Nenana Ridge Fire Behavior Report

B. Butler, D. Jimenez, P. Sopko, K. Shannon, and J. Forthofer

US Forest Service, Rocky Mountain Research Station, 5775 Hwy 10 W, Missoula, MT 59808

Introduction

Concerns about a growing wildland-urban interface (WUI) and the potential for forest fires to burn homes and impact other resources have pushed wildland fire risk mitigation strategies to the forefront of fire management activities. Mechanical (e.g., shearblading) and manual (e.g., thinning) fuel treatments have become the preferred strategy of many fire managers and agencies. However, few observations exist that document the actual effect of different fuel treatments on fire behavior. Scientists, engineers and foresters from RMRS Fire Fuels and Smoke program have been working closely with scientists from PNW station, the University of Alaska in Fairbanks, the Alaska Fire Service and local land managers to measure the effect of different treatments on fire behavior. A research prescribed burn was conducted in June of 2009 as part of this study. Here we report the results of the fire behavior measurements that were conducted as part of this burn.

Methods

The study site represents an ideal location because of its proximity to Fairbanks, existing road network, large area (550 acres) of homogenous fuels, and a current burn plan available for amendment. Two burn units were identified, labels Unit A and Unit B. Within each unit, four fuel treatment plots were constructed. They consisted of 8 x 8 ft thinnings pruned to 4 ft under two fuel removal strategies: (1) haul away and (2) burn piles on site. In addition, two shearblade treatments; with and without windrowing of debris were prepared. The units are shown in figure 1. The units and associated sensors are identified in table 1 and figure 2.

Our primary objective was to characterize fire behavior using temperature and energy sensors located in and around the burn area. Two fire proof systems were deployed: 1) the Fire Behavior Package (FBP) and 2) the in-fire video system. The FBP contains a fine gauge type K thermocouple to sense air kinetic temperature, a narrow angle radiometer that senses radiosity of the flames in the field of view, a hemispherical heat sensor that senses both total and radiant energy flux incident on the surface of the sensor, and horizontal and vertical flow sensors. The digital video cameras are housed in fire resistant cases and can be triggered by a wireless signal from the FBP initiated by heating on the sensors. Images from the cameras can be used to characterize fire behavior in terms of flame geometry, flame rate of spread, and local burning properties.

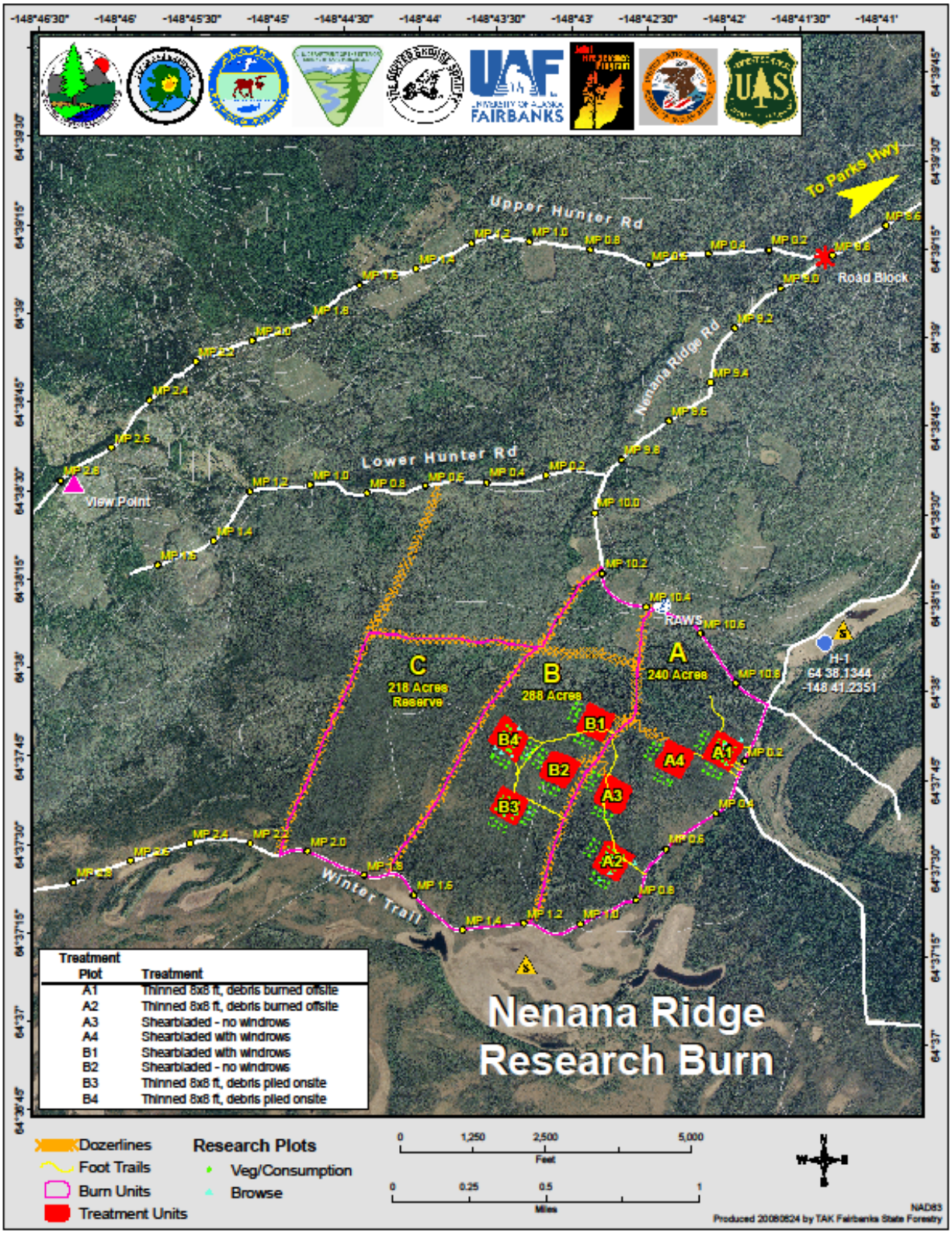


Figure 1--Burn layout and treatment map.

Table 1—Description of distribution of sensors and cameras and burn notes.

Unit	Treatment	Sensor Box #	Camera #	General location	Notes
A-1	Thinned and burned offsite	1, 6, 13	1, 8, 9	In unit	Sensor #1 failed, 13 did not trigger, 6 did not see any significant fire. Fire burned up to edge of treatment.
A-1 control		4, 14	10, 13	South of unit	Max temp >1150C, 240kW/m^2
A-2	Thin and burned offsite	7, 9, 10	11, 14	In unit	Only sensor 10 recorded heating from local ping pong ball ignition.
A-2 control		8, 12	4, 5	South of unit	Did not burn-no data or video
A-3	Shearblade no windrows	5	6	In unit	Very low intensity burn
A-4	Shearblade w/ windrows	2	2	In unit	Very low intensity

Fire behavior sensors and in-fire video recorders were deployed as shown in figure 2. The approximate location of the sensors and cameras are shown. A detailed description of the sensors and cameras is included in Appendix B.

