An Examination of Home Destruction

Roaring Lion Fire
Bitterroot Mountains, Montana

Jack D. Cohen, PhD
Research Physical Scientist, Missoula, MT

Letter from the chief

In September of 2016, just two months after the Roaring Lion Fire destroyed 16 homes in and on the edge of the Bitterroot National Forest, the Montana Department of Natural Resources and Conservation (DNRC) contracted Dr. Jack D. Cohen to conduct an examination of the home destruction there.

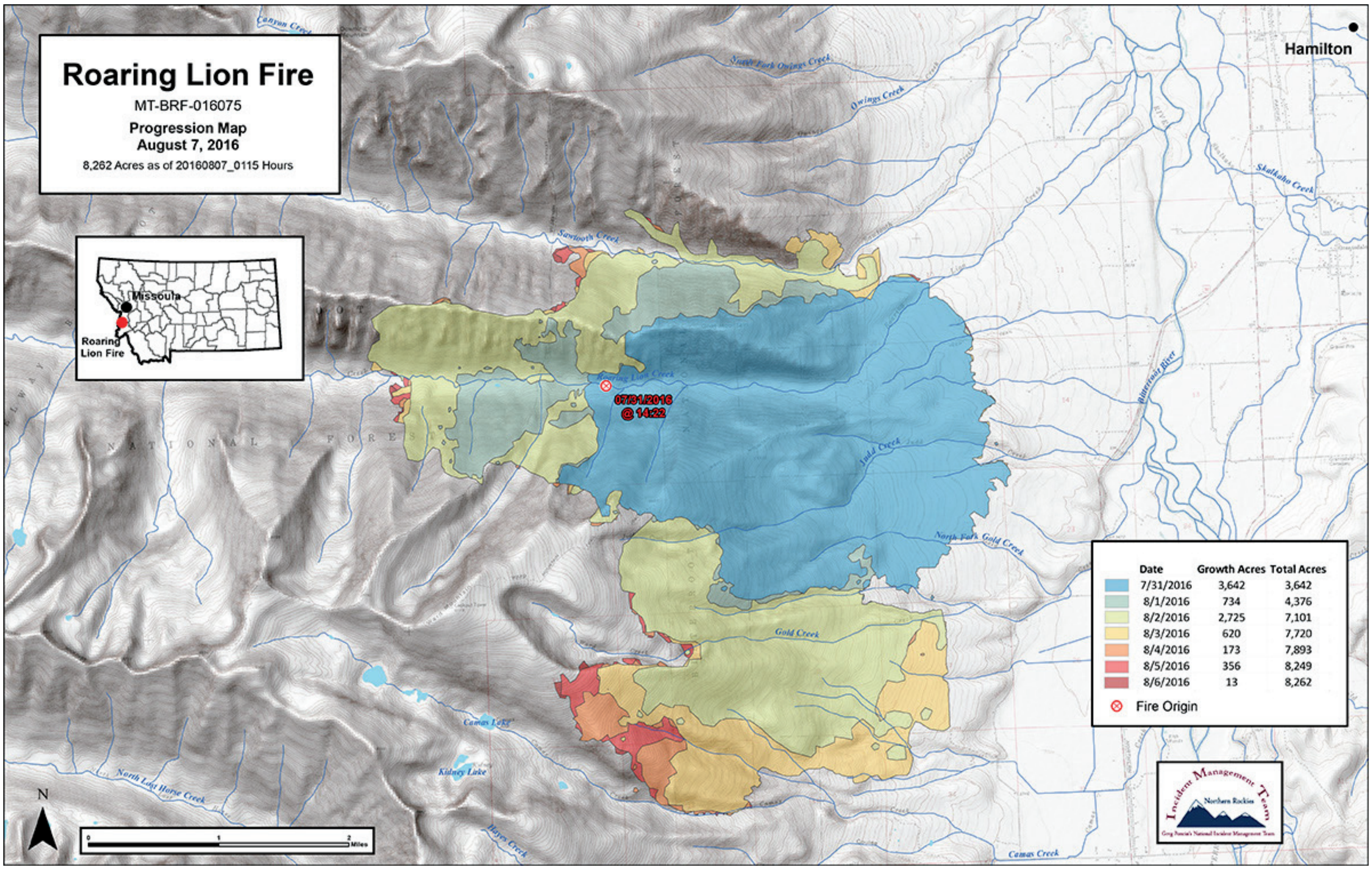
Cohen is a Research Physical Fire Scientist, recently retired from the USDA Forest Service Missoula Fire Sciences Laboratory; the pre-eminent researcher on wildfire and home ignitions; and a founder of the Firewise Communities/USA recognition program. He also coined the concept and phrase *home ignition zone* (HIZ). It was Cohen's HIZ concept that prompted this collaborative effort between the Hamilton Rural Fire Department, the DNRC and Dr. Cohen.

We were fortunate that Cohen was available to work with us, as Jack has examined the subject of home ignitions in both natural and experimental settings. Our charge to Dr. Cohen was threefold; examine both the destroyed and surviving homes associated with the Roaring Lion Fire; identify the fire behavior characteristics presented to each home; and determine, to the best of his ability, the mechanism of ignition at lost or damaged homes. We also wanted to know how the Roaring Lion Fire experience related to previous research findings that home ignitions during extreme wildfires are primarily determined locally by a home's ignition potential and the fire behavior in the immediate surroundings of the house. We now accept Dr. Cohen's report, consider his task complete, and want to thank Jack for making himself available to answer these fundamental questions for us.

