NIST Special Publication 1198

Summary of Workshop on Structure Ignition in Wildland-Urban Interface (WUI) Fires

Sponsored by ASTM International E05 Committee

Samuel L. Manzello
Stephen L. Quarles

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September 2015

U.S. Department of Commerce
Penny Pritzker, Secretary

National Institute of Standards and Technology
Willie May, Under Secretary of Commerce for Standards and Technology and Director

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1. Introduction
1.1 Workshop Objectives

A workshop entitled *Structure Ignition in Wildland-Urban Interface (WUI) Fires* was held on June 18-19, 2015 in Anaheim, CA. The workshop was sponsored by ASTM International Committee E05, and was under the direction of Dr. Samuel L. Manzello of the Fire Research Division, part of the National Institute of Standards and Technology's (NIST) Engineering Laboratory, and Dr. Stephen L. Quarles of the Insurance Institute for Business & Home Safety (IBHS).

Wildfires that spread into communities, commonly referred to as WUI fires, are a significant problem in Australia, Europe, and the United States. WUI fire spread is extraordinarily challenging and presents an emerging problem in fire safety science. While it is accepted that WUI fires are an important societal problem, little understanding exists on how to contain and mitigate the hazard associated with such fires.

From a simple point of view, the WUI fire problem can be seen as a structure ignition problem. Some building codes and standards already exist to guide construction of new structures in areas known to be prone to WUI fires in order to reduce the risk of structural ignition. These codes and standards have been developed based on best information at the time they were developed. Often this information was anecdotal.

This workshop has formally begun the discussion: *based on current research, are these current codes and standards adequate*? Proven, scientifically based retrofitting strategies are required for homes, and other buildings, located in areas prone to such fires.

The presentations of the workshop were separated into four topic areas: post-fire studies, structure ignition/firebrand accumulation and generation studies, WUI modeling, and evaluation of mitigation strategies.

This report is organized into specific sections with appendices. Specifically, Section 1.2 is the oral presentation schedule, Section 1.3 is participant listing, and there is an appendix that contains the oral presentations delivered at the workshop (Appendix 1).

<u>Dedication</u>
This workshop was dedicated to the memory of Dr. Robert Hawthorne White, a staff scientist at the US Department of Agriculture, Forest Service, Forest Products Laboratory, for 39 years. Dr. White made significant contributions to fire safety science and ASTM in particular. A slide highlighting his career was provided at the workshop and is also found in Appendix 1.

1.2 Program of Workshop

June 18 ,2015

1:00 pm	***Introduction to Workshop*** ***Dr. Samuel L. Manzello, Co-Chair, Engineering Laboratory, NIST, USA***
	Plenary Lecture **Session Chair Dr. Stephen L. Quarles (IBHS)**
1:10 pm	***Are Existing Building and Fire Codes Providing Adequate Protection for Communities Exposed to Wildland-Urban Interface Fires - An Overview of Existing Wildland-Urban Interface Fire Codes*** ***Mr. Nelson Bryner, Engineering Laboratory, NIST, USA***
	Regular Session **Session Chair Dr. Stephen L. Quarles (IBHS)**
2:30 pm	***Review of Pathways to Fire Spread in the Wildland Urban Interface*** ***Michael J. Gollner, Raquel Hakes, Sara Caton and Kyle Kohler, Department of Fire Protection, Engineering, University of Maryland, College Park, MD, USA***
3:00 pm	**Break**
3:30 pm	***Role of Event-Based Data in Wildland-Urban Interface Fire Mitigation – Limitations of Incident-based Data*** ***Nelson Bryner and Alexander Maranghides, Fire Research Division, National Institute of Standards and Technology (NIST), Gaithersburg, MD, USA***
4:00 pm	***EcoSmart Fire as Structure Ignition Model in WUI: Predictions and Validations*** ***Mark A. Dietenberger and Charles R. Boardman, USDA Forest Products Laboratory, Madison, WI, USA***
4:30 pm	***Firebrand Generation and Impact on Wooden Constructions in the Wildland-Urban Interface*** ***Kamila Kempna, Mohamad El Houssami, Eric Mueller, Jan C. Thomas, Rory Hadden, and Albert Simeoni, Fire Safety Engineering Department, University of Edinburgh, Edinburgh, UK***
5:00 pm	**Adjourn**

June 19, 2015

	Session Chair Dr. Samuel L. Manzello (NIST)
8:00 am	***Upgrading Heritage Buildings to Resist Exterior Fire Exposure by Sympathetic Means and a Method to Assess Aggregate Envelope Performance*** ***Geir Jensen, Tobias Jarnskjold, Thomas Haavi, COWI AS, Trondheim, Norway***
8:30 am	***Fire Hazard in Camping Park Areas*** ***Miguel Almeida, Luís Mário Ribeiro and Domingos Viegas, Center for Forest Fire Research ADAI – LAETA, Coimbra, Portugal; José Raul Azinheira, Alexandra Moutinho, João Caldas Pinto, IDMEC/CSI – LAETA, Universidade de Lisboa, Lisbon, Portugal; Jorge Barata, Kouamana Bousson and Jorge Silva, AEROG – LAETA, Universidade da Beira Interior, Covilhã, Portugal; Marta Martins, INEGI – LAETA, Instituto de Engenharia Mecânica e Gestão Industrial, Porto, Portugal; and Rita Ervilha and José Carlos Pereira, IDMEC/LASEF – LAETA, Universidade de Lisboa, Lisbon, Portugal***
9:00 am	***Firebrand Production from Building Components with Siding Treatments Applied*** ***Sayaka Suzuki, National Research Institute for Fire and Disaster (NRIFD), Chofu, Tokyo, Japan; and Samuel L. Manzello, National Institute of Standards and Technology (NIST), Gaithersburg, MD, USA***
9:30 am	***Accumulation Patterns of Wind-blown Embers around Buildings*** ***Stephen L. Quarles and Murray J. Morrison, Insurance Institute for Business & Home Safety (IBHS), Richburg, SC USA***
10:00 am	**Break**
10:30am	***Fire Performance of Exterior Wood Decks in Wildland-Urban Interface*** ***Laura E. Hasburgh and Samuel L. Zelinka, US Forest Products Laboratory, Madison, Wisconsin USA; and Donald S. Stone, Materials Science and Engineering, University of Wisconsin, Madison, Wisconsin USA***
11:00 am	***Spot Fire Ignition of Natural Fuel Beds of Different Characteristics by Hot Aluminum Particles*** ***James L. Urban, Casey D. Zak and Carlos Fernandez-Pello, Department of Mechanical Engineering, University of California Berkeley, Berkeley, CA USA***

11:30 am	***Experimental Investigation on Building Component Ignition by Mulch Beds Ignited by Firebrand Showers*** ***Samuel L. Manzello, Fire Research Division, National Institute of Standards and Technology (NIST), Gaithersburg, MD, USA; Sayaka Suzuki, National Research Institute of Fire and Disaster (NRIFD), Chofu, Tokyo, Japan; and Daisaku Nii, Building Research Institute (BRI), Tsukuba, Ibaraki, Japan***	
12:00 pm	**End of Workshop**	

1.3 Participant Listing

LAST_NAME	FIRST_NAME	AFFILIATION
Alfawakhiri	Farid	American Iron & Steel Institute
Alfrey	Robert	Not Provided
Almeida	Miguel	ADAI (Portugal)
Alvares	Norman	Suite 431
Anderson	Erik	Koffel Associates
Badders	Barry	Intertek Testing Services, NA, Inc.
Banks	Eric	BASF Corporation
Barajas	Miguel	Not Provided
Beaton	Michael	Intertek Testing Services NA, Inc.
Bokkes	Southern	Riverside County Fire
Bovard	Timothy	Pittsburgh Corning Corporation
Bragg	Tammy	Not Provided
Brewer	Sarah	Unifrax I LLC
Brooks	Robert	Rob Brooks & Associates
Bueche	David	Hoover Treated Wood Products
Bundy	Matthew	NIST
Cerda	Oscar	Not Provided
Chulahwat	Akshat	Colorado State University (CSU)
Craft	Steven	CHM Fire Consultants Ltd
Dean	Aaron	Orange County
Delos Reyes	Kathleen	Los Angeles County Fire Department
Dietenberger	Mark	USDA Forest Products Laboratory
Fernandez-Pello	Carlos	University of California Berkley
Fletcher	Karen	Riverside County Fire
Frater	George	Canadian Steel Construction Council
Gales	John	Carleton University
Gann	Richard	NIST
Gebhart	Richard	Owens Corning
Gollner	Michael	University of Maryland
Hadden	Rory	University of Edinburgh
Hasburgh	Laura	USDA Forest Products Laboratory
Hasegawa	Harry	Firequest
Hathorn	Stan	Royal Mouldings
Hendricks	William	Safer Building Solutions

Hirschler	Marcelo	GBH International
Janssens	Marc	Southwest Research Institute
Jarnskjold	Nils M Tobias	NTNU
Jensen	Geir	Securo As
Johnston	David	Vinyl Siding Institute
Jourdain	Charles	California Redwood Association
Jumper	Alan	LP Building Products
Kane	Daniel	Not Provided
Kearns	Lyn	Not Provided
Keating	Jay	IKO Industries
Keltner	Ned	Fires Inc
Ladwig	Richard	PABCO Building Products, LLC
Manzello	Samuel	NIST
Mathes	Dennis	Lomanco, Inc
Merrick	Paul	Louisiana-Pacific Corporation
Morel	Sid	Not Provided
Murrell	Janet	Warrington Fire Research
Oaks	Don	Not Provided
Onodera	Gina	CertainTeed
Palumbo	Christopher	HPVA Laboratories
Patashnik	Oren	Not Provided
Pazera	Marcin	Not Provided
Pepper	Freddie	Riverside County Fire
Phillips	Aaron	Tamko Building Products Inc
Pickett	Brent	Western Fire Center Inc.
Quarles	Stephen	Insurance Institute for Business & Home Safety
Samuels	Matthew	USG Corp
Scoville	Christopher	Trex Company Inc.
Shinkoda	Pamela	CGC Inc.
Shipp	Paul	USG Corporation
Simontacchi	John	Firefree Coatings, Inc
Sloan	Dwayne	Underwriters Laboratories Inc
Stacy	Howard	Priest & Associates Consulting LLC
Stansberry	Herbert	Intertek
Suzuki	Sayaka	NRIFD (Japan)
Swanson	Rex	Louisiana-Pacific Corp
Traw	Jon	Traw Associates Consulting
Trevino	Javier	Priest Associates Consulting, LLC
Urban	James	University of California Berkeley
Van Zeeland	Ineke	Canadian Wood Council

Vargas	Melissa	LA County Fire Department
Wangel	Robert	Koppers Peformance Chemicals
Wessel	Robert	Gypsum Association
Woychak	Ronald	Firewise 2000, Inc.
Yang	Jiann	NIST
Yeh	Borjen	Apa-The Engineered Wood Assn
Zhou	Aixi	UNC Charlotte
Zicherman	Joe	Berkeley Engineering and Research

2. Summary

The workshop was a success and clearly highlighted the need for better interaction between those involved in the WUI codes and standards business with researchers involved in the fire safety science field. It was apparent that many of the researchers present had no idea how codes and standards are implemented in the WUI area, even though they are engaged in WUI research. The converse was true for the codes and standards representatives: there appeared to be no idea there was so much ongoing research even though it was published in many venues.

The plenary talk highlighted the deficiencies in the current WUI codes and standards, with the research presentations reinforcing these issues. The overarching issue was the lack of firebrands (embers) in the current building codes and standards, yet firebrand ignition are an accepted major structure ignition mechanism in these fires. The development of the NIST firebrand generator (NIST Dragon), currently used at IBHS, ADAI in Portugal, BRI and NRIFD in Japan, is beginning to help address the firebrand problem prevalent in WUI fires but it was clear far more research is required. A major result of this workshop is that is clear more such activities need to be arranged to allow transfer of research knowledge to the WUI codes and standards area. Finally, the NIST WUI Hazard Scale provided a framework to rate building elements to various WUI exposures.

Papers that were presented orally are eligible for submission to a special issue of *Fire Technology*, to be Co-Guest Edited by Dr. Stephen L. Quarles of IBHS, and Dr. Samuel L. Manzello of NIST.

3. Acknowledgements

The support of Dr. Marc Janssens, ASTM E05 Committee Chair, Dr. Matthew Bundy, ASTM E05 Committee Research Executive, Ms. Ellen Diegel, ASTM International Event Coordination, and Mr. Thomas O'Toole, ASTM E05 Staff Manager, is gratefully acknowledged for all their hard work to make this event a reality. All the presenters are appreciated for their hard work to deliver excellent presentations.

Appendix 1 Oral Presentations Delivered at Workshop

Workshop on Structure Ignition in Wildland-Urban Interface (WUI) Fires

Introduction

Dr. Samuel L. Manzello
Fire Research Division
Engineering Laboratory (EL)
National Institute of Standards and Technology (NIST)
samuelm@nist.gov

Anaheim, CA USA
June 18th, 2015

Workshop Co-Chair:
Dr. Stephen L. Quarles
Insurance Institute for Business & Home Safety (IBHS)
Richburg, SC USA
squarles@ibhs.org

Special Thanks – ASTM Committee E05 Fire Standards

Workshop Dedicated to the Memory of Dr. Robert Hawthorne White

PhD University Wisconsin-Madison
MS Oregon State University
BS Penn State

Forest Products Laboratory
39 years

1951 - 2014

ASTM Award of Merit and an honorary title of Fellow for his outstanding contributions to the development of ASTM standards

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WUI Fires

- Wildfires fires that spread into communities, known as Wildland-Urban Interface (WUI) fires have destroyed communities throughout the world

2014 Chile Fires

2003 Southern California Fires

2007 Southern California Fires

WUI Fires: Growing International Problem

- Fire safety science research has spent a great deal of effort to understand fire dynamics within buildings
- Research into WUI and urban fires is far behind other areas of fire safety science research
- Due to the fact that large outdoor fire spread is incredibly complex, involving the interaction of topography, weather, vegetation, and structures

Europe
2007 fires in Greece
Several hundred structures destroyed
More than 70 people perished

Australia
2009 Fires in Victoria
More than a 1000 structures destroyed
More than 170 people perished

South America
2014 Chile
More than 1000 structures destroyed

USA
2003, 2007 Southern California Fires
2011 Bastrop Complex Fire in Texas
2012 Waldo Canyon Fire in Colorado
2013 Fires in California, Colorado, Texas

WUI Fires in the USA

Wildland Fires
- 80,000 wildland fires each year
- 2-3 % of fires spread into destructive WUI fires

WUI Communities
- At least 46 million structures
- Over 70,000 communities at risk
- Over 120 million people affected

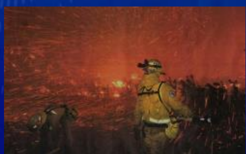
WUI Community Fires
- About 3000 homes lost in "average" year (38,601 homes since 2000)

Structure Ignition in WUI Fires

- **Post-fire studies – firebrands a major cause of ignition**
- **Understanding firebrand ignition of structures – important to mitigate fire spread in communities**

Improved understanding of structure ignition in WUI fires

Major recommendation (GAO 05-380)
National Science & Technology Subcommittee on Disaster Reduction
Homeland Security Presidential Directive (HSPD 8; Paragraph 11)
Royal Commission in Australia




Workshop Objectives

- **Some building codes and standards already exist to guide construction of new structures in areas known to be prone to WUI fires in order to reduce the risk of structural ignition**
- **These codes and standards have been developed based on best information at the time they were developed and often rely on flame contact and / radiant heat exposures to evaluate material performance**
- **Often this information was anecdotal**
- **The workshop will seek to answer the question whether current codes and standards are adequate since they do not usually explicitly address firebrand (ember) exposures**

International Interest

Accepted Presentations

University of Maryland (USA)
University of California – Berkeley (USA)
University of Edinburgh (UK)
USDA Forest Service (USA)
National Research Institute of Fire and Disaster (Japan)
COWI AS (Norway)
Center for Forest Fire Research – ADAI (Portugal)
NIST (USA)
Insurance Institute for Business & Home Safety – IBHS (USA)

Presentations Delineated into Four Areas

Research topics:

Post-fire studies

Structure ignition / firebrand (ember) accumulation/production

WUI modeling / hazard and risk

Evaluating mitigation strategies (USA)

Papers to be Published in Fire Technology

Special Issue Fire Technology
Guest Editors:
S. Manzello (NIST) and S. Quarles (IBHS)

NIST will also issue a NIST Special Publication – all presentations included

Special Thanks

- **Dr. M. Janssens (ASTM E05 Committee Chair)**
- **Dr. M. Bundy (ASTM E05 Committee Research Executive)**
- **Ms. Ellen Diegal, ASTM Event Coordinator**
- **Mr. Thomas O'Toole, ASTM E05 Staff Manager**
- **All presenters and attendees!!**

Are Existing Wildland-Urban Interface Codes Providing Adequate Protection

Nelson Bryner
Engineering Laboratory
National Institute of Standards and Technology (NIST)
Gaithersburg, MD

Symposium on Structure Ignition in Wildland-Urban Interface Fires
June 18, 2015

ASTM Committee E05 on Fire Standards

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Are Wildland-Urban Interface Fire Codes Providing Adequate Protection?

- **How big is the problem?**
- **What are the trends – is the problem growing?**
- **Is the problem preventable?**

- **WUI Codes**
  - International Wildland-Urban Interface Fire Code
  - California Wildland Hazard Building Code
  - Australian Bushfire Construction Code

- **Limitations of current WUI science and codes**

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How big is the problem?

Top 15 U.S. Fire Loss Incidents (NFPA)

Incident	Date	Adjusted Loss (2012 dollars)
1. World Trade Center, New York	2001	$43 billion
2. Earthquake and Fire, San Francisco	1906	$8.9 billion
3. Great Chicago Fire	1871	$3.2 billion
4. Oakland Hills Fire, CA	1991	$2.5 billion
5. So. California Firestorm, San Diego County	2007	$2.0 billion
6. Great Boston Fire, Boston	1872	$1.4 billion
7. Polyolefin Plant, Pasadena, TX	1989	$1.4 billion
8. Cerro Grande Wildland Fire, Los Alamos	2000	$1.3 billion
9. Wildland fire Cedar, Julian, CA	2003	$1.3 billion
10. Baltimore conflagration, Baltimore, MD	1904	$1.3 billion
11. "Old" Wildland Fire, San Bernadino, CA	2003	$1.2 billion
12. Los Angeles Civil Disturbance	1992	$0.9 billion
13. Cerro Grande Wildland Fire, Los Alamos	2000	$0.9 billion
14. Southern California Wildfires	2008	$0.9 billion
15. Laguna Beach Wildland Fire, CA	1993	$0.8 billion

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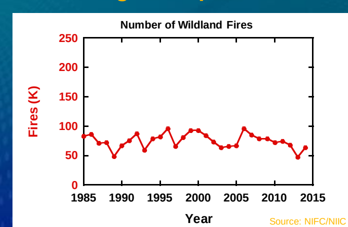
How big is the problem...cont'd



- 75,000 (average) wildfires annually in the U.S.
  - 97% contained < 10 acres
  - Remaining 3% (< 2300) of fire spread further
  - Only 3% of the remaining fires, < 100 fires, spread into communities

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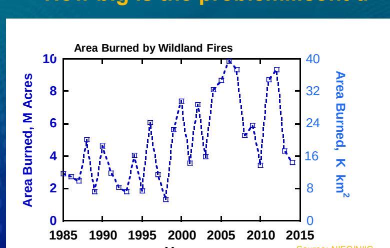
How big is the problem...cont'd



- Average Area Burned: (10 year)
  - 1985-1994: 3 M acres 12 K km^2
  - 1995-2004: 5 M acres 19 K km^2
  - 2005-2014: 7 M acres 28 K km^2

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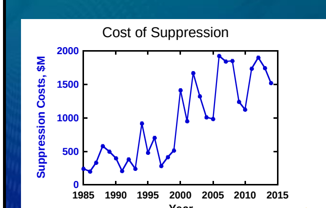
What are the Costs?



- Costs of wildland and WUI fire incidents less established and comprehensive
- most readily available cost associated with a wildland or WUI fire is suppression cost

Average Cost (10 year):	1985-1994	$ 400 M
	1995-2004	$ 880 M
	2005-2014	$1600 M

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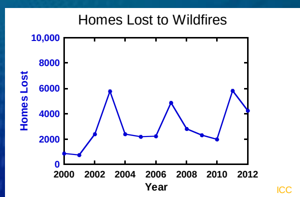
What are the trends- is the problem growing?



- Western US- 14% of WUI lands developed, 86% remain available for development
- United States – 30% of WUI lands developed; 70% still available for development

Total existing homes in WUI	46 Million	
Existing homes > 10 years old in WUI	25 Million	(54%)
Projected new homes in next 10 years	8 Million	
Project existing homes meeting IWUIC	15 Million	(35%)

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Is the Problem Preventable?

- Prevent expansion of communities into wildlands?
- Still need to address existing 46 M homes in WUI
- Prevent all the 75,000 wildland fires?
- Prevent 2-3 % of wildland fires spreading into WUI Communities?
- Need to harden communities to better resist exposure to WUI fires
- Building and Fire codes are an effective approach to hardening structures/communities

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Is the Problem Preventable?

- Are existing building and fire codes providing adequate protection?
- Can codes provide more adequate protection?
- Consider “urban” building and fire codes
  - In 1976, the U.S. experienced 2.9 million fires and 8,800 fatalities.
  - The Nation met this aggressive life safety goal. Between 1976 and 1995, the total number of fire deaths declined to about 4600 and the number of reported fires declined to 1.8 million, while the U.S. population grew by about 12 %
  - Since that time, the numbers of reported fires and fatalities have declined to 1.5 million and 3,300, respectively.
- Codes can be effective!!!

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Is the Problem Preventable?

- “Urban” Codes are effective
  - Identify vulnerabilities to ignition & fire spread
    - NFIRS & NFPA data
  - Understand the underlying science
  - Exposure test methods adequately simulate exposure
- “WUI” Codes do not provide adequate protection
  - Not able to systematically identify vulnerabilities
    - Need more post fire analysis
    - Community scale data
  - Need more comprehensive understanding of science
    - Extend “fire in the box” to include weather and terrain

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Is the Problem Preventable?

- “WUI” Codes do not provide adequate protection
  - Ongoing work on vulnerabilities & science
    - Pathways to fire spread (Gollner et al.)
    - Building components vulnerability to firebrand (Manzello et al.)
    - Spot fire ignition science (Urban et al.)
    - Mulch Bed ignition (Manzello et al.)
    - Wood Deck fire performance (Hasburgh et al.)
    - Firebrand generation and wooden structures (Kempna et al.)
    - Accumulation of firebrands (Quarles)
    - EcoSmart Fire Ignition Model (Dietenberger and Boardman)
    - Hardening Heritage Buildings (Jensen et al.)
    - Fire Hazards in Camping Parks (Almeida et al.)

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Is the Problem Preventable?

- “Urban” Codes are effective
  - Identify vulnerabilities to ignition & fire spread
    - NFIRS & NFPA data
  - Understand the underlying science
  - Exposure test methods adequately simulate exposure
- “WUI” Codes do not provide adequate protection
  - Not able to systematically identify vulnerabilities
    - Need more post fire analysis
    - Community scale data
  - Need more comprehensive understanding of science
    - Extend “fire in the box” to include weather and terrain
- Current standards do not adequately consider the range of exposures during a WUI fire

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Is the Problem Preventable?

- What are the exposures that building and fire codes need to simulate for WUI fires?
  - Thermal radiative flux (separation distances)
  - Flame contact (ignition/spread resistance)
  - Firebrands (cause 50% of ignitions lofted > 20 km)
  - Weather (low humidity and wind)
  - Terrain (slope and channeling of fire spread)
- WUI Codes
  - International Wildland-Urban Interface Fire Code
  - California Wildland Hazard Building Code
  - Australian Bushfire Construction Code

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Current Wildland-Urban Interface Fire Codes

- International Wildland-Urban Interface Code
  - First Edition - 2003
    - ICC (International Code Council)
    - BOCA (Building Officials and Code Administrators)
    - ICBO (International Conference of Building Officials)
    - SBCCI (Southern Building Code Congress International)
  - Fire Hazard Severity
    - Frequency of Critical Fire Weather (1, 2-7, >8 days)
    - Slope (< 40, 41-60, > 61%)
    - Fuel Load (Light, Medium, Heavy)

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- International Wildland-Urban Interface Code
- Fuel Load
  - Heavy –
    - Vegetation consisting of round wood 3 to 8 inches (76 to 203 mm) in diameter.
    - Fuel Models of Fire Danger Rating System (USFS)
      - Dense Conifer Stands (G); Clearcut conifer slash (I); Clearcut and heavily thinned conifer stands (J); Slash fuels (K); Closed stands of western long-needle pines (U)
  - Medium –
    - Vegetation consisting of round wood 0.25 to 3 inches (6.4 to 76 mm) in diameter
    - Fuel Models of Fire Danger Rating System (USFS)
      - Mixed chaparral (B); Palmetto-gallbery understory-pine overstory of Southeast (D); Mature closed chamise stands and oakbrush fields of Arizona (F); Short-needled conifers (H); Dense brushlike fuels of Southeast (O); Alaskan black spruce (Q); Hardwood after leaf out in spring (R); and Sagebrush-grass types (T)
  - Light-
    - Vegetation consisting of herbaceous plants and round wood less than 0.25 inch (6.4mm) in diameter
    - Fuel Models of Fire Danger Rating System (USFS)
      - Western Grasslands (A); Open pine stands (C); Hardwood and mixed conifer after leaf fall (E); Heavy grasslands (L); Sawgrass Florida (N); Closed thrifty stands of long-needled southern pine (P); Hardwood after leaf out in spring (R); and Alaskan or alpine tundra (S)

Only need to consider vegetative fuels? "Target" structures become "sources"

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International Wildland-Urban Interface Code

- Fire Hazard Severity
  - Frequency of Critical Fire Weather (1, 2-7, >8 days)
  - Slope (< 40, 41-60, > 61%)
  - Fuel Load (Light, Medium, Heavy)
- Moderate, High, or Extreme Hazard

TABLE 502.1
FIRE HAZARD SEVERITY

FUEL MODEL[b]	CRITICAL FIRE WEATHER FREQUENCY								
	≤ 1 Day[a]			2 to 7 days[a]			≥ 8 days[a]		
	Slope (%)			Slope (%)			Slope (%)		
	≤ 40	41-60	≥ 61	≤ 40	41-60	≥ 61	≤ 40	41-60	≥ 61
Light fuel	M	M	M	M	M	M	M	M	H
Medium fuel	M	M	H	H	H	H	E	E	E
Heavy fuel	H	H	H	H	E	E	E	E	E

E = Extreme hazard;
H = High hazard;
M = Moderate hazard.
a. Days per annum.
b. Where required by the code official, fuel classification shall be based on the historical fuel type for the area.

