Firefighter Safety Zones: How Big Is Big Enough?

Bret W. Butler and Jack D. Cohen

All wildland firefighters working on or near the fireline must be able to identify a safety zone. Furthermore, they need to know how "big" is "big enough."

Beighley (1995) defined a safety zone as "an area distinguished by characteristics that provide freedom from danger, risk, or injury." The National Wildfire Coordinating Group proposed that a safety zone be defined as "a preplanned area of sufficient size and suitable location that is expected to prevent injury to fire personnel from known hazards without using fire shelters" (USDA/USDI 1995).

In our study of wildland firefighter safety zones, we focused on radiant heating only. In "real" wildland fires, convective energy transport in the form of gusts, fire whirls, or turbulence could contribute significantly to the total energy received by a firefighter. However, convection is subject to buoyant forces and turbulent mixing, both of which suggest that convective heating is important only when a firefighter is relatively close to the fire. One reason that firefighters in potential entrapment situations are told to lie face down on the ground is to minimize their exposure to convective heating. We hope to define more clearly the relationship between convective heating and safety zone size in future work.

Bret Butler and Jack Cohen are research scientists in the Fire Behavior Research Unit, Rocky Mountain Research Station, Intermountain Fire Sciences Laboratory, Missoula, MT.

> A safety zone should be large enough so that the distance between the firefighters and flames is at least four times the maximum flame height.

What Do We Know?

Two questions are important when specifying safety zone size: 1) What is the radiant energy distribution in front of a flame? and 2) How much heat can humans endure before injury occurs? Concerning the first question, Fogarty (1996) and Tassios and Packham (1984) related the energy received by a firefighter to fireline intensity and distance from the flame front. Green and Schimke (1971) presented very specific information about fuel break construction on slopes and ridges in the Sierra Nevada mixed-conifer forest type. Others have discussed the performance of fire shelters under different heating regimes (for example, King and Walker 1964; Jukkala and Putnam 1986; Knight 1988). As one would expect, there is not much information related to the second question. The available information suggests that 0.2 Btu/ft^2/s (2.3 kW/m^2) is the upper limit that can be sustained without injury for a short time (Stoll and Greene 1959; Behnke 1982). Studies by Braun and others (1980) suggest that when a single layer of 6.3 oz/yd^2 (210 g/m^2) Nomex cloth is worn, second degree burns will occur after 90 seconds when a firefighter is subjected to radiant fluxes greater than 0.6 Btu/ft^2/s (7 kW/m^2).

The Nomex shirts and trousers currently used by wildland firefighters have fabric weights of 5.7 and 8.5 oz/yd^2 (190 and 280 g/m^2), respectively. Few studies, however, have explored relationships between flame height and the safety zone size necessary to prevent burn injury.

Theory Versus Reality

We formulated a theoretical model to predict the net radiant energy arriving at the firefighter wearing Nomex clothing as a function of flame height and distance from the flame (Butler and Cohen [In press]). Figure 1 displays the results.

The amount of radiant energy arriving at the firefighter depends both on the distance between the firefighter and the flame and on the flame height. The information shown suggests that in most cases safety zones must be relatively large to prevent burn injury.

We compared safety zone sizes predicted by our model against those reported on four wildfires: the