The DNRC was seeking to learn, from the Roaring Lion Fire, with the intent of incorporating lessons learned into our policies, procedures, and strategic direction so that we can better help Montana's citizens prepare for the impact of wildland fire. The report that follows serves to set us firmly on that path and will prove instrumental in strengthening the DNRC fire protection approach now and into the future.

Michael T. DeGrosky, Chief
Fire and Aviation Management Bureau - Forestry Division
Montana Department of Natural Resources and Conservation

Vicinity Map of the Roaring Lion Fire



EXECUTIVE SUMMARY

The Roaring Lion Fire was reported on July 31, 2016 at approximately 2:20 pm about one mile west of the Roaring Lion Creek trailhead. The initial active fire behavior coincided with a cold front that produced strong winds and low relative humidity. The rapid onset of high fire intensities and firebrand (lofted burning embers) spot ignitions in the heavy fuels of the drainage bottom and north aspect slopes lead to rapid fire growth rates that exceeded initial attack and later fire suppression efforts. The wildfire burned actively for 4 to 5 hours with areas of crown fire (active tree canopy fire spread) and torching trees that likely produced showers of firebrands downwind within ¼ to ½ mile ahead of the flaming front. The corresponding weather conditions during the period between 2:00 pm and 7:00 pm were warm temperatures, low relative humidity, and persistently strong winds. The fire burned an area of 3,642 acres along with all home destruction on the first day.

The post-fire examination of home destruction and survival along with the degree of burning vegetation immediately surrounding homes revealed that the causes of destruction were firebrand ignitions and flame contact from surface fires and not crown fires. Only two of the destroyed homes had high intensity burning close enough for radiant heating to ignite the structures, and these two homes likely had flame contact from high intensity crown fire within 30 feet of the structures. For the other 14 destroyed homes, active crown fire and torching trees were not close enough to generate ignitions from flame contact and radiant heating. These 14 destroyed homes were largely adjacent to and surrounded by unconsumed tree canopies (although severe tree canopy scorch was common). Importantly, most surviving homes within the initial fire perimeter were also associated with burn patterns of surface fire and unconsumed tree canopies.

Most homes exposed to the wildfire survived. Fifty-two homes were within the initial wildfire perimeter of July 31. Of those 52 homes 15 were destroyed with one destroyed home outside the primary burn perimeter by about 475 feet. Assuming the destroyed home outside the burn perimeter was ignited by firebrands at 475 feet beyond the burn perimeter, I extended the wildfire exposure boundary by 475 feet. Using this extended boundary, 16 homes were destroyed out of 74 homes exposed to the wildfire for 22 percent destruction and 78 percent survival. From past wildland-urban (WU) fire examinations the home survival percentage during the Roaring Lion Fire falls within the typical range of 65 to 85 percent of home survival. Importantly, this level of survival occurs without most structures being protected during the extreme wildfire conditions.

The Roaring Lion Fire home destruction shared characteristics in common with previous WU fire disasters in the U.S. As with all other WU fire disasters (where hundreds to thousands of homes were destroyed), home destruction during the Roaring Lion Fire occurred during extreme fire behavior characterized by rapid fire growth rates, high intensities, and wide spread firebrand exposures. Paradoxically however, most WU fire home destruction was caused by lower intensity surface fires and firebrands as indicated by unconsumed vegetation and structures adjacent to and surrounding total home destruction.

During extreme fire behavior conditions wildfire suppression fails and structure firefighting resources are not sufficient to protect most homes. Frequently, as with the Roaring Lion Fire, firefighter safety concerns prohibit engagement during the extreme fire conditions as well as access limitations due to downed trees, and downed power poles and powerlines. Thus, most homes cannot be protected during the intense wildfire activity resulting in any sustained structure ignition freely burning to total home destruction if follow-up protection cannot intervene soon enough.

Importantly, wildland fuel treatments surrounding residential areas do not necessarily reduce a home's ignition potential. During extreme fire conditions forest fuel treatments may reduce fire intensity within the treated area, but they do not prevent ignition exposures to homes from firebrands originating from outside fuel treatments and fires from spreading through treated areas. The unconsumed tree canopies associated with most of the home destruction in the Roaring Lion Fire indicate home exposures from lower intensity surface fires and firebrands. Thus, the local ignition conditions of the homes in relation to their adjacent surroundings produced the ignitions that destroyed at least 14 of the homes during the Roaring Lion Fire.

The Roaring Lion Fire and previous WU fire disasters indicate that the home destruction during extreme fire behavior is principally determined by the ignition conditions of a home in relation to a home's immediate surroundings within about 100 feet – the *Home Ignition Zone* (HIZ). This affords the opportunity to mitigate home ignition potential locally within the HIZ. Importantly, home ignition potential during extreme wildfires can be significantly reduced without necessarily controlling the extreme wildfire. This means that preventing home destruction can be effectively addressed separately from wildland fuel treatments and wildfire control.