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International Wildland-Urban Interface Code - IWUIC

Using Fire Hazard Severity

- Defensible Space
  - Nonconforming
  - Conforming

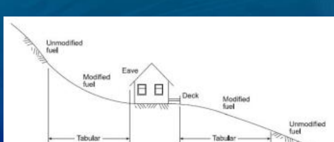

FIGURE 603.2
MEASUREMENTS OF FUEL MODIFICATION DISTANCE

TABLE 603.2
REQUIRED DEFENSIBLE SPACE

WILDLAND-URBAN INTERFACE AREA	FUEL MODIFICATION DISTANCE (feet)[a]
Moderate hazard	30
High hazard	50
Extreme hazard	100

For SI: 1 foot = 304.8 mm.

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International Wildland-Urban Interface Code - IWUIC

Using Fire Hazard Severity

- Ignition Resistant Construction
  - Class 1 (designed to be most resistant)
  - Class 2
  - Class 3

TABLE 503.1
IGNITION-RESISTANT CONSTRUCTION[a]

DEFENSIBLE SPACE[c]	FIRE HAZARD SEVERITY					
	Moderate Hazard		High Hazard		Extreme Hazard	
	Water Supply[b]		Water Supply[b]		Water Supply[b]	
	Conforming[d]	Nonconforming[e]	Conforming[d]	Nonconforming[e]	Conforming[d]	Nonconforming[e]
Nonconforming	IR 2	IR 1	IR 1	IR 1 N.C.	IR 1 N.C.	Not Permitted
Conforming	IR 3	IR 2	IR 2	IR 1	IR 1	IR 1 N.C.
1.5 × Conforming	Not Required	IR 3	IR 3	IR 2	IR 2	IR 1

a. Access shall be in accordance with Section 403.
b. Subdivisions shall have a conforming water supply in accordance with Section 402.1.
IR 1 = Ignition-resistant construction in accordance with Section 504.
IR 2 = Ignition-resistant construction in accordance with Section 505.
IR 3 = Ignition-resistant construction in accordance with Section 506.
N.C. = Exterior walls shall have a fire-resistance rating of not less than 1 hour and the exterior surfaces of such walls shall be *noncombustible*. Usage of log wall construction is allowed.
c. Conformance based on Section 603.
d. Conformance based on Section 404.
e. A nonconforming water supply is any water system or source that does not comply with Section 404, including situations where there is no water supply for structure protection or fire suppression.

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Ignition Resistance Construction

	Roof Rating	Eaves (resistance rating)	Exterior Walls (resistance rating)	Decks[a] (resistance rating)	Vents
Class 1	Class A	1 hr fire Protected underside	1 hr fire Or noncombustible	1 hr fire Or noncombustible	Noncombustible mesh openings < 6.4 mm
Class 2	Class B	Min. Thickness Of 0.75 inch Exposed rafter tails if heavy timber	1 hr fire Or noncombustible	1 hr fire Or noncombustible	Noncombustible mesh openings < 6.4 mm
Class 3	Class C				

Ignition Resistant Building Materials – flame spread index < 25 (extended ASTM E 84 Test)
Roof Assembly Rating – ASTM E 108
[a]Appendages and Projections - treated as attached feature

International Wildland-Urban Interface Code - IWUIC

- Fire Hazard Severity, Defensible Space and Ignition Resistant Construction addresses
  - Thermal radiative flux
    - 30, 50, 100 ft
    - Roof rating
  - Flame contact
    - 1 hr fire rating
    - Roof rating
  - Firebrands
    - Vents
    - Gutters
  - Weather
    - Frequency of dry weather
  - Terrain
    - 20% slope

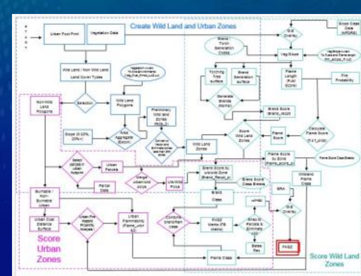
- Radiative feedback from component to component
- Wind-driven flame contact
- Firebrand exposure and penetration
- Firebrand generation
- Target structures become sources
- Wind-driven fire & firebrands
- Extreme fire events
- Increased fire spread upslope
- Channeling of fire by canyons

Current Wildland-Urban Interface Fire Codes

- California Wildland Hazard & Building Codes
  - CA Fire Code 2007
    - Chapter 47 Requirements for WUI Fire Areas
      - Fire hazard severity zones
  - CA Government Codes
      - Section 51175-51189 – Extreme Fire Hazard Zones
  - CA Building Code 2007
    - Chapter 7A Materials and Construction Methods for Exterior Wildfire Exposure
    - Chapter 15 Roofs
  - Public Resources Code
    - Section 4290 – hazardous fire area
    - Section 4291 – defensible space 30 & 100 feet zones

California Wildland Hazard & Building Codes

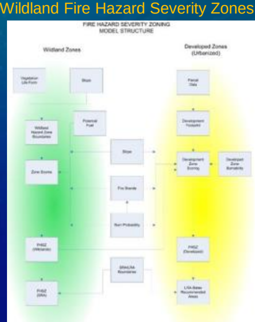
- Fire Hazard Severity Zoning
  - CA identifies Fire Hazard Severity Zones



California Wildland Hazard & Building Codes

- Urban and Wildland Fire Hazard Severity Zones

Wildland Zones



Urban Zones

California Wildland Hazard & Building Codes

- Fire Hazard Severity Zoning
  - Urban Zoning
    - Parcel – 20 acres
  - Wildland Zoning
    - Zone – 200 + acres
    - Potential hazard over lifetime of structure
    - Grass, brushlands, woodlands, conifer, & conifer woodland
    - Slope - < or > 20 %
    - Each cell – flame score
      - Fuels, slope, & 2 model runs, winds 0 and 20 mph
    - Firebrands modeled to be received by cell
  - Zones ranked - Moderate, High, and Very High

California Wildland Hazard & Building Codes

- Fire Hazard Severity Zones
  - Fuels and flame height
  - Slope < 20 % and > 20 %
  - Wind 0 mph and 20 mph
- Zones – Very High, High, and Moderate and designed WUI Zone
  - Identified across the state
  - Determine design and materials
  - Approved materials list

California Wildland Hazard & Building Codes

Fire Hazard Severity Zone	Roof Rating[a]	Eaves	Exterior Walls	Decks	Vents
Very High SRA/LRA[b]	Class A	FR Approved Material CA Listed	FR Approved Material CA Listed	FR Approved Material CA Listed	Corrosion Resistant Metal Mesh 3.2 mm < opening < 6 mm
State Responsibility Area	Class B	IR Material or noncombustible	IR Material or noncombustible	IR Material or noncombustible	
Other Areas	Class C	IR Material or noncombustible	IR Material or noncombustible	IR Material or noncombustible	
Wildland Urban Interface Area	Class A	FR Approved Material CA Listed	FR Approved Material CA Listed	FR Approved Material CA Listed	

[a]Chapter 15 California Building Code
[b]State Responsibility Area – SRA
[b]Local Agency Responsibility Area – LRA
Wildland-Urban Interface Fire Area – designated by enforcing agency
IR (Ignition Resistant Building Materials) – flame spread index < 25 (extended ASTM E 84 Test)
FR(Fire Resistant Material) passing CA test method
Eaves – 300 kW/m2 exposure (10 min) during 40 minute test
Exterior Walls – 150 kW/m2 exposure (10 min) during 70 minute test
Decks – 80 kW/m2 exposure (3 min) during 43 minute test

Roof Assembly Rating – ASTM E 108
Defensible Space – reduced fuel zone

California Wildland Hazard & Building Codes

- Defensible Zone
  - Firebreak - 30 ft from structure
  - Reduced Fuel Zone - 30 to 100 ft
    - Plant spacing guidelines
      - Trees and shrubs
      - Slope – 10- 20 feet depending on slope
        2 – 6 times depending on height of shrub

California Wildland Hazard & Building Codes

- Fire Hazard Severity Zones, Defensible Zone, Approved Materials List addresses
  - Thermal radiative flux
    - 30 and 100 ft
    - Roof rating
  - Flame contact
    - FR & IR Materials
    - Roof rating
  - Firebrands
    - Vents
    - Gutters
  - Weather
    - 0 and 20 mph
  - Terrain
    - 20% slope

- Radiative feedback from component to component
- Wind-driven flame contact
- Firebrand exposure and penetration
- Firebrand generation from structures
- Wind > 20 mph Diablo & Santa Ana conditions
- Wind-driven fire & firebrands
- Increased fire spread upslope
- Channeling of fire by canyons

Current Wildland-Urban Interface Fire Codes

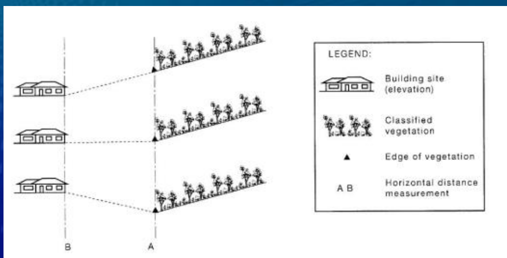
- Australian Standard AS 3959 - Construction of Buildings in Bushfire-Prone Areas
  - Environmental Planning and Assessment (1979)
  - Rural Fires Act (1997)
  - Rural Fires and Environmental Assessment Legislation (2002)
  - Planning for Bush Fire Protection (2006)
  - Bushfire-Prone Areas (1991,1999, 2009)
- Bushfire-prone areas designated by Building Code of Australia
- Fire Danger Index
  - Set by each state/region
- Assess Bushfire Attack Level

Australian Standard AS 3959

- Fire Danger Index
  - Set by each state/region
- Assess Bushfire Attack Level
  - Vegetation Classification
    - Forest, woodland, shrubland, scrub, mallee/mulga, rainforest, grassland
  - Distance from vegetation
  - Effective Slope
  - Determine Bushfire Attack Level (BAL)

Australian Standard AS 3959

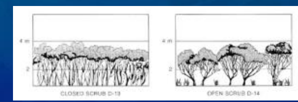
Vegetation Distance



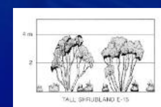
Australian Standard AS 3959

Classification of Vegetation

Scrub



Mallee / Mulga



Australian Standard AS 3959

DETERMINATION OF BUSHFIRE ATTACK LEVEL (BAL)—FDI 100 (1090 K)

Vegetation classification	Bushfire Attack Levels (BALs)				
	BAL—FZ	BAL—40	BAL—29	BAL—19	BAL—12.5
	Distance (m) of the site from the predominant vegetation class				
	All upslopes and flat land (0 degrees)				
A. Forest	<19	19–<25	25–<35	35–<48	48–<100
B. Woodland	<12	12–<16	16–<24	24–<33	33–<100
C. Shrubland	<10	10–<13	13–<19	19–<27	27–<100
D. Scrub	<7	7–<9	9–<13	13–<19	19–<100
E. Mallee/Mulga	<6	6–<8	8–<12	12–<17	17–<100
F. Rainforest	<8	8–<11	11–<16	16–<23	23–<100
	Downslope >0 to 5 degrees				
A. Forest	<24	24–<32	32–<43	43–<57	57–<100
B. Woodland	<15	15–<21	21–<29	29–<41	41–<100
C. Shrubland	<11	11–<15	15–<22	22–<31	31–<100
D. Scrub	<7	7–<10	10–<15	15–<22	22–<100
E. Mallee/Mulga	<7	7–<9	9–<13	13–<20	20–<100
F. Rainforest	<10	10–<14	14–<20	20–<29	29–<100
	Downslope >5 to 10 degrees				
A. Forest	<31	31–<39	39–<53	53–<69	69–<100
B. Woodland	<20	20–<26	26–<37	37–<50	50–<100
C. Shrubland	<12	12–<17	17–<24	24–<35	35–<100
D. Scrub	<8	8–<11	11–<17	17–<25	25–<100
E. Mallee/Mulga	<7	7–<10	10–<15	15–<23	23–<100
F. Rainforest	<13	13–<18	18–<26	26–<36	36–<100

Australian Standard AS 3959

Bushfire Attack Level and Constructions Requirements

BUSHFIRE ATTACK LEVELS AND CORRESPONDING SECTIONS FOR SPECIFIC CONSTRUCTION REQUIREMENTS

Bushfire Attack Level (BAL)	Classified vegetation within 100 m of the site and heat flux exposure thresholds	Description of predicted bushfire attack and levels of exposure	Construction Section
BAL—LOW	See Clause 2.2.3.2	There is insufficient risk to warrant specific construction requirements	4
BAL—12.5	≤12.5 kW/m^2	Ember attack	3 and 5
BAL—19	>12.5 kW/m^2 ≤19 kW/m^2	Increasing levels of ember attack and burning debris ignited by windborne embers together with increasing heat flux	3 and 6
BAL—29	>19 kW/m^2 ≤29 kW/m^2	Increasing levels of ember attack and burning debris ignited by windborne embers together with increasing heat flux	3 and 7
BAL—40	>29 kW/m^2 ≤40 kW/m^2	Increasing levels of ember attack and burning debris ignited by windborne embers together with increasing heat flux with the increased likelihood of exposure to flames	3 and 8
BAL—FZ	>40 kW/m^2	Direct exposure to flames from fire front in addition to heat flux and ember attack	3 and 9

Australian Standard AS 3959

- Fire Resistance Level structural adequacy/integrity/insulation
- FRL 120/60/30 structural adequacy120 min, integrity 60 min, and insulation for 30 min
- Bushfire Resistant Material – AS 3837
- Maximum heat release of 100 kW/m2
- HRR < 60 kw/m2 when exposed to 25 kw/m2
- Radiant Heat and Small Flaming Sources – AS 1530.8.1
- BAL 40 40 kw/m2 x 2 min; tapering flux to 3 kw/m2 over 10 min
- BAL 29 29 kw/m2 x 2 min; tapering flux to 3 kw/m2 over 10 min
- BAL 19 19 kw/m2 x 2 min; tapering flux to 3 kw/m2 over 10 min
- Large Flaming Sources – AS 1530.8.2
- BAL FZ 30 min flame contact
- Fire-resistance test of elements of construction AS 1530.8.4 (ISO 834)
- Standard time temperature curve conducted in furnace

Australian Standard AS 3959

Bushfire Attack Level	Roof Rating	Eaves	Exterior Walls	Decks	Vent
Flame Zone	Large Flame Approved	FR Approved Material CA Listed	Noncombustible Large Flame Approved FRL 30/30/30	Noncombustible Fiber cement, Large Flame Approved	Corrosion Resistant Metal mesh < 2mm opening
40	Noncombustible Tiled or Sheet Fully Sarked < 2mm opening	Fiber cement Calcium silicate, and lined Rad Heat & Small Flame Approved	Steel, Fiber cement Calcium silicate, Rad Heat & Small Flame Approved	Noncombustible Rad Heat & Small Flame Approved	Corrosion Resistant Metal mesh < 2mm opening
29	Noncombustible Tiled or Sheet Fully Sarked < 2mm opening	Metal, Fiber cement Bushfire resistant timber, and lined	Steel, Fiber cement Bushfire resistant timber	Noncombustible, Bushfire resistant timber	Corrosion Resistant Metal mesh < 2mm opening
19	Noncombustible Tiled or Sheet Fully Sarked < 2mm opening	Noncombustible, Fiber cement Bushfire resistant timber	Noncombustible, Fiber cement Bushfire resistant timber	Noncombustible, Bushfire resistant timber	Corrosion Resistant Metal mesh < 2mm opening
12.5	Noncombustible Tiled or Sheet Fully Sarked < 2mm opening	Noncombustible, Fiber cement Bushfire resistant timber	Noncombustible, Fiber cement Bushfire resistant timber		
Low	Insufficient risk to warrant specific construction requirements				

Fire Resistance Level structural adequacy/integrity/insulation
FRL 120/60/30 structural adequacy120 min, integrity 60 min, and insulation for 30 min
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Large Flaming Sources – AS 1530.8.2; BAL FZ 30 min flame contact
Fire-resistance test of elements of construction AS 1530.8.4 (ISO 834) Standard time temperature curve conducted in furnace

Australian Standard AS 3959

- Bushfire Attack Level and Construction addresses
  - Thermal radiative flux
    - BAL levels
    - Vegetation separation
    - Roof rating
    - Fire Resistance Level
  - Flame contact
    - Bushfire Resistand Materials
    - Roof rating
    - Fire Resistance Level
  - Firebrands
    - Vents
    - gutters
  - Weather ?
  - Terrain
    - Flat, upslope and 5 -20 % slope

- Radiative feedback from component to component
- Wind-driven flame contact
- Firebrand exposure and penetration
- Firebrand generation
- Wind-driven fire & firebrands
- Increased fire spread upslope
- Channeling of fire by canyons

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Do WUI Fire Codes Provide Adequate Protection

- **"WUI" Codes are not providing adequate protection –**
  - Focused on thermal radiation and flame contact
    - Firebrands-50% of the ignitions addressed only through ignition and fire spread resistance
  - Firebrand exposure and penetration not adequately addressed
    - Igniting wood crib on roof does not adequately represent wind-driven firebrand exposure
    - Vegetative firebrands
    - Burning structures generate firebrands
  - Weather- wind, wind-driven fire and firebrands not addressed
    - Wind in Fire Severity Zones
    - Difficult to improve design/materials

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Do WUI Fire Codes Provide Adequate Protection

- **"WUI" Codes are not providing adequate protection –**
  - Terrain - slope
    - Limited to 20%, not all codes consider upslope
    - Impact of canyons, hills, chutes, cliffs not addressed
  - Fire timeline
    - Firebrands arrive before fire front
    - Structures on edge of community exposed to firebrands & flames
    - Structures on interior of community exposed to firebrands
    - Do parts of community need same level of protection?
  - Defensive Actions
    - Fire department
    - Homeowner
    - Passive and active prevention technologies

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Do WUI Fire Codes Provide Adequate Protection?

"WUI" Codes are not providing adequate protection –

- **"WUI" Codes are a reflection of current science**
  - Lack of WUI fire data
    - Typically count destroyed structures
    - Useful data in structures that survived
    - Not able to identify vulnerable parts of structure/community
    - Need community-scale data to understand complex interactions
- Need more comprehensive understanding of the science
- Need more representative test methods
  - Drive development of better design/materials

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Questions or Comments?

•Thank you for the opportunity to discuss WUI Fire Codes

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UNIVERSITY OF MARYLAND
Department of Fire Protection Engineering

Pathways to Fire Spread in the Wildland Urban Interface (WUI)

Michael J. Gollner
Assistant Professor
Department of Fire protection Engineering

Sara Caton, Kyle Kohler and Raquel Hakes
Department of Fire Protection Engineering

THE FIRE PROTECTION RESEARCH FOUNDATION
Research in support of the NFPA mission

NFPA

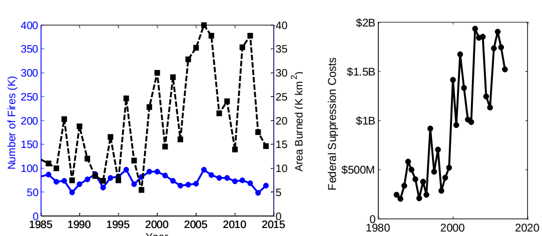
Report Outline

- **Wildland-Urban Interface Problem**
- **Exposure Conditions**
  - *Firebrands, radiant heating, direct flame contact*
- **Response of Components and Systems**
  - *Roofing, gutters, eaves, fences, etc.*
- **Case Studies and Investigations**
- **Mitigation Strategies**
  - *Codes and standards, zone concept, risk mapping.*
- **Gap Analysis**
  - *Future recommendations*

Cocos Fire, San Marcos, CA 2014

WILDLAND-URBAN INTERFACE PROBLEM

Increasing Size and Cost of Fires



(Left) While the number of wildfires is somewhat steady (solid blue), the size and intensity of these fires (dashed black) is drastically increasing. (Right) Federal firefighting costs are similarly increasing.

National Interagency Fire Center. www.nifc.gov/nicc

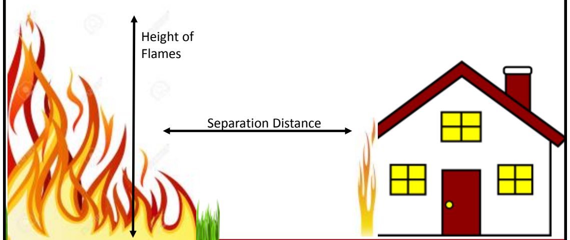
Destroyed neighborhood after 2007 San Diego Wildfires
Photo by Sandy Huffaker / Getty Images

What causes a home to ignite during a WUI fire?

EXPOSURE CONDITIONS

3 Exposure Conditions

1. **Radiation**
   – Originally thought to be responsible for most/all ignitions

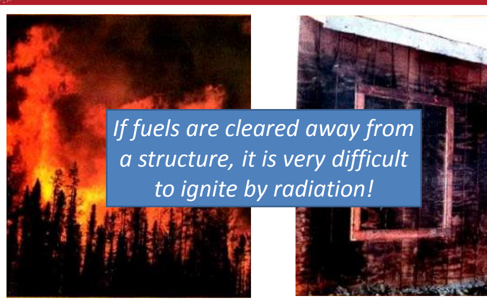


Aftermath – No Ignition

- Panels 40 m (130 ft) away could not ignite, even from the most intense fires.

Cohen, J., 2004a. Can. J. For. Res. 1626, 1616–1626

Aftermath – No Ignition



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3 Exposure Conditions

1. **Radiation**
   – Originally thought to be responsible for most/all ignitions
2. **Direct Flame Contact**
   – Smaller flames from nearby sources ignite portions of home

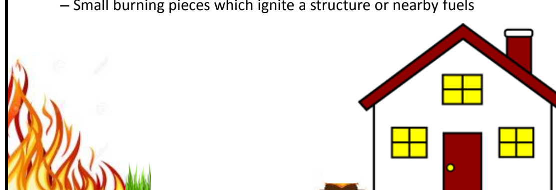
Direct Flame Contact

- Flames must directly contact long enough to cause ignition
- Typically, does not occur from the main fire front
  – Unless extreme conditions present
  – Often secondary source: nearby burning material (mulch, wood pile, etc.)
- Traditional wildfire literature describes flame lengths and ROS of vegetative fuels under various ambient conditions
- Existing fire models cannot determine effectiveness or size of a needed fuel break.

Finney, M.A., Cohen, J.D., McAllister, S.S., Jolly, W.M., 2013. Int. J. Wildl. Fire 22, 25.
Syphard, A.D., Keeley, J.E., Brennan, T.J., 2011. Int. J. Wildl. Fire 20, 764

3 Exposure Conditions

1. **Radiation**
   – Originally thought to be responsible for most/all ignitions
2. **Direct Flame Contact**
   – Smaller flames from nearby sources ignite portions of home
3. **Embers or Firebrands**
   – Small burning pieces which ignite a structure or nearby fuels



3 Exposure Conditions

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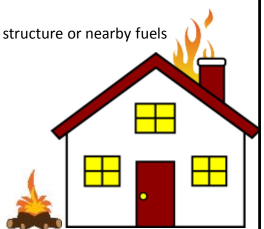


Firebrands

Firebrands or Embers

- Least understood of ignition pathways
- Typically broken into 3 processes
  - Production/Generation
  - Lofting/Transport
    - In 2007 NIST study in San Diego, firebrands arrived 1 hour before arrival of the flame front
    - Travelled up to 9 km igniting properties over the following 9 hours.
  - Ignition/Deposition
- Of the three, Production and Ignition are least understood

Maranghides, A., McNamara, D., Mell, W., Trook, J., Toman, B., 2013. A case study of a community affected by the Witch and Guejito fires : report #2

Firebrand Reproduction for Testing

A typical experiment with the NIST Dragon in BRI's FRWTF

"Ember storm" produced in the IBHS research facility

Manzello, S.L., 2014. Enabling the Investigation of Structure Vulnerabilities to Wind- Driven Firebrand Showers in Wildland-Urban Interface (WUI) Fires. Fire Saf. Sci. 11
IBHS, 2014. http://www.disastersafety.org.

Vinyl gutters and mulch and debris ignite and burn at a test in the IBHS research center

RESPONSE OF COMPONENTS AND SYSTEMS

A. JAMES CLARK SCHOOL *of* ENGINEERING • UNIVERSITY *of* MARYLAND

Roofing

- Often most susceptible component to firebrand attack
  – 1990 Santa Barbara Paint fire, 70% of houses with nonflammable roofs survived, 19% with flammable roofs survived.
  – 2007 San Diego Wildfires, 100% of exposed wood shake destroyed, 24% of exposed Spanish tile roofs destroyed (*in studied community*)
- Fire Ratings on Roofs
  – ASTM E-108, UL 790, NFPA 276
  – Evaluates resistance to spread into attic, spread onto roof covering, generating burning firebrands
  – Class A,B,C
  – "Brand" test may not be appropriate – no accumulation

Maranghides, A., McNamara, D., Mell, W., Trook, J., Toman, B., 2013. A case study of a community affected by the Witch and Guejito fires : report #2
Foote, E., 1994. Structure survival on the 1990 Santa Barbara "Paint" Fire : a retrospective study of urban-wildland interface fire hazard mitigation factors. M.S. Thesis, University of California, Berkeley

Roofing

- Even Class A roofs found to ignite *(Manzello et al.)*
  - "Brand" test may not be appropriate – no accumulation
  - Tile roofs
    - With tar paper and bird stops removed – OSB would ignite
    - Smoldering sometimes occurred with proper bird stop/tar paper installation
    - If needles and leaves are deposited under the tiles, ceramic tile roofing assemblies were ignitable under all conditions considered
    - Flat tile terracotta roofing assembly performed best (interlocking design)
  - Asphalt roof
    - Assemblies (OSB, tar paper, and asphalt shingles) failed to ignited under firebrand exposure in 60° and 90° valleys
    - Asphalt shingles did melt, but no ignition was observed
  - A potential cost-effective mitigation strategy would be to use a continuous underlayment of firebrand-resistant sarking

Quarles, S.L., 2012. Vulnerabilities of Buildings to Wildfire Exposures
Manzello, S.L., Hayashi, Y., Yoneki, T., Yamamoto, Y., 2010a. Fire Saf. J. 45, 35–43

Gutters

- Debris collected in gutters can be ignited by firebrands
  - Thought to be a significant cause of ignitions in the Grass Valley Fire
- PVC gutter tests showed ignition & melting of gutter, but only smoldering of asphalt roof assembly
  - Pine needles placed in gutter as litter
- IBHS large-scale tests of gutter ignitions
  - Vinyl gutter caught fire with litter inside, but gutter melted off after ignition
  - Metal gutter: house caught fire through flame contact to fascia and roof sheathing
- ***Must find ways to keep litter off roof/gutter***

Cohen, J.D., Stratton, R.D., 2008. USFS, General Technical Report R5-TP-026b.
Manzello, S., Shields, J., Hayashi, Y., Nii, D., 2008. Fire Saf. Sci. 9, 143–154.
IBHS, http://www.disastersafety.org.

