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"SLASH FIRE INTENSITY AND SMOKE EMISSIONS"[1/]

by

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A program of laboratory burning experiments was carried out to assess the air pollutant emissions potential of forest residues in the Pacific Northwest. The emphasis was on measuring particulate emission factors and their relation to fire intensity.

The fine fuel (<3 inch diameter) component of slash fuelbeds was burned in special laboratories at the University of Washington and the University of California, Riverside.

Particulate emissions from 13 Ponderosa pine fuelbeds averaged 12.5 pounds per ton of fuel burned. Hydrocarbon emissions averaged 12 lb/ton and carbon monoxide emissions averaged 195 lb/ton from 10 Ponderosa pine fuelbeds.

Particulate emissions from 23 fuelbeds of Douglas-fir slash without needles averaged 6 lb/ton of fuel burned. Six fuelbeds with needles as well as twigs and branches released 24 lb/ton.

A sampling period emission factor for particulates was calculated for each filter period at the UW laboratory, by measuring the filter mat weight gain and the dry fuel weight loss. A 20-second period emission factor for hydrocarbons and carbon monoxide was measured from the pine fuelbeds at Riverside.

In all cases, the period emission factors were approximately inversely proportional to the rate of fuel consumption. Fuelbed or fire management techniques that would double the average fire intensity of a residue reduction burn would apparently reduce pollutant emissions by one-half.

1/ Presented to the Third National Conference on Fire and Forest Meteorology of the American Meterological Society and the Society of American Foresters, April 2-4, 1974, at Lake Tahoe, California-Nevada.

INTRODUCTION

A program of laboratory burning experiments was carried out to assess the atmospheric emissions potential of some forest residues of the Pacific Northwest. The fine fuel (<3 inch diameter) component of Ponderosa pine slash, Douglas-fir slash with needles, and Douglas-fir slash without needles was burned in special laboratories at the University of California, Riverside, and the University of Washington, Seattle.

The experiment at Riverside was done with Dr. S. G. Pickford of the U. S. Forest Service PNW Experiment Station and Dr. E. F. Darley of the California Statewide Air Pollution Research Center, and was the pilot effort for the larger experiment in Seattle. This research was part of the dissertation research of the author.

OBJECTIVES

The objectives of the research were to:

1) Measure particulate emission factors for three typical Northwest slash fuelbeds. Previous published emission factors represent open burning of other debris, with their use extrapolated to forest burning.

2) Measure the emission factors for carbon monoxide and total hydrocarbon gases from the laboratory burning of Ponderosa pine slash fuelbeds.

3) Describe empirically the relationship between the fire intensity of the laboratory fuelbeds and the quantity of emissions released. The effect of fire or fuelbed management techniques on the emissions potential can be predicted if this relationship is known.

METHODS

Burning methods were similar at the two laboratories. The size distribution and arrangement of fuels resembled, as nearly as practical, typical slash fuelbeds. Fine fuel loadings ranged from 28 to 50 tons per acre. Fuelbeds with needles included an average 12% needles, by weight. The full perimeter of each fuelbed was ignited with a propane torch, then allowed to burn freely until fuel weight loss ceased. Fire intensity was derived from the rate of fuel weight loss rate by assuming heat of combustion equalled 8000 BTU/pound.

Three phases of fire behavior were identified and used to stratify other data:

1) Smouldering -- a glowing fuelbed with no visible flame.
2) Flaming -- a fuelbed with fire intensity not dominated by burning needles, and
3) Needle dominated flaming

Smoke was contained in a steel flue and a constant proportion removed isokinetically. Particulates were removed by filtration with a Gelman Type A glass fiber filter at 100° F and a face velocity of 1 ft/sce. Gases were measured by infrared absorption.

Emissions were expressed as the weight of pollutant released per ton of fuel weight burned. Emission factors were measured for the total fire duration and also for each plume sampling periods. Sampling period emission factors represented 20-second to 30-minute sampling periods.

Figure 1 is an example of the fire intensity and emissions measured for one low intensity fire in Douglas-fir slash. The sampling period average fire intensity and emission factor for each filter period is shown below the plot.

Fuelbeds representative of only the fine fuel component of slash fuelbeds were used in these experiments. The fuelbeds were incomplete in that they did not include large material, stumps, rotten wood, ground fuels, or associated live vegetation which would increase emissions and burning time.