Key Findings

- A total of 16 homes were destroyed during the Roaring Lion Fire.
- Extreme fire behavior conditions prevailed in the first 5 hours of the wildfire on July 31.
- Two destroyed homes were associated with high intensity crown fire flames while the other 14 ignited from firebrands (burning embers) and flame contact from surface fires.
- The wildfire rapidly developed to a high intensity crown fire with a firebrand shower that produced ignitions ahead of the flame front resulting in rapid fire growth rates. This influenced potential home destruction in several ways:
    1. The wildfire exposed a wide area of residential development within a few hours of discovery,
    2. Firebrands lofted within ½ mile down wind of the active crowning flame front likely generated multiple, simultaneous ignitions in surface fuels that rapidly spread the fire and increased surface fire intensities above those expected from a spreading line fire,
    3. The home destruction was primarily due to extensive firebrands and surface fires within the residential area with most home destruction associated with unconsumed tree canopies in both treated and untreated areas of forest fuels and ,
    4. Wildfire control was overwhelmed by extreme fire behavior conditions, and structure protection was overwhelmed by the wide area of residential exposure to firebrands and surface fires along with the significant firefighter safety threat. This resulted in most homes being unprotected during the extreme wildfire conditions. Most structure protection resumed and was effective when conditions moderated in the early evening and through the night.
- The opportunity to effectively mitigate home ignition potential within the HIZ does not suggest that wildland fuel treatment and fire management has no purpose if it does not necessarily prevent WU fire destruction. Rather, the findings (from the Roaring Lion Fire and previous WU fires) show how home destruction occurs

during extreme wildfires and indicate that we have two different problems with wildfires:

1. The management of wildlands outside the HIZ, and
2. The mitigation of the HIZ to prevent home destruction.

We have the opportunity to be compatible with inevitable wildfires if we recognize that the two different problems can be separated and effectively addressed with different approaches that reduce each problem yielding mutually supporting results.

INTRODUCTION

The Roaring Lion Fire was reported on July 31, 2016 at 2:22 pm approximately 1 mile up the creek from the Roaring Lion trailhead (see vicinity map). The fire started its rapid growth from the origin in the abundant standing and down and dead forest fuels of the drainage bottom during the warm temperatures, low relative humidity and strong winds that accompanied a cold front. The drainage roughly runs from west to east. The vegetation at the fire origin was spruce and mixed conifer characteristic of drainage bottoms at an elevation around 4,600 feet. Above the drainage bottom and particularly on the north aspect was a dense, mixed conifer forest type characteristic of middle to upper elevations that commonly burns with high intensity, stand-replacement fires. The initial fire spread was up the steep slopes and east down the canyon. Within an hour after discovery the fire was reported to be several hundred acres in size, largely spreading as an active crown fire, and producing spot ignitions from firebrands ¼ mile ahead of the flaming front that grew to individual fires of several acres within 5 to 10 minutes. Effective wildfire suppression was not possible until the fuels, weather and topography changed later in the day.

The home destruction occurred during the first burning period on July 31. By the end of the day, 16 homes were totally destroyed and the wildfire burned across 3,642 acres. Although the initial fire behavior was dominated by crown fire, the lower slopes where the homes were had a less dense stand of Ponderosa pine (*Pinus ponderosa*) with a more open understory and the active crown fire transitioned to largely surface fire spread with tree torching and brief, isolated crown fire runs.

Weather Conditions

Weather conditions during the fire on July 31 were estimated from the Little Rock Creek RAWS (Remote Automatic Weather Station) that is 5,500 feet in elevation and approximately 11 miles south of the Roaring Lion Fire. The Little Rock Creek RAWS hourly data for 1:00 pm to 9:00 pm was extrapolated to the area of destroyed homes using the assumptions that:

- The air mass and frontal passage was the same at the two locations,
- The dew point was constant,
- The temperature lapse rate was neutral (5.5 F per 1000 feet).

The estimated hourly weather conditions (1:00 pm to 9:00 pm) for the wildfire are geographically referenced to the residential area at the intersection of Roaring Lion Rd and Judd Creek Hollow Rd (4,100 feet elevation) and listed in Table 1.

Time (MDT)	Temp (ºF)	Relative Humidity (%)	Wind Speed (mph) Avg / Max
1:00 PM	82	13	20 / 31
2:00 PM	84	10	20 / 31
3:00 PM	85	11	22 / 32
4:00 PM	84	10	21 / 33
5:00 PM	84	10	20 / 31
6:00 PM	82	9	21 / 32
7:00 PM	80	9	18 / 34
8:00 PM	76	12	11 / 23
9:00 PM	73	14	9 / 20

Table 1. Estimated weather conditions in the area of destroyed homes during the Roaring Lion Fire.

Importantly, local conditions can occur that are not reflected in otherwise representative weather station data. Within the residential area of the lower Judd Creek Hollow Road and Itza Road, severe tree blow down and breakage occurred. This was likely the result of very strong in-line winds from a down draft related to the towering convection column of the extreme wildfire.

Firebrand Spot-fire Ignitions

An important aspect of the Roaring Lion Fire was the spot-fires ignited from firebrands that were generated from burning tree canopies. Numerous spot-fires created area ignitions that coalesced and joined with the main fire area resulting in higher fire spread than would have occurred for the same line fire spreading down slope. This resulted in the rapid fire growth rates and the very high intensities exhibited by the Roaring Lion Fire (Figure 1). In addition, firebrands ignited spot-fires across discontinuous fuels that would have otherwise slowed the spread rate and multiple ignitions burned together to increase the area burning at one time and thus increasing the fire intensity. The calculated probability of ignition (Cohen and Deeming 1978) shown in Table 2 should be considered an index of ignition probability rather than an exact description of spot-fire potential. However, the trend of the ignition probabilities is consistent with the experienced fire behavior before and after 7:00 pm.

Figure 1. This is the Roaring Lion Fire on July 31 as it spreads eastward and down slope to approach the residential areas near the base of the slope. Significant sections of the flaming front is high intensity crown fire and showering an area downwind with firebrands. The white ovals identify firebrand ignited spot-fires. The black oval identifies an area of down draft that rapidly resulted in spreading spot-fires seen after the smoke cleared.

