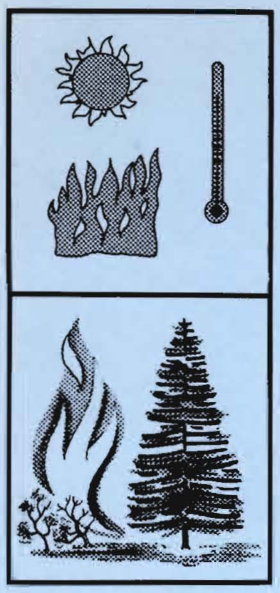
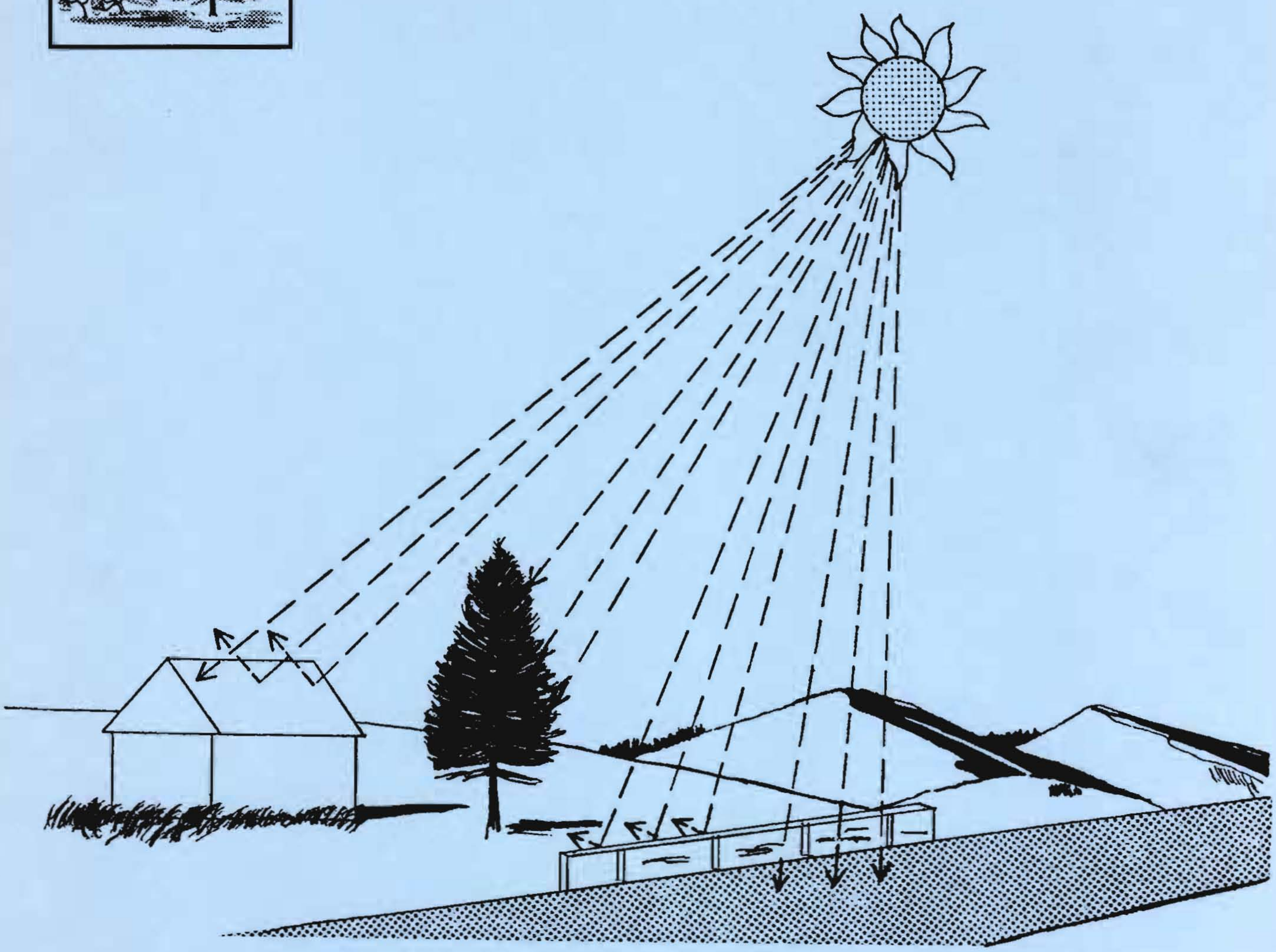


