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# Spotting Distance from Wind-Driven Surface Fires — Extensions of Equations for Pocket Calculators

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# Spotting Distance from Wind-Driven Surface Fires — Extensions of Equations for Pocket Calculators

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## **ABSTRACT**

*Extends equations for calculating the maximum spot fire distance to include wind-driven fires burning in surface fuels as a firebrand source. Predictions are based upon prevailing windspeed, vegetational cover, and local terrain. The equations can be used on a programmable pocket calculator. Previous methods of calculating spotting distance from torching trees and burning piles are also included. For copies of a program for the Texas Instruments TI-59, send eight blank TI-59 magnetic cards to the author. (Only two cards are required if the user has the previous version of the program.) Potential uses are in fire management planning and in predicting real-time fire behavior.*

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**KEYWORDS:** spot fire, spotting, firebrands, fire management

## **MODEL DESCRIPTION**

Spot fires ignited by flying embers from wildfires and prescribed fires have long been a problem for fire managers. Spotting is difficult to prevent; therefore it is useful to be able to forecast when spotting is likely to occur and predict its maximum distance and direction.

Roussopoulos and Johnson (1975) and Rothermel (1983) provide guidelines based on fireline intensity that indicate when severe fire behavior such as torching, crown fires, and spot fires can be expected. Albini (1979, 1981) and Chase (1981) document calculation of the maximum distance firebrands can travel when the source of the firebrands is:

1. The transient flame produced by a torching tree (or group of trees burning with a single flame structure), and
2. A continuous steady flame as provided by burning piles of slash or "jackpots" of heavy fuel.

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<sup>1</sup>The author is a mathematician stationed at the Intermountain Station's Northern Forest Fire Laboratory, Missoula, Mont.

Albini (1983) considers another source of firebrands:

3. A wind-driven fire burning in surface fuels (such as grass, shrubs, litter) without timber cover.

This note extends the equations for predicting maximum spotting distance to include the third case, and documents a revised program for the Texas Instruments TI-59<sup>2</sup> calculator that includes all three sources.

In all three instances an updraft lofts burning material vertically; then it is carried horizontally by the wind while also falling back to earth to land some distance downwind from the source. In the case of wind-driven fires burning in surface fuels, the firebrand drifts downwind as it is being lofted. When firebrands are produced by surface fires, significant overstory or timber cover may provide a barrier for the firebrands and interfere with the development of an updraft that lofts the firebrands vertically. Consequently, spotting distance in these situations is generally insignificant.

Albini's model covers intermediate range spotting (generally a few tenths of a mile to a mile). It does not address short-range spotting of a few tens of yards from fires of low intensity or very long-range spotting associated with severe fire behavior such as crown fires and firewhirls. The firebrand of interest is the one of optimum size. That is the particle whose dimensions, weight, and aerodynamics allow the wind to loft it a considerable distance and that is still burning when it lands. Particles smaller than optimum could travel farther, but would burn up before landing. Particles larger than optimum would often be burning when they land, but would not travel as far. The model does not consider the numbers of optimum firebrands produced by a fire. If particles of optimum size are not present, spot fire distance will be less than the maximum predicted. The model does not address whether the firebrand causes an ignition, or the number of spot fires caused.

Mountainous terrain is modeled as a washboard. If this simple representation does not describe your situation, perhaps the model will not give you a good approximation of spotting distance.

The surface-fire spotting model requires two fuel-model-dependent parameters used to relate thermal energy to windspeed. Albini (1983) derives these parameters for 12 of the 13 standard NFFL fuel models (Albini 1976; Anderson 1982) and they are presented in table 1 as parameters A and B. A is used as a coefficient in the windspeed function and B is used as a power. Some models ordinarily have overstories, but are sometimes used to represent fuels without overstory cover. Model 9 (hardwood litter) can be used when the deciduous overstory is bare of leaves or the stand is sparse. Model 10 (timber litter and understory) is sometimes used to represent timber harvest debris overgrown with shrubs or other vegetation. Model 8 (closed timber litter) was omitted in Albini's analysis because it is seldom used to represent a model without cover.

The model-dependent parameters can also be derived for custom fuel models (Burgan and Rothermel 1984). Calculation speed and memory considerations preclude calculation of these parameters in the TI-59 program. Current plans are to include derivation of surface-spotting parameters for custom fuel models in the expected update of the BEHAVE system of interactive computer programs (Andrews 1983; Andrews, review draft; Burgan and Rothermel 1984).

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<sup>2</sup>The use of trade, firm, or corporation names in this publication is for the information and convenience of the reader. Such use does not constitute an official endorsement or approval by the U.S. Department of Agriculture of any product or service to the exclusion of others that may be suitable.

**Table 1.**—Corrected values of windspeed function parameters for 12 of the 13 NFFL fuel models (erratum notice, Albini 1983). Units of A are seconds; B is dimensionless.

| Fuel model              | Coefficient<br>A | Power<br>B |
|-------------------------|------------------|------------|
|                         | <i>Seconds</i>   |            |
| Grass and litter        |                  |            |
| 1 Short grass           | 545              | – 1.21     |
| 2 Grassy understory     | 709              | – 1.32     |
| 3 Tall grass            | 429              | – 1.19     |
| 9 Hardwood litter       | 1121             | – 1.51     |
| Shrub types             |                  |            |
| 4 Mature chaparral      | 301              | – 1.05     |
| 5 Young chaparral       | 235              | – .92      |
| 6 Dormant brush         | 242              | – .94      |
| 7 Southern rough        | 199              | – .83      |
| Logging slash           |                  |            |
| 10 Overgrown slash      | 224              | – .89      |
| 11 Light conifer slash  | 179              | – .81      |
| 12 Medium conifer slash | 163              | – .78      |
| 13 Heavy conifer slash  | 170              | – .79      |

When available, these parameters can be entered in the TI-59 program according to the operating procedures described subsequently.

Users who desire to use NFFL model 8 (closed timber litter) as a surrogate for fuels without overstory should create a custom model with the BEHAVE system using parameters for model 8. The updated version of BEHAVE will then calculate the surface spotting parameters required.

The predictions provided by the program are only as good as the model on which they are based. Confidence in predictions can be improved by field verification. Personal communication (Catchpole 1983) indicates that the model may underpredict maximum spotting distance in eucalyptus forests due to the aerodynamical nature of the tree bark. The author invites submission of any validation data obtained.

Equations are given for English and metric units of measure. The TI-59 program uses English units, so only English units appear in the text. The transformation of the 20-foot reference windspeed to windspeed at heights required for input to Albini's (1983) model has been incorporated in the equations. The logarithmic windspeed profile and the power law profile both yield similar results when referenced near the surface and projected upwards; therefore the power law profile was used because it is simpler.

Table 3 of Albini (1983) presents values necessary for the derivation of the spotting parameters. The table was later found to contain inaccuracies. Corrected table entries are presented in the Appendix (table A). Also presented in the Appendix are the corrected values for the numerical examples appearing in Albini (1983).