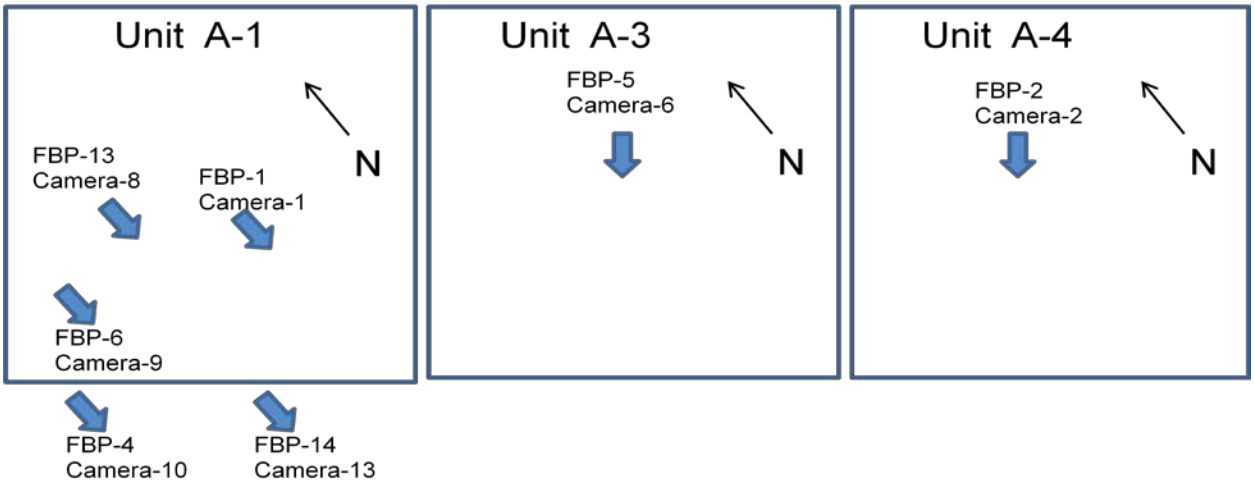


Figure 2--Layout of sensors in burn units.

Results

Table 2 summarizes the data collected by the sensors. A detailed presentation of all data is provided in Appendix A. Fire intensity can be measured using several metrics. They include maximum air temperature, maximum energy flux, heating period (time that temperature spikes above 50 deg C occurred), cumulative fire radiative and total energy (over the heating time), flame length, and fire rate of spread (from evaluation of video images). We attempt to present all of these metrics for each sensor location that saw fire.

Table 2—Summary of measured quantities

Unit	Heating time (s)	Cumulative total energy load (J)	Max Temperature (C)	Peak total heating flux (kW/m^2)	Flame Length (m)	Fire Rate of Spread (m/s)
A-1	1100	600	71	2.2	N/A	N/A
A-1 control sensor 4/14	380/450	5105/3450	1150/780	227/50	8-11m	0.6m/s
A-2	510	2600	267	16	0.6m	0.1-0.3m/s
A-3	4100	2500	170	51	0.3m	N/A
A-4	5300	1800	66	3	N/A	N/A

Helicopter ping-pong ignition was initiated at approximately 1400 hours local time. Ignition followed a roughly head strip fire moving from South to North along East/West aligned lines. Ambient temperature was 25 C and relative humidity 26 %. The ignition began at the southern edge of the A block. Unfortunately the Block did not burn uniformly (figure 3). The southern half did not burn as completely as the Northern half.

Unit A-1 was a thinned treatment. It contained three fire behavior sensors and three in-fire video cameras. One sensor package failed and a second did not see high enough energy to begin recording data. The third recorded a maximum heat flux of 2.2 kW/m^2 and maximum temperature of 71 C. The heating time was 1100 seconds with a cumulative total energy of 600 J. Evaluation of the video indicated that the fire spread with very low intensity up to the edge of the treatment but very little fire spread occurred in the treated unit, thus no flames were detected. The heating would have been generated by the fire that burned up to the edge of the treatment.

Figure 3--Photo of block A burn pattern, camera looking north from south of block.

The highest fire intensities were found in the untreated control south of Unit A-1. This location recorded maximum flame temperatures as high as 1150 C and peak total energy fluxes of 227kW/m^2. Figure 4 presents the temperature and heat flux time history for this location. The heating period was relative short (approximately 400 seconds) and the cumulative total energy release averaged 4277 J between the two sensors. Flames were 8 to 11m tall, burning through the entire forest canopy of Black Spruce at a nominal spread rate of 0.6m/s.

Unit A-2, a thinned treatment, contained three sensor arrays but did not see consistent fire. Only the easternmost sensor recorded any fire and it was a flanking fire that from the video seemed to originate solely from an ignited ping pong ball. The resultant fire was localized in the vicinity of the FBP and camera. Heating time was 510 s, cumulative total energy release was 2600 J, peak air temperature was 267 C and peak total heat flux was 16 kW/m^2. Flame length was 0.6 m and fire rate of spread was 0.1-0.3m/s.

Unit A-3 contained a shearblade treatment with no windrows. One sensor array was deployed near the center of the unit. This sensor recorded fire in the area for 4100 s with a cumulative total energy release of 2500 J. The peak measured air temperature was 170 C and the peak total heat flux was 51 kW/m^2. Flame lengths were 0.3m in the distributed slash located near an

FBP. No clear fire rate of spread was detected as the fuels were disbursed and did not burn as a uniform front.