Time (MDT) PM	2:00	3:00	4:00	5:00	6:00	7:00	8:00	9:00
Probability of ignition	0.91	0.87	0.83	0.80	0.86	0.85	0.73	0.68

Table 2. These probabilities of ignition used the hourly temperatures and relative humidity from Table 1.

A principal contribution of extreme wildfires to home destruction is a broad area of exposure to firebrands. This, in turn leads to wide spread, simultaneous firebrand ignitions of highly ignitable homes. As the Roaring Lion Fire spread to within ¼ to ½ mile of residential development, homes were exposed to potential ignition across a fire front of approximately 2.5 miles. This had two principal impacts on structure fire protection:

1. Limited firefighting resources could not protect most homes exposed to ignition and also suppress structure fires that had occurred, and
2. Structure firefighters could not safely remain in the area to protect homes during the several hours of extreme fire conditions.

When fire behavior conditions moderated after 7:00 pm, firefighters were able to effectively engage in follow-up structure protection.

Home Ignitions and Structure Protection

After the first burning period on July 31 the fire perimeter included 52 homes of which 15 were destroyed with one home destroyed outside the perimeter. If we assume the fire perimeter represents the principal area of wildfire exposure to firebrands and flames, then 29 percent of the homes were destroyed and 71 percent survived. The destroyed home beyond the fire perimeter as well as numerous spot-fires suggest an extension of the exposure area. Using the distance of the destroyed home outside the perimeter and designating this the wildfire exposure area adds 475 feet beyond the perimeter that includes 74 homes. The proportion of home destruction was 22 percent with 78 percent survival. This level of survival is within the 65 to 85 percent range typical of previous WU fire disaster examinations. For example, 78 percent survival occurred during the 1961 Bel Air-Brentwood Fire in southern California (Howard et al. 1973), 83 percent survival occurred during the 2002 Hayman Fire in Colorado (Cohen and Stratton 2003) and 65 percent survival occurred during the 2010 Fourmile Canyon Fire in Colorado (Graham et al. 2012; Calkin et al. 2014).

Structure firefighting resources were mobilized from the surrounding area and available for structure protection in the initial hours of the Roaring Lion Fire. The fire apparatus included 12 Type 6, 2 Type 5, 4 Type 3, 7 structure engines (Type 1 or 2), and 6 water tenders for a total of 31 pieces of fire apparatus and over 90 firefighters to protect 74 homes exposed to the wildfire. Given engagement without safety considerations (unrealistic), if a home was protected from ignition by two firefighters and supported by one firefighter in roaming apparatus support, the best case was about 30 homes protected or 41 percent coverage with 59 percent of homes largely unprotected at one time. However, firefighter safety considerations dominated the period of extreme wildfire behavior. Firefighters re-engaged when fire conditions moderated after 7:00 pm with the exception of heavy blow-down areas that limited access and threatened firefighter safety. The residential protection during the Roaring Lion Fire was greater than other WU fire disasters. For example, during the 2010 Fourmile Canyon Fire in Colorado protection resources at best (and not figuring in safety) could only protect 16 percent of the exposed homes with 84 percent unprotected.

WILDLAND-URBAN (WU) FIRE EXAMINATION

Introduction

The examination of the home destruction was conducted started on August 31, one month after the destruction occurred. During that time the debris of home destruction and burned vegetation was moved and removed in varying degrees from the home sites. Due to this site disturbance the goal of the examination was limited to evaluating the relationship between the home destruction and the degree of vegetation consumption that indicates fire intensity. No attempts were made to assign cause of ignition other than categorically determining whether or not the home could have ignited from high intensity crown fire or ignited due to flame contact from lesser intensity surface fires and directly from firebrands. This WU fire examination specifically addresses what aspects of the Roaring Lion Fire were responsible for home ignitions (for example, crown fire, surface fire and firebrands). The term “wildland-urban fire” identifies a relationship between wildland fire or a wildfire and the involvement of structures igniting and burning; however, the term does not specify how home ignitions occur. More specifically, what wildfire flame and firebrand characteristics are sufficient to ignite homes and how close must they be to ignite the flammable parts of homes? Previous WU fire research and examinations have addressed this question and the area principally responsible for home ignition has been called the *Home Ignition Zone* (HIZ) (Cohen 2001; Cohen and Stratton 2003; Finney and Cohen 2003; Cohen 2004; Cohen and Stratton 2008; Graham et al. 2012; Calkin et al. 2014). Determining the size of the HIZ (its scale) is critical for identifying where and what mitigations can effectively reduce home ignitions and thus prevent home destruction. The previous research and examinations found that the HIZ includes the home and the home’s immediate surroundings within 100 feet during extreme wildfire conditions.

The Roaring Lion WU Fire Characteristics

Active Crown Fire:

Active crown fire propagates through the tree canopies without requiring surface fire to initiate tree canopy ignition. The high degree of canopy consumption suggests active crown fire. These two houses (Figure 2) were located along Roaring Lion Creek next to a dense stand of Engelmann spruce (*Picea engelmannii*) and Douglas-fir (*Pseudotsuga menziesii*) that likely burned as an active crown fire. Both houses were within 30 feet of the forest edge. The photos show evidence of the crown fire. Prior experimental crown fire research (Cohen 2004) suggests that these houses could have ignited from flame radiation but flame contact at these proximities was likely.

Figure 2. ACTIVE CROWN FIRE. These two separate but associated houses, a) and b) were several hundred feet apart. Both of these structures were 30 feet or closer to active crown fire.

