WILDFIRE RESEARCH CENTER

UNDERSTANDING AND IMPROVING WILDLAND FIREFIGHTER HEALTH AND SAFETY: ENVIRONMENTAL STRESS AND EXPOSURE

2012 FEMA FP&S RESEARCH AND DEVELOPMENT PROPOSAL

SAN DIEGO STATE UNIVERSITY

IN PARTNERSHIP WITH

International Association of Firefighters, CAL FIRE, CDF Firefighters,

US Forest Service, and the National Institute of Standards and Technology

Prepared by Matt Rahn, PHD, MS, JD. mrahn@mail.sdsu.edu 619-846-1916

Summary

We are witnessing a dramatic shift in the frequency and intensity of wildfires due to a variety of factors, including increases in human caused fires, unnatural accumulation of hazardous fuels, inability to withstand insect and disease outbreaks, and climate change. These wildfires threaten natural resources, timber harvests, rangelands, homes, businesses and human lives, and can result in annual recovery costs in the billions of dollars. Although firefighting response and effectiveness has improved, many of the basic issues have not been researched and considerable uncertainty remains. Maintaining and improving wildland firefighter health and safety of foremost concern, especially as we struggle to deal with a national trend of increased fire frequency and intensity. We do not adequately understand the risks firefighters face, including exposure to hazardous air pollutants and carbon monoxide, and the concomitant stress of substantially increased heart rates, core body temperature, and respiration.

Recognizing the need for additional scholarship in the area of wildland and WUI fires, we created a research program in collaboration with academic researchers, firefighters, and regulatory/resource agencies. Since 2007, we have been working to identify ways to decrease the risk of injuries and fatalities to wildland firefighters, and improve firefighting effectiveness and response. This requires targeted research into the the traditional (e.g. heart-rate) and novel factors (e.g. carbon monoxide exposure) that may contribute to morbidity and mortality in wildland firefighters. By better understanding and improving firefighter health and safety, we can advance our national ability to respond to and combat wildland fires.

This project is designed to immediately and quantitatively evaluate attack effectiveness and firefighter health and safety by conducting assessments on controlled burns and actual wildland fire events. This includes an evaluation of certain risk factors that may influence firefighter morbidity and mortality, which ultimately impacts attack effectiveness and safety. This program has a specific emphasis on understanding heart rate, temperature, respiration, carbon monoxide, particulates, and hazardous air pollutants. The research will be conducted through a partnership between San Diego State University, the International Association of Firefighters, CAL FIRE, CDF Firefighters, the National Institute of Standards and Technology (NIST), the US Forest Service, and our local agencies, municipalities, and tribal governments.

We are requesting support from FEMA to conduct a comprehensive assessment of wildland firefighters. The purpose is to understand the relationship between diverse factors including carbon monoxide, carbon dioxide, hazardous air pollutants, particulates, core body temperature, heat exposure, heart rate, respiration rate, and dehydration. Our partners will work together to disseminate the results of this research and support the development and testing of enhanced fire ground protocols and rehabilitation procedures.

Our primary goal is to understand and improve wildland firefighter health and safety. Our objectives are:

- *Develop field-based protocols that accurately measure ambient environmental conditions on wildland fires*
- *Develop protocols for measuring and monitoring wildland firefighters while they are actively engaged in their duties*
- *Understand the relationship between the diverse factors that may be contribute to firefighter morbidity and mortality*
- *Identify which factors can serve as overall indicators for firefighter health and safety*
- *Provide workshops for stakeholders to foster discussion on the results of the study*
- *Assist in identifying strategies, protocols, and/or rehabilitation procedures to improve wildland firefighter health and safety*

1.0 Project Purpose

1.1 Wildfire History

A new wildfire paradigm is emerging. For thousands of years, the frequency and intensity of natural wildfires shaped the distribution and configuration of the forests and grasslands in the United States.[1] Over time, ecosystems became adapted to wildfires; many plant and animal species are now dependent on fire as part of their natural history.[2] Today we are experiencing a shift in our natural fire regimes due to a multitude of anthropogenic factors, including man-made fires, increases in the wildland-urban interface (WUI), invasive species, and climate change. Since the 1970's the frequency and intensity of wildfires has increased across the United States, expanding from three million to an overwhelming seven million acres burned each year, with further increases projected.[3]

There are 46 million homes in 70,000 communities at risk within the WUI in the US[4], and the annual cost of WUI fires nationwide exceeds $14 billion.[5] WUI fires destroy an average of 3,000 homes a year. One of the most alarming trends is in California where half of the twenty largest wildfires in California's recorded history have occurred in only the past decade. Many of these events have had an unprecedented physical and financial impact to the state.[6] For example, the 2003 wildfire event that consumed much of San Diego County cost the region nearly $2.5 billion. More recently, the 2008 lightning-caused wildfires in northern California burned over 1.2 million acres, destroyed over 500 structures, and killed 15 people.[7] The 2011 Texas WUI fires burned over 1,600 homes with an estimated cost of $2 billion.

Modern catastrophic wildfires are significantly different from the historic fire regime. Fires once started by lightening strikes or Native Americans would ignite smaller burn areas that created a heterogeneous vegetated landscape[8] whose patchiness created "natural fuel breaks" that prevented larger fire events.[9] Today, only a fraction of the wildfires we experience in California are caused by natural events, with nearly ninety-five percent started by human activities.[10]

We do not suggest that future wildfire risk is the exclusive result of human negligence or accidents. Rather, it highlights the concerns of firefighting agencies throughout the country; wildfire response must anticipate and adapt its practices and policies to deal with changing circumstances. Failures in fire suppression occur when wildfires exceed the suppression goals established by the firefighting community, such as the CAL FIRE policy of keeping 95% of all wildfires below ten acres. This is not simply an arbitrary size, but rather represents the size of a wildfire that is logistically manageable and typically has minor economic and physical impacts. We have witnessed a dramatic increase in the size and intensity of wildfires in recent years; the goals of our emergency services agencies and the health and safety of our firefighters are at risk.