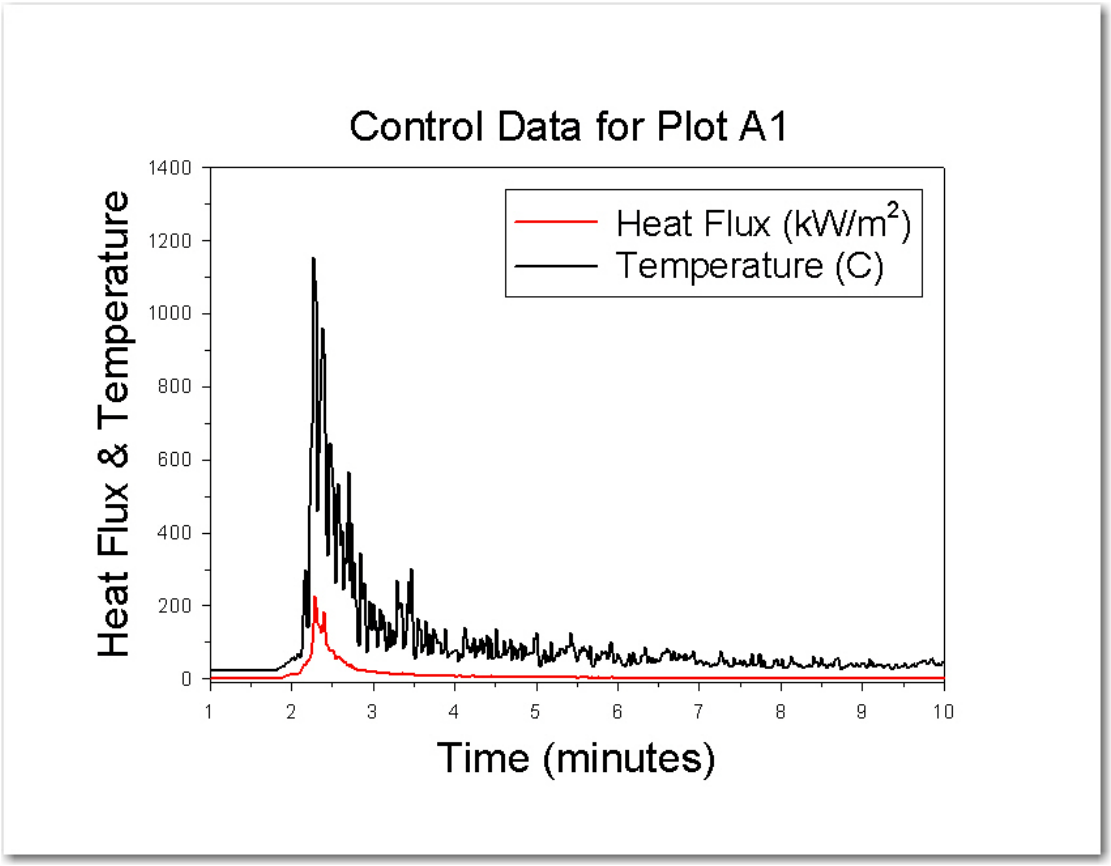


Figure 4--Temperature and heat flux data from unit A-1

Unit A-4 was a shearblade treatment with fuels disbursed in windrows. One sensor array was placed in the center of the unit. This location depicted the presence of fire for 5300 s and a total cumulative energy load of 1800 J but low maximum air temperature of 66 C and minimal total energy flux of 3 kW/m^2. No clear flame length or rate of spread was detected. The post burn inspection indicates that the windrows in the unit did not burn completely. The low energy levels were likely due to the burning of slash windrows in a nonuniform low intensity pattern and to energy emitted from the crown fire at the edge of the treatment unit.

Discussion

The primary objective of the project was to characterize the effectiveness of the treatments in reducing fire intensity. All treatments that burned resulted in significant reductions in fire

intensity. Averaging the results from A-1 and A-2 suggests that the thin and burn treatments resulted in the lowest heating time and cumulative energy load. Air temperatures and incident peak energy fluxes were substantially below the ignition threshold of 300 C and 20 kW/m^2. It appears that one effect of the shearblade treatments was the development of slash piles that resulted in long duration albeit low intensity burning. The A-3 treatment resulted in fire intensities that exceeded the generally held 20 kW/m^2 ignition threshold although only for a few seconds (figure 5). As shown in figure 3 Unit A-3 exhibited broad scale burning as indicated by the extensive charring while the windrows in Unit A-4 did not burn as completely.

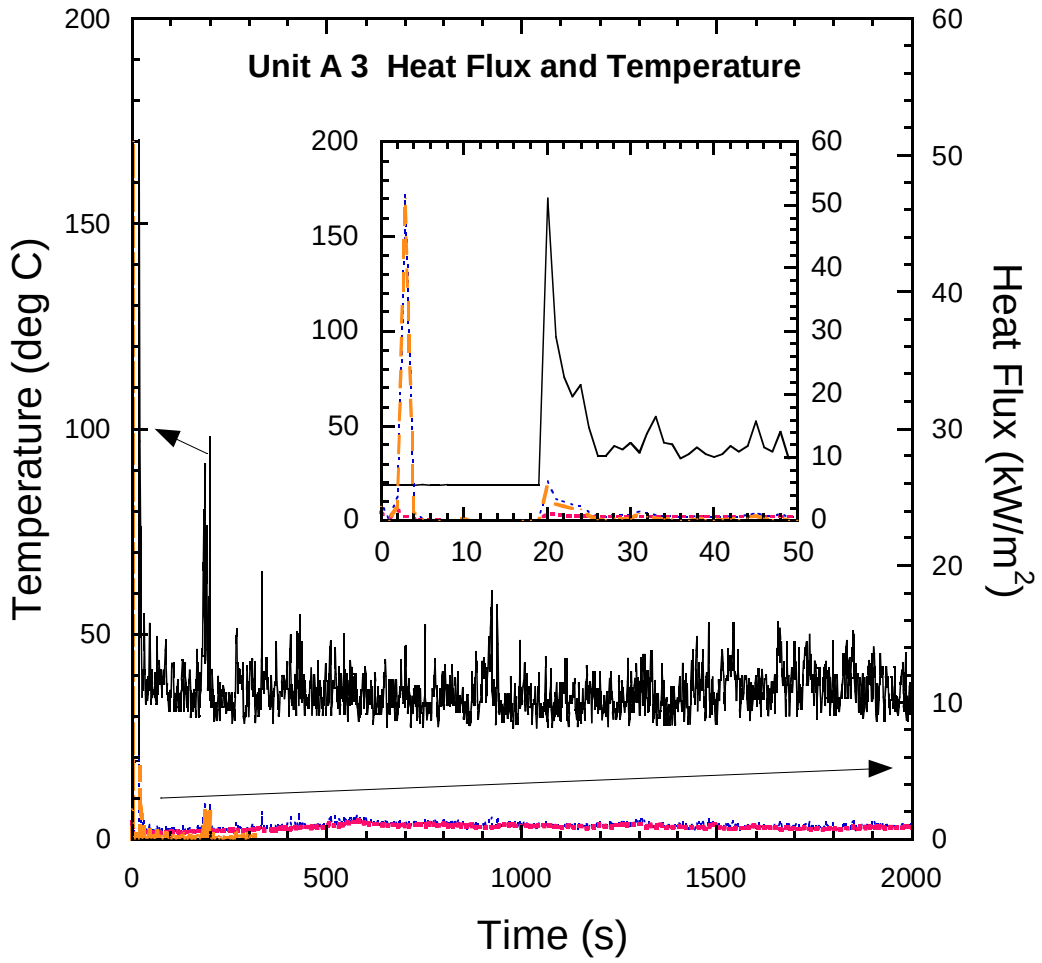


Figure 5--Temperature and heat flux data from Unit A-3

Comparison between the A-1 treatment and the control as presented in Figure 6. As shown the fire behavior in the treatment was effectively zero.