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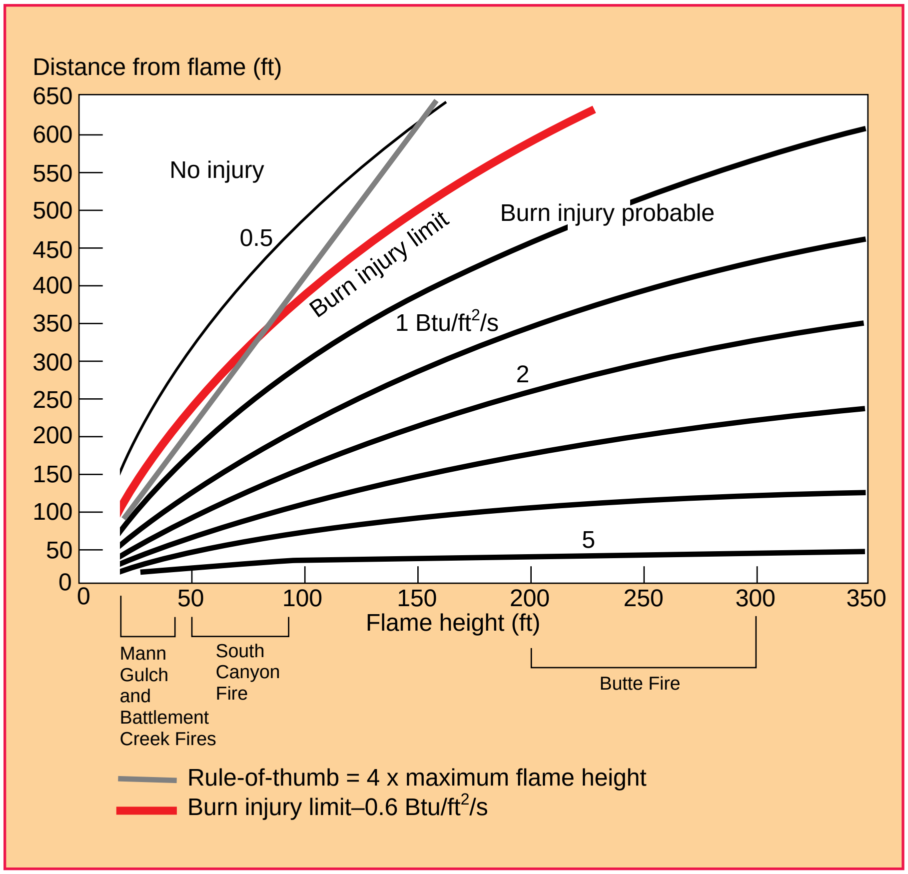

Figure 1—*Lines represent predicted radiant energy arriving at the firefighter as a function of flame height and distance from the flame. It is assumed that the firefighter is wearing fire-retardant clothing and protective head and neck equipment. The heavy shaded line represents the burn injury threshold of 0.6 Btu/ft²/s (7 kW/m²). The heavy solid black line indicates the rule of thumb for the size of the safety zone.*

Mann Gulch Fire, the Battlement Creek Fire, the Butte Fire, and the South Canyon Fire.

The Mann Gulch Fire overran 16 firefighters on August 5, 1949. Wag Dodge, one of only three survivors, lit a fire and then lay face down in the burned-out area as the main fire burned around him. The Mann Gulch Fire occurred in an open stand of scattered, mature ponderosa pine (60 to 100+ years old) with a grass understory. Flame heights of 10 to 40 feet (3 to 12 m) were estimated to have occurred at the time of entrapment. Rothermel (1993) indicates that Dodge's fire burned about 300 feet (92 m) before the main fire overran it. Assuming an elliptical shape for the burned area, with its width approximately half the length, the safety zone created by Dodge's escaped fire would have been about 150 feet (46 m) wide. Figure 1 indicates that the safety zone needed to be large enough to separate the firefighters and flames by 90 to 150 feet (27 to 46 m) or approximately the same width as the area created by Dodge's fire.

The Battlement Creek Fire occurred in western Colorado during July of 1976 (USDI 1976). The fire burned on steep slopes covered with 6- to 12-foot- (2- to 4-m-) high Gambel oak. Flames were estimated at 20 to 30 feet (6 to 9 m) above the canopy. Four firefighters were cut off from their designated safety zone. When the fire overran them, they were lying face down on the ground without fire shelters in a 25-foot- (8-m-) wide clearing near the top of a ridge. Tragically, only one of the four survived, and he suffered severe burns over most of his body. Figure 1 suggests that for this fire, the safety zone should have been large enough to separate firefighters from flames by 150 feet (46 m). Clearly, the 25-foot- (8-m-) wide clearing did not qualify as a safety zone.

Flame heights were reported to be 200 to 300 feet (62 to 92 m) high on the Butte Fire that burned on steep slopes covered with mature lodgepole pine and Douglas-fir during August of 1985 (Mutch and Rothermel 1986). Figure 1 indicates that a cleared area greater than 1,200 feet (370 m) across would have been needed to prevent injury to the firefighters standing in its center. In fact, safety zones 300 to 400 feet (92 to 123 m) in diameter were prepared (Mutch and Rothermel 1986). This diameter was not sufficiently large enough to meet the definition of a safety zone, as indicated by the fact that 73 firefighters had to deploy in fire shelters to escape the radiant heat. As the fire burned around the edges of the deployment zone, the intense heat forced the firefighters to crawl while inside their shelters to the opposite side of the clearing.

