Introduction

Safety zone separation distance, size, and radius are calculated in the SAFETY module. The number of people and equipment can be specified. The calculation is based on flame height or length, which can be specified by the user. Alternatively the surface fire flame length calculated in SURFACE can be used directly in SAFETY. While flame length can be calculated for crown fire, SAFETY cannot be linked to CROWN.

Objectives

1. Define safety zone model assumptions and limitations.
2. Describe input and output variables for SAFETY.
3. Calculate safety zone separation distance, size, and radius for surface and crown fire using direct entry of flame length.
4. Calculate safety zone size using surface fire flame length calculated in SURFACE.
5. Demonstrate that head fire flame length is used to calculate safety zone size even if SURFACE calculations are for other directions.

Where This Lesson Fits In

This is a lesson in the Modeling Unit. It is assumed that the trainee has completed the four lessons in the Introduction Unit and has basic BehavePlus operation skills.

The **Surface Fire Spread and Intensity** lesson covers calculation of surface fire flame length using the SURFACE module.

The **Crown Fire Intensity** lesson covers calculation of crown fire flame length using the CROWN module.

Introduction

A safety zone is an area that firefighters can retreat to and not have to deploy fire shelters to remain safe. A safety zone is *not* a deployment zone. Safety zones are an *integral* part of fireline safety. The minimum separation distance between the fire and a person depends on Flame Length, which varies with conditions—fuel, wind, slope, and fuel moisture. The size of a safety zone also depends on the number of people and equipment to be protected.

The SAFETY module is based on research by Butler and Cohen (1998a, b; 1996).

Some of the material in this lesson is taken from the course *S-390—Introduction to Wildland Fire Behavior Calculations*. A handout for this lesson is an update of a portion of S-390, Unit 5, Lesson C (2nd Edition, Feb. 2007). The handout describes some of the background of the model and additional research that is being done to improve the model.

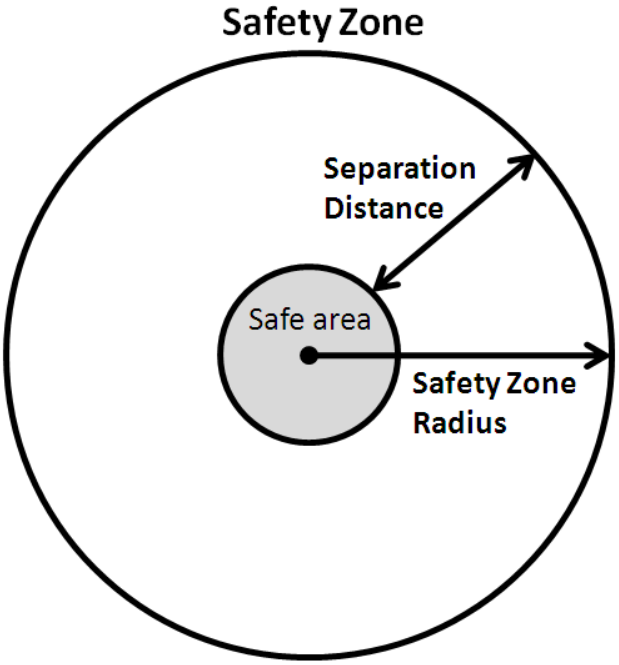
The Safety Zone Model

Safety Zone Size calculations are done on the "worst case scenario" that fire will burn around the safety zone on all sides with each side of the safety zone receiving the same amount of heat.

The basic model is based on calculation of the minimum separation distance between a firefighter and flames required to prevent burn injury. The safety zone must be large enough to allow the firefighter to be at least 4 flame heights in distance from the fire front.

SAFETY Output Variables

The basic model is a calculation of Safety Zone Separation Distance. This is used along with calculation of the size and radius of a safe area to calculate the radius and area of a circular Safety Zone Size. An example in this lesson covers the relationship to the size of a square safety zone.



Separation Distance is the minimum distance a firefighter in protective clothing must be separated from flames to prevent radiant heat injury. Separation Distance is calculated as 4 x flame height. **Flame Length** is used as a worst case estimator of flame height.

Safety Zone Radius is the radius of a circular safety zone just large enough to protect the specified number of personnel and heavy equipment from radiant burn injury. Calculation is based on Safety Zone Separation Distance plus the radius of a circle that fits all personnel and equipment. This core area represents the only safe area of the safety zone. Outside the core area persons may receive burns.

Safety Zone Size is the area of a circular safety zone just large enough to protect the specified number of personnel and heavy equipment from radiant burn injury. Calculation is based on the **Safety Zone Radius**.

SAFETY input variables

Number of Personnel to be located within the safety zone includes all firefighters, overhead team members, and any other personnel to be protected in the safety zone.

Area per Person is the average area occupied by each person to be located within the safety zone. A reasonable figure is 50 ft^2 per person, which is enough to allow shelter deployment in the event it becomes necessary.

Number of Heavy Equipment is the number of pieces of heavy equipment to be sheltered within the safety zone. Each piece is assumed to occupy the area specified by the Area per Heavy Equipment variable. In the calculations, space is allocated in the safety zone for equipment brought in or already present. Equipment is a liability in a

safety zone and often carries flammable liquids. In no other situation is heavy equipment allowed to operate in such close proximity to personnel. Heavy equipment or engines should not be brought into a safety zone if such equipment compromises the safety of personnel in the safety zone.

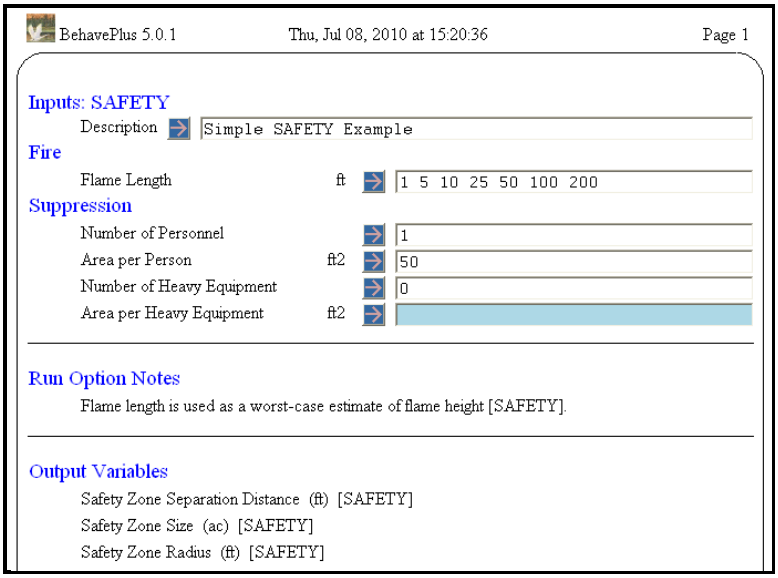
Area per Heavy Equipment is the average area needed for each piece of equipment to be located within the safety zone. For general planning, when the equipment types are not known, use a mean area of 300 ft^2.

