

# Field Verification of a Firefighter Safety Zone Model

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**Abstract:** Safety zones are a primary component of firefighter safety. A theoretical study has been presented suggesting that burn injury can be avoided if safety zones provide a minimum separation distance between the fire and the firefighter equal to 4 times the average flame height. In this study measurements of radiant energy emitted from crown fires burned through a uniform, 12m tall stand of jack pine and black spruce are compared to predictions from the firefighter safety zone model. The comparisons suggest that the model underpredicts incident radiant flux near the flames (within 10m). The comparisons also suggest that the data are sensitive to the width of the flame as well as the flame height. If the effect of reduced heat transfer due to flames narrow than the simulated flames is taken into account then it can be argued that the measurements generally support the predictions in the region of 3 to 5 flame heights. In general the data support the model and do not suggest a strong need for modification of the model.

Key words: wildfire, safety, radiation, heat transfer

## Introduction

Firefighter safety is a primary objective of all firefighting organizations. In North America, firefighters are taught to maintain adequate safety zones. These zones are areas that are clear of fuels to which firefighters working in the area can retreat to escape injury when threatened by the fire. Recently Butler and Cohen (1998) presented an analytical study comparing predicted radiant energy transfer from a 20m wide fire front as a function of flame height and distance from the flames. This information was compared against available data on burn injury by thermal radiation to humans wearing Nomex clothing. Based on this comparison it was concluded that in general firefighter safety zones must be large enough to provide a minimum separation distance

between the fire and the firefighter equal to 4 times the flame height.

This study compares measured radiant energy emitted from crown fires burned as part of the International Crown Fire Modeling Experiment (Alexander and others, 2000) against the safety zone model suggested by Butler and Cohen (1998).

## Experiments

The International Crown Fire Modeling Experiment provided researchers with an opportunity to deploy instruments and firefighter personal protective equipment ahead of an approaching crown fire. Descriptions of the site, environmental conditions, fuels and studies are provided elsewhere (Alexander and others 2000). Figure 1 is an aerial photograph of the experimental site.



Figure 1—Aerial view of experiment.

Figure 2 is a schematic of the site. Experiment plots were square with side dimensions varying from 75m to 150m. Vegetation consisted of 12m tall Jack pine with a black spruce understory. The vegetation was approximately 65 years old. A 1 to 10cm thick duff layer covered the mineral soil. The location was selected for its uniformity of fuel and accessibility. Once the instruments were deployed the environmental conditions were monitored until the target conditions were met. The fires were ignited using a truck mounted flame thrower developed for prescribed burning. The general procedure was to ignite the windward edge of the plots. In

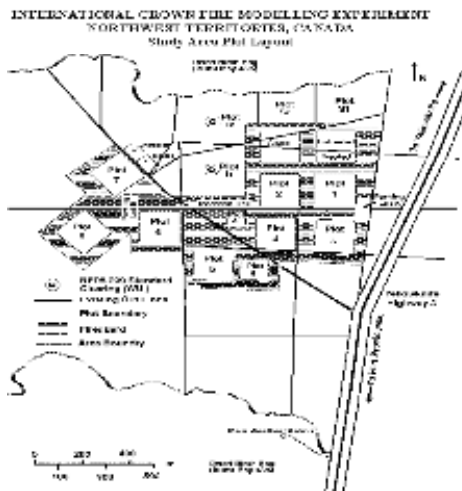


Figure 2—Schematic of experiment plots. This study focuses on data gathered from plots 1, 3, 4 and 9.

most cases the fire moved into the tree crowns within 15m of the ignition line.

The safety zone data were collected by deploying radiant heat flux sensors in the cleared area downwind of the fuel plot. Other sensors were deployed that measured air temperature, air velocity, radiant emission from the flames, and convective energy transfer, their data is reported elsewhere.

The safety zone sensors were located approximately 1.2m above the ground and were oriented with the sensing surface “facing” the approaching fire. The sensors used were of the Schmidt-Boelter thermopile design manufactured by Medtherm Corporation of Huntsville, Alabama USA. The sides and backs of the sensors were insulated with ceramic blanket material to reduce the effects of flame and solar heating.

Four plots were instrumented with safety zone instrumentation. Table 1 summarizes the conditions and fire behavior for each experiment.

Campbell Scientific CR-10X dataloggers collected the signals from the sensors at a rate of 1hz. The data were smoothed using a 10 second moving average. The peak incident radiant flux corresponding to each measurement location was selected from the smoothed data. The smoothed value was compared against the model. Figure 3 is a graph of a typical heat flux versus time signal and a smoothed trace. The rapid rise in measured flux is associated with the appearance of the flame through the intervening vegetation, followed by a peak and then rapid decline. Typical flaming combustion lasted approximately 30 seconds.