Passive Crown Fire and Torching:

Passive crown fire is when surface fire initiates canopy burning as the surface fire spreads. Torching occurs when surface fire initiates canopy burning of individual trees without significant spread to other tree canopies. The patchy, unconsumed tree canopy foliage around this house (Figure 3) indicates limited passive crown fire and torching canopies resulting in much lower fire intensities than active crowning. However, the complete consumption of surface fuels and the likelihood of multiple spot-fires from firebrands suggest high surface fire intensities. The complete surface fuel consumption continuous to the house suggests surface fire flame contact.

Figure 3. PASSIVE CROWN FIRE. Photos a) and b) are two different views from the same house. The incomplete canopy consumption indicates individual tree torching with brief passive crown fire in the background. The house was more than 60 feet from high intensity burning but note the complete consumption of continuous surface fuels leading to the house.

Active Crown Fire Too Distant for Ignition:

Areas of active crown fire primarily occurred at the western extent of the residential development; however, were the nearest houses close enough to ignite? WU fire research and examinations (Howard et al. 1973; Foote 1994; Cohen

2000; Cohen 2004; Cohen and Stratton 2008; Graham et al. 2012) have described and verified that crown fire flaming fronts at distances greater than 100 feet do not heat wood surfaces sufficiently for ignition. Two examples from the Roaring Lion Fire are provided in Figure 4. The high degree of tree canopy consumption about 240 feet upwind of the destroyed house indicates active crown fire (Figure 4a). One might initially conclude that the high intensity crown fire flaming front ignited the house. However, closer inspection of the site reveals wood fence surfaces at comparable distances from the crown fire no charring (Figure 4b). The evidence indicates lesser intensity ignition sources such as firebrands and structure flame contact from adjacent surface fire ignited the destroyed house. The second example is a smaller area of active crown fire about 45 feet from a wooden mailbox post (Figure 4c). Inspection of the wooden post surface facing the crown fire indicates no charring but the deformed plastic newspaper box indicates that some heating occurred. In both cases the crown fire would have produced a significant shower of firebrands to the immediate downwind area of vegetation and structures.

a.

b.

c.

d.

Figure 4. a) The crown fire in this scene is more than 200 feet from the destroyed house and wood rail fence. b) The top rail facing the crown fire has no thermal degradation (charring) indicating that heating from the crown fire was well below the requirements for igniting the house. Burn areas on the wood fencing are from firebrands that lodged in crevices, ignitions from surface fire and from the burning house. c) The mail box and post at the bottom of the photo is about 45 feet from the area of crown fire. d) The side of the wood post facing the crown fire was not charred although heating was sufficient to soften the plastic newspaper.

Firebrands and Surface Fire:

Most of the 16 destroyed houses during the Roaring Lion Fire had unconsumed tree canopies similar to the two houses in Figure 5. The remaining tree canopies and other vegetation surrounding and adjacent to the house indicate the home ignitions occurred by firebrands and flame contact from burning surface fuels and not crown fires. These conditions that included structure vulnerabilities in relation to burning materials with 10 feet of so of the structure determined the ignitions and destruction of the homes. Firebrands could have directly ignited flammable structure materials in locations such as crevices and inside corners, as well as ignited flammable debris such as needle and leaf litter, firewood on decks, and dead vegetation on and adjacent to flammable exterior materials. Surface fires spreading through continuous dead grass, needles and branches do not radiate sufficient heat to ignite wood surfaces and thus requiring flame contact for ignition.

Figure 5. Two different houses a) and b). Neither house had adjacent high intensity burning. The charred and partially consumed trees adjacent to the houses burned from the burning house. The a) house did not have forest fuel treatment; the b) house had forest fuel treatment.

Firebrand Ignitions:

As with all extreme wildfire conditions such as the Roaring Lion Fire, firebrands are a principal ignition factor. As seen in Figure 6, firebrand generated spot-fires do not depend on the main wildfire flames spreading to the house or the wildfire flames heating the house. Each of the spot-fires shown ignited in surface fuels and spread to flammable structure materials with the potential for home destruction. Given an exposure to firebrands during extreme conditions, the home ignition potential is strongly influenced by the local conditions at the home:

- The home's materials and design (e.g., flammable wood roofs and structural junctions),
- Deposits of flammable debris on the home (e.g., pine needles and firewood), and
- Adjacent flammable materials that can ignite and spread fire to the house with flame and smoldering contact causing home ignition (e.g., dead needles and grasses, mulches).

Figure 6. Three examples (a, b and c) of spot-fires ignited by firebrands. Each of these spot-fires demonstrate how important the house and its immediate surroundings are to the home ignition potential. It could not be determined if firefighters extinguished the spot-fires and prevented home ignitions.

Determining firebrand ignitions of destroyed and damaged structures can be less obvious. Figures 7 and 8 provide examples of two different structures that ignited from firebrands. One could not be protected and free burned to total destruction (Figure 7) and the other damaged but not destroyed due to successful follow-up firefighter protection (Figure 8). These examples show how common observer perceptions of extreme wildfires as an all-consuming wall of flames belie how homes ignite and burn to total destruction.

Figure 7. a) A wider view of the destroyed structure and surroundings. b) A narrower view detailing the surroundings. The destroyed structure is surrounded by unburned grass and unconsumed trees. The immediately adjacent trees were scorched and charred by the burning structure.