Flame Length is used to calculate separation distance. The mathematical model is based on flame height. Flame Length is used as a worst case estimator of flame height. Flame Length is an input variable if SAFETY is used as an independent module. Flame Length from either surface or crown fire can be specified. If SURFACE is used to calculate Flame Length, the maximum Flame Length is used for SAFETY even if SURFACE calculations are for a direction other than for the direction of maximum spread. Although it is possible to calculate crown fire Flame Length with the CROWN module, BehavePlus does not offer a link between CROWN and SAFETY.

Size for one person for various flame length values

We will first calculate Safety Zone Size using the SAFETY module alone. We will look at size requirements for a single person for various Flame Length values.

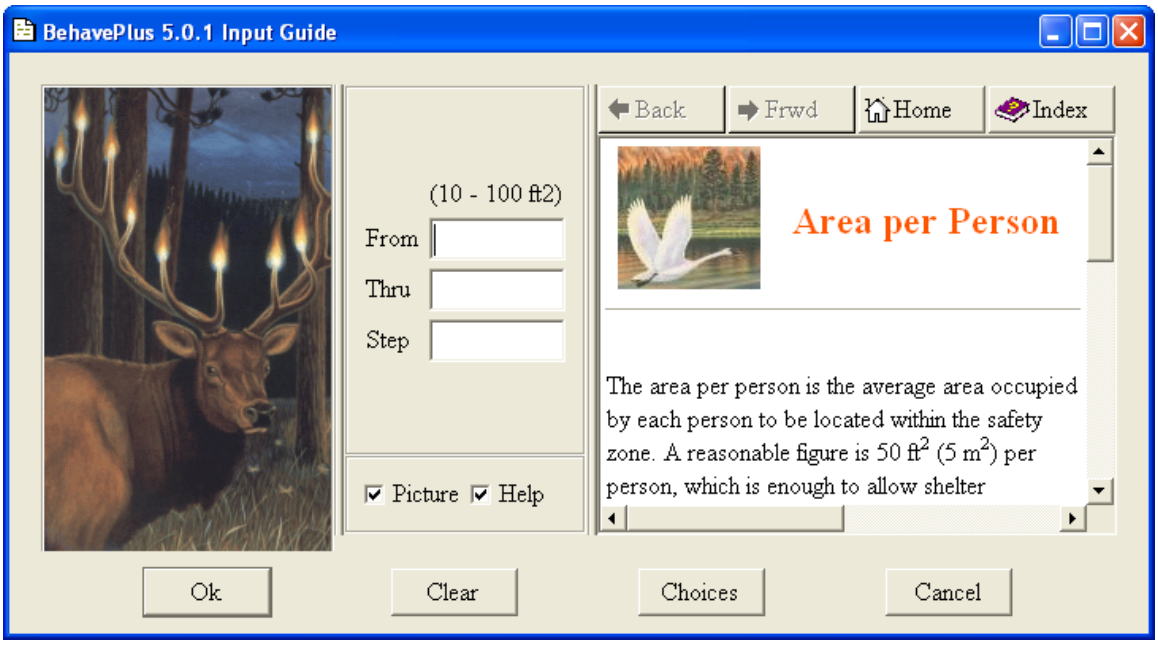
- Open **BasicStart.bpw**.
- Remove selection of SURFACE.
- Select SAFETY.
- Click **Options…**.
- Select all three output variables.
- Click **Ok** twice.
- Enter values on the Worksheet as shown below.



As an alternative to typing in the value of 50 ft^2 for Area per Person, you can try the following:

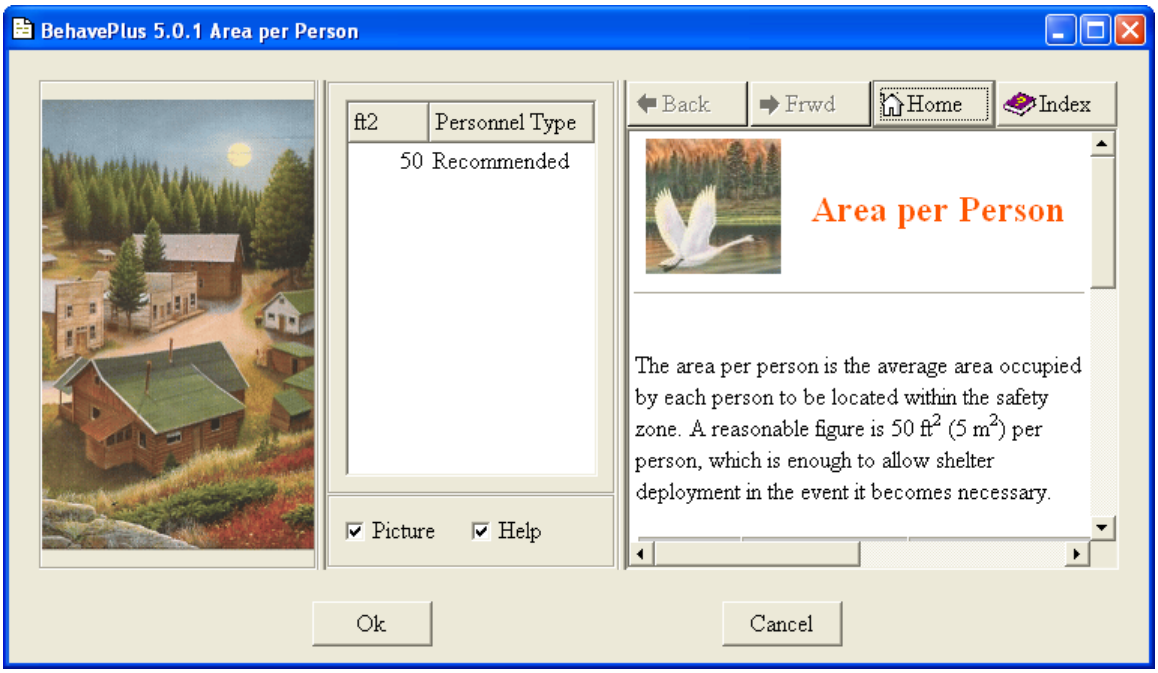
- Click on the **Guide** button beside Area per Person.

Note that the valid range of values is 10 to 100 ft^2.



- Click on **Choices**.

The recommended value is the only choice in the list.



- Calculate the Run. Look at the resulting table and graphs.

Note that for every Flame Length value, Safety Zone Radius is 4 ft greater than the Safety Zone Separation Distance, to allow for the safe area required for one person. A circle with an area of 50 ft^2 has a radius of 4 ft (8 ft diameter).

The Safety Zone Radius required for a 1 foot flame is 8 ft (a circle with a 16 ft diameter).

A 200 ft flame, on the other hand, would require nearly a 47 acre circular zone, with a radius of 804 ft –a diameter of 1608 feet or 0.3 mile.

