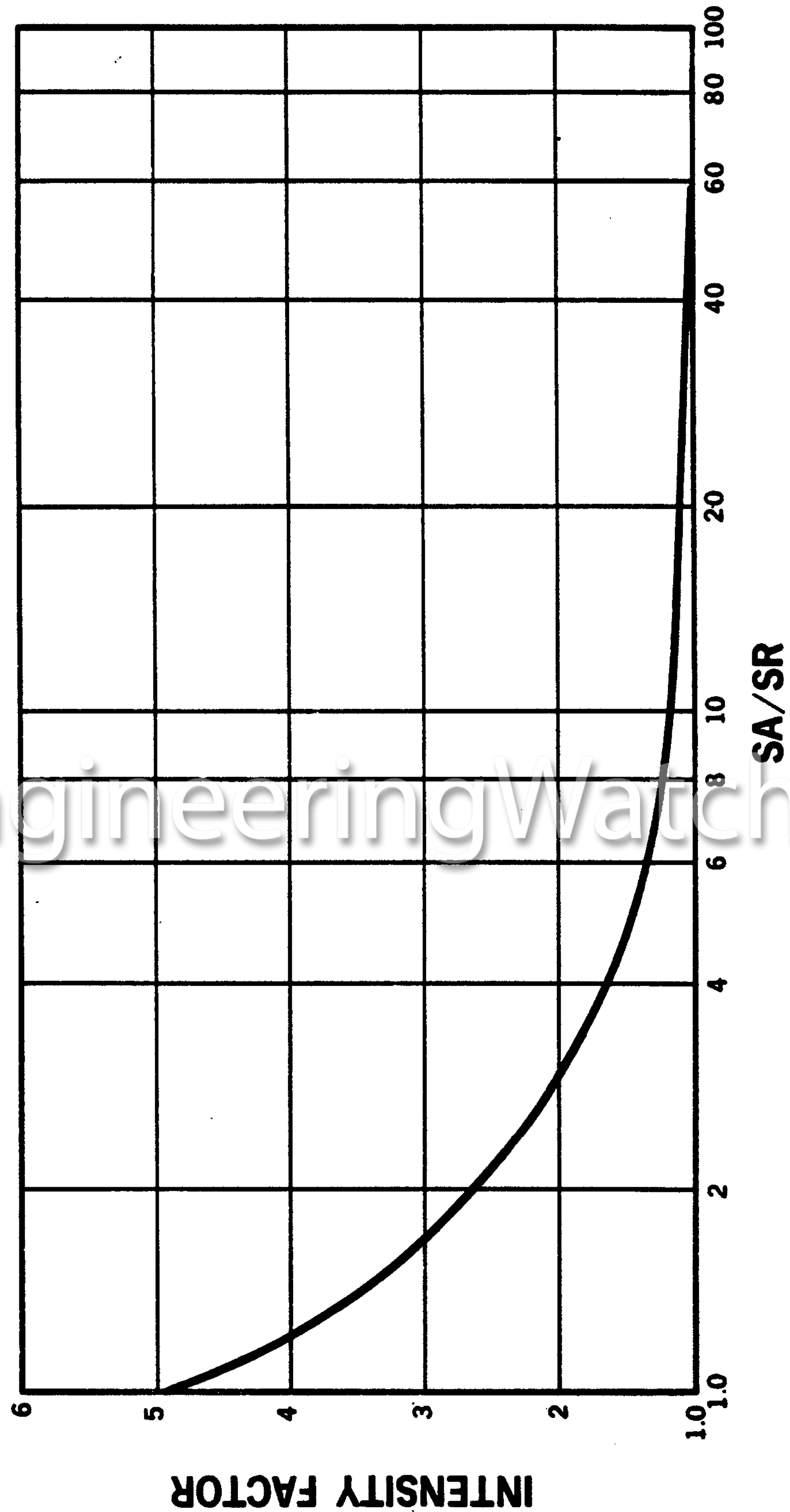


FIG 43

INTENSITY FACTOR



The advantages of multiple ignition are shown even more clearly in Figure 44 which shows the type of fire that can be expected for any combination of Nominal Incendiary Spacing and Intensity Factor. Operation Hot Tip, which spaced incendiaries at nearly optimum distances, came much closer to achieving a crown fire (in fact, 17 percent of the area did crown out) than did the single ignitions of the U Minh forest, even though U Minh burned under weather conditions 4 times as facorable for fire spread.

Incendiary Devices

The proper spacing of incendiary sets is much more critical to the success of forest burning operations than is the the type of device used to produce ignition. But there are certain optimum criteria to be considered in selecting (or designing) incendiary ordnance for use over forests. These criteria differ in several respects from those used to optimize the results of attacks on buildings or personnel. For use on structures, an incendiary needs sufficient weight and strength to penetrate the roof (and upper floors of multi-story structures), and a sufficiently high heat output to ignite materials within a room even though the incendiary filling does not come into direct contact with easily ignitable material. This requires a relatively high weight, high strength casing with a high heat output filling. For anti-personnel purposes the weapon should maximize radiant heat output. This requires an incendiary that produces a large volume of flame with a rapid combustion rate and high flame temperature.

Initiation of forest fires is a different problem. In the outdoors, most of the convective and radiative heat from large, intense, incendiaries is lost to the surroundings, and only flames in contact with the fuel produce ignition. An old and proven rule of thumb is that fire will not spread in a litter fuel if it cannot be ignited by a well-placed kitchen match. Small scattered flames are therefore much more effective than large radiant heat sources in starting fires in forest litter. As a practical matter, ignition of forest litter is most readily accomplished by small, cluster-type incendiary weapons designed for direct flame contact with the fuel.

Table 11 lists the thermal properties of common incendiary fillings. This table shows why napalm, developed as an anti-personnel incendiary, has been notoriously unsuccessful in starting forest fires. Not only does napalm have the lowest burning rate per square foot of coverage of any common filling, but the material boils off from the covered surface at temperatures below that at which it ignites. Thus, napalm produces a large volume of flame, but the flaming starts at some distance above the fuel surface. Even PT-1, the best of the petroleum-based fillings from the standpoint of forest ignition, has a significant fraction of volatiles whose distillation temperatures are below ignition temperature.

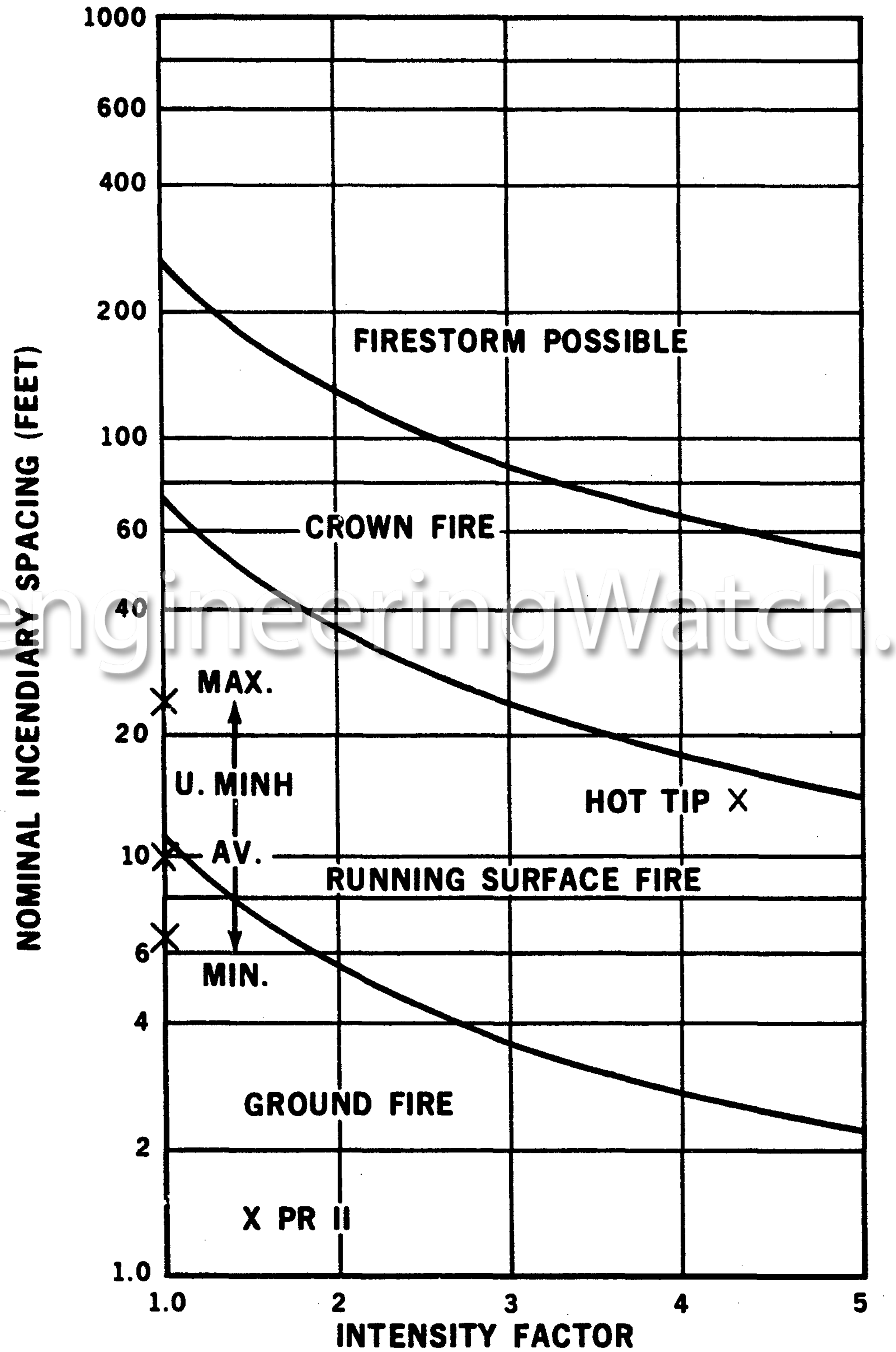
The ideal incendiary device for forest burning operations would be a cluster of a great many light-weight, unarmoured, low-volatile devices. The experimental CBU53-54B series should be a great improvement over existing munitions for use over forests

Table 11

Agent	Heat Value 1000 Btu./lb.	Ignition T^{O} ^{O}F.	Distillation T^{O} Initial (^{O}F.)	End Point	Burning Rate lb./ft.^{2}Min.	Flame T^{O} ^{O}F.
Napalm B	19.0	825	95	390	.05 – .2	3140
JP – 4	18.6	470	325	450	.1 – .4	2640
PT – 1	13.7	510	370	680	.3 – .7	2400
Magnesium	11.8	1000	1100	–	.9 – 1.4	2400
White Phosphorus	10.6	34	280	–	.2 – .4	–

FIG.44

EXPECTED FIRE BEHAVIOR



DISCUSSION

The deliberate initiation of forest fires can result in significant damage to enemy troops and facilities provided that incendiary operations are carefully planned with due consideration given to three essential ingredients: fuel, weather, and ignition pattern.

Forest fires must get their start in a surface layer of fallen leaves, twigs, or dry grass, and spread from there into the aerial parts of shrubs and trees. This surface litter is generally lacking in arid or arctic areas where vegetation is sparse. Litter if often scanty in the humid tropics where termites and decay consume dead vegetation nearly as fast as it falls. In situations where natural surface fuel is insufficient to carry fire, measures must be taken to increase the amount of flammable material on the ground. Chemical defoliation of overstory trees and shrubs is the only logistically feasible method of augmenting the surface fuel supply. Defoliation missions should be flown at least 4 months in advance of the incendiary missions. This means that the opportunities for planned forest fire raids in humid areas of the tropics are restricted to situations where the military environment is essentially static, and targets can be selected months in advance. In temperate climates where the surface fuel supply is adequate, defoliation is unnecessary and forest fire operations can be conducted on short notice whenever conditions are optimum.

Weather is crucial for success in forest burning. Incendiary operations must be preceded by at least a week of dry weather, and cloud cover should be 3/8 or less with relative humidity below 50 percent in the target area at the time of ignition. Under most circumstances, these requirements mean that forest incendiary operations must be conducted in the early afternoon. No external environmental modification technique can overcome the effects of adverse weather conditions. Consequently, a good meteorologist is an absolute necessity as a member of any team planning fire raids against forests.

If fuels and weather are within acceptable limits for fire initiation, the intensity of forest fires resulting from properly spaced ignition devices can be increased by as much as a factor of 5 over that of naturally occurring fires. Maximum fire intensity is achieved by spacing ignitions so that adjacent fires begin to interact with each other at the exact time that each fire has reached its maximum normal intensity. Proper use of this area ignition technique can greatly increase the effectiveness of forest fire as a military weapon. But area ignition will not compensate for wet weather or insufficient ground fuel: five times zero still equals zero.

APPENDIX A

U Minh Forest Fires
10 March - 29 April, 1968

U MINH FOREST FIRES

PROLOGUE

Around the middle of April 1968, the stateside newspapers began carrying accounts of a devastating forest fire in the lower Mekong Delta. The following quotes from the UPI dispatch of 13 April are typical:

> B-52's flew rare missions in the Mekong Delta today to bomb Viet Cong hideouts already ravaged by forest fires. The U Minh Forest, 140 miles southwest of Saigon have been a Communist stronghold for more than 20 years. The forest has been ravaged by at least 70 forest fires this week and many Viet Cong units were forced to the open ground to escape the flames. Intelligence sources say the fires have done more damage than any attack on the area in 20 years.

Since we had rejected the U Minh as a suitable target for incendiary operations in 1966 and 1967, it wasn't long before the Forest Service began receiving pointed queries from the Pentagon.

From long experience, we have an innate distrust of forest fire stories as reported in the popular press. Consequently, we requested ARPA's permission to include an analysis of the U Minh fires as part of the mission of Project EMOTE.

The data were collected in June 1968 by a Forest Service team which was in Vietnam on a helicopter operations study. They are included in this report because they vividly illustrate several important points in the planning and conduct of forest incendiary operations.

U MINH FOREST FIRES

POST-FIRE ANALYSES

Summary:

Based on the narrative report from Advisory Team 96, complete weather records from the nearest weather stations, and analysis of aerial photographs taken 2 months after the fire, the following conclusions were reached.

1. The spring of 1968 was the driest in 25 years throughout the Gulf of Siam. Forest fires were severe in Malasia and Thailand as well as in Cambodia and Vietnam.

2. The U Minh fires burned for 50 days and burned through a variety of cover types. The final extent of the fire incompassed an area 48 miles long and 24 miles wide. Ninety-two percent of this area (680,000 acres) shows evidence of fire, 72 percent (530,000 acres) shows evidence of some burning of shrub cover, and 24 percent (175,000 acres) has been denuded of high foliage cover.

3. Despite this extensive damage, less than 0.5 percent of the area (3,400 acres, in small patches) shows positive evidence of crown fires. In most cases where the forest cover is gone, the cause was the burning of a sufficient depth of peat soil so that shallow-rooted species simply tipped over. In some cases the trees were wind thrown or water thrown many days after the fire. The cases can be distinguished since trees which fell during the fire had their foliage burned, while trees which fell later show unburned foliage.

4. Neither fire behavior nor rates of fire spread were significantly different from those experienced during previous forest fire operations in War Zones C and D. The destinctive feature of the U Minh fires was the fact that they

occurred in peat soils and thus continued to smoulder overnight and take off the next day. Close examination of more than 60 miles of the outside fire perimeter showed only 4 small segments where fire burned further than one-fourth mile from the boundary of the peat-muck soil type as mapped by Moorman.[A1]

5. Areas which had been treated with defoliants definitely burned better than adjacent unsprayed areas (although we could not establish a quantitative measure of the difference). In some places, ground fires actually ceased burning at the margins of the sprayed strips. This usually occurred only on higher ground, where we assume the litter layer was shallow and not underlain with peat. Even though burning was more intense in sprayed areas, the effect was not sufficient to produce crown fires.

6. By the time the aerial photos were taken (June 26 - 30), much of the area had been flooded by the early monsoon rains. In many places, the downed trees had floated and formed windrows up to 4 miles long, a half mile wide, and 10 - 15 trees deep. These will pose a significant hindrance to any type of ground movement.

Data Available:

1. Memorandum: 24 May 1968 from MACV-IVC-2 to MACV-J2P. Subject U Minh Forest Fire (U).
2. Daily Surface Weather Summary 1 Nov. 1967 through 30 April 1969 for stations 48907 (Rach Gia), 48911 (Quan Long), 48913 (Soc Trang) and 48914 (Kien Giang).
3. Hourly surface weather observations 7 March through 30 April 1968 for Kien Giang and Rach Gia.
4. VNAF Photo Missions 06069, 6075, 6079, 6080, 07002 and 07006.

Comments on Data:

1. Memorandum excellent.
2. Records spotty, but combining Rach Gia and Kien Giang (only 4 miles apart) gives a record with only 3 missing days.
3. Hourly observations very spotty, but sufficient to establish typical "normal" and "high spread" days.
4. Quality of photography very good.

   Scale quite variable (nominal 1:5000, but typically varies ± 15 - 20 percent along single flight line.

   Very poor coordinate location. Could positively identify ground control on less than 25 percent of flight lines.

   No coverage for three areas of interest:
   VR8040 – 9343 – 9348 – 8254
   VR8366 – 9366 – 9582 – 8882
   VR8882 – WR00882 – 0299 – VR8882

   Insufficient overlap for sterio on about 25 percent of area south of $9^{o}20'$N.

[A1] Moorman, F. R. The Soils of the Republic of Vietnam, RVN Ministry of Agric. 66 pp., illus 1961

Spread Analysis:

Spread to Kahn Binh firebreak, as scaled from five possible points of origin, showed a maximum of 6 miles in 18 days or 1760 feet per day.

Calculated spread rates from the hourly burning indexes for the period 20 March through 7 April predict an average of 1960 ft. per day. Maximum rates 4.8 - 8.7 ft/min.

Excellent agreement considering distance of weather station from fire (52 miles) and uncertainty of a day or two in time of arrival at firebreak.

Applying same calculation procedure to all days from 10 March through 29 April we find only 7 days during which spread rates would have exceeded one mile per day, and no days on which fire intensity would be great enough for extensive crown fires to develop.

FIG. A-1

AREA BURNED IS U MINH FOREST FIRES
MARCH-APRIL, 1968

HEADQUARTERS

US ARMY ADVISORY GROUP, IV CTZ

ADVISORY TEAM 96, APO SAN FRANCISCO 96215

MACV-IVC-2 24 May 1968

SUBJECT: U MINH FOREST FIRE (U)

TO: Commanding General
Military Assistance Command, Vietnam
ATTN: J2 Production
APO 96222

1. (C) References:

a. MACV Secret message 12539, dtg 030545Z May 68, Subject: U Minh Fire (U).

b. MACV Secret message 13510, dtg 100345Z May 68, Subject: U Minh Fire (U).

2. (C) An analysis of reports received by this headquarters concerning the fire in the U Minh area indicates that the fire began on or about 10 March 1968. It is not known precisely how the fire began although several explanations have been presented. CORDS personnel suggest that it began after a group of irate fishermen, who were denied access to the area by the Viet Cong, started several fires at approximately VR 970 390 (see incl 1, item 1) as a means of retaliation. Regardless, the fire reportedly spread rapidly from this area to the southwest through the aid of thirty knot winds from the northeast, extremely dry conditions in the entire area, and the ignition of a large ammunition dump located within 200 meters of the original fire.

a. On or about 14 March 1968, a fire also started through the use of white phosphorous ammunition from Thoi Binh (WR 105 335) in the area near WR 080 330 (see incl 1, item 2). Again, the relatively strong winds and extremely dry conditions caused this fire to spread rapidly and throughout a large area.

b. Although the exact cause is not known, a fire also started on approximately 20 March 1968, in the area of VR 970 140 (see Incl 1, item 3). Initially this fire spread to the southwest also, although a sudden change in wind direction caused it to burn to the north at an even more rapid rate.

c. During the latter part of March and the early part of April, the fire spread over an enormous area. This increase in the burning rate was largely caused by coastal wind shifts which occur throughout the U Minh area during this time of year.

3. (C) Several reports were received on approximately 6 April 1968 which indicated that the VC were attempting to establish firebreaks in several areas throughout the forest. One such report stated that the VC were using a large number of forced laborers in the area of VR 900 130 to VR 900 300 to construct such a firebreak. A visual reconnaissance of this area on 12 April partially confirmed this report, and although the laborers could not be seen, there was evidence that a dried up canal in the area might have been used for this purpose. This canal did not contain the fire, however, since large areas on both sides were thoroughly burned.

MACV-IVC-2 24 May 1968

SUBJECT: U MINH FOREST FIRE (U)

4. (C) During this period in late March and early April, the benefits of such a vast fire became increasingly obvious. As a result, O-1 aircraft using white phosphorous rockets and grenades started fires in numerous other areas (see incl 1, item 4). These efforts were further aided by sky spots on 3 reported ammunition caches (i.e., 2 on each position) in the areas of VR 850 650, VR 855 255, and VR 670 120, respectively. Also, several daylight forward air controller (FAC) controlled sorties were flown in the area using primarily napalm, although some high explosive ordnance was used.

5. (C) During the second and third weeks of April, hundreds of secondary ammunition and petroleum explosions were reported. The FAC from An Xuyen sector estimated that at one point during this period secondary explosions were occurring at a rate of one per twenty minutes. Recent visual reconnaissance flights show a large number of craters caused by these explosions throughout the entire forest area.

6. (C) Besides the tinder like condition of the forest, the fire was also aided by the peat or coal like state of the forest floor. Once the timber and underbrush were burned off the fire would continue burning beneath the surface of the soil at an extreme intensity. When the winds decreased this portion remained burning and when the winds rose in early afternoon the flames and heavy smoke would again become visible.

7. (C) Although napalm was used in an effort to spread the fire, it was not as effective as anticipated. An example of this is cited in a report prepared by the An Xuyen sector FAC where four airstrikes were used having partial napalm loads in an effort to ignite areas which had not burned. Three of the four areas did burn, but in each instance it was the marking rockets that started the fire and the value of the napalm was only negligible.

8. (C) There have been various reports regarding the percentage of forest area that was actually destroyed by the fire. An Xuyen sector FAC estimated that from 80 to 85 percent of the useful true forest had been destroyed while the sector S2 advisors in An Xuyen and Kien Giang provinces estimate from 70 to 75 percent destruction. These latter figures correspond favorably with estimates derived through several recent visual reconnaissance flights conducted by IV Corps DASC and IV Corps G2 Air.

a. The swamp area (VR 920 300) was apparently too wet to burn. Because of this, neither rocket, napalm or CBU-12 caused any type of sizeable fires in this area. This portion contains very few trees and because of the lack of natural cover it is used only rarely by the enemy. Furthermore, there are very few canals and trails that run through this area which further limits its value. A report from the S2 at Ca Mau (An Xuyen province) states that enemy activity increased substantially in the southern most portion of the U Minh area in mid April and it is estimated that the Viet Cong were using this location to relocate their supplies from the central portion of the U Minh forest.

b. The only heavily forested area remaining unburned lies in the area of WR 140 560. Much of this area has a heavy water content which precluded any initial destruction. The fire in this general area burned very slowly and would not spread by flash fire even though the forest was burning 360 degrees around it. Even those areas which burned within this larger area did not burn completely because of the underlying water. On several occasions white phosphorous rockets were fired into this area but did not produce resulting fires.

MACV-IVC-2 24 May 1968

SUBJECT: U MINH FOREST FIRE (U)

9. (C) Naval gunfire, operating off the coast of An Xuyen and Kien Giang provinces fired into the area on a constant basis (see incl 2). From 27 March to 13 May 1968, Naval gunfire expended 8,331 rounds of 5 inch min stabilized rockets, 1,878 rounds of 5 inch/38, 455 rounds of 5 inch/54 and 1,097 rounds of 40mm ammunition. The spin stabilized rockets were all high explosive ordnance, while many of the 5 inch/38 rounds included both high explosive white phosphorous ammunition. Together they accounted for hundreds of structures destroyed and numerous secondary explosions. This constant shelling also hampered VC attempts to transfer ammunition and supplies out of the area and prohibited this concentration of laborers who were attempting to stop the fire from spreading to new areas.

10. (C) USAF flew 10 missions with 29 sorties over the U Minh area from the period 27 March to 26 April 1968. (see incl 3) 5 of these missions were flown with the purpose of starting new fires, while the remainder were flown to assist the burning process in areas where the fire was already in progress. Their ordnance consisted primarily of napalm although white phosphorous and anti-material fragmentation bombs were also used.

11. (C) As a result of the fire, enemy activity increased throughout the U Minh area. The S2 of Kien Giang Province reported that the VC during much of April were frantically seeking new storage areas for their supplies and ammunition. It is estimated that a large portion of the goods removed were taken back up normal routes of resupply where they were then exfiltrated by sea to the three sisters area (XS 885 165) or stored in areas lying to the north-northeast of the forest. By the same token, the S2 of An Xuyen providence reported a similar increase in activity in the extreme southwestern portion of the forest, (vic VR 85 15). This area has long been used as a storage area and it is estimated that the number of caches in this area has increased as a result of the fire.

12. (C) Within the forest proper there is very little cover and concealment remaining. Trails and canals which were formerly covered by several layers of jungle canopy are now clearly visible by aerial observation. In essence, enemy activity in this area has ceased.

13. (C) A final analysis of the U Minh fire indicates that its success came from several contributing factors. First, the area experienced an exceptionally long dry season. Second, the constant shift in winds along the coastal area literally fanned the fire causing it to burn rapidly and over a vast area. Third, the peat-like substance of the forest floor caused the fire to continue burning with only a minimal amount of combustible material and very little wind. Fourth, fires were started in several areas at about the same time which prohibited a concentration of laborers in any one area. Furthermore, personnel who were attempting to put out the blaze were constantly in danger of friendly firepower and therefore could not make large and open attempts at stopping the fires' progress. Finally, measures were taken by friendly personnel to assist the overall burning process.