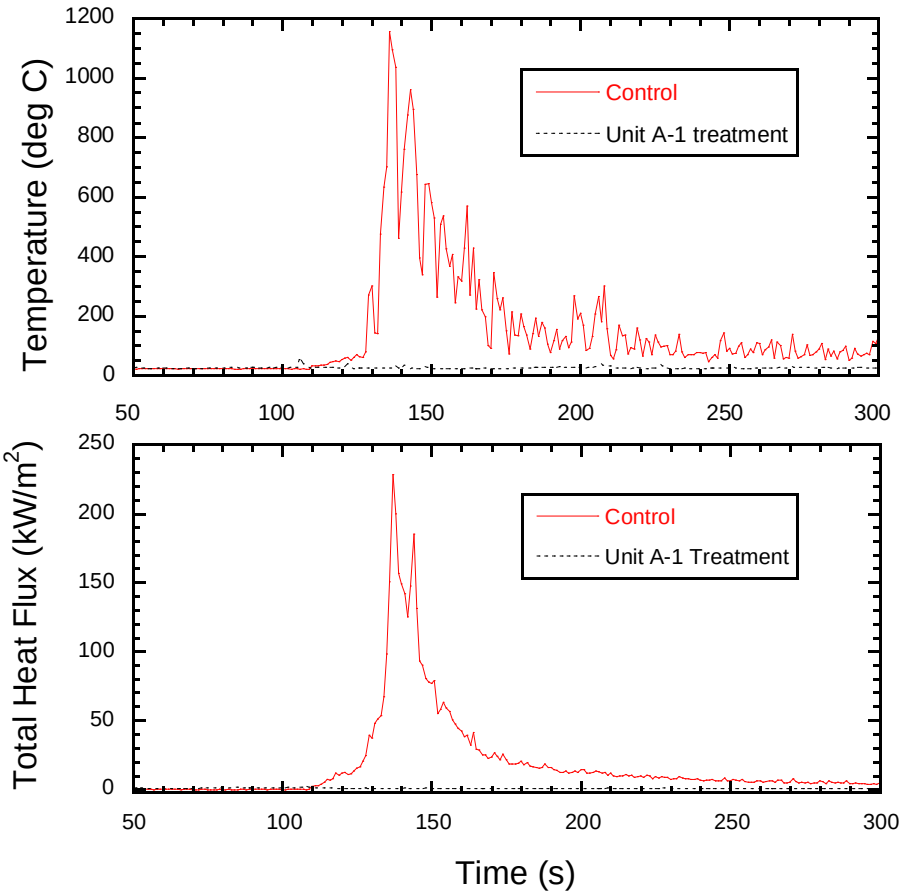


Figure 6--Comparison of heating and temperature data from A-1 treatment and control.

It is unclear what effect a dry season wildland fire will have on the results presented. It is possible that in a dry season significantly higher fire intensity will occur in the thin and burn units. However, similar increases in fire behavior could also occur in the shearblade treatment due to the high grass loading that seemed to be developing.

Conclusions

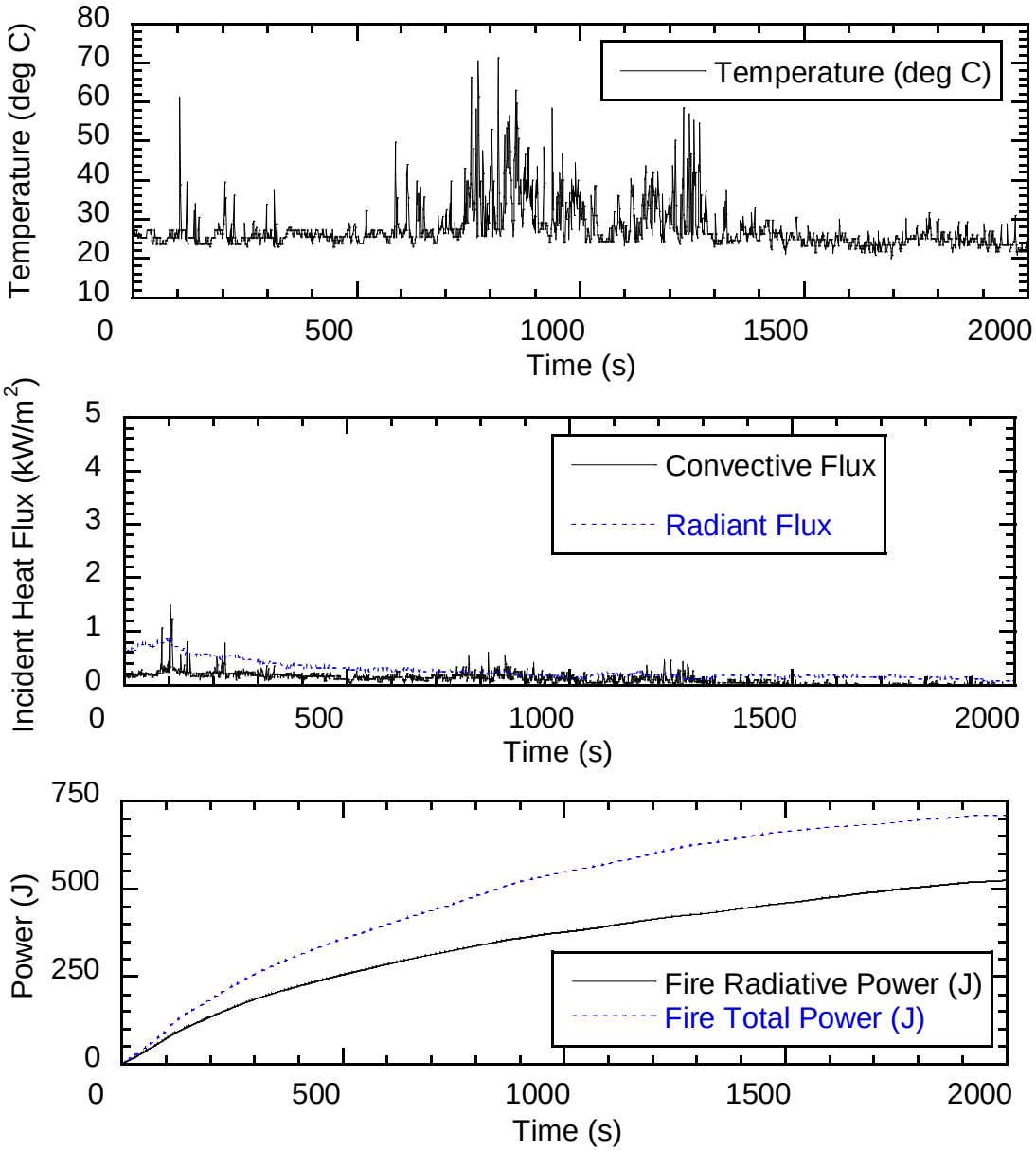
All three treatments that burned resulted in significant reductions in fire intensity. While any conclusions from a single data point cannot be conclusive the data suggest that the thin and burn treatments result in substantial reduction in burning time and total cumulative heating energy. If low air temperatures are the desired condition then the shearblade treatments is the most effective, if reduction in peak heating rate or flux is the desired condition then the thin and burn treatments are best. Ignition and flame spread process is complex, but occurs through the presence of flames in the location of unburned but heated fuels. Thus it seems

that the most effective deterrent to fire burning across a treatment unit would result from reduction in heating rate as indicated in the thin and burn treatment.