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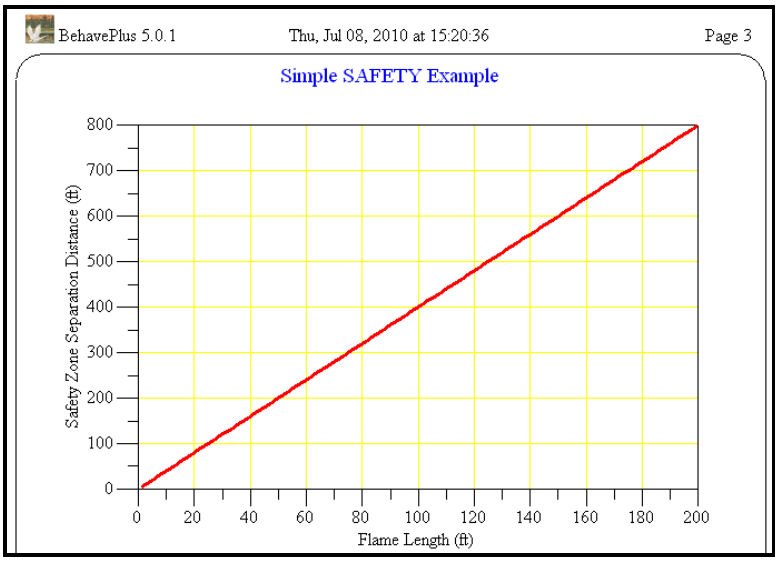
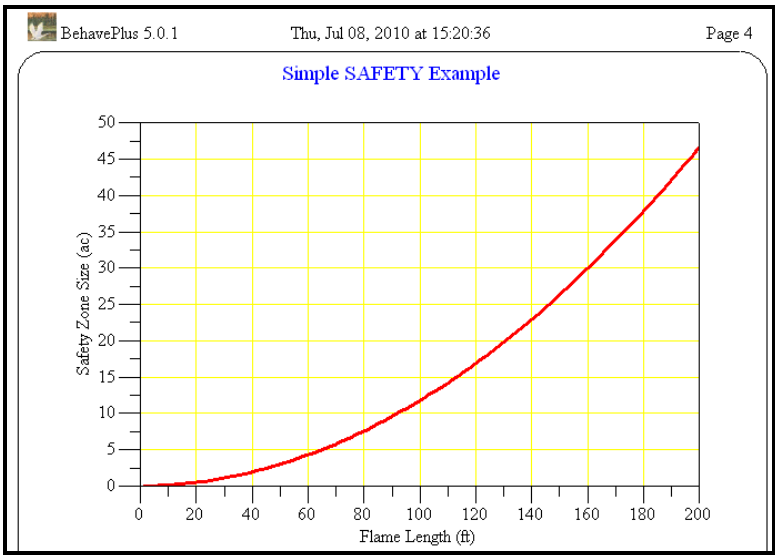
Simple SAFETY Example

Flame Length ft	Separation Distance ft	Zone Size ac	Zone Radius ft
1	4	0.00	8
5	20	0.04	24
10	40	0.14	44
25	100	0.78	104
50	200	3.00	204
100	400	11.77	404
200	800	46.62	804

This plot illustrates the simple calculation—Safety Zone Separation Distance is 4 times Flame Length.



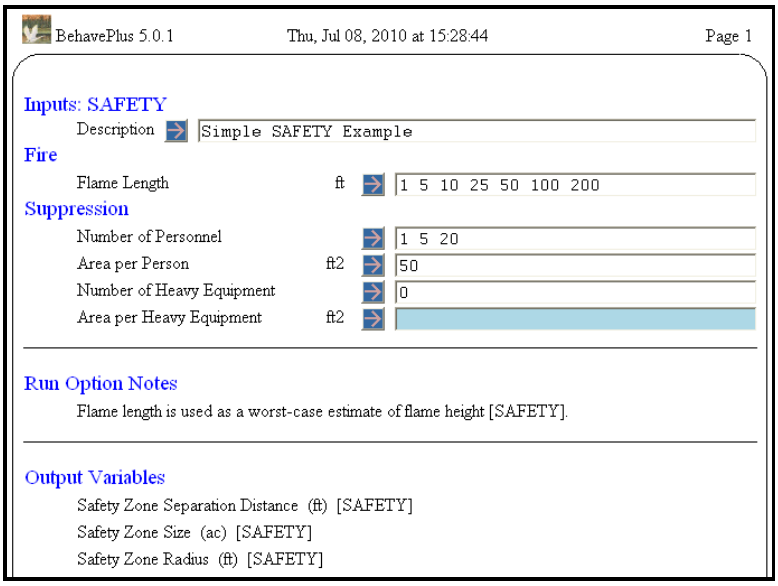
This plot shows that area (A) of a circular safety zone does not have a linear relationship with Flame Length, since $A = \pi R^2$.



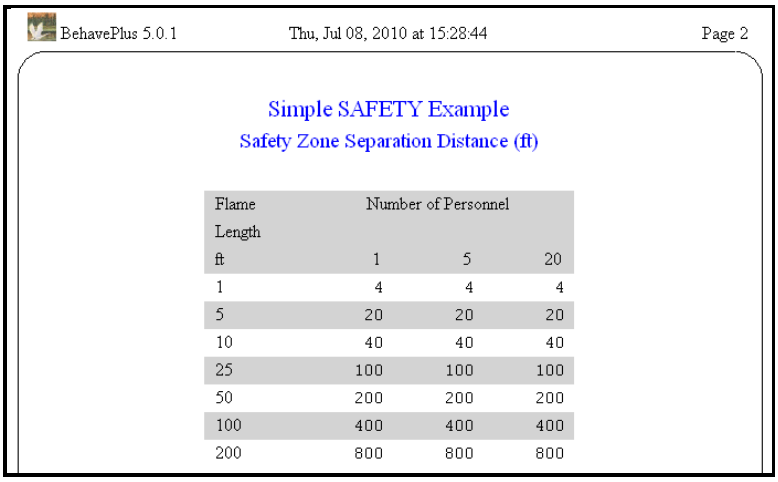
Increased size for additional people

Let's look at the results for more than one person.

- Add 5 and 20 to the input field for Number of Personnel.



Notice that the Safety Zone Separation Distance does not change for an increased number of personnel. The closest person still needs to be at least the calculated separation distance from the fire.



Flame Length ft	Number of Personnel 1	5	20
1	4	4	4
5	20	20	20
10	40	40	40
25	100	100	100
50	200	200	200
100	400	400	400
200	800	800	800

However, the Safety Zone Size requirement does increase to accommodate additional people.

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Simple SAFETY Example

Safety Zone Size (ac)

Flame Length ft	Number of Personnel 1	5	20
1	0.00	0.01	0.03
5	0.04	0.06	0.10
10	0.14	0.17	0.24
25	0.78	0.86	1.00
50	3.00	3.15	3.42
100	11.77	12.06	12.59
200	46.62	47.19	48.24

The safety zone itself is larger because the Safety Zone Radius is larger, the result of the requirement for a larger safe area.