14. (C) As a result of the above factors, the following estimate of final damage is submitted:

a. 75 to 85 percent of the true forest was destroyed.

b. 50 percent of various outlying swamps were destroyed (vic VR 920 300; VR 830 300; VR 960 610; WR 100 530; WR 120 370; WR 070 290).

c. Hundreds of tons of ammunition, rice and petroleum products were destroyed.

d. 100-200 Viet Cong were killed or incapacitated while either fighting the fire or by rocket ships and airstrikes in the area.

e. The probable dislocation of large quantities of supplies and ammunition and the relocation of several major VC headquarters and rear service areas.

f. The increased opportunity for aerial reconnaissance of the area.

g. The lack of lumber and possible food shortage for the local populace.

h. The increased danger of floods in areas adjacent to the forest since there are no longer trees or underbrush to provide watershed.

4 Inclosures
1 – Map of U Minh area
2 – Naval Gunfire Missions
3 – USAF Support Missions
4 – Pictures of U Minh Fire

WILLIAM K. CAREY
LTC MI
Sr Intel Advisor

NAVAL GUNFIRE MISSIONS

DATE	TYPE	AMOUNT	RESULTS
07 APR 68	5 INCH/38	465	3 Structures dest, 17 structures damaged, 14 sampans damaged
13 APR 68	5 INCH/SSR 5 INCH/38	532 24	5 Structures dest, 1 sampan dest, 11 structures damaged, 4 sampans damaged
14 APR 68	5 INCH/SSR	480	2 Structures dest, 2 sampans dest, 23 structures damaged, 1 VC tax collection point damaged
15 APR 68	5 INCH/SSR	490	3 Structures dest, 1 sampan dest, 1 secondary explosion, 20 structures damaged, 4 sampans damaged, 3 secondary fires, 1 footbridge dam
16 APR 68	5 INCH/SSR	36	
17 APR 68	5 INCH/38 5 INCH/SSR 40 mm	78 370 99	1 Structure dest, 1 sampan dest, 43 structures damaged, 14 sampans damaged, 3 secondary fires
18 APR 68	5 INCH/SSR	514	7 Structures dest, 3 sampans dest, 1 ocean junk dest, 16 structures dam, 5 sampans damaged, 13 secondary fires
19 APR 68	5 INCH/38 5 INCH/SSR	106 382	5 Structures dest, 1 sampan dest, 16 structures damaged, 3 sampans damaged, 5 secondary fires
20 APR 68	5 INCH/38 5 INCH/SSR	32 924	4 Structures dest, 8 sampans dest, 9 sampans damaged, 19 secondary fires
25 APR 68	5 INCH/38 5 INCH/SSR	26 627	4 Structures dest, 20 structures damaged, 7 bunkers damaged, 1 spiderhole damaged, 5 VC KIA (poss)
26 APR 68	5 INCH/38 5 INCH/SSR	103 94	12 Structures damaged, 8 sampans damaged
27 APR 68	5 INCH/38 5 INCH/SSR	37 252	29 Structures damaged, 10 sampans damaged, 2 junks damaged, 1 large junk damaged, 1 secondary fire, 2 VC KIA (poss)
28 APR 68	5 INCH/38 5 INCH/SSR 40mm	13 332 480	1 Structure dest, 1 sampan dest, 23 structures dam, 8 sampans dam, 6 junks damaged, 4 secondary fires
29 APR 68	5 INCH/SSR	117	4 Structures dest, 12 structures dam, 7 sampans damaged, 1 secondary explosion, 2 secondary fires
30 APR 68	5 INCH/38 5 INCH/SSR 40mm	25 180 164	5 Structures dest, 1 sampan dock area dest, 19 structures damaged, 1 secondary fire
01 MAY 68	5 INCH/38 5 INCH/SSR	54 328	5 Structures dest, 3 sampans dest, 18 structures damaged, 8 sampans damaged, 1 secondary fire
02 MAY 68	5 INCH/38 5 INCH/SSR 40mm	81 394 344	5 Structures dest, 1 sampan dest, 1 bunker dest, 72 structures damaged, 18 sampans damaged, 1 secondary fire, 1 footbridge damaged, 4 VC KIA (conf)
03 MAY 68	5 INCH/38 5 INCH/SSR	87 75	1 Structure dest, 6 structures dam, 1 secondary fire, 55 meters trail damaged
04 MAY 68	5 INCH/SSR	251	4 Structures dest, 1 sampan dest, 14 structures damaged, 3 sampans damaged, 1 secondary explosion, 2 secondary fires
04 MAY 68	5 INCH/SSR	554	1 Sampan dock area dest, 19 structures dam, 3 sampans damaged, 3 secondary fires, 1 bridge damaged

USAF SUPPORT MISSIONS

DATE	MISSION	SORTIES	ORDNANCE USED
27 MAR 68	9964	2 F4C	4-FIN N, 6-MK82, 1 CBU-2
04 APR 68	2332	2 F100	4-MK82, 2-BLU-27, 2-CBU-2
06 APR 68	1849	2 F100	2-FIN N, 2-M117's, 4-LAU-3
18 APR 68	*8529	2 A37	4-MK82, 4-500 N
18 APR 68	*8516	2 F100	4-MK82, 4-500 N
19 APR 68	*10807	2 F100	4-CBU-12, 4 N
19 APR 68	*10808	2 F100	4-CBU-12, 4 N
20 APR 68	10903	2 F4C	12-M117
20 APR 68	10927	2 F4C	6-MK82, 4 BLU-27
20 APR 68	*12526	2 A37	4-MK82, 4-BLU-32

*Those dropped specifically to start fires.

Rach Gia – Kien Giang
Hourly Surface Weather

Time	T (°F)	RH (%)	Wind (knots)	Cld Cover (8ths)	Shrub Burning Index
			Average Day		
0200	79	90	4	5	0
0500	75	95	1	4	0
0800	75	96	1	6	0
1100	87	62	4	6	1
1400	91	53	9	6	4
1530	92	47	10	5	6
1700	90	50	9	4	5
2000	82	76	7	3	1
2300	81	80	5	5	0
			High Spread Day		
0200	79	90	4	4	0
0500	76	93	1	4	0
0800	76	93	1	4	0
1100	92	54	6	5	4
1400	94	49	16	4	20
1530	96	38	20	3	28
1700	92	47	12	3	19
2000	83	73	8	3	1
2300	81	80	6	4	0

Rach Gia – Kien Giang
Hourly Surface Weather

Date	T (°F)	RH (%)	Wind (knots)	Cld Cover (8ths)	Shrub Burning Index	Rain (in.)	Remarks
12/20/67						2.76	
12/21/67						0.20	
					76 rainless days		
3/7/68	88	45	6	5	6		
3/8/68	95	42	6	6	8		
3/9/68	92	37	22	2	28		
3/10/68	95	42	16	6	25		
3/11/68	96	42	6	6	8		1st fire start
3/12/68	95	37	11	5	28		
3/13/68	93	41	16	5	26		
3/14/68	93	42	25	3	30		
3/15/68	89	70	15	7	6		2nd fire start
3/16/68	92	49	6	5	6		
3/17/68	92	46	6	6	6		
3/18/68	92	49	6	6	6		
3/19/68	93	50	7	3	5		
3/20/68	88	57	8	3	3		
3/21/68	92	49	6	6	6		3rd fire start
3/22/68	93	44	6	6	7		
3/23/68	93	47	7	5	6		
3/24/68	93	44	2	6	6		
3/25/68	93	47	7	6	6		
3/26/68	93	44	7	6	7		
3/27/68	93	46	7	3	6		
3/28/68	91	45	7	5	6		1st air strike
3/29/68	93	52	16	3	18		
3/30/68	93	47	11	1	19		
3/31/68	93	56	5	6	4		
4/1/68	91	48	6	6	5		
4/2/68	93	49	11	5	18		
4/3/68	93	52	12	6	18		
4/4/68	91	52	15	4	18		
4/5/68	88	48	12	7	18		2nd air strike
4/6/68	95	42	20	4	26		
4/7/68	93	44	6	6	7		3rd air strike, VC start firebreak
4/8/68	94	44	6	5	7		
4/9/68	93	46	7	4	6		
4/10/68	94	47	9	4	7		
4/11/68	91	49	6	5	5		
4/12/68	94	43	12	6	24		
4/13/68	93	41	16	5	26		
4/14/68	94	44	15	5	23		
4/15/68	91	57	17	5	13		
4/16/68	92	45	14	4	22		
4/17/68	93	45	12	3	22		
4/18/68	92	49	9	6	6		
4/19/68	93	48	3	5	6		1st incendiary strike
4/20/68	95	43	7	5	7		2nd incendiary strike
4/21/68	missing						3rd incendiary strike
4/22/68	missing						
4/23/68	92	47	14	5	18		
4/24/68	missing						
4/25/68	88	65	11	6	8		125th rainless day
4/26/68	92	49	15	3	18	showers seen	
4/27/68	94	46	18	6	23		
4/28/68	92	50	15	5	18		
4/29/68	80	88	0	8	0	1.62	
4/30/68	92	56	5	5	0	drizzle	

APPENDIX B

Pertinent Incendiary Data
by Climatic Types

PERTINENT INCENDIARY DATA BY CLIMATIC TYPE

The key to identification of each fire climate class is shown in Table 5, page 35, of the text. The representative locations given for each class are listed, from top to bottom, in order of decreasing winter temperatures. In most cases, the warmest location shown for a class (for example, the first location for MI–HUSB) is very similar to the coolest location for another class (the last location for FF–HUSB). Likewise, the wettest location is a class (such as CL–HULB) often is similar to the driest in another class (such as CL–HUSB).

Descriptions of the fire climates by world climate classes and by precipitation patterns are from Papadakis, footnote 13, page 34, of the text.

Humid months ("H"), dry months ("D"), and burn months ("B") are described on pages 34 to 37. Procedures for determining the (+) and (–) humidity values are on pages 29 to 31.

In the graphs of climates at representative locations, the temperature and precipitation scales are adapted from the criteria of Bagnouls[1/] The period of plant moisture stress corresponds closely with the time, or times of the year when the curve for average monthly precipitation lies below the curve for average monthly mean temperature.

The date, or dates, recommended for herbicide applications at each location illustrated in Figures B1 – B27 represent a satisfactory combination of air temperature and soil moisture, and allow maximum feasible time for dying and drying of vegetation before burning. At other locations having the same climate, some adjustments in treatment dates may be necessary to fit a somewhat different yearly weather pattern. The herbicide dosages should be increased if treatments are to be applied under other than the most satisfactory weather conditions, as explained on pages 63 to 65 of the text.

CLIMATE FF–HUYL
FROSTFREE WINTER; HUMID YEARLONG

All equatorial and frostfree tropical climates having no "D" months and no "B" months. Examples are:

Location	Precipitation Pattern	No. of Months "H"	"D"	"B"	Yearly Humidity Values (+)	(–)
Andagoya, Colombia	Humid	12	0	0	+480	0
Kuala Lumpur, Malasia	Humid	11	0	0	+454	0
Kieta, Bougainville I.	Humid	12	0	0	+480	0
Guam I.	Humid	9	0	0	+351	0
San Juan, P.R.	Humid	11	0	0	+431	0
Entebbe, Uganda	Humid	11	0	0	+320	0
Quang-Tri, R. V. N.	Humid	7	0	0	+263	0
Santos, Brazil	Humid	12	0	0	+424	0
Hamilton, Bermuda	Humid	12	0	0	+416	0

Temperature: Not limiting; allows growth of tender-leaved plants.

Precipitation: Not limiting, except for short dry periods.

[1/] F. Bagnouls (1957) Les climates biologiques et leur classification. Ann. de Geographic, 66 (355): 193–220.

Major vegetation type: Tropical evergreen rain forest. Man-made secondary forests and grassy openings are relatively temporary.

Ground-story vegetation: Often dominated by succulent plants (banana). Vines, tree seedlings, and scattered shrubs usually are present.

Amount: Usually low in dry weight.

Moisture content: High yearlong.

Litter layer: Only current leaf fall. No accumulation of dead woody material; rapid chemical and biological breakdown.

Total available fuel weight on a good burning day: 0.10 pounds per square foot.

Burn days: No burn season. Few suitable days, not easily predicted—best odds in driest months.

Desiccation needs: Must remove forest canopy and kill understory plants for successful burning. Use either foliar sprays or an application of pellets to the soil.

Foliar sprays: Apply a defoliant spray at least 6 months ahead of planned burning date. Wait at least 6 weeks and apply a repeat spray on the exposed understory. On each date, apply the following mixture per acre:

8 lbs., acid equivalent, of a 1:1 mix of 2,4-D and 2,4,5-T plus 2 lbs., acid equivalent, of picloram; both herbicides combined in diesel oil to make 5 gallons total spray mixture.

Soil application: Apply picloram pellets at 20 pounds, acid equivalent, per acre at least 6 months ahead of planned burning date.

Dates for example location (Kuala Lumpur, Fig. B1):

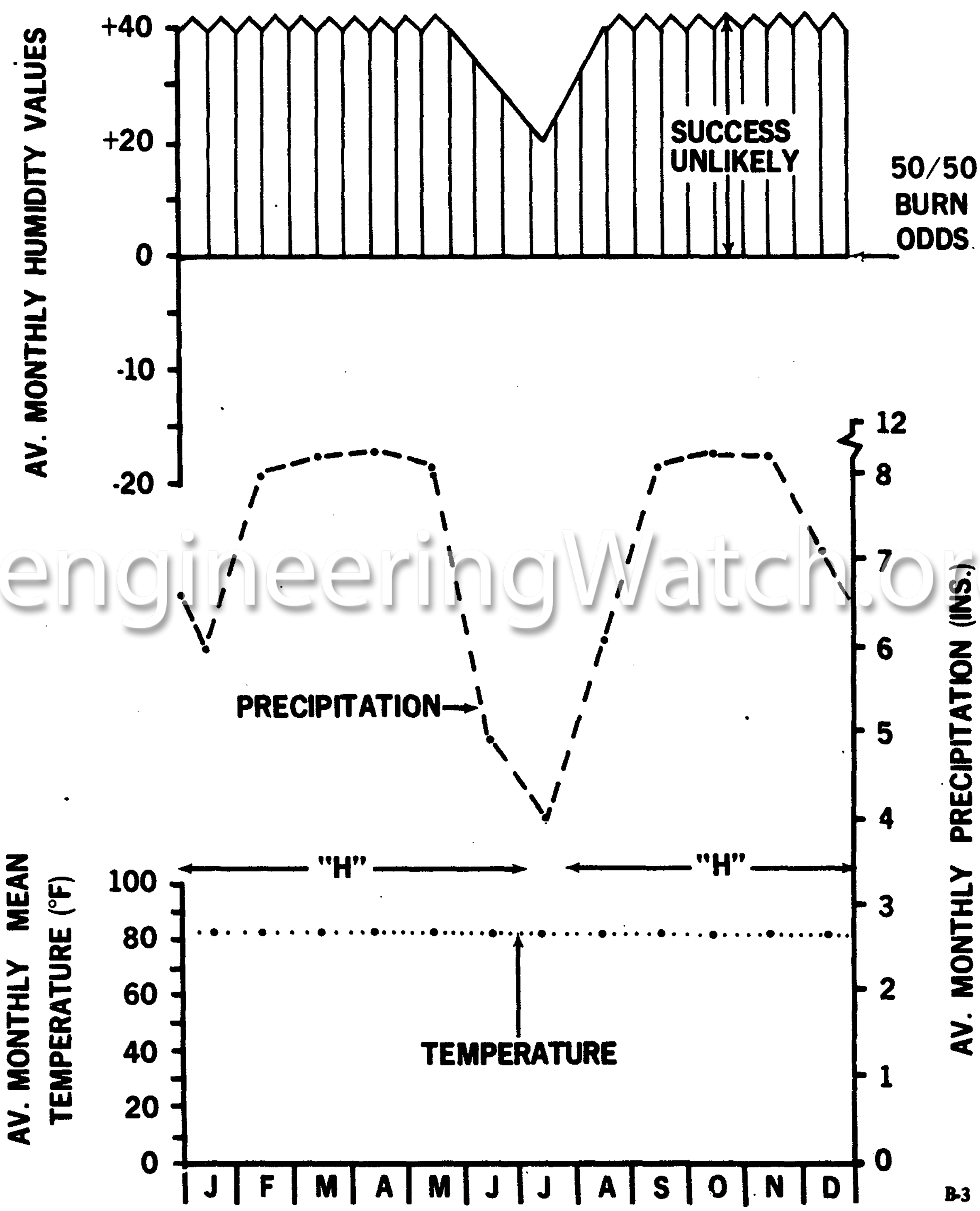
1. Apply first spray in November and second spray in February.

Or

1. Apply pellets in January (when trees are growing and leaching rainfall is at a reduced level).
2. Burn in June or July, whenever a dry period occurs.

FIG. B1

CLIMATE FF-HUYL
KUALA LUMPUR, MAL.



CLIMATE FF–HUSB

FROSTFREE WINTER; HUMID, SHORT BURN SEASON

All equatorial and frostfree tropical climates having 1–4 "B" months and low yearly (–) values. Examples are:

Location	Precipitation Pattern	No. of Months "H"	"D"	"B"	Yearly Humidity Values (+)	(–)
Phuket, Thailand	Humid	8	0	2	+329	–18
Paramaribo, Sur.	Humid	10	0	2	+351	–5
Lagos, Nigeria	Humid	8	0	2	+235	–6
Port of Spain, Trin.	Monsoon	6	2	2	+313	–5
Recife, Brazil	Monsoon	6	1	3	+264	–18
Havana, Cuba	Humid	7	0	3	+208	–11
Nassau, Bahamas	Monsoon	6	0	4	+237	–12
Key West, Florida	Monsoon	5	1	4	+151	–17
Cairns, Australia	Humid	7	0	2	+253	–4
Hanoi, N. Vietnam	Humid	7	0	2	+266	–4

Temperature: Not limiting.

Precipitation: Limits plant growth for a short period, especially under monsoon patterns.

Major vegetation types: Evergreen tropical hardwood forest; blends with semi-deciduous forest under monsoon climate. Many areas of man-made secondary forest and savana types.

Understory vegetation: Woody plants are tree seedlings, vines, and scattered shrubs.

Amount: Usually low in dry weight.

Moisture content: High yearlong.

Litter layer: Only current leaf fall. Rapid chemical and biological breakdown of woody material.

Total available fuel weight on a good burning day: 0.11 pounds per square foot.

Burn days: Short dry period in most years, but a few rainy days are apt to occur any month.

Desiccation needs: Must remove forest canopy and kill understory vegetation for successful burning. Use either foliar sprays or an application of pellets to the soil.

Foliar sprays: Apply a defoliant spray at least 6 months ahead of planned burning date. Wait at least 6 weeks and apply a repeat spray on the exposed understory. On each date, apply the following mixture per acre:

8 lbs., a.e., of a 1:1 mix of 2,4–D and 2,4,5–T plus 2 lbs., a.e., of picloram ester, both combined in diesel oil to make a total mixture of 5 gallons.

Soil application: Apply 20 lbs., a.e., of picloram pellets per acre.

<u>Dates for example location (Hanoi, Fig. B2):</u>

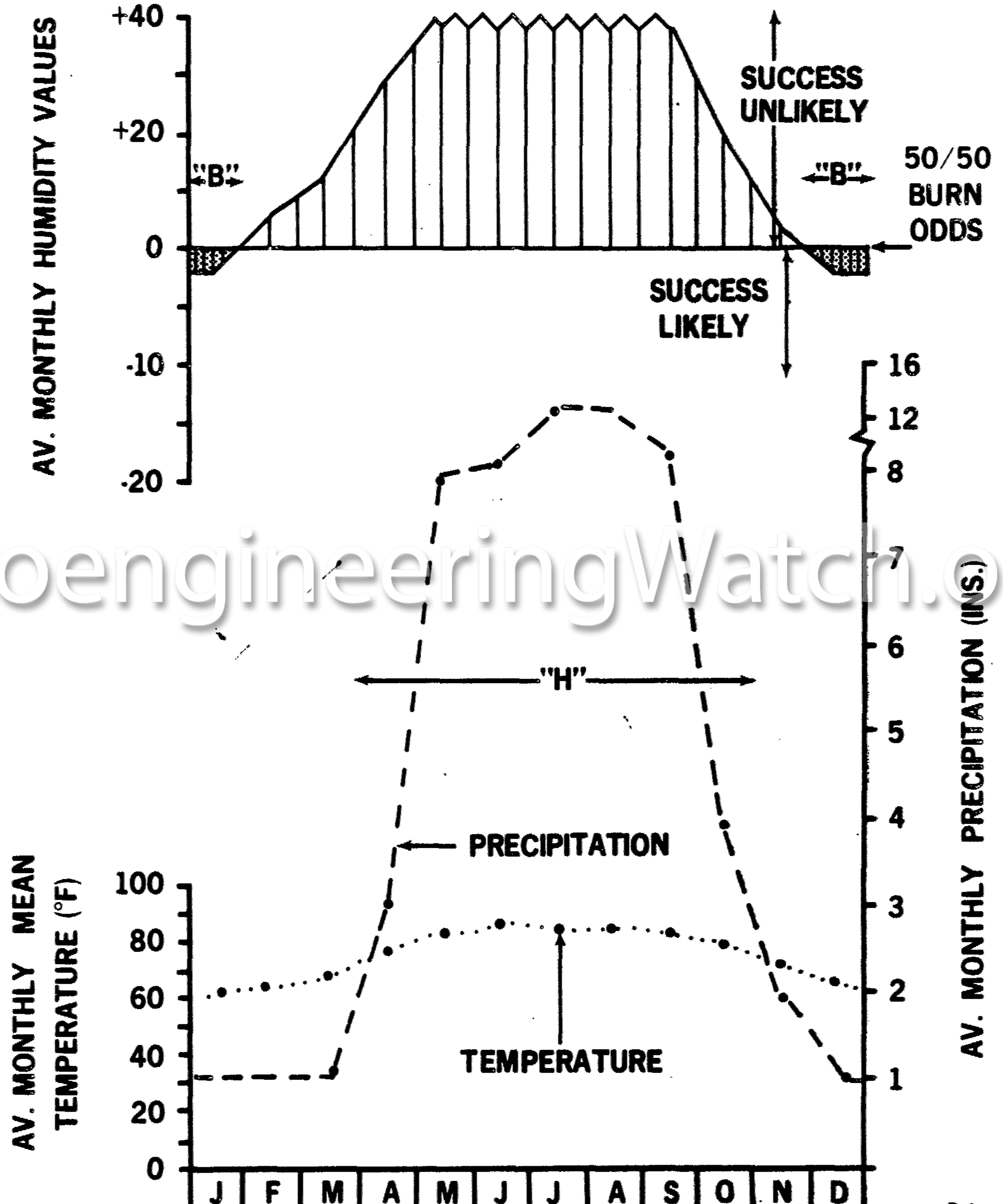
1. Apply first spray in June and second spray in August.

   <u>Or</u>

1. Apply pellets in April.
2. Burn in December or January, or in February.

FIG. B2

CLIMATE FF-HUSB
HANOI, N. VIETNAM



CLIMATE FF–HULB

FROSTFREE WINTER; HUMID, LONG BURN SEASON

All equatorial and frostfree tropical climates having high (+) values and high (–) values for the year, or at least 5 "B" months. Examples are:

Location	Precipitation Pattern	No. of Months "H"	"D"	"B"	Yearly Humidity Values (+)	(–)
Balboa Hts., Panama	Monsoon	8	2	3	+320	-32
Saigon, R. V. N.	Monsoon	7	3	4	+273	-45
Malindi, Kenya	Monsoon	4	4	6	+157	-58
Kadugli, Sudan	Monsoon	5	5	7	+116	-79
Bombay, India	Monsoon	4	6	8	+145	-89
Cook town, Aust.	Monsoon	5	2	5	+206	-34
Leopoldville, Congo	Monsoon	8	3	4	+202	-41
Vientiane, Laos	Monsoon	6	3	5	+239	-42
Mandalay, Burma	Monsoon	3	5	6	+130	-56
San Jose, Costa R.	Monsoon	7	3	5	+270	-29

Temperature: Not limiting.

Precipitation: Plant growth is restricted during several dry months; causes leaf fall from most tree species, and grasses become dry.

Major vegetation types: Semi–evergreen, semi–deciduous, and deciduous tropical hardwood forests. Man–made savana types and secondary forests are common.

Ground–story vegetation: Woody plants under forest canopy are tree seedlings, vines, and scattered shrubs.

Amount: Low to moderate in dry weight.

Moisture content: Drops during long dry season, but woody stems retain 100–120 percent of dry weight.

Litter layer: Only current leaf fall. Rapid chemical and biological breakdown during the wet season.

Total available fuel weight on a good burning day: 0.13 pounds per square foot.

Burn days: Dependable long burning season.

Desiccation needs: Must remove forest canopy and kill understory plants for successful burning. Use either foliar sprays or an application of pellets to the soil.

Foliar sprays: Apply a defoliant spray at least 6 months ahead of planned burning date. Wait at least 6 weeks and apply a repeat spray on the exposed understory. On each date, apply the following mixture per acre:

8 lbs., a.e., of a 1:1 mix of 2,4–D and 2,4,5–T plus 2 lbs., a.e., of picloram ester, both herbicides combined in diesel oil to make a total mixture of 5 gallons.

Soil application: Apply 20 lbs., a.e., of picloram pellets per acre.