Mulch and Debris

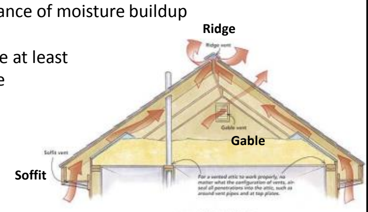
- Mulch, woody vegetation, wood piles and other flammable debris should not be stored near a structure
  - Ignite by direct flame contact or firebrands and ignite the home
- Mulch Ignition & Flaming Tests
  - Manzello et al. (2006b) mulches including shredded hardwood, pine straw and dried cut grass.
    - Ignition dependent on ***number or flux of brands*** (one insufficient)
  - Steward (2003) tested 13 different mulches
    - When igniting with a torch, all mulches eventually ignited, but with ground rubber and pine needles igniting significantly faster than other mulches.
  - Quarles and Smith (2004) measured some relative flammability properties for 8 mulches in 8 foot (2.5 m) diameter plots
    - Except for composted wood chips, all exhibited flaming combustion

Quarles, S. and Smith, E., 2004, The combustibility of landscape mulches. University of Nevada Cooperative Extension
Manzello, S.L., Cleary, T.G., Shields, J.R., Yang, J.C., 2006b. Int. J. Wildl. Fire 15, 427.
Steward, L.G., Sydnor, T.D., Bishop, B., 2003. Journal of Aboriculture 29(6) 317-321

Eaves and Vents

- Eaves and vents have been recognized to be significant sources of ignition for homes in the WUI
- Most homes have these vents both for thermal efficiency and to minimize the chance of moisture buildup

It is common to have at least one outlet vent type
- Gable
- Ridge
- Soffit

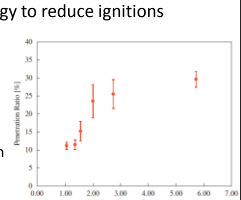


A schematic of vents used to ventilate an attic space

www.finehombuilding.com

Mesh Sizes

- Reducing mesh size - primary strategy to reduce ignitions
- Firebrands still don't quench with mesh
  - Continues to burn until it passes though opening
  - Even as small as 1 mm
  - Smaller mesh reduces prob. of ignition
  - Larger mesh sizes ignite more quickly
- Eave vents had less accumulation than gable or foundation vents in NIST Dragon
  - Horizontal vent created recirculating flow that did not carry firebrands as well



Firebrand penetration ratio as a function of mesh opening size

Manzello, S.L., Park, S.-H., Suzuki, S., Shields, J.R., Hayashi, Y., 2011. Fire Saf. J. 46, 568–578.
Manzello, S.L., Suzuki, S., Hayashi, Y., 2012a. Fire Saf. J. 54, 181–196

Ember Penetration Test

- New standard: ASTM E2886, Standard Test Method for Evaluating the Ability of Exterior Vents to Resist the Entry of Embers and Direct Flame Impingement
- Ember exclusion/intrusion test and a flame intrusion test
- Different than previous tests performed with NIST Dragon
  - Embers fall through vertical shaft and through a vent onto a cotton target
  - Considered a worst-case scenario, therefore used in test standard
  - Compared to NIST Dragon tests performed horizontally in a large-scale fire wind tunnel

Manzello, S.L., Park, S.-H., Shields, J.R., Hayashi, Y., Suzuki, S. 2010c. Comparison Testing Protocol for Firebrand Penetration through Building Vents: Summary of BRI / NIST Full Scale and NIST Reduced Scale Results NIST Technical Note 1659 Comparison Testing Protocol for Firebrand Penetration through Building Vents : Summary. Gaithersburg, MD.

Fences

- In investigation of the 2007 Witch Creek and Guejito fires, 45% of homes with attached wood fences were destroyed
  - Wooden trellises and other yard structures were also burned
  - Post-fire studies on the Waldo Canyon Fire in Colorado determined wood fences were vulnerable to ignition from firebrand showers
- No experimental verification of this ignition mechanism
- NIST is currently performing research on this topic
- Obvious to keep all flammable materials away from home
  - ***Separation distances required needs research***

Manzello, S.L., 2014. Fire Saf. Sci. 11.
Maranghides, A., McNamara, D., Mell, W., Trook, J., Toman, B., 2013. NIST report #2
IBHS, 2008. MEGA FIRES: The Case for Mitigation. http://www.disastersafety.org

Decks, Porches and Patios

- Decks significant source of ignition in 2007 San Diego Fires
  - Wooded slopes with overhanging decks created a large hazard
  - Combustibles under deck major hazard
    - Direct flame impingement from small surface fire observed
    - Angora fire: surroundings had small or no fire, but decks ignited homes
- Deck material tested for flame spread properties and ignition potential from direct flame contact, but not firebrands or the potential radiant energy production from the deck to ignite the adjacent structure
- Manzello and Suzuki tested deck sections in re-entrant corner
- **Decks need better national tests (CA has CBC 12-7A-4)**

Quarles, S., Leschak, P., Cowger, R., Worley, K., Brown, R., Iskowitz, C., 2012.
Murphy, K., Rich, T., Sexton, T., 2007. US For. Serv. Tech. Pap. R5-TP-025.
Mell, W., Maranghides, A., 2009. NIST Technical Note 1635
Manzello, S.L., Suzuki, S., 2014. Fire Saf. Sci. 11

Sidings, Windows and Glazing

- Ignition of materials on exterior walls major concern
  - Siding often ignites due to direct flame contact or radiant heat
- Under wind-driven conditions, **re-entrant corners** lead to the formation of a small recirculation zone which can attach the flame close to a wall (essentially mimicking a fire whirl) and lead to a higher vulnerability to ignition.
- Siding treatments have been studied using NIST Dragon
  - Vinyl siding: firebrands melted through siding
  - Polypropylene siding: melted, did not ignite
  - In actual wildfire: winds can be above 20 m/s
  - Test illustrates potential hazards

Wildfire Home Assessment and Checklist. http://www.disastersafety.org
Manzello, S.L., Suzuki, S., Hayashi, Y., 2012a. Fire Saf. J. 54, 181–196
Manzello, S.L., Suzuki, S., Hayashi, Y., 2012b. Fire Saf. J. 50, 25–34

Sidings, Windows and Glazing

- Firebrand accumulation around glazing assemblies possible mechanism for window breakage
  - Contributor to fire penetration into a structure?
  - Embers could accumulate in the framing of a double hung assembly, more so in a vertical wall assembly, but none sustained sufficient damage to break the glass or penetrate the structure
- Windows tested for radiant exposure
  - Glass is the most vulnerable part of a window
    - Dual-pane tempered glass did not fail even with a 25 min exposure 35kW/m^2
    - Conclusion supports code, such as NFPA 1144 5.7.2 which requires the use of tempered or other fire-resistant glass (NFPA, 2013).
- Plastic Skylights – highlighted as risk
  - While obvious, no data available to back up the assessment

Manzello, S.L., Suzuki, S., Hayashi, Y., 2012b. Fire Saf. J. 50, 25–34 and disastersafety.org

Structure-to-Structure Spacing

- Siding ignition from ICFME proposed 2 story structures spaced about 39 feet apart (*based on radiant heat fluxes*)
- Large-scale experiments at NIST (*only in literature*)
  - Fire spread to buildings clad with combustible material vs. non-combustible (fire-rated gypsum wallboard)
  - Spread rate was significantly slowed with non-combustible cladding (1-hour fire rated assembly, spaced 6 ft (1.8 m))
  - Most significant spread from flames exiting/entering broken windows
  - Heat fluxes on adjacent wall peaked between 60 - 110 kW/m^2 at the top of the wall
  - A 1-hour fire-rated wall could increase protection for closely spaced homes, but complete hardening of a home will require other protection methods (Quarles et al., 2012).
- **More testing needed**

Cohen, J.D., 1995. USDA Forest Service Gen. Tech. Rep. PSW-GTR-158.
Maranghides, A., Johnsson, E., 2008. NIST Technical Note 1600.

Community Planning

- Waldo Canyon fire
  - 12 -20 ft (3 -6 m) spacing where home-to-home ignition occurred
- Witch and Guejito Fires
  - Correlation found between vegetation near a home and number of structures destroyed
  - Spread within community primarily governed by structure-to-structure spread
- Syphard studied effect of land use planning (California)
  - Areas with low structure density or isolated clusters (separation of 100m or more) more likely to burn (more than high density).
  - The most important location-dependent variable found was **historical fire frequency**, which corresponded with **wind corridors**.
  - Structures on edge of community or steep slopes also susceptible

Quarles, S., Leschak, P., Cowger, R., Worley, K., Brown, R., Iskowitz, C., 2012. Lessons Learned
Maranghides, A., McNamara, D., Mell, W., Trook, J., Toman, B., 2013. NIST report #2
Syphard, A.D., Keeley, J.E., Massada, A.B., Brennan, T.J., Radeloff, V.C., 2012. PLoS One 7, e33954

MITIGATION STRATEGIES

A. JAMES CLARK SCHOOL *of* ENGINEERING • UNIVERSITY *of* MARYLAND

Some Available Codes and Standards

- NFPA 1141: Standard for fire protection infrastructure for land development in wildland, rural, and suburban areas
- NFPA 1142: Standard on water supplies for suburban and rural firefighting
- NFPA 1143: Standard for wildland fire management
- NFPA 1144: Standard for reducing structure ignition hazards from wildland fire
- ICC International Wildland-Urban Interface Code
- California Building Code Chapter 7A: Materials and Construction Methods for Exterior Wildfire Exposure
- Designed for AHJ's, planners, developers and communities

Available Tools for Communities

FIREWISE COMMUNITIES | FIRE ADAPTED COMMUNITIES | Insurance Institute for Business & Home Safety | READY, SET, GO!

Duerksen, C., Elliott, D., Anthony, P., 2011. Addressing Community Wildfire Risk : A Review and Assessment of Regulatory and Planning Tools, NFPA Fire Protection Research Foundation Report

Defensible Space

- NIST investigation of the Witch Creek and Guejito Fires

Zone	Destroyed Structures With Wildland Vegetation	Destroyed Structures Without Wildland Vegetation
0 – 30 ft from the structure	67%	32%
30 – 100 ft from the structure	59%	27%
100 – 200 ft from the structure	54%	27%
Beyond 200 ft	64%	17%

Percent structure destroyed with and without wildland vegetation

- Many Firewise recommendations effective in reducing ignition
- *Firewise does not explicitly recognize the hazard that an untreated property can have on an adjacent properties*
  - e.g. homeowners pushed fuel piles away from their homes, but in effect pushed closer to neighbor's house
- Recent study: structures were more likely to survive a fire with defensible space immediately adjacent to them

Syphard, A.D., Brennan, T.J., Kelley, J.E., 2014. Int. J. Wildland Fire
Maranghides, A., McNamara, D., Mell, W., Trook, J., Toman, B., 2013. NIST Report #2

Fuel Treatments

- Physically altering vegetation (e.g. removing, thinning, pruning, mastication, etc.)
  - Reduce intensity of fire (flame length, ROS)
  - Remove ladder fuels & space fuels to prevent crowing in tree canopy
  - Mechanical treatments: (hand/machine, chipping/pile burning or grazing) or prescribed burning
  - Continued maintenance important to retain effectiveness.
- General consensus on effectiveness of lowering fire intensity
  - Shown in 2007 Angora Fire
- Southern California study
  - Did not stop fires on own, but improved firefighter access & effectiveness

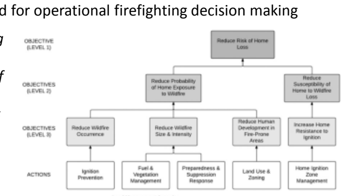
Fuel treatment area which met the full force of a crowning head fire. It transitioned to a lower intensity surface fire at the fuel treatment area.

Hudak et al. Gen. Tech. Rep. RMRS-GTR-252. USFS
Murphy, K., Rich, T., Sexton, T., 2007., USFS Tech. Pap. R5-TP-025

Risk Assessment Methodologies

- Risk-based approach can reduce losses by efficiency
  - Mitigation, structure hardening, suppression, evacuation, etc.
- Still need more input data, but early results may help
  - CA – FRAP program (highlight WUI areas)
  - USFS – WFDSS, used for operational firefighting decision making

Conceptual model highlighting means-based objectives and actions for reducing the risk of home loss as a result of wildfire. The risk of home loss is jointly determined by the probability of home exposure to wildfire and the susceptibility of home to wildfire



Calkin, D.E., Cohen, J.D., Finney, M.A, Thompson, M.P., 2014. Proc. Natl. Acad. Sci. 111

Wetting/Covering Agents

- Exterior sprinklers, gel and foam agents, exterior blankets, etc.
  - Some mentioned in 2012 ICC WUI Code
  - Most not evaluated in actual-scale WUI event
- Bench-scale tests focus on radiant heating
  - Unrealistic conditions (flame contact, firebrands)
- Some gel and foam coatings delay ignition
  - Benefit is short term (hours after application)
  - Note the benefit is short term (hours) and it _must not blow off_! (*typical hot, dry, windy conditions*)
- Only 1 published study on exterior sprinklers
  - All but one structure with a working sprinkler system survived ***a*** fire
  - Does not *PROVE* this works – no record of individual exposure conditions
  - ***Water availability issues if implemented at large scale***

Urbas, J., 2013. Fire Mater. 563–580. *Johnson, J.F., Downing, T., Nelson, K.C., 2008.*

Rim Fire
Yosemite, CA
112 Buildings Destroyed
257,314 Acres Burned
2013

GAP ANALYSIS

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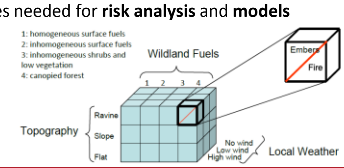
Identified Gaps

- Quantification of Risk and Hazard
  - Pre- and Post-Fire Data Collection
  - Testing of Firebrands
  - Understanding of Ember Fundamentals
  - Understanding of Wildland Fire Fundamentals
  - Structural Ignition
- Practical and Specific Issues
  - Fuel Management, Defensible Space and Community Planning
  - Test Standards and Design of WUI Materials
  - Effectiveness of Mitigation Strategies
  - Impact of Wildland Fires on Health and Environment
  - Firefighting Techniques
  - Identification of Educational Needs

Overarching Theme

- Most all studies fail to _*quantify*_ effects in a repeatable manner
  - Difficult to create test standards or regulations without a scale
  - Performance-based design difficult without know-how
  - Basic knowledge still lacking on HOW to quantify (e.g., ember flux?)
- Available knowledge focused on wildland fire behavior (fuel, slope topography) and density of structures
- Quantitative values needed for **risk analysis** and **models**

Proposed scale for WUI exposure from wildland fuels by Maranghides and Mell (2013)



Maranghides, A., Mell, W., 2013. Framework for Addressing the National Wildland Urban Interface Fire Problem Tolhurst, K., Duff, T., Chong, D., 2014 Fire Note 126, Bushfire CRC, Australia.
Lautenberger, 2015. Wildland Fire Hazard Modeling Tools (WFHMT)

Pre and Post-Fire Data Collection

- Data could greatly enhance our current understanding of how WUI fires spread to help better address the problem
  - Identify risks
  - Build statistical/risk models
- Some guidelines and tools for WUI data collection have been proposed by workshops
- More verification of Mitigation Strategies
  - Some Firewise recommendations validated after Witch & Guejito fire
  - ***Implementation of home fire sprinklers***, which is offered to decrease home separation distance from 30 ft to 15 ft in NFPA 1141 have no data in the literature to support them.
  - What if power/water goes out during WUI fire – need for ***resilience***

Pellegrino, J.L., Bryner, N.P., Johnsson, E.L., 2013. Wildland-Urban Interface Fire Research Needs: Workshop Summary Report, NIST.

Understanding Firebrands

- Firebrands least understood component of WUI fires
  - More knowledge needed on generation & ignition
  - Testing needed on different fuels under more extreme conditions
- Firebrand tests on structural components
  - *Most tests on fuel beds, not structural components*
  - Higher velocities and flux of firebrands needed
  - *Interaction of multiple building components*
  - Re-entrant corners (worst case?)
- With more knowledge – can build materials & assemblies that resist ignition and deposition of brands
- Fundamental knowledge will enable scale model testing and development of new solutions & test standards

Community Planning – Best Practices

- Very little work has been done to develop strategies to design a WUI community
- No publication was found in which a strategy was proposed to aid in the design of a WUI community
  - Most aimed at homeowner maintenance
  - Codes say what you can't do – but what can we do?
- Greenbelts, parks, walking/bike paths or other defensible spaces *may* be particularly effective design strategies, however no guidance appears available for their use
- Two sides to WUI home protection: engineering and maintenance
  - Just like inside a structure, ***education and enforcement*** are needed to ensure proper function
  - Continue community-wide programs such as Firewise

Test Standards and Design of Components

- Measure ignition and fire resistance
  - Must be coupled to exposure, which needs further study
  - Still need to fundamentally know how items ignite!
  - Can we engineer a solution for debris?
- Specific tests needing development/improvement
  - Roof tests: Class A rated by UL 790, ASTM-E108 or NFPA 276 have failed wind-tunnel firebrand shower tests (Manzello et al., 2013)
  - Gutters and other roofing products - to keep debris accumulation minimal or nonexistent
  - Fences and sidings: little known, research first
  - Mulch: test standards proposed (Beyler et al, 2014), but still need to look at ability of these mulches to ignite homes.
  - Decks/Porches: need better national tests (CA has CBC 12-7A-4.)
  - Sprinklers: on home outside or inside. Need tests for coatings, first we need to understand more!

Acknowledgements

Project Technical Panel

- Randall Bradley, Nelson Bryner, Ryan Depew, Steve Gage, Steve Quarles, Don Oaks, Michele Steinberg, Rick Swan

Casey Grant (NFPA FPRF) for his efforts coordinating this project

Comments from many experts in the field

- Jack Cohen, Alexander Maranghides and Kevin Tolhurst

NFPA for funding this research

THE FIRE PROTECTION RESEARCH FOUNDATION
Research in support of the NFPA mission

Read our Report:
ter.ps/wuireport

Event-Based Data in Wildland-Urban Fire Mitigation

Nelson Bryner and Alexander Maranghides
Engineering Laboratory
National Institute of Standards and Technology (NIST)
Gaithersburg, MD

Symposium on Structure Ignition in Wildland-Urban Interface Fires
June 18, 2015

ASTM Committee E05 on Fire Standards

Wildland-Urban Interface Data

- Fire Data
  - Role in fire safety
- National Fire Data Collection Systems
  - History
  - Focus/limitations
- Building-Centric versus Event-Centric Data
- Community-Scale Data
  - Witch Creek/Guejito Fire

Role of Wildland-Urban Interface Data

- Fire Data
  - Identify specific vulnerabilities or issues
  - Monitoring of trends
  - Tracking of progress
  - Critical to a science-based approach to improving fire safety

National Fire Data Collection Systems

Great Britain
- Loss of urban structures during World War II in London and other cities
- Original National Data Form – K433

United States
- Loss of urban structures during late 1960s and early 1970s
- Creation of National Fire Incident Reporting System NFIRS in 1976

Australia
- Australian Fire Incident Report System (AFIRS) Incorporated into AS 2577- Collection of Data on Fire Incidents in 1983

Canada
- Examine the feasibility of creating and maintaining a National Fire Incident Database (NFID) in 2010

National Fire Data Collection Systems

Current Fire Data Limitations

- May not be mandatory
  - AFIRS was capturing 81% of fires by 1990
  - NFIRS is currently capturing about 44% of fires
- Calibrating and incomplete national fire data set
  - NFPA conducts statistically designed stratified random sample of 3000 fire departments
  - NFPA analysis used to extend NFIRS data set

National Fire Data Collection Systems

Current Fire Data Limitations
- May not be mandatory
- Calibrating and incomplete national fire data set

- Fire Data Focus
  - Typically developed after urban structure losses
  - Structure fires
  - Urban Buildings
  - Identify issues and vulnerabilities
  - Prioritize research

National Fire Data – NFIRS & NFPA

- Urban Structure Fires
  - Identify issues and track trends
  - Prioritize or focus research efforts

First Item Ignited- Urban Structure Fires Home/Residential Fires – 2013[a]	Fires	Civilian Deaths	Civilian Injuries	Direct Property Damage ($M)
Upholstered Furniture	6,300	450	810	334
Mattress/Bedding	9,900	330	1,360	361
Combustible liquids or gases	15,500	200	1,060	317
Cooking materials, including food	106,300	130	3,580	471
Structural member or framing	20,500	130	410	1,088
Clothing	7,700	130	520	176
Unclassified furniture or utensil	6,500	120	440	209
Electric wire or cable insulation	17,600	100	440	443
Interior wall covering	7,500	100	290	313
Unclassified structural component or finish	7,900	70	200	358
Subtotal of Above Categories	205,700	1,760	9,110	4,070
Totals	366,600	2,570	13,210	7,208

[a]Ahrens, M., Home Structure Fires, National Fire Protection Association, Quincy, MA, 146 p., April 2014, www.nfpa.org

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National Fire Data

Focused on fires in urban structures

- Building- or structure-centric
- Fire in a specific building
- Less than 5% of urban structure fires spread beyond the structure
- Data captures interaction within building
  - Fuel configuration
  - Thermal radiation
  - ventilation

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Need for Event-Centric WUI Fire Data

Building Centric Data

- Does not adequately capture complex interactions when community exposed to WUI fire
- Need to shift to event-centric fire data collection
  - Collect data on community-scale
  - Interaction between multiple structures
  - Vegetation to structure interaction
  - Weather
  - Terrain
- Difficult to identify WUI structure/community vulnerabilities
- Difficult to prioritize WUI research

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Event-Centric Fire Data – WUI

- Wildland-Urban Interface Fires
  - Difficult to identify issues and track trends
  - Difficult to focus research efforts

First Item Ignited-Wildland Fires Home/Residential Fires-2014[a]	Fires	Structures Damaged	Structures Destroyed	Direct Property Damage ($M)
Roof				
Attic				
Decks				
Exterior Walls				
Combustibles				
Exterior Trim				
Other structures				
Fences				
Wood Piles				
Vehicles				
Subtotal of Above Categories				
Totals	2400	2135		14,000

[a] National Interagency Fire Center, https://www.nifc.gov/fireInfo/fireInfo_statistics.html , accessed January 2015.

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Event-Centric Data for WUI

Community-Scale Data

- Interaction between multiple structures
  - Thermal flux
  - Structural firebrand generation
- Vegetation to structure interaction
  - Thermal flux
  - Flame contact
  - Firebrand exposure
- Weather
  - Low moisture
  - Wind-driven fire
  - Wind-driven embers
- Terrain
  - Slope- upslope vs downslope
  - Canyons, hills, and cliffs channeling fire spread

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WUI Fires in NFIRS

- Limited number of homes destroyed by WUI fires entered into NFIRS

Fire	Date	Structures Burned	Structures Identified as Burned in NFIRS[a]	Percent WUI Fires Captured in NFIRS
Angora California	6/24/2007 – 7/2/2007	329	1	< 1 %
Witch, Harris, and Slide California	10/20/2007 – 11/9/2007	2470	339 (structures burned near San Diego)	< 14 %
Humboldt California	6/11/2008 – 6/19/2008	351	82 (structures burned near Butte County)	< 23 %
Sayre California	11/14/2008 – 11/20/2008	604	176 (structures burned near Los Angeles)	< 29 %
Waldo Canyon Colorado	6/23/2012 – 7/10/2012	354	0	< 1 %

[a] The identification of wildland fires uses methods outlined in Thomas, Douglas and David Butry. 2012 "Wildland Fires within Municipal Jurisdictions." Journal of Forestry. Vol 110, no. 1: 34-41

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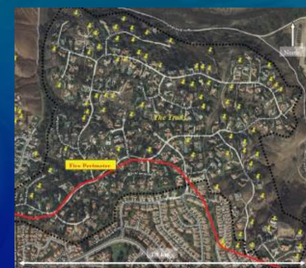
Witch Creek Fire- Event Centric Fire Data

Witch and Guejito Fires, October , 2007

- 274 residences
- 245 within fire line
- 74 residences completely destroyed
- 16 partly damaged

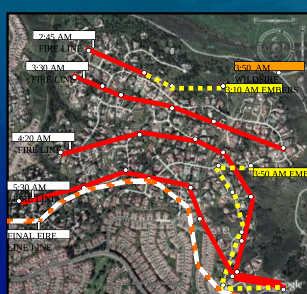
Witch Creek Fire – Event Centric Fire Data

- Less than 14% of home destroyed were reported in NFIRS
- None of 90 homes destroyed/damaged in the Trails Community were entered into NFIRS
- Post-fire analysis by Maranghides et al. document community events
- Demonstrate need to collect community scale data



Witch Creek Fire – Event Centric Fire Data

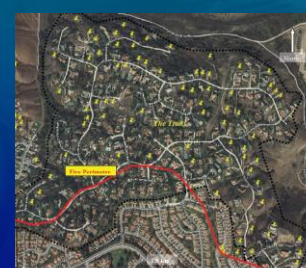
- Event occurred over 12 hours
- Community experienced at least three different exposures
- Firebrands arrived an hour ahead of fire
- Fire ignited structures on edge of community
- Structure firebrands ignited additional structures



Building-centric data has little ability to capture different exposures

Witch Creek Fire – Event Centric Fire Data

- Impact of location on fire losses
- 82 homes on periphery and 136 homes in the interior
- 38 destroyed periphery structures – 40 %
- 36 destroyed interior homes – 20 %



Building-centric data doesn't focus on overall trends

Witch Creek Fire – Event Centric Fire Data

- Terrain impacts fire spread
- Small canyons/chutes channeled fire spread into specific areas of community
- Wind carried firebrands, structural and vegetative, into interior of community
- Building-centric data has difficulty documenting terrain and wind

Witch Creek Fire – Event Centric Fire Data

	Sample Population	Destroyed Structures with Wood Shake Roofs	Destroyed Structures with Spanish Tile Roofs	Typical Comparisons	
Typical (only destroyed homes)	74	12	37	**16% of destroyed** homes had wood shake roofs	**50% of destroyed** homes has Spanish tile roofs
Complete (all structures within fire line)	275	12	154		
Technically Valid Comparisons		**100% of exposed** wood shake roofs were destroyed	**24% of exposed** Spanish tile roofs were destroyed		

- Community-scale data provides better understanding and identifies vulnerabilities

Role of Wildland-Urban Interface Data

- Event-Centric Fire Data
  - Critical to a science-based approach to improving fire safety
  - Identify specific vulnerabilities or issues
- National Fire Data Systems
  - Developed out of urban fire scenarios
  - Incomplete data
  - Building-centric approach
- Community-Scale Fire Data
  - Captures complex interactions
    - Exposures - thermal flux and firebrands
    - Structure location- periphery vs interior
    - Identifies vulnerabilities
  - Impact of weather and terrain
  - Needed to focus research

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Questions or Comments?