---

[1] Kaufmann, et al. . 2005. Good fire, bad fire: how to think about forest land management and ecological processes. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

[2] Bond, W. J., and J. E. Keeley. 2005. Fire as a global 'herbivore': the ecology and evolution of flammable ecosystems. Trends in Ecology & Evolution 20: 387-394.

[3] National Interagency Fire Center. 2007. Fire information: Wildland fire statistics, 1960-2006). Boise, ID.

[4] U.S. Communities Dealing with WUI Fire Fact Sheet (ICC); Headwater Economics, www.headwaterseconomics.org

[5] Hamins, A., Averill, J., Bryner, N., Gann, R., Butry, D., Amon, F., Gilman, J., Maranghides, A., Madrzykowski, D., Manzello, S. and Mell, W. 2012. Reducing the Risk of Fire in Buildings and Communities: A Strategic Roadmap to Guide and Prioritize Research. NIST Special Publication 1130. National Institute of Standards and Technology. Gaithersburg, MD .

[6] Rahn , M.E. 2009. Wildfire Impact Analysis: 2003 Wildfires in Retrospect. http://fire.sdsu.edu. San Diego State University. Wildfire Research Report No. 1. Montezuma Press. San Diego, CA.

[7] Cal Fire Incident Report. http://www.fire.ca.gov/index_incidents_overview.php. August 11, 2008.

[8] Bonnicksen, T. M. 2000. America's Ancient Forests: from the Ice Age to the Age of Discovery. John Wiley & Sons, Inc., New York. 594 p.

[9] Bonnicksen, T. M. and E. C. Stone. 1981. The giant sequoia-mixed conifer forest community characterized through pattern analysis as a mosaic of aggregations. Forest Ecology and Management 3(4): 307-328.

[10] See generally, http://cdfdata.fire.ca.gov/pub/cdf/images/incidentstatsevents_106.pdf

A critical factor associated with wildfires is urbanization and the expansion of the WUI. Across the United States, approximately 40% of housing units are located within this wildland-urban interface.[11] As our national population grows in the coming decades, decisions on where to locate future development and how to manage the WUI will determine our vulnerability and potential increases in wildfire risk. Compounding this risk is the prediction that large fires (defined as 500 acres or more) would increase by nearly 35% by 2050, and an alarming 55% by the end of the century.[12] If our population expands into and increases the WUI, there is a concomitant increase in the probability of life and property losses due to wildfires requiring a thoughtful and aggressive strategy for dealing with emergency response and initial attack effectiveness. Given the hazardous conditions and environmental contaminants associated with these types of incidents, there will likely be a direct impact on our firefighters.

1.2 Firefighter Health and Safety

The leading causes of firefighter morbidity and mortality include overexertion, cardiac issues, and exposure to smoke and air contaminants.[13, 14, 15]. A total of 338 firefighters were killed on wildland fires over a 30-year period (1977-2006). Although the total number of on-duty deaths has dropped significantly in recent years, the number of cardiac-related deaths has not decreased as dramatically. The number of such cardiac events has been relatively stable since 2005.[16] Many of these fatalities are related to sudden cardiac death during fire ground activities and when responding to, or returning from fires.[17,18] In its investigations of on-duty cardiac-related fatalities, NIOSH reports "*Firefighting activities are strenuous and often require firefighters to work at near maximal heart rates for long periods. The increase in heart rate has been shown to begin with responding to the initial alarm and to persist through the course of fire suppression activities.*"[19] Additional studies have suggested that the risk of dying from coronary heart disease (and related factors) was 10 to 100 times higher during firefighting activities than during non-emergency fire department duties.[20]

This should not be surprising. The typical responsibilities of a firefighter are a leading contributor to the health risk they face. Firefighters often go from a state of sleep to near 100 percent alertness and extreme physical exertion in a matter of minutes. When combined with the heavy equipment and gear they carry through extended periods of intense heat and brutal environmental conditions, wildland firefighters experience the limits of what the human body was meant to withstand. Wildland and WUI firefighters are also exposed to other harsh environmental conditions including toxic and hazardous substances, particulates, and carbon monoxide (CO). While the direct and indirect causes of firefighter morbidity and mortality are difficult to determine, it is undeniable that the physical exertion and atmospheric exposures that firefighters experience have a significant impact. This is an important component of this research

---

[11] Areas must contain at least 1 housing unit per 40 acres (16 units/mi^2 or 6.17 units/km^2) Intermix in which 50% of area is vegetated and interface in which less than 50% is vegetated but is within 1.5 miles (2.4 km) of a large area >5 km^2) that is 75% vegetated. Radeloff, et al., "The wildland-urban interface in the US" 2005.

[12] A.L. Westerling, H.G. Hidalgo, D.R. Cayan, and T.W. Swetnam, Warming and Earlier Spring Increase Western U.S. Forest Wildfire Activity, 313 Science 940 (2006).

[13] Fahy, R.F., P.R. LeBlanc, and J.D. Molis. 2011. Firefighter fatalities in the United States. National Fire Protection Assn, Fire Analysis and Research Division.