Dates for example location (Vientiane, Fig. B3):

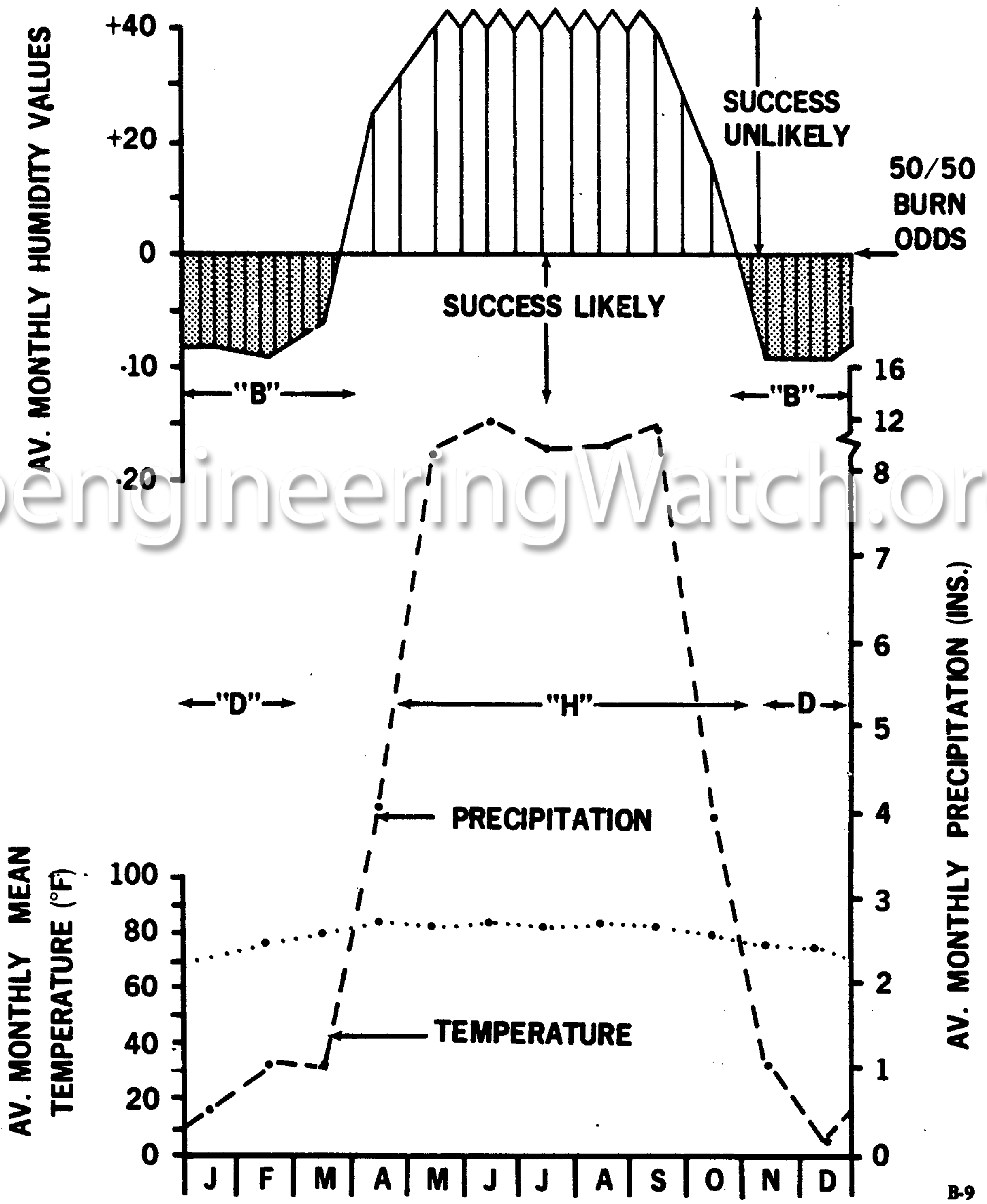
1. Apply first spray in June or July and second in August.

Or

1. Apply pellets in April.
2. Burn in January or February.

FIG.B3

CLIMATE FF-HULB
VIENTIANE, LAOS



CLIMATE FF–NHLB
FROSTFREE WINTER; NON-HUMID, LONG BURN SEASON

All equatorial and frostfree tropical climates having low to moderate (+) values and high (–) values for the year; usually with at least 5 "B" months. Examples are:

Location	Precipitation Pattern	No. of Months "H"	"D"	"B"	Yearly Humidity Values (+)	(–)
Maracaibo, Venez.	Monsoon	1	5	10	+24	-108
Kingston, Jamaica	Monsoon	4	4	6	+74	-42
Cabinda, Angola	Monsoon	4	3	7	+62	-50
Mabote, Mozamb.	Monsoon	0	9	11	+ 7	-82

Temperature: Not limiting.

Precipitation: Restrictive most of year.

Major vegetation types: Tropical thorny woodland and open deciduous forest.

Ground-story vegetation: Grasses and low shrubs.

Amount: Usually low in dry weight.

Moisture content: Drops during the long dry season. Woody plants retain 80–100 percent of dry weight.

Litter layer: Thin; no accumulation of old material.

Total available fuel weight on a good burning day: 0.10 pounds per square foot.

Burn days: Long dependable burning season.

Desiccation needs: Grasses burn readily during dry season. Removal of woody vegetation requires desiccation treatment. Apply a foliar spray of 3 lbs., a.e., of 1:1 mix of 2,4–D and 2,4,5–T in diesel oil to make a total mixture of 5 gallons per acre.

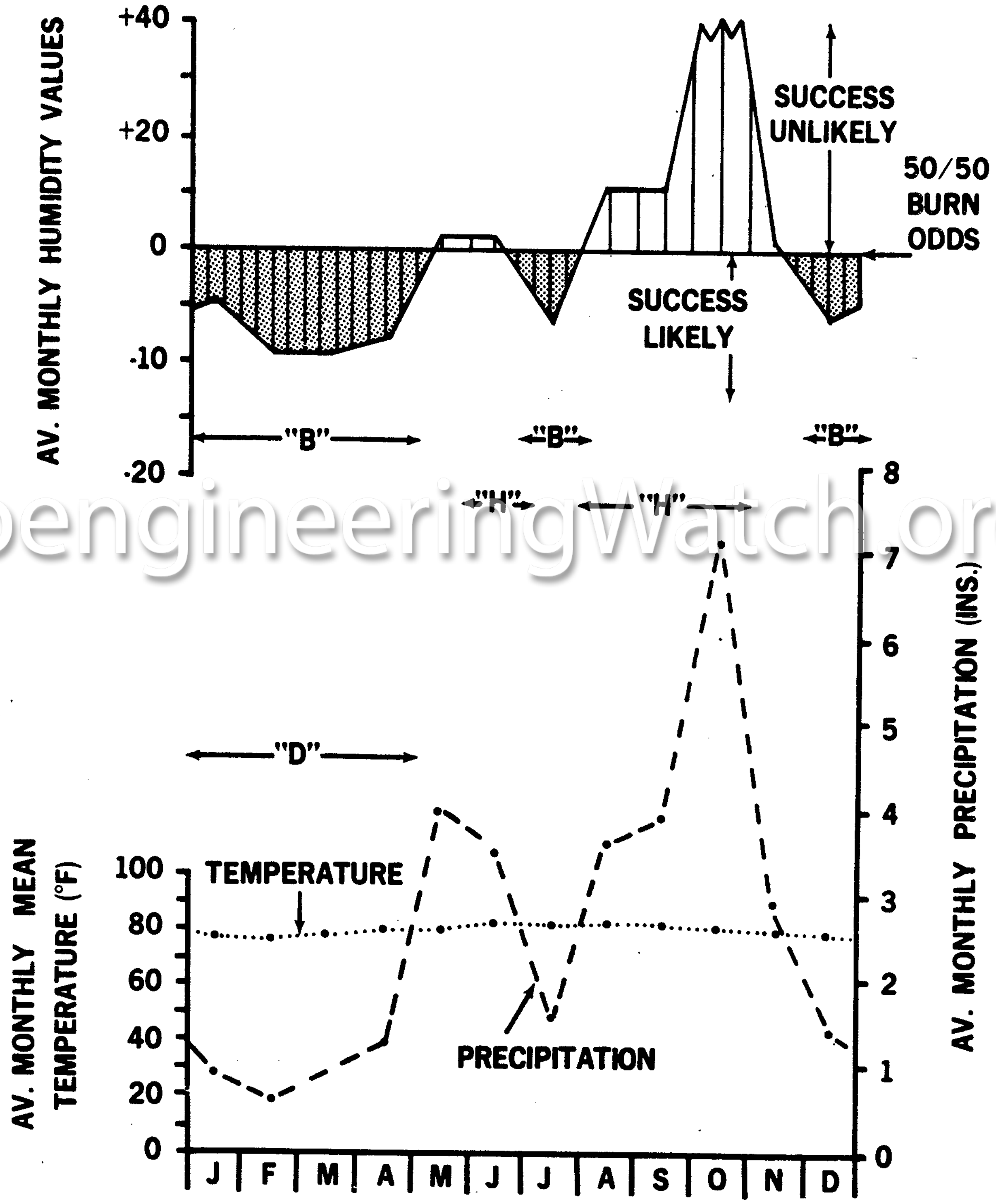
Dates for example location (Kingston, Jamaica, Fig. B4):

1. Spray in late September or early October.

2. Burn in May.

FIG. B4

CLIMATE FF-NHLB
KINGSTON, JAMAICA



CLIMATE FF–DRYL
FROSTFREE WINTER; DRY YEARLONG

Equatorial and frostfree tropical desert climates having 12 "B" months. Examples are:

Location	Precipitation Pattern	No. of Months "H"	"D"	"B"	Yearly Humidity Values (+)	(-)
Lodwar, Kenya	Desert	0	12	12	0	-141
Wajir, Kenya	Desert	0	12	12	0	-136
Lobito, Angola	Monsoon	1	7	12	0	-104
Guaymas, Mexico	Monsoon	0	11	12	0	-110
La Paz, Mexico	Desert	0	12	12	0	-121

Temperature: Not limiting.

Precipitation: Extremely restrictive.

Major vegetation types: Open desert shrub or thornbush.

Ground-story vegetation: Semi-shrubs and ephemeral herbaceous plants.

Amount: Thin, discontinuous stand with very low weight.

Moisture content: Low, except for short periods after infrequent rains.

Litter Layer: Absent.

Total available fuel weight on a good burning day: 0.01 pounds per square foot.

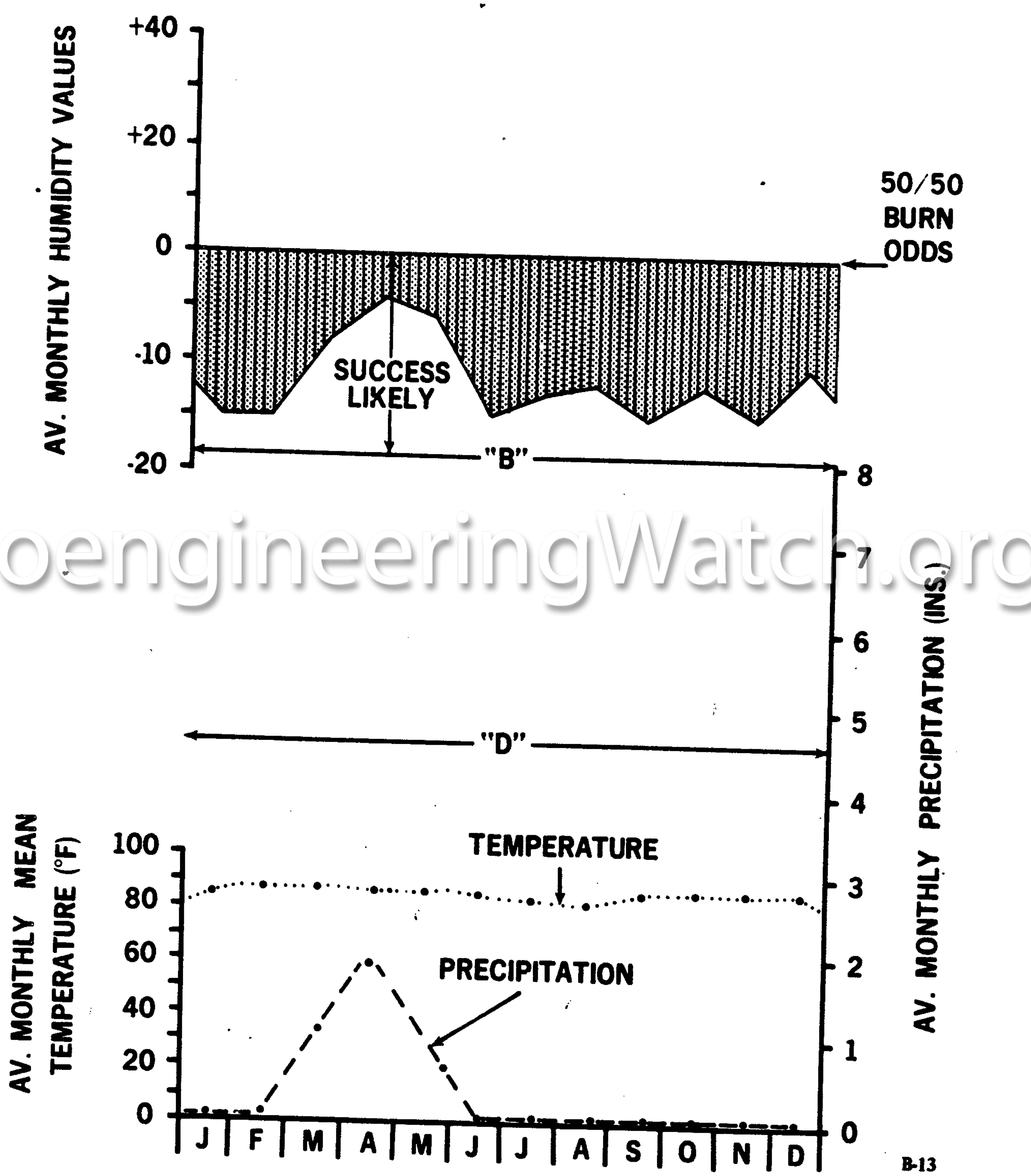
Burn days: Yearlong burn season, except for short periods after heaviest rains.

Desiccation needs: Fuel is insufficient for burning.

Example location (Lodwar, Kenya, Fig. B5).

FIG. B5

CLIMATE FF-DRYL
LODWAR, KENYA



CLIMATE MI–HUYL

MILD WINTER; HUMID YEARLONG

Semi-tropical, cool tropical, subtropical, warm marine, and warm continental climates–from virtually frostfree to occasional frost in most years–having no "D" months and "B" months. Examples are:

Location	Precipitation Pattern	No. of Months "H"	"D"	"B"	Yearly Humidity Values (+)	(-)
Miami, Florida	Humid	6	0	0	+268	0
Brisbane, Aust.	Monsoon	8	0	0	+218	0
Bogota, Colombia	Humid	7	0	0	+146	0
New Orleans, La.	Humid	11	0	0	+287	0
P. Macquarie, Aust.	Humid	12	0	0	+343	0
Sydney, Aust.	Humid	11	0	0	+333	0
Pensacola, Fla.	Humid	12	0	0	+234	0
Houston, Texas	Steppe	8	0	0	+146	0
Charleston, S.C.	Humid	8	0	0	+209	0

Temperature: Evergreen woody plants and most grasses grow throughout the winter. Under continental climate–with more frost–many woody plants are deciduous.

Precipitation: Not limiting under humid pattern, but plant growth may be restricted for short periods each year under monsoon or steppe pattern. Steppe pattern limits the abundance of woody vegetation.

Major vegetation types: Tropical and subtropical hardwood forest; or deciduous forest under continental climate. Prairie or woodland under steppe precipitation pattern. Man-made secondary forests and savana also occur.

Ground-story vegetation: Tree seedlings, woody vines, scattered shrubs and grasses, and plants such as palmetto. Grass is dominant under steppe precipitation pattern.

Amount: Relatively low in dry weight.

Moisture content: High most of year.

Litter layer: Mainly current leaf fall. Little accumulation of dead woody material.

Total available fuel weight on a good burning day: 0.13 pounds per square foot.

Burn days: No burn season; best odds during period, or periods, of lowest monthly rainfall.

Desiccation needs: Must remove forest canopy and kill understory plants for successful burning. Use either foliar sprays or an application of pellets to the soil.

Foliar sprays: Apply a defoliant spray at least 6 months ahead of the planned burning date. If a second spray is needed, wait at least 6 weeks and apply a repeat spray on the exposed under-story. On each date, apply the following mixture per acre:

8 lbs., a.e., of 1:1 mix of 2,4-D and 2,4,5-T plus 2 lbs., a.e., of picloram ester, both combined in diesel oil to make 5 gallons of total mixture.

Soil application: Apply picloram pellets at 15 pounds, a.e., per acre.

Alternate dates for example location (New Orleans, La., Fig. B6):

1. Apply first spray in April.

2. Burn in October or November if vegetation is dead.

Or

1. Apply a second spray in June.

2. Burn in October or November.

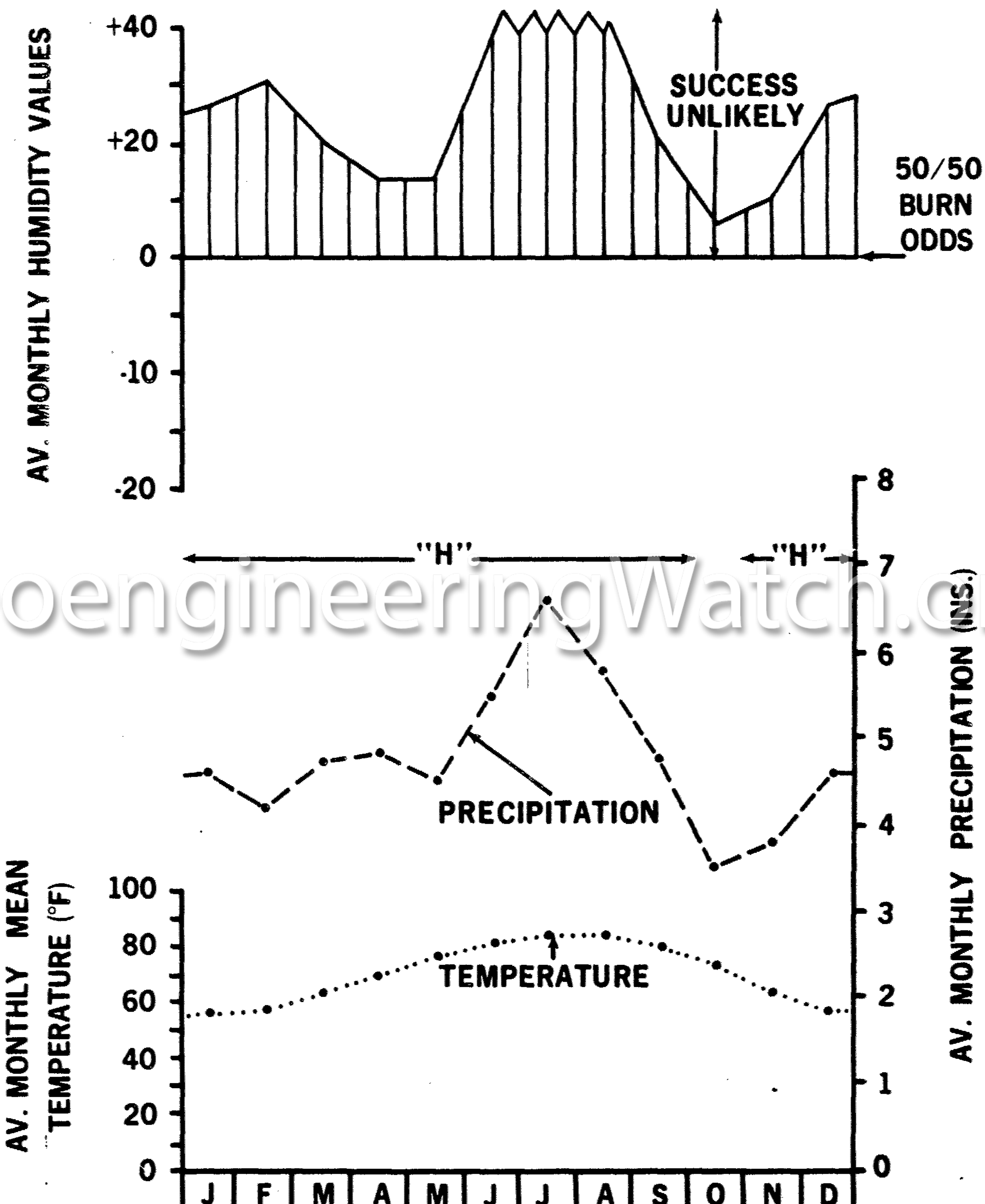
Or

1. Apply pellets in February or March.

2. Burn in October or November.

FIG. B6

CLIMATE MI-HUYL NEW ORLEANS, LA.



CLIMATE MI–HUSB

MILD WINTER; HUMID, SHORT BURN SEASON

Tropical highlands, semi-tropical, subtropical and warm marine climates–nearly frostfree to occasional frost in most years–having high yearly (+) values, but 1–4 "B" months and low yearly (–) values. Examples are:

Location	Precipitation Pattern	No. of Months "H"	"D"	"B"	Yearly Humidity Values (+)	(–)
Hong Kong, B.C.C.	Humid	8	0	3	+252	– 9
Tampa, Florida	Monsoon	4	1	2	+383	– 6
Mackay, Australia	Humid	7	0	3	+229	–11
Eldoret, Kenya	Monsoon	5	3	4	+210	– 2
Equator, Kenya	Humid	7	0	1	+287	– 2
Albany, W. Australia	Humid	7	0	1	+270	– 3
Lisbon, Portugal	Medit.	7	3	3	+166	–21
Monaco, Monaco	Medit.	8	0	3	+106	–21
Melbourne, Australia	Steppe	4	0	2	+130	– 2

Temperature: Many woody plants and grasses grow through the winter.

Precipitation: Limits plant growth for short periods; particularly limiting during hot summers under mediterranean climate. Steppe pattern favors grasses.

Major vegetation types: Subtropical forest, evergreen and semi-deciduous. Low, thick-leaved evergreen forest under mediterranean climate. Grassy woodland under steppe pattern.

Ground-story vegetation: Woody plants are tree seedlings, vines, and shrubs. Coarse grass, palmetto, or similar plants under open canopy.

Amount: Low to moderate dry weight.

Moisture content: High most of year; drops slightly in dry season.

Litter layer: Mainly current leaf fall. Little accumulation of dead material.

Total Available fuel weight on a good burning day: 0.16 pounds per square foot.

Burn days: Short burn season, or seasons–usually totaling 1 to 3 months–almost every year.

Desiccation needs: Must remove forest canopy and kill understory plants for successful burning. Use either foliar sprays or an application of pellets to the soil.

Foliar sprays: Apply a defoliant spray at least 6 months ahead of planned burning date. Under humid or monsoon climates, wait at least 6 weeks and apply a repeat spray. Under mediterranean or steppe climate, a second spray should not be needed. On each date apply per acre:

8 lbs., a.e., of a 1:1 mix of 2,4–D and 2,4,5–T plus 2 lbs., a.e., of picloram ester, both combined in diesel oil to make 5 gallons of total mixture. The picloram can be omitted under mediterranean and steppe climates.

Soil application: Apply 15 pounds, a.e., of picloram pellets per acre.

Dates for example location (Tampa, Fla., Fig. B7):

1. Spray in late June and repeat spray in August if needed.

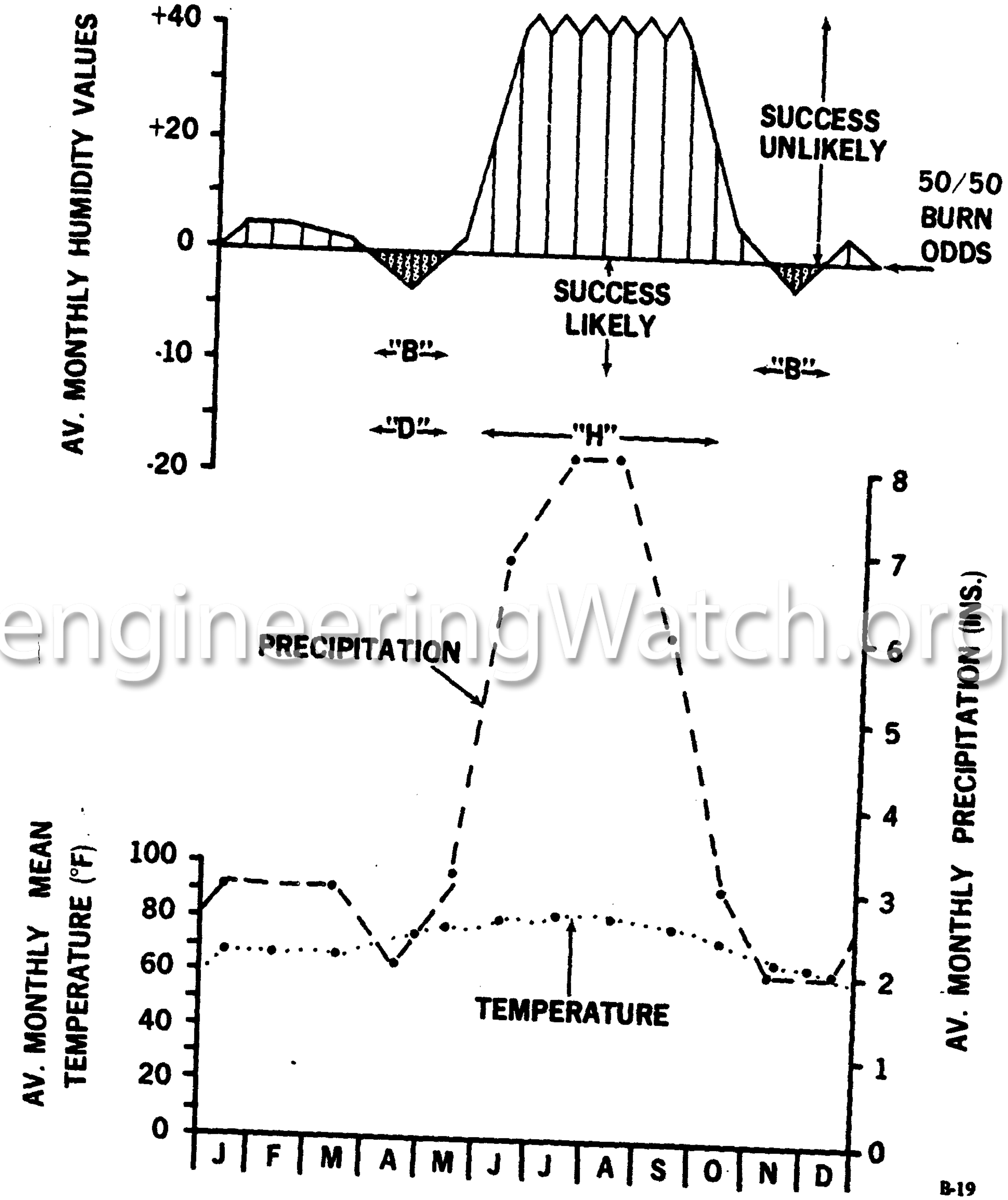
Or

1. Apply pellets in April or May.
2. Burn during dry weather, November or December, if the vegetation is dead; otherwise, wait and burn in March or April.