•Thank you for the opportunity to discuss community-scale fire data

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EcoSmart Fire as Structure Ignition Model in WUI: Predictions and Validations

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Outline

- Modeling Heat Damage & Ignition of Structures from Landscaped Tree Fires
- Damage/Ignitability Model versus Litter Fire Under HRR Hood
- Model Verifications with PC Version
- Ecosmart Landscape Website Implementation using Google Earth

Selective Fuel Clearances to Mitigate Heat Damage and Ignition on Structures

- Model Fuel Flame Threat to Structures for Added Protection as Separate from the Firebrand-only Threats
- Collaboration with Greg McPherson of PSW station and with UC Davis to develop Ecosmart Landscape Website
- Funded by CalFire

Tree Heat Release Model

- Douglas fir (from SPFE Figure 3.1.67)

$$HRR = \frac{2 \times mass \times 400}{(1 + 0.0538 \times MCper)}$$

- Generic tree (from SFPE Figure 3.1.70)

$$HRR = \frac{2 \times mass \times 700}{(1 + 0.1295 \times MCper)}$$

- Burntime estimation is foliar mass times heat of combustion (13.1 MJ/kg) as divided by HRR (Usually about 30s)

Thermal Radiation Heat Transfer Model

- Fire Viewfactor to Elemental Surface (Eq. 47, SFPE -Tien et. al., 2008)

$$q_j = \varepsilon_m E_b (F_1 + F_2 + F_3)$$

- Flame Height (Eq. 8, SFPE -Heskestad, 2008)

$$FlameH = -1.02 \times TreeD + 0.235 \times HRR^{0.4}$$

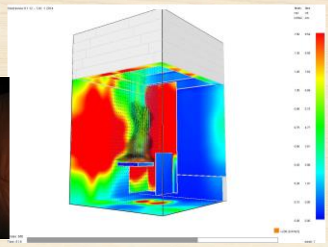
- Emissivity and Emissive Power

$$\varepsilon_m = (1 - e^{-\kappa S}) \qquad E_b = \sigma \times T_f^{\,4}$$

Extinction Coefficient and Flame Radiation Temperature Formulation

- SFPE handbook: $\kappa = 0.8 m^{-1}, T_f = 1732K$
- These values will give radiant fraction, $\chi_r = \varepsilon_m E_b A_f / HRR$ greater than 1
- Using FDS provides radiant fraction = 0.3 for the litter fire to agree with heat flux data

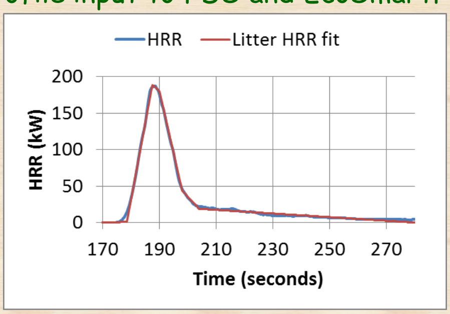
Litter Burn under HRR Hood and FDS results – Radiant Fraction Equals 0.3



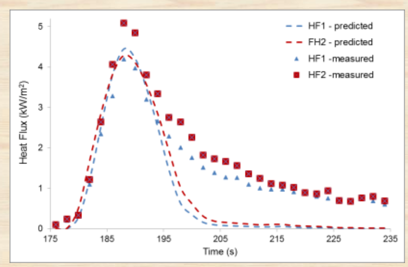
Extinction Coefficient and Flame Radiation Temperature Formulation

- Tewarson data in SFPE handbook and other sources also suggests: $\chi_r = 0.3$
- Flame Radiation Temperature
  $$T_f = 1991 - 23.4(D - 0.019)^{0.044}(7.9 - D)^{1.73}$$
  $$- 425.4D^{0.457} / (1 + 0.166Qdstar^{1.069})$$
- Extinction Coefficient
  $$\kappa = 2.8 * (T_f / 1353) * (Qdstar / 3.96)^{0.5}$$
  $$Qdstar = (HRR / D^{2.5}) / 1110$$

Litter Burn under HRR Hood: HRR Profile input to FDS and EcoSmartFire



Litter Burn under HRR Hood: Predicting Heat Fluxes

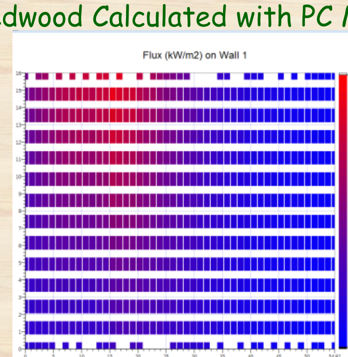


Object Blocking, Ground Reflection and Tree Flame Attenuation

- Vector analysis for partial object blockage
- Mirror image analysis for ground reflection
- Attenuation through burning blocking trees

$$q_{j,ise} = q_j R_j \prod_{k=1,n}^{k \neq j} \left[(A_{proj,k} - A_{ov,k}) / A_{proj,k} + \tau_k (A_{ov,k} / A_{proj,k}) \right]$$

Fluxes for 3Trees off North Edge on Redwood Calculated with PC Model



Transient Surface Heat Conduction: Required with Short Burn Time of 30 s

$$T_{s,ise}(t) = T_a + (\varepsilon_{ise} q_{j,ise} / h_{ig}) / \left\{1 + (F_{thick}^n + F_{thin}^n)^{(-1/n)}\right\}$$

$$\varepsilon_{ise} q_{cr} = h_c (T_{ig} - T_a) + \varepsilon_{ise} \sigma (T_{ig}^4 - T_a^4) \equiv h_{ig}(T_{ig} - T_a)$$

$$n = (2.68 + 0.4 Bi) / (1 + Bi)$$

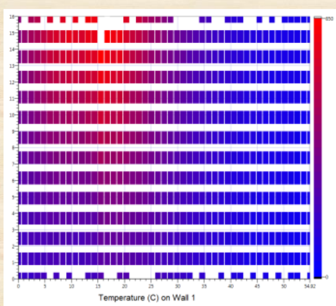
$$F_{thick} = \sqrt{\frac{4}{\pi} Bi^2 Fo} \qquad F_{thin} = \exp\left(\frac{BiFo}{1 + 0.254 Bi}\right) - 1$$

$$Bi = h_{ig} \delta_m / k \qquad Fo = (k / \rho c) t / \delta_m^{\ 2}$$

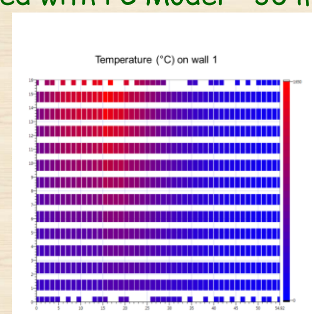
Material Properties of Surfaces

	mm		W/m K	kg/m^3	J/kg K	Temp (K)	Temp (K)
	thickness	**emissivity**	**conductivity**	**density**	**specific heat**	**Tdamage**	**Tignite**
Roof Type							
Cedar	25	0.85	0.156	395	2300	473	629
Asphalt Shingle - Class A	6	0.91	0.324	1560	920	473	642
ACQ-SYP	25	0.92	0.284	607	2300	473	581
EverX	24	0.95	0.264	1033	2000	473	578
Exterior surfaces							
Vinyl siding + XPS foam	0.93	0.89	0.145	1889	882.3	473	700
Clear Grade Redwood T&G	19.2	0.82	0.171	410	2512.5	473	600
#2 ponderosa pine T&G	18.5	0.83	0.169	420	2313	473	621
Painted plywood	12.8	0.83	0.211	500	2654	473	629

Temperatures for Redwood Siding Calculated with PC Model – 30 sec burn

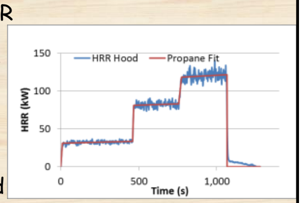


Temperatures for Redwood Siding Calculated with PC Model – 30 min burn

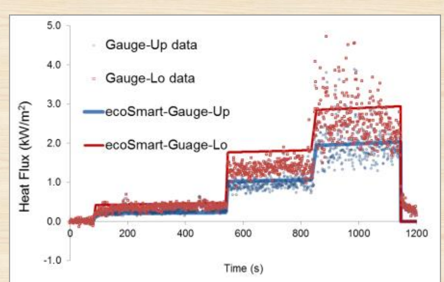


Model Validation Under HRR Hood: Propane Burner with Vertical Walls

- 3 steps of propane HRR measured accurately
- Material properties of propane given
- Measure and predict surface irradiances
- ISO 9705 burner used



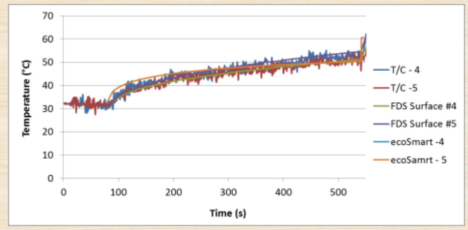
Model Versus Data of Propane Burn Irradiances on Tall Inert Wall



Temperature Response of Redwood Wall

- Redwood properties from Wood Handbook
- Measure and predict surface temperatures
- T/Cs at center and 4 corners
- Heat damaging sap flow around 120 degrees Celsius

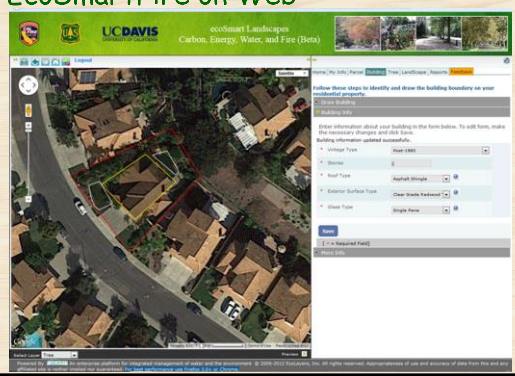
Temperature Response of Redwood Wall



Simplifications for Ecosmart Landscape Website Implementation

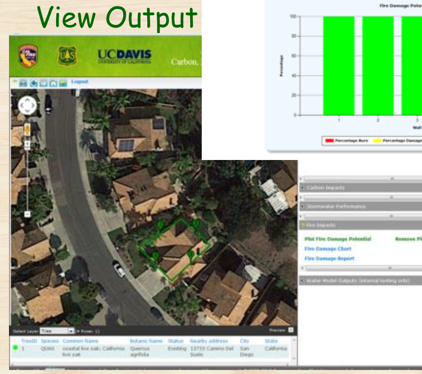
- 4 walls and 1 flat roof
- Choice of redwood or vinyl wall
- Choice of Asphalt shingle or cedar shakes
- Up to 9 trees total anywhere on property
- Trees considered dried at 20% MC
- Wind speed is 5.7 m/s
- Ambient temperature is 25 Celsius
- PC version is much more flexible

EcoSmartFire on Web



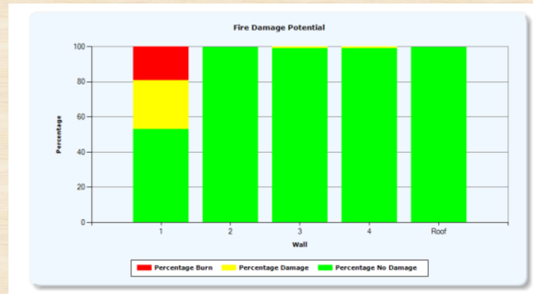
Add a Tree

View Output

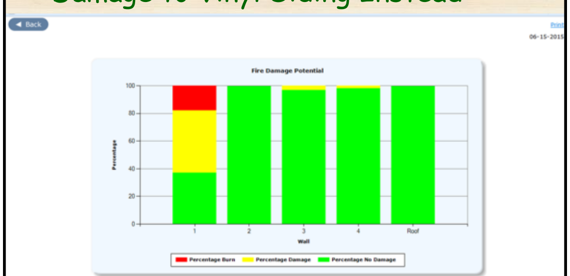


Setup for 3 Trees North Edge and 1 Tree South Corner on Redwood

3 Trees North Edge and 1 Tree South Corner Cause Fire Damage



Damage to Vinyl Siding Instead



Conclusion

- Successful Modeling required empirical functions for flame radiation temperature and smoke extinction
- Short tree burn times required abandonment of critical fluxes in favor of damaging or ignition temperature.
- Ecosmart Landscape Website Implementation using Google Earth Demonstrated

Model Development Needs

- Need new data on HRR of ornamental vegetation
- Need cone calorimeter data on additional surfaces of buildings
- Need new features for fire model
- Need validations of fire model
- Need funding to replace CalFire support

Description of Firebrand Generation in a Pine Stand fire

R Hadden, M El Houssami, E Mueller,
D Kasymov, A Filkov, J Thomas,
N Skowronski, M Gallagher,
K Clark, R Kremens, A Simeoni
University of Edinburgh, Tomsk State University, US Forest Service, Rochester institute of Technology

Overview and Acknowledgement

JFSP

Academic Partners

Aim — Characterize the effect of fuel treatments of fire intensity and spread rates

Philosophy: Ignition of structures in WUI

- Identify the failure mode
- Quantify the fire load to the structure
  - Multi-scale experimental observations
  - Firebrand flux, radiation, flame impingement, exposure duration
- Identify fundamental controlling mechanisms
  - Smouldering ignition, flaming ignition, heat transfer

Philosophy: Ignition of structures in WUI

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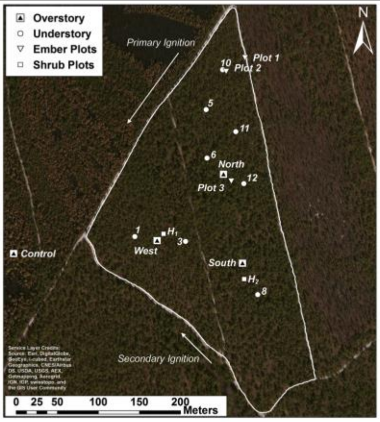
JFSP Project

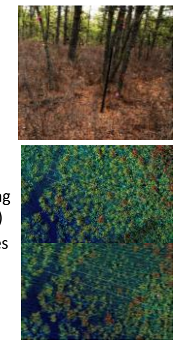
- 3-year goal – Effectiveness of fuel treatment
- Long-term goal – Improved understanding of wildland fire behavior
- 3 field experiments to date in NJ Pine barrens
- NJ Pine barrens
  - 1.1 million acres, ~23% of NJ
  - 1300 wildfires per year (2003-2013 average)
  - Large crown-fire event every 5-10 years
  - High level of WUI
  - RxB conducted on 12,000 acres per year

Field Site



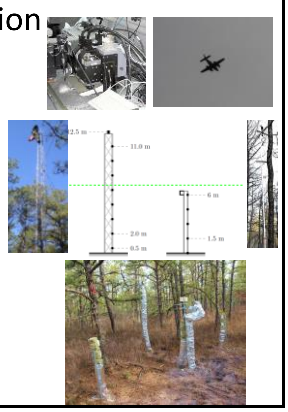
Fuel characterization

- 36 pre- and post-fire clip plots (3 per understory tower)
- Fuels sampled by size class
  - Forest floor: fine, repro., 1hr, 10hr, 100hr
  - Shrub and Oak layer: 1hr, 10hr (live and dead)
- Pre- and post-fire Airborne Laser Scanning data (400 kHz, pulse density 5.12 pts/m^2)
- Provides canopy height and bulk densities (calibrated by upward sensing LiDAR)
- Resolution of 10 x 10 x 1 m



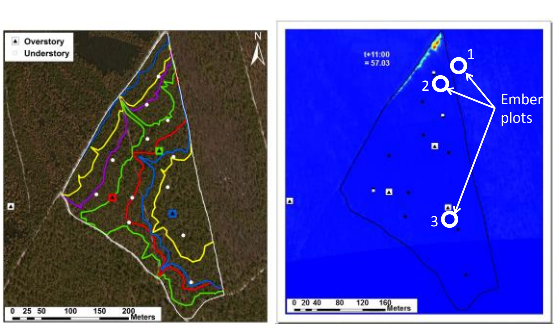
Fire Characterization

- Aerial imagery: Series of georeferenced stills taken using RIT's Wildfire Airborne Sensor Program (WASP)
- Towers: overstory (8 thermocouples and 1 3D Sonic Anemometer) and understory (5 thermocouples, 1 vertical flow sensor, 1 vertical dual-band radiometer)
- Fire behaviour packages: 4 thermocouples, 6 thin-skin calorimeters (total heat flux), 3D flow velocity

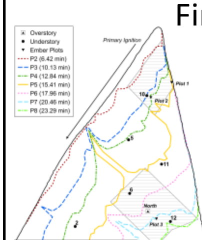


Firebrand measurement

Fire Progression



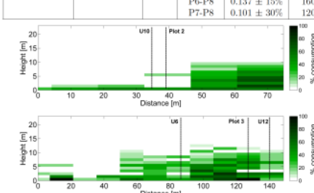
Fire Progression



Local Fire-Line Intensity

Location	Δ m [kg.m^{-2}]	%Δm	Distance	ROS [m.s^{-1}]	I_{surf} [kW.m^{-1}]
Understory 10	0.73 ± 41 %	56 %	P2-P3	0.095 ± 11%	1300 ± 42%
			P2-P4	0.074 ± 10%	1000 ± 42%
			P2-P5	0.073 ± 9%	1000 ± 42%
			P3-P4	0.039 ± 36%	500 ± 55%
			P3-P5	0.055 ± 28%	700 ± 50%
			P4-P5	0.074 ± 49%	1000 ± 64%
Understory 6	0.93 ± 36 %	64 %	P5-P6	0.186 ± 18%	3200 ± 40%
			P5-P7	0.180 ± 18%	3100 ± 40%
			P6-P7	0.161 ± 35%	2800 ± 50%
Understory 12	0.64 ± 26 %	62 %	P6-P7	0.161 ± 35%	1900 ± 44%
			P6-P8	0.137 ± 15%	1600 ± 30%
			P7-P8	0.101 ± 30%	1200 ± 40%

LiDAR models of 'Available Fuels'



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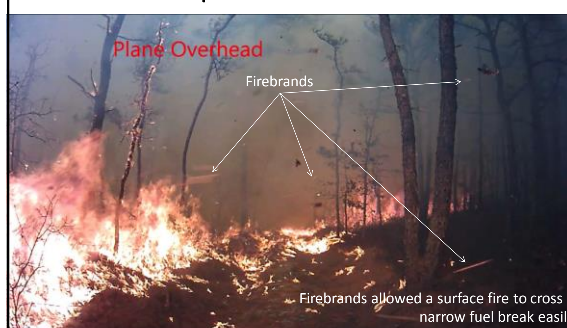
Fire spread – visual data

Fire spread – Surface fire

Fire spread – Crown fire

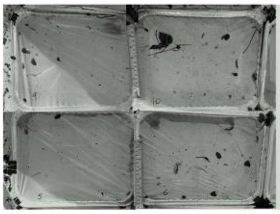
Fire spread - Firebrands



Firebrand collection

Firebrand collection

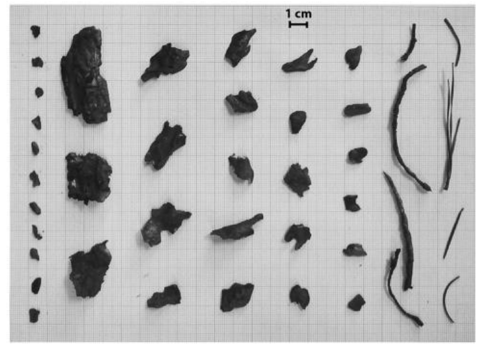
Post-fire pans



Plot 2

Plot 3

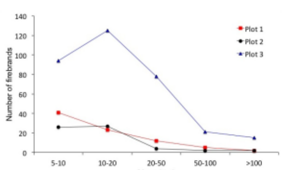
Firebrand characteristics

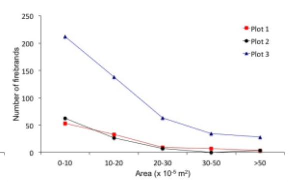


Fire brand characterization

Number of embers

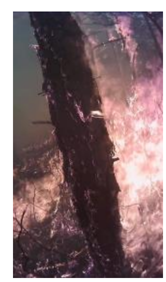
Location	Quantity	Density $[m^{-2}]$
Plot 1	83	60
Plot 2	61	44
Plot 3	333	238





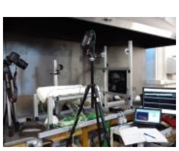
Firebrand source characterisation

Branch fragments



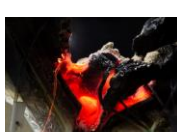
Bark fragments

Structural vulnerability



Experimental conditions

- Wind
- Wood material
- Amount of firebrands
- Size and material of firebrand
- Wedge angle
- Tilt angle
- Sample gap

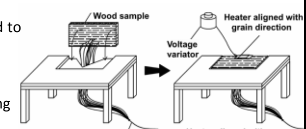


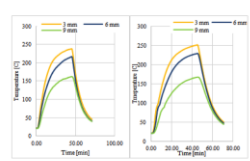
→Flaming ignition occurs when the smoldering front has created a hole through the sample (air flow)

→Flaming occurs on the backface of the sample

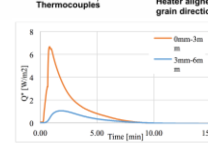
Structural vulnerability – quantifying the 'ember load/flux'

- Repeatable thermal exposure (linked to ember data)
- Addition of external radiant flux (radiant + ember attack)
- Smouldering and transition to flaming





Temperature measurements to probe controlling phenomena



Inverse modelling to transform ember load to heat flux

Conclusions

- Much more work to be done to thoroughly analyze results from both years!!
- Valuable data collected on fire behavior in a forested environment
- Firebrand characterization linked to
  - Both fire progression/behavior and total fuel consumption
  - Estimation of fire-line intensity for different types of fire spread
  - Analysis of fire behavior related to fuel distribution and wind
- Use of field data to inform laboratory experiment
- Lab experiments used to calculate 'ember load/flux' to predict impact on structure

The whole story…

Fire Technology
May 2015

Date: 12 May 2015

Experimental Procedures Characterising Firebrand Generation in Wildland Fires

Mohamad El Houssami, Eric Mueller, Alexander Filkov, Jan C. Thomas, Nicholas Skowronski, Michael R. Gallagher, Kenneth Clark, Robert Kremens, Albert Simeoni

R Hadden, M El Houssami, E Mueller, D Kasymov, A Filkov, J Thomas, N Skowronski, M Gallagher, K Clark, R Kremens, A Simeoni

ASTM Workshop WUI 2015

Upgrading Heritage Buildings to Resist Exterior Fire Exposure by Sympathetic Means and a Method to Assess Aggregate Envelope Performance

Geir Jensen, BSc COWI AS
Tobias Jarnskjold, MSc NTNU University
Thomas Haavi, PhD COWI AS

NTNU COWI

NORTHERN EUROPE: NORDIC AND BALTIC COUNTRIES

Exterior characteristics

Wooden facades
Conflagrations/wildfires rare
Generally wet and green

When occur

- Dry weather
- Wind
- Compare to wildfire in general globally
- Threaten scattered residences and wooden town centres

2014 Global climate change?

- 2 severe incidents: town conflagration and wildfire in NO (90 houses lost)
- 1 severe wildfire SE (woodland lost)
- Each set record incident loss since WW2

COWI

EXTERIOR FIRE RISKS TO HERITAGE AND RESIDENTIAL CONSTRUCTION - NORTHERN EUROPE

- Wooden heritage, 200-800 years old
- Wooden residences, historic town centres
- Rainscreen (termed PER or double-barrier weather protection) common
- 2 or 3 glass layer windows common
- ISO 834 enclosure fire resistance rating used for facades – need to review practice in terms of wildfire, conflagration.

COWI

RECENT PROTECTION STRATEGIES AND MEASURES

Ignition resistant vs fire resistance rated
Fire resistance rated shield delay fire penetration. Untreated wood cladding to roofs/facades as way of hardening fire shield (ISO 834/ASTM E119).

Open state fire resistance of ventilation openings
Vents block flames, embers, radiation *during open state* (ASTM E2912 and E2886) *prior to and during sealed state* (ISO 834/E119).

Fixed robotic nozzles (water monitors)
to protect historic buildings. Study initiated (COWI-RA)
(similar applied in Japan) (FM DS 4-7N).

Fire gel or Class C foam
Tested. Attractive following 2014 incidents in Nordic countries (NFPA 1145).