The highest fire intensity produced in the laboratory for a filter period was 2300 BTU per square foot per minute. Higher fire intensity is not uncommon in real situations and remain outside the scope of this investigation.

RESULTS AND DISCUSSION

Particulate emissions from 13 Ponderosa pine fuelbeds averaged 12.5 pounds per ton of fuel burned. Twenty-three fuelbeds of Douglas-fir slash without needles released an average of 6 lb/ton of fuel burned. Six Douglas-fir fuelbeds without needles released 24 lb/ton. Hydrocarbon emissions from 10 Ponderosa pine fuelbeds averaged 12 lb/ton. Carbon monoxide averaged 195 lb/ton.

Sampling period emission factors, EF, were regressed on fire intensity, I. In each case the log of the emission factor decreased linearly with an increase in the log of fire intensity. The regression for total hydrocarbons (as C) was:

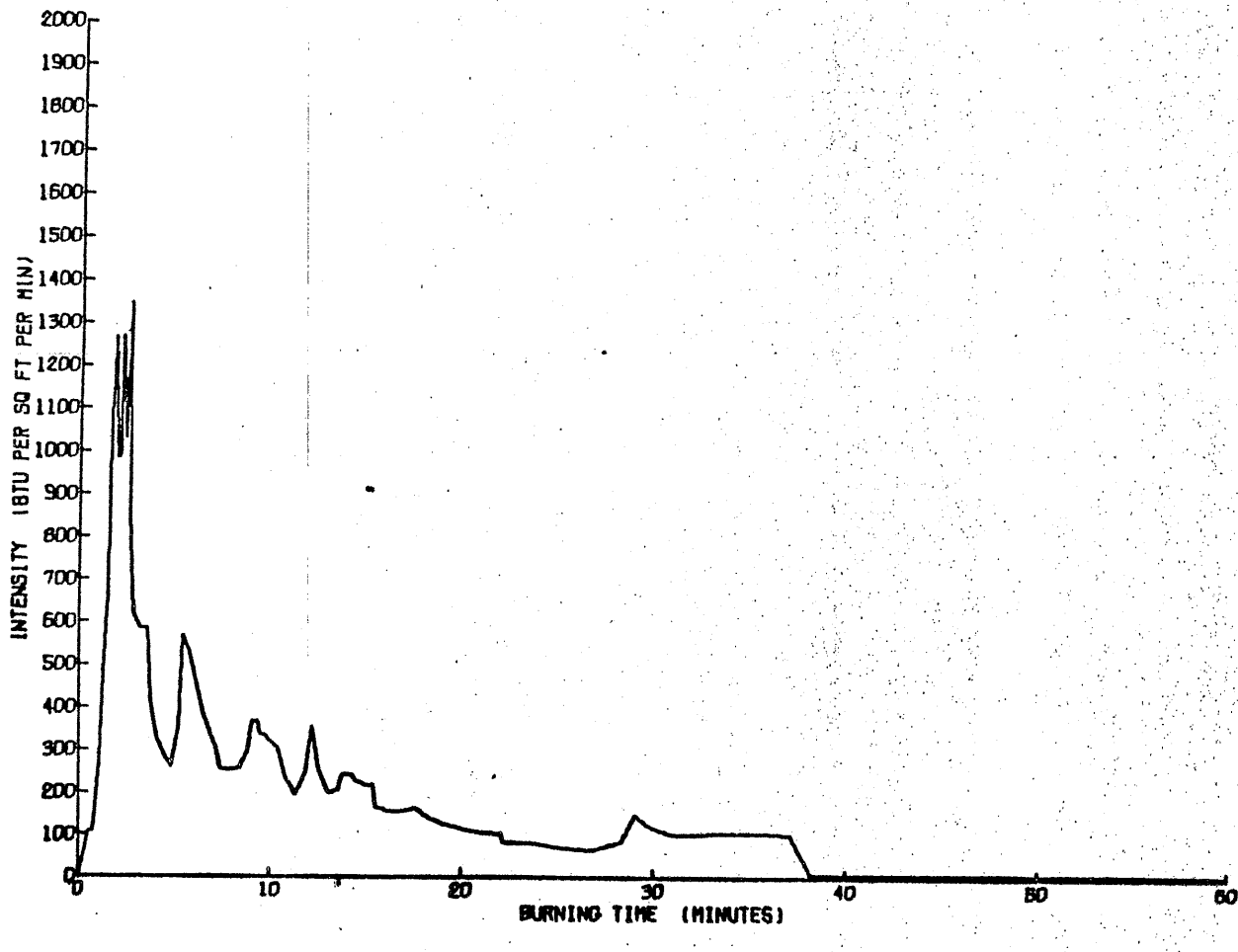
$$LØG\ (EF_c) = 4.14 - 0.90\ LØG\ (I)$$

A regression coefficient of -1.00 would represent inverse proportionately between emissions and intensity. Ninety-two percent in the variation in the dependent variable was explained by the regression.