NOTE: Under mediterranean climate, which has a definite dry summer burn period, timing of spraying and burning is similar to CL–HUSB. Hong Kong is similar to Hanoi, FF–HUSB.

FIG. B7

CLIMATE MI-HUSB
TAMPA, FLORIDA



CLIMATE MI–HULB

MILD WINTER: HUMID, LONG BURN SEASON

Tropical highland, semi-tropical, subtropical, and marine climates–almost frostfree to occasional winter frost–having high (+) values and high (–) values for the year, or at least 5 "B" months. Examples are:

Location	Precipitation Pattern	No. of Months "H"	"D"	"B"	Yearly Humidity Values (+)	(–)
Mupa, Angola	Monsoon	2	7	7	+108	-51
Vila Cabral, Mozamb.	Monsoon	4	5	6	+188	-36
Lashio, Burma	Monsoon	6	4	4	+247	-26
Rhodes, Greece	Medit	5	4	7	+145	-54
Messina, Sicily	Medit.	6	2	4	+227	-30
Capetown, S. Africa	Medit.	4	4	6	+100	-32
Algers, Algeria	Medit.	6	2	4	+149	-36
Adelaide, Aust.	Medit.	4	5	5	+125	-33
San Francisco, Calif.	Medit.	5	4	6	+108	-21

Temperature: Plant growth is slowed by cold weather, but many woody species and grasses remain green through the winter.

Precipitation: Plant growth is restricted during the long dry season, especially during the hot summers under mediterranean climate.

Major vegetation types: Deciduous hardwood forest under monsoon climates; dense stands of thick-leaved trees or shrubs under mediterranean climate.

Ground-story vegetation: In monsoon forests, the woody plants are tree seedlings and shrubs. In Mediterranean woodland and shrub types, the ground story is shrubs, with grasses and semi-shrubs under open canopy.

Amount: Moderate in monsoon forests; light to heavy in M[illegible]rranean types.

Moisture content: Drops during dry season. Woody plants retain 80–90 percent of dry weight; grasses 5–10 percent.

Total available fuel weight on a good burning day: 0.19 pounds per square foot in hardwoods; 0.28 pounds per square foot in dense shrubs.

Burn days: Dependable long burning season. Under extreme burning weather, intense fires may spread out of control and become a major hazard.

Desiccation needs: Dry grass and dead woody material burn readily as ground fires during the long dry season. But removal of canopy and killing of stems is needed for consumption of woody plants under normal weather conditions. Use either a foliar spray or an application of pellets to the soil.

Foliar sprays: Apply a spray at least 4–6 months ahead of the planned burning date. Apply per acre:

6 lbs., a.e., of a 1:1 mix of 2,4-D and 2,4,5-T in diesel oil to make a total mixture of 5 gallons. Under monsoon climate, add 2 lbs., a.e., of picloram ester.

Soil application: Apply 15 lbs., a.e., of picloram pellets per acre. Under monsoon climate, apply 20 lbs., a.e., per acre.

Dates for example location (Rhodes, Greece, Fig. B12):

1. Spray in late March.

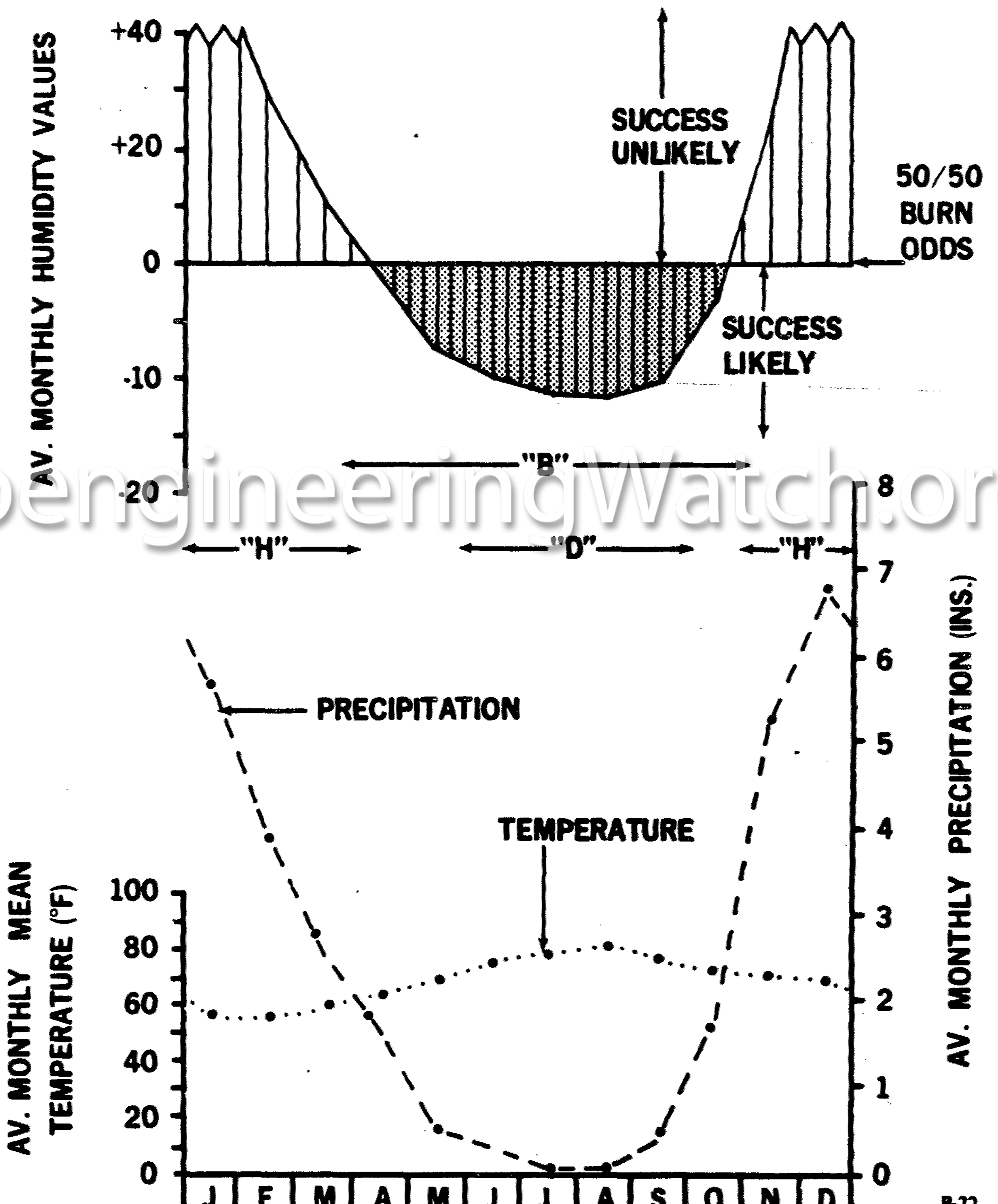
Or

1. Apply pellets in late January or February.

2. Burn in September, allowing all of summer for drying.

FIG. B8

CLIMATE MI-HULB
RHODES, GREECE



CLIMATE MI–NHSB

MILD WINTER; NON-HUMID, SHORT BURN SEASON

Cool to frosty subtropical and similar climates–nearly frostfree to occasional frosts–having low to moderate (+) values and low (–) values for the year; 1–4 "B" months. Examples are:

Location	Precipitation Pattern	No. of Months "H"	"D"	"B"	Yearly Humidity Values (+)	(–)
Rosario, Argen.	Steppe	5	0	1	+90	–1
Austin, Texas	Steppe	1	3	3	+49	–22

(NOTE: This climate and FF–NHSB are of limited occurrence. Warm or hot climates that are non–humid will usually have a long burning season.)

Temperature: Slows plant growth during winter, but grasses are green at that time.

Precipitation: Limits growth of trees; steppe pattern favors grassland.

Major vegetation types: Grassland with woodland thickets.

Ground-story vegetation: Grass and low shrubs.

Amount: Low to moderate dry weight.

Moisture content: low at end of dry season.

Litter layer: Mainly current grass production; little accumulation.

Total available fuel weight on a good burning day: 0.16 pounds per square foot.

Burn days: Fairly definite burning period at the driest locations, but burn days are not predictable under the moister steppe climates.

Desiccation needs: Not needed except in woodland thickets, which should receive a foliar spray of 3 lb., a.e., of a 1:1 mix of 2,4–D and 2,4,5–T in diesel oil to make a total of 5 gallons per acre.

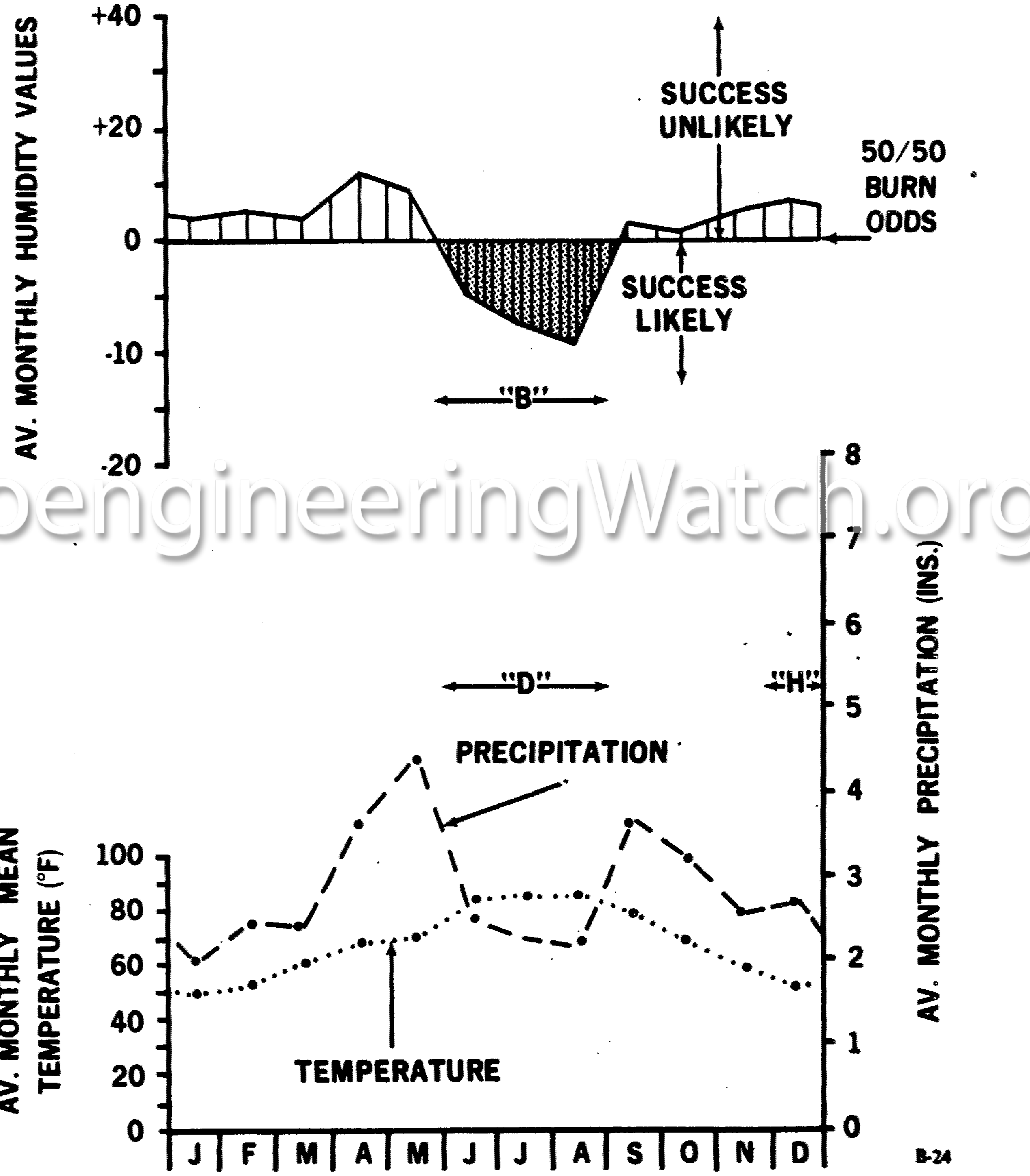
Dates for example location (Austin, Texas, Fig. B9):

1. Spray in late March or early April.

2. Burn in August.

FIG. B9

CLIMATE MI-NHSB
AUSTIN, TEXAS



CLIMATE MI–NHLB

MILD WINTER; NON-HUMID, LONG BURN SEASON

Mainly subtropical climates–nearly frostfree to occasional winter frosts–having low or moderate (+) values and high (-) values for the year; or with at least 5 "B" months. Examples are:

Location	Precipitation Pattern	No. of Months "H"	"D"	"B"	Yearly Humidity Values (+)	(-)
Cloncurry, Aust.	Desert	0	12	10	+7	-88
Brownsville, Texas	Semi-arid	1	3	7	+34	-38
San Diego, Calif.	Medit.	0	8	8	+13	-57
Cape Agulhas, S. Afr.	Medit.	7	1	5	+54	-18
Los Angeles, Calif.	Medit.	3	7	8	+25	-50
Candia, Greece	Medit.	4	4	7	+96	-53

Temperature: Limiting in winter, but many woody species and grasses grow throughout the winter.

Precipitation: Restrictive much of the year; extremely so during the hot, dry summer.

Major vegetation types: Semi-dense thorny woodland or thick-leaved shrub types. Open desert shrub type under driest climate.

Ground-story vegetation: Usually shrubs; also grass and semi-shrubs in open types.

Amount: Moderate dry weight in semi-dense woodland or shrub types; low in open desert shrub type.

Moisture content: Drops during long dry season. Shrub stems retain about 70–80 percent of dry weight; grasses 5–10 percent.

Litter layer: Scant, because of low current production and weathering during mild winter. However, shrubs have many dead stems caused by frequent drought years.

Total available fuel weight on a good burning day: 0.23 pounds per square foot.

Burn days: Long dependable burning season.

Dessiccation needs: Grass and dead woody material burn readily during the dry season. But removal of all woody vegetation under normal burning weather requires desiccation with a foliar spray or an application of pellets to the soil. Under extreme weather, intense fires may burn out of control and present a major hazard.

Foliar spray: Spray during the Spring. Apply per acre:

3 lbs., a.e., of a 1:1 mix of 2,4-D and 2,4,5-T in diesel oil to make a total mixture of 5 gallons.

Soil application: Apply 7.5 lbs., a.e., of picloram pellets per acre.

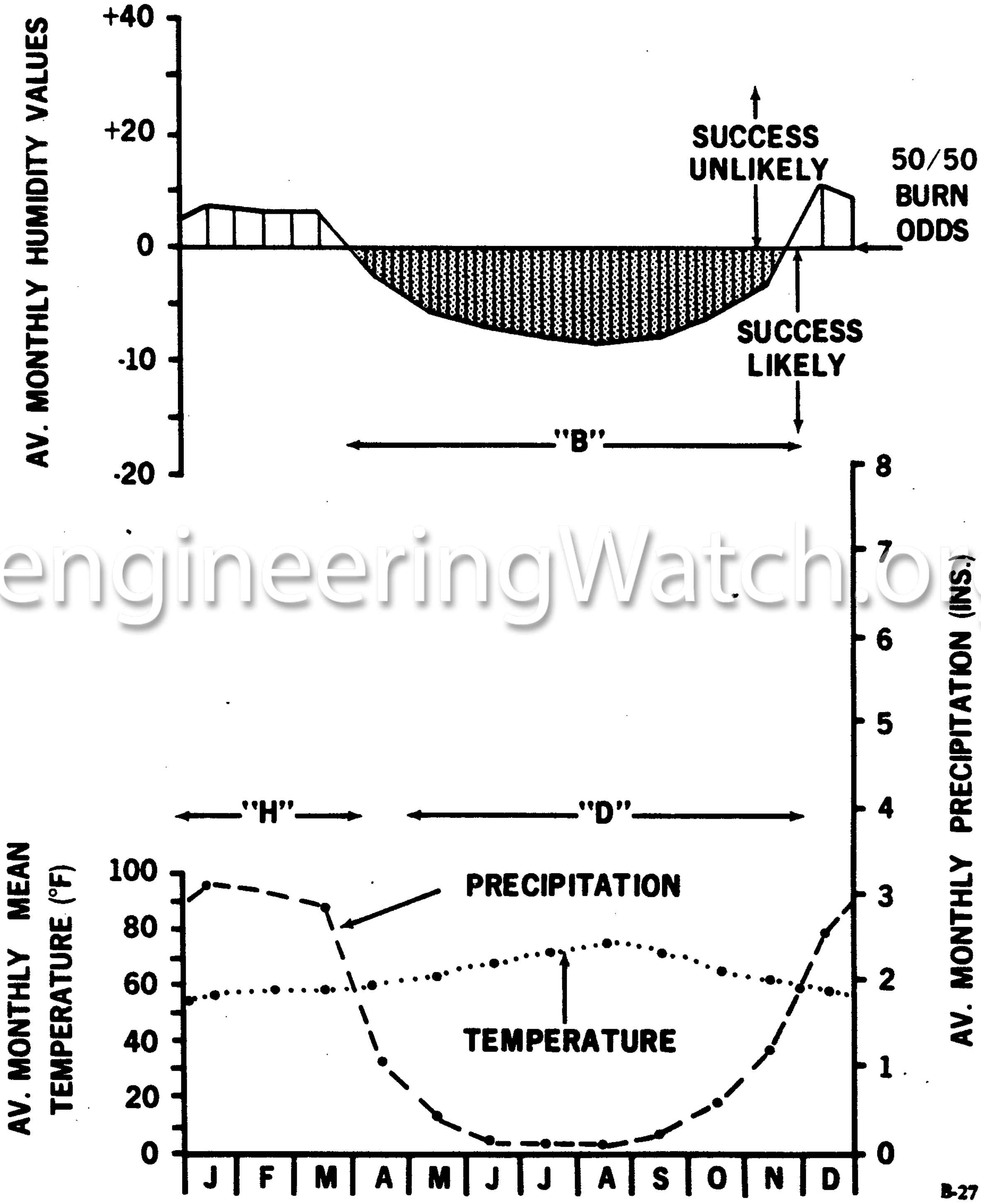
Dates for example location (Los Angeles, Calif., Fig. B10):

1. Spray in March or early April.

2. Burn in October or in September.

FIG. B10

CLIMATE MI-NHLB
LOS ANGELES, CALIF.



CLIMATE MI–DRYL
MILD WINTER; DRY YEARLONG

Semi-tropical and subtropical desert climates–occasional winter frosts–having 12 "B" months. Examples are:

Location	Precipitation Pattern	No. of Months "H"	"D"	"B"	Yearly Humidity Values (+)	(–)
Suez, Egypt	Desert	0	12	12	0	-118
Windorah, Aust.	Desert	0	12	12	0	-102
Cairo, Egypt	Desert	0	12	12	0	-112
In Salah, Algeria	Desert	0	12	12	0	-149
Fort de Polignan, Alg.	Desert	0	12	12	0	-139
Yuma, Arizona	Desert	0	12	12	0	-109
Phoenix, Arizona	Desert	0	12	12	0	- 98
Cook, S. Aust.	Desert	0	12	12	0	- 62

Temperature: Slightly limiting during short winter period.

Precipitation: Extremely restrictive.

Major vegetation types: Open desert shrub or thornbush.

Ground-story vegetation: Semi-shrubs, cacti, and ephemeral herbaceous plants.

Amount: Thin, discontinuous stand with very low dry weight.

Moisture content: Low in woody plants and herbs except for short periods after infrequent rains.

Litter layer: Absent.

Total available fuel weight on a good burning day: 0.04 pounds per square foot.

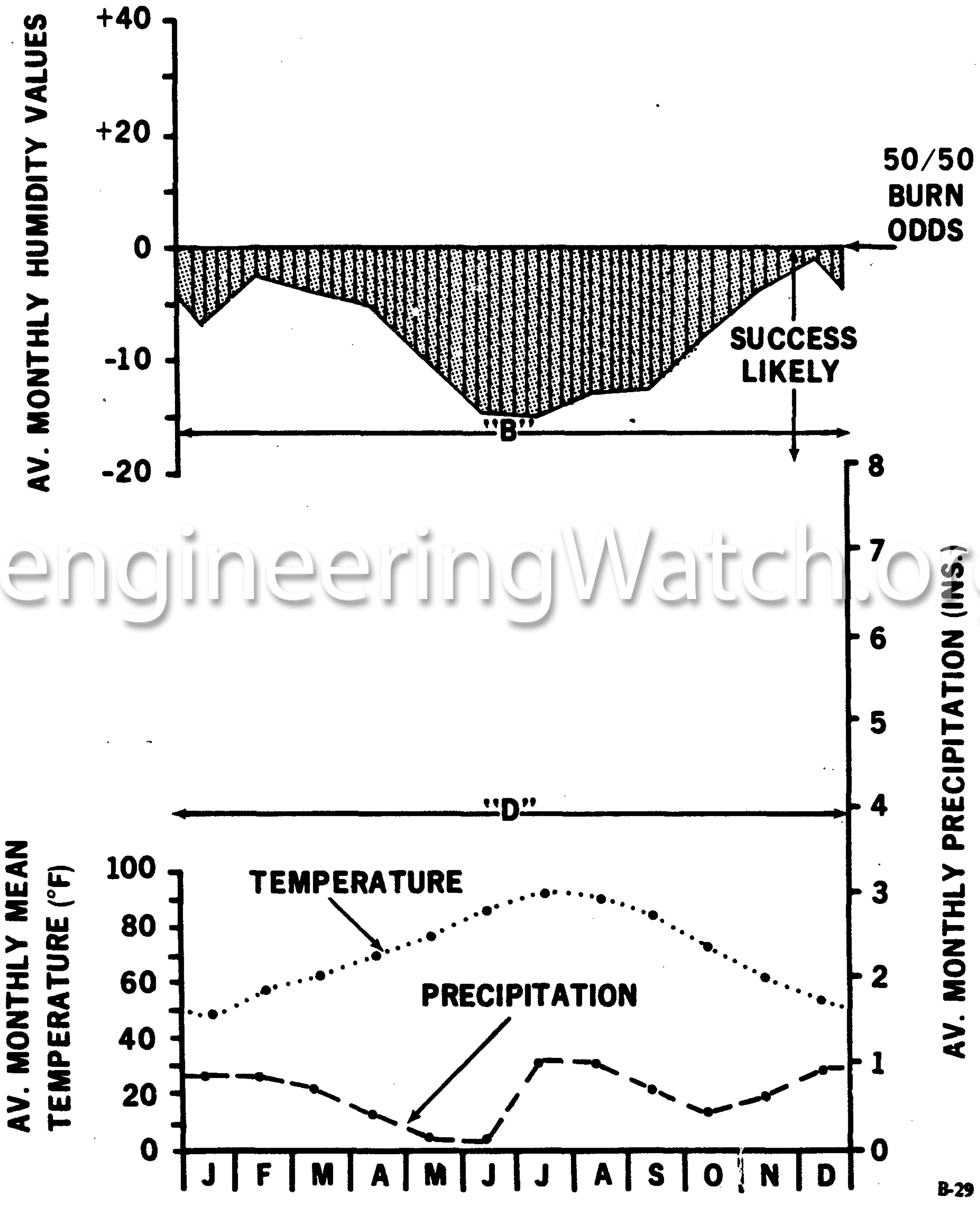
Burn days: Yearlong burn season, except for short periods after heaviest rains.

Desiccation needs: Fuel is insufficient for burning.

Example location (Phoenix, Arizona, Fig. B11).

FIG. B11

CLIMATE MI-DRYL
PHOENIX, ARIZONA



CLIMATE CL–HUYL

COOL WINTER; HUMID YEARLONG

Cool to semi-cold marine, frosty subtropical, and warm continental climates—with winter frosts—having no "D" months and no "B" months. Examples are:

Location	Precipitation Pattern	No. of Months "H"	"D"	"B"	Yearly Humidity Values (+)	(-)
Alexandria, La.	Humid	6	0	0	+186	0
Vicksburg, Miss.	Humid	8	0	0	+257	0
Table Mtn., S. Afr.	Humid	9	0	0	+329	0
Columbia, S.C.	Humid	6	0	0	+205	0
Atlanta, Ga.	Humid	6	0	0	+252	0
Little Rock, Ark.	Humid	7	0	0	+197	0
Tatoosh I., Wash.	Humid	12	0	0	+386	0
Holyhead, Wales	Humid	12	0	0	+339	0
Edinburgh, Scot.	Humid	12	0	0	+306	0

Temperature: Some evergreen woody plants and many grasses grow through the winter. Typically, the winter frosts restrict occurrence of broad-leaved evergreen trees.

Precipitation: Not limiting under the typical humid precipitation pattern, except for short dry periods in most years.

Major vegetation types: Mainly deciduous hardwood or conifer forests, with many mixtures of the two. Heath grows under coolest marine climates.

Ground-story vegetation: Under forest canopy the woody plants are tree seedlings, vines, and scattered shrubs. Heath or grass occur outside of forest types.

Amount: Low to moderate dry weight.

Moisture content: High most of year; lowest in the Fall.

Litter layer: Mainly current leaf fail and grass rough; some accumulation of old dead material, especially in coolest climates.

Total available fuel weight on a good burning day: 0.16 pounds per square foot in hardwoods; 0.23 pounds per square foot in conifers.

Burn days: No burn season; best odds during driest Fall months.

Desiccation needs: Must remove forest canopy and kill understory woody plants for successful burning. Use either a foliage spray or an application of pellets to the soil.

Foliar spray: Apply a spray during early summer after tree leaves are fully grown. Apply per acre:

8 lbs., a.e., of a 1:1 mix of 2,4-D and 2,4,5-T mixed in diesel oil to make a total mixture of 5 gallons.