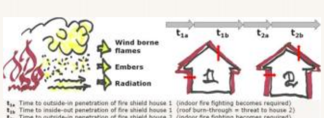
COWI

DESIGN TOOL TO VERIFY EXTERIOR FIRE SAFETY

Index Based Method
Next slides COWI-NTNU, by Tobias Jarnskjold

Planned scope of IBM tool extends to:

- Time Concept: Exposure + Fire Shield + Fire Fighting
- Verification against prescriptive and performance code
- Community planning: Rescue resources vs building codes



TOOL OBJECTIVES

Verify fire safety design of:

- Heritage structures
- Wooden houses scattered or grouped

at exterior risk from:

- wildfire
- arson, fire incidents near facade
- conflagration

COWI

ASTM Workshop WUI 2015

Exterior Fire Index Method

NTNU COWI

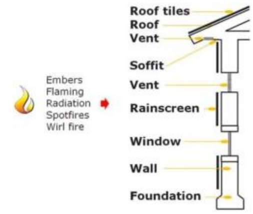
Case study: The fire in Lærdal 19th January 2014

Characteristics
- 42 houses completely destroyed
- Fire reported 22:53
  (Under control 16:45, 18h)
- Building-to-Building

Interviews (qualitative analysis)
- Interesting exceptions
  (hip roof, no ventilation, newly painted, the work of fire fighters)
- Ignition high above ground
  (gable wall, cornice, rooftop)
- Factors and parameters

Exterior Fire Index Method

- Why an Index Method?
  - Simple risk assessment
  - Transparent to improve communication
  - Documentation
  - Design of protective envelope
  - Reduce to a system
- Method comprises two parts:
  - Exposure
  - Fire Protective Envelope
  (Further work to handle active measures)



Exterior Fire Index Method

Calculation

- Exposure:
  important factors (E)
- Fire protective envelope:
  important parameters and details in the building envelope (B)

EXPOSURE MAIN FACTORS	Sub-factors	Weighting
E1 Climate	$K_{E1.1}$ Fire spread index $K_{E1.2}$ Wind speed	18%
E2 Protection zones		12%
E3 Fire stairs	$K_{E3.1}$ Fire stairs in protective zone $K_{E3.2}$ Ignite able material to exterior walls	6%
E4 Fire break		6%
E5 Gardening		6%
E6 Outdoor tidiness and maintenance		11%
E7 Fences and connections		11%
E8 Location		12%
E9 Other buildings in protection zone		18%
PROTECTIVE ENVELOPE ELEMENTS	**Parameters**	**Weighting**
C1 Materials	$K_{C1.1}$ Type of material $K_{C1.1}$ Time to burn through	Depended on fire element
B1 Decks	$K_{B1.1}$ Design of deckings $K_{B1.2}$ Type of decks	18%
B2 Roof	$K_{B2.1}$ Type of roofing $K_{B2.2}$ Ventilation	28%
B3 Exterior walls	$K_{B3.1}$ The surface of the cladding $K_{B3.2}$ Cavities	18%
B4 Foundation	$K_{B4.1}$ The height of the foundation $K_{B4.2}$ Ventilation	14%
B5 Doors	$K_{B5.1}$ Crevices $K_{B5.2}$ Cavities , vent, drainage	9%
B6 Windows	$K_{B1.2}$ Type of window $K_{B1.3}$ Cavities, vent, drainage	13%

Exterior Fire Index Method (sample exterior wall)

Calculation example

Grip Stave Church:

B3 Exterior wall (protective cladding): Rehabilitation, increasing cladding thickness and installation of EI classified vents.

Wooden facade cavity need adequate air exchange rate and fire resistance rated linear vents.

Exterior Fire Index Method (sample exterior wall)

$K_{B3.1}$: Surface of the cladding		Rating
The surface is characterized by gaps and cracks.		0
The surface is painted and has some cuts or cracks.		3
The surface is relatively freshly painted, and is without deep cuts or cracks.		4
$K_{B3.2}$: Cavities in ventilated facades		**Rating**
There is a continuous cavity in the façade.		0
Cavities with fire resistance rated vents that prevent fire spreading at the bottom of the cladding.		4
Cavities with fire resistance rated vents that prevent fire spreading at the top and bottom of the cladding		5
$K_{C1.1}$: Euro classes	**Typical products**	**Rating**
F	Plastic	0
E	Low density wood	1
D	Wood	2
C	Plasterboard with wallpaper	3
B	FR treated wood	4
A2	Gypsum board	5
A1	Concrete	5
$K_{C1.2}$: Time to burn through		**Rating**
$K_{C1.2}$ < 10min		0
10min ≤ $K_{C1.2}$ < 20min		3
20min ≤ $K_{C1.2}$		5

B3 Exterior walls:
$K_{B3.1}$ Surface of the cladding
$K_{B3.2}$ Cavity in ventilated facades

C1 Materials:
$K_{C1.1}$ Material classification
$K_{C1.2}$ Time to burn-through

$C1_{B3} = 0,20(K_{C1.1}) + 0,80(K_{C1.2})$

Total rating of B3 is given by the expression:
B3 $= 0,40(C1_{B3}) + 0,25(K_{B3.1}) + 0,35(K_{B3.2})$

Exterior Fire Index Method (sample exterior wall)

B3 Exterior walls: The cladding will be rehabilitated and painted. All gaps and cracks should be sealed, providing a smooth and fine surface, which in turn will reduce the risk of ignition.	Surface of the cladding: $K_{B3.1} = 5$	$B3 = 0,40(C1_{B3}) + 0,25(K_{B3.1}) + 0,35(K_{B3.2})$	$V_{B3} = 0,18 * 4,41$
It is also fitted fire resistance rated vents at the bottom of the cladding.	Cavities in ventilated facades: $K_{B3.2} = 4$		
The church has a wooden facade, which will be replaced with a thicker one. This will make sure the fire resistance exceeds 20min. $K_{C1.1} = 2$ $K_{C1.2} = 5$	Materials: $C1_{B2.2} = 0,20(K_{C1.1}) + 0,80(K_{C1.2})$ $C1_{B3} = 4.4$	B3 = 4,41	= 0,79

Exterior Fire Index Method

Final calculation and results

Comparative basis	Results
Grip Stavkirke with fire protective envelope	1,46
Common wooden house	0,92
Annex	0,69

Total score for exposure:
$E_{tot} = V_{E1}E1 + V_{E2}E2 + V_{E3}E3 + V_{E4}E4 + V_{E5}E5 + V_{E6}E6 + V_{E7}E7 + V_{E8}E8 + V_{E9}E9$

Residual risk of exposure:
$R_r = 5 - E_{tot}$

Total score for fire protection envelope:
$B_{tot} = V_{B1}B1 + V_{B2}B2 + V_{B3}B3 + V_{B4}B4 + V_{B5}B5 + V_{B6}B6$

What can we make of this?
- Comparative basis
- Indicates vulnerable houses
- Valuable information to fire fighters
- Documentation
- Tables indicate good or bad design

NTNU COWI

Exterior Fire Index Method

Method characteristics

- To some extent a need for qualified personell
- Transparent, communication across disciplines
- Simple
- Checklist
- Can be adapted for wildfire, wildfire–to-urban, bulding–to-building

NTNU COWI

Exterior Fire Index Method

Suggestion for further work

- In depth study of all factors and parameters
- Validate by expert panel/Delphi method
- Improved visualization
- Fire resistance and results in time domain
- Add active protection

NTNU COWI

Workshop on Structure Ignition in WUI Fires

FireCamp - Analysis of fire hazard in camping park areas

Presented by: Miguel Almeida
LAETA/ADAI/CEIF
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Anaheim, June 19th, 2015

Authors: Miguel Almeida, José Raul Azinheira, Jorge Barata, Kouamana Bousson, Rita Ervilha, Marta Martins, Alexandra Moutinho, José Carlos Pereira, João Caldas Pinto, Luís Mário Ribeiro, Jorge Silva, Domingos Xavier Viegas

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Outline

- General motivation
- FireCamp Project
- Work developed and results
- Conclusions and achievements
- Next steps

General motivation

- The fire spread in camping parks is possible when the concentration of camping equipment is high.
- The projection of firebrand increases the risk of fire in CP

General motivation

FIRES IN CAMPING PARKS

- Location of CP in forested areas
- Several camping materials with propensity to ignite, burn or explode
- Camping activities may drive to fire ignitions and are developed by a great heterogeneity of people
- Poor knowledge, sensibility and conscience by the campers and the CP staff and public in general

Portuguese legislation on fire risk in CP barely adapted to the reality
Several fire events in CP are reported
There is a lack of knowledge on this thematic

FireCamp Project

MAIN GOALS:

- Understand and model the fire spread in CP
- Present alternatives to reduce fire risk in CP
  - Increase the fire safety in CP
  - Produce a base study for subsequent projects on this thematic
  - Create a base for the assessment of the fire risk in camping parks
  - Develop supporting material to the camping park managers and other stakeholders

Protocol stablished between ADAI and FCMP (Mountaineering and Camping Portuguese Federation)

FireCamp Project

PROJECT STRUCTURE:

- CHARACTERIZATION OF THE PROBLEM
  - Analysis of the legislation and normative regulation.
  - Analysis of the fire events in CP.
- CHARACTERIZATION OF THE FIRE RISK IN CP
  - Characterization of materials and equipment used in CP.
  - Characterization of the fuel cover inside the CP and its surrounding.
  - Simulation of the fire spread in CP area
- SAFETY MEASURES
  - Reduction of fuel availability.
  - Systems of fire prevention and extinguishment.
  - Fire safety.

FireCamp Project 7

Pilot case study – CP of Coja (Coimbra - Portugal)

FireCamp Project, ADAI-LAETA — Anaheim, USA, 02/07/2015

Work developed – analysis of fire events in CP 8

Fire event nearby the CP of Coja

- ✓ Date: September 6th, 2012
- ✓ Origin: Industrial area of Coja
- ✓ Fuel cover: mainly composed by forest areas - *Pinus pinaster*, *Eucaliptus globulus* and shrubs.

- ✓ Fire arrived to the CP peripheral road at 23h00

FireCamp Project, ADAI-LAETA — Anaheim, USA, 02/07/2015

Work developed – analysis of fire events in CP: causes 9

Lighting

- Candle causes the destruction of a caravan: 2 fatalities
- Gas lamp ignites a sleeping bag propagating the fire to the tent: 1 fatality + 1 injured
- Gas cylinder for lighting explodes: 7 injured (4 serious injured)

Deficient connections to the electric network

- Short circuits are the major cause
- More frequent in larger tents or caravans as well as in semi-permanent regimes
- Normally occur during the absence of people
- No fatalities registered, some injuries, several equipment lost

FireCamp Project, ADAI-LAETA — Anaheim, USA, 02/07/2015

Work developed – analysis of fire events in CP: causes 10

Cooking activities

- Camp fires close to the tents of combustible materials
- Fire resistant kitchen tents not well maintained
- No fatalities registered, several injuries and many equipment lost

Wildfires coming from outside

- Spotting assumes an important role in the fire spread
- In Portugal: no fatalities registered, several injuries and many equipment destroyed
- July/1978 - PCC Los Alfalques (Els Alfacs) in Alcanar - Montsià - Tarragona: 217 fatalities + more then 300 injuries

FireCamp Project, ADAI-LAETA — Anaheim, USA, 02/07/2015

FireCamp Project 11

PROJECT STRUCTURE:

Characterization of the problem
- Analysis of the legislation and normative regulation.
- Analysis of the fire events in CP.

Characterization of the fire risk in CP
- Characterization of materials and equipment used in CP.
- Characterization of the fuel cover inside the CP and its surrounding.
- Simulation of the fire spread in CP area

Safety measures
- Reduction of fuel availability.
- Systems of fire prevention and extinguishment.
- Fire safety.

FireCamp Project, ADAI-LAETA — Anaheim, USA, 02/07/2015

Combustibility analysis : burning tests 12

Reference	Date	Tent	Under layer	Material inside	Induced airflow	Ignition
TC1	16/Mai/2012	Igloo 1	yes	1 blanket 4 duvets	no	Fb_{ST}
TC2	25/Jan/2013	Canada tent	no	empty	no	Fb_T
TC3	16/Jun/2013	Igloo 2	yes	empty	no	Fb_T
TC4	27/Jan/2014	Igloo 3a	no	1 sleeping bed 1 camping mattress	no	Ff_S
TC5	27/Jan/2014	Igloo 3b	no	1 sleeping bed 1 camping mattress	1,1 $m.s^{-1}$	Ff_S
TC6	10/Fev/2014	Igloo 3c	no	straw fuel bed	no	S_{int}

TC1 

TC2 

TC3 

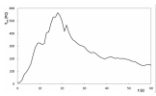
TC4 

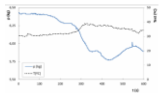
TC5 

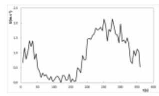
TC6 

FireCamp Project, ADAI-LAETA — Anaheim, USA, 02/07/2015

Combustibility analysis: burning tests


Inside temperature variation


Outside temperature and weight variation


Convective up airflow variation

Test	Burning time	Inside maximum temperature (ºC)	Sustainable combustion
TC1	162	N/D	yes
TC2	273	N/D	yes
TC3	287	N/D	yes
TC4	276	535	yes
TC5	N/A	N/A	partially
TC6	38	565	yes

Combustibility analysis : burning tests

Experimental findings:

- Very fast burning of the tents and great dependence of the origin of the ignition;
- Melted incandescent material drip;
- Release of toxic smoke;
- Extinguishing the fire with water is very dangerous;
- Relevance of cotton sublayer to support combustion;
- Great importance of the inside materials in the combustion. Irrelevance of the fireproof treatment when there is flammable material inside, except when this tissue is the source of ignition;
- In the presence of wind the tent can inflate and be dragged easily causing new spot fires.

Combustibility analysis: materials characterization

Code Sample	R1	E1	B1	W1	I1	P1	SB1	CP1
Picture								
Description	Tent roof	Tent entrance door	Tent base	Tent wall	Tent interior	Tent entrance mosquito protective net	Sleeping bag	Camping mattress
Material	Polyester or polyamide coated with a PU or silicone	Rip stop nylon	Woven PE Sheeting "Poly Tarp"	coated polyester and vinyl	cotton with polyester	Oxford cloth and mesh	100% polyester	PE foam

Higher Calorific Value (HCV) results

Code Sample	R1	E1	B1	W1	I1	P1	SB1	CP1
HCV (MJ/Kg)	23.13	29.27	45.51	22.58*	22.09	22.86	22.45	41.45

*this sample requires specific accessories for measurements as it contains halogenated components

Ignition time at 25kW.m^{-2} results

Sample		Mean ignition time (s)
Q	Roof	>1200
R	Base	118
S	Sleeping bag	224
T	Camping mattress	118

Characterization of the area: CP and surroundings

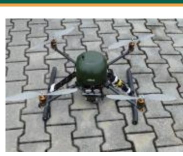
Elements of interest
- Type of vegetation
- Fuel load
- Distribution of the land use
- Sources of water
- Refugee places
- Possible evacuation routes
- Etc.

Determination of the higher risk areas

Harnessing the potential of the area (routes of evacuation, refugee areas, etc)

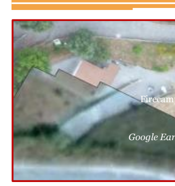
Modelling the fire spread in camping parks

Characterization of the area: CP and surroundings


Quadrotor UX-401

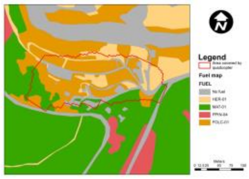

Fixed-wing TWINSTAR II

Characterization of the area: CP and surroundings



Characterization of the area: CP and surroundings

Fuel map




HER-01

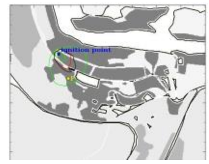

MAT-01

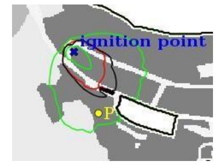

PPIN-04


FOLC-01

Simulation of the fire spread

- stochastic simulations to predict the effect of parametric input uncertainty through the model
- forecast of the fire front (stochastic mean) and its error bar area at a certain time after ignition





Prediction for 4 hours after the ignition

- Black line: deterministic mean;
- Red line: stochastic mean;
- Area between green lines: error burnt area (confidence interval of 95%)

FireCamp Project

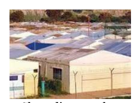
PROJECT STRUCTURE:

CHARACTERIZATION OF THE PROBLEM
- Analysis of the legislation and normative regulation.
- Analysis of the fire events in CP.

CHARACTERIZATION OF THE FIRE RISK IN CP
- Characterization of materials and equipment used in CP.
- Characterization of the fuel cover inside the CP and its surrounding.
- Simulation of the fire spread in CP area

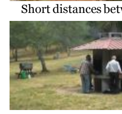
SAFETY MEASURES
- Reduction of fuel availability.
- Systems of fire prevention and extinguishment.
- Fire safety.

Issues related to fire risk in CP to be solved




Short distances between combustible equipment


Unmannerly parking


Use of fire wood to cook


Use of gas to lighting and cook


Poor maintenance of equipment


Fire suppress equipment not properly located


Lack of training and education


Incorrect connections to electric network

Findings

- Fire resistant tents may ignite if the material inside is combustible
- Tents not well stretched have a higher probability to ignite as the firebrands accumulate in the wrinkles
- The ignition of a tent is easily propagated, showing the importance of having the adjacent area free of fuels
- On windy days a burning tent may be dragged over the CP causing spot fires or even wounding people
- The higher resolution mosaic resulted in a good tool to produce the fuel map of the camping area.

Achievements

- A preliminary model to simulate the fire spread inside the CP was developed
- A list of causes and measures to mitigate the fire risk in CP was produced
- The results were disseminated among several camping interested parties: camping materials producers, CP managers, firefighters, camping federation and tourism associations, among others

Future work

- Extend the analysis to other equipment and materials – e.g. caravans
- Develop a methodology to classify the CP in respect to fire risk
- Extend the results to other realities – e.g temporary CP of music festivals
- Support the adaptation of the existing legislation.

Workshop on Structure Ignition in WUI Fires

FireCamp - Analysis of fire hazard in camping park areas

Presented by: Miguel Almeida
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Anaheim, June 19th, 2015

Authors (alphabetic order): Miguel Almeida, José Raul Azinheira, Jorge Barata, Kouamana Bousson, Rita Ervilha, Marta Martins, Alexandra Moutinho, José Carlos Pereira, João Caldas Pinto, Luís Mário Ribeiro, Jorge Silva, Domingos Xavier Viegas

Firebrand Production from Building Components with Siding Treatments Applied

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Samuel L. Manzello, Ph.D.
National Institute of Standards and Technology, USA

Workshop on Structure Ignition in Wildland-Urban Interface (WUI) Fires
Sponsored by ASTM International Committee E05
Anaheim, CA, USA

Structure Ignition in WUI Fires

- **Post-fire studies – firebrands a major cause of ignition**
- **Understanding firebrand ignition of structures – important to mitigate fire spread in communities**

Improved understanding of structure ignition in WUI fires
- Major recommendation (GAO 05-380)
- National Science and Technology Subcommittee on Disaster Reduction
- Homeland Security Presidential Directive (HSPD 8; Paragraph 11)


2007 Southern California Fire


2003 Southern California Fire

Previous Research on Firebrands

- **Firebrands: generation, transport, ignition**
- **Research focused on how far firebrands travel for 40 yrs!!**
- **Nice Academic Problem – Not helpful to design structures**
- **NIST Dragon (ignition research)**
  - **Simulate firebrands by coupling with the wind tunnel in BRI, Japan**
  - **Firebrands by NIST Dragon are tied with the firebrand data from vegetation and from Angora fire (2007)**

Firebrand Generation from Structures

- **Firebrands are produced not only as vegetation burns but also as structures are ignited and burned**
- **Little data exists regarding firebrand production from actual structures**
- **Firebrand production from burning structures needed for EL-NIST's modeling of WUI fires**
- **Data will also enable the NIST Firebrand Generator to generate firebrand showers representative of burning structures**

Previous studies

	Peak Fire Intensity	Material Used	Wind Speed	Measurement Techniques	Significant Results
Vodvarka	Not provided	standard frame construction with wood siding /asphalt siding applied over sheet rock / brick veneer over a wood frame	Not specified	Sheets of polyurethane plastic	89% of firebrands less than 0.23 cm^2
Vodvarka	Not provided	all wood construction /cement-block construction with wooden floors and asphalt shingles over wood sheathing	Not specified	Sheets of polyurethane plastic	85% of firebrands less than 0.23 cm^2
Manzello and Foote	Not mentioned	Not specified	4.5 m/s to 6.7 m/s	trampoline outdoor furniture	more than 95 % of firebrands less than 1.0 cm^2
Rissel and Ridenour	Not mentioned	Not specified	5.4 m/s to 6.3 m/s	Trampolines	more than 90 % of firebrands less than 0.5 cm^2

Previous studies

	Peak Fire Intensity	Material Used	Wind Speed	Measurement Techniques	Significant Results
Shinohara et al.	Not measured	Not mentioned	an average wind speed of 7.2 – 12.1 m/s	Collected after fire	Most of the firebrands less than 10 cm^2 and 0.5 g
Ohmiya and Iwami	Not measured	Not mentioned	an average 7 m/s	Survey	Most of the firebrands less than 5 cm maximum dimension
Yoshioka et al.	1.08 MW/m^2	fire prevented wood with outer wall siding and slate roofing	4 m/s	Pan filled with water and no water	83 % of firebrands in the wet pan between 0.25 and 1 cm^2
3 story school building burn	Not mentioned	Wood and gypsum boards	4.6 m/s	Collected after fire	Most firebrands were found to be between 1 and 3 cm

Previous Study by Vodvarka

- **Measured firebrand generation by laying out 3 m x 3 m plastic sheets downwind from five separate residential buildings burned in full-scale fire experiments**
- **Measured firebrand size and transport distances of 4,748 firebrands that were collected from five full-scale experimental building fires**
- **Very small firebrands dominated the size distribution**
  - ***89% of the firebrands less than 0.23 cm² (0.1875 in x 0.1875 in)***

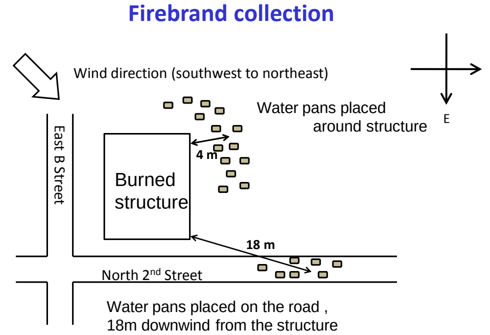
Firebrand Generation - Research Plan

- Firebrand production from an actual full-scale structure burn conducted by NIST in Dixon, CA
- Firebrand production from a real-scale structure burn in BRI's wind tunnel
- Firebrand production from real-scale building components under well-controlled laboratory conditions in BRI's wind tunnel
  - **Firebrand production from building components with sidings under well-controlled laboratory conditions in BRI's wind tunnel in order to see the influence of siding treatment applied**

Full Scale burn in CA

- **In collaboration with Northern California Fire Prevention Officers, (NORCAL FPO), a full scale, proof-of-concept experiment conducted to investigate firebrand production from burning structure**
- **The structure is mainly built from wood and brick**
- **Wind speed – 5.8 m/s**
- **This burn was as a part of firefighter training**

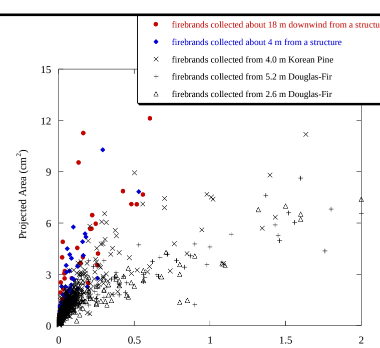
Firebrand collection



The dimensions and mass are measured after dried

4:15 House Burn started

6:30 House Burn ended



- The size distribution of firebrands at two different places were similar to the ones from vegetation
- Most firebrands with mass less than 1g

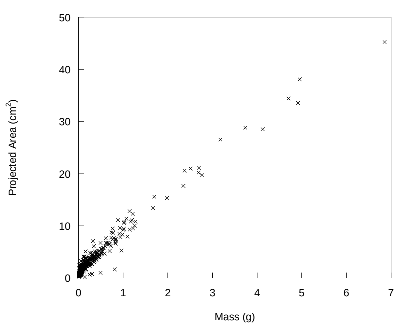
Full-Scale Structure

Wind speed – 6 m/s

OSB & studs

Performed in BRI's wind tunnel

Size and Mass Distribution



More than 90 % of firebrands are less than 1 g
less than 10 cm²

Firebrand Generation from Components

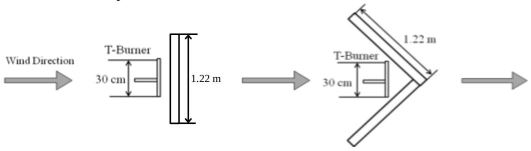
- **To determine if simple component tests can provide insights into firebrand generation data from full-scale structures**
- Simple building components
  - OSB & studs
- Two configurations
  - Wall & reentrant corner assembly
- Varying wind speed
  - 6 & 8 m/s

Wind Velocity – 8 m/s
Corner assembly

Experimental Condition

Wall assembly

Re-entrant corner assembly



Experiment No. 1 6 m/s

Experiment No. 2 6 m/s

Experiment No. 3 8 m/s

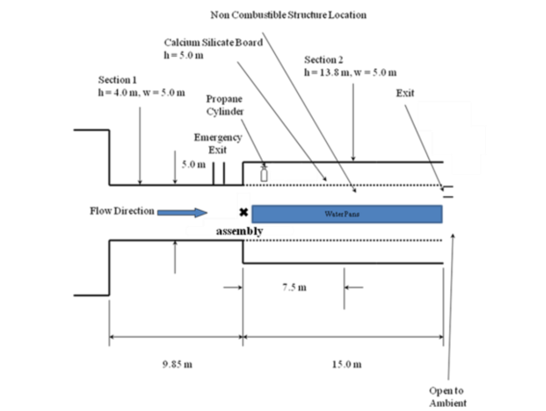
Ignition Sequence

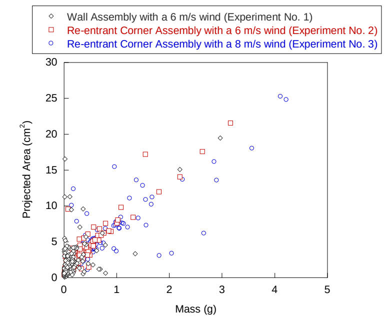
Burner Applied – No Wind

Burner off –
6 m/s Wind Applied

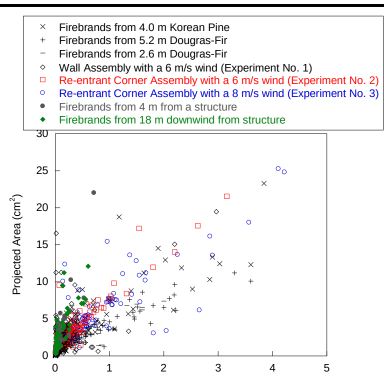
Intense sustained Smoldering Ignition (SI)

6 m/s

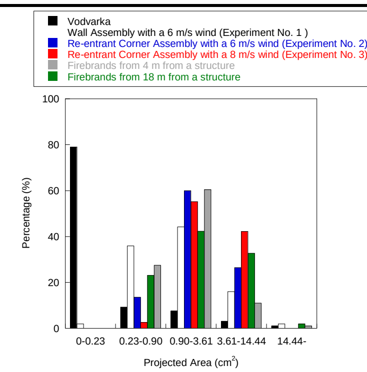




- The size and mass distribution of firebrands from experiment No.2 and No.3 were similar
- The one from experiment No.1 had more variety of projected area at a certain mass, especially within 10 cm² projected area