## SUMMARY OF EQUATIONS

| Symbol                                 | English units | Metric units   | Description  |
|--|---------------|----------------|--|
| <b>Torching tree option</b>            |               |                |  |
| d                                      | inches        | cm             | Diameter at breast height (d.b.h.) of tree(s) torching out   |
| h                                      | ft            | m              | Height of burning tree(s)  |
| n                                      | none          | none           | Number of trees burning simultaneously to produce a single merged flame and buoyant plume structure  |
| $h_F$                                  | ft            | m              | Adjusted steady flame height (perpendicular measurement from base of flame to tip of flame)  |
| $d_F$                                  | none          | none           | Adjusted steady flame duration   |
| <b>Pile burning option</b>             |               |                |  |
| $H_F$                                  | ft            | m              | Continuous flame height for pile burning   |
| <b>Wind-driven surface fire option</b> |               |                |  |
| A                                      | s             | s              | Fuel model-dependent parameter used as coefficient in windspeed function (see table 1)   |
| B                                      | none          | none           | Fuel model-dependent parameter used as power in windspeed function (see table 1)   |
| f(U)                                   | s             | s              | Windspeed function   |
| E                                      | Btu/ft        | kJ/m           | Strength of a thermal updraft generated by a wind-driven line fire   |
| I                                      | Btu/ft/s      | kW/m           | Fireline intensity   |
| <b>Common to all options</b>           |               |                |  |
| $\bar{h}$                              | ft            | m              | Mean vegetation cover height downwind of source (see "Operating instructions")   |
| $\bar{h}_c$                            | ft            | m              | Minimum value of $\bar{h}$ used to calculate spotting distance using the logarithmic windspeed variation with height (Albini 1981)             |
| $\bar{h}^*$                            | ft            | m              | The greater of $\bar{h}$ and $\bar{h}_c$   |
| U                                      | mi/h          | km/h           | Windspeed 20 feet (6 m) above vegetation   |
| D                                      | mi            | km             | Ridge-to-valley horizontal distance (map)  |
| H                                      | 1000's of ft  | mult. of 300 m | Ridge-to-valley elevational difference   |
| M                                      | none          | none           | Code number for location of firebrand source<br>0 = midslope, windward side<br>1 = valley bottom<br>2 = midslope, leeward side<br>3 = ridgetop |
| z(0)                                   | ft            | m              | Initial firebrand height above ground  |
| F                                      | mi            | km             | Flat-terrain spotting distance   |
| S                                      | mi            | km             | Mountainous-terrain spotting distance (map)  |

## Equations Using English Units

$$z(0) = \left\{ \begin{array}{l} 4.24d_F^{0.332}(h_F) + h/2, \\ 3.64d_F^{0.391}(h_F) + h/2, \\ 2.78d_F^{0.418}(h_F) + h/2, \\ 4.70(h_F) + h/2 \\ 1.055E^{1/2}, \\ 12.2H_F, \end{array} \right. \left. \begin{array}{l} h/h_F \geq 1 \\ 0.5 \leq h/h_F < 1 \\ h/h_F < 0.5, d_F < 3.5 \\ h/h_F < 0.5, d_F \geq 3.5 \end{array} \right\} \begin{array}{l} \text{torching tree option} \\ \text{wind-driven surface fire option} \\ \text{pile burning option} \end{array}$$

where

$$h_F = \left\{ \begin{array}{l} 16.5d^{0.515}n^{0.4}, \\ 15.7d^{0.451}n^{0.4}, \\ 12.9d^{0.453}n^{0.4}, \end{array} \right. \begin{array}{l} \text{grand fir, balsam fir} \\ \text{Engelmann spruce, subalpine fir, Douglas-fir, western hemlock} \\ \text{ponderosa pine, lodgepole pine, white pine} \end{array}$$

$$d_F = \left\{ \begin{array}{l} 12.6d^{-0.256}n^{-0.2}, \\ 10.7d^{-0.278}n^{-0.2}, \\ 6.3d^{-0.249}n^{-0.2}, \end{array} \right. \begin{array}{l} \text{ponderosa pine, lodgepole pine, Engelmann spruce} \\ \text{subalpine fir, Douglas-fir, balsam fir, grand fir, white pine} \\ \text{western hemlock} \end{array}$$

$$f(U) = A (0.474 U)^B, \quad \text{where } A \text{ and } B \text{ are fuel model-dependent parameters} \\ \text{(see table 1)}$$

$$E = I \cdot f(U)$$

$$F = \left\{ \begin{array}{l} 7.18 \times 10^{-4} U \bar{h}^{*1/2} \left\{ 0.362 + \left( \frac{z(0)}{\bar{h}^*} \right)^{1/2} \left( \frac{1}{2} \right) \ln \left( \frac{z(0)}{\bar{h}^*} \right) \right\}, \\ 7.18 \times 10^{-4} U \bar{h}^{*1/2} \left\{ 0.362 + \left( \frac{z(0)}{\bar{h}^*} \right)^{1/2} \left( \frac{1}{2} \right) \ln \left( \frac{z(0)}{\bar{h}^*} \right) \right\} + 2.78 \times 10^{-4} U z(0)^{0.643}, \end{array} \right. \begin{array}{l} \text{torching tree,} \\ \text{pile burning options} \\ \text{wind-driven} \\ \text{surface fire option} \end{array}$$

where

$$\bar{h}_c = 2.2z(0)^{0.337} - 4.0$$

$$\bar{h}^* = \max(\bar{h}, \bar{h}_c)$$

$$S = D \cdot X_6,$$

where  $X_6$  is from the iteration:

$$X_0 = A$$

$$X_{n+1} = A - B (\cos(\pi X_n - M\pi/2) - \cos(M\pi/2))$$

$$A = F/D$$

$$B = H/(10\pi)$$

## Equations Using Metric Units

$$z(0) = \left\{ \begin{array}{l} 4.24d_F^{0.332}(h_F) + h/2, \\ 3.64d_F^{0.391}(h_F) + h/2, \\ 2.78d_F^{0.418}(h_F) + h/2, \\ 4.70(h_F) + h/2 \end{array} \right. \left. \begin{array}{l} h/h_F \geq 1 \\ 0.5 \leq h/h_F < 1 \\ h/h_F < 0.5, d_F < 3.5 \\ h/h_F < 0.5, d_F \geq 3.5 \end{array} \right\} \begin{array}{l} \text{torching tree option} \\ \\ \\ \text{wind-driven surface fire option} \\ \text{pile burning option} \end{array}$$

where

$$h_F = \begin{cases} 3.11d^{0.515}n^{0.4}, & \text{grand fir, balsam fir} \\ 3.14d^{0.451}n^{0.4}, & \text{Engelmann spruce, subalpine fir, Douglas-fir, western hemlock} \\ 2.58d^{0.453}n^{0.4}, & \text{ponderosa pine, lodgepole pine, white pine} \end{cases}$$

$$d_F = \begin{cases} 16.0d^{0.256}n^{-0.2}, & \text{ponderosa pine, lodgepole pine, Engelmann spruce} \\ 13.9d^{0.278}n^{-0.2}, & \text{subalpine fir, Douglas-fir, balsam fir, grand fir, white pine} \\ 7.95d^{0.249}n^{-0.2}, & \text{western hemlock} \end{cases}$$

$f(U) = A (0.295 U)^B$ , where A and B are fuel model-dependent parameters (see table I)

$$E = I \cdot f(U)$$

$$F = \left\{ \begin{array}{l} 1.30 \times 10^{-3} U \bar{h}^{*1/2} \left\{ 0.362 + \left( \frac{z(0)}{\bar{h}^*} \right)^{1/2} \left( \frac{1}{2} \right) \ln \left( \frac{z(0)}{\bar{h}^*} \right) \right\}, \\ 1.30 \times 10^{-3} U \bar{h}^{*1/2} \left\{ 0.362 + \left( \frac{z(0)}{\bar{h}^*} \right)^{1/2} \left( \frac{1}{2} \right) \ln \left( \frac{z(0)}{\bar{h}^*} \right) \right\} + 5.03 \times 10^{-4} U z(0)^{0.643}, \end{array} \right. \begin{array}{l} \text{torching tree,} \\ \text{pile burning options} \\ \\ \text{wind-driven} \\ \text{surface fire option} \end{array}$$

where

$$\bar{h}_c = z(0)^{0.337} - 1.22$$

$$\bar{h}^* = \max(\bar{h}, \bar{h}_c)$$

$$S = D \cdot X_6,$$

where  $X_6$  is from the iteration:

$$X_0 = A$$

$$X_{n+1} = A - B (\cos(\pi X_n - M\pi/2) - \cos(M\pi/2))$$

$$A = F/D$$

$$B = H/(10\pi)$$

## THE TI-59 PROGRAM

The program for predicting maximum spot fire distance (Chase 1981) had to be extended to include spotting from wind-driven surface fires. Some user convenience in program operation was given up to obtain the advantage of having a single set of program cards, one set of operating instructions, and a single worksheet covering all options. In this revised version, the user may have to reenter up to three unchanged inputs to revise a single value. The user must also be careful to select reasonable data and enter those data without error since there are no checks on the validity of input data.