[14] Karter, M.J., and J.L. Molis. 2010. US Firefighter Injuries, 2009. National Fire Protection Assn, Fire Analysis and Research Division.

[15] Federal Emergency Management Agency, United States Fire Administration, and National Fire Data Center. 2002. Firefighter Fatality Retrospective Study. April 2002/FA–220, Prepared by TriData Corporation.

[16] Fahy, R.. 2010. U.S. Fire Service Fatalities in Structure Fires, 1977-2009. NFPA.

[17] Fahy, R. P. LeBlanc, and J. Molis. 2007. What"s Changed Over the Past 30 Years? NFPA.

[18] Fahy, R. 2005. U.S. Firefighter Fatalities Due to Sudden Cardiac Death. NFPA.

[19] Report Number FACE-F2004-46. http://www.cdc.gov/niosh/face200446.html.

[20] Kales, S. E. Soteriades, C. Christophi, and D. Christiani. 2007. Emergency Duties and Deaths from Heart Disease among Firefighters in the United States. New England Journal of Medicine 356(12): 1207-1215.

program because increases in physical stress or heart rate (and respiration) may have a significant impact on the overall exposure and risk to wildland firefighters, and can in turn have a significant effect on attack effectiveness and response.

1.3 Project Need

The proposed research addresses several of the top priorities of the National Fire Service Research Agenda.[21] In the most recent report, the National Fire Service Research Agenda identified several priorities for wildland firefighting, which included improved understanding of the chemical and thermal environment that firefighters are typically exposed to during operations. They further recommended that it is important to understand the acute and chronic exposures experienced by firefighters. Finally, the group prioritized the collection of data in a standardized format and incorporating those data into a central database, which would be accessible to firefighters, local, state, and Federal agencies. The study proposed herein is focused on responding to these needs.

This research effort building on prior health and safety studies carried on by San Diego State University (SDSU), CAL FIRE, the International Association of Fire Fighters (IAFF), CDF Firefighters, the US Forest Service (USFS) and National Institute of Standards and Technologies (NIST). In addition, this research builds on a recent project that the USFS has completed which measuring the levels of CO, particulates (PM), and crystalline silica in ambient wildfire conditions. However, the current project expands this effort to measure not just ambient conditions and exposure levels, but to provide (for the first time) a comprehensive assessment of wildland firefighters' physiological responses as they are exposed to these (and additional) factors. This initiative also has a future goal of developing tools for real-time monitoring of firefighters in the field through biometric sensors that are compatible with personal protective equipment (PPE) and do not interfere with the firefighter's safety, duties, or mobility. However, before this can be produced, we must first understand which factors are most important to monitor with regard to exposure, stress, and firefighter health and safety.

This study addresses both traditional (e.g. heart-rate and stress) and novel factors (e.g. CO exposure) that pose a health risk for firefighters. This study will also help identify fire-ground strategies and protocols that may help decrease the risk of injuries and fatalities on the fire-ground. Third, this study helps identify how certain fire-ground factors (e.g. CO exposure) may contribute to morbidity and mortality in wildland firefighters. Ultimately, this study will improve our understanding of the complex interrelationship of these factors, and may inform suitable options for mitigating or minimizing exposure and risk for the wildland firefighter.

The importance of this research cannot be overstated. There is a serious deficiency in the current understanding of wildfire practices and firefighter health and safety. Advancements in wildland firefighter health and safety lag significantly behind those of structural firefighter programs. Throughout the United States, there is an ongoing debate that questions the adequacy of modern land management, staffing, resources, and wildfire response protocols. A lack of thorough and collaborative research in this area creates a situation in which pivotal decisions regarding firefighting practices and the health and safety of firefighting personnel are being made based on such malleable factors as public perception, environmental concerns, or budgetary constraints. These fundamental uncertainties create a situation in which sound and well-informed decisions are extremely challenging, if not impossible to make, paralyzing leadership and jeopardizing the welfare of those who risk their lives in defense of our

[21] National Fallen Firefighters Foundation, National Fire Service Research Agenda Symposium. Report of the National Fire Service Research Agenda Symposium, 2005 and 2011.

communities. This project is intended to support the national research priorities, provide a solid foundation for clear and reasoned decision-making, and improve wildland firefighter health and safety.

Our primary goal is to understand and improve wildland firefighter health and safety. We are requesting support from FEMA for this research initiative, to provide a comprehensive assessment of wildland firefighters under both controlled and actual wildland/WUI fire incidents. The purpose of this study is to understand the relationship between diverse factors including carbon monoxide, carbon dioxide, hazardous air pollutants, particulates, core body temperature, heat exposure, heart rate, respiration rate, and dehydration. Our partners will work together to disseminate the results of this research and support the development and testing of enhanced fire ground protocols and rehabilitation procedures.

1.4 Prior Research Succes

In 2009-2010, a SDSU/CAL FIRE research team developed a study that established a baseline assessment of how different staffing levels may influence initial attack effectiveness.[22] In summary, the results suggested that by increasing the number of firefighters on an individual hose lay, the efficiency, effectiveness and the overall ability to potentially control a wildland fire significantly increased, thus enhancing emergency response and the ability to protect California from modern wildfires. This study also had serious implications for firefighter health and safety. To estimate firefighter exertion during differing staffing levels, heart rate was monitored for all individuals participating in a hose lay. The most startling differences were the peak heart rates recorded by a 3-0 engine. During these trials, these firefighters traveled nearly ½ a mile longer than a 4-0 engine on the same 2,000-foot hoselay.[23] Furthermore, adding a single firefighter to a 3-0 engine resulted in completion times that were up to 50 percent faster. Firefighters on a 3-0 engine sustained peak heart rates of over 220 beats per minute, well beyond safe and acceptable limits, increasing the risks of complications and tachycardia.[24] It should be noted that this initial study was conducted under "ideal" conditions in southern California, lacking the intensity, heat, and stress that a true wildfire creates. It is likely that both heart rate and physical stress is greater under the duress of real wildfire situations.