Soil application: Apply 15 lbs., a.e., of picloram pellets per acre.

Dates for example location (Columbia, S. C., Fig. B12):

1. Apply a spray in late May or early June.

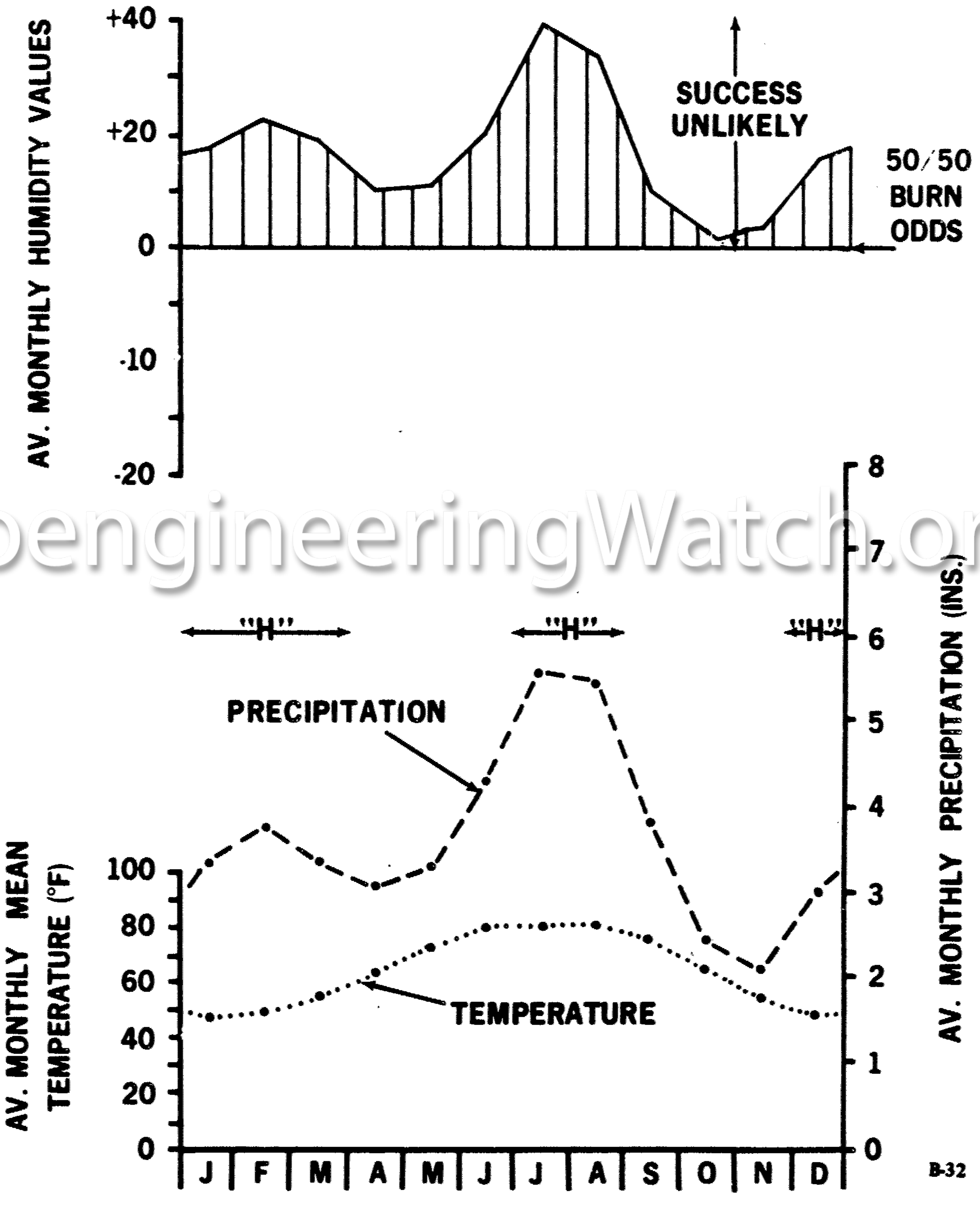
Or

1. Apply pellets in March or early April.

2. Burn in October or November before onset of winter rainy period.

FIG. B12

CLIMATE CL-HUYL
COLUMBIA , S.C.



CLIMATE CL HUSB

COOL WINTER: HUMID, SHORT BURN SEASON

Warm to semi-cold marine, warm temperate, and warm continental climates–with winter frosts–having high yearly (+) values but 1–4 "B" months and low yearly (–) values. Examples are:

Location	Precipitation Pattern	No. of Months "H"	"D"	"B"	Yearly Humidity Values (+)	(–)
Oporto, Portugal	Medit.	7	1	2	+292	-11
Stanley, Tasmania	Humid	10	0	2	+164	- 3
Launceston, Tasm.	Medit.	7	1	1	+208	- 3
Eureka, Calif.	Humid	8	0	4	+242	-11
Dallas, Texas	Steppe	6	3	3	+ 92	-11
Marseilles, France	Medit.	6	2	2	+118	-11
Istanbul, Turkey	Medit.	7	1	3	+185	-15
Roseburg, Oregon	Medit.	3	2	4	+235	-16
Tacoma, Wash.	Medit.	7	1	2	+269	-10

Temperature: Some evergreen woody plants and many grasses grow through the winter.

Precipitation: Limits plant growth for short periods, especially during hot summers under mediterranean precipitation pattern.

Major vegetation types: Conifer forests or thick-leaved woodland or forest. Prairie or woodland under steppe pattern.

Ground-story vegetation: Woody plants are shrubs plus some tree seedlings. Grass grows in open forest or woodland.

Amount: Moderate in dry weight.

Moisture content: Drops during the dry season, but woody plants retain about 100 percent of dry weight.

Litter layer: Current leaf fall plus light accumulation of woody material.

Total available fuel on a good burning day: 0.26 pounds per square foot in hardwoods; 0.37 pounds per square foot in conifers.

Burn days: Rather dependable burn season, usually 2-3 months in length.

Desiccation needs: Dense forest or woodland should be defoliated. Killing of woody ground-story plants needed for successful removal by burning. However, dry grass in open forest or woodland will burn without desiccation.

Folier spray: Apply one spray 4–6 months, or longer, before burning. Apply per acre:

8 lbs., a.e., of a 1:1 mix of 2,4-D and 2,4,5-T in diesel oil to make a total of 5 gallons.

Soil application: Apply 15 lbs., a.e., of picloram pellets per acre.

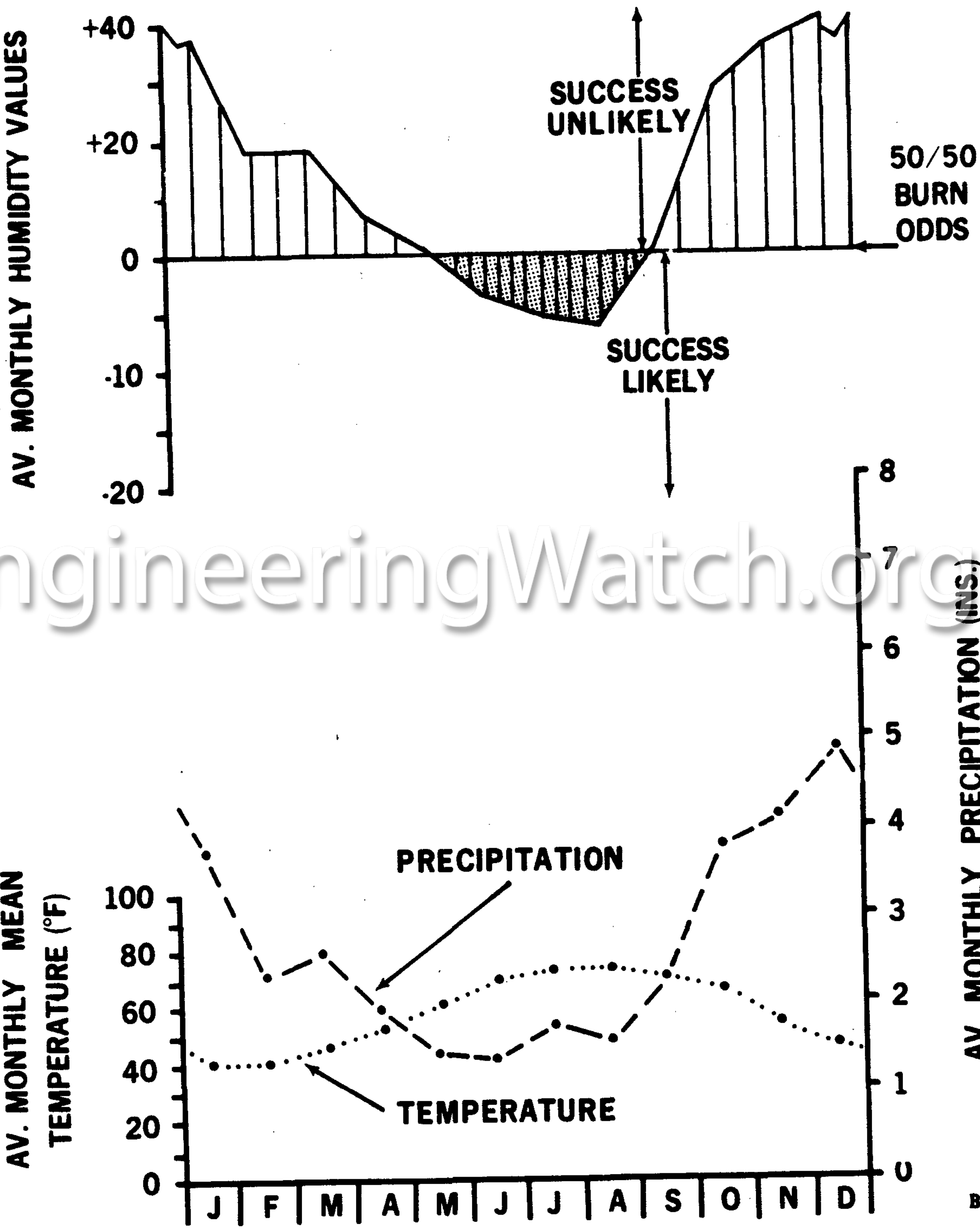
Dates for example location (Istanbul, Turkey, Fig. B13):

1. Spray in late April, or soon after daily mean temperature is above 50°F. This climate allows only a short period of favorable temperature before moisture stress occurs in late Spring.

2. Burn in September, or wait until the next summer after grasses have dried.

FIG. B13

CLIMATE CL-HUSB
ISTANBUL, TURKEY



CLIMATE CL HULB

COOL WINTER, HUMID, LONG BURN SEASON

Frosty tropical highland, warm temperate, and warm continental climates common winter frosts having fairly high (+) values and high (-) values, or at least 5 "B" months. Examples are:

Location	Precipitation Pattern	No. of Months "H"	"D"	"B"	Yearly Humidity Values (+)	(-)
Kroonstad, S. Afr.	Monsoon	0	7	5	+ 91	-13
Mitilini, Greece	Medit.	6	3	5	+157	-49
Kástrav, Greece	Medit.	6	4	6	+108	-46
Mt. Wilson, Calif.	Medit.	5	5	6	+ 94	-39
Alexandroupolis, Gr.	Medit.	5	4	6	+106	-34

Temperature: Some evergreen woody plants and many grasses grow through the winter.

Precipitation: Restricts plant growth during several dry months, especially during hot summer under mediterranean climate.

Major vegetation types: Under monsoon climates open subtropical forest, often thorny. Under mediterranean climate dense stands of thick-leaved trees or shrubs, and pine forests.

Ground-story vegetation: Mainly shrubs, with grasses and semi-shrubs under open tree or shrub canopy.

Amount: Fairly heavy in dry weight.

Moisture content: Drops during dry season. Woody stems retain 80-100 percent of dry weight; grasses 5-10.

Litter layer: Leaf litter accumulates because of cool winters and long dry season. Many small dead stems on shrubs add to available fuel.

Total available fuel weight on a good burning day: 0.32 pounds per square foot in dense shrubs; 0.22 pounds per square foot in open forest.

Burn days: Dependable long burning season. Under extreme burning weather intense fires may spread out of control and become a major hazard.

Desiccation needs: Dry grass and dead woody material burn readily as ground fires during the long dry season. But removal of canopy and killing of stems is needed for assured hot fires and consumption of woody plants under normal weather conditions. Use either a foliar spray or an application of pellets to the soil.

Folier spray: Spray at least 4-6 months ahead of the planned burning date. Apply per acre:

4 lbs., a.e., of a 1:1 mix of 2,4-D and 2,4,5-T in diesel oil to make a total mixture of 5 gallons.

Soil application: Apply 10 lbs., a.e., of picloram pellets per acre.

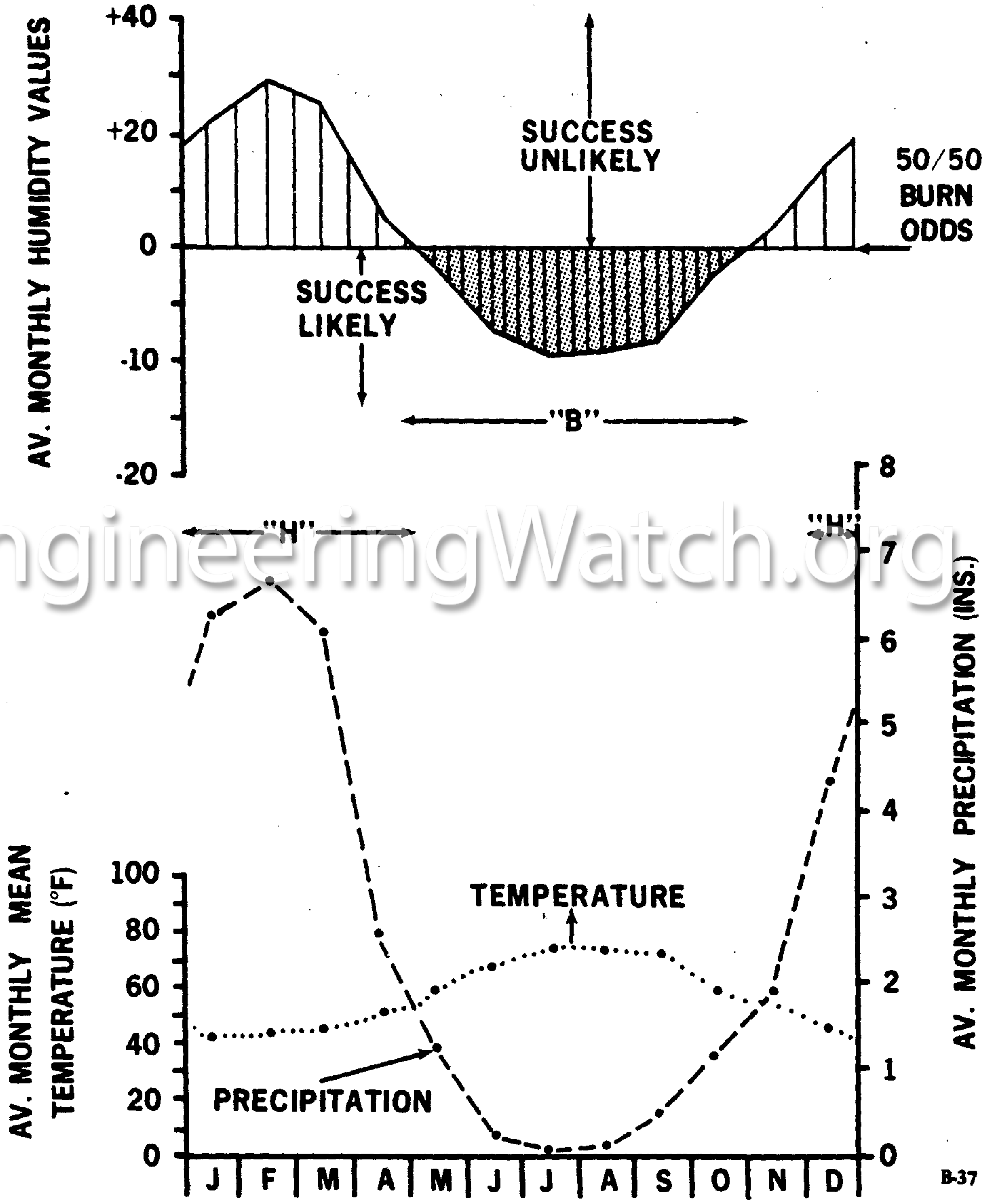
Dates for example location (Mt. Wilson, Calif., Fig. B14):

1. Spray in late April.

2. Burn in September or October.

FIG. B14

CLIMATE CL-HULB
MT.WILSON, CALIF.



CLIMATE CL NHSB

COOL WINTER, NON-HUMID, SHORT BURN SEASON

Warm marine, warm temperate, and semi-warm continental climates occasional to common winter frosts having low to moderate (+) values and low (-) values for the year; 1-4 "B" months. Examples are:

Location	Precipitation Pattern	No. of Months "H"	"D"	"B"	Yearly Humidity Values (+)	(-)
Nice, France	Medit.	6	2	4	+48	-25
Canberra, Aust.	Medit.	4	3	1	+67	- 1
Edirne, Turkey	Medit.	5	3	3	+61	-18

Temperature: Slightly limiting during a short winter period, but many woody plants and grasses grow throughout the winter.

Precipitation: Restrictive during dry, hot summer.

Major vegetation types: Savana-like with open stand of thick-leaved shrubs and trees. Some dense shrubby vegetation.

Ground-story vegetation: Grasses and shrubs; or mainly shrubs where woody canopy is dense.

Amount: Light in savana types; moderate dry weight in dense shrubby types.

Moisture content: Drops during dry season, woody stems retain about 30 percent of dry weight.

Litter layer: Limited yearly leaf production; little accumulation of old material.

Total available fuel weight on a good burning day: 0.19 pounds per square foot.

Burn days: Predictable burning season each year.

Desiccation needs: Dry grass and dead woody material will burn readily during the dry summer. Desiccation is needed for effective removal of live woody material. Use either a foliar spray or an application of picloram pellets to the soil.

Foliar spray: Apply per acre:

4 lbs., a.e., of a 1:1 mix of 2,4-D and 2,4,5-T in diesel oil to make a total mixture of 5 gallons.

Soil application: Apply 7.5 lbs., a.e., of picloram pellets per acre.

Dates for example location (Nice, France, Fig. B15):

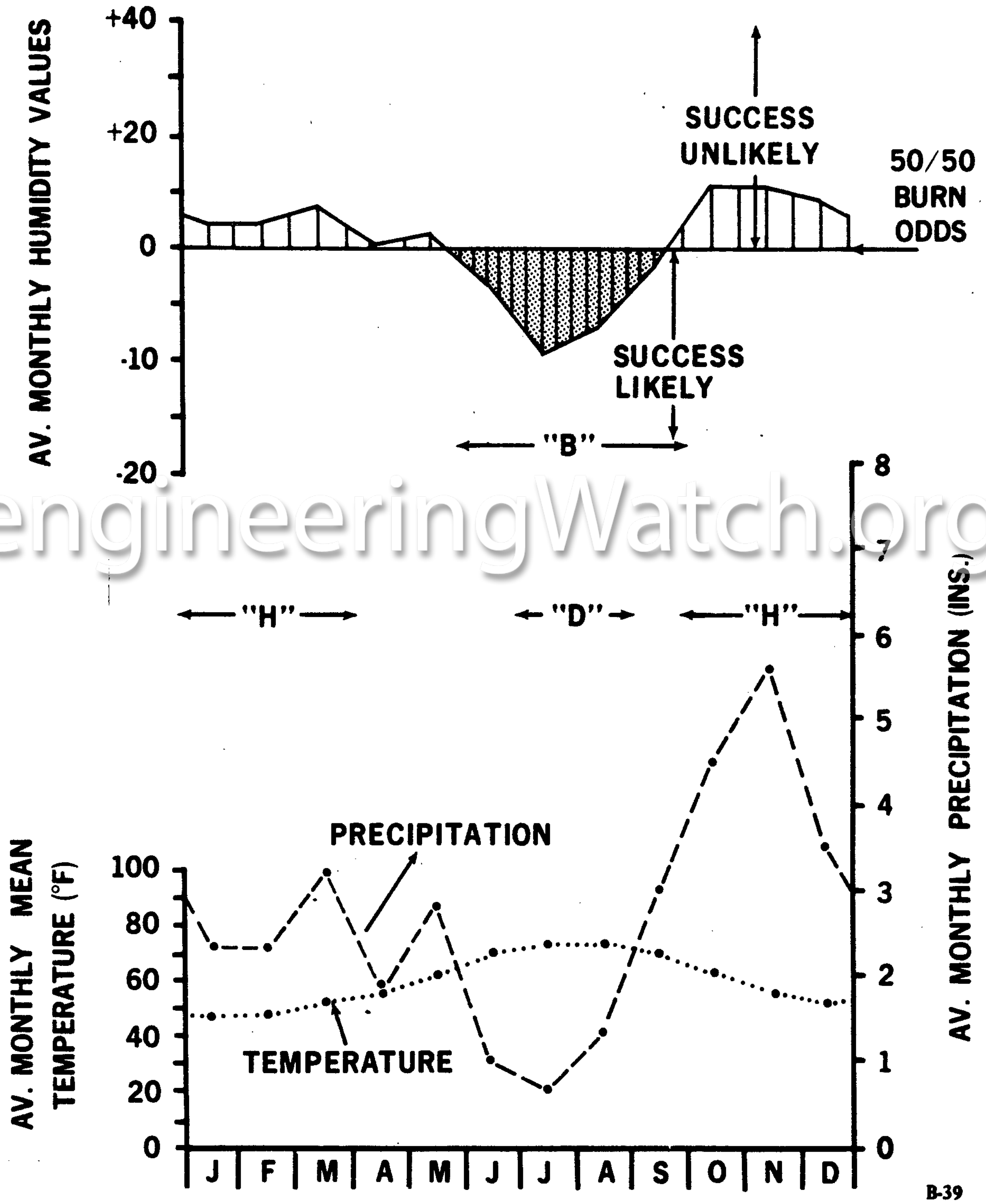
1. Spray in early April.

Or

1. Apply pellets in December.
2. Burn in August.

FIG. B15

CLIMATE CL-NHSB
NICE, FRANCE



CLIMATE CL[illegible] NHLB
COOL WINTER, NON-HUMID, LONG BURN SEASON

Subtropical, warm temperate, and warm continental climates occasional to common winter frosts having low to moderate (+) values an[illegible]h (–) values for the year, or at least 5 "B" months. Examples are:

Location	Precipitation Pattern	No. of Months "H"	"D"	"B"	Yearly Humidity Values (+)	(–)
Palma de Mallorca, Sp.	Medit.	5	3	6	+17	-39
Athens, Greece	Medit.	4	4	7	+41	-55
San Jose, Calif.	Medit.	3	6	7	+58	-38
Sacramento, Calif.	Medit.	4	5	6	+73	-44
Bahia Blanca, Argen.	Steppe	0	6	7	+ 7	-14
Fresno, Calif.	Medit.	1	8	8	+15	-64
Granada, Spain	Medit.	5	5	6	+28	-40
Abilene, Texas	Steppe	0	8	6	+20	-15
Madrid, Spain	Medit.	3	4	5	+27	-30

Temperature: Limiting during winter, but many woody species and grasses grow through the winter.

Precipitation: Restrictive most of year; extremely so during dry, hot summer.

Major vegetation types: Semi–dense to dense stands of thick–leaved shrubs. Desert shrub in driest portion. Grassland–like vegetation under steppe pattern.

Ground–story vegetation: Shrubs in dense stands of woody vegetation. Grasses and semi–shrubs in open desert shrub and grassland.

Amount: Heavy to moderate dry weight in dense shrub stands. Low in desert shrub and grassland types.

Moisture content: Drops during long dry season. Shrubs retain 70–80 percent of dry weight; grasses, 5–10 percent.

Litter layer: Thin layer accumulates under dense shrub stands; many dead stems in the shrubs caused by frequent draught years. Light litter from current leaf growth in grassland or desert shrub types.

Total available fuel weight on a good burning day: 0.28 pounds per square foot.

Burn days: Long dependable burning season.

Desiccation needs: Dry grass and dead woody material will burn readily during the dry season. But removal of all woody vegetation under normal burning weather requires desiccation with a foliar spray or an application of pellets to the soil. Under extreme weather, intense fires may burn out of control and present a major hazard.

Foliar spray: Apply during the Spring. Apply per acre:

4 lbs., a.e., of a 1:1 mix of 2,4-D and 2,4,5-T in diesel oil to make a total mixture of 5 gallons.

Soil application: Apply 7.5 lbs., a.e., of picloram pellets per acre.