The destroyed structure in Figure 7 was located in an irrigated meadow with fuel treatment in parts of the adjacent forested area. Unconsumed vegetation surrounded the destroyed structure without evidence of fire spreading to the structure; the adjacent scorched and charred trees were due to the burning structure. The total lack of wildfire flame exposure immediately surrounding the destruction indicated a firebrand ignition source. This conclusion was supported by an active crown fire within ¼ mile and up wind of the destroyed structure.

Determining an ignition source for the burning deck (Figure 8) required a more detailed examination. The wildfire spread as surface fire to the area immediately surrounding the house (Figure 8a) and ignited a small firewood on the downhill side of the deck about 20 feet away and opposite where the deck burned. The initial impression had the burning firewood igniting the deck. However, the uncharred deck supports, facing boards and rail posts facing the area of surface fire and burning firewood indicates insufficient heating from radiation and flame contact to ignite the deck (Figure 8b). An examination of the burn pattern, degree of consumption and charred surfaces indicated that burning started on the deck with fire spreading across deck joists and planks and down the side of the support post not facing outward (Figure 8c). Tree torching and active crown fire occurred upwind of and within ¼ mile of the house. A firebrand exposure at the house was indicated by numerous small char marks found all across the horizontal surface of the deck (Figure 8d). A discussion

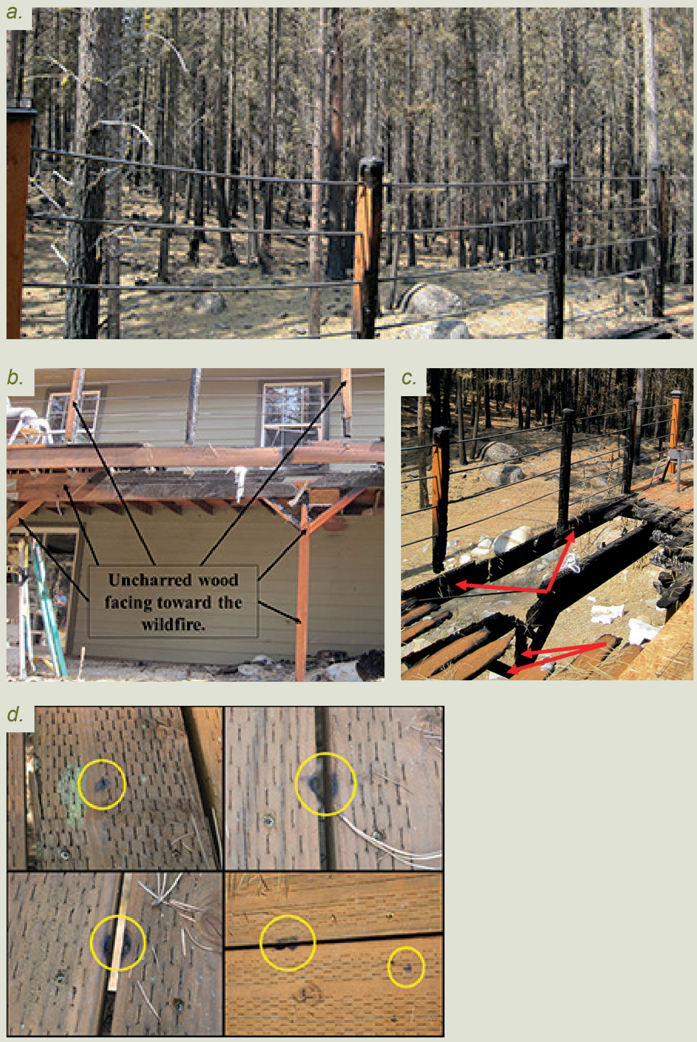


Figure 8. a) View from the burned deck at where surface fire spread to the house. No canopy fire occurred in the area immediately surrounding the house. Forest thinning and fuel treatment had not been done. b) Uncharred deck members on the sides facing the wildfire (black arrows). c) View of a portion of the burned deck (sheet of OSB covers burned-out gap in the lower right corner). The facing board and deck post sides are charred and had been burning (red arrows). d) Examples of the many firebrand char marks on the deck.

with the homeowner revealed that a paper bag of barbeque charcoal and a plastic bottle charcoal lighter fluid had been sitting alongside a smoker at the identified location of ignition. The burn pattern was consistent with a firebrand ignition of the paper bag (and perhaps other items) that melted the plastic lighter fluid bottle spilling its contents and accelerating the deck fire. A successful follow-up fire protection action kept this house from destruction (and provided evidence to analyze what happened).

Firebrand Vulnerabilities:

Vulnerabilities to firebrand ignition primarily occur from: a home's flammable materials and design that collect firebrands and enhance sustained ignition, a home's flammable appurtenances, and especially from flammable debris and dead litter on and immediately adjacent to a home that can produce flaming or smoldering combustion in contact with the home. Figure 9a, b and c provide three common situations found within the Roaring Lion Fire perimeter that increase a home's firebrand ignition potential. These examples serve to emphasize how the conditions of a home and its immediate surroundings can determine a home's ignition potential during extreme wildfires without a wildfire flame exposure. The homes in these examples (Figure 9a, b and c) all had spot-fires within their HIZs (100 feet of the home) but not with the vulnerabilities shown.

a.

b.

c.

Figure 9. Example firebrand ignition vulnerabilities of houses. a) Burning dead pine needles in the rain gutter can ignite the house at the eave. b) Burning evergreen shrub from ignited dense dead material inside produces structure flame contact on the wall and under the "push-out." c) Flammable patio furniture cushions and pillows can burn to produce flame contact with the wall and fracture windows that collapse to allow firebrands and flames to penetrate the interior.