Maximum spot fire distance is predicted from three sources of firebrands: torching trees, burning piles, and wind-driven surface fires. Figure 1 is a chart showing program flow. Species data cards for the torching tree option from the original program (Chase 1981) contain data that are still valid, but the cards must be rerecorded under a new memory partition before being used with the revised version. Directions for rerecording these cards are given in the section entitled "Program Duplication."

The program is recorded on two cards (magnetic strips). A listing is in the appendix. A prerecorded copy of the program may be obtained by sending two blank magnetic cards for the TI-59 (eight cards if species data cards are also desired) to the author at the Northern Forest Fire Laboratory.

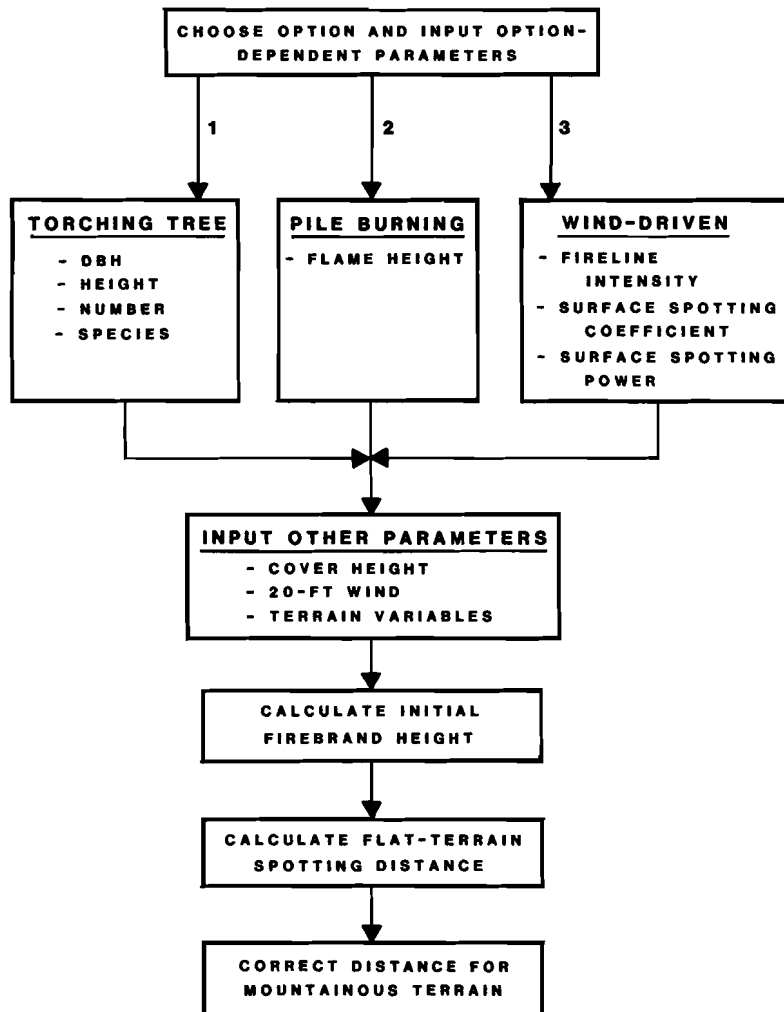


Figure 1.— This chart shows the general organization of the program to predict maximum spotting distance.

## OPERATING INSTRUCTIONS

The program for calculating spot fire distance may be run on the TI-59 with any solid-state module in the calculator (such as NFDR/fire behavior module, library module, statistics module) or with no module in place.

### Preliminaries

1. Turn on the calculator. (If it is already on, turn it off momentarily to clear program and memory registers.)
2. Partition memory before reading in the program. Press **4** **2nd** **OP** **1** **7**. The display should read 639.39.
3. Press **1**. Feed side 1 of the program cards into the lower slot on the right side of the calculator. The motor will start and stop automatically. If the display flashes, press **CLR** and repeat step 3.
4. Press **2**. Feed side 2 of the program into the slot. If the display flashes, press **CLR** and repeat step 4.
5. Press **3**. Feed side 3 of the program into the slot. If the display flashes, press **CLR** and repeat step 5.

### Inputs

Record the necessary inputs on the worksheet (exhibit 1). Enter **one** of the following **three** groups of option-dependent inputs. The inputs in the selected group must be entered in the order given. The group number represents the option selected:

1. **Torching tree option:** Input of this group of values indicates choice of the torching tree option
  - Enter diameter at breast height (d.b.h.) in inches of tree(s) torching out Press **A**
  - Enter height in feet of tree(s) torching out Press **R/S**
  - Enter the number of identical tree(s) burning at once to produce a single flame Press **R/S**
  - A **4** will appear in the display; feed in the tree species data card for the species desired
2. **Pile burning option:** Input of this value indicates choice of the pile burning option.
  - Enter estimated flame height in feet from observation of continuous flame Press **B**
3. **Wind-driven surface fire option:** Input of this group of values indicates choice of the wind-driven surface fire option
  - Enter the fireline intensity in Btu/ft/s (for assistance in obtaining this input, see section entitled "Estimating Fireline Intensities") Press **C**
  - Enter the surface spotting coefficient (A) for the fuel model which represents your fuel complex (see table 1 for models 1-7, 9-13; 1985 BEHAVE for custom fuel models) Press **R/S**
  - Enter surface spotting power (B) for your fuel model (see table 1 for models 1-7, 9-13; 1985 BEHAVE for custom models) Press **R/S**

Enter all of the following groups of inputs. Groups may be entered in any order, but inputs within a group must be entered in the order specified.

Name \_\_\_\_\_ Date \_\_\_\_\_ Sheet \_\_\_\_\_ of \_\_\_\_\_

Purpose \_\_\_\_\_

( 4 2nd OP 1 7 )

INPUTS

| Option-dependent parameters  | Reg. no.    | Option |        |           | Option |        |           | Before entry | After entry |
|--|-------------|--------|--------|-----------|--------|--------|-----------|--------------|-------------|
|  |             | Tree 1 | Pile 2 | Surface 3 | Tree 1 | Pile 2 | Surface 3 |              |             |
| Torching tree d.b.h., inches   | 39          | _____  |        |           | _____  |        |           |              | A           |
| Torching tree height, ft   | 38          | _____  |        |           | _____  |        |           |              | R/S         |
| Number of trees torching together  | 37          | _____  |        |           | _____  |        |           |              | R/S         |
| Species  | (read card) | _____  |        |           | _____  |        |           | 4            |             |
| Continuous flame height, ft  | 31          |        | _____  |           |        | _____  |           |              | B           |
| Fireline intensity, Btu/ft/s   | 30          |        |        | _____     |        |        | _____     |              | C           |
| Surface spotting coefficient (A)   | 29          |        |        | _____     |        |        | _____     |              | R/S         |
| Surface spotting power (B)   | 28          |        |        | _____     |        |        | _____     |              | R/S         |
| <u>Other parameters</u>  |             |        |        |           |        |        |           |              |             |
| Mean cover height, ft  | 35          | _____  |        |           | _____  |        |           |              | D           |
| 20-foot windspeed, mi/h  | 36          | _____  |        |           | _____  |        |           |              | E           |
| Ridge/valley elevational difference, ft  | 34          | _____  |        |           | _____  |        |           |              | 2nd A       |
| Ridge/valley horizontal distance, mi   | 33          | _____  |        |           | _____  |        |           |              | R/S         |
| Spotting source location code  | 32          | _____  |        |           | _____  |        |           |              | R/S         |
| 0=midslope, windward side<br>1=valley bottom<br>2=midslope, leeward side<br>3=ridgetop |             |        |        |           |        |        |           |              |             |

OUTPUT

Maximum spotting distance corrected for mountainous terrain, mi      21      \_\_\_\_\_      \_\_\_\_\_      SBR =

Exhibit 1.—Maximum Spotting Distance Worksheet

**4. Cover**

—Enter the mean cover height, in feet, of the area downwind of the firebrand source. Where timber or shrub cover exists, enter the height. If there is broken forest cover, enter one-half the treetop height of the forest-covered portion. If there is little or no forest cover (as is the case for option 3), enter vegetation height. This value is used to characterize the general forest cover as it influences the wind.