Therefore, from 2011-2012, our research team has been conducting a preliminary investigation into the effects that these ambient wildfire conditions have on firefighters during controlled burns. While the results are preliminary and collected at only a handful of controlled burns, we recorded ambient CO levels of nearly 500 ppm, and detected SpCO (carboxyhemoglobin) of over 20%. It should be noted that these results were observed during smaller controlled burns that included both shrub and grassland, with exposure times of only a few hours. It has become apparent that we must develop assessment protocols that allow us to monitor a variety of factors, and be able to relate these ambient conditions to the actual physical condition of the wildland firefighter. This will provide a better understanding of what threshold or combination of environmental conditions pose a significant health/safety risk to wildland firefighters. Funding for this research program will develop a large-scale study that employs controlled burns and actual wildfire events. The proposed study also integrates several additional factors that wildland firefighters are exposed to on the fire ground (that were not examined in the

[22] Rahn, M. 2010. Initial Attack Effectiveness: Wildfire Staffing Study. 2010 California Wildfire Staffing Study, Wildfire Research Report No. 2. Summer 2010. Montezuma Publishers.
[23] This included the distance travelled by a firefighter to extend a 2,000-foot hose line, and the distance required to retrieve additional hose to advance the line.
[24] The American Heart Association advises that peak heart rates should be roughly 220 bpm minus your age.

initial study). Funding for this research program is intended to provide a follow-up to our preliminary study and will include an assessment of controlled burns and actual wildfire events. The proposed study also integrates several of the health and safety risks that firefighters are exposed to on the fire ground that were not examined in the initial study.

2.0 METHODS

The effects of smoke exposure on the body are diverse and cover a range of conditions including eye and respiratory tract irritation to more serious disorders, including reduced lung function, bronchitis, exacerbation of asthma, and premature death. Concrete data are not available for calculating total health impacts from wildfires, but it has been estimated at over $10 million in health care costs for a single large (500+ acres) incident.[25] During the Cedar Fire in 2003 (California's largest wildfire on record), hospitals experienced significantly higher than average numbers of complaints from local residents for illnesses plausibly associated with exposure to fire or smoke such as asthma, burns, and respiratory distress. There was also an increase in potentially related complaints such as altered neurological function, cardiac-related chest pain, and palpitations.[26]

The physical effects associated with a fire are a result of the types of pollutants found in the smoke, which can be unpredictable and chaotic. The smoke from wildfires is a highly variable and complex mixture of CO_2, water vapor, CO, particulates, unburned fuel, polycyclic aromatic hydrocarbons (PAH),, nitrogen oxides, trace minerals and diverse toxic constituents. Composition depends on variables such as fuel type, moisture content, temperature, and wind. Different types of wood and vegetation contain cellulose, lignin, tannins and other polyphenols, oils, fats, resins, waxes, and starches, which produce different compounds when burned, some of which are hazardous. When wildland fires become WUI fires, man-made materials release a chemicals, many of which are considered carcinogenic and highly toxic. The composition of this chemical mixture is largely unknown during various stages of a wildfire, and hazard assessments and decision-making cannot adequately account for firefighter and community risk.

While smoke exposure at wildfires and prescribed burns is usually no more than an inconvenience, on occasion it is known to approach or exceed legal and recommended occupational exposure limits.[27] This study will evaluate how to develop a system that integrates enhanced ambient air monitoring with firefighter monitoring, creating a tool for improving our understanding of air pollution risk associated with WUI and wildland fires while also creating predictive capabilities of hazards as a wildfire progresses. This can provide, for the first time, the ability to understand how these diverse factors are related to firefighter health/safety, and a future mechanism for detecting and responding high risk situations for wildland firefighters.

2.1 Air Pollutant Monitoring and Firefighters

We will focus on assessing ambient levels of CO, CO2, PM, and Hazardous Air Pollutants and PAHs, along with other stochastic environmental conditions (e.g. wind speed, direction, elevation, temperature, relative humidity, barometric pressure, slope, etc.). Equipment used during this study has been evaluated during preliminary tests and initial studies from 2010-2012. The equipment proposed for this experiment is considered to be the most accurate, robust, and appropriate for this research. However, this research program will provide a continued

[25] Rahn 2009 (cited above).
[26] County of San Diego HHSA, EMS QA Net MICN records, 2003
[27] Reinhardt, T. and R. Ottmar. 1997. Smoke exposure among wildland firefighters: a review and discussion of current literature. Gen. Tech. Rep. PNW-GTR-373. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station.

assessment of the rigor and accuracy of the equipment, and we will make recommendations regarding the broader applicability to training and protocols for wildland firefighting.

Ambient air monitoring will be achieved by either placing sensors (when available) within the breathing area of firefighters while they are on duty, or having research staff adjacent to firefighters and using environmental monitoring devices. Ideally, the data will be collected in 1-minute intervals and all devices used in the study will be synched to the same clock (for subsequent bivariate and multivariate analyses). Proven methods from protocols used in environmental assessments, research, and industrial hygiene applications will be used where applicable. Occupational Safety and Health Administration (OSHA) and National Institute for Occupational Safety and Health (NIOSH) methods will be used when assessing exposures. A complete description of the methods is provided below.