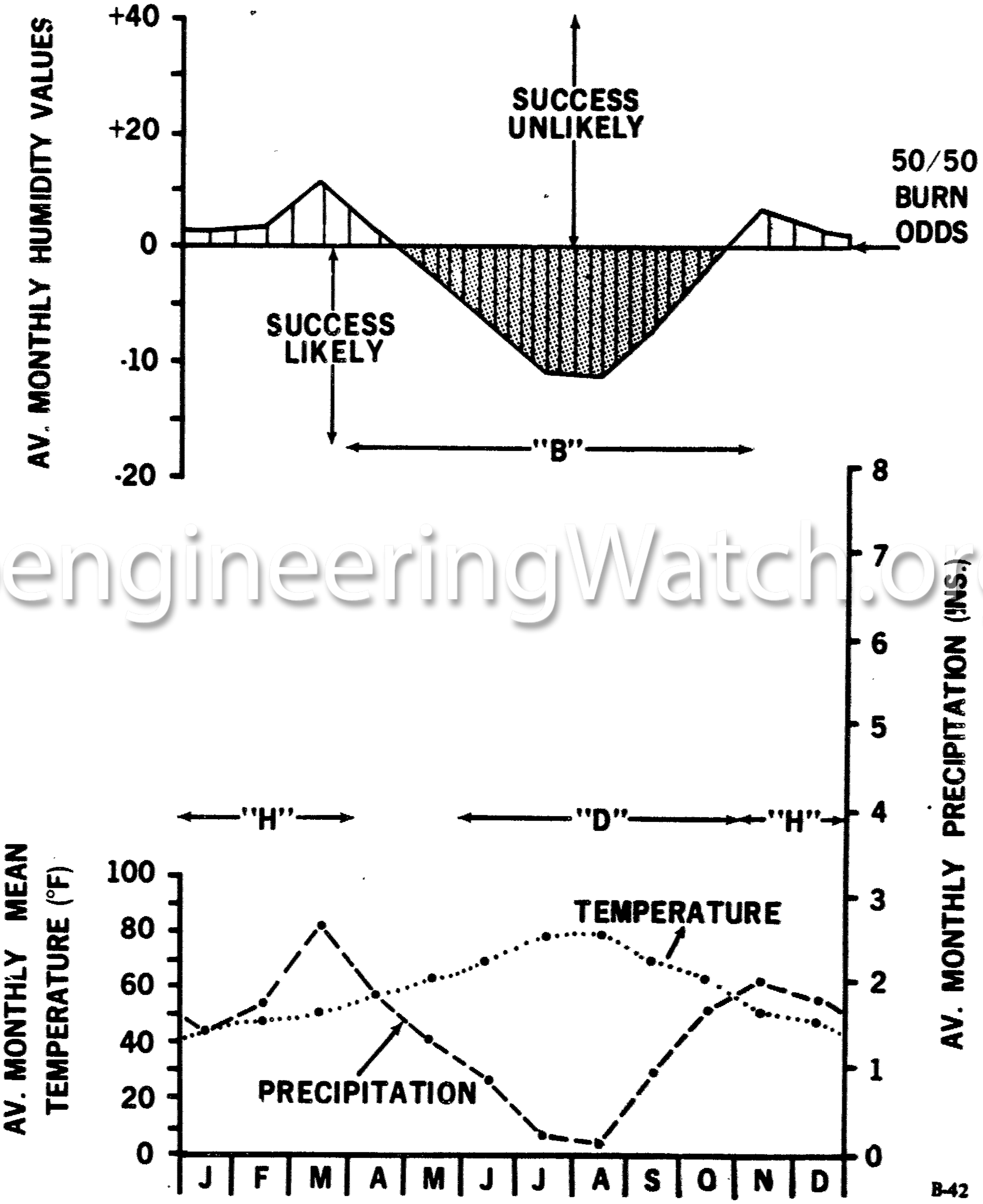
Dates for example location (Granada, Spain, Fig. B16):

1. Spray in April.

2. Burn in September or October.

FIG. B16

CLIMATE CL-NHLB
GRANADA, SPAIN



B-42

CLIMATE CL–DRYL

COOL WINTER; DRY YEARLONG

Subtropical, temperate, and continental desert climates – common winter frosts – having 12 "B" months. Examples are:

Location	Precipitation Pattern	No. of Months "H"	"D"	"B"	Yearly Humidity Values (+)	(-)
Puerto Madryn, Argen.	Desert	0	12	12	0	-47
Alice Sprs., Aust.	Desert	0	12	12	0	-87
Las Vegas, Nev.	Desert	0	12	12	0	-85
El Paso, Texas	Desert	0	12	12	0	-57
Cipolleti, Argen.	Desert	0	12	12	0	-52

(NOTE: DRYL climates with 12 "B" months are of limited occurrence under colder winters.)

Temperature: Limiting during short winter period.

Precipitation: Extremely restrictive.

Major vegetation types: Open desert shrub stands.

Ground-story vegetation: Semi-shrubs and grasses.

Amount: Low dry weight; discontinuous.

Moisture content: Low most of year.

Little layer: Absent.

Total available fuel weight on a good burning day: 0.07 pounds per square foot.

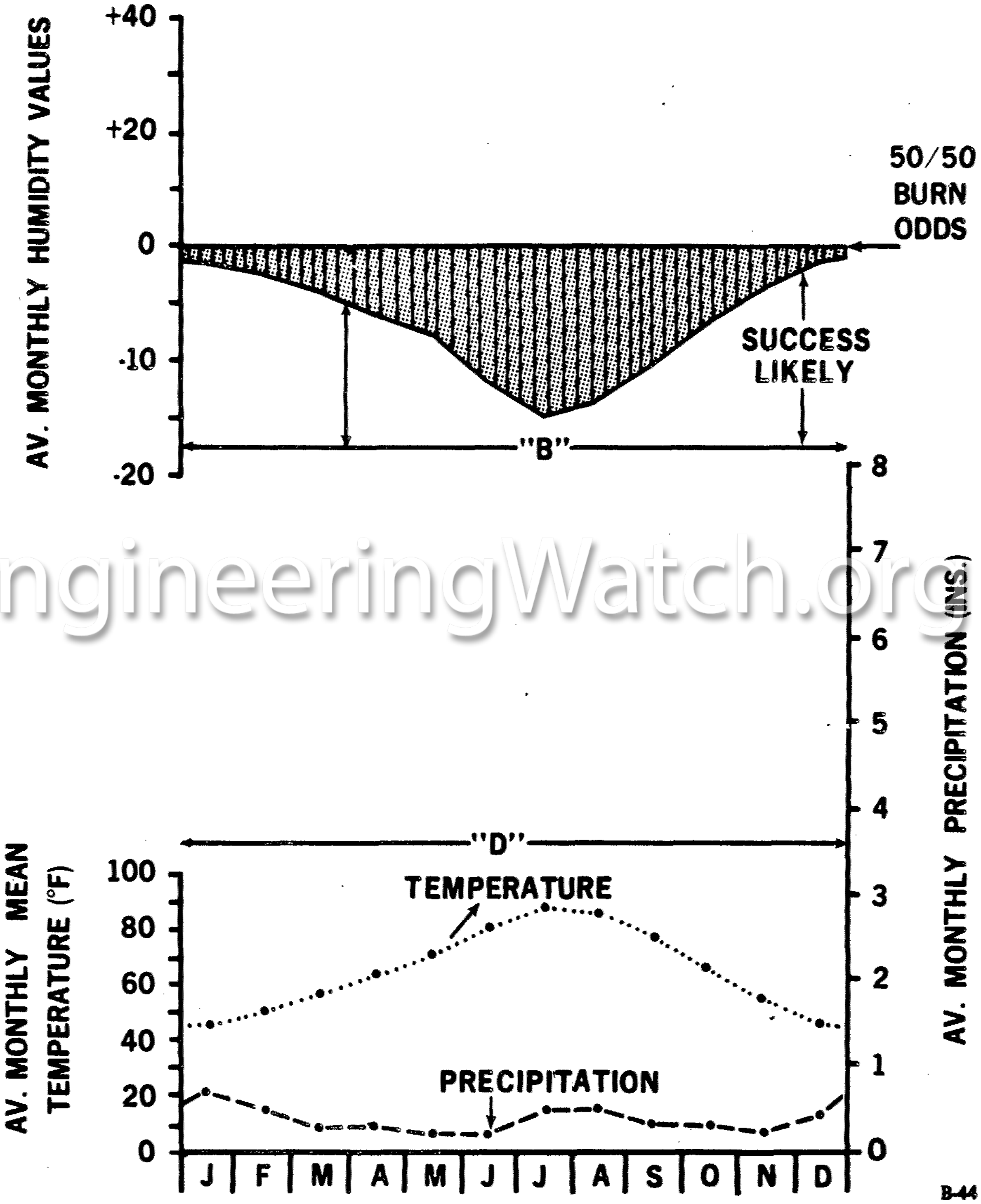
Burn days: Yearlong burn season except for short rainy periods.

Desiccation needs: Fuel is insufficient for burning.

Example location (Las Vegas, Nevada, Fig. B17).

FIG. B17

CLIMATE CL-DRYL
LAS VEGAS, NEVADA



B-44

CLIMATE SC–HUYL

SHORT COLD WINTER: HUMID YEARLONG

Cool to cold marine, cool temperate and warm to semi-warm continental climates -- with frosts, freezes, and snow being common – having no "D" months and no "B" months. Examples are:

Location	Precipitation Pattern	No. of Months "H"	"D"	"B"	Yearly Humidity Values (+) Months ≥40°	(+) Months ≤40°	(-) Total
Nashville, Tenn.	Humid	6	0	0	+227	+ 37	0
Liverpool, England	Humid	12	0	0	+290	0	0
Inverness, Scot.	Humid	12	0	0	+234	+ 83	0
Washington, D.C.	Humid	9	0	0	+170	+ 63	0
Springfield, Mo.	Humid	8	0	0	+177	+ 39	0
Staranger, Norway	Humid	12	0	0	+235	+131	0
Bern, Switzerland	Humid	12	0	0	+233	+ 67	0
Vienna, Austria	Humid	8	0	0	+114	+ 30	0
Prague, Czech.	Steppe	5	0	0	+123	+ 47	0

Temperature: All plant growth restricted by cold weather for one or more months; herbaceous plants mature and dry each year. Deciduous trees are favored.

Precipitation: Not limiting under typical humid precipitation pattern. Steppe pattern, favors grassland.

Major vegetation types: Typically deciduous forest, but replaced in many areas by conifers. Conifer and heath under cold marine climates. Prairie and woodland grow under steppe pattern.

Ground-story vegetation: Under forest canopy the woody plants are tree seedlings and scattered shrubs and vines; plus some grass rough. Grass is mixed with woodland under steppe climate.

Amount: Moderate to low in dry weight.

Moisture content: High during Spring and Summer, but drops during frosty fall weather. Grasses mature and dry in early Fall.

Litter layer: Mainly current leaf fall and grass rough. Some accumulation of old leaf litter.

Total available fuel weight on a good burning day: 0.19 pounds per square foot in hardwoods; 0.28 pounds per square foot in conifers.

Burn days: No burn season. Best odds are during driest Fall months.

Desiccation needs: Must remove forest canopy and kill understory woody plants for successful burning. Use either a foliar spray or an application of pellets to the soil.

Foliar spray: Apply per acre:

6 lbs., a.e., of a 1:1 mix of 2,4-D and 2,4,5-T mixed in diesel oil to make a total of 5 gallons.

Soil application: Apply picloram pellets at 15 lbs., a.e., per acre.

Dates for example location (Washington, D.C., Fig. B18):

1. Apply spray in late May when trees are growing vigorously.

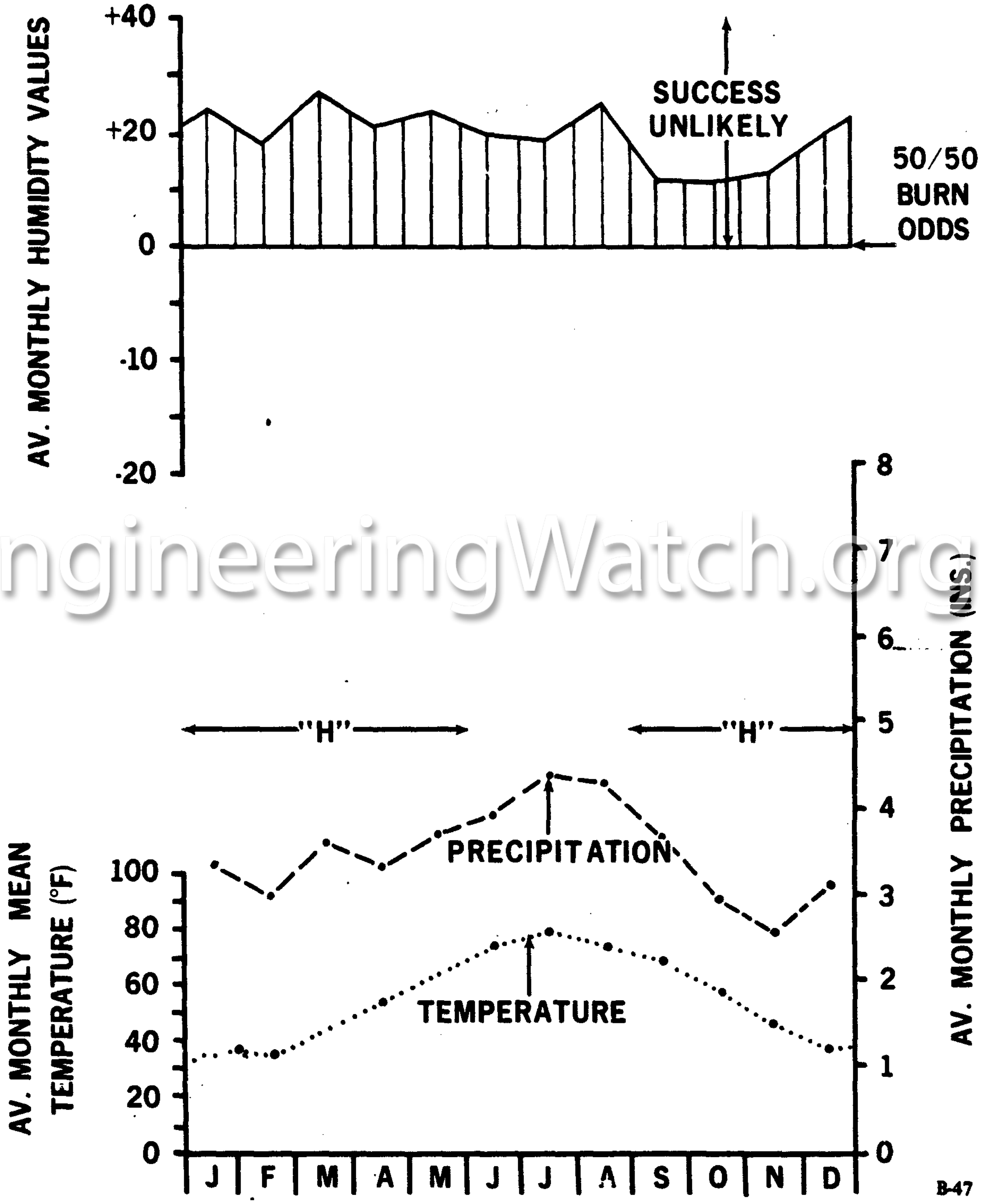
Or

1. Apply pellets in late March after daily mean temperature is above 40^{o} C.

2. Burn during driest Fall weather – September or October – after grasses have matured and dried. Burn grassland in late Fall or late Winter.

FIG. B18

CLIMATE SC-HUYL WASHINGTON, D.C.



CLIMATE SC--HUSB

SHORT COLD WINTER: HUMID, SHORT BURN SEASON

Warm continental climates with frosts, freezes, and snow being common – having moderate yearly (+) values but 1 - 4 "B" months and low (–) values for the year. Examples are:

Location	Precipitation Pattern	No. of Months "H"	"D"	"B"	Yearly Humidity Values (+) Months ≥40°	(+) Months ≤40°	(-) Total
Lenkoran, U.S.S.R.	Medit.	8	2	3	+237	+ 40	-24
Mt. Shasta, Calif.	Medit.	6	3	3	+ 82	+110	-18
Oklahoma City, Okla.	Steppe	2	2	2	+ 67	+ 8	- 1
Tbiliski, U.S.S.R.	Steppe	3	3	2	+ 73	+ 4	- 2

Temperature: All plant growth restricted by cold weather during a few months. Favors conifers under mediterranean climate and grasses, under steppe climate.

Precipitation: Under mediterranean climate the excess winter precipitation favors forest. Under steppe climate the shortage of winter precipitation favors grassland.

Major vegetation types: Conifer forest or brushfields under mediterranean climate; grassland with woodland areas under steppe climate.

Ground-story vegetation: Mainly shrubs under mediterranean climate; grasses and low shrubs under steppe climate.

Amount: Fairly heavy under mediterranean climate.

Moisture content: Moisture drops during dry season under mediterranean climate; woody stems at 80-100 percent of dry weight, grasses at 5-10 percent. Under steppe climate grasses are dry during Fall and Winter.

Litter layer: Under forest and shrub canopies the leaf litter accumulates because of cold winter and dry summer. In grassland areas the litter mainly is current grass rough.

Total available fuel weight on a good burning day: 0.26 pounds per square foot in brush or hardwood; 0.37 pounds per square foot in conifers.

Burn days: Dependable summer burning period under mediterranean climate. No definite season under steppe climate, but best odds during Fall and Winter.

Desiccation needs: In forest and brushfield types, the dry grass and dead woody material will burn during the dry season. But desiccation of woody canopy and killing of understory shrubs are needed for effective plant removal. Use either a foliar spray or an application of pellets to the soil.

Foliar spray: Spray in late Spring after mean daily temperature is above 50° F. Apply per acre:

4 lbs., a.e., of a 1:1 mix of 2,4-D and 2,4,5-T in diesel oil to make a total of 5 gallons.

Soil application: Apply 10 lbs., a.e., of picloram pellets per acre.

Dates for example location (Mt. Shasta, Calif., Fig. B19):

1. Spray in May.

   Or

1. Apply pellets in March or early April.

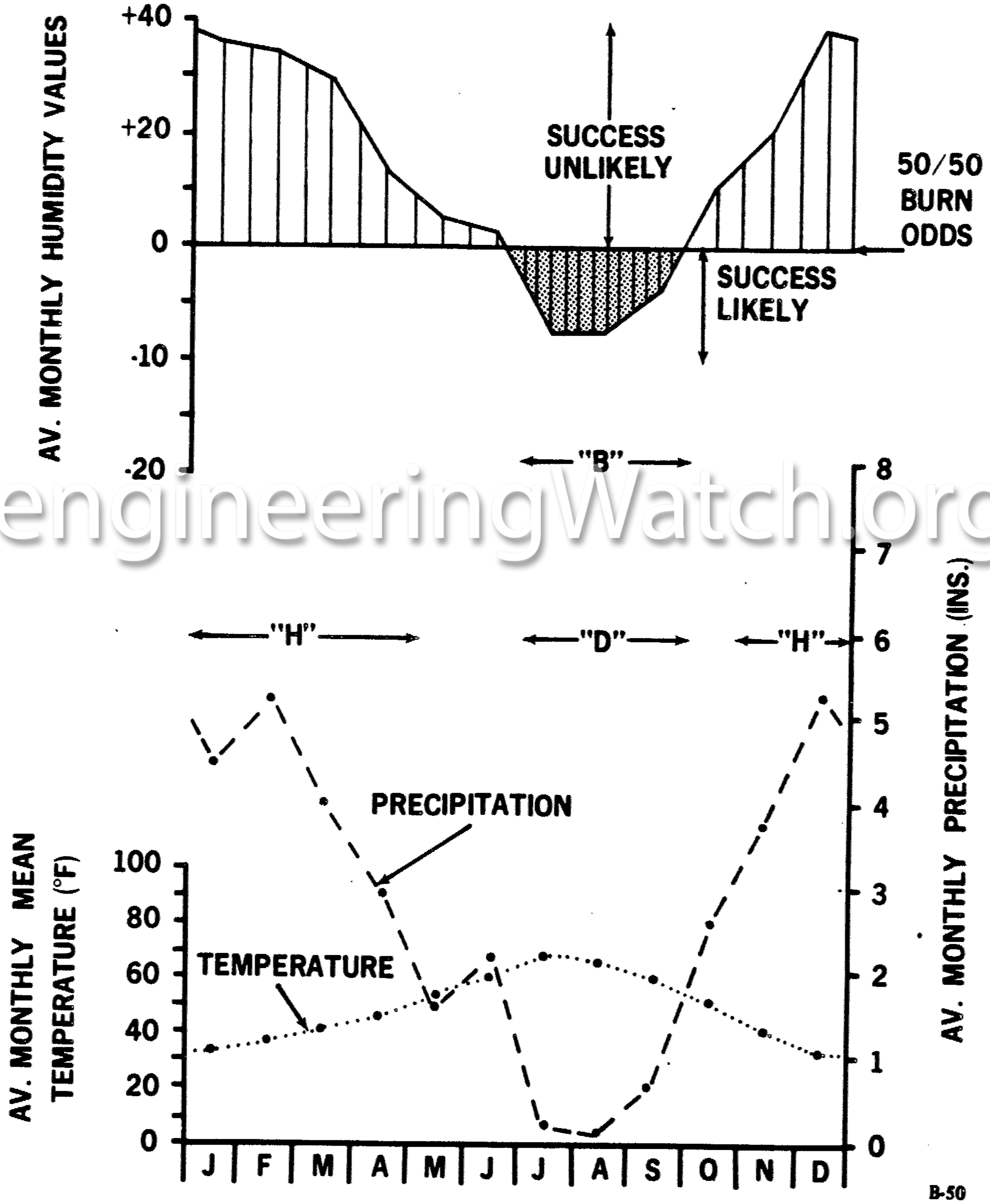
2. Allow long as possible drying period; burn in September or early October.

   Or

2. Burn during late Spring or Summer of the next year. Stems continue to die and dry during the Winter and will be fully consumed.

FIG. B19

CLIMATE SC-HUSB
MT. SHASTA, CALIF.



CLIMATE SC–HULB

SHORT COLD WINTER; HUMID, LONG BURN SEASON

Cool temperate or warm continental climate short winter period of freezes and snows – having fairly high (+) values and fairly high (-) values for the year, or at least 5 "B" months. Examples are:

Location	Precipitation Pattern	No. of Months "H"	"D"	"B"	Yearly Humidity Values (+) Months ≥40°	Months ≤40°	(-) Total
Blue Canyon, Calif.	Medit.	7	3	4	+81	+157	-26

(NOTE: Under cold winter climate, the long burn season usually is associated with non-humid conditions because of limited rainfall in months having mean temperature below 40° F.)

Temperature: Plant growth is restricted during a few winter months.

Precipitation: Restrictive during the dry, hot summer. But excess winter precipitation favors forests.

Major vegetation types: Conifer forests, or mixture with deciduous trees.

Ground-story vegetation: Mainly shrubs, mixed with grasses under open canopy.

Amount: Fairly heavy in dry weight.

Moisture content: Drops during dry season. Woody plants retain 80-100 percent of dry weight; grasses, 5-10.

Litter layer: Fairly heavy accumulation because of cold winter and long dry season. Some dead stems on shrubs add to available fuel.

Total available fuel weight on a good burning day: 0.46 pounds per square foot in conifer forests; 0.32 pounds per square foot in mixed forests.

Burn days: Dependable burning season. Escape fires may become a serious hazard under the most extreme weather conditions.

Desiccation needs: Dry grass and dead woody material will burn readily during the dry season. But removal of canopy and killing of woody plants is needed to assure successful removal under normal weather conditions. Use either a foliar spray or an application of pellets to the soil.

Foliar spray: Apply in late spring after daily mean temperature is above 50° F. Apply per acre:

4 lbs., a.e., of a 1:1 mix of 2,4-D and 2,4,5-T in diesel oil to make a total of 5 gallons.

Soil application: Apply 10 lbs., a.e., of picloram pellets per acre.

Dates for example location (Blue Canyon, Calif., Fig. B20):

1. Spray in May.

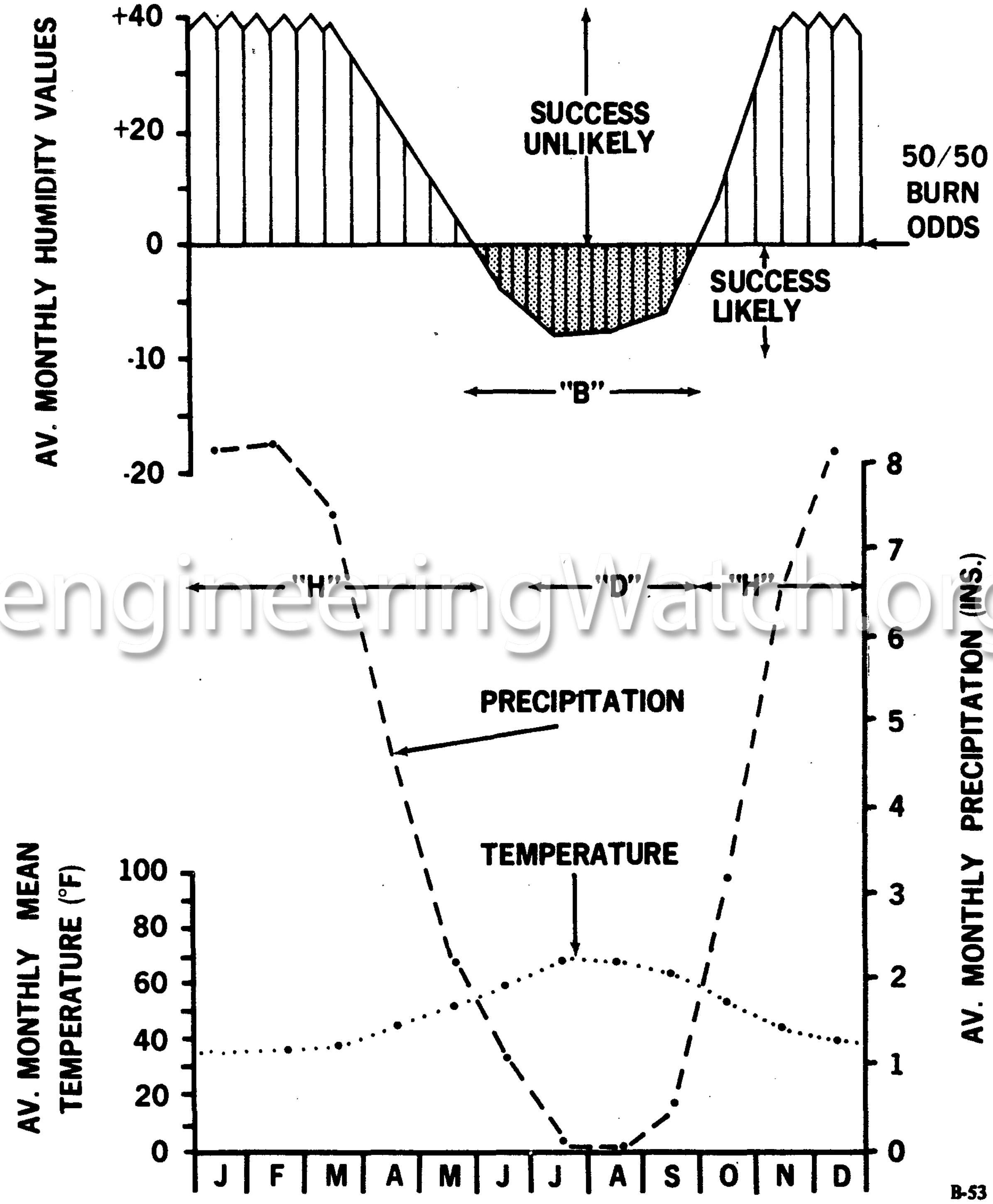
Or

1. Apply pellets in March.

2. Burn in September or wait until the next year and burn in July or August.

FIG. B20

CLIMATE SC-HULB
BLUE CANYON, CALIF.