Press **D**

**5. Wind**

—Enter the average windspeed, in miles per hour, 20 feet above the vegetation

Press **E**

**6. Terrain variables**

—If terrain is flat, enter zero here (do not skip this step—an incorrect nonzero value may be carried over from a previous run), then proceed to “Recall and Correction of Input”. If terrain is not flat, enter average elevational difference in feet from ridge-top to valley bottom as would be shown on a map. (The model is not very sensitive to this input; rounding to nearest thousand is probably adequate.) The entry is in feet even though the equations use multiples of 1,000 feet.

Press **2nd** **A**

—Enter the ridgetop-to-valley bottom horizontal distance in miles as would be shown on a map.

Press **R/S**

—Enter the firebrand source location code from the following list.

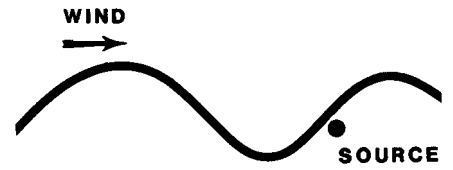
Press **R/S**

**Enter**

**for**

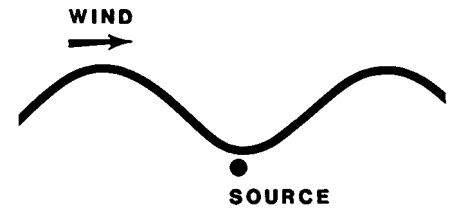
0

Midslope, windward side



1

Valley bottom



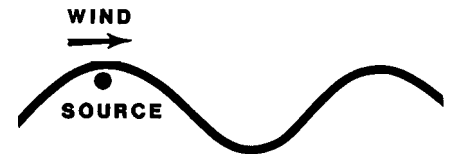
2

Midslope, leeward side



3

Ridgetop



## Recall and Correction of Input

1. Recall flashing display of option number chosen by pressing **SBR** **RCL**. If flashing 9's appear in the display, no option has been chosen. If a flashing 6 appears, more than one option has been chosen. Press **CLR** to halt the flashing display. Press **SBR** **CLR** to clear option flags. Enter the group of option-dependent inputs desired and repeat this step.
2. Follow with a series of **R/S** to view successive inputs for the selected option in the order listed on the worksheet. Items appearing in parentheses are not recalled (i.e., tree species in torching tree option is not recalled). The number of **R/S** required for each option is:
 

|                  |   |
|------------------|---|
| Torching tree    | 8 |
| Pile burning     | 6 |
| Surface spotting | 8 |

 If an additional **R/S** is pushed, flashing 9's will appear in the display to signal the end of the recalled values. Press **CLR** to halt the flashing display.
3. To change any item of input, reenter the group of inputs down through the correction for the wrong value as described in the input section.

## Performing Calculations

1. Press **SBR** **=**. When calculations are completed, the mountainous terrain spotting distance in miles will appear in the display. A flashing display at this point indicates an invalid calculation in the computation sequence. A list of conditions known to cause a flashing display here follows. There may be other causes.

| Cause                                 | Option  | Flashing display |
|---------------------------------------|---------|------------------|
| Windspeed = 0                         | 1, 2, 3 | 0.00             |
| Windspeed less than 0                 | 1, 2, 3 | Nonzero          |
| Fireline intensity = 0                | 3       | 0.00             |
| Custom model spotting coefficient = 0 | 3       | 0.00             |
| Number of trees torching = 0          | 1       | Nonzero          |
| No option selected                    | 1, 2, 3 | 9's              |
| More than one option selected         | 1, 2, 3 | 6.00             |

Press **CLR** to halt a flashing display and check your inputs.

## Making Successive Runs

1. If changing options, press **SBR** **CLR** to clear option flags. Reenter group of option-dependent variables desired (group 1, 2, or 3).
2. Change one or more other groups of inputs by entering the group as described in input section. Then check entire input list, using **SBR** **RCL**, **R/S**, **R/S**, . . . .
3. Perform calculations (**SBR** **=**).

Following are some tips for users who don't wish to reenter valid inputs needlessly, but are willing to remember extra procedures:

1. If not changing options, the user can input a changed value manually by entering **value** **STO** **nn** where nn is the register number where that value is stored (see exhibit 1).
2. Proceed to reinput the group of parameters, but stop after all changed values have been entered.
3. If changing options, but valid inputs from a prior run are still in place, input only the first value in the group of option-dependent parameters. This serves to set the option flag.

Name Sample Problems Date \_\_\_\_\_ Sheet 1 of 2

Purpose \_\_\_\_\_

(4) 2nd OP 1 7

INPUTS

| Option-dependent parameters  | Reg. no.    | Tree             |   |   | Option Pile |             |   | Surface | Before entry | After entry |
|--|-------------|------------------|---|---|-------------|-------------|---|---------|--------------|-------------|
|  |             | 1                | 2 | 3 | 1           | 2           | 3 |         |              |             |
| Torching tree d.b.h., inches   | 39          | <u>20</u>        |   |   |             |             |   |         |              | A           |
| Torching tree height, ft   | 38          | <u>137</u>       |   |   |             |             |   |         |              | R/S         |
| Number of trees torching together  | 37          | <u>1</u>         |   |   |             |             |   |         |              | R/S         |
| Species  | (read card) | <u>Grand fir</u> |   |   |             |             |   |         | 4            |             |
| Continuous flame height, ft  | 31          |                  |   |   |             | <u>45</u>   |   |         |              | B           |
| Fireline intensity, Btu/ft/s   | 30          |                  |   |   |             |             |   |         |              | C           |
| Surface spotting coefficient (A)   | 29          |                  |   |   |             |             |   |         |              | R/S         |
| Surface spotting power (B)   | 28          |                  |   |   |             |             |   |         |              | R/S         |
| <u>Other parameters</u>  |             |                  |   |   |             |             |   |         |              |             |
| Mean cover height, ft  | 35          | <u>130</u>       |   |   |             | <u>100</u>  |   |         |              | D           |
| 20-foot windspeed, mi/h  | 36          | <u>20</u>        |   |   |             | <u>15</u>   |   |         |              | E           |
| Ridge/valley elevational difference, ft  | 34          | <u>4000</u>      |   |   |             | <u>2000</u> |   |         |              | 2nd A       |
| Ridge/valley horizontal distance, mi   | 33          | <u>.25</u>       |   |   |             | <u>1</u>    |   |         |              | R/S         |
| Spotting source location code  | 32          | <u>3</u>         |   |   |             | <u>1</u>    |   |         |              | R/S         |
| 0=midslope, windward side<br>1=valley bottom<br>2=midslope, leeward side<br>3=ridgetop |             |                  |   |   |             |             |   |         |              |             |

OUTPUT

|   |    |            |  |  |  |            |  |  |       |
|---|----|------------|--|--|--|------------|--|--|-------|
| Maximum spotting distance corrected for mountainous terrain, mi | 21 | <u>.31</u> |  |  |  | <u>.21</u> |  |  | SBR = |
|---|----|------------|--|--|--|------------|--|--|-------|

13

Purpose \_\_\_\_\_  
 (4 2nd OP 1 7)