HEAT—ITS ROLE IN WILDLAND FIRE — Part 5

RADIATION AND WILDLAND FIRE

Clive M. Countryman



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NOTE

This publication is part of a group designed to acquaint fire control personnel, wildland managers, and forestry students with important concepts of fire behavior and the application of these concepts to wildland fire problems. The level of difficulty of the treatment of topics in these publications varies, as signaled by the color of the cover: the blue cover group is generally elementary and the yellow cover group is intermediate. The following publications, by Clive Countryman, are available on request to:

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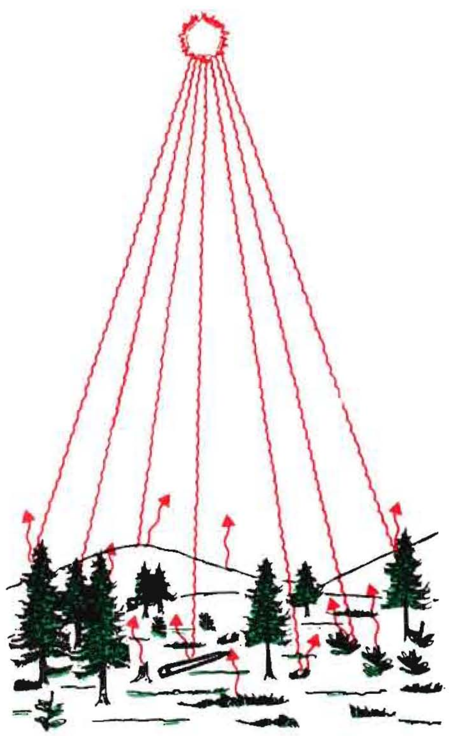
This Humidity Business: What It Is All About and Its Use in Fire Control. 1971 (blue)
Fire Whirls . . . Why, When, and Where. 1971 (blue)
Carbon Monoxide: A Firefighting Hazard. 1971 (yellow)
The Fire Environment Concept. 1972 (blue)
Heat–Its Role in Wildland Fire (blue)

Part 1–The Nature of Heat. 1975
Part 2–Heat Conduction. 1976
Part 3–Heat Conduction and Wildland Fire. 1976
Part 4–Radiation. 1976
Part 5–Radiation and Wildland Fire. 1976

RADIATION AND WILDLAND FIRE

Before a wildland fire can start, heat must be transferred from a firebrand to the fuel. Then heat must be transferred from the fuel surface to deeper layers if the fire is to continue to burn. Finally, heat must be transferred to surrounding unburned fuel if the fire is to spread. And decreasing or eliminating heat transfer is about the only way we have of controlling and extinguishing a fire. Heat transfer is hence an essential part of wildland fire and fire control.

Heat can be transferred in three ways—by conduction, by radiation, and by convection. All three methods are usually operating at the same time in a wildland fire. In Parts 2, 3, and 4 of this series, we explored the role of conduction in the combustion process and in fire control, and the characteristics of heat transfer by radiation. Now we will examine heat transfer by radiation in relation to fire behavior, fire control, and firefighting safety.



RADIATION AND WEATHER

Heat reaches the earth through radiation

One way radiation affects fire behavior and fire control is through its effect on weather. Almost all the heat at the earth's surface and in its atmosphere comes from the sun as radiant energy. Because of the sun's high temperature, most solar radiation is in the short wavelengths of thermal radiation—much of it is visible light. A small part of the shortwave radiation is absorbed by the atmosphere, mostly in the upper layers, but the majority passes through the air without warming it much. When the shortwave radiation strikes a solid object, such as the earth's surface or something on it, a large part of the radiant energy is converted to heat, warming the object. The heated object radiates energy too, but mostly in long waves because of the object's relatively low temperature. Water vapor and carbon dioxide in the air can absorb the longwave radiation, thereby raising the temperature of the air.