CLIMATE SC–NHYL

SHORT COLD WINTER: NON-HUMID, NO BURN SEASON

Warm to cool temperate, semi-warm continental, and cool to cold marine climates – common frosts or freezes or snow having limited summer precipitation; may have "D" months but no "B" months. Examples are:

Location	Precipitation Pattern	No. of Months "H"	"D"	"B"	Yearly Humidity Values (+) Months ≥40°	(+) Months ≤40°	(-) Total
Paris, France	Humid	6	0	0	+66	+30	0
Copenhagen, Den.	Humid	11	0	0	+90	+62	0
Belgrade, Yugo.	Steppe	6	0	0	+78	+29	0
Budapest, Hungary	Steppe	6	1	0	+77	+29	0
Berlin, Germany	Humid	8	0	0	+82	+62	0
Ushuaia, T. del Fuego	Humid	11	0	0	+96	+44	0
Grimsey, Iceland	Humid	12	0	0	+14	+27	0

(NOTE: The NHYL condition is not expected to occur under warmer climates where non-humid conditions are associated with short or long burn seasons.)

Temperature: All plant growth restricted by cold weather for one or two months. Favors grass under steppe pattern.

Precipitation: Borderline humid, with no dry season. Favors grass under steppe pattern.

Major vegetation types: Typically deciduous forest with interspersed conifers. Woodland or prairie under steppe pattern.

Ground-story vegetation: Woody plants under forest canopy are tree seedlings and scattered shrubs.

Amount: Moderate to light in dry weight.

Moisture content: High in summer; low in winter.

Litter layer: Some leaf litter accumulation under forest canopy.

Total available fuel weight on a good burning day: 0.28 pounds per square foot in mixed forest; 0.19 pounds per square foot in hardwoods.

Burn days: No burning season. Best odds during fall after leaves have dropped and grasses have matured.

Desiccation needs: Must remove forest canopy and kill understory woody plants for successful burning. Use either a foliar spray or an application of pellets to the soil.

Foliar spray: Spray in early summer soon after leaves are fully formed on deciduous trees. Apply per acre:

4 lbs., a.e., of a 1:1 mix of 2,4-D and 2,4,5-T in diesel oil to make a total mixture of 5 gallons.

Soil application: Apply 10 lbs., a.e., of picloram pellets per acre.

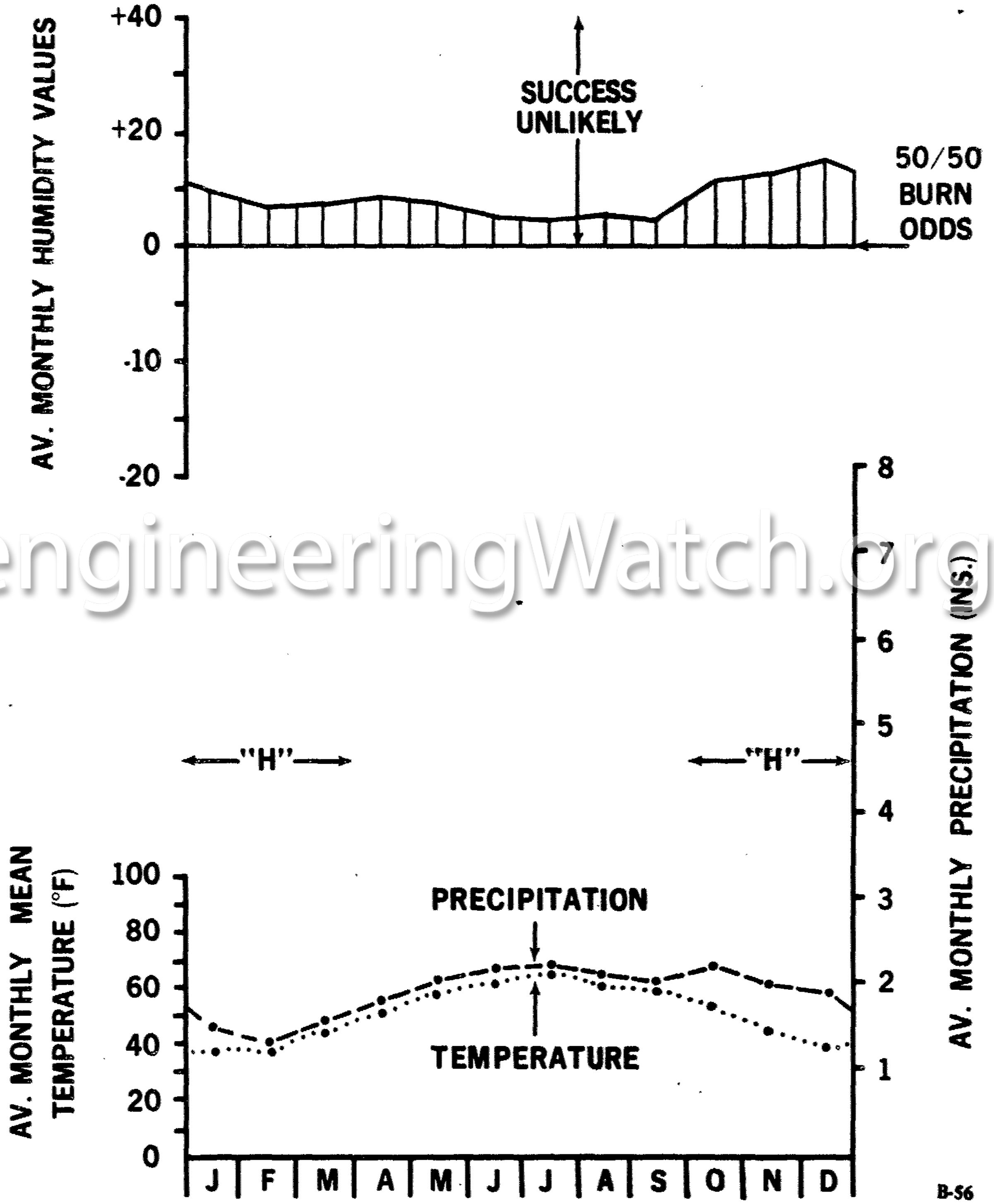
Dates for example location (Paris, France, Fig. B21):

1. Apply spray in May.

2. Burn in October or during a winter dry period.

FIG. B21

CLIMATE SC-NHYL
PARIS, FRANCE



B-56

CLIMATE SC–NHSB

SHORT COLD WINTER: NON-HUMID, SHORT BURN SEASON

Warm and semi-warm continental climates – common winter frosts and freezes, occasional blizzards – having low (+) values and low (-) values for the year; 1-4 "B" months. Examples are:

Location	Precipitation Pattern	No. of Months "H"	"D"	"B"	Yearly Humidity Values (+) Months ≥40°	(+) Months ≤40°	(-) Total
Amarillo, Texas	Semi-arid	0	10	3	+36	+1	-1
Santa Fe, N. M.	Monsoon	0	9	1	+34	+6	-3

Temperature: Restrictive during a short winter period.

Precipitation: Restrictive most of year.

Major vegetation types: Short grass plains, or grassland-like vegetation with scattered shrubs or trees, such as juniper.

Ground-story vegetation: Grasses and/or low shrubs.

Amount: Light in dry weight.

Moisture content: Low, except during summer rainy period.

Litter layer: Limited yearly leaf production; thus, little accumulation of old material.

Total available fuel weight on a good burning day: 0.19 pounds per square foot.

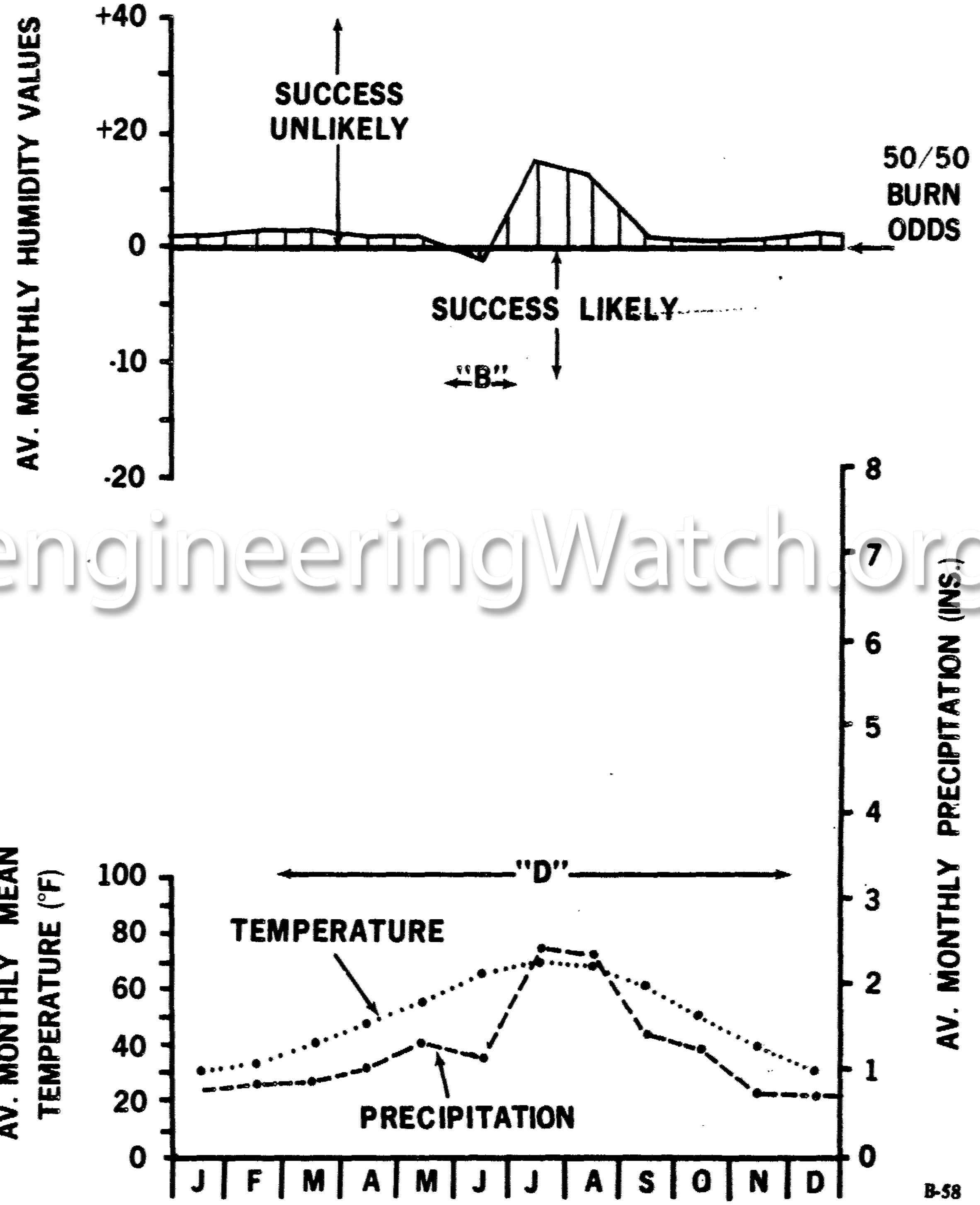
Burn days: Few days with better than 50/50 odds, but most Fall, Winter, and Spring months have many burning days. Best odds are in late Spring or in the Fall.

Desiccation needs: Usually not needed because of limited woody fuel for burning, or because of poor ground fuels under woody canopy.

Example location: Santa Fe, N. M. (Fig. B22).

FIG. B22

CLIMATE SC-NHSB SANTA FE, N. MEX.



CLIMATE SC–NHLB

SHORT COLD WINTER; NON-HUMID, LONG BURN SEASON

Temperate and continental climates – short winter period of heavy frosts, freezes, or snow – having low (+) values and high (-) values for the year, or at least 5 "B" months. Examples are:

Location	Precipitation Pattern	No. of Months			Yearly Humidity Values (+)		(-)
		"H"	"D"	"B"	Months ≥40°	Months ≤40°	Total
Roswell, N. Mex.	Monsoon	0	12	11	+ 1	+ 1	-22
Sarmiento, Argen.	Desert	0	10	9	+ 1	+ 1	-35
Reno, Nevada	Desert	1	8	8	+ 1	+12	-35
Boise, Idaho	Medit.	3	5	5	+17	+32	-32
Winnemuca, Nev.	Medit.	0	9	6	+ 5	+17	-40

Temperature: Restrictive during short winter period.

Precipitation: Restrictive all year.

Major vegetation types: Open shrub (sagebrush) to grassland-like vegetation with scattered shrubs.

Ground-story vegetation: Low shrubs and/or thin grass cover (often invaded by dense stands of annual grass).

Amount: Relatively low in dry weight.

Moisture content: Drops during long dry season and through the winter.

Litter layer: Thin, because of low leaf production each year. Many dead shrub stems because of frequent drought years.

Total available fuel weight on a good burning day: 0.19 pounds per square foot.

Burn days: Long dependable burning season.

Desiccation needs: Dry grass and dead woody material will burn readily during the dry season. Best success in burning under normal weather requires a foliar spray to kill the brush stems.

Foliar spray: Apply per acre:

3 lbs., a.e., of 2,4-D in diesel oil to make a total mixture of 3 gallons.

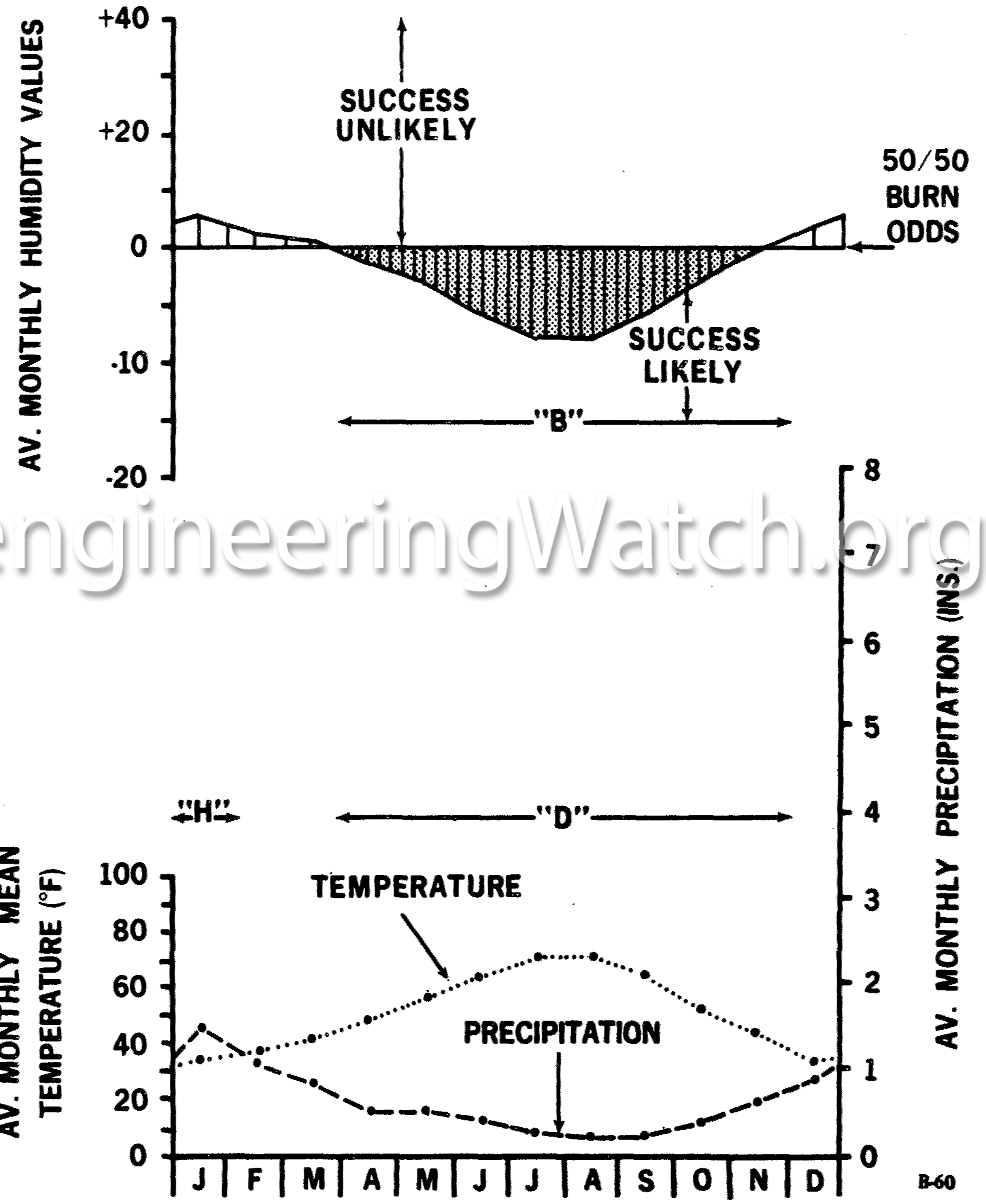
Soil application: Not recommended.

Dates for example location (Reno, Nevada, Fig. B23):

1. Spray in late May or early June.
2. Burn in September, or wait and burn during the next August.

FIG. B23

CLIMATE SC-NHLB
RENO, NEVADA



CLIMATE LC–HUYL

Cool to cold temperate and semi-warm continental climates – common freezes and snows – having no "D" months and no "B" months. Examples are:

Location	Precipitation Pattern	No. of Months "H"	No. of Months "D"	No. of Months "B"	Yearly Humidity Values (+) Months ≥40°	Yearly Humidity Values (+) Months ≤40°	Yearly Humidity Values (-) Total
Kansas City, Mo.	Steppe	10	0	0	+184	+ 18	0
Omaha, Nebr.	Steppe	7	0	0	+ 81	+ 14	0
Scranton, Penna.	Humid	11	0	0	+163	+ 95	0
L'vov, U.S.S.R.	Steppe	10	0	0	+131	+ 16	0
Detroit, Mich.	Humid	9	0	0	+122	+ 80	0
Uppsala, Sweden	Humid	10	0	0	+ 96	+ 51	0
Portland, Maine	Humid	12	0	0	+141	+155	0
Albany, N.Y.	Humid	9	0	0	+150	+ 97	0
Helsinki, Finland	Humid	11	0	0	+116	+101	0

Temperature: All plant growth restricted by cold weather during several winter months; herbaceous plants mature and dry by early Fall. Conifers are favored by frosty weather.

Precipitation: Not limiting under typical humid precipitation pattern. Steppe pattern favors grassland.

Major vegetation types: Typically coniferous forests and mixtures with deciduous hardwoods. Large areas of secondary forest are hardwoods. Heath under cold marine climate, and prairie or woodland under steppe pattern.

Ground-story vegetation: Under forest canopy the woody plants are tree seedlings and scattered deciduous shrubs, plus some grass rough. Grass is mixed with woodland under steppe climate.

Amount: Moderate in dry weight.

Moisture content: High in summer; low during cold winter weather.

Litter layer: Current leaf fall plus accumulated old litter, but limited dead woody material. Breakdown of litter is slowed during cold weather.

Total available fuel weight on a good burning day: 0.22 pounds per square foot in hardwoods; 0.32 pounds per square foot in conifers.

Burn days: No burn season. Best odds during driest fall months.

Desiccation needs: Must remove forest canopy and kill understory woody plants for successful burning. Use either a foliar spray or an application of pellets to the soil.

Foliar spray: Apply per acre:

6 lbs., a.e., of a 1:1 mix of 2,4-D and 2,4,5-T mixed in diesel oil to make a total of 5 gallons.

Soil application: Apply picloram pellets at 15 lbs., a.e., per acre.

Dates for example location (Albany, N.Y., Fig. B24):

1. Apply foliar spray in early June, after trees and shrubs are fully leaved and growing vigorously.

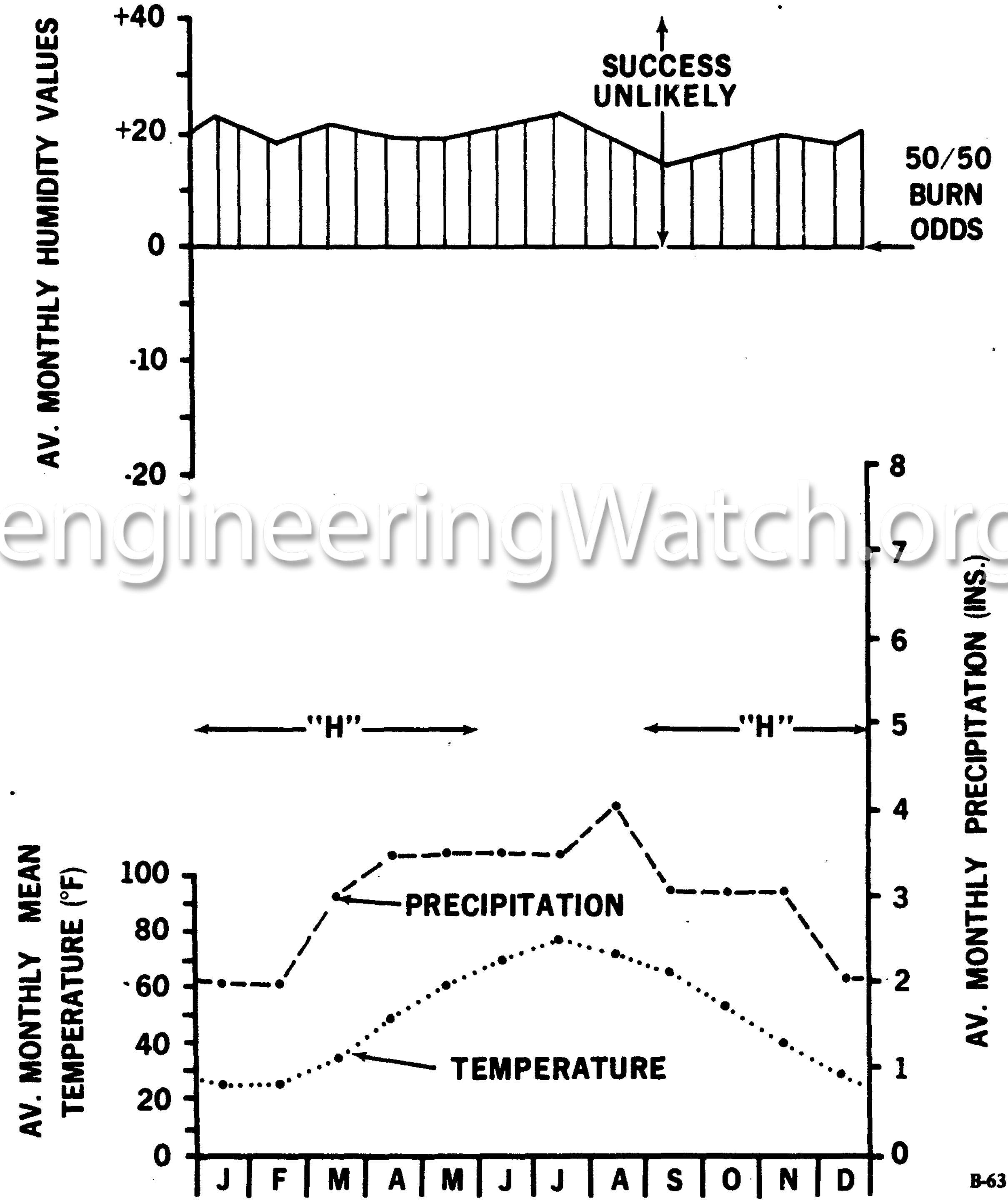
Or

1. Apply pellets in April, after daily mean temperature is above 40° F.

2. Burn in October.

FIG. B24

CLIMATE LC-HUYL
ALBANY, N. Y.



CLIMATE LC–HUSB

LONG COLD WINTER; HUMID, SHORT BURN SEASON

Continental climates - common freezes and snows - having fairly low yearly (+) values but 1-4 "B" months and low (-) values for the year. Examples are:

Location	Precipitation Pattern	No. of Months "H"	"D"	"B"	Yearly Humidity Values (+) Months ≥40°	Months ≤40°	(-) Total
Bucharest, Romania	Steppe	5	2	2	+62	+18	-3

(NOTE: This climate and VC-HUSB are of limited geopraphical occurrence. Cold climates with "B" months usually will be classed as non-humid.)

Temperature: Restricts all plant growth during a long winter period. Favors grassland under a steppe pattern.

Precipitation: Usually a steppe pattern.

Major vegetation types: Prairie or woodland.

(NOTE: Information on fuels and burning is of little interest in this climate.)

CLIMATE LC–NHYL

LONG COLD WINTER; NON-HUMID, NO BURN SEASON

Cold temperate and continental climates – with long periods of freezing weather or snows – having limited precipitation but no "B" months. Examples are:

Location	Precipitation Pattern	No. of Months "H"	"D"	"B"	Yearly Humidity Values (+) Months ≥40°	Months ≤40°	(-) Total
Georghien, Romania	Steppe	9	0	0	+72	+10	0

Temperature: Restrictive during several cold months.

Precipitation: Borderline humid. Favors grassland under steppe pattern; open conifer forest if precipitation is uniformly distributed.

Major vegetation types: Grassland or open conifer forest.

(NOTE: Under a forest type the fuel and burning conditions, and the recommended desiccation treatments are similar to JC-NHYL.)