INPUTS

| Option-dependent parameters             | Reg. no.    | Option       |        |           | Option       |        |           | Before entry | After entry |
|---|-------------|--------------|--------|-----------|--------------|--------|-----------|--------------|-------------|
|   |             | Tree 1       | Pile 2 | Surface 3 | Tree 1       | Pile 2 | Surface 3 |              |             |
| Torching tree d.b.h., inches            | 39          | _____        | _____  | _____     | _____        | _____  | _____     | A            |             |
| Torching tree height, ft                | 38          | _____        | _____  | _____     | _____        | _____  | _____     | R/S          |             |
| Number of trees torching together       | 37          | _____        | _____  | _____     | _____        | _____  | _____     | R/S          |             |
| Species                                 | (read card) | _____        | _____  | _____     | _____        | _____  | 4         |              |             |
| Continuous flame height, ft             | 31          | _____        | _____  | _____     | _____        | _____  | _____     | B            |             |
| Fireline intensity, Btu/ft/s            | 30          | Fuel model 1 |        |           | Fuel model 4 |        |           | 14 400       | C           |
| Surface spotting coefficient (A)        | 29          | 580          |        |           | 545          |        |           | 301          | R/S         |
| Surface spotting power (B)              | 28          | -1.21        |        |           | -1.05        |        |           |              | R/S         |
| <u>Other parameters</u>                 |             |              |        |           |              |        |           |              |             |
| Mean cover height, ft                   | 35          | _____        | _____  | 1         | _____        | _____  | 6         | D            |             |
| 20-foot windspeed, mi/h                 | 36          | _____        | _____  | 10        | _____        | _____  | 35        | E            |             |
| Ridge/valley elevational difference, ft | 34          | _____        | _____  | 0         | _____        | _____  | 1000      | 2nd A        |             |
| Ridge/valley horizontal distance, mi    | 33          | _____        | _____  | -         | _____        | _____  | .25       | R/S          |             |
| Spotting source location code           | 32          | _____        | _____  | -         | _____        | _____  | 0         | R/S          |             |

0=midslope, windward side  
 1=valley bottom  
 2=midslope, leeward side  
 3=ridgetop

OUTPUT

|   |    |       |      |       |      |       |
|---|----|-------|------|-------|------|-------|
| Maximum spotting distance corrected for mountainous terrain, mi | 21 | _____ | 0.27 | _____ | 1.58 | SBR = |
|---|----|-------|------|-------|------|-------|

14

## ESTIMATING FIRELINE INTENSITIES

You may wish to use fire behavior calculations (Burgan 1979) to produce realistic fireline intensity values for input to the spot fire program. In this case, the NFDR/fire behavior CROM (custom read only memory) must be in place.

Switching from calculator to module memory (from spot fire distance to fire behavior calculations) and vice versa causes memory problems due to partitioning. Overcoming the problems involves a cumbersome procedure. Therefore it is recommended that the user make all the runs he/she wishes using one program, momentarily turn the calculator off and then on again, then access the other program (by pressing **2nd** **PGM** **2** **SBR** **R/S** [see Burgan 1979] or by reading the program cards) to make the desired runs.

Note that 20-foot windspeed is the input for the spot fire program, while midflame windspeed is used for fire behavior. Refer to Rothermel (1983) for guidelines in adjusting windspeeds.

Another method of estimating fireline intensity for real-time predictions is to use observed flame lengths in Byram's (1959) formula, which relates fireline intensity and flame length:

$$I = 5.66L^{2.17}$$

where

I = fireline intensity, Btu/ft/s

L = flame length, ft

## SAMPLE PROBLEMS

Exhibits 2a and 2b contain the inputs and outputs for four examples — one for torching tree option, one for pile burning, and two for the surface spot fire option.

## CONDENSED INSTRUCTIONS

1. **4** **2nd** **OP** **1** **7**
2. Press **1**, feed side 1 (flashing: **CLR**, try again).
3. Press **2**, feed side 2 (flashing: **CLR**, try again).
4. Press **3**, feed side 3 (flashing: **CLR**, try again).

### Preliminaries

### Input

| <b>Enter</b>                             | <b>Press</b>        |
|--|---------------------|
| Torching tree d.b.h.                     | <b>A</b>            |
| Group 1 Torching tree height             | <b>R/S</b>          |
| No. trees torching together              | <b>R/S</b>          |
| Read species card                        |                     |
| or                                       |                     |
| Group 2 Observed flame height            | <b>B</b>            |
| or                                       |                     |
| Fireline intensity                       | <b>C</b>            |
| Group 3 Surface spotting coefficient (A) | <b>R/S</b>          |
| Surface spotting power (B)               | <b>R/S</b>          |
| Group 4 Mean cover height                | <b>D</b>            |
| Group 5 20-foot windspeed                | <b>E</b>            |
| Ridge/valley elevational difference      | <b>2nd</b> <b>A</b> |
| Group 6 Ridge/valley horizontal distance | <b>R/S</b>          |
| Firebrand source location code           | <b>R/S</b>          |

**Check Inputs**      **SBR** **RCL**; follow by series of **R/S**

**Calculations**      **SBR** **=**

**To Clear Option  
Flags**      **SBR** **CLR**

## REGISTER ASSIGNMENTS

For completeness, the following list gives memory locations assigned to the inputs, outputs, and selected intermediate values.

| Register | Symbol         | Contents                          |
|----------|----------------|-----------------------------------|
| 39       | d              | Torching tree d.b.h.              |
| 38       | h              | Torching tree height              |
| 37       | n              | Number of trees torching together |
| 31       | H <sub>F</sub> | Continuous flame height           |
| 30       | I              | Fireline intensity                |
| 29       | A              | Surface spotting coefficient      |
| 28       | B              | Surface spotting power            |
| 35       | $\bar{h}$      | Mean cover height                 |
| 36       | U              | 20-foot windspeed                 |
| 34       | 1000H          | Ridge/valley elevation difference |
| 33       | D              | Ridge/valley horizontal distance  |
| 32       | M              | Spotting source location code     |
| 17       | $\bar{h}^*$    | Cover height used in calculations |
| 16       | none           | Downwind drift during lofting     |
| 25       | z(0)           | Initial firebrand height          |
| 26       | d <sub>F</sub> | Adjusted steady flame duration    |
| 27       | h <sub>F</sub> | Adjusted steady flame height      |
| 24       | F              | Flat terrain spotting distance    |
| 21       | S              | Corrected spotting distance       |

## PROGRAM DUPLICATION

The program recorded on one set of magnetic cards can be duplicated on another blank set as follows:

### Program Cards

1. Turn on your calculator. Enter the program into memory using the set of cards to be duplicated.

**4** **2nd** **OP** **1** **7**

**1**; feed side 1 (if flashing; press **CLR**, try again)

**2**; feed side 2 (if flashing; press **CLR**, try again)

**3**; feed side 3 (if flashing; press **CLR**, try again)

2. Press **1** **2nd** **R/S** and feed in side 1 of the set of blank cards. If the display flashes, press **CLR** and repeat step 2.

3. Press **2** **2nd** **R/S** and feed in side 2 of the set of blank cards. If the display flashes, press **CLR** and repeat step 3.

4. Press **3** **2nd** **R/S** and feed in side 3 of the set of blank cards. If the display flashes, press **CLR** and repeat step 4.

5. Label the cards appropriately, using a pen with permanent, fast-drying ink. A suggestion for labeling is shown in figure 2.

|                                   |             |                |                 |                   |
|-----------------------------------|-------------|----------------|-----------------|-------------------|
| 1                                 |             | 2              |                 |                   |
| <b>REVISED SPOT FIRE DISTANCE</b> |             |                |                 |                   |
| <b>TERRAIN</b>                    |             |                |                 |                   |
| <b>TORCH</b>                      | <b>PILE</b> | <b>SURFACE</b> | <b>COVER HT</b> | <b>20-FT WIND</b> |

|                                       |                     |   |                |
|---------------------------------------|---------------------|---|----------------|
| 4                                     |                     | 4 |                |
| <b>DATA CARD : SPOT FIRE DISTANCE</b> |                     |   |                |
|                                       | <b>SPECIES NAME</b> |   |                |
|                                       |                     |   | <b>REVISED</b> |

Figure 2.—Suggested labeling for spot fire program cards.

## Data Cards

To re-record data cards for original program under new partition for revised program.