The relationship between the logarithm of carbon monoxide sampling period emission factors and fire intensities was similar, except that

LABORATORY FIRE BEHAVIOR AND EMISSIONS
27 JUN 73B BLOEDEL FIRE LABORATORY
DOUGLAS-FIR SLASH (WITH NEEDLES)

FINES (1/2 INCH)	25.0 (PERCENT)
FUEL MOISTURE	28.9 (PERCENT)
PEAK INTENSITY	1349.5 (BTU FT-2 MIN-1)
VIOLENT PERIOD	1.0 (MINUTES)
PARTICULATES	94.5 (LB PER TON BURNED)



585	382	260	133	9 AVERAGE INTENSITY
46.5	38.8	12.4	20.8	72. PARTICULATES
F	FIL	FIL	FILTER	FILTER

INTENSITY AND EMISSIONS PER SAMPLING PERIOD

FIGURE 1. BLOEDEL LABORATORY FIRE BEHAVIOR AND EMISSIONS.

CO emissions were higher than hydrocarbon emissions at any fire intensity:

$$LØG\ (EF_{co}) = 4.82 - 0.88\ LØG\ (I)$$

The two regressions are shown in figure 2.

A similar statistical relationship for particulate emissions existed only if the data were stratified by the burning period. In all three periods, approximate inverse proportionately existed between fire intensity and emission factors. The regression coefficients ranged from -0.84 to - 0.98, and coefficients of determination (R^2) from 0.71 to 0.83. (Figure 3.) The sampling period emission factors were not dependent on the length of sampling period.

Where the ranges of fire intensity overlapped, needle dominated flaming produced 7.5 times as much particulate emission as flaming without needles. Flaming fuelbed particulate emissions were 3.6 to 4.0 times as great as those from smouldering fuelbeds.

When the objective of a prescribed fire is reduction of fire hazard, this objective is met when the finest fuels (<1/2" diameter) are consumed. Twigs this size made up less than 20% of laboratory fuel weight. Yet when 75% of the available fuel was consumed, only 25% of the gaseous emissions and 45% of the particulates had been released. Figure 4 shows the cumulative weight of particulates released in relation to the cumulative fuel burned at any time. The majority of emissions occurred during very low intensity, transient flaming periods. In other words, the majority of emissions occurred after the objectives for burning had been met.

SUMMARY

It was observed from the laboratory burning of the fine fuel component of slash fuelbeds that:

1) Douglas-fir slash with needles released 4 times as much particulate matter as the same amount of fuel burned with no needles (24 vs. 6 lb/ton). Ponderosa pine fuelbeds released 12.5 lb/ton.