CLIMATE LC–NHSB

LONG COLD WINTER: NON-HUMID, SHORT BURN SEASON

Cold temperate and warm to cold continental climates – long periods of winter freezes or snow – having low (+) values and low (-) values for the year; 1-4 "B" months. Examples are:

Location	Precipitation Pattern	No. of Months "H"	"D"	"B"	Yearly Humidity Values (+) Months ≥40°	Months ≤40°	(-) Total
Salt Lake City, Utah	Medit.	4	5	4	+29	+30	-23
Spokane, Wash.	Medit.	4	5	3	+16	+72	-14
Flagstaff, Ariz.	Medit.	4	3	2	+47	+40	- 5
Baker, Oregon	Medit.	3	6	3	+11	+40	-14
Missoula, Montana	Medit.	4	4	2	+24	+28	- 8
Cheyenne, Wyoming	Steppe	0	8	1	+48	+ 8	- 1
Sivas, Turkey	Steppe	5	4	4	+12	+21	-22
Helena, Mont.	Steppe	2	4	2	+33	+18	- 6
Khar Kov, U.S.S.R.	Steppe	6	2	1	+30	+37	- 1

Temperature: Restrictive during several winter months.

Precipitation: Limiting all year; restrictive during hot, dry summer under mediterranean climate.

Major vegetation types: Under a mediterranean precipitation pattern, the vegetation is open conifer forest (such as juniper) or shrubs (such as Sagebrush) or mixtures. Mountain slopes (borderline HUSB climate) have pine forests Under steepe climate, the vegetation is grassland or grass and shrub mixtures.

Ground-story vegetation: Shrubs and/or grass.

Amount: Moderate to low in conifer and sagebrush types. Low in grassland types.

Moisture content: Low during late summer and fall, and under cold winter weather.

Litter layer: Needles accumulate under conifers, but limited accumulation in grass and shrub types.

Total available fuel weight on a good burning day: 0.32 pounds per square foot in conifers; 0.22 pounds per square foot in shrubs.

Burn days: Most of the short burn season occurs while the vegetation is still green and growing. Best odds for successful burning are in early Fall.

Desiccation needs: In conifer and brush types, removal of canopy and killing of the understory are needed .r successful burning under normal weather conditions. Use either a foliar spray or an application of pellets to the soil.

Foliar spray: Apply during the spring soon after leaves are fully formed on deciduous plants. Apply per acre:

4 lbs., a.e., of a 1:1 mix of 2,4-D and 2,4,5-T in diesel oil to make a total mixture of 5 gallons.

Soil application: Apply 10 lbs., a.e., of picloram pellets per acre.

Dates for example location (Spokane, Wash., Fig. B25):

1. Spray in May.

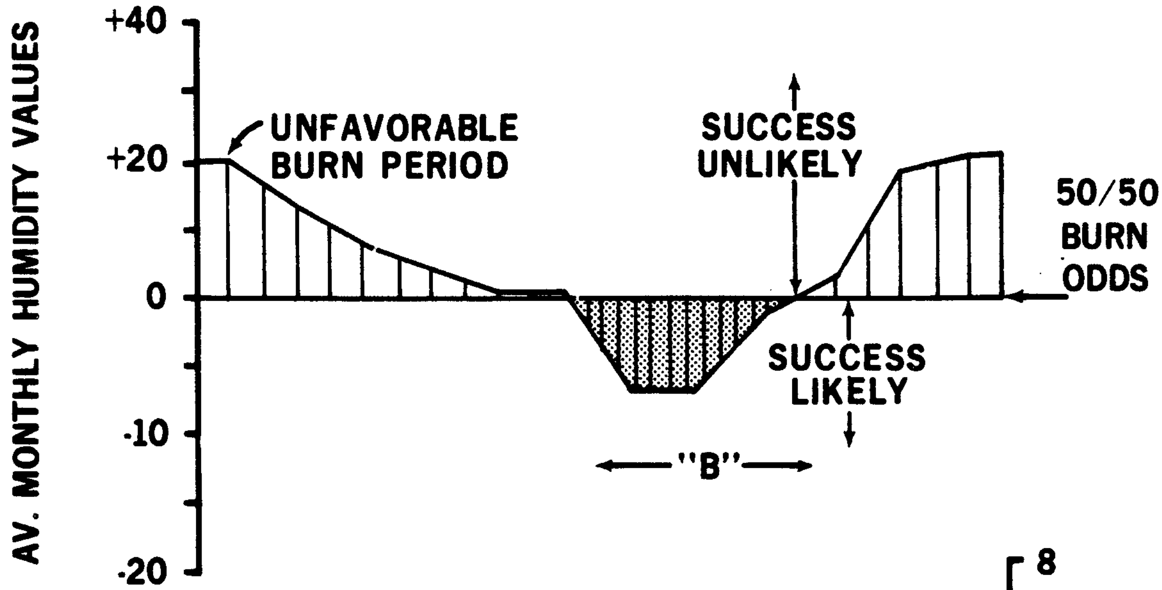
Or

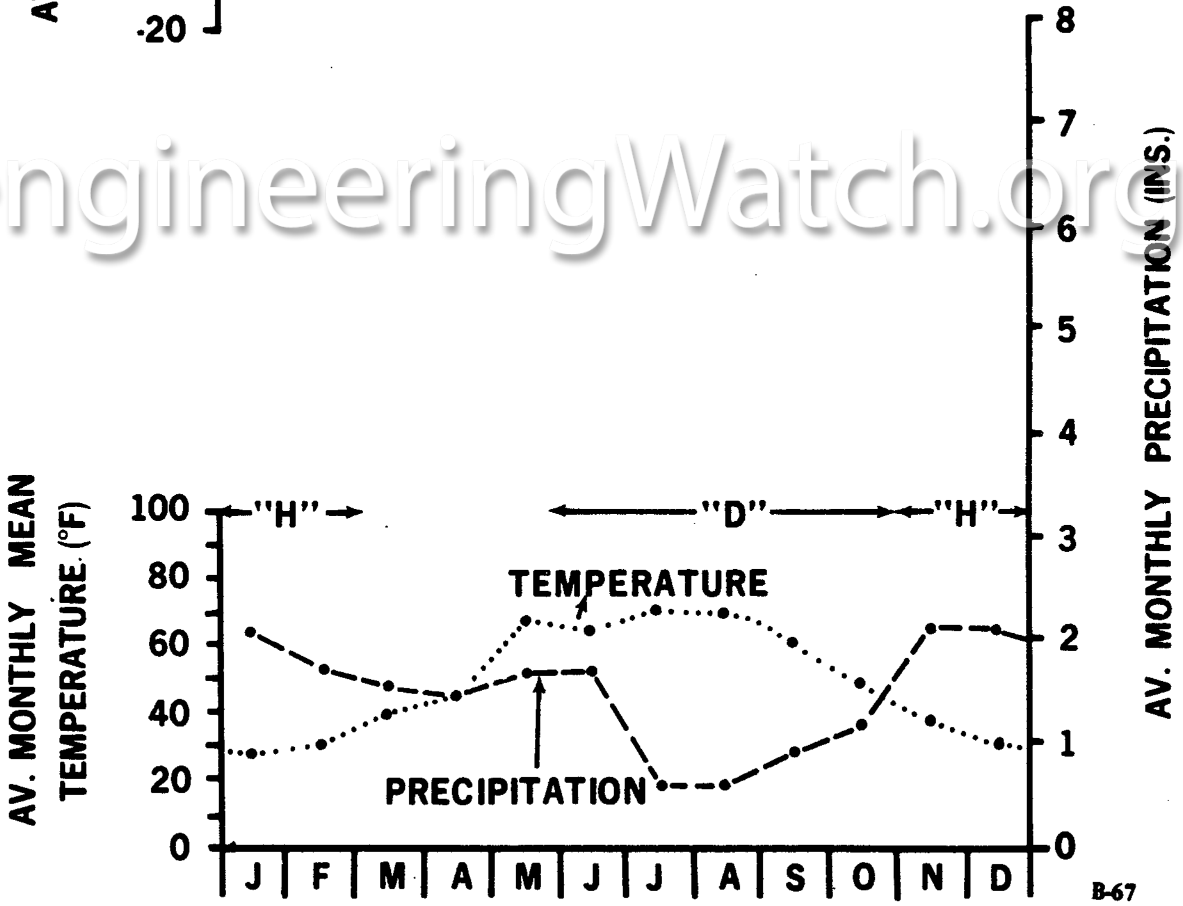
1. Apply pellets in March.

2. Burn in late September or October.

FIG.B25

CLIMATE LC-NHSB SPOKANE, WASH.





CLIMATE LC–NHLB

LONG COLD WINTER: NON-HUMID, LONG BURN SEASON

Cold temperate or continental climates – long periods of freezes or snows – having low (+) values and high (-) values for the year, or at least 5 "B" months. Examples are:

Location	Precipitation Pattern	No. of Months "H"	"D"	"B"	Yearly Humidity Values (+) Months ≥40°	(+) Months ≤40°	(-) Total
Pueblo, Colorado	Semi-arid	0	11	5	+ 9	+ 1	-10
Grand Junct., Colo.	Desert	0	10	7	+ 2	+ 5	-29
Modena, Utah	Semi-arid	0	8	5	+12	+11	-13

(NOTE: Long burn season is not expected to occur in colder climates.)

Temperature: Restrictive during long winter period.

Precipitation: Restrictive most of year.

Major vegetation types: Open stands of low trees, shrubs, and grassland-like vegetation.

Ground-story vegetation: Shrubs and/or grasses.

Amount: Low in dry weight; usually discontinuous.

Moisture content: Drops during long dry season and remains low during cold winter.

Litter layer: Thin and discontinuous because of low yearly leaf production.

Total available fuel weight on a good burning day: 0.15 pounds per square foot.

Burn days: Many suitable days, but of variable occurrence during the summer months because of rainstorms.

Desiccation needs: Little use of fire because of scant, discontinuous fuel. Semi-dense shrub stands can be sprayed with 2 lbs., a.e., of 2,4-D in diesel oil to make a total of 3 gallons per acre.

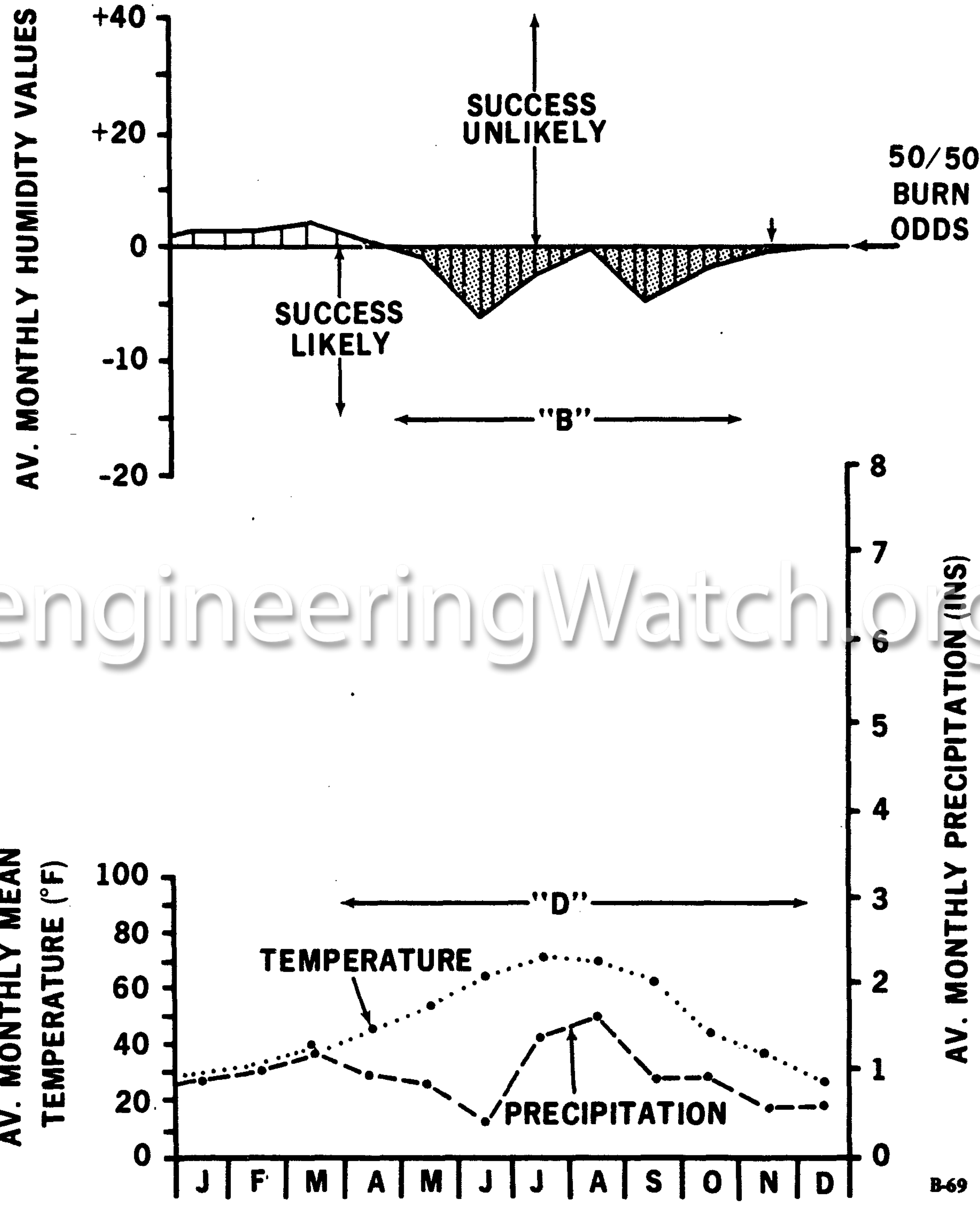
Dates for example location (Modena, Utah, Fig. B26):

1. Spray in July.

2. Burn in September or October, or wait and burn during the next June.

FIG. B26

CLIMATE LC-NHLB
MODENA, UTAH



CLIMATE VC-HUYL
VERY COLD WINTER: HUMID YEARLONG

Cold temperate, cold continental, and polar (incl. alpine) climates – long periods of freezing weather having no "D" months and no "B" months. Examples are:

Location	Precipitation Pattern	No. of Months "H"	"D"	"B"	Yearly Humidity Values (+) Months ≥40°	(+) Months ≤40°	(-) Total
Madison, Wisc.	Humid	10	0	0	+106	+ 43	0
Minneapolis, Minn.	Steppe	9	0	0	+113	+ 28	0
Escabana, Mich.	Humid	12	0	0	+118	+ 71	0
Chatham, N. Brunswich	Humid	12	0	0	+163	+163	0
Duluth, Minn.	Humid	12	0	0	+136	+ 49	0
Mt. Washington, N.H.	Humid	12	0	0	+160	+320	0
Watson Lake, Yukon T.	Humid	5	0	0	+ 53	+ 59	0

Temperature: All plant growth restricted for a long period; herbaceous plants grow, mature, and dry during a few months. Conifers are favored in warmest sections; weather is too cold for trees under most extreme conditions.

Precipitation: Not restrictive, except for short periods, because temperature is a more limiting factor in plant growth.

Major vegetation types: Conifer forest; open stands of short trees in coldest portions. Forest grades into tundra, alpine grassland, or heath-like vegetation.

Ground-story vegetation: Under forest canopy the woody plants are tree seedlings and deciduous shrubs. In non-forest areas the plants are heath-like, grasses and forbs, or tundra.

Amount: Moderate in dry weight.

Moisture content: High in summer; low during very cold winter.

Litter layer: Current leaf fall plus accumulation under cold climate; limited in amount by short growing season. Lower layers may remain moist yearlong.

Total available fuel weight on a good burning day: 0.37 pounds per square foot in conifer forest; 0.19 pounds per square foot in open forest or tundra.

Burn days: No burn season. At southern limits of this fire climate class the best odds may be in late winter or early spring.

Desiccation needs: Little reason to burn except at southern limits. Here, the recommended treatments are the same as for LC-HUYL.

Example (southern-limit climate), Duluth, Minn., (Fig. B27):

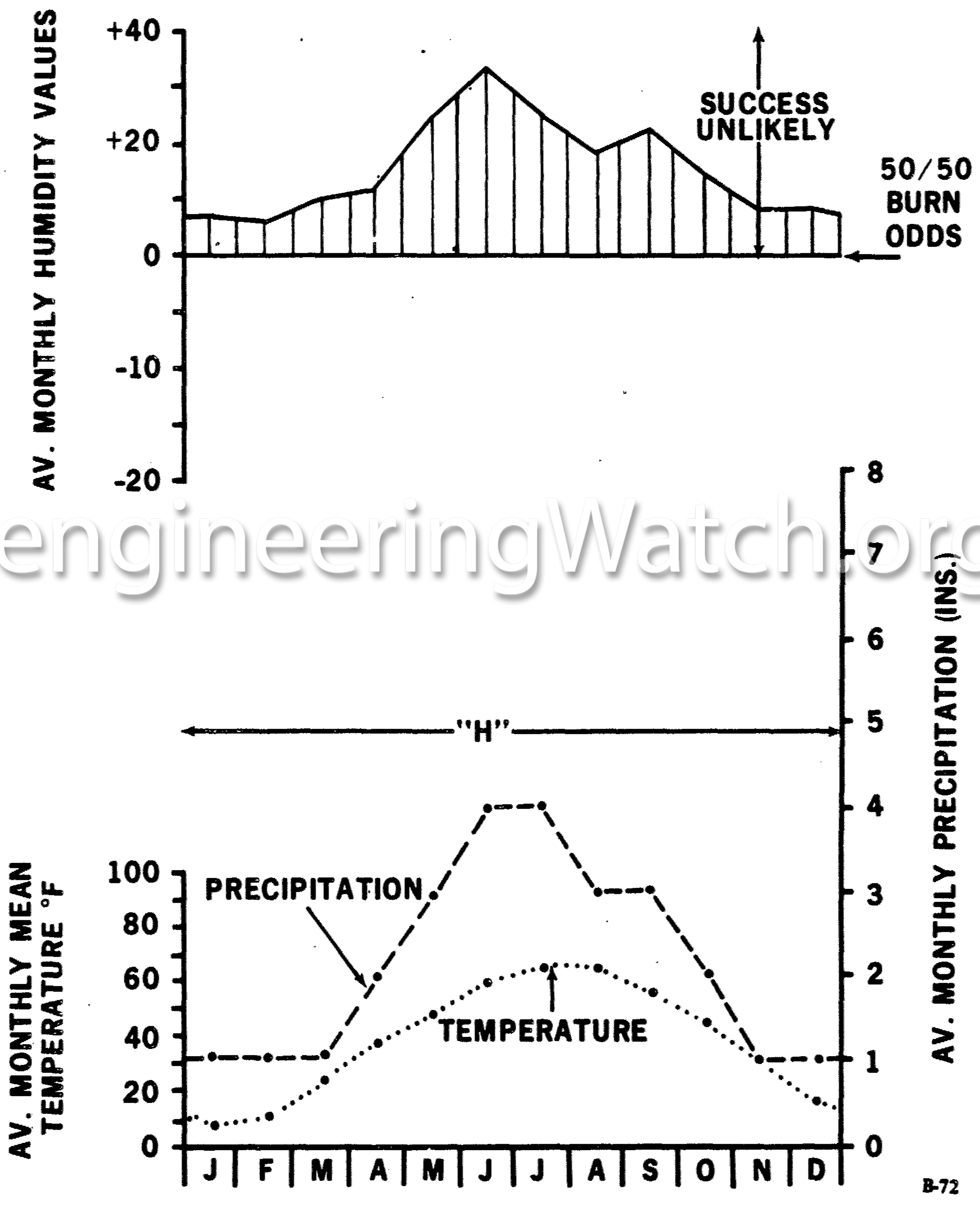
1. Spray in late June or July.

Or

1. Apply pellets in early May.
2. Burn during winter or spring.

FIG. B27

CLIMATE VC-HUYL
DULUTH, MINN.



CLIMATE VC-NHYL
VERY COLD WINTER; NON-HUMID, NO BURN SEASON

Cold temperate, cold continental, or polar (incl. alpine) climates – long periods of freezing weather or snows having limited precipitation, but no "B" months. Examples are:

Location	Precipitation Pattern	No. of Months "H"	"D"	"B"	Yearly Humidity Values (+) Months ≥40°	(+) Months ≤40°	(-) Total
Yellowstone Pk., Wyo.	Medit.	5	2	0	+42	+65	0
Abisco, Sweden	Steppe	9	0	0	+33	+18	0
Tambov, U.S.S.R.	Steppe	7	0	0	+32	+47	0
Bismark, N.D.	Steppe	2	4	0	+49	+16	0
Karesuando, Sweden	Humid	8	0	0	+45	+22	0
Kazan, U.S.S.R.	Humid	6	0	0	+29	+46	0
Bogolovsk, U.S.S.R.	Humid	10	0	0	+35	+ 8	0
Tomsk, U.S.S.R.	Monsoon	6	1	0	+54	+74	0
Dawson, Yukon T.	Monsoon	7	2	0	+34	+35	0

Temperature: Restrictive for long periods. Warmest favors conifers, but coldest is too low for forest growth.

Precipitation: Low during warm season; favors open forest or grassland-like vegetation.

Major vegetation types: Wide range of types: Open conifer forest under humid pattern; grassland-like with scattered trees and shrubs under monsoon or mediterranean pattern; short grass to mixed prairie under steppe pattern; tundra, with scattered woody plants, under coldest. Often semi-barren.

(NOTE: The small amount of woody material to be removed seldom warrants burning. If burning is to be attempted, apply a contact desiccant spray about 2 months ahead of the burning date.)

CLIMATE VC–NHSB

VERY COLD WINTER; NON-HUMID, SHORT BURN SEASON

Cold continental and polar (incl. alpine) climate very long periods of winter freezes or snow – having low (+) values and low (-) values for the year; 1-4 "B" months. Examples are:

Location	Precipitation Pattern	No. of Months "H"	"D"	"B"	Yearly Humidity Values (+) Months ≥40°	(+) Months ≤40°	(-) Total
Meeker, Colo.	Semi-arid	0	6	2	+33	+18	-2
Pierre, S. D.	Steppe	0	5	2	+36	+ 9	-3
Calgary, Alberta	Steppe	1	1	2	+67	+ 5	-1
Ulan-Bator, U.S.S.R.	Monsoon	1	9	4	+30	+ 1	-1
Krasnoyarsk, U.S.S.R.	Monsoon	3	4	2	+10	+ 5	-3
Olek Minsk, U.S.S.R.	Monsoon	5	2	1	+10	+ 9	-1

Temperature: Restrictive during long winter period.

Precipitation: Limiting all year; usually low in winter.

Major vegetation types: Short grass and grassland-like vegetation.

(NOTE: Fuels and desiccation treatments are of little importance in this climate because of the limited use of burning for woody plant removal.)

SECRET

APPENDIX C

Publications: Project EMOTE

SECRET

Publications: Project EMOTE

1965 Breit, J. M., et al. Neutralization of Viet Cong Safe Havens. Research Analysis Corp. Technical Paper RAC-TP-191. 74 pp., illus. SECRET

1966 Bentley, J. R., et al. Forest Fire Research, Vol. I. USDA-Forest Service. 54 pp., illus. SECRET.

Bentley, J. R., et al. Forest Fire Research, Vol. II. USDA-Forest Service. 225 pp., illus. SECRET.

1967 Lund, H. G., et al. Aerial Photo Interpretation of Understories in Two Oregon Oak Stands. USDA-Forest Service Res. Note PNW-58. 6 pp., illus.

Mutch, R. W., et al. Operation PINK ROSE. USDA-Forest Service. 121 pp., illus. SECRET

Olson, C. E. Optical Sensing of the Moisture Content in Fine Forest Fuels. Univ. of Mich., Inst. of Sci. and Tech. Report 8036-1-F. 22 pp., illus.

1968 Chandler, C. C. Urban Firefighting by Helicopter. Completion Report ARPA Order 818, Amendments 3 and 5. USDA-Forest Service. 50 pp. Processed.

Lund, H. G. and G. R. Fahnestock. A Test of Color Aerial Photography for Interpreting Understory Vegetation in Two Oregon Tanoak Madrone Stand. USAD-Forest Service. Final Progress Report PNW-1203:FA-2.2. 79 pp., illus.

Mutch, R. W. Tropical Wildland Fires How Successful? USDA-Forest Service. 29 pp., illus. SECRET.

Orgill, M. M. Availability of Meteorological Data in SE Asia and the Philippines. USDA-Forest Service, Pacific Southwest Forest and Range Exp. Sta. 50 pp., illus.

Philpot, C. W. Mineral Content and Pyrolysis of Selected Plant Materials. USDA-Forest Service Res. Note INT-84. 4 pp., illus.

Philpot, C. W. and R. W. Mutch. Flammability of Herbicide Treated Guava Foliage. USDA-Forest Service Res. Paper INT-54. 9 pp., illus.

1969 Anderson, H. E. Heat Transfer and Fire Spread. USDA-Forest Service Res. Paper INT-69. 20 pp., illus

Berlad, A. L. Fire Spread in Solid Fuel Arrays. Combustion and Flame. 13(5): 565-566.

Berlad, A. L. Some Fundamental Parameters in Fire Research. Combustion and Flame. 14(1): in press.

Berlad, A. L. and C. Prasad. The Pre-Flame Region of Spreading Forest Fires. State Univ. of N.Y. at Stony Brook, Coll. of Eng. 4 pp.

McCutchan, M. H. and R. S. Helfman. Synoptic-Scale Weather Disturbances That Influence Fire Climate in Southeast Asia During Normally Dry Periods. Preliminary Report. USDA-Forest Service, Pacific Southwest Forest and Range Exp. Sta. 69 pp., illus.

McCutchan, M. H. and B. Taylor. Synoptic-Scale Weather Disturbances That Influence Fire Climate in Southeast Asia During Normally Dry Periods. Final Report. USDA-Forest Service, Pacific Southwest Forest and Range Exp. Sta. 144 pp., illus.

Meteorology Research Inc. Forest Dryness System. TM-95. 14 pp., illus.

O'Dell, C. A. Climatological and Meteorological Analysis for Operation PINK ROSE. USDA-Forest Service, Pacific Southwest Forest and Range Exp. Sta. 75 pp., illus. SECRET.

Shafizadeh, F., et al. Combustibility of Plant Materials. Univ. of Montana. Department of Chemistry. Final Report 12-11-204-1. 21 pp. Processed.

Webb, W. L. Desiccation of Woody Stems -- Influenced by Connected Live Tissues. USDA-Forest Service Res. Note PSW-168. 4 pp.