1. Turn on calculator.
2. Read card for original program:  
Press **4**; feed card (either side) (if flashing; press **CLR**, try again).
3. Repartition memory: **4** **2nd** **OP** **1** **7**
4. Re-record:  
Press **4** **2nd** **WRITE**; feed card; (if flashing; press **CLR**, try again)  
Repeat step 4 for all sides of cards for this species.
5. Label the card appropriately (see fig. 2).
6. If there are data cards for another species to re-record:  
**6** **2nd** **OP** **1** **7**  
Repeat steps 2-5.

To duplicate valid data cards for the revised program:

1. Turn on calculator.  
Repartition memory: **4** **2nd** **OP** **1** **7**
2. Press **4** and feed in one side of the data card to be duplicated. If the display flashes, press **CLR** and try again.
3. Press **4** **2nd** **RS** and feed in one side of the blank card. If the display flashes, try again. Repeat step 3 for the other side of the blank card.
4. Label the card appropriately (see fig. 2).  
Repeat steps 2 through 4 for remaining data cards.

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APPENDIX  
PROGRAM LISTING

|     |    |     |     |    |     |     |    |     |     |    |     |     |
|-----|----|-----|-----|----|-----|-----|----|-----|-----|----|-----|-----|
| 000 | 25 | CLR | 057 | 32 | XIT | 114 | 71 | SBR | 171 | 22 | INV | 228 |
| 001 | 91 | R/S | 058 | 09 | 9   | 115 | 34 | FX  | 172 | 77 | GE  | 229 |
| 002 | 76 | LBL | 059 | 42 | STO | 116 | 76 | LBL | 173 | 52 | EE  | 230 |
| 003 | 22 | INV | 060 | 23 | 23  | 117 | 33 | XE  | 174 | 42 | STO | 231 |
| 004 | 53 | (   | 061 | 01 | 1   | 118 | 53 | (   | 175 | 17 | 17  | 232 |
| 005 | 43 | RCL | 062 | 00 | 0   | 119 | 73 | RC* | 176 | 92 | RTN | 233 |
| 006 | 01 | 01  | 063 | 42 | STO | 120 | 23 | 23  | 177 | 76 | LBL | 234 |
| 007 | 65 | X   | 064 | 22 | 22  | 121 | 65 | X   | 178 | 52 | EE  | 235 |
| 008 | 43 | RCL | 065 | 61 | GTO | 122 | 43 | RCL | 179 | 32 | XIT | 236 |
| 009 | 39 | 39  | 066 | 47 | CMS | 123 | 26 | 26  | 180 | 42 | STO | 237 |
| 010 | 45 | YX  | 067 | 76 | LBL | 124 | 45 | YX  | 181 | 17 | 17  | 238 |
| 011 | 43 | RCL | 068 | 24 | CE  | 125 | 73 | RC* | 182 | 92 | RTN | 239 |
| 012 | 02 | 02  | 069 | 07 | 7   | 126 | 22 | 22  | 183 | 76 | LBL | 240 |
| 013 | 65 | X   | 070 | 42 | STO | 127 | 65 | X   | 184 | 53 | (   | 241 |
| 014 | 43 | RCL | 071 | 23 | 23  | 128 | 43 | RCL | 185 | 53 | (   | 242 |
| 015 | 37 | 37  | 072 | 08 | 8   | 129 | 27 | 27  | 186 | 27 | 27  | 243 |
| 016 | 45 | YX  | 073 | 42 | STO | 130 | 85 | 85  | 187 | 00 | 0   | 244 |
| 017 | 93 | (   | 074 | 22 | 22  | 131 | 43 | RCL | 188 | 00 | 0   | 245 |
| 018 | 04 | 4   | 075 | 61 | GTO | 132 | 38 | 38  | 189 | 00 | 0   | 246 |
| 019 | 54 | (   | 076 | 47 | CMS | 133 | 55 | 55  | 190 | 07 | 7   | 247 |
| 020 | 53 | (   | 077 | 76 | LBL | 134 | 02 | 2   | 191 | 01 | 1   | 248 |
| 021 | 42 | STO | 078 | 23 | LNK | 135 | 54 | (   | 192 | 08 | 8   | 249 |
| 022 | 27 | 27  | 079 | 05 | 5   | 136 | 61 | GTO | 193 | 65 | 65  | 250 |
| 023 | 35 | 1/X | 080 | 42 | STO | 137 | 42 | STO | 194 | 43 | RCL | 251 |
| 024 | 65 | X   | 081 | 23 | 23  | 138 | 76 | LBL | 195 | 36 | 36  | 252 |
| 025 | 43 | RCL | 082 | 06 | 6   | 139 | 44 | SUM | 196 | 65 | 65  | 253 |
| 026 | 54 | (   | 083 | 42 | STO | 140 | 53 | (   | 197 | 43 | RCL | 254 |
| 027 | 54 | (   | 084 | 22 | 22  | 141 | 01 | 1   | 198 | 17 | 17  | 255 |
| 028 | 32 | XIT | 085 | 76 | LBL | 142 | 02 | 2   | 199 | 34 | FX  | 256 |
| 029 | 01 | 1   | 086 | 47 | CMS | 143 | 93 | 93  | 200 | 65 | 65  | 257 |
| 030 | 22 | INV | 087 | 92 | RTN | 144 | 02 | 2   | 201 | 53 | (   | 258 |
| 031 | 77 | GE  | 088 | 76 | LBL | 145 | 65 | 65  | 202 | 93 | 93  | 259 |
| 032 | 23 | LNK | 089 | 34 | FX  | 146 | 43 | RCL | 203 | 03 | 03  | 260 |
| 033 | 93 | (   | 090 | 53 | (   | 147 | 31 | 31  | 204 | 06 | 6   | 261 |
| 034 | 05 | 5   | 091 | 43 | RCL | 148 | 54 | (   | 205 | 02 | 2   | 262 |
| 035 | 22 | INV | 092 | 03 | 03  | 149 | 61 | GTO | 206 | 85 | 85  | 263 |
| 036 | 77 | GE  | 093 | 65 | X   | 150 | 42 | STO | 207 | 53 | (   | 264 |
| 037 | 24 | CE  | 094 | 43 | RCL | 151 | 76 | LBL | 208 | 43 | RCL | 265 |
| 038 | 43 | RCL | 095 | 39 | 39  | 152 | 45 | YX  | 209 | 25 | 25  | 266 |
| 039 | 26 | 26  | 096 | 45 | YX  | 153 | 43 | RCL | 210 | 55 | 55  | 267 |
| 040 | 32 | XIT | 097 | 43 | RCL | 154 | 35 | 35  | 211 | 43 | RCL | 268 |
| 041 | 03 | 3   | 098 | 04 | 04  | 155 | 32 | XIT | 212 | 17 | 17  | 269 |
| 042 | 93 | (   | 099 | 65 | 65  | 156 | 53 | (   | 213 | 54 | (   | 270 |
| 043 | 05 | 5   | 100 | 43 | RCL | 157 | 02 | 2   | 214 | 34 | FX  | 271 |
| 044 | 77 | GE  | 101 | 37 | 37  | 158 | 93 | 93  | 215 | 55 | 55  | 272 |
| 045 | 32 | XIT | 102 | 45 | YX  | 159 | 02 | 2   | 216 | 02 | 2   | 273 |
| 046 | 01 | 1   | 103 | 93 | 93  | 160 | 65 | 65  | 217 | 55 | 55  | 274 |
| 047 | 01 | 1   | 104 | 02 | 2   | 161 | 43 | RCL | 218 | 53 | (   | 275 |
| 048 | 42 | STO | 105 | 94 | +/- | 162 | 25 | 25  | 219 | 43 | RCL | 276 |
| 049 | 23 | 23  | 106 | 54 | (   | 163 | 45 | 45  | 220 | 25 | 25  | 277 |
| 050 | 01 | 1   | 107 | 42 | STO | 164 | 93 | 93  | 221 | 55 | 55  | 278 |
| 051 | 02 | 2   | 108 | 26 | 26  | 165 | 03 | 03  | 222 | 43 | RCL | 279 |
| 052 | 42 | STO | 109 | 92 | RTN | 166 | 03 | 03  | 223 | 17 | 17  | 280 |
| 053 | 22 | 22  | 110 | 76 | LBL | 167 | 07 | 7   | 224 | 54 | (   | 281 |
| 054 | 61 | GTO | 111 | 35 | 1/X | 168 | 75 | 75  | 225 | 23 | LNK | 282 |
| 055 | 47 | CMS | 112 | 71 | SBR | 169 | 04 | 4   | 226 | 54 | (   | 283 |
| 056 | 76 | LBL | 113 | 22 | INV | 170 | 54 | (   | 227 | 54 | (   | 284 |