Safety zone measurements were conducted on plots 1, 3, 4 and 9. Wind

Table 1—Conditions and burning rates

Plot	Air Temp (C)	RH (%)	10m Wind Speed (km/h)	Rate of Spread (m/min)	Comments	Estimated Flame Height (m)
1	26	29	11	28	Fire did not reach leeward edge as uniform front.	17
3	31	23	11	24	Fire burned along one side only.	17
4	25	48	15	45	Fire burned center but not sides.	20
9	31	23	25	70	Fast burn, relatively uniform flame front.	30

speed, temperature, relative humidity, rate of spread of the fire, and estimated flame height are noted in Table 1.

Flame height is one of the primary factors affecting the amount of energy transferred ahead of the flames. For the purposes of this study, visual estimates of the flame height were made. These estimates were then applied to the model to predict the distribution of radiant energy ahead of the flame.

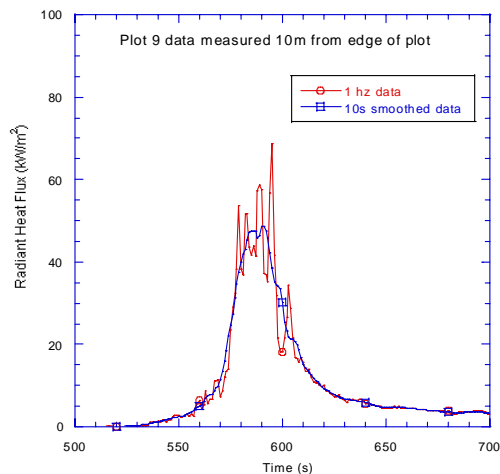


Figure 3— Thermal radiation measured at a location 10m from the downwind edge of Plot 9.

## Discussion

The safety zone model presented by Butler and Cohen (1998) assumes a constant flame temperature of 1200K

and a constant flame width of 20m. The model predicts the minimum distance between a firefighter and flame needed to prevent second degree injury through Nomex cloth as a function of flame height.

A comparison of model predictions against measured energy levels requires flame height information from the experiments. For these fires the vegetation height was approximately 12m. Figures 4-7 are photographs taken when the fire was burning along the downwind edge of the experiment plots. Using the vegetation height as a gauge, estimates of the height of the continuous flaming zone were made. These data are included in Table 1. Figure 8 graphically compares the predicted radiant energy flux profile versus the measured values. The separation distances shown in figure 8 are measured from the edge of the vegetation. The distances corresponding to the intersection of the horizontal solid black line at  $7 \text{ kW/m}^2$  and the lines of constant flame height are the predicted separation distances required to prevent injury.

It is clearly shown that the data from plots 1, 3 and 4 are relatively consistent with each other in the region from 25 to 50m from the flame. However as noted in Table 1. These data do not agree with the predicted radiant energy distribution based on the



Figure 4--Plot 1 fire. This fire was characterized by torching rather than a coherent uniformly spreading flame as a function of separation distance.



Figure 5--Plot 3 fire. Note that the fire is burning mostly on far right corner of the plot. The aluminum foil structures shown in the foreground are structure ignition sensor assemblies.



Figure 6--Plot 4 fire. Note that the fire has nearly reached the edge of the fuel and is not forming a uniform flame front.



Figure 7--Plot 9 fire. Note that the flames are relatively large and uniform. The flame height was visually estimated to be 30 m.

estimated flame heights. In fact the data most closely match the distribution for a 5m tall flame. The initial impression is that the model overpredicts the distribution of radiant energy. The lack of agreement between the measured and predicted profiles shown in figure 8 is not encouraging.

We believe that the disparity between the measured and predicted profiles can be explained by differences between the model assumptions and the actual flame size and behavior. The model presented by Butler and Cohen (1998) assumes that the flame is a uniformly radiating source of constant temperature and height and is 20m wide. Photographs taken of the fires in plots 1, 3 and 4 indicated an approximate flame height of 17 to 20m. Observers who watched the fires burn through these plots noted that when the fires reached the back edge of these plots, it did so along limited areas. Some of this behavior is shown in Figures 4-6 where flames are observed adjacent to unburned trees. Figures 4-6 indicate that in general the fire did not exit plots 1, 3 and 4 as uniform front. In our opinion this was caused by the lack of alignment between the principle axes of the plots

and the wind direction. Plots 1, 3, and 4 were oriented along north-south and east-west coordinates. Plots 1 and 3 were ignited under the influence of a quartering wind, the wind pushed the fire toward one corner of the plot. This resulted in a flame at the downwind edge of the plot that was much narrower than the actual width of the plot.