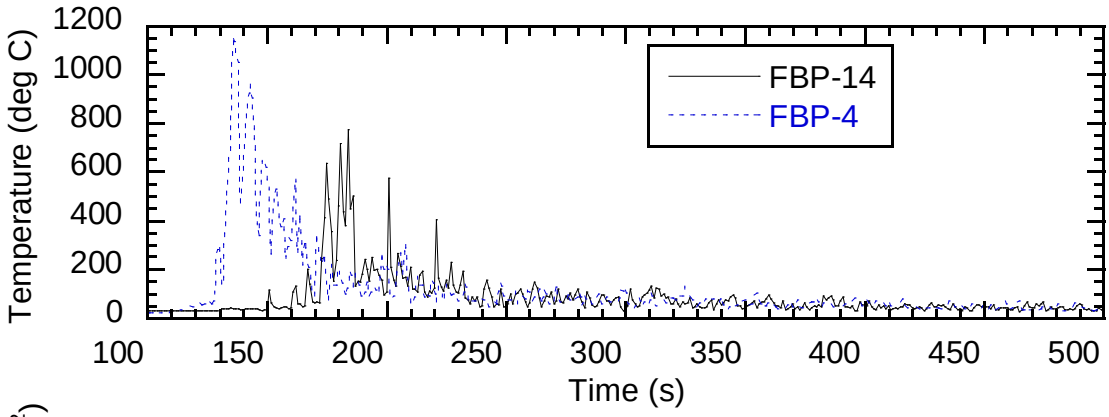
Acknowledgements

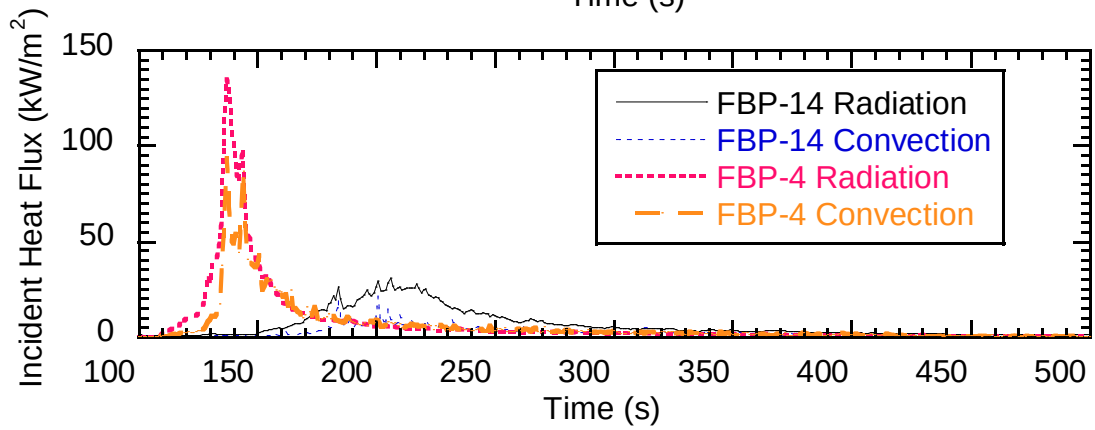
This research could not have been accomplished without the financial support of the Joint Fire Science Program. The Alaska Fire Service, The University of Alaska Fairbanks, and the Alaska Division of Forestry provided significant logistical and programmatical support for the study.