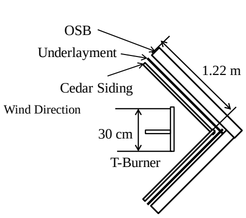
The size and mass distribution from components was found to be similar to the one from vegetation and the one from a full-scale burn

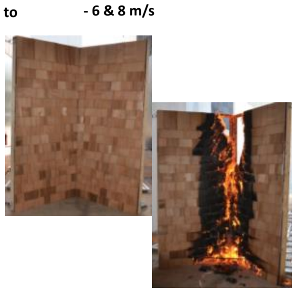


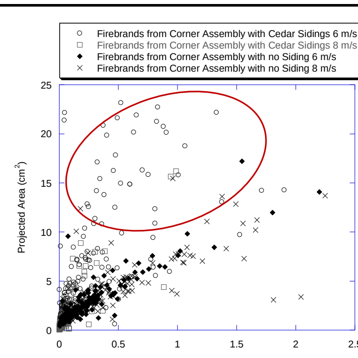
The size distributions of our studies are larger and broader than the one from Vodvarka

Firebrand Generation from Building Components with Cedar Sidings

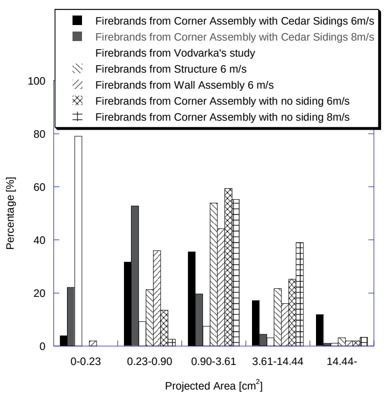
- **Wall with cedar siding**
  Cedar Siding & Tar Paper added to Wall made from OBS & Studs
- **Wind Velocity**
  - 6 & 8 m/s







Firebrand collected in this study were larger at a certain mass



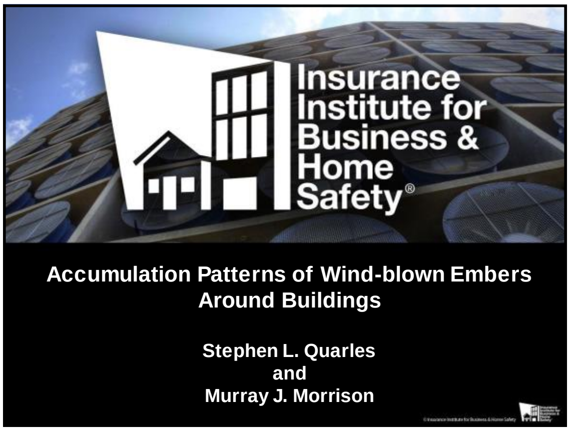
- These peaks are found to be shifted to smaller side compared to the ones from experiments with no siding
- The size distributions of these experiments were still larger and broader than the ones from Vodvarka's study

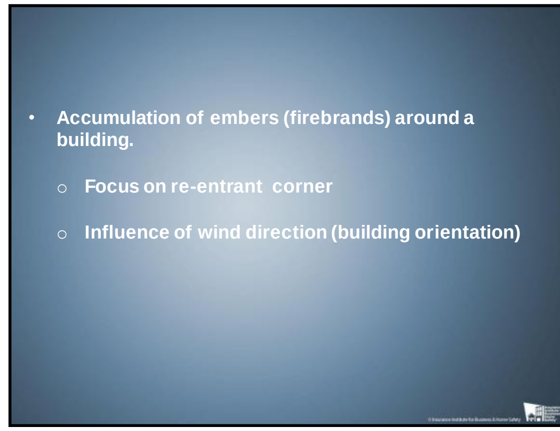
Summary

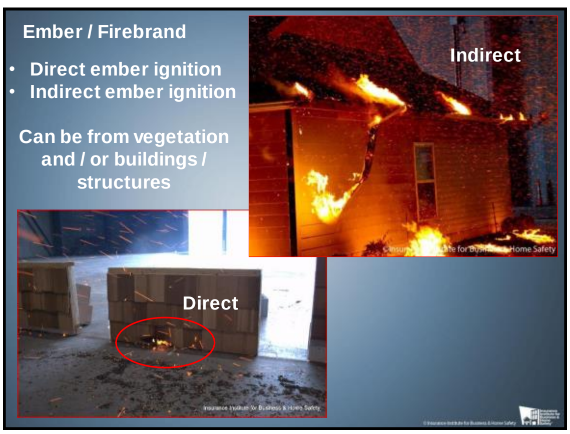
- Firebrands were collected from burning building components with cedar siding and compared with the previous firebrand data <u>in order to see the influence of siding treatment applied</u>
- The same ignition method was used to ignite assemblies and a series of water pans were used to collect firebrands
- Firebrands collected here had larger projected area and lower mass class compared to the ones collected from previous components test with no siding
- The results suggest that <u>siding treatment do influence of firebrand production process</u>

Acknowledgements

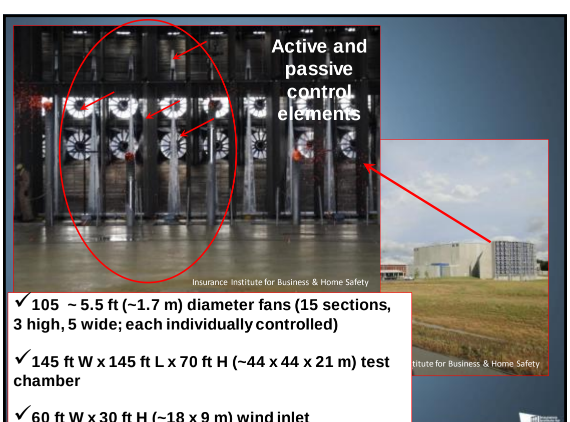
- Dr. Daisaku Nii from BRI
- Dr. Ichiro Hagiwara from BRI
- Mr. Marco Fernandez from EL-NIST

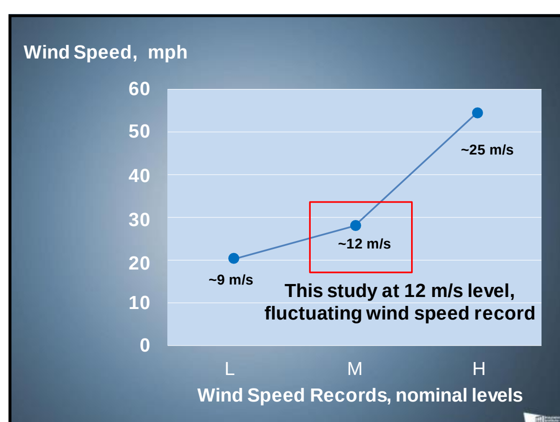

Insurance Institute for Business & Home Safety®
Accumulation Patterns of Wind-blown Embers Around Buildings
Stephen L. Quarles
and
Murray J. Morrison


• Accumulation of embers (firebrands) around a building.
○ Focus on re-entrant corner
○ Influence of wind direction (building orientation)


Ember / Firebrand
• Direct ember ignition
• Indirect ember ignition
Can be from vegetation and / or buildings / structures
Indirect
Direct

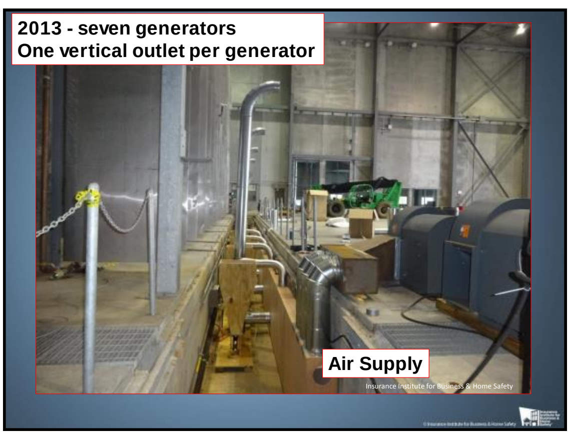

2011
Wildfire experiments at the IBHS Research Center
2013/14
Re-entrant corner

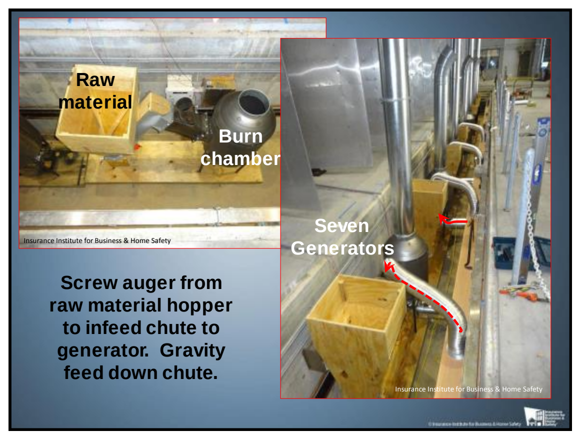

Active and passive control elements
Insurance Institute for Business & Home Safety
✓105 ~5.5 ft (~1.7 m) diameter fans (15 sections, 3 high, 5 wide; each individually controlled)
✓145 ft W x 145 ft L x 70 ft H (~44 x 44 x 21 m) test chamber
✓60 ft W x 30 ft H (~18 x 9 m) wind inlet

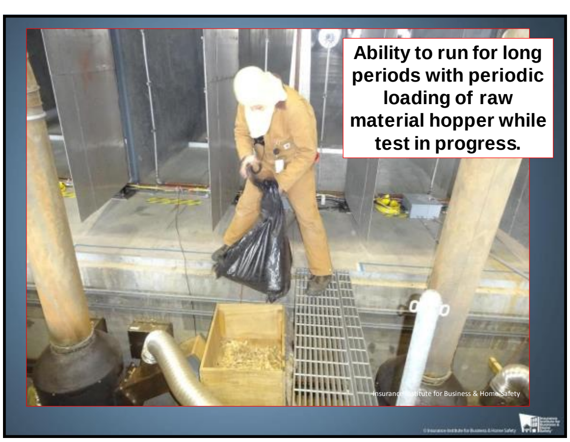

Wind Speed, mph
60
50
40
30
20
10
0
~9 m/s
~12 m/s
~25 m/s
This study at 12 m/s level, fluctuating wind speed record
L
M
H
Wind Speed Records, nominal levels


2011 – batch process
Raw material
✓ Bark mulch
✓ Wood dowels

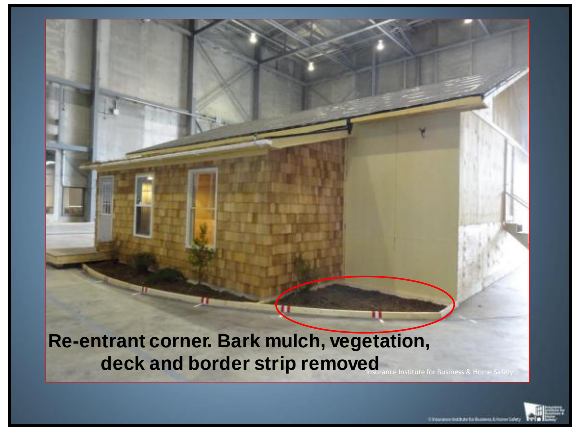

2011 - five generators:
Three vertical outlets per generator
Insurance Institute for Business & Home Safety

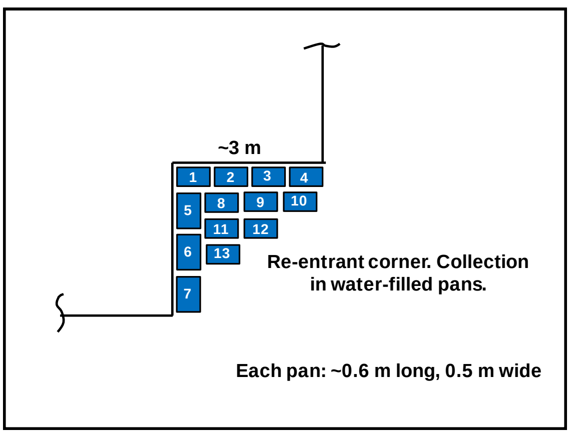

2013 - seven generators
One vertical outlet per generator
Air Supply
Insurance Institute for Business & Home Safety

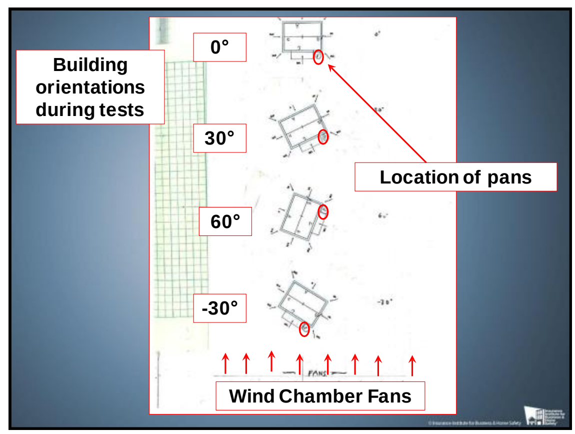

Raw material
Burn chamber
Insurance Institute for Business & Home Safety
Seven Generators
Screw auger from raw material hopper to infeed chute to generator. Gravity feed down chute.
Insurance Institute for Business & Home Safety

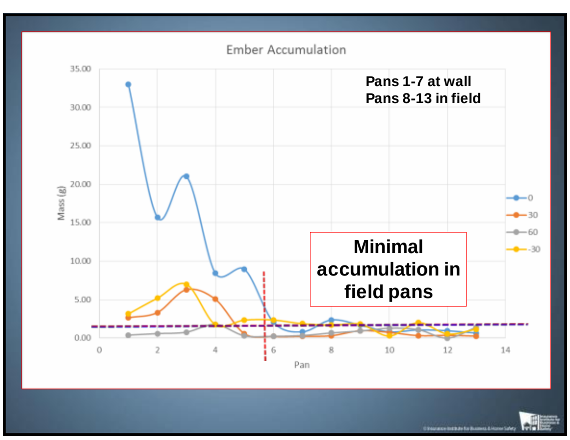

Ability to run for long periods with periodic loading of raw material hopper while test in progress.


Insurance Institute for Business & Home Safety
Insurance Institute for Business & Home Safety
Raw material consisted of a mixture of dried wood chips and dowels. 85:15 chip-to-dowel by volume.



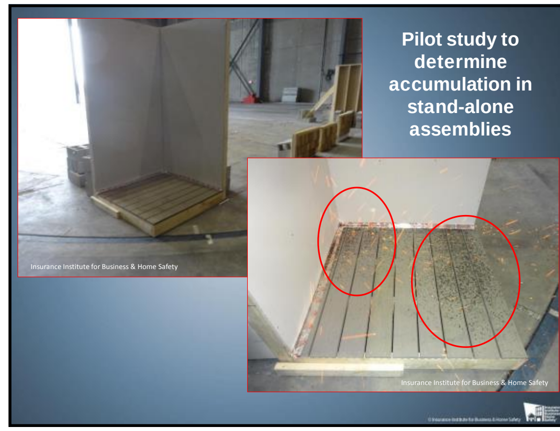






Relative amount of total mass of embers collected for four tests, as a function of building orientation.

Building Orientation, deg.	Relative Amount, %
0	61
30	13
60	6
-30	20



Summary –

- Wind-blown ember accumulation in the re-entrant corner occurred predominantly occurred in Pans 1 – 5 which were located in the corner and along one wall.
- With stand-alone corner assemblies, accumulation also occurred in the field of the deck, away from the re-entrant corner.

Fire Performance of Exterior Wood Decks in the Wildland-Urban Interface

Laura E. Hasburgh[1], Donald S. Stone[2], Samuel L. Zelinka[1]

[1] US Forest Products Laboratory, Madison, Wisconsin
[2] Materials Science and Engineering, University of Wisconsin, Madison, Wisconsin

Background

- In 2012, two fires in Colorado, the Waldo Canyon Fire and the High Park Fire, had an estimated property loss of $453,700,000 and $113,700,000, respectively.[1]
- One scenario hypothesized as resulting in property loss was the ignition of attached wood decks
- Two main sources for ignition of wood decks
  - Burning brands on top of deck
  - Unmaintained debris below the deck

[1]Karter, M. 2013. Fire Loss in the United States During 2012. National Fire Protection Association, Fire Analysis and Research Division. 13 p.

WUI Building Codes

- California Building Code
  - Chapter 7A, *Materials and Construction Methods for Exterior Wildfire Exposure*
- International Code Council
  - International Urban Wildland Interface Code (IWUIC)

Current Decking Standards

- California SFM 12-7A-4, *Decking*
- ASTM E2632, *Standard Test Method for Evaluating the Under-Deck Fire Test Response of Deck Materials*
- ASTM E2726, *Standard Test Method for Evaluating the Fire-Test-Response of Deck Structures to Burning Brands*

CBC Chapter 7A

- 704A.4 requires decking materials to be one of the following:
  - Ignition-resistant and tested per SFM 12-7A-4, Parts A and B
  - Heavy timber, exterior FRT wood or approved noncombustible material
  - Identified as exterior, comply with SFM 12-7A-4 Part A with a net peak HRR of 25 kW/ft^2 over a 40 minute observation time and the exterior wall covering at the deck and within 10 feet of the deck are approved noncombustible or ignition resistant material

Part A: Under Deck Flame Test

- Conditions of Acceptance
  - Net peak HRR $\le$ 25 kW/ft^2
  - No flaming or glowing combustion at 40-minutes
  - No falling particles that are still burning when hitting the burner or floor

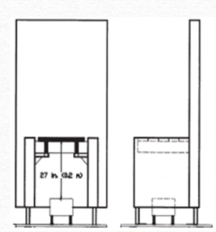


Image from 2010 California SFM 12-7A-4

Part B: Burning Brand Test

- Conditions of Acceptance
  - No flaming or glowing combustion at 40-minutes
  - No falling particles that are still burning when hitting the burner or floor

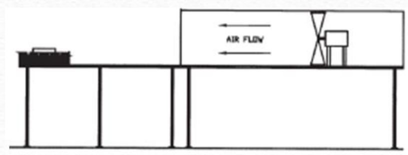


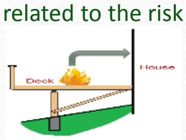
Image from 2010 California SFM 12-7A-4

IWUIC

- For Class 1 and Class 2, appendages and projections must meet one of the following:
  - Not less than 1-hour fire resistance-rated construction
  - Heavy timber construction
  - Approved noncombustible materials
  - FRT wood identified for exterior use
  - Ignition-resistant building materials

Motivation

- Improve the survivability of structures during wildland fires
- Understand how deck fires contribute to ignition of attached home
- Develop a test and acceptance criteria that are more closely related to the risk of structural ignition



Initial Objectives

- Develop test protocol
  - Geometry
  - Wind direction/speed
- Worst case scenario

Methods - Decks

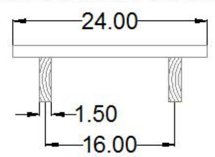
- Similar to existing CSFM/ASTM Decking Standards
- Modifications
  - Back wall for burning brand tests
  - Deck Size
  - Thermocouples
  - Heat Flux Sensors
  - Various burner fire sizes

Methods - Decks

- Five 2” by 6” nominal redwood deck boards cut 24” in length were used to construct the deck surface for a total surface of 24” by 28”
- The redwood deck boards were separated by a 3/16” gap

Methods - Joists

- The joists were constructed of 2” by 6” Doug fir which were spaced 16” on center
- The front deck board was flush with the end of the joists and attached with 2 ½” deck



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Methods - Conditioning

The decks were conditioned in a 70ºF/50 relative humidity room for more than 30 days prior to testing to allow the wood to reach equilibrium with the environment

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Methods – Test Frame

- Metal test frame was used to hold the deck
- The frame was high enough so that the bottom of the deck was 28 ¾” inches above a 12” x 12” propane burner that was used for below-test tests
- The frame allows the deck to sit directly next to a wall

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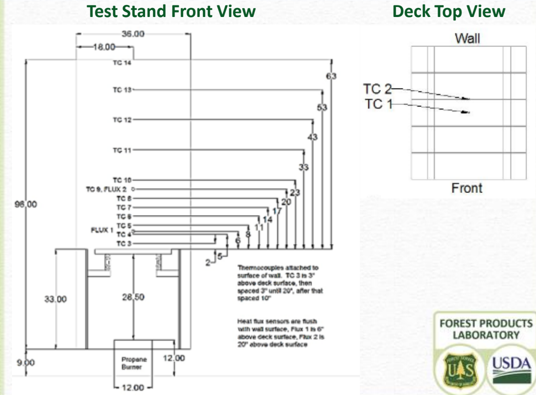
Test Stand Front View **Deck Top View**



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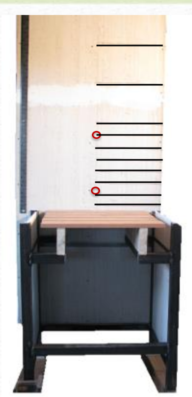

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FDS Modeling

- Conducted a parametric study with FDS changing the wind speeds to aid in determining the worst case scenarios

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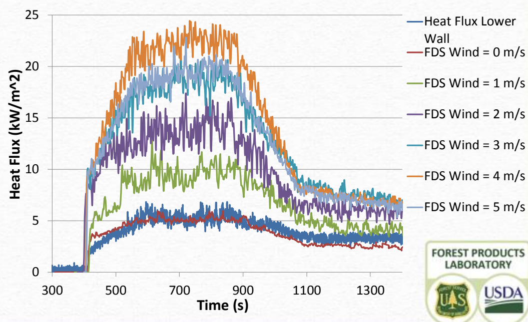
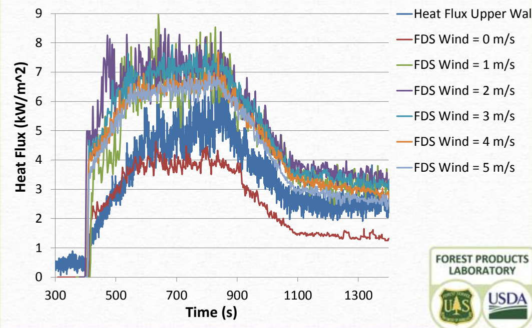
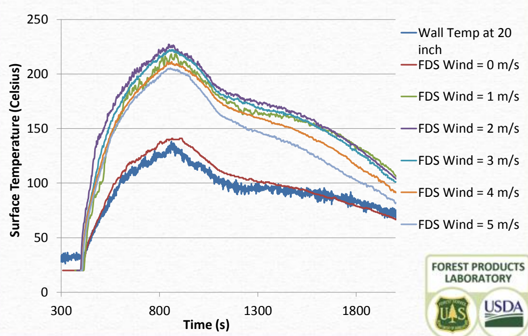
Results – FDS Modeling (6” HF)



Results – FDS Modeling (20” HF)



Results – FDS Modeling (Temp)



Initial Under Deck Test Matrix

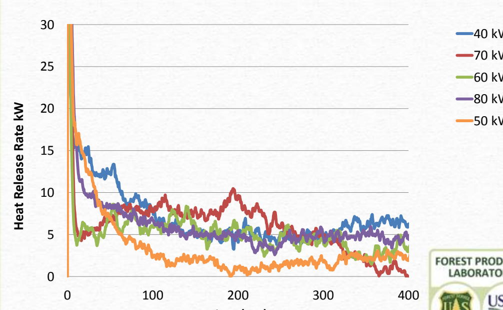
Test #	Fire Size (kW)	Wind	Orientation (w/ respect to wind direction)
1	40	Yes	Perpendicular
2	70	Yes	Perpendicular
3	60	Yes	Perpendicular
4	80	No	Perpendicular
5	50	Yes	Perpendicular

Ignition – Under Deck Test

0 min 9:30 min 10:30 min

11 min 30 min

Under Deck Results - HRR



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Under Deck Test Flame Spread

40 kW Fire | 70 kW Fire | 60 kW Fire | 80 kW Fire

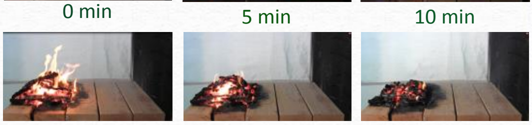
50 kW Fire

Initial Burning Brand Test Matrix

Test #	Brand	Wind (m/s)	Orientation (w/ respect to wind direction)
6	A	0	Perpendicular
7	A	1.4	Perpendicular
8	A	2.9	Perpendicular
9	A	2.9	Parallel
10	A	5	Perpendicular

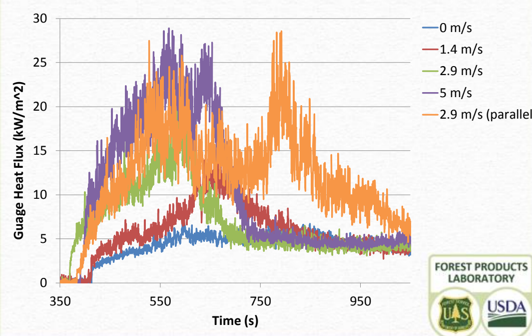
Ignition – Burning Brand Test

0 min | 5 min | 10 min

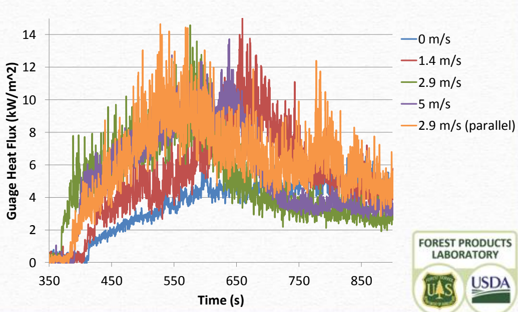


15 min | 20 min | 30 min

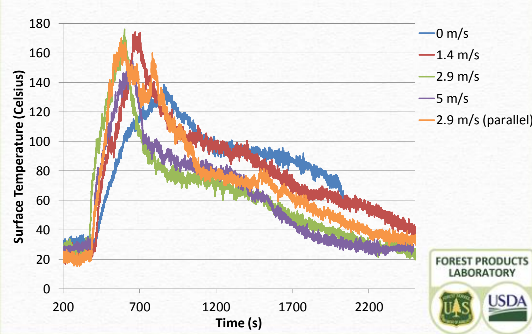
Results – Heat Flux at 6”



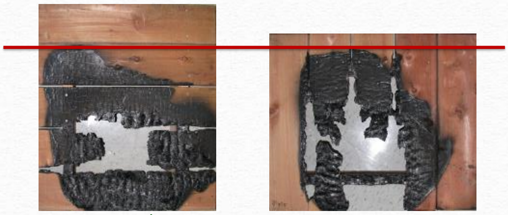
Results – Heat Flux at 20”



Results - Temperature



Burning Brand Test Damage



2.9 m/s Perpendicular

2.9 m/s, Parallel

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3 m/s → worst case scenario

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Wind Generator

Future Work

- Burning Brand Standard Test
  - Redwood, Western Red Cedar, Southern Pine
- Modified Burning Brand test (3 m/s wind)
  - Redwood, Western Red Cedar, Southern Pine
- Effect of Moisture Content
  - Redwood @ 4% MC
- Effect of brand placement
  - 3-4 different locations
  - Redwood conditioned at 50% RH

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Future Work

- Effect of wall material
  - Selected approved wall materials
- Other Decking Materials
  - Pressure Treated , WPCs (FRT and not), Aluminum decking, FRT Wood, Weathered Wood Decking
- Mitigation Techniques
  - Flashing on wall
  - Non-combustible or FRT decking material close to house
  - Deck geometry / corners

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Recent Class A Burning Brand Tests

Southern Yellow Pine | Western Red Cedar | Redwood

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Acknowledgments

- Mark Dietenberger, USDA FPL
- Kuma Sumathipala, AWC
- Steve Quarles, IBHS

AMERICAN WOOD COUNCIL

FOREST PRODUCTS LABORATORY

Questions?