Surface and air temperatures follow radiation intensity

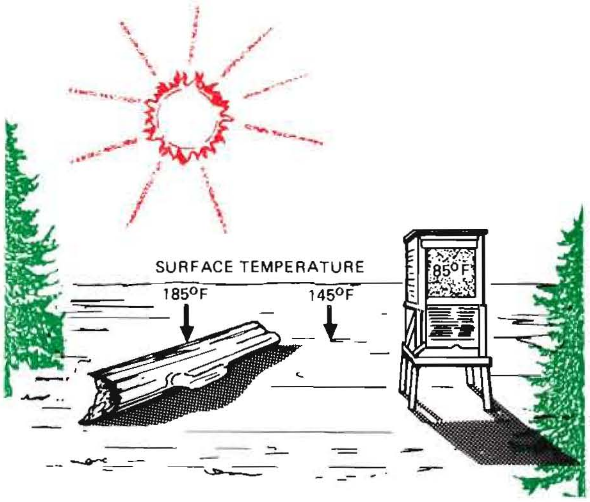
The temperature of the surface receiving solar radiation follows the radiation rate quite closely during the day, reaching maximum temperature at about the same time the radiation reaches maximum intensity. The air temperature very near the ground surface also follows the radiation intensity closely, but because heat is slowly distributed upward in the air, there is an increasing lag in air temperature behind the surface temperature as height above the ground increases. In an instrument shelter 4.5 feet above the ground, where air temperature is commonly measured, the maximum temperature may occur 2 to 3 hours later than the maximum at the ground surface. The temperature in the shelter is also usually much lower than that at the surface. On a clear, calm, mid-summer day in the open, the temperature of the ground surface and the fuel on it is often 40° to 60° F higher than the air temperature in the instrument shelter. Because wind mixes the hot air near the surface with cooler air above it, these temperature differences are less on a windy day than on a calm one.

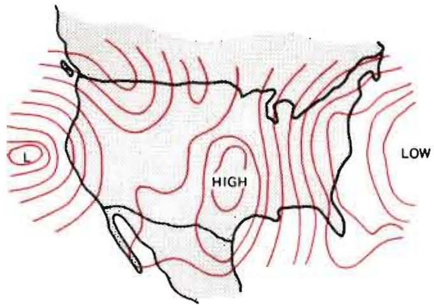
At night the process is reversed. The ground and other solid materials are better radiators than air, and lose heat more rapidly, especially dark-colored materials. Consequently, the solid materials become colder than the surrounding air. This is why frost may form on exposed surfaces, particularly dark ones, when the air temperature remains above freezing. Air near the ground is cooled by the ground surface, and this cooling process extends upward as the night progresses. Thus, at night the air temperature tends to increase with height above the ground, particularly when weather is calm and clear. Cloud cover slows the radiation loss—part of the radiation from the surface is reflected back to earth, and part is absorbed by the clouds and radiated back. As in the daytime, wind increases the mixing of the air and reduces the temperature difference between the ground surface and the air at some point above it.

Variation in radiative heating controls weather

The angle at which the sun's radiation strikes the earth's surface varies with the time of year and with latitude. Heating is greatest along a band at the equator, where the incoming radiation is most nearly perpendicular, and least at the poles, where the radiation strikes the earth at a low angle. At any latitude, land masses are heated more than are the oceans. This variation with latitude and between land and water masses creates widespread temperature differences in the atmosphere, thus generating large-scale air circulation patterns. These circulations are the basic cause and control of our weather and climate. If the earth were heated uniformly over its whole surface, the air circulation patterns could not exist, and we would not have "weather" as we now know it.

Variations in the amount of heating from solar radiation occur on a local scale, too. The angle at which the sun's





radiation strikes the surface varies with slope aspect and steepness, time of day and year, and amount of cloud cover and atmospheric haze. Variations in surface characteristics and ground cover also affect the amount of heating. The air currents set up by these small-scale temperature differences have an important influence on local climate and weather, particularly wind patterns. Such local variations, in turn, strongly influence fire behavior—they will be discussed in a separate paper on heat transfer by convection.