2.2 Carbon Monoxide

Carbon monoxide (CO), termed the "silent killer" is a significant air pollutant associated with fires, entering the bloodstream and reducing oxygen delivery to the body. This is particularly problematic for at risk individuals with existing respiratory or cardiovascular disease. Closer to the source, higher levels of CO can cause headache, weakness, dizziness, confusion, nausea, disorientation, visual impairment, coma, and death even in otherwise healthy individuals. Unfortunately, the exposure and effects of CO may be largely overlooked, since the symptoms are similar to dehydration, exhaustion, and heat stroke. It is therefore imperative to understand the relationship between wildland/WUI fires and first responders.

In a series of comprehensive literature reviews on atmospheric exposures, a recent study found that both structure and wildland firefighters are exposed to hazardous pollutants, though the types of pollutants are different.[28] This review paper also suggested that fire fighters have a higher rate of long-term adverse health effects (e.g. cancer), than the rest of the general population. This prompted the recommendation of additional protective measures to help combat these respiratory hazards. However, one of the most important conclusions of this study was that there appears to be no clear indication of what fire departments should be measuring in the field, suggesting that additional guidance is needed for the "measurement of multiple components of the hazardous environment for fire departments that are focusing only on individual airborne contaminants." Shortly after this study was published, a groundbreaking collaborative research program led by International Association of Fire Fighters (IAFF) investigated the impacts of carbon monoxide related to structure fires was completed. This study conducted a comprehensive assessment of CO exposure in structure fire incidents, which included an aggressive outreach and education campaign, designating CO the "silent killer."

Today, our current understanding of CO has been vastly expanded. CO poisoning may result in long-term heart and brain damage, and is known to cause short-term mental confusion, which can lead to poor decision-making.[29] This can place both the exposed firefighter and others on the fire scene at risk.[30] Even mild CO exposure can limit oxygen to the heart and brain, and also significantly increases long-term health risks. A single severe CO poisoning incident can nearly double the risk of premature death.[31] As a result of these studies, National Fire Protection Association (NFPA) 1584 rehab standards support the use of on-scene CO testing.[32] However,

[28] Grant. C. 2007. Respiratory exposure study for fire fighters and other emergency responders. NFPA, Fire Protection Research Foundation, Quincy, MA.
[29] Bledsoe BE. 2007. Journal of Emergency Medical Services.
[30] 2 Jakubowski G. 2004. FireRescue Magazine. 22(11): 52-55.
[31] Hampson NB et al. 2009. Critical Care Medicine. 37(6): 1941-47.
[32] NFPA 1584: Standards on the Rehabilitation Process for Members During Emergency Operations and Training Exercises. Annex A section A.6.2.6.4(1)

integration of these protocols into WUI and wildland firefighting is not a common practice.

Firefighters that respond to wildland and WUI fires are exposed to a significantly different environment than those that respond to structure incidents. Unfortunately, analogous research programs on WUI and wildland fire incidents are more limited, however this prior research provides an exceptional foundation on which to conduct these studies. Previous research suggested that wildland firefighters may be exposed to CO concentrations in excess of recommended ceiling/excursion limits during as much as 25% of their firefighting efforts.[33] And in California, a study in the late 1980's suggested that wildland firefighters might be exposed to concentrations of CO at levels higher than recommended occupational exposure limits.[34] Other studies have tried to link ambient air CO measurements to firefighter risk, but lack sufficient data on long-term and intense exposure events.[35]

2.2.1 Carbon Monoxide Monitoring

Exposure to CO is measured with electronic datalogging dosimeters according to OSHA Method ID-209. Carbon monoxide will be measured using MSA Company Altair Pro dosimeters, placed in the breathing zone of the firefighter, and will record 1-minute average CO levels throughout the study. The MSA sensor has a range of 0-500 ppm. Therefore, field researchers adjacent to the firefighters will also be using the Extech® Carbon Monoxide (CO) Meter which has a range up to 1,000 ppm. Unlike other factors (discussed below), CO levels of the firefighter themselves can be directly measured. To assess CO exposure in firefighters, we will be using two types of sensors, the BreathCO Carbon Monoxide Monitor (2970) and the Masimo Rad-57 Rainbow Pulse CO-Oximeter.[36] The Masimo Rad-57 Rainbow Pulse CO-Oximeter can provide single sample and continuous monitoring of a subject. Through periodic and frequent sampling of the firefighters, we will measure Carboxyhemoglobin (SpCO), oxygen saturation (SpO_2), pulse rate, and perfusion index. Samples will be collected as frequently as possible, without interfering with firefighter duties (with a target of assessing firefighters every 5-10 minutes). In independent clinical trials, the Rad-57 accurately measured SpCO when compared to arterial blood gas analysis.[37] This method provides a significant advantage in non-invasive data collection, particularly since the dangers of arterial blood draws (in the field) pose a significant risk to firefighters, and the transportation of samples from the fire ground to the laboratory poses logistical constraints.

While there is still some debate over the accuracy of this method, there are limited options for non-invasive field methods. Those studies that have questioned the accuracy of this method also admit that the results may not be applicable in an out-of-hospital setting.[38] Furthermore, recent assessments have revealed that clinical tests using the Rad-57 show that in 6 of the 7 recent assessments of the device, SpCO accuracy is within or above the conservative accuracy parameters presented by Masimo.[39] This means the majority of the time, the device is expected to provide an accurate measurement of SpCO in test subjects.