|     |    |     |     |    |     |     |    |     |     |    |     |     |    |     |     |
|-----|----|-----|-----|----|-----|-----|----|-----|-----|----|-----|-----|----|-----|-----|
| 285 | 76 | LBL | 352 | 03 | 03  | 419 | 75 | -   | 486 | 48 | EXC | 553 | 91 | R/S | 553 |
| 286 | 93 | .   | 353 | 54 | )   | 420 | 53 | (   | 487 | 00 | 0   | 554 | 43 | RCL | 554 |
| 287 | 87 | IFF | 354 | 76 | LBL | 421 | 43 | RCL | 488 | 35 | 1/X | 555 | 31 | 31  | 555 |
| 288 | 03 | 03  | 355 | 55 | ÷   | 422 | 32 | 32  | 489 | 91 | R/S | 556 | 91 | R/S | 556 |
| 289 | 30 | TAN | 356 | 00 | 0   | 423 | 65 | ×   | 490 | 76 | LBL | 557 | 61 | GTD | 557 |
| 290 | 61 | GTD | 357 | 32 | X↑  | 424 | 09 | 9   | 491 | 38 | SIN | 558 | 29 | CF  | 558 |
| 291 | 75 | -   | 358 | 43 | RCL | 425 | 00 | 0   | 492 | 87 | IFF | 559 | 76 | LBL | 559 |
| 292 | 76 | LBL | 359 | 33 | 33  | 426 | 54 | )   | 493 | 01 | 01  | 560 | 11 | H   | 560 |
| 293 | 30 | TAN | 360 | 67 | EQ  | 427 | 39 | CDR | 494 | 94 | +/- | 561 | 86 | STF | 561 |
| 294 | 03 | 3   | 361 | 85 | +   | 428 | 54 | )   | 495 | 87 | IFF | 562 | 01 | 01  | 562 |
| 295 | 06 | 6   | 362 | 43 | RCL | 429 | 54 | )   | 496 | 02 | 02  | 563 | 42 | STD | 563 |
| 296 | 94 | +/- | 363 | 34 | 34  | 430 | 42 | STD | 497 | 28 | LOG | 564 | 39 | 39  | 564 |
| 297 | 34 | FX  | 364 | 67 | EQ  | 431 | 19 | 19  | 498 | 09 | 9   | 565 | 91 | R/S | 565 |
| 298 | 91 | R/S | 365 | 85 | +   | 432 | 97 | DSZ | 499 | 94 | +/- | 566 | 42 | STD | 566 |
| 299 | 76 | LBL | 366 | 53 | (   | 433 | 00 | 00  | 500 | 34 | FX  | 567 | 38 | 38  | 567 |
| 300 | 36 | PGM | 367 | 43 | RCL | 434 | 61 | GTD | 501 | 91 | R/S | 568 | 91 | R/S | 568 |
| 301 | 00 | 0   | 368 | 24 | 24  | 435 | 53 | (   | 502 | 43 | RCL | 569 | 42 | STD | 569 |
| 302 | 35 | 1/X | 369 | 55 | ÷   | 436 | 43 | RCL | 503 | 30 | 30  | 570 | 37 | 37  | 570 |
| 303 | 91 | R/S | 370 | 43 | RCL | 437 | 19 | 19  | 504 | 91 | R/S | 571 | 04 | 4   | 571 |
| 304 | 76 | LBL | 371 | 33 | 33  | 438 | 65 | ×   | 505 | 43 | RCL | 572 | 91 | R/S | 572 |
| 305 | 75 | -   | 372 | 54 | )   | 439 | 43 | RCL | 506 | 29 | 29  | 573 | 76 | LBL | 573 |
| 306 | 87 | IFF | 373 | 42 | STD | 440 | 33 | 33  | 507 | 91 | R/S | 574 | 12 | B   | 574 |
| 307 | 01 | 01  | 374 | 20 | 20  | 441 | 54 | )   | 508 | 43 | RCL | 575 | 86 | STF | 575 |
| 308 | 35 | 1/X | 375 | 42 | STD | 442 | 42 | STD | 509 | 28 | 28  | 576 | 02 | 02  | 576 |
| 309 | 87 | IFF | 376 | 19 | 19  | 443 | 21 | 21  | 510 | 91 | R/S | 577 | 42 | STD | 577 |
| 310 | 02 | 02  | 377 | 53 | (   | 444 | 91 | R/S | 511 | 76 | LBL | 578 | 31 | 31  | 578 |
| 311 | 44 | SUM | 378 | 43 | RCL | 445 | 76 | LBL | 512 | 29 | CF  | 579 | 91 | R/S | 579 |
| 312 | 53 | (   | 379 | 34 | 34  | 446 | 85 | +   | 513 | 43 | RCL | 580 | 76 | LBL | 580 |
| 313 | 53 | (   | 380 | 55 | ÷   | 447 | 43 | RCL | 514 | 35 | 35  | 581 | 13 | C   | 581 |
| 314 | 53 | (   | 381 | 01 | 1   | 448 | 24 | 24  | 515 | 91 | R/S | 582 | 86 | STF | 582 |
| 315 | 43 | RCL | 382 | 00 | 0   | 449 | 42 | STD | 516 | 43 | RCL | 583 | 03 | 03  | 583 |
| 316 | 29 | 29  | 383 | 00 | 0   | 450 | 21 | 21  | 517 | 36 | 36  | 584 | 42 | STD | 584 |
| 317 | 65 | ×   | 384 | 00 | 0   | 451 | 91 | R/S | 518 | 91 | R/S | 585 | 30 | 30  | 585 |
| 318 | 53 | (   | 385 | 00 | 0   | 452 | 76 | LBL | 519 | 43 | RCL | 586 | 91 | R/S | 586 |
| 319 | 93 | .   | 386 | 55 | ÷   | 453 | 43 | RCL | 520 | 34 | 34  | 587 | 42 | STD | 587 |
| 320 | 04 | 4   | 387 | 89 | 4   | 454 | 87 | IFF | 521 | 91 | R/S | 588 | 29 | 29  | 588 |
| 321 | 07 | 7   | 388 | 54 | )   | 455 | 01 | 01  | 522 | 43 | RCL | 589 | 91 | R/S | 589 |
| 322 | 04 | 4   | 389 | 42 | STD | 456 | 71 | SBR | 523 | 33 | 33  | 590 | 42 | STD | 590 |
| 323 | 65 | ×   | 390 | 18 | 18  | 457 | 87 | IFF | 524 | 91 | R/S | 591 | 28 | 28  | 591 |
| 324 | 43 | RCL | 391 | 06 | 6   | 458 | 02 | 02  | 525 | 43 | RCL | 592 | 91 | R/S | 592 |
| 325 | 36 | 36  | 392 | 42 | STD | 459 | 37 | P/R | 526 | 32 | 32  | 593 | 76 | LBL | 593 |
| 326 | 54 | )   | 393 | 00 | 00  | 460 | 22 | INV | 527 | 91 | R/S | 594 | 14 | I   | 594 |
| 327 | 45 | YX  | 394 | 76 | LBL | 461 | 87 | IFF | 528 | 00 | 0   | 595 | 42 | STD | 595 |
| 328 | 43 | RCL | 395 | 61 | GTD | 462 | 03 | 03  | 529 | 35 | 1/X | 596 | 35 | 35  | 596 |
| 329 | 28 | 28  | 396 | 53 | (   | 463 | 48 | EXC | 530 | 91 | R/S | 597 | 91 | R/S | 597 |
| 330 | 54 | )   | 397 | 43 | RCL | 464 | 61 | GTD | 531 | 76 | LBL | 598 | 76 | LBL | 598 |
| 331 | 65 | ×   | 398 | 20 | 20  | 465 | 38 | SIN | 532 | 94 | +/- | 599 | 15 | E   | 599 |
| 332 | 43 | RCL | 399 | 75 | -   | 466 | 76 | LBL | 533 | 01 | 1   | 600 | 42 | STD | 600 |
| 333 | 30 | 30  | 400 | 43 | RCL | 467 | 71 | SBR | 534 | 94 | +/- | 601 | 36 | 36  | 601 |
| 334 | 54 | )   | 401 | 18 | 18  | 468 | 87 | IFF | 535 | 34 | FX  | 602 | 91 | R/S | 602 |
| 335 | 34 | FX  | 402 | 65 | ×   | 469 | 02 | 02  | 536 | 91 | R/S | 603 | 76 | LBL | 603 |
| 336 | 65 | ×   | 403 | 53 | (   | 470 | 39 | CDR | 537 | 43 | RCL | 604 | 16 | H   | 604 |
| 337 | 01 | 1   | 404 | 53 | (   | 471 | 76 | LBL | 538 | 39 | 39  | 605 | 42 | STD | 605 |
| 338 | 93 | .   | 405 | 01 | 1   | 472 | 37 | P/R | 539 | 91 | R/S | 606 | 34 | 34  | 606 |
| 339 | 00 | 0   | 406 | 08 | 8   | 473 | 87 | IFF | 540 | 43 | RCL | 607 | 91 | R/S | 607 |
| 340 | 05 | 5   | 407 | 00 | 0   | 474 | 03 | 03  | 541 | 38 | 38  | 608 | 42 | STD | 608 |
| 341 | 05 | 5   | 408 | 65 | ×   | 475 | 39 | CDR | 542 | 91 | R/S | 609 | 33 | 33  | 609 |
| 342 | 54 | )   | 409 | 43 | RCL | 476 | 61 | GTD | 543 | 43 | RCL | 610 | 91 | R/S | 610 |
| 343 | 76 | LBL | 410 | 19 | 19  | 477 | 38 | SIN | 544 | 37 | 37  | 611 | 42 | STD | 611 |
| 344 | 42 | STD | 411 | 75 | -   | 478 | 76 | LBL | 545 | 91 | R/S | 612 | 32 | 32  | 612 |
| 345 | 42 | STD | 412 | 43 | RCL | 479 | 39 | CDR | 546 | 61 | GTD | 613 | 91 | R/S | 613 |
| 346 | 25 | 25  | 413 | 32 | 32  | 480 | 03 | 3   | 547 | 29 | CF  | 614 | 76 | LBL | 614 |
| 347 | 71 | SBR | 414 | 65 | ×   | 481 | 06 | 6   | 548 | 76 | LBL | 615 | 25 | CLR | 615 |
| 348 | 45 | YX  | 415 | 09 | 9   | 482 | 94 | +/- | 549 | 28 | LOG | 616 | 81 | RST | 616 |
| 349 | 71 | SBR | 416 | 00 | 0   | 483 | 34 | FX  | 550 | 04 | 4   | 617 | 25 | CLR | 617 |
| 350 | 53 | (   | 417 | 54 | )   | 484 | 91 | R/S | 551 | 94 | +/- | 618 | 25 | CLR | 618 |
| 351 | 87 | IFF | 418 | 39 | CDR | 485 | 76 | LBL | 552 | 34 | FX  | 619 | 25 | CLR | 619 |