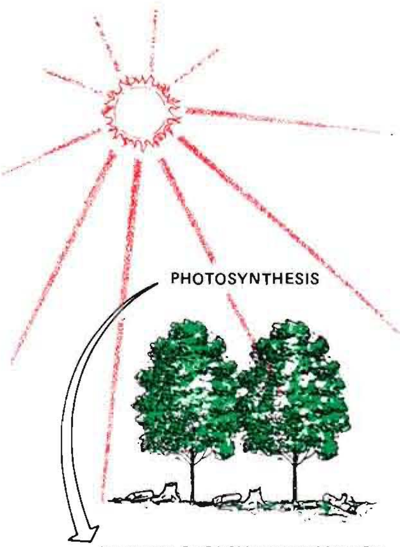
RADIATION AND FUELS

Radiation helps create fuels

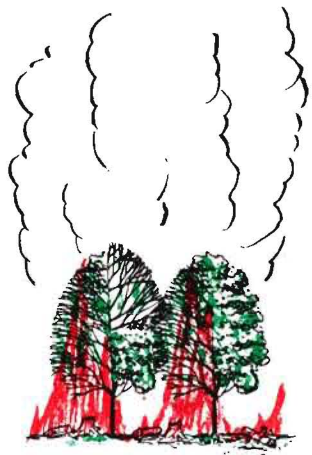
Radiation from the sun provides the energy for photosynthesis—the basic process of plant growth. Through the continuous production of cellulosic materials, the wild land vegetation in effect provides a storage reservoir for the sun's energy. This stored energy, often accumulated over many years, is released in a brief time span when the vegetation burns. The amount of energy released, along with the rate and manner of its release, are the primary regulators of fire behavior. Thus, factors influencing the amount of fuel and its burning characteristics will also affect fire behavior.

Radiation intensity affects fuel moisture

In the absence of precipitation, the moisture content of dead fuel is controlled mainly by the relative humidity of the surrounding air, although fuel temperature also has some influence. In turn, relative humidity in a given air mass is controlled almost entirely by air temperature, and decreases as the temperature rises and increases as the temperature goes down. Because of the strong tie between air temperature and relative humidity, and between air temperature and solar



RADIANT ENERGY TRANSFORMED
TO STORED CHEMICAL ENERGY



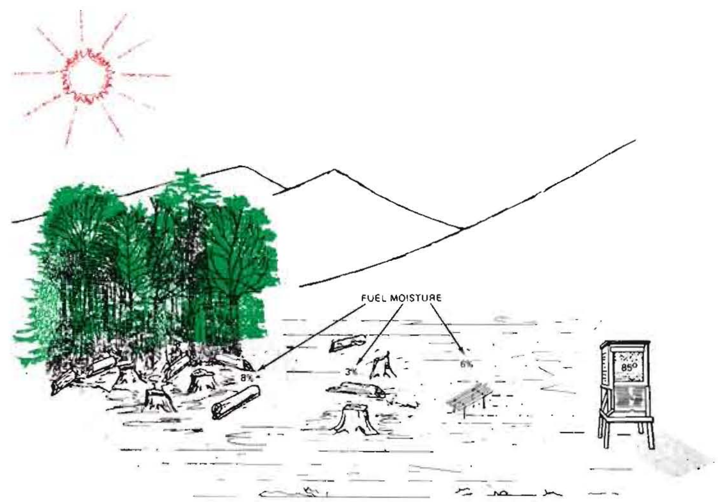
CHEMICAL ENERGY TRANSFORMED
TO THERMAL AND RADIANT ENERGY

radiation intensity, we can expect that whatever affects radiation intensity will also affect fuel moisture. Thus, the moisture content of dead fuel is normally higher at night than during the day, and greater in the shade than in the open. Because radiation intensity changes with angle, moisture content varies with slope aspect and steepness, and with time of day and year. Fuels on slopes with an easterly aspect dry out earlier in the day, but do not become as dry as those on slopes with a westerly aspect. The moisture content of fuels on north slopes is usually greatest. During the day, the temperature is highest at the surface, so fuels on the ground are likely to have a lower moisture content than those above ground. Variations in amount of cloud cover, haze, and smog from day to day result in corresponding variations in fuel moisture.

RADIATION AND FIRE BEHAVIOR

Fire is a high-temperature heat source

Flame temperatures in a hot wildland fire can exceed 2500° F, and temperatures of 1800° to 2200° in the combustion zone are prevalent. Glowing material ranges from 700° to 1400° F or more. At such high temperatures, much of the radiant energy from a fire is in the visible wavelengths. The peak radiation from a fire tends more toward the longwave or infrared range of the thermal radiation spectrum than for solar radiation, however, because the sun radiates as a black body at a temperature between 10,000° and 11,000°F.



Radiation influences fire spread

Although heat transfer by conduction is necessary to keep many fuels burning, conduction of heat is a rather slow process in woody materials. Consequently, fire spread, which requires the transfer of heat to unburned fuel ahead of the fire edge, is accomplished principally by radiation and convection. Under windy conditions or on steep slopes, heat transfer by convection is likely to be most important. But with light winds and gentle terrain, the fire convection column is nearly vertical, and radiation becomes the major method of heat transfer.