---

[33] McCammon, J. and L. McKenzie. 2000. Health Hazard Evaluation Report 98-0173-2782 Colorado Dept. of Public Health and Environment.
[34] Materna et al. 1992. Occupational exposures in California wildland fire fighting. J. of the Am. Indus. Hygiene Assoc. 53(1):69-76.
[35] Brotherhood, et al. 1990. Fire fighters' exposure to carbon monoxide during Australian bushfires. J. of the Am. Indus. Hygiene Assoc. 51(4):234-40.
[36] These devices are commonly used among fire agencies, and is considered by medical professionals to provide an accurate measurement of CO exposure. See generally http://www.fireengineering.com/index/articles/display/258056/articles/fire-engineering/volume-159/issue-6/departments/technology-today/chronic-co-poisoning-in-firefighters.html for more information.
[37] Mottram et al. 2005. Comparison of the Masimo Rad-57 Pulse Oximeter with SpCO technology against a Laboratory CO-oximeter Using Arterial Blood. Respiratory Care. 50(11): 1471.
[38] Touger et al. 2010. Performance of the RAD-57 Pulse Co-Oximeter Compared With Standard Laboratory Carboxyhemoglobin Measurement. Annals of Emergency Medicine. 56(4): 382-388.
[39] O'Reilly, M. 2010. Performance of the Rad-57 Pulse Co-Oximeter Compared With Standard Laboratory Carboxyhemoglobin Measurement. Anals of Emergency Medicine. 56(4): 442-444.

We have conducted preliminary tests with the Rad-57 under various conditions, and our results have shown that it is compatible with the research we are proposing, particularly under the demanding conditions that firefighters will experience during the experiments. To ensure that the research conducted, and data collected are accurate and reliable, we will be working directly with a Masimo technician in the field during the controlled burns and preliminary assessments to ensure that the device is being used within expected specifications and limits.

To provide additional data, and a comparison to the Rad-57 protocols, we will also collect CO exposure data using a breath analyzer. The BreathCO unit measures expired CO in ppm with an accuracy of ±3 ppm. Control valves and individual mouthpieces eliminate possible contamination. At the start and end of the controlled burn, firefighters will be asked to take a deep breath in, hold for as long as possible and then breathe out slowly and steadily through the mouthpiece over a period of approximately 20 seconds. To ensure accuracy, calibration of the sensors will be done prior to each experiment. If CO readings are outside the safe exposure range for firefighters during the study, medical attention will be provided, along with appropriate remediation measures (monitored and administered by on-site emergency medical technicians (EMTs) following standard protocols for CO exposure). Where acute levels are detected, appropriate rehabilitation will be immediately provided based on existing medical protocols.

2.3 Particulate Matter

Exposure to particulates can result in increased mortality and complication of pre-existing respiratory and cardiovascular diseases. According to the California Air Resources Board, particulate matter (PM) is the principal public health threat from short-term exposures to wildfire smoke. For PM studies, we will be using protocols similar to the US Forest Service (USFS) study (2010-2012). Exposure to PM is measured using modified NIOSH Method 0600. According to the USFS, and given their preliminary results, we will be monitoring particles approximatley 4 micrometers (μm) in size. Respirable particulate is comprised of small particles of ash and nonvolatile organic and inorganic matter that are mainly less than 4 μm in diameter—specifically, it is sampled with size-selective inlets that exclude large particles and selectively capture particles by their size. This method allows fewer large airborne particles to be collected, and more small particles to be sampled. These samplers have a 50% sampling efficiency at a mass median aerodynamic diameter (MMAD) of 4 μm. Older, OSHA samplers use an MMAD of 3.5 μm, but the modern international convention is an MMAD of 4.

Respirable and fine particulates will be measured using pre-weighed 37-mm diameter 5 μm pore size polyvinyl chloride filters in clear 3-piece polystyrene cassettes. The top to the filter assembly is removed in the field and the main portion housing the filter is fitted on a precleaned BGI Triplex SCC 1.062 aluminum cyclone. The assembly is kept in the firefighter's breathing zone hanging vertically to keep large particles from depositing on the filter. Air is drawn through the filter at a flow rate of 1.05 liters per minute for 4 μm sampling.

2.4 Carbon Dioxide

Carbon dioxide (CO_2) is a colorless, odorless, non-flammable gas that is a product of cellular respiration and combustion of fuels. In terms of safety, OSHA has set a permissible exposure limit (PEL) for CO_2 of 5,000 ppm over an 8-hour work day, which is equivalent to 0.5% by volume of air. OSHA and the American Conference of Governmental Industrial Hygienists (ACGIH) has set a permissible exposure limit (PEL) for CO_2 of 5,000 ppm over an 8-hour work day, with a ceiling exposure limit of 30,000 ppm for a 10-minute period based on acute inhalation data.[40,41] A value of 40,000 ppm is considered extremely dangerous to life and health because a 30-minute exposure to 50,000 ppm produces intoxication, and concentrations greater than that (7-10%) produce unconsciousness. Additionally, acute toxicity data show the lethal concentration (LCLo) for CO_2 is 90,000 ppm (9%) over 5 minutes.[42,43] Measuring ambient CO_2 levels is relatively simple, with a wide variety of options available (although they are generally larger, hand-held devices that will likely be operated by field researchers rather than attached to firefighters).