On July 2, 1994, the South Canyon Fire was ignited by a lightning strike to a ridgetop in western Colorado. During the afternoon of July 6, the South Canyon Fire "blew up," burning across the predominately Gambel-oak-covered slopes with 50- to 90-foot- (15- to 28-m-) tall flames (South Canyon

Fire Accident Investigation Team 1994). Tragically, 14 firefighters were overrun by the fire and died while attempting to deploy their fire shelters. Twelve of the firefighters died along a 10- to 12-foot- (3- to 4-m-) wide fireline on a 55-percent slope, the other two in a steep narrow gully. Eight other firefighters deployed their fire shelters in a burned out area approximately 150 feet (46 m) wide. They remained in their shelters during three separate crown fire runs that occurred 450 feet (138 m) away from them; none of these eight firefighters was injured (Petrilli 1996). One firefighter estimates that air temperatures inside the shelters reached 115 °F (46 °C) and remembers smoke and glowing embers entering the fire shelters during the crown fire runs. Survivors felt they were far enough from the flames that survival with minor injuries would have been possible without the protection of a fire shelter (Petrilli 1996). A firefighter who did not deploy in a shelter but remained on a narrow ridge below the eight firefighters during the "blowup" experienced no injuries (South Canyon Fire Accident Investigation Team 1994). Figure 1 suggests that in this situation, the safety zone must be large enough to separate the firefighters and flames by 250 to 350 feet (77 to 115 m).

A general rule of thumb can be derived from figure 1 by approximating the injury limit with a straight line. After doing so, it appears that a safety zone should be large enough that the distance between the firefighters and flames is at least four times the maximum flame height. In some instances—such as the Mann Gulch, Battlement Creek, and Butte fires—the fire may burn completely around the safety zone. In such fires, the separation distance suggested in figure 1 is the radius of the safety zone, meaning the safety zone diameter should be twice the value indicated.

What About Fire Shelters?

We calculated the net radiant energy transferred through a fire shelter like those used by firefighters in the USDA Forest Service. The fire shelter is based on the concept that the surface will reflect the majority of the incoming radiant energy. An average emissivity for the aluminum-foil exterior of a fire shelter is 0.07, indicating that approximately 93 percent of the energy incident on a fire shelter is reflected away (Putnam 1991). Model predictions shown in figure 2 suggest that heat levels remain below the injury limits for deployment zones wider than 50 feet (15 m), even with 300-foot- (92-m-) tall flames. However, this model does not account for convective heating that could significantly increase the total energy transfer to shelters deployed within a few flame lengths of the fire.

Conclusions

Radiant energy travels in the same form as visible light, that is, in the line of sight. Therefore, locating safety zones in areas that minimize firefighters' exposure to flames will reduce the required safety zone size. For example, topographical features that act as radiative shields are the lee side of rocky outcroppings, ridges and the tops of ridges, or peaks containing little or no flammable vegetation. Safety zone size is proportional to flame height. Therefore, any feature or action that reduces flame height will have a corresponding effect on the required safety zone size. Some examples are burnout operations that leave large "black" areas, thinning operations that reduce fuel