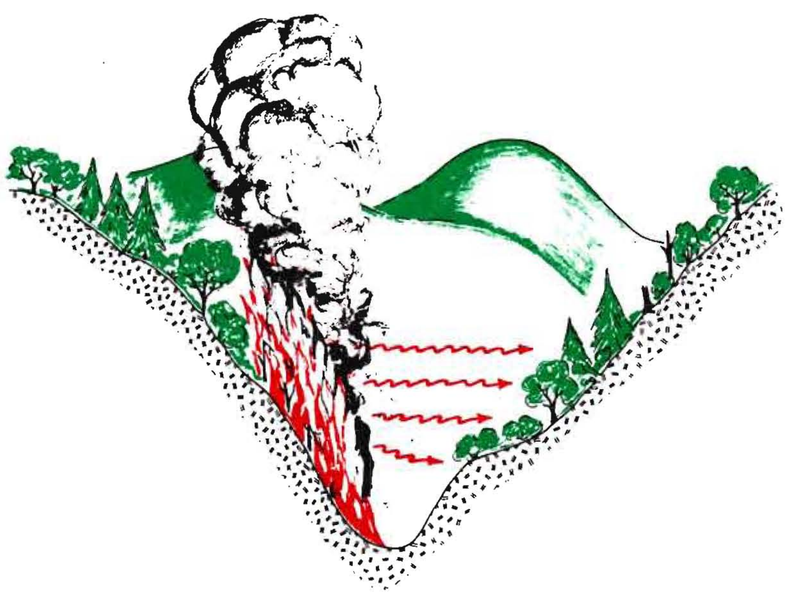
Fire spread by radiation usually tends to be slow. As we have seen, radiation intensity decreases rapidly with distance,

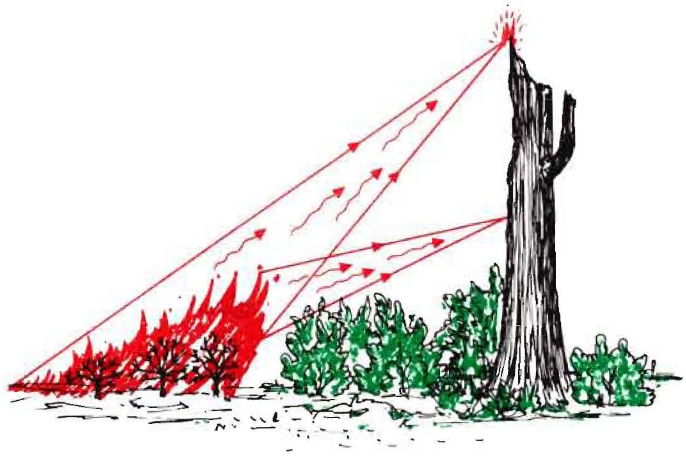
so fuels more than a short way from the flames are heated slowly and are not likely to ignite until the flames approach them closely or until they have been exposed to radiation for a considerable time. Also, radiation travels only along straight lines, so that often much of the fuel is shielded from direct radiation by other fuel until the flames are close.

Radiation creates problems in fire behavior and fire control

Although heat transfer by radiation in wildland fires is usually slower than that by convection, it is still highly significant in fire behavior and fire control activities. Unlike convection, heat transfer by radiation from a fire does not depend on the movement of flames and hot combustion products—radiation transfers heat in all directions, even against the wind. This property of radiation can cause unexpected fire behavior and create problems in fire control as a result.

In Part 4 of this series, it was pointed out that the area of the radiating surface substantially affects the amount and intensity of radiation received by an object. Thus, the amount of heat transferred to the fuel by radiation from a fire depends greatly on the extent of fire or hot area the fuel is exposed to or can "see." A fire burning on one slope of a narrow ravine, for example, may expose the opposite slope to strong radiation and heating. This heat can dry the fuel and preheat it sufficiently to make it highly susceptible to ignition from sparks and embers. Occasionally, the radiation may be intense enough to ignite the whole slope, or a large part of it, almost simultaneously. Because radiation is not affected by wind, which usually determines the direction of fire spread, the fire may move in an unexpected direction.