Carbon dioxide is a significant part of smoke from wildland fires, however ambient CO_2 conditions on the fire ground are not well understood. Furthermore, the interrelationship between elevated CO_2 levels and carbon monoxide exposure are not well understood. However, CO_2 is known to increase cardiac output, which leads to increased heart rate, blood pressure, and a dilation of the cerebral blood vessels. This can significantly diminish performance on tasks requiring psychomotor coordination, visual perception, attention, and rapid response. The interaction between these effects and those of CO exposure are cause for concern, particularly where levels of oxygen in the blood are significantly altered.[44] While not readily measured in the field, the Rad-57 provides additional useful information on the oxygen content in the firefighter's blood (SpOC); by calculating hemoglobin and oxygen saturation, this provides a more complete assessment of the firefighter in the field. Additional studies also suggest that helmet-based monitoring is a feasible safety protocol worthy of future study (although the impact of motion continues to pose a potential problem in data collection).[45] Since the 2010 study (above) was completed, Masimo may have developed an adequate solution; the E-1 Ear sensor may provide a more robust way of monitoring firefighters in the field with near-real-time capabilities.[46] Further options are emerging from research funded by the US Army (Telemedicine and Advanced Technology Research Center), which have similar promise. During this study, we will evaluate the potential of this type of technology as a surrogate measure of CO, CO_2, and O_2.

2.5 Hazardous Air Pollutants

Wildfire smoke contains toxic chemicals that are linked to cancer and other ailments. It is not clear how repeated short-term elevated exposures to wildfire carcinogens relate to lifetime exposures and risk, however, epidemiological studies have shown that urban firefighters exposed to smoke have a three- fold increased risk of developing lung cancer.[47] Fortunately, not everyone who is exposed to smoke will have health problems. Factors such as the level and duration of exposure, age, susceptibility, and pre-existing conditions help determine whether someone will experience short or long-term complications. A variety of methods are available for monitoring toxic air pollutants. We will focus primarily on volatile organic compounds, benzene, formaldehyde, and species of sulfur and nitrogen oxides (SOx and NOx). Unfortunately, no single device has emerged that can measure all of these diverse factors. There are several sensors that measure the main constituents of concern separately. We will evaluate these tools

[40] Massachusetts Department of Public Health (MDPH). 2005. Appendix 1 – Carbon Dioxide and its Use in Evaluating Adequacy of Ventilation in Buildings. Massachusetts Bureau of Environmental Health Assessment, Department of Public Health. www.mass.gov/dph/beha/iaq/appendices/co2app.htm

[41] National Institute for Occupational Safety and Health (NIOSH). 1976. Criteria for a Recommended Standard, Occupational Exposure to Carbon Dioxide. August 1976.

[42] NIOSH. 1996. Documentation for Immediately Dangerous to Life or Health Concentrations (IDLHs) for carbon dioxide. www.cdc.gov.

[43] Toxicological Review of Selected Chemicals. 2005. Carbon Dioxide. OSHA's comments from the January 19, 1989 Final Rule on Air Contaminants Project. www.cdc.gov.

[44] See generally: http://www.netl.doe.gov/publications/proceedings/03/carbon-seq/PDFs/173.pdf for summary of current understanding and literature review.

[45] Forsyth, J.B. 2010. Wearable pulse oximetry in construction environments. MS Thesis. Virginia Polytechnic Institute and State University

[46] http://www.masimo.com/E1-ear-sensor/

[47] Hansen, ES. A cohort study on the mortality of firefighters. Br J Ind Med 47: 805-809, 1990.

and determine the most reliable and robust techniques. However, other opportunities exist to use multi-constituent, compact units. Some of the more promising technology comes from two main sources at UC San Diego[48] and the Research Triangle Institute.[49] We will evaluate the adequacy of these sensors during this project.

2.6 Firefighter Monitoring and Assessment

In addition to the exposure data described above, each firefighter will also be assessed and monitored for additional factors. During all phases of the research involving firefighters, the highest level of care and concern will be given to the safety and health of the participants. If at any time the health or safety of a firefighter is in question, they will be immediately removed from the study and given proper medical care. Firefighter safety is also a top priority. We will prepare an incident action plan (IAP) for each controlled burn. The approval for studies involving human test subjects is also strictly supervised. All information collected will be carefully protected per human subject protocol requirements. No information will be available that can be cross-walked back to the identity of a particular individual. Firefighters involved in the study will be identified only by a unique number rather than by name.

Key variables that we will monitor will include heart rate, respiratory rate, skin temperature, and core body temperature. As mentioned above, the RAD-57 sensor, and other pulse oximeters measure heart rate at regular intervals. However, we will also be using the BioHarness™ (designed by Zyphr Technology) that incorporates BlueTooth communications, medical-grade ECG, heart rate monitoring, and respiration and movement monitoring in a single, small chest strap. Skin temperature will be monitored with data loggers from Onset, with additional sensors placed on the outside of the PPE to record ambient environmental conditions. Core body temperature will be recorded using a CorTemp® Ingestible Core Body Temperature Sensor (designed by HQInc.) that wirelessly transmits core body temperature as it travels through the digestive tract. The sensor's signal passes harmlessly through the body to the CorTemp Data Recorder worn on the outside of the body.

For each firefighter involved in the study, we will collect data on current fitness using the USFS step test.[50] These tests will be conducted on the volunteers the day before the controlled burns. Most likely, we will be unable to use step test on actual wildfire events given the timing and logistics involved. Additional data collected will include an estimate of each firefighter's fitness level, experience, shift duration, age, gender, weight, hydration, nutritional information, PPE, distance traveled, elevation gain, speed, etc. For hydration, we will measure urine specific gravity before and after activity.[51] This will require the use of a refractometer (a simple hand-held device), urine specimen containers for urine collection, distilled water, cleaning cloth / disposable tissues, and gloves. Nutritional information will be collected from each volunteer, documenting his or her nutritional and fluid intake 24-hours prior to the study, and during the event. Finally, a small global positioning system (GPS) unit will be attached to each individual to track their distance, rate, elevation change, etc. This information will also be used to assess the firefighters position relative to the fire and smoke and during the various conditions of the fire (e.g. whether they are up or down wind, in an inversion) and fire behavior (e.g. smoldering, rate of spread, crowning, spot fires, etc.).