	POLLUTANT	FUELS	NEEDLES	PHASE
+	CARBON MONO	PONDEROSA	WITH NEEDLES	FLAMES
×	HYDROCARBON	PONDEROSA	WITH NEEDLES	FLAMES

REGRESSION	RSQ	F	SE
LOGY = 4.817 - .884 LOGX	.939	2782.4	.1311
LOGY = 4.144 - .899 LOGX	.924	2198.2	.1500

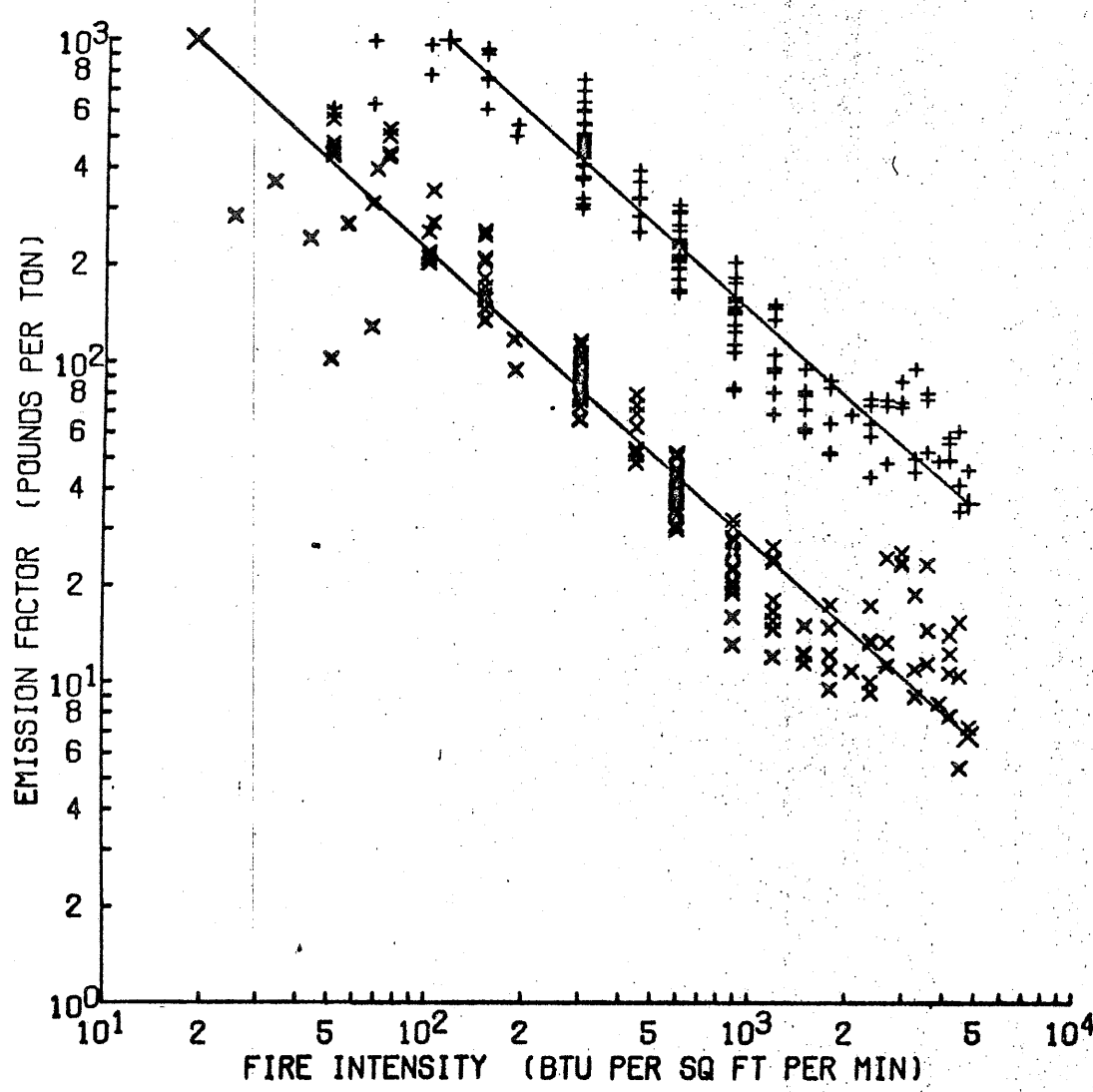


FIGURE 2. EMISSION FACTORS VS. FIRE INTENSITY

	POLLUTANT	FUELS	NEEDLES	PHASE
◇	PARTICULATE	PINE, FIR	WITH NEEDLES	PEAK
□	PARTICULATE	PINE, FIR	NO NEEDLES	FLAMES
○	PARTICULATE	DOUG FIR	NO NEEDLES	SMOULDER

REGRESSION	RSQ	F	SE
LOGY = 4.230 - .983 LOGX	.832	34.6	.1671
LOGY = 3.335 - .976 LOGX	.815	184.8	.0718
LOGY = 2.506 - .835 LOGX	.706	38.5	.1345