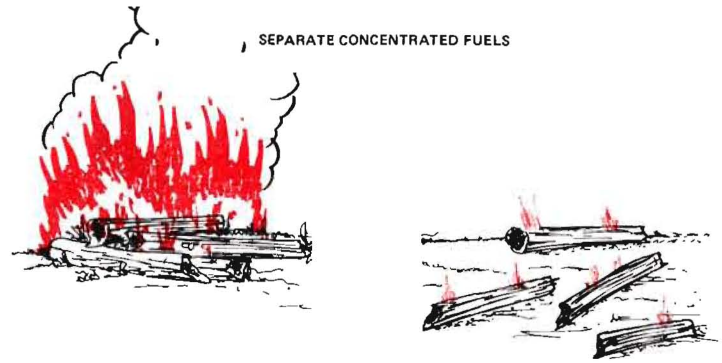


A snag in front of an advancing fire may also ignite in an unexpected way from the effects of radiation. Because of the shielding action of low-level fuels, the upper portion of the snag is likely to be exposed to radiation longer, and often to greater radiation intensity too, than is the lower portion of the snag until the fire approaches it closely. Thus, the snag may ignite first at some point well above the ground, either from radiation directly, or because preheating and drying permit easy ignition by flying sparks and embers. This phenomenon is particularly important when there are snags outside the control line, since the ignition occurs at a point where the burning snag can scatter firebrands over a wide area. Also, fire high in a snag is not likely to be quickly discovered, and is usually difficult to put out.

Radiation from the burning fuels inside a control line continues to heat and dry fuels outside the line after spread has been stopped, making them easier to ignite, or at times causing ignition directly. This hazard is greatest where there are fuel concentrations that can burn hot and for a long time. Such "hot spots" along the control line need early attention in mop-up activities, not only because they are a prolific source of firebrands, but also because of the intense radiation they produce.

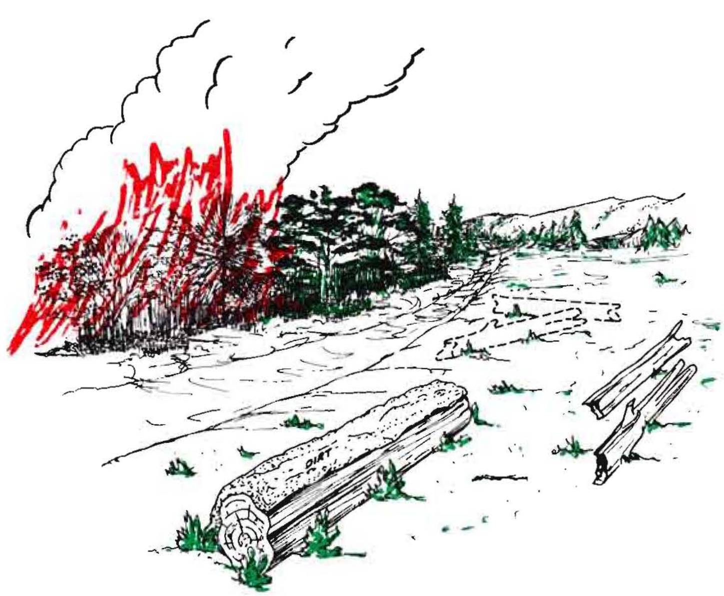
Some radiation problems can be alleviated

Ordinarily, a piece of burning wood larger than about an inch in diameter does not continue to burn well or goes out if it is burning by itself and in a position where it can radiate thermal energy in all directions. The heat losses from radiation and convection are so great, and the heat conduction into the interior of the fuel so slow, that the flame at the surface cannot produce enough heat to keep the combustion process going. But when several pieces of fuel are close together, the heat losses are greatly reduced--each burning piece supplies heat to others--and the fuel can burn intensely. This is why a single log in a fireplace can seldom be made to burn, but three or four logs together burn well. This need of



the larger fuels to have more heat than they can produce individually to continue burning can be utilized in fire-fighting, particularly in mop-up work. Fire intensity can be reduced or active flaming stopped if the individual pieces in fuel concentrations are separated by only a few feet. Similarly, raking away hot coals and burning debris from around a log too large to move or from around the base of a burning snag also often reduces the fire intensity or causes the flames to go out.