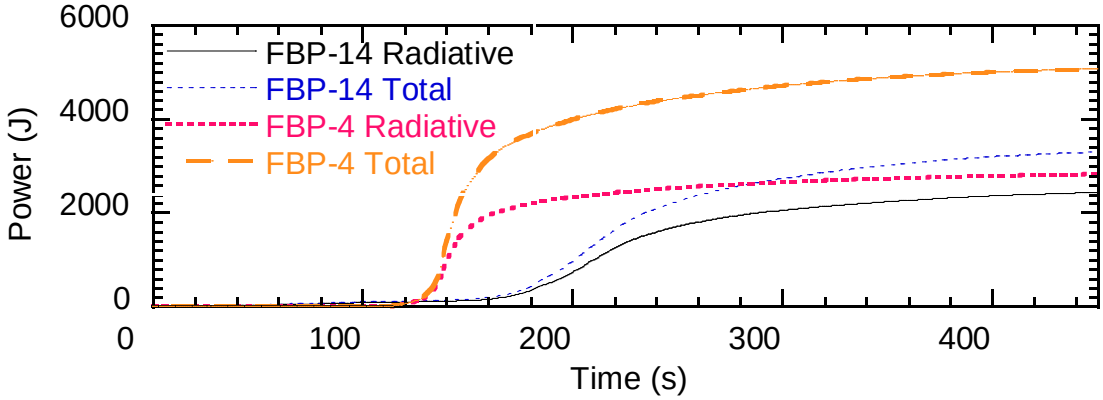
Unit A-1 treatment



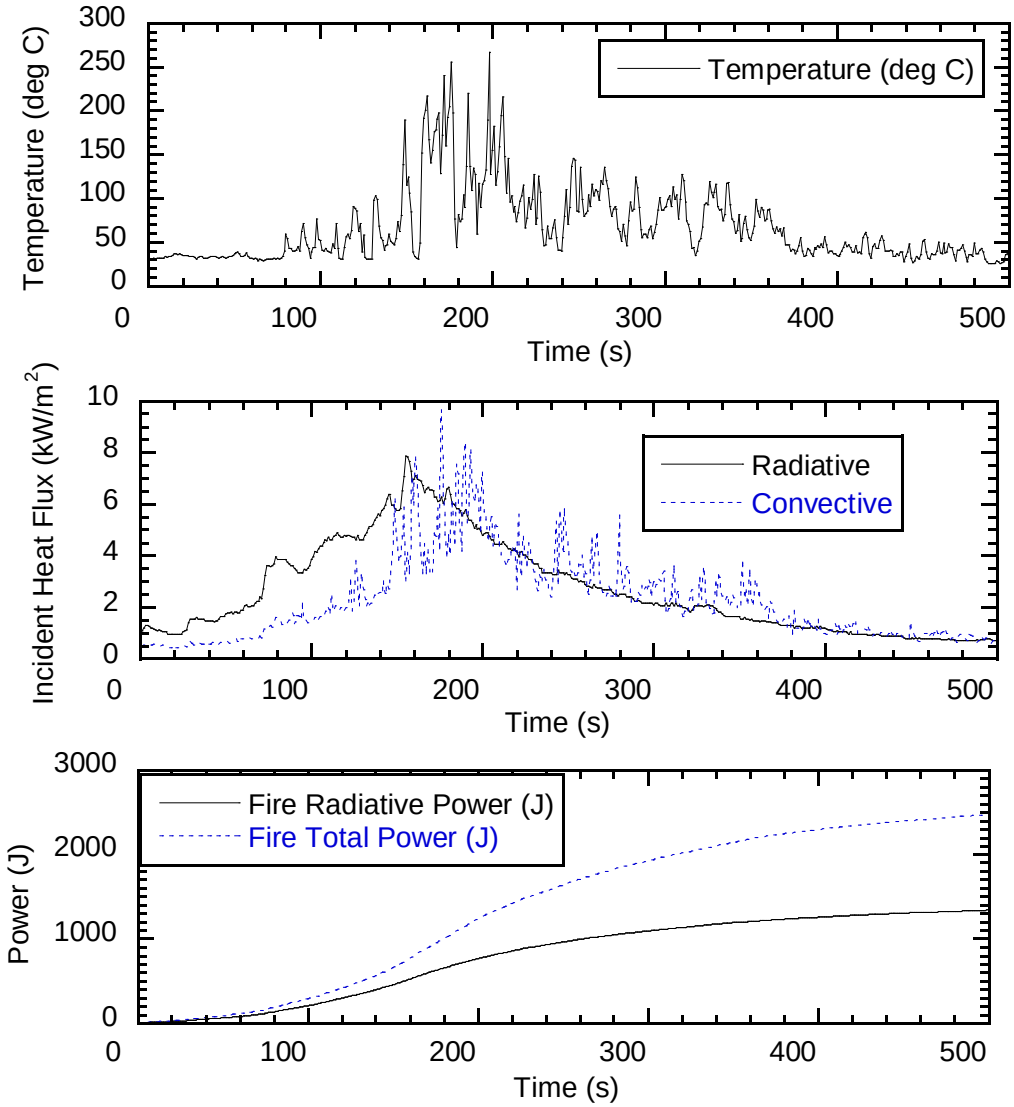
Unit A-1 Control



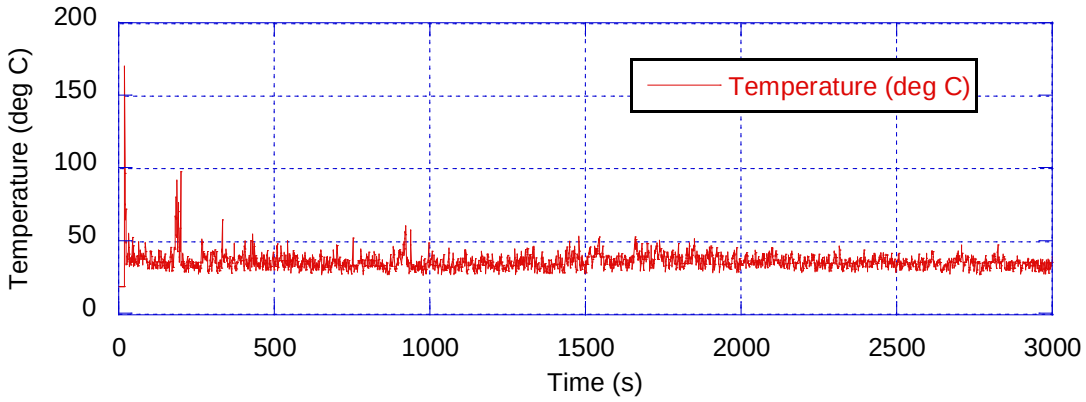


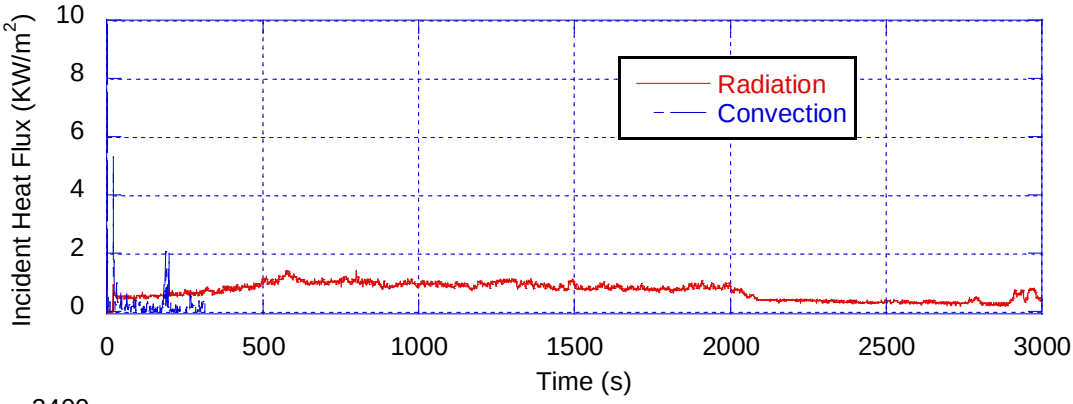


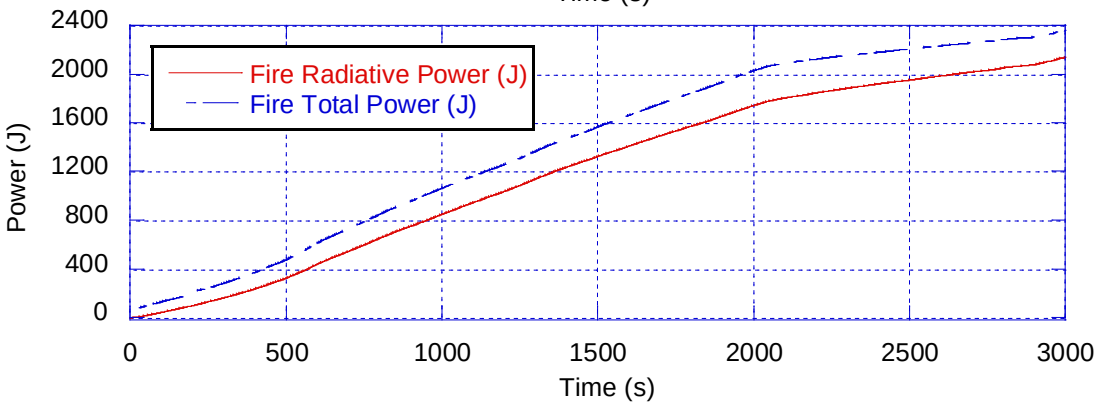
Unit A-2


Temperature (deg C)
Temperature (deg C)
Time (s)
Incident Heat Flux (kW/m2)
Radiative
Convective
Time (s)
Power (J)
Fire Radiative Power (J)
Fire Total Power (J)
Time (s)