FS protecting a WUI home from wildfire.

FS photo, Audit Report Forest Service Large Fire Suppression Costs, www.usda.gov

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Spot Fire Ignition of Natural Fuels by Hot Aluminum Particles

James L. Urban, Casey D. Zak & Carlos Fernandez-Pello

Combustion & Fire Processes Laboratory
Department of Mechanical Engineering
University of California Berkeley

Berkeley UNIVERSITY OF CALIFORNIA · NSF · NDSEG NATIONAL DEFENSE SCIENCE & ENGINEERING GRADUATE FELLOWSHIP

Background | Spot Fire Ignition by Hot Particles

Spot fire ignition of natural fuels is an important ignition pathway by which wild fires are started

- Power lines, equipment, and railroads cause approximately 28,000 natural fuel fires annually in the United States [NFPA & USFA]

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Background | Spot Fire Ignition by Hot Particles

guel.jpg/1024px-Harris_fire_Mount_Miguel.jpg

Witch Fire

- The Largest Fire of 2007 California Firestorm
- $1.8 Billion in losses

Alleged Cause:

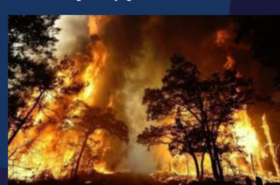
- Hot particles from clashing power lines landing in dry grass

Bastrop County Complex Fire (Texas)

- Largest loss fire in the USA in 2011
- Burned ~13,000 Hectacres

Alleged Cause:

- Hot particles from power lines interacting with trees and landing in dry grass



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Background | Particle Produced by Arcing Powerlines

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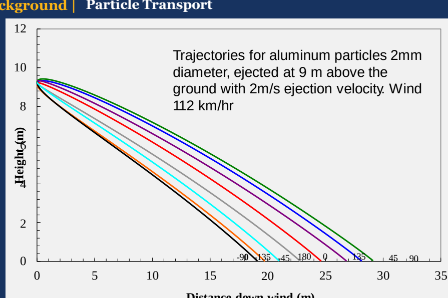
Background | Particle Transport



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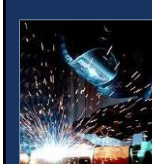
Background | Particle Sources

Other Hot Particle Sources



Hot Work

Machine Friction

Bullet Fragments

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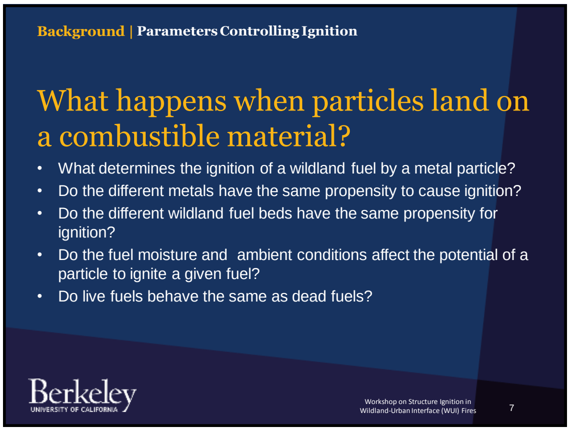
Background | Parameters Controlling Ignition
What happens when particles land on a combustible material?
• What determines the ignition of a wildland fuel by a metal particle?
• Do the different metals have the same propensity to cause ignition?
• Do the different wildland fuel beds have the same propensity for ignition?
• Do the fuel moisture and ambient conditions affect the potential of a particle to ignite a given fuel?
• Do live fuels behave the same as dead fuels?
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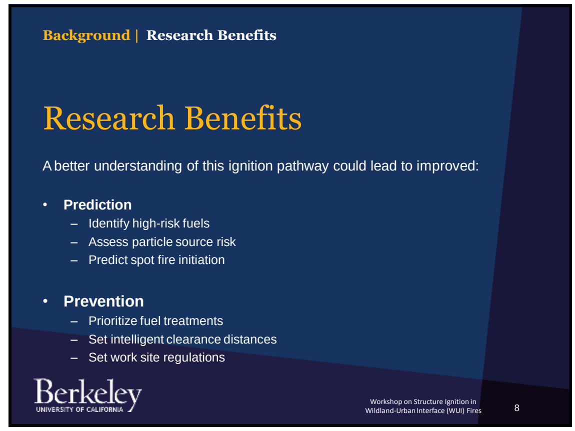
7


Background | Research Benefits
Research Benefits
A better understanding of this ignition pathway could lead to improved:
• Prediction
– Identify high-risk fuels
– Assess particle source risk
– Predict spot fire initiation
• Prevention
– Prioritize fuel treatments
– Set intelligent clearance distances
– Set work site regulations
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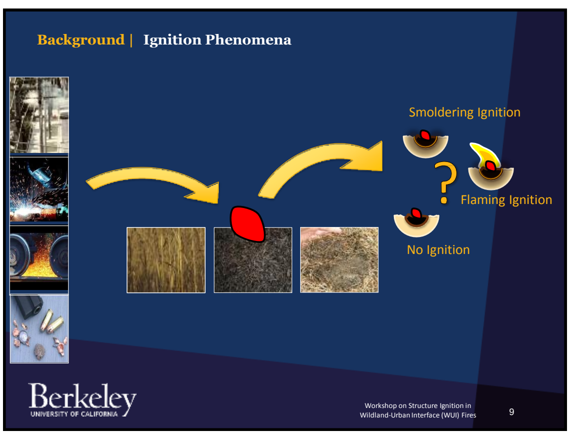
Background | Ignition Phenomena
Smoldering Ignition
Flaming Ignition
No Ignition
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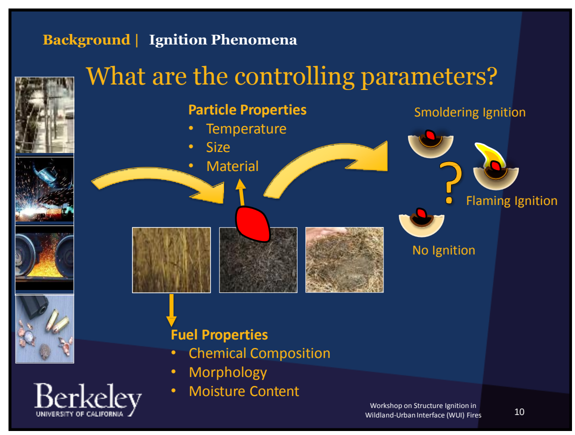
9


Background | Ignition Phenomena
What are the controlling parameters?
Particle Properties
• Temperature
• Size
• Material
Smoldering Ignition
Flaming Ignition
No Ignition
Fuel Properties
• Chemical Composition
• Morphology
• Moisture Content
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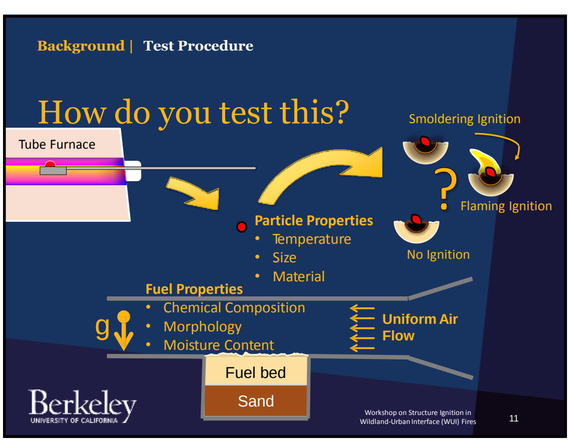
10


Background | Test Procedure
How do you test this?
Tube Furnace
Smoldering Ignition
Flaming Ignition
No Ignition
Particle Properties
• Temperature
• Size
• Material
Fuel Properties
• Chemical Composition
• Morphology
• Moisture Content
g
Uniform Air Flow
Fuel bed
Sand
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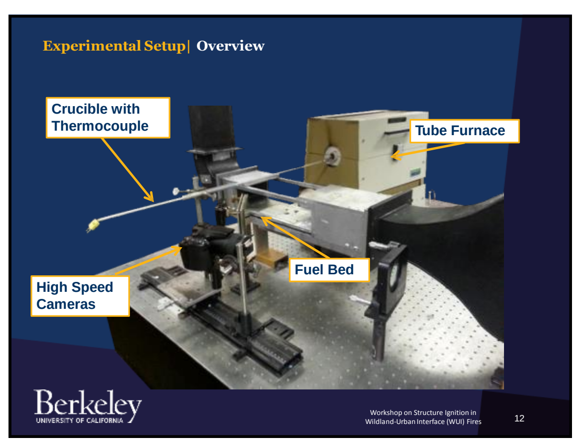
11


Experimental Setup | Overview
Crucible with Thermocouple
Tube Furnace
Fuel Bed
High Speed Cameras
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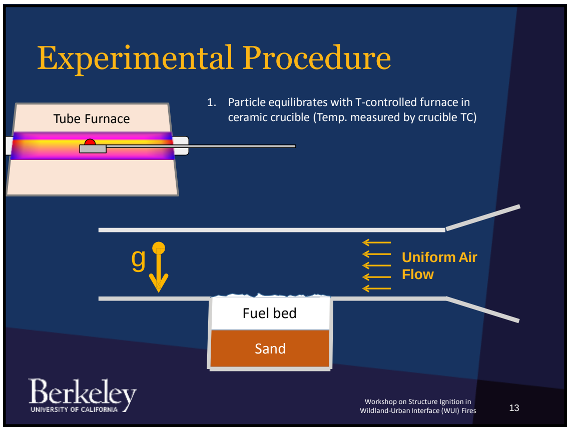
12


Experimental Procedure
Tube Furnace
1. Particle equilibrates with T-controlled furnace in ceramic crucible (Temp. measured by crucible TC)
g
Uniform Air Flow
Fuel bed
Sand
Berkeley
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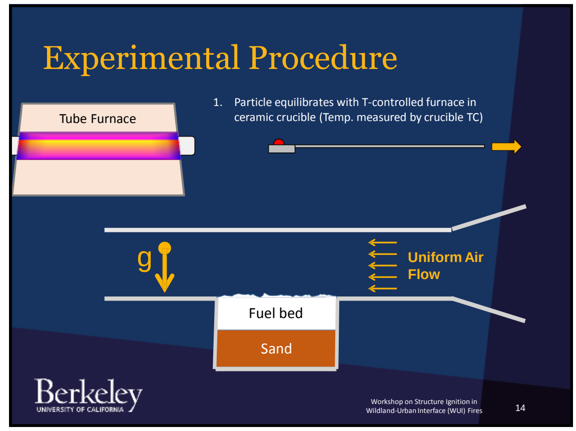
13


Experimental Procedure
Tube Furnace
1. Particle equilibrates with T-controlled furnace in ceramic crucible (Temp. measured by crucible TC)
g
Uniform Air Flow
Fuel bed
Sand
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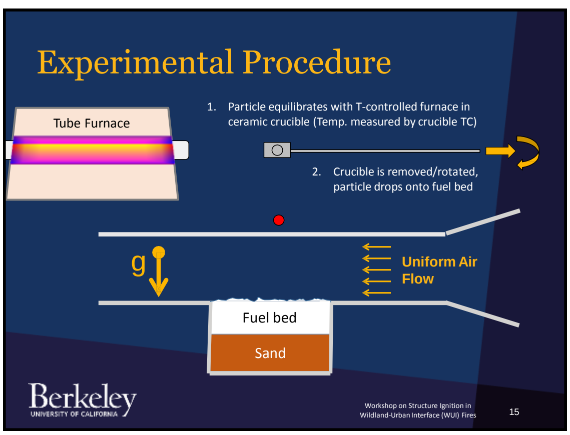
14


Experimental Procedure
Tube Furnace
1. Particle equilibrates with T-controlled furnace in ceramic crucible (Temp. measured by crucible TC)
2. Crucible is removed/rotated, particle drops onto fuel bed
g
Uniform Air Flow
Fuel bed
Sand
Berkeley
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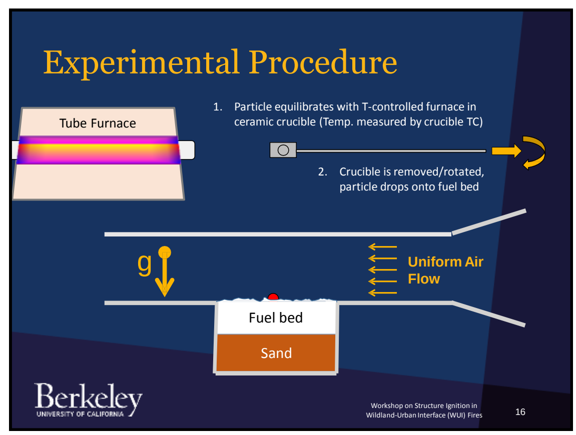
15


Experimental Procedure
Tube Furnace
1. Particle equilibrates with T-controlled furnace in ceramic crucible (Temp. measured by crucible TC)
2. Crucible is removed/rotated, particle drops onto fuel bed
g
Uniform Air Flow
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Sand
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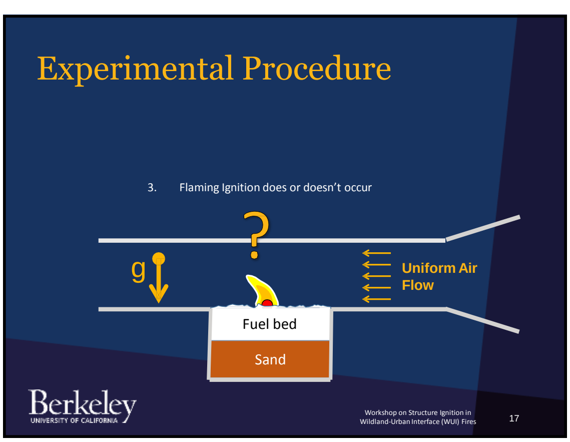
Workshop on Structure Ignition in Wildland-Urban Interface (WUI) Fires
16


Experimental Procedure
3. Flaming Ignition does or doesn't occur
?
g
Uniform Air Flow
Fuel bed
Sand
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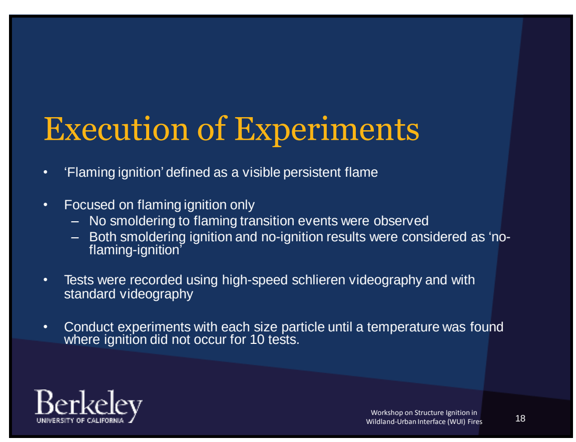
Execution of Experiments
• 'Flaming ignition' defined as a visible persistent flame
• Focused on flaming ignition only
– No smoldering to flaming transition events were observed
– Both smoldering ignition and no-ignition results were considered as 'no-flaming-ignition'
• Tests were recorded using high-speed schlieren videography and with standard videography
• Conduct experiments with each size particle until a temperature was found where ignition did not occur for 10 tests.
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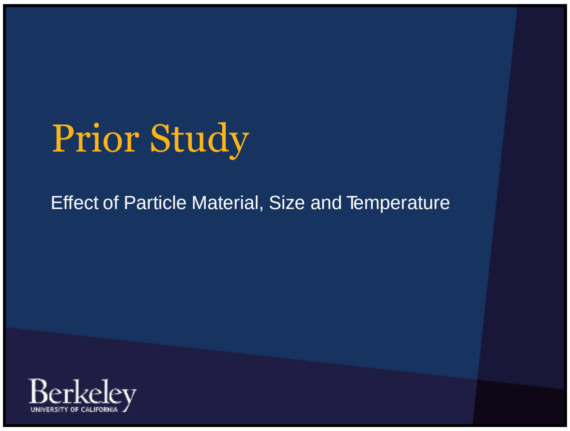
Prior Study
Effect of Particle Material, Size and Temperature
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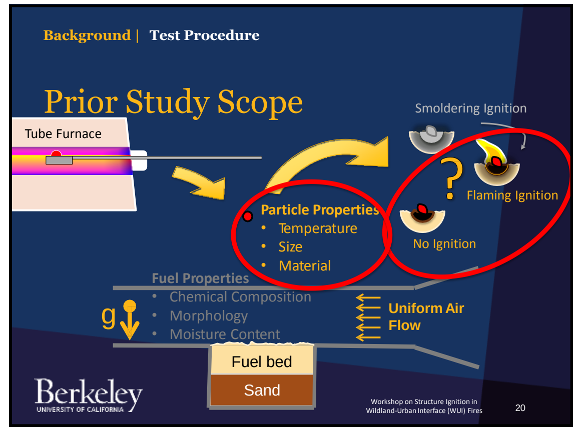
Background | Test Procedure
Prior Study Scope
Tube Furnace
Smoldering Ignition
Flaming Ignition
No Ignition
Particle Properties
• Temperature
• Size
• Material
Fuel Properties
• Chemical Composition
• Morphology
• Moisture Content
g
Uniform Air Flow
Fuel bed
Sand
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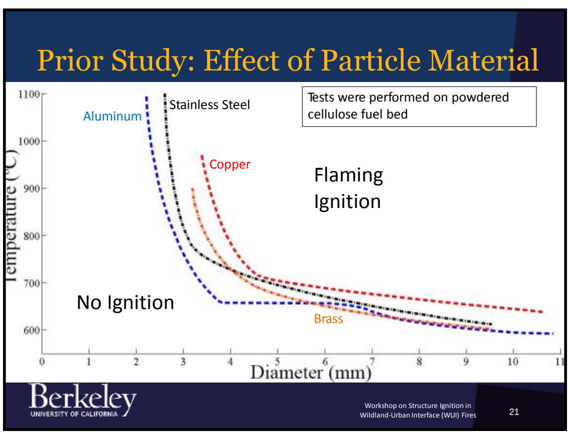
20


Prior Study: Effect of Particle Material
Aluminum
Stainless Steel
Tests were performed on powdered cellulose fuel bed
Copper
Flaming Ignition
No Ignition
Brass
Temperature (°C)
Diameter (mm)
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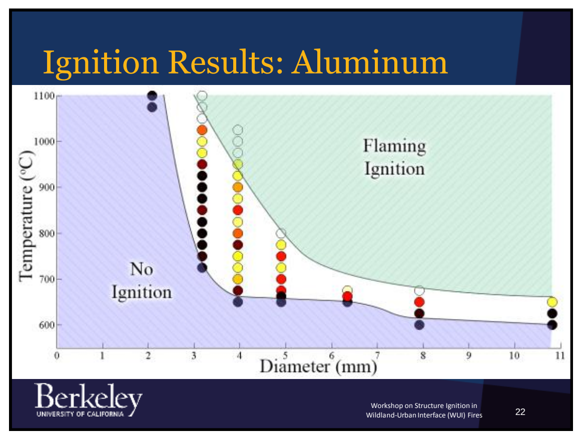
Ignition Results: Aluminum
Flaming Ignition
No Ignition
Temperature (°C)
Diameter (mm)
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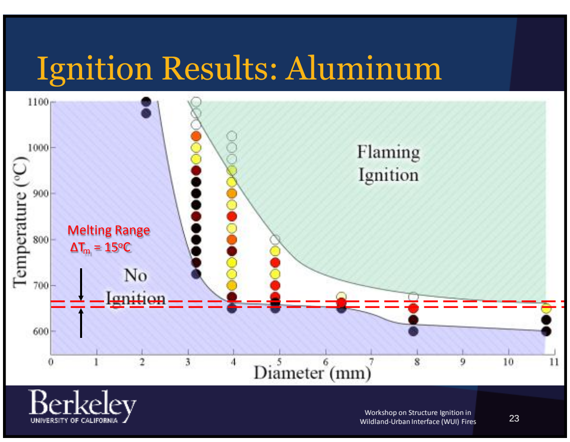
Ignition Results: Aluminum
Flaming Ignition
Melting Range
ΔTm = 15°C
No Ignition
Temperature (°C)
Diameter (mm)
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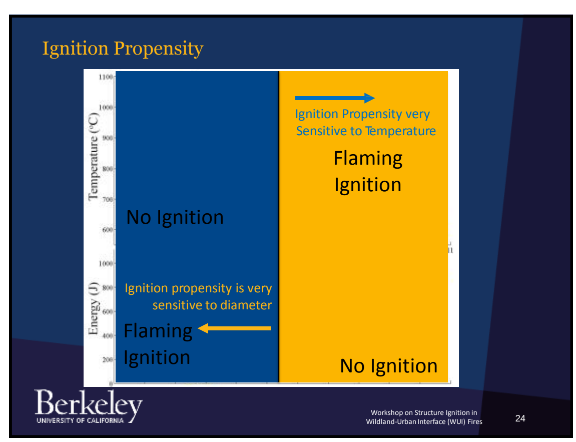
Ignition Propensity
Ignition Propensity very Sensitive to Temperature
Flaming Ignition
No Ignition
Ignition propensity is very sensitive to diameter
Flaming Ignition
No Ignition
Temperature (°C)
Energy (J)
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Current Study

Effect of Fuel Bed Chemical Composition and Morphology

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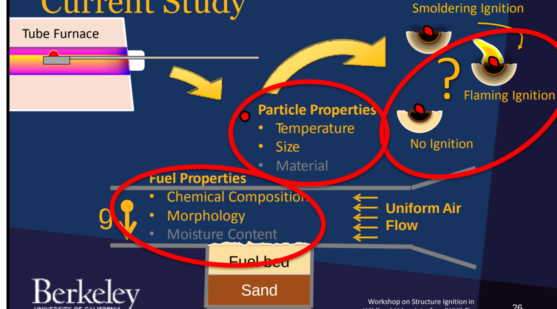
Background | **Test Procedure**

Current Study



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Fuel Bed Parameters

- Chemical Composition
  - α-Cellulose
  - Grass blend (α-cellulose, lignin, hemi-cellulose, ash and proteins)
  - Pine Needles (α-cellulose, lignin, hemi-cellulose, and ash)
- Fuel Bed Morphology (grass/strips vs. powder)

	Density [kg/m³]	d_{char} [mm]
Strips/grass	45 - 79	2-7
Powder	300 - 363	0.4 - 0.5

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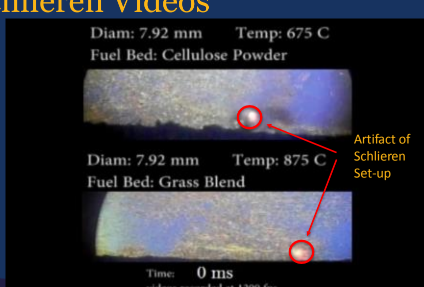
Schlieren Videos



Artifact of Schlieren Set-up

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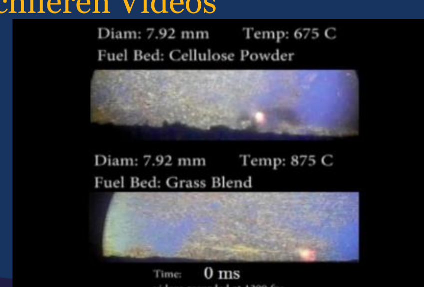
Schlieren Videos



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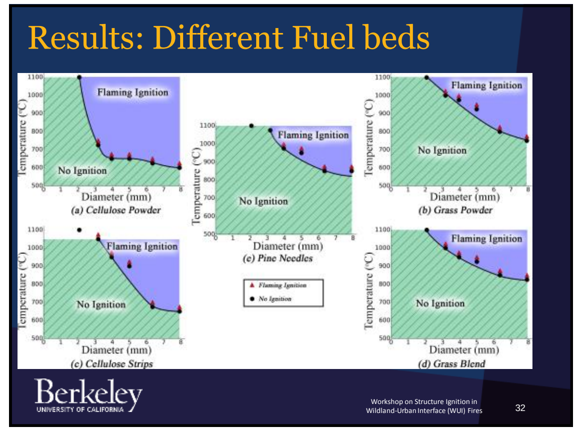

Results: Different Fuel beds
Flaming Ignition
No Ignition
Temperature (°C)
Diameter (mm)
(a) Cellulose Powder
(b) Grass Powder
(c) Pine Needles
(c) Cellulose Strips
(d) Grass Blend
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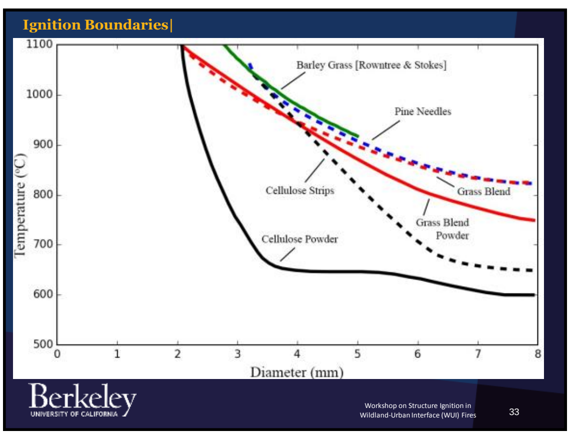