The peculiarities of heat transfer by radiation are also useful in reducing the chance that a fire will ignite fuel across the control line. Because radiation travels only along straight lines and its intensity decreases rapidly with distance, the likelihood of ignition of highly susceptible fuels can be reduced by moving them away from the edge of the control line or to a place where they will be shielded from direct radiation by nonflammable material or less flammable fuels. Heating by radiation occurs at the surface, so even a thin layer of dirt over fuels that cannot be moved, such as stumps or large logs, is often sufficient to prevent them from



igniting. Locating the cleared control line just over the crest of a ridge on the slope away from the fire reduces the amount of fire the fuel can see, decreases the time it is exposed to radiation, and increases the distance of the fuel from flames inclined over the ridge. Lopping dead fuel so that it lies closer to the ground can also reduce the fire area to which it is exposed and the amount of heat it receives.

RADIATION AND FIREFIGHTING SAFETY

The body's ability to withstand heat is limited

Firefighters working along an actively burning fire edge are exposed to heating by radiation just as adjacent fuels are. The human body's cooling system has a limited capacity to deal with heat, and this capacity can be overtaxed if the body is exposed to even low-intensity fire at close range. For example, more than 80 percent of the body's cooling capacity is utilized when a firefighter is working 6 feet away from flames about 1 foot high. With flames 2 feet high this capacity is exceeded at the same distance. Greater flame heights and radiation intensity cause pain and burns to exposed skin in a short time.

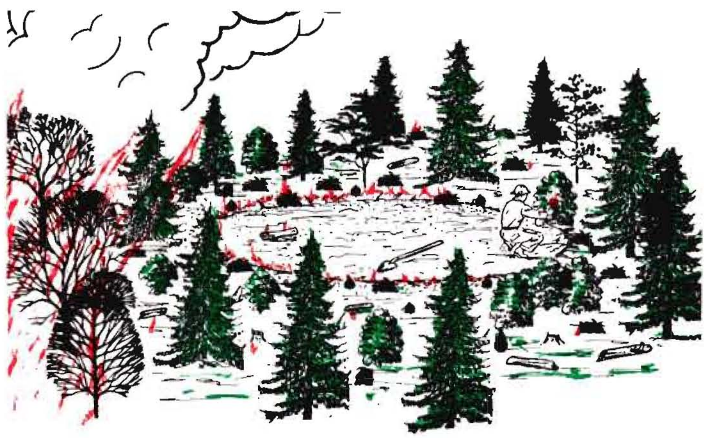
Proper clothing will reduce heating by radiation

The simplest way to reduce the amount of heating by radiation is through adequate clothing. Heavy cotton or wool clothing is more effective than most synthetic fabrics, and two layers of clothing are far better than a single layer. Gloves protect the hands, and a hard hat or helmet protects the head. Face and neck shields can cover and protect normally exposed skin. Sudden increases in radiation from temporary flare-ups can be avoided by moving further away from the fire or taking shelter behind some solid object, such as a tree or boulder.

Survival in wildland fires is possible

Well-trained and well-led firefighters, following approved firefighting practices and aware of designated and adequate escape routes, are not likely to find themselves in a position in a wildland fire from which a safe retreat cannot be made. But knowing what to do if one is caught in a situation from which escape is not possible can mean the difference between survival and severe injury or death. A cardinal rule is to use every means possible to protect yourself from excessive radiation. The best way to do this will vary with circumstances, but all ways depend on the characteristics of radiant heat transfer–radiation intensity decreases with distance from the source, radiation travels only along straight lines, and the intensity of the radiation an object receives depends on the size of the radiating area to which it is exposed.

The main flame wave is the greatest hazard



In most wildland fires, the main flame wave moving through the fuel bed lasts only a few minutes. This is the burning period in which flame lengths are greatest and heat production is at a maximum. If you can find adequate protection for this period, your chances of survival are greatly enhanced. Bare ground or burned-over areas provide good protection, and you can enlarge or create these by burning out the fuel around you to increase the distance between you and the main fire when it passes—always carry matches for this purpose. At least partial shelter from radiation can often be found in road cuts or at the base of a cut bank on the fire side of the road. Fine fuel should be cleared from these areas before they are used, however. On bare ground, additional shelter can be found behind boulders and logs, or in depressions in the ground. If time permits and no better refuge exists, scoop out a narrow trench and lie in it. Always cover exposed skin and keep your face close to the ground where the air is cooler and more free from smoke. The effectiveness of these temporary shelters can be greatly increased by some fireproof covering, such as the shelter tents issued to most fire crews or the asbestos cloth blankets usually carried in firefighting equipment. A dirt covering can also help. The airflow in a fire front is often strong and turbulent, so any lightweight covering must be adequately secured.