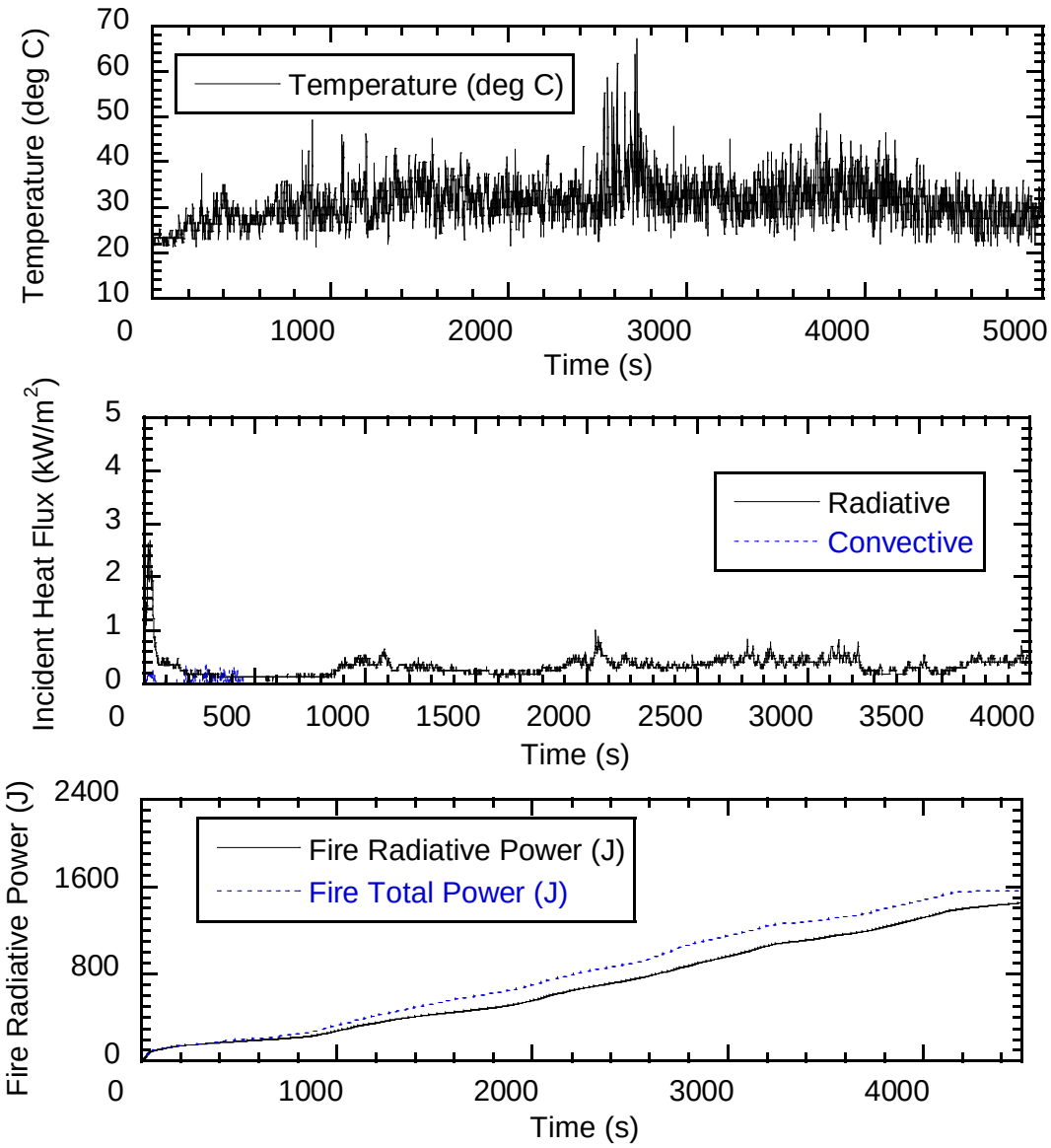
Unit A-3


Temperature (deg C)
Temperature (deg C)
200
150
100
50
0
0
500
1000
1500
2000
2500
3000
Time (s)


Incident Heat Flux (KW/m2)
Radiation
Convection
10
8
6
4
2
0
0
500
1000
1500
2000
2500
3000
Time (s)


Power (J)
Fire Radiative Power (J)
Fire Total Power (J)
2400
2000
1600
1200
800
400
0
0
500
1000
1500
2000
2500
3000
Time (s)

Unit A-4


Temperature (deg C)
Temperature (deg C)
Time (s)
Incident Heat Flux (kW/m2)
Radiative
Convective
Time (s)
Fire Radiative Power (J)
Fire Radiative Power (J)
Fire Total Power (J)
Time (s)

Sensor System: The system consists of two enclosures: The sensor/data logger package is termed the Fire Behavior Flux Package (FBP). It measures 27 cm by 15 cm by 18 cm and in its current configuration weighs approximately 5.3 kg (fig. B-1). Various enclosure materials have been used from mild steel, stainless steel and aluminum, the latest design consists of 3.7mm thick aluminum welded at the seams. A 12 volt 2.2Ah sealed lead acid battery or 8 AA dry cells provide power to the logger. A separate 8 AA dry cell battery array provides power for the flow sensors. Wiring and circuit diagrams can be found at www.firelab.org

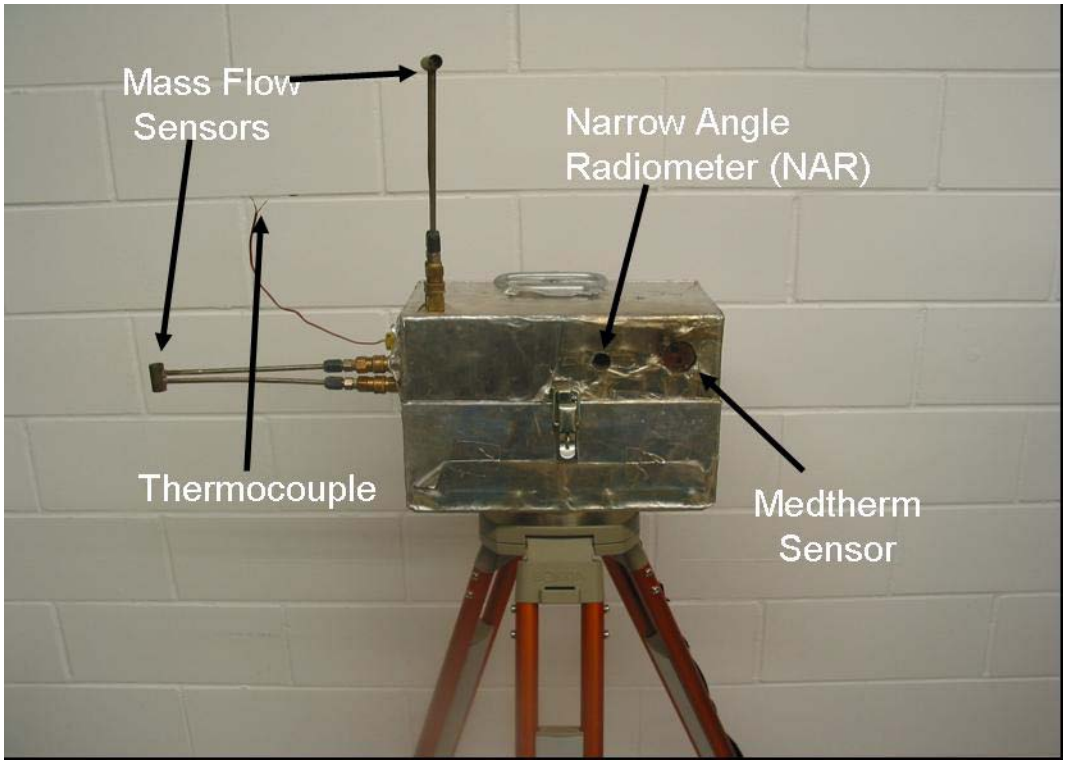


Figure B-1 Image of Fire Behavior Package.

The dataloggers used are Campbell Scientific® model CR1000. The dataloggers are capable of logging over one million samples, providing 20 hours of continuous data logging. This logger is user-programmable and accepts a wide range of analog and digital inputs and digital output. It is thermally stable and has been relatively insensitive to damage incurred in shipping and handling. Alternative and lower cost dataloggers are available but generally do not have all of the features found in the aforementioned. The standard sensors consist of a Medtherm® Dual Sensor Heat Flux sensor (Model 64-20T). These sensors provide incident total and radiant energy flux, a type K fine wire thermocouple (nominally 0.13 mm diameter wire), a custom designed narrow angle radiometer (Butler, 1993), and two pressure based flow sensors (McCaffrey and Heskestad, 1976). Table B-1 provides details about individual sensors and their engineering specifications.