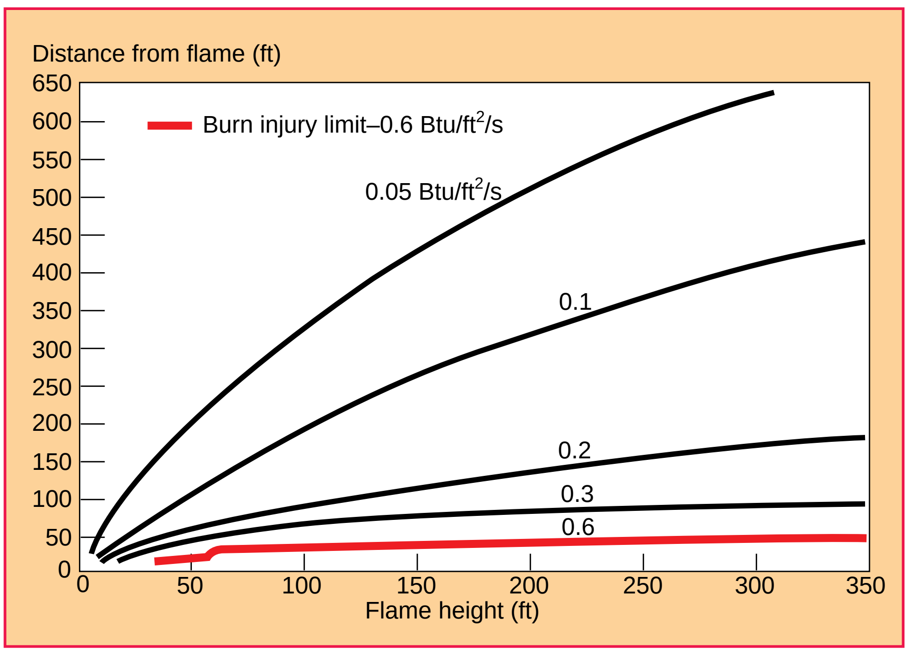

Figure 2—*Predicted radiant energy on a fire shelter as a function of distance between the fire shelter and flames, and flame height. The heavy shaded line represents the burn injury threshold for a firefighter inside a deployed fire shelter.*

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load, and retardant drops that decrease flame temperatures.

We emphasize that while this study addresses the effects of radiant energy transfer, convection is not addressed. Convective energy transfer from gusts, fire whirls, or turbulence could significantly increase the total heat transfer to the firefighter and thus the required safety zone size. Further work in this area is needed.

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Literature Cited

Behnke, W.P. 1982. Predicting flash fire protection of clothing from laboratory tests using second degree burn to rate performance. London: International Conference on Flammability; 30 p.

Beighley, Mark. 1995. Beyond the safety zone: Creating a margin of safety. Fire Management Notes. 55(4): 22-24.

Braun, E.; Cobb, D.; Cobble, V.B.; Krasny, J.F.; Peacock, R.D. 1980. Measurement of the protective value of apparel fabrics in a fire environment. Journal of Consumer Product Flammability. 7: 15-25.

Butler, B.W.; Cohen, J.D. [In press]. Firefighter safety zones: A theoretical model. International Journal of Wildland Fire.

Fogarty, L.G. 1996. Two rural/urban interface fires in the Wellington suburb of Karori: Assessment of associated burning conditions and fire control strategies. FRI Bulletin No. 197, Forest and Rural Fire Scientific and Technical Series, Rep. No. 1. Rotorua and Wellington, NZ: New Zealand Forest Research Institute in association with the National Rural Fire Authority. 16 p.

Green, L.R.; Schimke, H.E. 1971. Guides for fuel-breaks in the Sierra Nevada mixed-conifer type. Berkeley, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Forest and Range Experiment Station. 14 p.

Jukkala, A.; Putnam, T. 1986. Forest fire shelter saves lives. Fire Management Notes. 47(2): 3-5.

King, A.R.; Walker, I.S. 1964. Protection of forest firefighters. Unasylva. 18(1): 29-32.

Knight, Ian. 1988. What intensity of fire can a fire fighter survive in a reflective shelter? Fire Technology. 24(4): 312-332.

Mutch, R.W.; Rothermel, R.C. 1986. 73 firefighters survive in shelters. Fire Command. 53(3): 30-32, 48.

Petrilli, A. May 21, 1996. [Personal communication with B. Butler]. Missoula, MT.

Putnam, T. 1991. Your fire shelter: Pub. NFES 1570. Boise, ID: National Interagency Fire Center, National Wildfire Coordinating Group, National Fire Equipment System, 18 p.

Rothermel, R.C. 1993. Mann Gulch Fire: A race that couldn't be won. GTR INT-299. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 10 p.

South Canyon Fire Accident Investigation Team. 1994. Report of the South Canyon Fire Accident Investigation Team. Atlanta, GA: U.S. Department of Agriculture Forest Service, Southern Region. 39 p. plus appendices.

Stoll, Alice M.; Greene, Leon C. 1959. Relationship between pain and tissue damage due to thermal radiation. Journal of Applied Physiology. 14(3): 373-382.

Tassios, S.; Packham, D. 1984. An investigation of some thermal properties of four fabrics suitable for use in rural firefighting. National Center for Rural Fire Research. Tech. pap. no. 1. Canberra, ACT, Australia: Forest Research Institute, Forestry and Timber Bureau. 13 p.

U.S. Department of the Interior. [Unpublished July 17, 1976, report]. Accident report of Battlement Creek Fire fatalities and injury. U.S. Department of the Interior. 125 p.

USDA/USDI. [Review copy, 10/31/95]. Glossary of wildland fire terminology. Boise, ID: National Interagency Fire Center, National Fire and Aviation Support Group. 160 p. ■