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Simple SAFETY Example

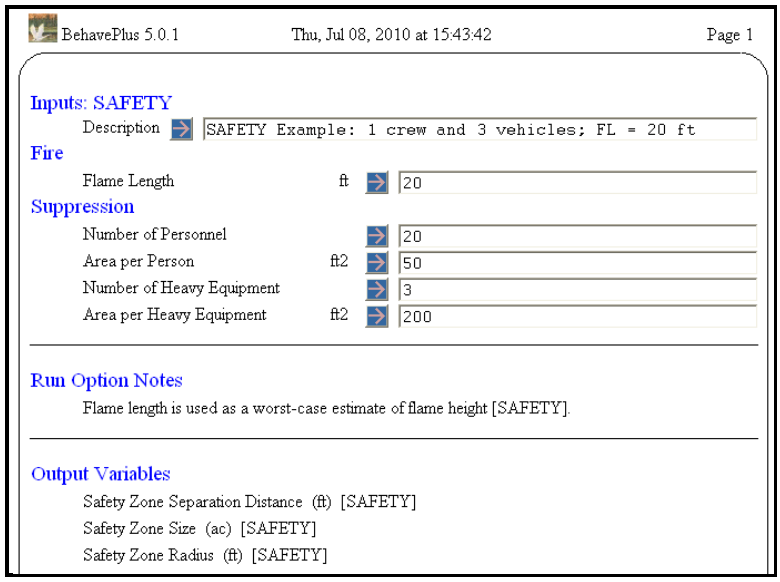
Safety Zone Radius (ft)

Flame Length ft	Number of Personnel 1	5	20
1	8	13	22
5	24	29	38
10	44	49	58
25	104	109	118
50	204	209	218
100	404	409	418
200	804	809	818

Equipment in the safety zone

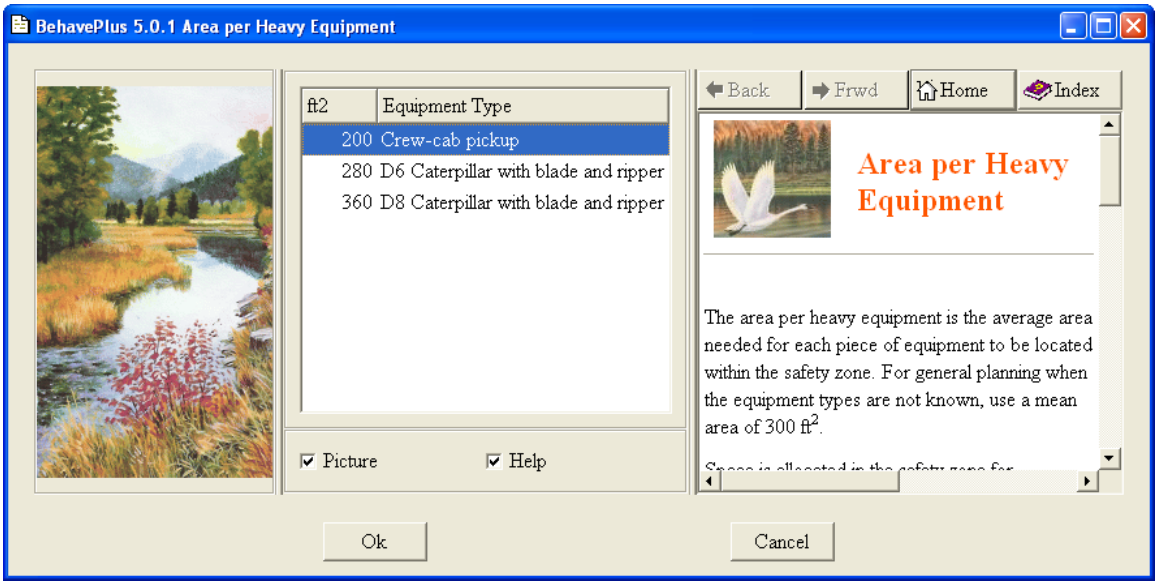
Now calculate safety zone size for 1 crew and 3 vehicles for a 20 ft flame.

- Enter values on the Worksheet as shown.



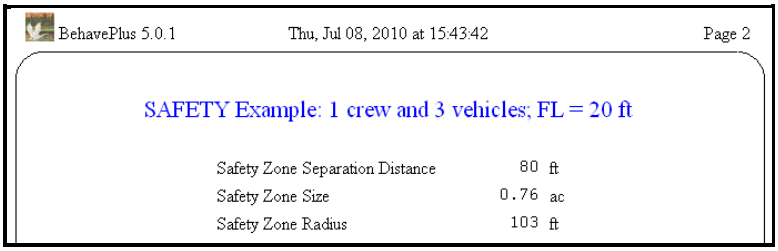
As an alternative to typing in values for Area per Heavy Equipment,

- Click on the **Guide** button for Area per Heavy Equipment.
- Click **Choices** to see some guidelines.
- Select **Crew-cab pickup**, which is 200 ft2.



- Calculate the Run.

Notice that the entry in the **Description** line appears on the output table.



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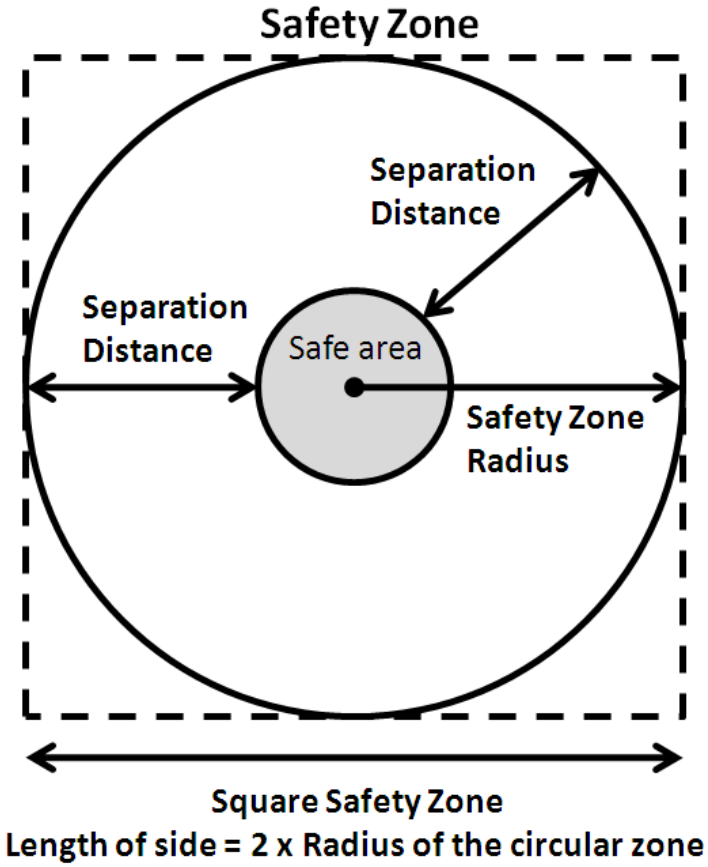
SAFETY Example: 1 crew and 3 vehicles; FL = 20 ft

Safety Zone Separation Distance	80	ft
Safety Zone Size	0.76	ac
Safety Zone Radius	103	ft

Square safety zone size

BehavePlus calculates the size of a circular safety zone size.
Safety zones are often shaped more like a square.