DISCUSSION

The Roaring Lion WU Fire had a pattern of home destruction similar to previous WU fire disasters (Cohen 2000; Cohen and Stratton 2003; Cohen and Stratton 2008; Graham et al. 2012). The wildfire burned during strong winds and dry conditions to produce rapid growth rates, high fire intensities and firebrands igniting spot-fires that overwhelmed attempted wildfire suppression. The extreme wildfire rapidly spread to expose a broad area of homes that overwhelmed the available structure protection and threatened firefighter and resident safety. Homes were largely not protected during the wildfire exposure. The homes that ignited and became significantly involved in fire before firefighters could return, freely burned to total destruction. This is the sequence of WU fire destruction identified for all WU fire disasters (Cohen 2008; Calkin et al. 2014) and described in Figure 10.

Importantly, all WU fire disasters have occurred during extreme wildfire conditions. Previous national WU fire disasters and the Roaring Lion Fire were among the 2

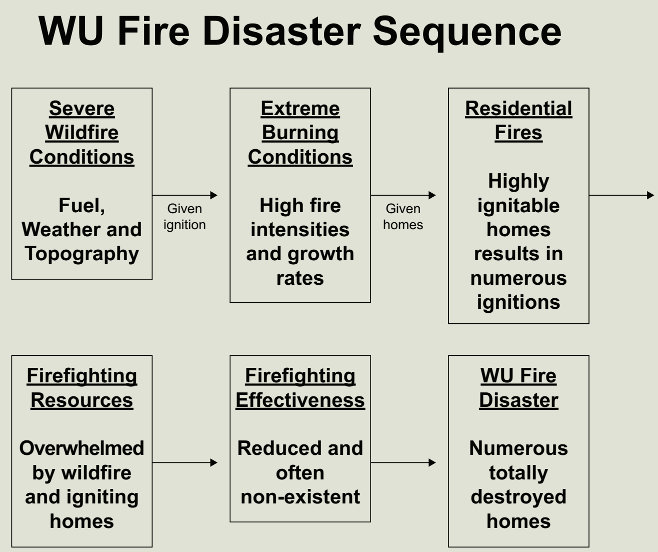


Figure 10. Each of the boxes describe a contingency for extreme wildfire conditions producing ignition exposures for igniting vulnerable structures and overwhelming structure protection leading to many totally destroyed homes. Note that disastrous home destruction depends on highly ignitable homes and not just an extreme wildfire.

percent of wildfires that could not be controlled during initial attack (Reinhardt et al. 2008; Cohen 2008; Calkin et al. 2014). Given that wildfires are inevitable and wildfires during extreme conditions are inevitable (Reinhardt et al. 2008; Cohen 2008; Calkin et al. 2014), one might conclude that home destruction is also inevitable during extreme wildfires. However, inspection of the WU fire disaster sequence (Figure 10) suggests an opportunity for intervention that prevents home destruction inevitability. The disaster sequence depends on homes igniting and burning during extreme wildfires (Figure 10, third factor); however, if homes do not ignite during extreme wildfires then the sequence stops and extreme wildfires occur without disastrous home destruction. This suggests that we can prevent WU fire disasters by mitigating home ignition potential without necessarily controlling the inevitable extreme wildfires.

As with previous WU fire disasters, home destruction during the Roaring Lion Fire occurred due to the ignition conditions of a house and the burning in the immediate surroundings of a house that produced home ignitions. The massive smoke column and big flames of an extreme wildfire (Figure 1) do not indicate an all-consuming, continuous blanket of heat that "explodes" houses in flame. The examinations showed how firebrands had to land on and surface fires had to make contact with flammable structure materials before homes could ignite in the absence of sufficiently close crown fire exposures. WU fire research and WU fire disaster examinations (Cohen 2000a, b; Cohen and Stratton 2003; Cohen 2004; Cohen and Stratton 2008; Graham et al. 2012) have determined that home ignitions during extreme wildfires occur due to the ignition conditions of a home in relation to firebrands and burning materials within 100 feet of a home – the HIZ. The HIZ identifies the area where mitigations can effectively reduce home ignition potential and block the WU fire disaster sequence. Mitigations to the home and within the HIZ (see www.firewise.org for mitigation guidance) can effectively change the "highly ignitable homes" factor to "ignition resistant homes" (Figure 10, third factor). This does not "fire proof" homes but will eliminate most ignitions and keep the ignitions that do occur small for longer periods of time. Mitigations in the HIZ increase the chances for effective structure protection as well as increase life-safety for residents and firefighters.

Wildland and HIZ "fuel treatments" or mitigations must be appropriately applied to effectively produce the desired results (Reinhardt et al. 2008; Calkin et al. 2014). Previous research, WU fire examinations and this examination of the Roaring Lion Fire home destruction confirm that the HIZ principally determines home ignition potential during extreme wildfires. In the WU fire context, homes become the fuel and firebrands and burning materials within the HIZ become heat sources for home ignition. Thus, effectively reducing home ignition potential requires the reduced availability of the "home fuel" in relation to firebrands and the elimination and reduction of potential flame exposure from burning objects within the HIZ. Going beyond the HIZ will not eliminate firebrand exposure and is farther than necessary to reduce flame exposures (Cohen 2000a). Importantly, vegetation fuel treatments outside the HIZ for preventing home destruction during extreme wildfire conditions do not prevent fire spread through the treatment area into the HIZ and do nothing to change home ignition potential within the HIZ (Reinhardt et al. 2008; Calkin et al. 2014).