In the case of plots 1, 3 and 4 the lack of agreement between the model and measurements is attributed to the nonuniformity and narrow width of the fires as they exited the leeward edge of the plot. In support of this argument the authors note that the measured data compare very well against the predicted profile corresponding to a 5m flame height. Mathematically speaking, there is very little difference in terms of radiated energy between a flame that is 20m wide and 5m tall and another that is 5m wide and 20m tall. Therefore if one supposes that the 5m profile also represents a flame 20m tall and 5m wide then the data actually support the assumption that the flames exiting plots 1, 3 and 4 were very narrow (i.e. about 5 m wide and 20m tall).

Examination of the data collected from plots 4 and 9 indicate that for distances relatively close to the flames (within about 20m) the model agrees relatively well with the data in the 10-20m range but the underpredicts the radiant flux within 10m. Video footage of the plot 9 fire indicates that the flames moved out the downwind edge of plot 9 a distance of more than 10m into the fire break. This convection of the flame into the fire break is one possible cause of the of the high measured radiant energy fluxes.

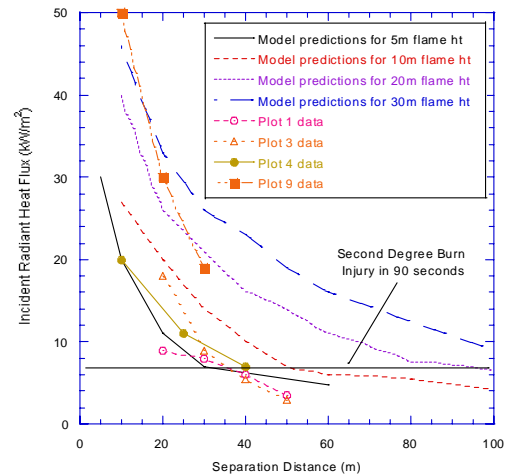


Figure 8—Predicted and measured distribution of thermal radiation ahead of a spreading flame front. The solid lines represent predicted values and the symbols and dashed lines represent measured values.

## Conclusions

The theoretical model of radiant energy distribution in front of a solid flame was compared against measured values of the incident radiant energy. The model assumes an isothermal radiating source 20m wide. In general the shape of the measured flux distribution agrees reasonably well with that from the model. While there is a definite disparity between the measured and predicted flux distributions, the authors attribute these to differences between the assumed and actual values of flame width and height.

The model underpredicts the experimentally measured incident radiant energy within 10m of the flame front, this has been attributed to advection of the flames into the fire break area. The disparity between the data from plots 1, 3 and 4 and the predicted profiles can be attributed to the discontinuity in the flame as it reached the downwind edge of the plots. The

result was a narrow radiator than that assumed in the model. These data suggest that predictions assuming a narrower flame front would improve the agreement between the measured and predicted fluxes for these fires.

The authors believe that at this time there is no compelling reason to change the suggested rule of thumb that safety zones be large enough to provide a minimum separation distance between the firefighters and fire equal to 4 times the maximum flame height for the current and expected fuel and environmental conditions.

These data provide a quantitative measurement of the duration and range of intensities that can be expected in crown fires burning through 12m tall forests. The data also are indicative of the variability that can be expected in field experiments, even when conducted under relatively uniform conditions.

The instruments developed for this study provide a relatively robust method for quantifying the thermal environment in and around high intensity flames.

## **References**

Butler, B.W. and J.D. Cohen. Firefighter Safety Zones: A Theoretical Model Based on Radiative Heating. *Int. J. Wildland Fire* 8(2):73-77, 1998.

Alexander, M.E.; B.J. Stocks, B.M. Wotton, M.D. Flannigan, J.B. Todd, B.W. Butler, R.A. Lanoville. The International Crown Fire Modelling Experiment: An Overview and Progress Report. Second Symp. on Fire and For. Met., 11-16 January 1998, Phoenix, AZ, by the American Meteorological Society, Boston, MA. Pages: 20-23

Alexander, M.E.; R.A. Lanoville; B.M. Wotton, B.J. Stocks. An Introduction to the International Crown Fire Modelling Experiment. In proceedings of 2000 Wildland Firefighter Safety Summit, International Association of Wildland Fire, Edmonton, Alberta Canada, October 10-12, 2000.