The diameter of the circle (twice its radius) is equal to the side of a square large enough to accommodate the safe area and the separation distance.



Following is a comparison of size of related circular and square safety zones.

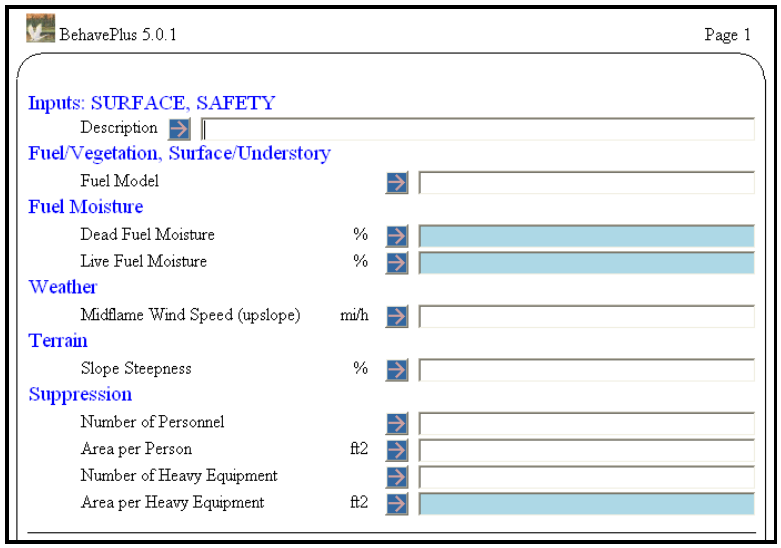
Safety Zone Radius, ft	Square side, ft	Circular safety zone, ac	Square safety zone, ac
50	100	0.2	0.2
100	200	0.7	0.9
150	300	1.6	2.1
200	400	2.9	3.7
250	500	4.5	5.7
300	600	6.5	8.3
350	700	8.8	11.2
400	800	12	15
450	900	15	19
500	1000	18	23
550	1100	22	28
600	1200	26	33
650	1300	30	39
700	1400	35	45
750	1500	41	52
800	1600	46	59
850	1700	52	66
900	1800	58	74
950	1900	65	83
1000	2000	72	92

Using Calculated Surface Fire Flame Length

Thus far in this lesson, we have specified a value for Flame Length to estimate safety zone size. We now use surface fire Flame Length calculated in the SURFACE module.

- Open the Example worksheet **SurfaceSimple.bpw**.
- Change the SURFACE output variable selection to only Flame Length.
- Select the SAFETY module.
- Select all of the SAFETY output variables.

Your Worksheet should look like the one below. Note that Flame Length is no longer an input variable.

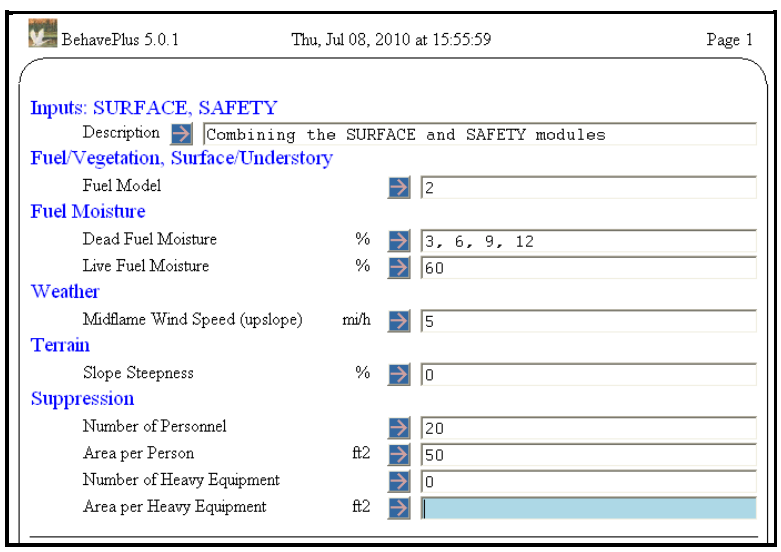


All of the variables that affect head fire Flame Length (Fuel Model, Dead and Live Fuel Moisture, wind speed, and slope) affect Safety Zone Size.

Effect of dead fuel moisture

We will look at the effect of changes in fuel moisture on Safety Zone Size.

- Enter values as shown on the Worksheet below.



Notice that for drier fuels, Flame Length is higher and Safety Zone Size is larger. Think about how fine dead fuel moisture can vary throughout the day.

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Combining the SURFACE and SAFETY modules

Dead Fuel Moisture %	Flame Length ft	Separation Distance ft	Zone Size ac	Zone Radius ft
3	8.0	32	0.18	50
6	6.8	27	0.15	45
9	6.2	25	0.13	43
12	4.8	19	0.10	37

Effect of fuel model

Now look at the effect of Fuel Model on Safety Zone Size.

- Using the previous Worksheet, compare results for the following four Fuel Models:

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Inputs: SURFACE, SAFETY

Description Combining the SURFACE and SAFETY modules

Fuel/Vegetation, Surface/Understory

Fuel Model 2, 5, gr2, sh3

Recall that the last page of results is a list of Fuel Model codes and names. This page is added whenever you calculate a Run.

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Discrete Variable Codes Used

Combining the SURFACE and SAFETY modules

Fuel Model

2	Timber grass and understory (S)
5	Brush (S)
gr2	Low load, dry climate grass (D) (102)
sh3	Moderate load, humid climate shrub (S) (143)

Look at variation in Safety Zone Separation Distance by Fuel Model and Dead Fuel Moisture.