Motor vehicles can provide shelter

Cars and trucks can provide good temporary shelter. Move the vehicle to bare ground or to as sparse fuel as possible. Close the doors and windows, lie on the floor, and cover yourself with a coat or blanket. Quite possibly, the vehicle will not catch fire at all, but if it does, the main flame wave will probably have passed before you must abandon the vehicle. Contrary to general belief, it is improbable that the fuel tank will explode and quickly engulf the car in flame, even after the car is burning. Experience and tests indicate that a sound fuel tank will usually remain intact in a burning car.

Buildings can sometimes be used

Temporary shelter can also be found in or behind buildings that are in good condition and not easily ignited, particularly where the surrounding fuel loading is not heavy. Although most structures are likely to catch fire in a critical situation, usually they do not do so immediately, and the fire buildup is often relatively slow. Thus, the main flame wave will probably have passed by the time the heat in the building becomes intolerable. If you use the interior of the building, check first to see that your exit will not be blocked by debris when you must leave. Avoid flimsy, unpainted wooden structures–they ignite easily and burn hot and fast. Wooden buildings in heavy fuels are also a poor choice because of the length of time a hot fire persists in such fuels.

Escape from the fire if possible

It must be emphasized that emergency survival action should be taken *only* if escape from the fire is not feasible. But do not attempt to escape if there is little chance of success–you may make your situation worse. By keeping calm and making maximum use of the available opportunities to protect yourself from heat, you can greatly increase your chances of survival.

SUMMARY

Almost all of the heat at the earth's surface and in its atmosphere comes from the sun by shortwave radiation. Solar radiation only slightly warms the air it passes through, but much is converted to heat when it reaches the ground surface and things on it. The heated surface and materials radiate energy in the longwave part of the thermal radiation spectrum, and such radiation warms the air when it is absorbed and converted to heat by the water vapor and carbon dioxide in the air.

Variations in the amount of radiant energy received at different latitudes; unequal heating of land and water masses; variations in the amount of heating of areas with different aspects, slopes, and surface characteristics, all set up temperature differences in the atmosphere. The air circulation patterns created by these temperature differences are the basic cause and control of both large-scale and local climate and weather.

Solar radiation provides the energy for photosynthesis, hence vegetation provides a storage reservoir for the sun's energy. This energy, often accumulated over years, is released quickly when the vegetation burns. In the absence of precipitation, the moisture content of dead fuel is affected to some extent by the fuel temperature, but the effect of relative humidity is much stronger. And for a given air mass, relative humidity is controlled almost entirely by air temperature, which in turn is closely related to solar radiation intensity. Thus, influences that change the intensity of solar radiation affect the moisture content of dead fuels, and consequently the ease of ignition and the behavior of a fire.

Fire is a high temperature heat source—much of its thermal radiation is in the visible wavelengths. When heat is transferred from a fire to unburned fuel principally by radiation, rate of spread of fire is usually slow. However, the characteristics of radiation often make it significant in fire behavior. Because transfer of heat by radiation does not depend on movement of flames and hot combustion products, it transfers heat in all directions and against the wind. Thus, a fire may spread in an unexpected direction when radiation is significant. Heat transmitted by radiation across a control line can preheat and dry fuels, making them more susceptible to ignition, or igniting them directly. Some topographic configurations facilitate preheating and drying of fuels by increasing the hot area the fuels can see, and this may result in ignition of large areas at one time.

The peculiarities of heat transfer by radiation can also be used to advantage in fire control. Separating piles of burning logs or limbs, or raking away hot embers from around a large log or the base of a burning snag, increases heat loss by radiation and reduces or stops active flaming. Fuels highly susceptible to ignition on the unburned side of a control line can be covered with a layer of dirt or moved further from the line or to a sheltered place to prevent ignition from heat transmitted by radiation.

Firefighters working along an actively burning fire are exposed to heating from radiation. The effects of radiation can be reduced through the use of proper clothing. Heavy cotton or wool is preferable to other common fabrics, and two layers of clothing are better than one. Hard hats or helmets, gloves, and face and neck shields provide additional protection.

If you are caught in a wildland fire situation from which escape is not possible, your survival may depend on protection from intense radiation while the main flame wave passes. Possible temporary shelters include road cuts and cut banks, boulders, large logs, depressions in the ground, motor vehicles, and buildings in good conditions. Because fire and radiation intensity usually increase with fuel loading, refuge should be sought in areas where the fuel is as sparse as can be found.

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