Ignition Boundaries|
Temperature (°C)
Diameter (mm)
Barley Grass [Rowntree & Stokes]
Pine Needles
Cellulose Strips
Grass Blend
Grass Blend Powder
Cellulose Powder
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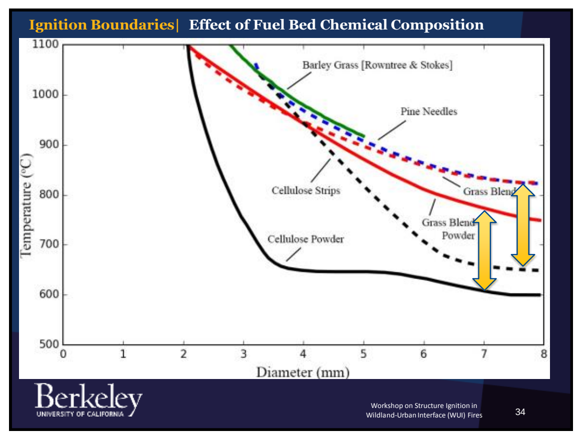

Ignition Boundaries| Effect of Fuel Bed Chemical Composition
Temperature (°C)
Diameter (mm)
Barley Grass [Rowntree & Stokes]
Pine Needles
Cellulose Strips
Grass Blend
Grass Blend Powder
Cellulose Powder
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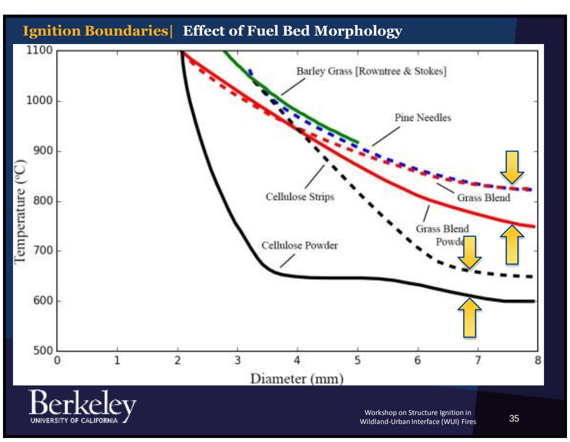

Ignition Boundaries| Effect of Fuel Bed Morphology
Temperature (°C)
Diameter (mm)
Barley Grass [Rowntree & Stokes]
Pine Needles
Cellulose Strips
Grass Blend
Grass Blend
Cellulose Powder
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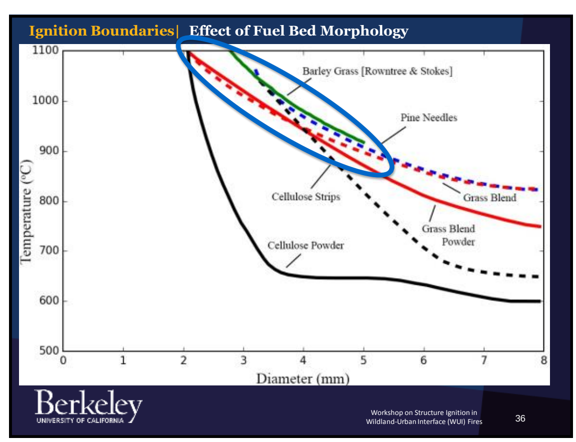

Ignition Boundaries| Effect of Fuel Bed Morphology
Temperature (°C)
Diameter (mm)
Barley Grass [Rowntree & Stokes]
Pine Needles
Cellulose Strips
Grass Blend
Grass Blend Powder
Cellulose Powder
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Summary

- Simulated spot fire ignition by dropping hot aluminum particles onto cellulose and natural fuel beds
- Investigated role of fuel bed chemistry and morphology on ignition propensity
- Powdered fuels are more easily ignited than their strip/grass counterparts
- The effects of fuel bed composition and morphology appear to be more important for larger particles than for smaller particles
- The results indicate (as in previous studies) that the ignition mechanisms for large – low temperature particles and small – high temperature particles appear to be different

References

- C. Egan, S. Holland, The AGE National, 2009.
- S. Badger, Large-Loss Fires in the United States – 2011, Technical Report, National Fire Protection Association, U.S., Quincy, Massachusetts 02169, 2012.
- H. Wakelin, Ignition Thresholds for Activity Controls on Public Conservation Land in Canterbury, Technical Report, University of Cantebury, Cantebury, NZ, 2010.
- U.S. Fire Administration. <http://www.usfa.fema-gov/statistics/estimates/wildfire.shtm> (accessed 04.12.14).
- Emergency Incident Statistics 2009–2010, New Zealand Fire Service, Wellington, New Zealand, 2010.

NDSEG NATIONAL DEFENSE SCIENCE & ENGINEERING GRADUATE FELLOWSHIP

Acknowledgements

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- The authors would also like to thank others for their contribution to this work this work
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  - Markus Fromm
  - Jimmy Huang
  - Vi Tran
  - Khanh Do
  - Maxime Mense
  - Adam Martin
  - Andreas Ronellfitch

Questions?

Presenter:
James L Urban
JLUrban@Berkeley.edu

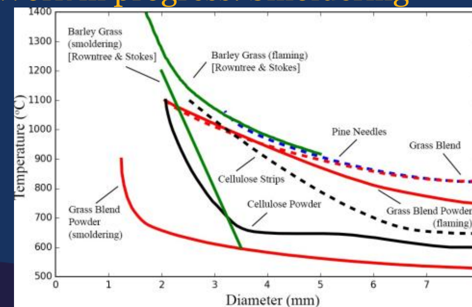
Back Up Slides

Fuel Beds

Fuel Bed Properties

Fuel	Density [kg/m³]	MC [%]	Chemical Composition	d_{char} [mm]
Cellulose Powder	363 ± 34.4	6.5 ± 2	100% α – Cell.	0.4
Cellulose Strips	45 ± .2	7.3 ± 2		5
Pine Needles	59 ± 1.0	8.5 ± 2	38-42% Cellulose 13-21% Lignin 6-8% Ash [33]	2
Grass Blend Powder	299 ± 2.4	6.9 ± 2	33-45% α – Cell. 22-27% Hemi-Cell. 6-15% Lignin 5-7% Protein 8-10% Ash	0.5
Grass Blend	79 ± 1.0	7.6 ± 2		7.5

Work in progress: Smoldering

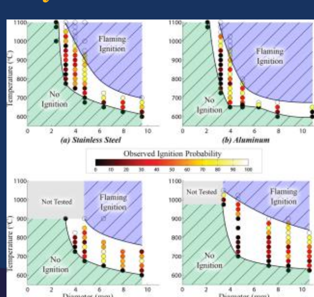


Aluminum Particle Parameters

	Aluminum (solid)	Aluminum (molten)
k (W/mK)	237	90
α (mm^2/s)	90	33
ρc_p (MJ/m³K)	2.4	2.71
ΔT_m (°C)	650	n/a
Δh_m (MJ/kg)	390	n/a

- Heated using tube furnace: Max Temp. 1100°C
  - Aluminum
- Diameter range:
  - ~2 – 8 mm

Prior Study: Effect of Particle Material



Building Component Ignition From Mulch Beds Ignited by Firebrand Showers

Samuel L. Manzello[1,2,3], Sayaka Suzuki[3], and Daisaku Nii[2]
Engineering Laboratory (EL)
National Institute of Standards and Technology (NIST)[1]

Guest Researcher, Building Research Institute (BRI)[2]
Tsukuba, JAPAN

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ASTM Workshop – Structure Ignition in WUI Fires
Anaheim, CA
June 19th, 2015

engineering laboratory

Large Outdoor Fires

- Wildfires fires that spread into communities, known as Wildland-Urban Interface (WUI) fires have destroyed communities throughout the world
- Japan numerous earthquakes - many fires produced in the aftermath
- Large outdoor fires that pose risk to built environment are urban fires in Japan

2014 Chile Fires

1995 Kobe Earthquake

2007 Southern California Fires

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Challenges

- Post-fire studies – firebrands a major cause of ignition
- Understanding firebrand ignition of structures – important to mitigate fire spread in communities
- Firebrands: generation, transport, ignition
- Research focused on how far firebrands travel for 40 yrs!!
- Nice Academic Problem – Not helpful to design structures
- Vulnerable points where firebrands may enter structure
  - Unknown/guessed!
- Difficult to replicate firebrand attack!
- Entirely new experimental methods needed!

Goals
Science - Building Codes/Standards; Retrofit construction
Harden structures to resistant firebrand ignition

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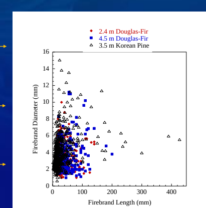
Development of NIST Dragon

Douglas-Fir Tree Burns at NIST

- Firebrand Collection using water pan array
  - Range of crown heights: 2.4 m – 4.5 m
  - Different moisture regimes
- Mass loss using load cells

4.5 m Douglas Fir



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Firebrand Sizes from Angora Fire

Determine Firebrand Size from Burn Patterns

More data from real fires needed!!

NIST and CAL FIRE Partnership

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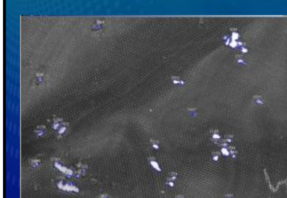
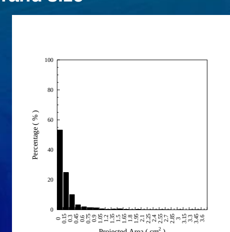
Firebrand Sizes from Angora Fire

Image analysis:
Determine firebrand size





Numerous small wind-driven firebrands observed in actual WUI fires
Texas Forest Service observed similar results in 2011 Texas Fires

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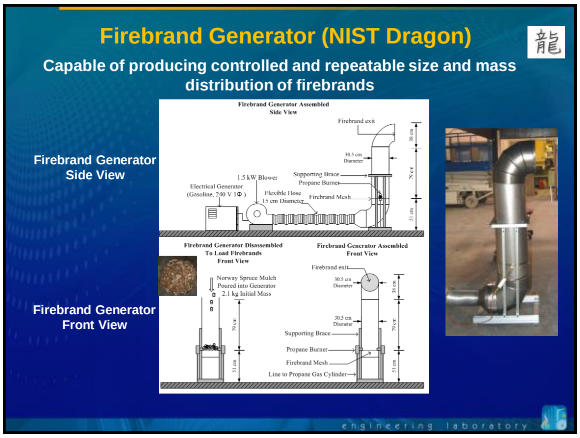
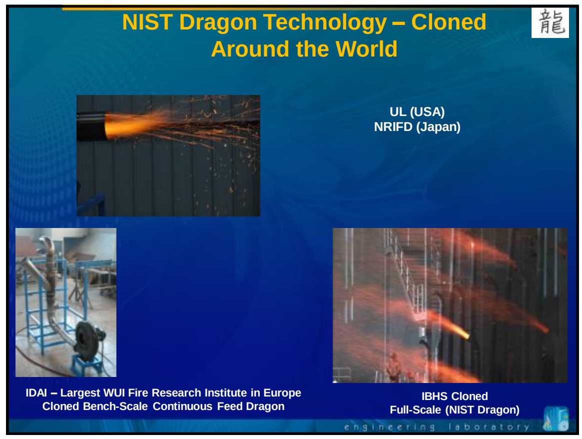
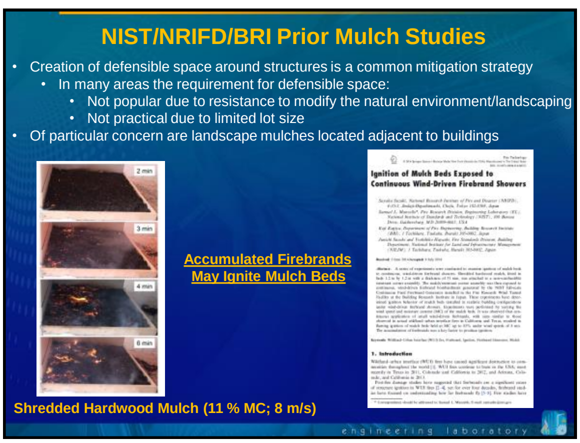
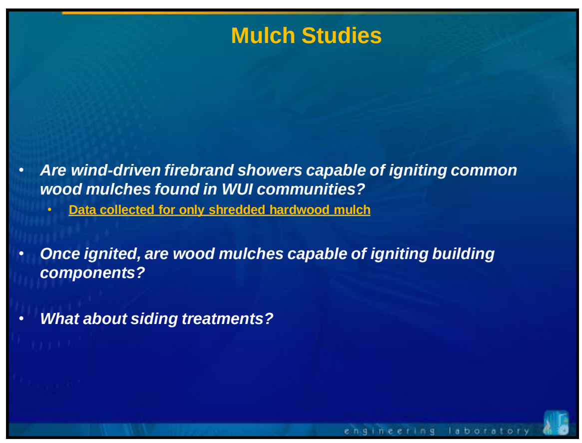

Firebrand Generator (NIST Dragon)
龍
Capable of producing controlled and repeatable size and mass distribution of firebrands
Firebrand Generator Side View
Firebrand Generator Front View
Firebrand Generator Assembled Side View
Firebrand exit
1.5 kW Blower
Electrical Generator (Gasoline, 240 V 1Φ)
Flexible Hose 15 cm Diameter
Supporting Brace
Propane Burner
Firebrand Mesh
Firebrand Generator Disassembled To Load Firebrands Front View
Norway Spruce Mulch Poured into Generator 2.1 kg Initial Mass
Firebrand Generator Assembled Front View
Line to Propane Gas Cylinder
engineering laboratory


Building Research Institute (BRI)
• Fire Research Wind Tunnel Facility (FRWTF)
• Unique facility – investigate influence of wind on fire
FRWTF
engineering laboratory

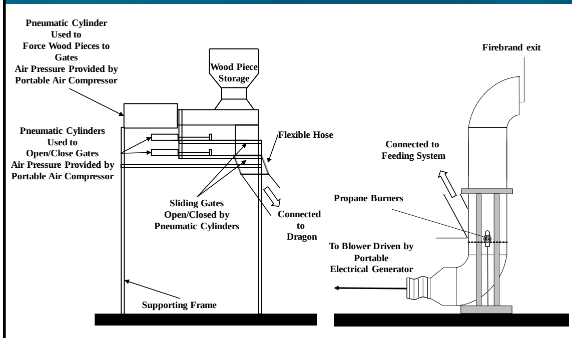

NIST Dragon 龍
Firebrand size/mass commensurate to full scale tree burns and actual WUI fire (2007 Angora Fire)
engineering laboratory


NIST Dragon Technology – Cloned Around the World
龍
UL (USA)
NRIFD (Japan)
IDAI – Largest WUI Fire Research Institute in Europe
Cloned Bench-Scale Continuous Feed Dragon
IBHS Cloned
Full-Scale (NIST Dragon)
engineering laboratory


NIST/NRIFD/BRI Prior Mulch Studies
• Creation of defensible space around structures is a common mitigation strategy
• In many areas the requirement for defensible space:
• Not popular due to resistance to modify the natural environment/landscaping
• Not practical due to limited lot size
• Of particular concern are landscape mulches located adjacent to buildings
2 min
3 min
4 min
6 min
Accumulated Firebrands
May Ignite Mulch Beds
Ignition of Mulch Beds Exposed to Continuous Wind-Driven Firebrand Showers
Shredded Hardwood Mulch (11 % MC; 8 m/s)
engineering laboratory


Mulch Studies
• Are wind-driven firebrand showers capable of igniting common wood mulches found in WUI communities?
• Data collected for only shredded hardwood mulch
• Once ignited, are wood mulches capable of igniting building components?
• What about siding treatments?
engineering laboratory

Continuous-Feed Full-Scale Firebrand Generator



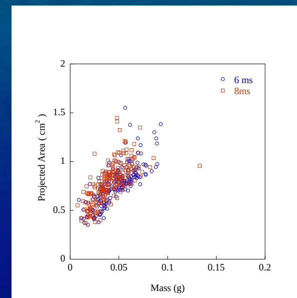
NIST Dragon 龍

Firebrand Size/Mass Distribution

Firebrand size/mass full scale tree burn; actual WUI fire (2007 Angora Fire)

200 g every 15 s used as feed rate (800 g/min)
Generates firebrand mass flux of 17 g/m²s at this feed rate

Douglas-fir wood pieces:
7.9 mm (H) by 7.9 mm (W) by 12.7 mm (L)



Mulch to Wall Ignition Studies

First-step – possible for mulch to ignite walls with no siding?

Re-entrant corner (wood studs with OSB)
1.2 m by 1.2 m by 2.44 m (H)

Shredded Hardwood Mulch
(51 mm depth)

Wood Chip Mulch
(51 mm depth)

Pine Bark Nugget Mulch
(51 mm depth)

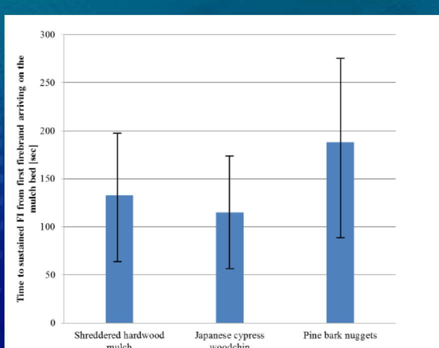
Mulch to Wall Ignition Studies

Shredded Hardwood Mulch
(oven dried)

Wall Ignition (WI)
Flame penetration to back-side

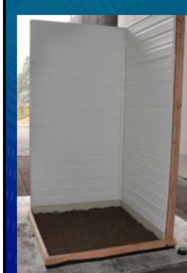
Wind Speed	Shredded Hardwood Mulch	Japanese Cypress Woodchip Mulch	Pine Bark Nugget Mulch
6 m/s	WI	WI	WI
8 m/s	WI	WI	WI

Time to Sustained Flaming Ignition



Mulch to Wall Ignition Studies

What about the addition of siding?

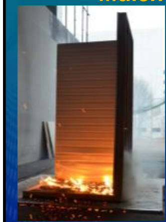


Re-entrant Corner
1.2 m by 1.2 m by 2.44 m high
Vinyl Siding (Tyvek over OSB over 2 x 4)

Shredded Hardwood Mulch Bed
(51 mm depth)
Oven Dried

Vertical Separation 102 mm Vertical Separation 203 mm

Mulch to Wall Ignition Studies (6 m/s)



Glowing firebrands produce smoldering ignition (SI) in mulch bed

SI transitions to flaming ignition of mulch bed

102 mm

203 mm

Mulch to Wall Ignition Studies (8 m/s)

<u>As wind speed increased from 6 m/s to 8 m/s, ignition for 203 mm separation!</u>

8 m/s
Wind Speed

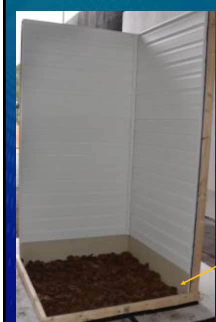
Glowing firebrands produce smoldering ignition (SI) in mulch bed

SI transitions to flaming ignition of mulch bed

<u>Sustained flaming ignition on backside of wall</u>

Mulch to Wall Ignition Studies

What about other mulch types?



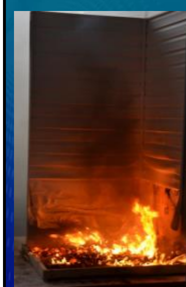
Re-entrant Corner
1.2 m by 1.2 m by 2.44 m high
Vinyl Siding (Tyvek over OSB over 2 x 4)

Pine Bark Nugget Mulch Bed
(51 mm depth)
Oven Dried

Separation Distance
<u>203 mm from mulch bed to siding</u>

Mulch to Wall Ignition Studies

What about other mulch types?



<u>Wall ignition observed at only 6 m/s</u>

<u>Even with 203 mm separation distance!</u>

Separation Distance (mm)	Shredded Hardwood Mulch	Japanese Cypress Woodchip Mulch	Pine Bark Nuggets Mulch
102	WI	NT	NT
203	NWI	WI	WI

Translating Full-Scale Experimental Results to Laboratory Test Standards

ASTM/NIST Vent Studies

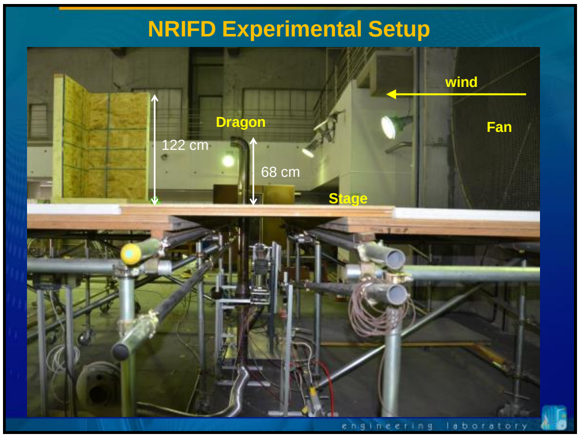
<u>Without standard laboratory test methods</u>:
- Impossible to evaluate/compare performance of building elements ability to resist ignition

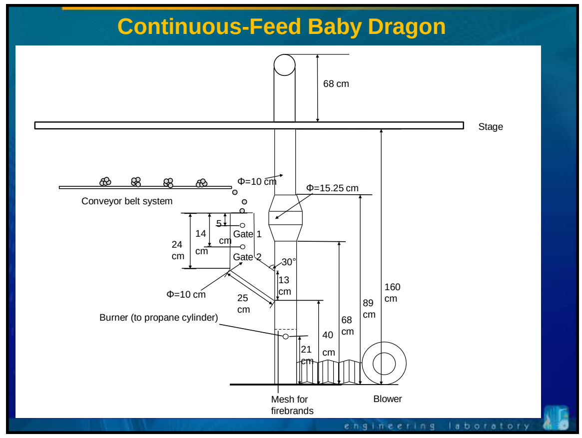
Before test standards are developed - detailed full-scale experiments required:
- Determine necessary size of building component sections for standard laboratory test methods

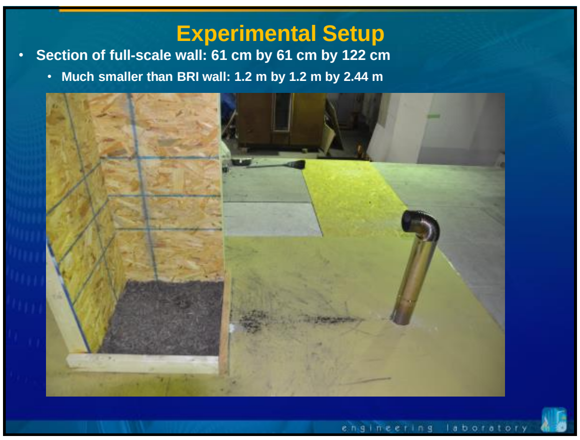
ASTM/NIST Building Vent Studies

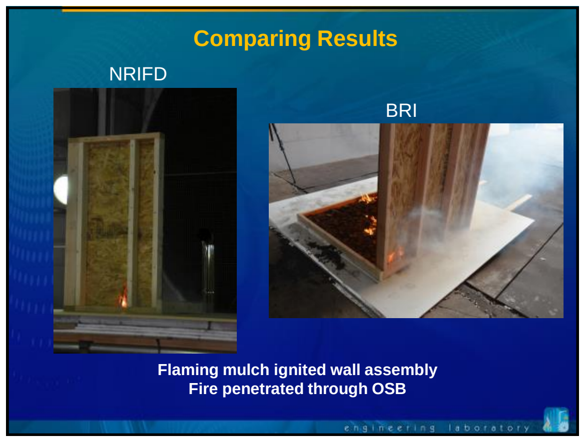

Standard Test Method for
Evaluating the Ability of Exterior Vents to Resist the Entry of Embers and Direct Flame Impingement

Full-scale experiments used to guide Standard laboratory test methods

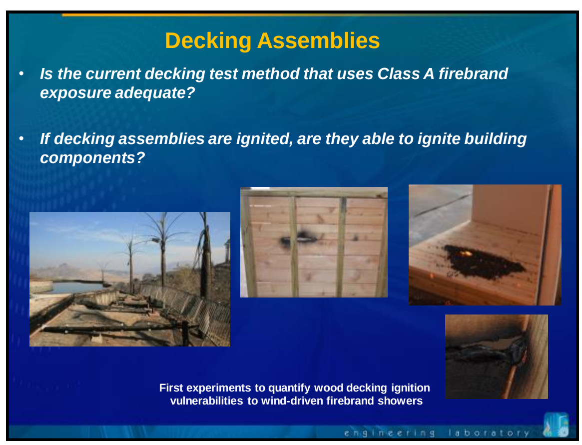

NRIFD Experimental Setup
wind
Dragon
Fan
122 cm
68 cm
Stage
engineering laboratory


Continuous-Feed Baby Dragon
68 cm
Stage
Φ=10 cm
Φ=15.25 cm
Conveyor belt system
5
14 cm
24 cm
Gate 1
Gate 2
30°
13 cm
Φ=10 cm
25 cm
Burner (to propane cylinder)
160 cm
89 cm
68 cm
40 cm
21 cm
Mesh for firebrands
Blower
engineering laboratory


Experimental Setup
Section of full-scale wall: 61 cm by 61 cm by 122 cm
Much smaller than BRI wall: 1.2 m by 1.2 m by 2.44 m
engineering laboratory

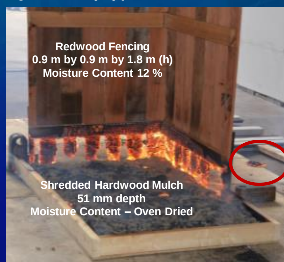

Comparing Results
NRIFD
BRI
Flaming mulch ignited wall assembly
Fire penetrated through OSB
engineering laboratory


Roofing Assemblies
Are Class 'A' roofing assemblies really ignition resistant?
May legacy ASTM E108; UL 790 roofing test be modified to consider wind-driven firebrand exposure to roofing assemblies?
Quantified Performance of Concrete and Terracotta Roofing Assemblies
Two types of Concrete/Two Types of Terracotta Tiles
Firebrands Penetrated Tile Gaps (3 mm) melted underlayment 3/4 tiles roofing assemblies tested
engineering laboratory


Decking Assemblies
Is the current decking test method that uses Class A firebrand exposure adequate?
If decking assemblies are ignited, are they able to ignite building components?
First experiments to quantify wood decking ignition vulnerabilities to wind-driven firebrand showers
engineering laboratory

Fencing Assemblies

- *Do fencing assemblies, ignited by firebrand showers, transfer or link the fire to the structure ?*
- *Are certain fencing assembly types more amenable to firebrand generation?*



Firebrands Generated From Ignited Fencing

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Summary

- Research into WUI fires, and how to potentially mitigate the loss of structures in such fires, is far behind other areas of fire safety science research
- Fire spread in the WUI is incredibly complex, involving the interaction of structures with topography, weather, and vegetation, and other structures
- Attempted to delineate a series of current research gaps in order to be able to begin to harden structures to firebrand showers, an important aspect of WUI fire exposures

Physical understanding collected from full-scale experiments will be used develop reduced-scale test methods that will be able to reproduce results of the full-scale experiments

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