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Combining the SURFACE and SAFETY modules

Safety Zone Separation Distance (ft)

Fuel Model	Dead Fuel Moisture %			
	3	6	9	12
2	32	27	25	19
5	34	31	29	17
gr2	21	18	17	13
sh3	13	11	10	9

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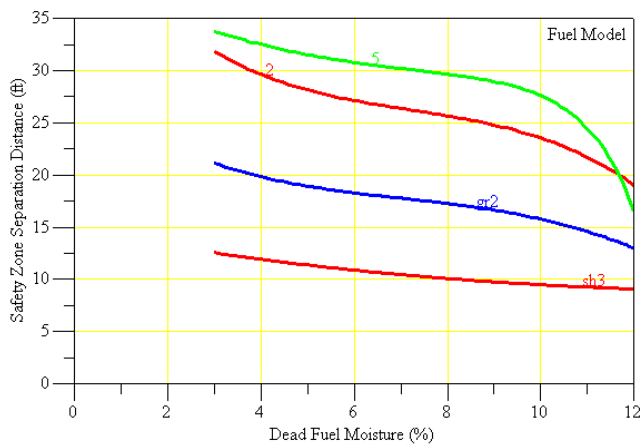
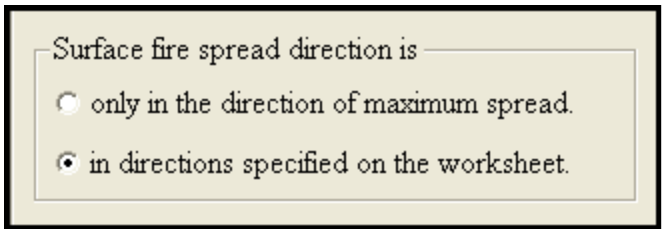
Combining the SURFACE and SAFETY modules



Non- head fire Flame Length in SURFACE

Continuing with the current worksheet:

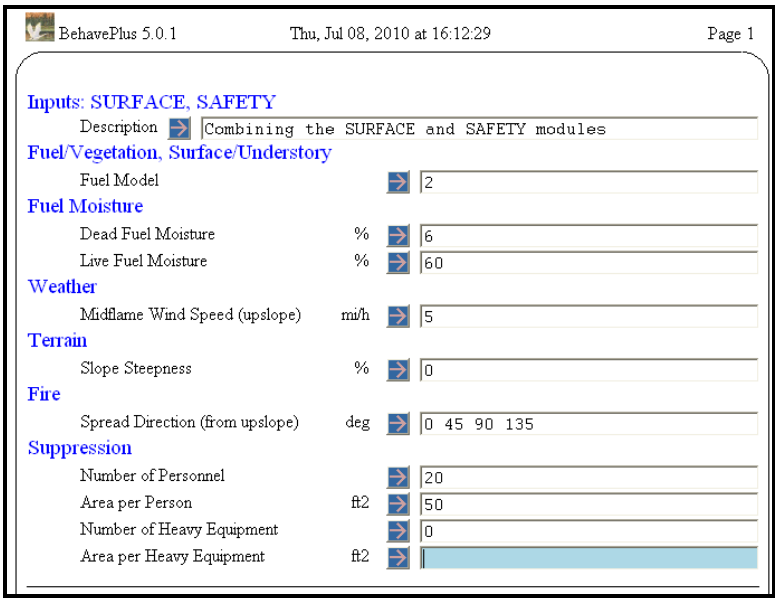
- Click SURFACE **Options**….
- Select the **Directions** tab.
- Select **Surface fire spread direction is in directions specified on the worksheet**.



- Click **Ok** twice.

We will do a calculation for one Fuel Model and one value of Dead Fuel Moisture and several Spread Directions.

- Modify the Worksheet to look like the one below.



Although the calculated Flame Length changes for spread direction, the safety zone calculations do not.

NOTE: The head fire Flame Length is always used in safety zone calculations. This worst-case calculation accounts for a potential change of fire direction.

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Combining the SURFACE and SAFETY modules

Spread Dir deg	Flame Length ft	Separation Distance ft	Zone Size ac	Zone Radius ft
0	6.8	27	0.15	45
45	3.8	27	0.15	45
90	2.4	27	0.15	45
135	1.9	27	0.15	45

Flame length for crown fire

If both SUFACE and SAFETY are selected, the surface fire Flame Length from SURFACE is used in SAFETY.

BehavePlus does not, however, offer the ability to link CROWN and SAFETY. To estimate Safety Zone Size for crown fire, you can use CROWN to calculate crown fire Flame Length and then enter that value in a separate SAFETY Run.

- Open **BasicStart.bpw**.
- Select only the CROWN module (not SURFACE or SAFETY).
- Click on CROWN **Options…**.
- Remove all of the selected output variables from the **Spread Outputs** tab.
- Click on the **Intensity Outputs** tab.
- Select only Crown Flame Length.
- Click **Ok** twice.
- Enter values on the Worksheet as shown below and calculate the Run.

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Inputs: CROWN

Description		Calculating Crown Flame Length
Fuel/Vegetation, Overstory		
Canopy Height	ft	60
Canopy Base Height	ft	5
Canopy Bulk Density	lb/ft3	0.019
Fuel Moisture		
1-h Moisture	%	6
10-h Moisture	%	6
100-h Moisture	%	6
Live Woody Moisture	%	60
Weather		
20-ft Wind Speed (upslope)	mi/h	20 25 30
Fire		
Heat per Unit Area	Btu/ft2	1325

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Calculating Crown Flame Length

20-ft Wind mi/h	Crown Flame Leng ft
20	109.9
25	134.7
30	159.4

This gives you an estimate of crown fire Flame Length for the specified conditions. It would not be a good idea, however, to report that the expected Flame Length is 134.7 feet. The program will give you even more false precision, if you reset the decimal places for display. We will use these values to establish a range of reasonable Flame Length inputs to calculate Safety Zone Size.

- Select only SAFETY (remove CROWN selection), and select all outputs.
- Enter values on the Worksheet as shown and calculate the Run.

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Inputs: SAFETY

Description: Calculating Safety Zone Size from Crown Flame Length

Fire

Flame Length ft: 110, 130, 150, 170, 190

Suppression

Number of Personnel: 20

Area per Person ft2: 50

Number of Heavy Equipment: 0

Area per Heavy Equipment ft2:

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Calculating Safety Zone Size from Crown Flame Length

Flame Length ft	Separation Distance ft	Zone Size ac	Zone Radius ft
110	440	15.12	458
130	520	20.86	538
150	600	27.53	618
170	680	35.12	698
190	760	43.64	778

A fairly large safety zone would be required for a fire with these Flame Lengths. Note the different size requirements for 110 vs. 190 ft flames.

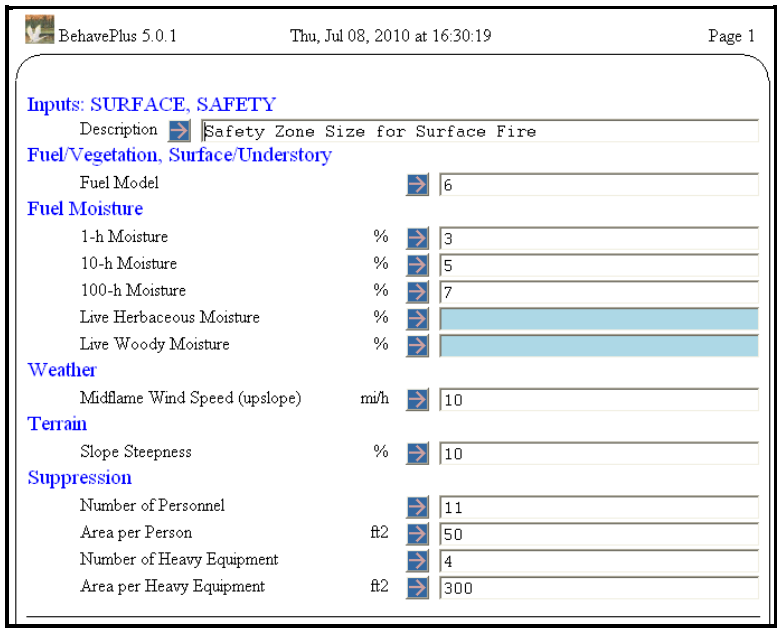
Recall that the calculated Safety Zone Size is for a circular area. A square area would be even larger. Note on the comparison table given earlier in this lesson that a Safety Zone Radius of 600 ft is a circular safety zone of 26 acres, corresponding to a square zone of 33 acres.