## CORRECTED VALUES

**Table A.**—Corrected values of the standard deviation of fire intensity, as a percentage of the mean intensity (coefficient of variation) for 12 fuel models that occur without timber cover (supercedes Albini, 1983, table 3).

| Fuel model              | Mean horizontal windspeed at 10 m ht, m/s |      |      |      |      |      |
|-------------------------|---|------|------|------|------|------|
|                         | 5   | 10   | 15   | 20   | 25   | 30   |
| Grass and litter        |   |      |      |      |      |      |
| 1 Short grass           | 37.5                                      | 27.9 | 22.0 | 18.0 | 15.0 | 12.8 |
| 2 Grassy understory     | 56.5                                      | 45.6 | 37.3 | 31.0 | 26.1 | 22.4 |
| 3 Tall grass            | 49.1                                      | 35.9 | 27.2 | 21.3 | 17.2 | 14.2 |
| 9 Hardwood litter       | 70.4                                      | 63.3 | 56.2 | 49.8 | 44.3 | 39.6 |
| Shrub types             |   |      |      |      |      |      |
| 4 Mature chaparral      | 40.0                                      | 24.9 | 17.3 | 13.0 | 10.3 | 8.42 |
| 5 Young chaparral       | 24.4                                      | 14.1 | 10.0 | 7.75 | 6.32 | 5.33 |
| 6 Dormant brush         | 48.9                                      | 33.1 | 24.2 | 18.8 | 15.3 | 12.8 |
| 7 Southern rough        | 43.4                                      | 27.6 | 19.9 | 15.4 | 12.5 | 10.5 |
| Logging slash           |   |      |      |      |      |      |
| 10 Overgrown slash      | 55.1                                      | 39.7 | 30.3 | 24.4 | 20.3 | 17.4 |
| 11 Light conifer slash  | 52.1                                      | 35.5 | 26.5 | 21.0 | 17.4 | 14.8 |
| 12 Medium conifer slash | 50.1                                      | 33.4 | 24.6 | 19.3 | 15.9 | 13.4 |
| 13 Heavy conifer slash  | 49.6                                      | 32.5 | 23.8 | 18.7 | 15.4 | 13.0 |

Following are corrected example calculations (Albini 1983) using the author's equation numbers and nomenclature.

Example 1.

$$f(U) = AU^B = 545 \times (5)^{-1.21} = 77.7 \text{ s} \quad (9)$$

$$E = I f(U) = (2000)(77.7) = 155\,400 \text{ kJ/m} \quad (10)$$

$$H = 0.173 E^{1/2} = (0.173)(155\,400)^{1/2} = 68.2 \text{ m} \quad (11)$$

2.93 m = effective cover height

$$F = \text{flat terrain spotting distance} = 0.30 \text{ km} \quad (13)$$

$$U(68) = U(10\text{m}) \times \left( \frac{68}{10} \right)^{1/7} = (5)(1.32) = 6.6 \text{ m/s} \quad (14)$$

$$X = (2.78)(6.6)(68.2)^{1/2} = 151 \text{ m} = 0.151 \text{ km} \quad (15)$$

Spotting distance = 0.30 + 0.15 = 0.45 km

Example 2.

$$f(U) = AU^B = 301 (20)^{-1.05} = 13.0 \text{ s} \quad (16)$$

$$E = I f(U) = (50\,000)(13.0) = 650\,000 \text{ kJ/m} \quad (17)$$

$$H = 0.173 E^{1/2} = (0.173)(806) = 139 \text{ m} \quad (18)$$

$$F = 1.87 \text{ km}$$

$$U(139) = U(10) \times \left( \frac{139}{10} \right)^{1/7} = 29.1 \text{ m/s} \quad (19)$$

$$X = (2.78)(29.1)(139)^{1/2} = 954 \text{ m} = 0.954 \text{ km} \quad (20)$$

Spotting distance = 1.87 + 0.95 = 2.82 km

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The Intermountain Station includes the States of Montana, Idaho, Utah, Nevada, and western Wyoming. About 231 million acres, or 85 percent, of the land area in the Station territory are classified as forest and rangeland. These lands include grasslands, deserts, shrublands, alpine areas, and well-stocked forests. They supply fiber for forest industries; minerals for energy and industrial development; and water for domestic and industrial consumption. They also provide recreation opportunities for millions of visitors each year.

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