The natural history of wildland fire and its inevitability in the northern Rocky Mountains suggest we take a management approach of facilitation rather than exclusion (Reinhardt et al. 2008; Calkin et al. 2014). Our attempted wildfire exclusion has not excluded wildfires but has largely eliminated most wildland fire that historically burned during less than very high and extreme conditions resulting in what is called the "fire paradox" (Reinhardt et al. 2008; Calkin et al. 2014). Given the current residential development within and adjacent to wildland areas, restoring a more ecologically appropriate wildland fire occurrence will require ignition resistant homes (and a fire compatibility perspective). Because the conditions of the HIZ principally determine home ignition potential we have the opportunity to separate the problem of home destruction from the problem of wildland fire occurrence. Fuel treatments outside the HIZ facilitate wildland management and are no less important than mitigating home ignition potential within the HIZ; and accomplishing both will provide mutual benefits.

CONCLUSIONS

Home destruction during the Roaring Lion Fire was an example of how WU fire disasters occur during extreme wildfire conditions (Figure 10). The Roaring Lion Fire exhibited the same general characteristics of extreme WU fire disasters that have been previously found (Cohen 2000b; Cohen and Stratton 2003; Cohen 2004; Cohen and Stratton 2008; Graham et al. 2012). Also, the home destruction amid adjacent unconsumed vegetation and other structures was consistent with the findings of computational modeling, laboratory and field experiments and disaster examinations (Howard et al. 1973; Foote 1994; Cohen 2000a, b; Cohen and Stratton 2003; Cohen 2004; Cohen and Stratton 2008; Graham et al. 2012).

Research has found that the big flames of wildfires are largely not directly responsible for WU fire destruction.

Although the extreme wildfires overwhelm fire suppression capabilities, high intensity wildfires are not spreading through residential developments to ignite and destroy most homes. The Roaring Lion Fire analysis and previous analyses (Howard et al. 1973; Foote 1994; Cohen 2000a, b; Cohen and Stratton 2003; Cohen 2004; Cohen and Stratton 2008; Graham et al. 2012) have found that WU fire destruction during extreme wildfires primarily results from firebrand showers over a wide area initiating ignitions directly on structures and creating numerous spot fires that largely spread through surface fuels within residential areas igniting homes and thereby overwhelming structure fire protection.

Research and analyses of WU fires, of which the Roaring Lion Fire examination is a part, have shown that home ignitions during extreme wildfires are primarily determined locally by a home's ignition characteristics in relation to the size and duration of flames within 100 feet of the home – the HIZ (Howard et al. 1973; Foote 1994; Cohen 2000a, b; Cohen and Stratton 2003; Cohen 2004; Cohen and Stratton 2008; Graham et al. 2012). Understanding how homes ignite along with the HIZ concept defines WU fire as a home ignition problem, not a wildfire problem; and thus, home ignition potential and WU fire can be addressed separately from wildfire. The preventive HIZ approach provides an effective alternative to our current reactive approaches of wildfire suppression and structure protection for preventing home destruction (Finney and Cohen 2003; Cohen 2008; Calkin et al. 2014). Mitigating home ignition factors within the HIZ can effectively reduce home ignitions resulting in home survival without the necessity of changing wildfire behavior with wildland fuel treatments and managing wildfires with suppression (Finney and Cohen 2003; Reinhardt et al. 2008). Thus, the inevitability of extreme wildfires does not necessarily produce the inevitability of home destruction; extreme wildfires can occur without WU fire disasters.

Agencies with wildland fire management responsibilities face an effectiveness crisis related to community wildfire protection. The management approach to wildland fire is dominated by wildfire suppression with community fire protection as a strong influence for maintaining a suppression approach (Cohen 2008). However, fire suppression fails to meet the fundamental requirement of effective management; that is, successful management activities must produce the intended outcome (Calkin et al. 2014). For example,

- Our society's attempt to control wildfires on initial attack fails for 2 percent of wildfires and these are the wildfires when WU fire disasters occur.
- The 98 percent initial attack success rate across the United States actually increases the potential for future extreme wildfires which in turn, increases the potential for WU fire exposure and the detrimental ecological effects of extensive high severity fires – the "fire paradox" (Cohen 2008; Reinhardt et al. 2008; Calkin et al. 2014).
- Wildland fuel treatment for community protection largely using forest thinning adjacent to but outside the HIZ does not mitigate the ignition factors that primarily determine home ignition potential within the HIZ (Cohen 2000a; Finney and Cohen 2003; Cohen 2008; Reinhardt et al. 2008; Calkin et al. 2014).

We have the opportunity to address the problems of wildland fire management and home destruction during wildfires separately and with equal priority and our successes with each problem mutually benefits the other. To do this our largely reactive suppression and protection approaches must change to be consistent with the realities that wildfires are inevitable and an appropriate ecological factor, and home destruction can be more effectively prevented by addressing home ignition vulnerabilities within the HIZ. In general, this would be an approach of wildland fire compatibility rather than one of exclusion and control. Ignition resistant WU communities would effectively reduce the risk of home destruction during extreme wildfires that, in turn would reduce the risk of any wildland fire occurrence destroying homes (Calkin et al. 2014). Importantly, reduced risk of home destruction would increase the opportunity for land managers to both actively and passively facilitate ecologically appropriate wildland fire occurrence. This can take us to a future condition that is readily achievable where WU communities have prepared for and fire adapted ecosystems sustain with appropriate wildland fire management.

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An Examination of Home Destruction

Roaring Lion Fire

Bitterroot Mountains, Montana

Jack D. Cohen, PhD
Research Physical Scientist, Missoula, MT