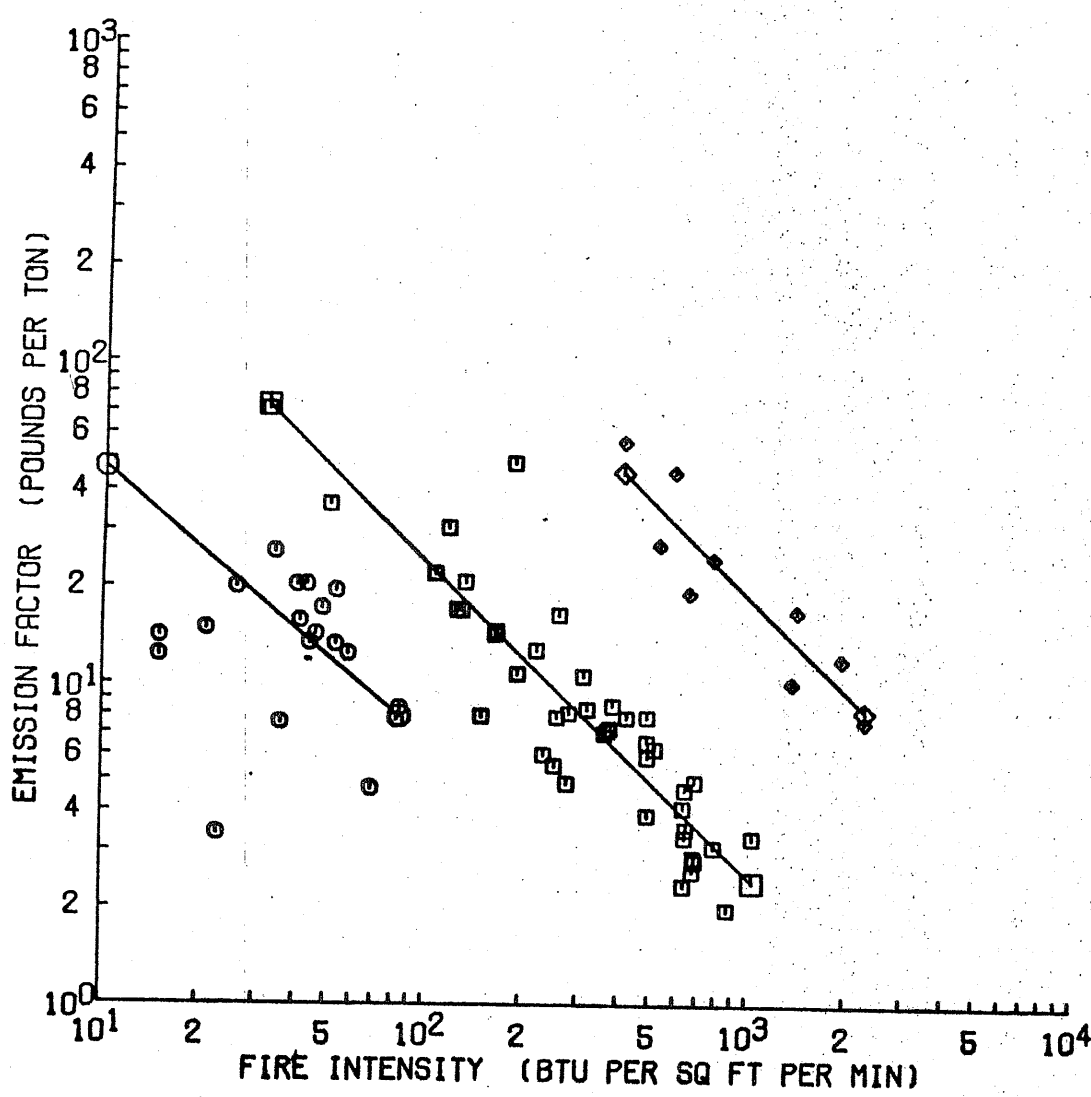


FIGURE 3. EMISSION FACTORS VS. FIRE INTENSITY

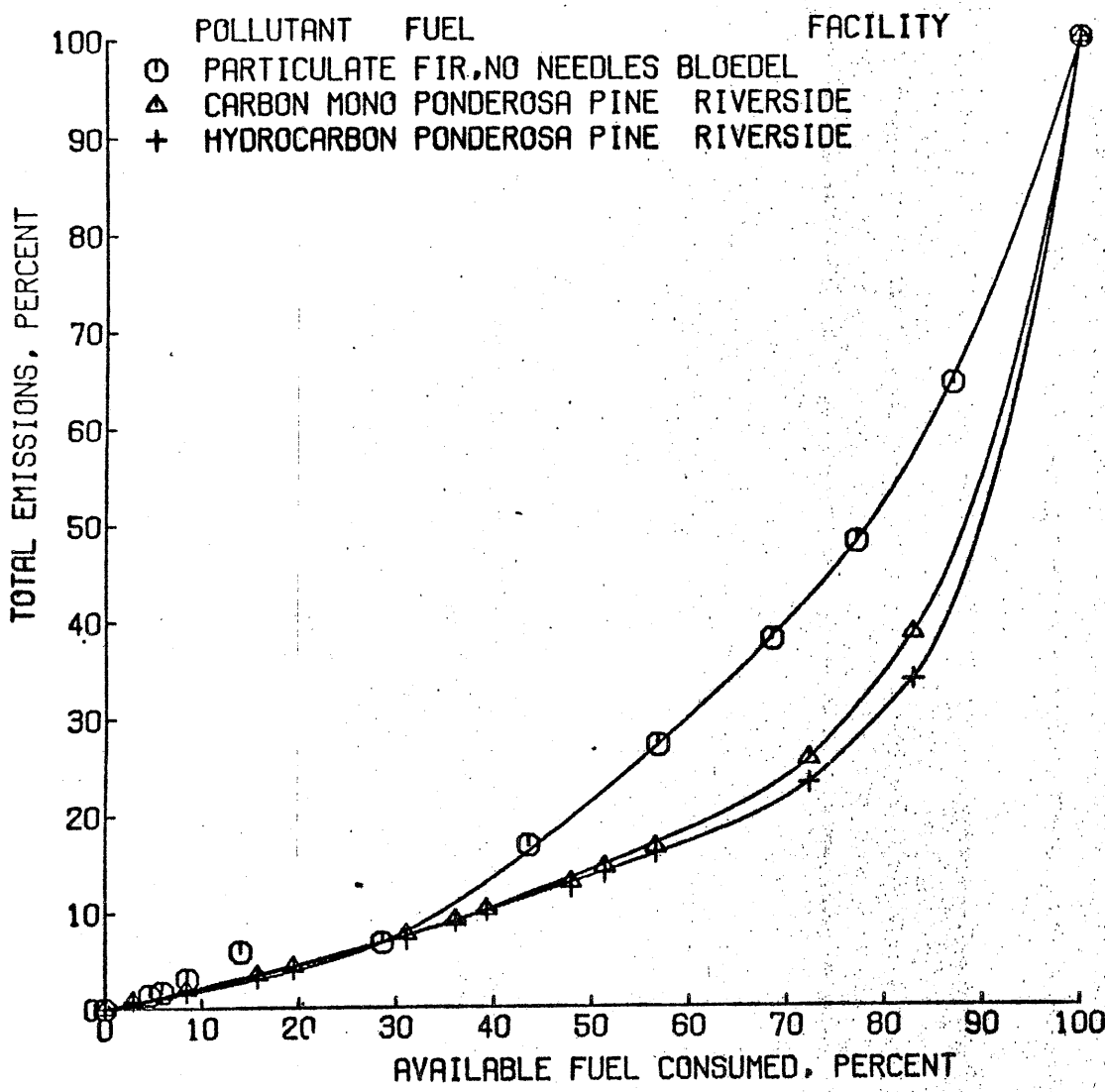


FIGURE 4. THE CUMULATIVE WEIGHT OF POLLUTANTS EMITTED IN RELATION TO THE PERCENTAGE OF AVAILABLE FUEL BURNED IN LABORATORY EXPERIMENTS.

2) The sampling period emission factors for all pollutants measured were nearly inversely proportional to the fire intensity in that period. When average fire intensity (reaction intensity) was doubled, the emission factor was reduced by about 45%.

3) Sampling period particulate emission factors were similar for Ponderosa pine and Douglas-fir fuels burning at the same intensity. Differences in overall emission factors can be explained by differences in fire intensity and the quantity of needles.

IMPLICATIONS

The research implies that the emissions from slash burning could be substantially reduced by fire or fuelbed management techniques that would:

1) Minimize the duration of burning, i.e., increase the average fire intensity. Peak fire intensity is not an important determinate of emission factors, but average fire intensity is. Dry fuelbeds, the use of fuel boosters or accelerants, pile burning, area-ignition, yum-yarding before burning, and agressive mop-up action might be considered.

2) Minimize the burning of needles. Windrowing or otherwise handling of dried fuels would promote needle fall. Burning when needles have fallen and the litter layer is wet might reduce the weight of fuel consumed.

3) Minimize the amount of fuel consumed. Obviously, fuel that does not burn does not produce smoke. The ideal fire hazard reduction burn would be a quick, hot fire that consumed only the finest fuels.