Table B-1. ***Insitu* Fire Behavior Package (FBP) Specifications**

Narrow Angle Radiometer	
Sensor	20-40 element thermopile
Spectral Band of Sensor	0.15 – 7.0 µm with sapphire window
Field of View	~4.5º controlled by aperture in sensor housing
Transient Response	Time constant of sensor nominally 30msec
Units of Measurement	Calibrated to provide emissive power of volume in FOV in kW-m^{-2}
Total Energy Sensor	Medtherm Corp® Model 64-20T Dual total Heat Flux Sensor/Radiometer
Sensor	Schmidt-Boelter Thermopile
Spectral Band of Sensor	All incident thermal energy
Field of View	~130º controlled by aperture in sensor housing
Transient Response	< 290msec
Units of Measurement	Total heat flux incident on sensor face in kW-m^{-2}
Hemispherical Radiometer	Medtherm Corp® Model 64-20T Dual total Heat Flux Sensor/Radiometer
Sensor	Schmidt-Boelter Thermopile (Medtherm Inc)
Spectral Band of Sensor	0.15 – 7.0 µm with sapphire window
Field of View	~130º controlled by window aperture
Transient Response	< 290msec
Units of Measurement	Radiant energy incident on sensor face in kW-m^{-2}
Air Temperature	
Sensor	Type K bare wire butt welded thermocouple, new, shiny, connected to 27ga lead wire
Wire Diameter	0.13mm
Bead Diameter	~0.16-0.20mm
Units of Measurement	Degrees Celsius
Air Mass Flow	
Sensor	SDXL005D4 temperature compensated differential pressure sensor
Pressure Range	0-5 in H_2O
Sensor Design	Pressure sensor is coupled to custom designed bidirectional probe with ±60º directional sensitivity.
Units of Measurement	Calibrated to convert dynamic pressure to velocity in m-s^{-1} assuming incompressible flow
Sensor Housing Dimensions	150× 180 × 270 (mm)
Housing Weight	7.7 kg
Insulation Material	Cotronics Corp® 2.5cm thick ceramic blanket
Tripod Mount	½ inch female NCT fitting permantly mounted to base of enclosure.
Power Requirements	12V DC
Power Supply	Rechargeable Internal Battery
Data Logging	Campbell Scientific Model CR1000
Sampling Frequency	Variable but generally set at 1 Hz
File Format	ASCII

The second part of the system is a fire proof enclosure housing a video camera and is termed the In-situ Video Camera (IVC). The IVC measures 10 cm by 18 cm by 19 cm and is constructed of 1.6 mm aluminum for a weight of approximately 1.8 kg (fig. B-2). The front of the IVC has a two circular

windows nominally 45 and 20 mm in diameter. A double lens configuration of high temperature pyrex glass and a second lens of hot mirror coated glass (Edmund Optics) is mounted in the ports. This multi-layer dielectric coating reflects harmful infrared radiation (heat), while allowing visible light to pass through. The cameras can either be turned on manually or can be set to trigger and record through a wireless link to the FBP data loggers (Jimenez, et al. 2007). The wireless trigger is based on the SONY proprietary LANC technology, thus only SONY cameras are compatible with the automatic trigger system. The preferred model is the SONY PC-1000 HandyCam digital video camera; however other models can be substituted. These cameras were chosen for their relatively high quality construction, image quality, and reliability. The system allows users to trigger the recording mechanism of the camcorder remotely by using its own unique internal computer source code. Radio frequency was chosen over Infra Red (IR) technology due primarily to line-of-sight and interfering reflectance issues. Once the FBP and IVC boxes are deployed the trigger system is armed from readily accessible switches in the respective enclosures.

Figure B-2 Insitu video camera system.

The enclosures are designed to be mounted on low cost tripods. Thin wall galvanized 2.5 cm diameter mild steel pipe presents an optimum design in terms of weight to thermal resistance. The tripods typically have one extendable leg to facilitate deployment on slopes. Once mounted on the tripods the

FBP and IVC are powered up, and a single layer of 2.5 cm thick ceramic blanket is wrapped around the box. The ceramic blanket is enclosed in a single layer of fiberglass reinforced aluminum foil.

The FBP enclosures can be constructed for approximately $500 USD per box plus cost of data loggers, and sensors. The IVC enclosures can be constructed for $700 USD per box plus cost of cameras.

The system has been used extensively in full scale wildland fires. Analysis of the visual video images provides an objective method for measuring flame height, flame length, flame depth, flame angle and fire rate of spread. Typically each FBP is coupled with an IVC for simultaneous recording of video and in-situ measurements allowing researchers to better evaluate fire behavior measurements relative to flame size and local spread rate. Provided that a calibration object is in the camera field-of-view estimates of flame height, depth, angle and fire rate of spread can be acquired for the video record. The result is a system that is not only robust, but also easy to operate, simple to deploy, fire proof, and light weight.

The packages are typically deployed so that the sensors are directed towards the oncoming fire front and arranged so that most often an FBP and IVC are deployed in pairs. The FBP is oriented to “look” at the expected fire approach direction, while the IVC is positioned to image both the FBP and approaching fire front (fig. B-3 and B-4). The FBP and IVC’s are mounted on tripods, the cameras are powered up, and they are positioned. The FBP’s have LED’s to indicate that the logger is indeed running, the IVC’s also have an LED to indicate that they are running and have entered “sleep” mode if they are used with the remote automatic trigger system.

Figure B-3 Insitu video camera system on tripod in low intensity fire in Long Leaf Pine forest.

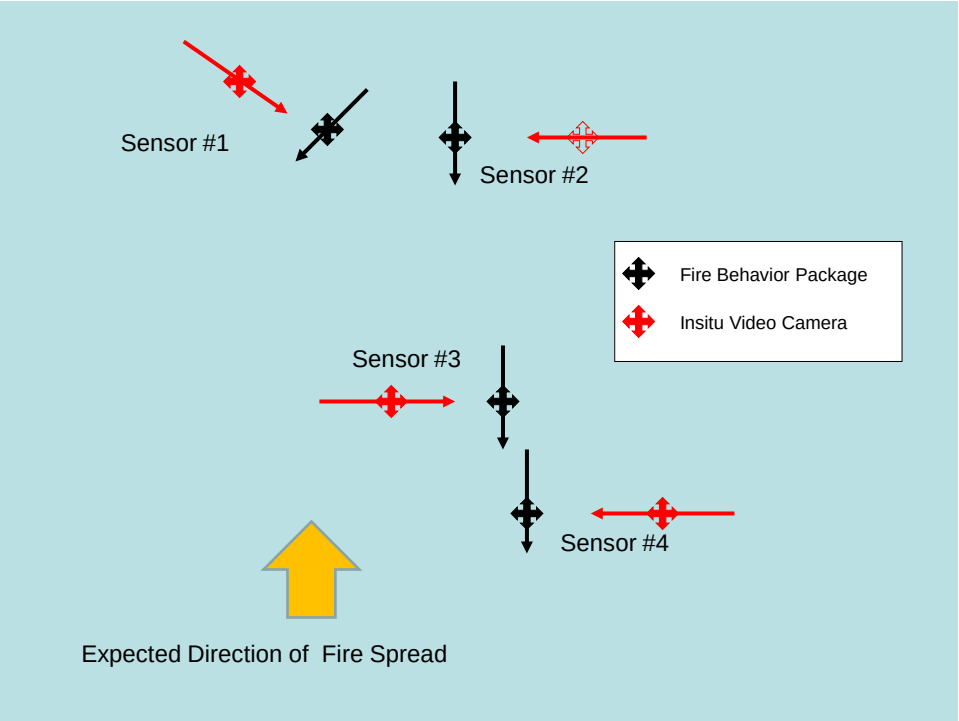


Figure B-4 Typical instrument layout.

After the enclosures are mounted, positioned and "turned on" a GPS position is recorded for each, including reference orientation (compass direction), height above the ground, and any other local vegetation, or environment information deemed relevant. The insulation is then installed.

Due to the automatic trigger system the sensors can be deployed hours or days ahead of the expected arrival of the fire. However, if the system is exposed to precipitation or significant moisture there is the possibility that moisture could affect the transmission properties of the radiometer window and pressure ports on the flow sensors.

At the completion of a burn, the research team carefully records evidence of burning around the sensors, the condition and consumption of fuels, and any other pertinent information. The sensors are then turned off and transported to a secure location. At that point the data is downloaded from the loggers and they can be reset for a subsequent deployment.