EXAMPLE 1-- Calculating Safety Zone Separation Distance, Size, and Radius for Surface Fire

You are a task force leader on a brush fire (fuel model 6). Your team consists of a medium-sized dozer (Type 2 or D-3), three small engines (Type 6 or brush/pumper truck), and 11 personnel, including yourself. You need to calculate an adequate safety zone for your crew and equipment.

- Open the **BasicStart.bpw** Worksheet.
- Select the Safety Zone (SAFETY) module. (Both SURFACE and SAFETY should be selected.)
- Open SAFETY **Options…**.
- Select the Safety Zone Separation Distance, Safety Zone Size, and Safety Zone Radius.
- Click **Ok** twice.

Enter the following values on the Worksheet. Note that 50 ft^2 and 300 ft^2 are used as the area for personnel and equipment respectively.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Inputs: SURFACE, SAFETY

Description		Safety Zone Size for Surface Fire
Fuel/Vegetation, Surface/Understory		
Fuel Model		6
Fuel Moisture		
1-h Moisture	%	3
10-h Moisture	%	5
100-h Moisture	%	7
Live Herbaceous Moisture	%	
Live Woody Moisture	%	
Weather		
Midflame Wind Speed (upslope)	mi/h	10
Terrain		
Slope Steepness	%	10
Suppression		
Number of Personnel		11
Area per Person	ft2	50
Number of Heavy Equipment		4
Area per Heavy Equipment	ft2	300

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Safety Zone Size for Surface Fire

Surface Rate of Spread (maximum)	111.5	ch/h
Flame Length	11.5	ft
Safety Zone Separation Distance	46	ft
Safety Zone Size	0.35	ac
Safety Zone Radius	70	ft

An adequate Safety Zone Size for your equipment and personnel is **.35 ac**, with a Separation Distance of **46 ft** and a Radius of **70 ft**.

Example 2-- Calculating Safety Zone Separation Distance, Size, and Radius for Crown Fire

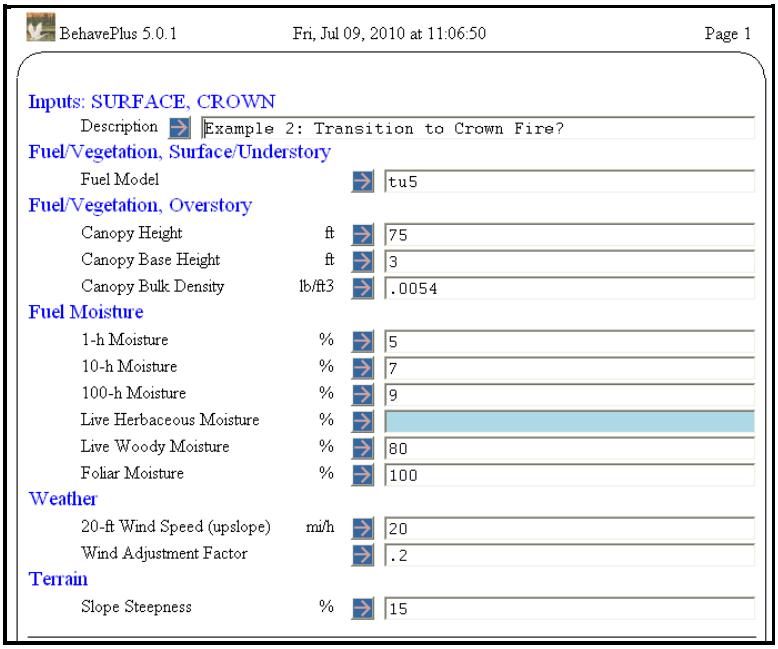
Several days later, at the morning briefing, you are informed you will be working in a different division with *two additional dozers* (4 additional personnel). Weather and fuel conditions have moderated since your surface run, but you will be in timber (Ponderosa Pine & Douglas-fir / TU5). Your dozers will be punching in a line and your engines will follow behind burning out. You want to calculate the appropriate size of a safety zone given your additional resources, the change in fuel type, and the weather forecast.

We first estimate the potential of the fire making the transition from surface to crown fire.

Let's first run SURFACE and CROWN.

- Open the **BasicStart.bpw** Worksheet.
- In the **Module Selection** window, select SURFACE and CROWN.
- Open SURFACE **Options….**
- On the **Basic Outputs** tab, unselect Surface Rate of Spread.
- Click on the **Wind Speed** tab.
- Select **Wind speed is entered as 20-ft wind and Input Wind adj factor**.
- Click **Ok**.
- Open CROWN **Options….**
- Click on the **Spread Outputs** tab (the default), and unselect all spread outputs *except* Fire Type.
- Click on **Intensity Outputs** and select Crown Flame Length.
- Click **Ok** twice.

➢ Enter the following values on the Worksheet.



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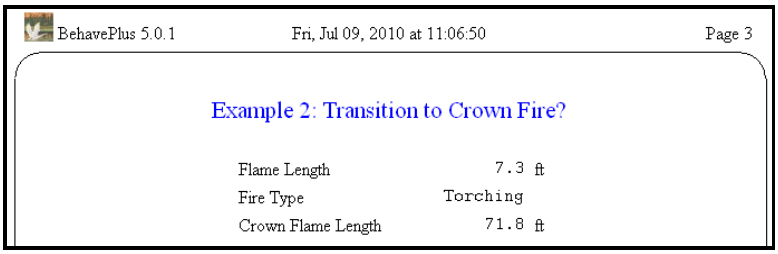
Inputs: SURFACE, CROWN		
Description		Example 2: Transition to Crown Fire?
Fuel/Vegetation, Surface/Understory		
Fuel Model		tu5
Fuel/Vegetation, Overstory		
Canopy Height	ft	75
Canopy Base Height	ft	3
Canopy Bulk Density	lb/ft3	.0054
Fuel Moisture		
1-h Moisture	%	5
10-h Moisture	%	7
100-h Moisture	%	9
Live Herbaceous Moisture	%	
Live Woody Moisture	%	80
Foliar Moisture	%	100
Weather		
20-ft Wind Speed (upslope)	mi/h	20
Wind Adjustment Factor		.2
Terrain		
Slope Steepness	%	15



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Example 2: Transition to Crown Fire?

Flame Length	7.3	ft
Fire Type	Torching	
Crown Flame Length	71.8	ft

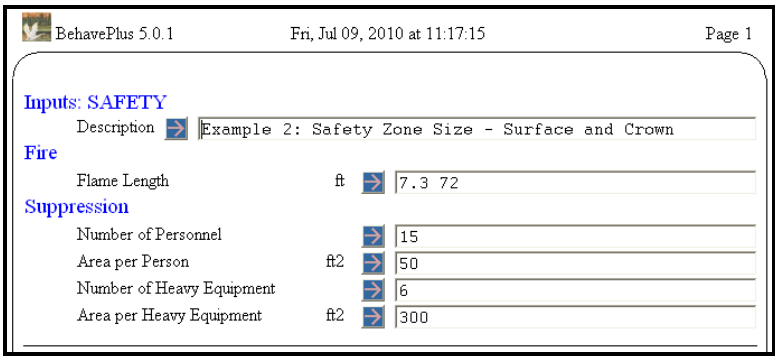
The Flame Length of the surface fire is calculated to be **7.3 ft**.
The Fire Type is estimated to be 'torching', which is a passive crown fire. If the fire were nevertheless able to spread as an active crown fire (crowning), the calculated flame length is **71.8 ft**.

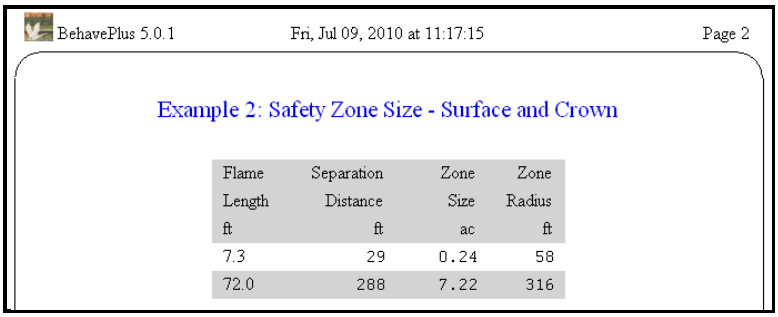
Note: A modeler should do additional calculations examining ranges around the selected input values. It would be informative to look at the variables Transition Ratio and Active Ratio to better understand the 'torching' result.

We will now run SAFETY and input the surface and crown Flame Length values.

- In the **Module Selection** window, select only the SAFETY module.
- Open SAFETY **Options….**
- Select Safety Zone Separation Distance, Size, and Radius as output variables.

Enter the following values on the Worksheet and calculate the Run.





Flame Length ft	Separation Distance ft	Zone Size ac	Zone Radius ft
7.3	29	0.24	58
72.0	288	7.22	316

An adequate safety zone size for your equipment and personnel for a surface fire is a quarter acre with a separation distance of **29 ft** and a radius of **58 ft**. For a crown fire, the safety zone should be is **7.22 ac**, with a separation distance of **288 ft** and a radius of **316 ft**.

Reality Checks

- Good safety zones are often recognized, not built (such as meadows).
- The distance to safety zones needs to reflect the potential rate of spread of the fire.
- Situational awareness—size of safety zones and length of escape routes change depending on conditions; continual re-evaluation is a must.
- Is the size of the safety zone too large for resource objectives?
- Is the safety zone being used for a parking area / fuel storage/ equipment?
- Is construction of a large safety zone feasible within the time constraints?
- If the safety zone requirement is large, do we need to put people in that area?
- What are other tactical options?

Where should we put safety zones?

- Meadows
- Large open areas below the fire.
- On the lee side of ridges outside of eddy effect when windy
- Broad open ridgelines (if not windy)
- Cross slope from the head of the fire
- Areas with good access for personnel
- In previously burnt areas if it is hard black

Where should we NOT put safety zones?

- Saddles
- Chimneys
- Heavy fuel concentrations
- Areas with poor access
- Razor back ridges
- Windward side of ridge above the fire
- Midslope above the fire
- Above the fire

Summary

Safety Zone Separation Distance, Size, and Radius were calculated using the SAFETY module. Surface fire Flame Lengths can be calculated in SURFACE and used directly in SAFETY. The head fire Flame Length (worst case scenario) is always used, even if SURFACE calculations are for other than head fire. Crown fire Flame Lengths can be estimated using CROWN, but there is not a direct link between CROWN and SAFETY.

It is critical to remember that calculations of Flame Length and Safety Zone Size are based on models, which have simplifying assumptions and cannot include all of the real-world conditions that must be considered.

References

(Available on http://www.FireModels.org)

Butler, B. W. and J. D. Cohen. (1998a) Firefighter safety zones: how big is big enough? *Fire Management Notes* **58**(1): 13-16. (4 pages)

Butler, B. W. and J. D. Cohen. (1998b) Firefighter safety zones: a theoretical model based on radiative heating. *International Journal of Wildland Fire* **8**: 73-77. (5 pages)

Butler, B. W. and J. D. Cohen (1996) An Analytical Evaluation of Firefighter Safety Zones. In 'Proceedings 13th Conference on Fire and Forest Meteorological Society'. 27-31 October 1996, Lorne, Australia. (7 pages)

Butler, B. and J. Forthofer. (2002) Get into the zone. *Wildfire* **September/October**: 16-22. (6 pages)

Exercise

1. The following is a page from the *Incident Response Pocket Guide* (January 2010).

Safety Zones

A safety zone is an area where a firefighter can survive without a fire shelter. Considerations for effective safety zones:

- Take advantage of heat barriers such as lee side of ridges, large rocks, or solid structures.
- When possible, burn out safety zones prior to arrival of fire front.
- Avoid locations upslope or downwind from the fire; chimneys, saddles, or narrow canyons; and steep uphill escape routes.
- Not intended for structure protection.

Separation distance between the firefighter and the flames should be at least four times the maximum continuous flame height. Distance separation is the radius from the center of the safety zone to the nearest fuels.

Flame Height	Separation Distance (firefighters to flames)	Area in acres*
10 ft	40 ft	1/10 acre
20 ft	80 ft	1/2 acre
50 ft	200 ft	3 acres
100 ft	400 ft	12 acres
200 ft	800 ft	46 acres

*Area in acres is calculated to allow for distance separation on all sides for a 3-person engine crew (1 acre is approximately the size of a football field, or 208 feet by 208 feet).

Calculations are based on radiant heat only and do not account for convective heat from wind and/or terrain influences. Since calculations assume no wind and no slope, safety zones downwind or upslope from the fire may require larger separation distances.

7

Compare BehavePlus calculations to those in the table. The table is for a “3-person engine crew.” Is the Safety Zone Size calculated for the three people alone, or is the engine included in the safety zone? What are safety considerations of having the engine in the safety zone?