---

[48] See generally: https://sosa.ucsd.edu/confluence/display/CitiSensePublic/CitiSense

[49] See generally: http://www.rti.org/page.cfm?objectid=E19BDB1B-A77F-E4A3-F83126CB83065E76

[50] See both: Sharkey, B.J. (1979) Physiology of Fitness: Prescribing Exercise for Fitness Weight Control and Health, Human Kinetics Publishers and Whitlock, Chuck; Sharkey, Brian. 2003. Work capacity test: administrator's guide. NWCG PMS 307 NFES 1109. Boise, ID: National Wildfire Coordinating Group, National Interagency Fire Center. 28 p.

[51] Urinalysis has been shown to be the most valid and reliable method for determining moderate changes in fluid balance. Armstrong, L.E., Soto, J.A., Hacker, F.T., Casa, D.J., Kavouras, S.A., Maresh, C.M. (1998). "Urinary indices during dehydration, exercise, and rehydration." Int. J. Sport Nutr. 8: 345-355.

The combination of all the above data will be used to assess each firefighter's status in relation to ambient environmental conditions, to assist in understanding how the myriad of wildfire exposure factors are impacting health and safety. This information can also be used to help identify whether these factors differ among various body types, time of day, operational task, and other extraneous variables.

2.7 Wildfire Field Assessments

2.7.1 Controlled Burns

We will conduct field assessments at controlled burns, where specific environmental conditions can be documented and possibly standardized (e.g. vegetation types, resources, prior land management practices, etc). The conditions of each experimental controlled burn will be standardized to the maximum extent practicable. We will design and implement protocols to evaluate firefighters for health effects associated with smoke caused air pollutants, and compare results to ambient conditions (described above). The study will design initial testing protocols to be used at the controlled burns, with a final application developed for real fire events (described below). Through this research, we will assess firefighters who are actively engaged in fighting a fire and working on the fire ground. We will be conducting trials with firefighters from diverse ages, experience levels, and physical conditions (based on a random draw of firefighters available for each day of the experiment). The conditions of each experimental controlled burn will be standardized to the maximum extent practicable. The following procedures will be followed for each experiment:

- Controlled burns: Each ignition will occur on test plots with similar vegetation types, density, and slope. Time between ignition and response will also be standardized. We anticipate standardizing test plot size as practicable (from 10, 50, and 100 acre sizes), depending on availability of controlled burns during the research period.
- Firefighters: Each participant will wear full wildland PPE, use standard canvas packs (capable of holding 200 feet of synthetic hose) and use similar equipment (e.g clamps). Engine pressure will also be standardized. Each participant will be wearing the monitoring equipment as described above.
- Environmental: Burns will occur during similar weather conditions (to the maximum extent practicable) and will be assessed throughout the trials (e.g. temperature, relative humidity, wind speed/direction, slope, fuel moisture, fuel density, fuel configuration, etc.)
- Active-burn data: During the controlled burn, each firefighter will be monitored per the methods described above. Additional information will be collected on the type of activity each individual is engaged in throughout the study. Observers will also be monitoring the fire ground for the rate of spread (feet per minute, and acreage per minute) and the rate of attack (production rate in feet per minute). They will also monitor the fire ground for ambient conditions as described above (e.g. CO, PM, CO_2, HAPs). Other environmental conditions will also be continuously monitored during the trials (e.g. wind speed, direction, and relative humidity). Observers will also note any errors that occurred during the simulation (e.g. broken hose, clamping problems, etc.).
- Post-burn data: After the controlled burn is extinguished, the following data will be collected: total time to completion, rate of attack (feet per minute), total distance covered, total area burned, etc. Data on ambient conditions and firefighters will continue to be collected after the controlled burn has been completed and during all clean-up/mop-up activities.

2.7.2 Wildfire Research (Fire Event Assessment)

Once the controlled burn study is completed, an assessment team will be deployed to real fire events. The incidence of wildfires and the ability to quickly deploy an assessment team to the fire will dictate how many actual events can ultimately be included in this study. For this portion of the project, we are estimating (based on previous experience and wildfire trends) deployment of the assessment team to at least 6 wildfires during the 12-month study period. The purpose of this portion of the study is to collect data, similar to those collected at the controlled burns, on real wildfire events and develop standardized assessment and monitoring protocols. While research on controlled burns can substantially improve our understanding, it is not completely representative of the conditions, risks, and exposure at a real wildfire. This is an acknowledged and often dismissed flaw in research design in other studies of initial attack effectiveness and CO exposure.

The assessment team will be in direct contact with CAL FIRE, and notified of wildfire incidents within their region as they occur. The team will be able to deploy to wildfires primarily in San Diego, Riverside, and San Bernardino Counties, but can be deployed state wide as conditions dictate. The team will collect data on the following factors:

- Initial Assessment: point of origin, estimated time of ignition, cause of fire, response time, number of engines responding during the initial attack, and number of firefighters per engine.
- Firefighters: age, experience, height, weight, gender, smoking habits, and PPE.
- Environmental: (e.g. temperature, relative humidity, wind speed and direction, slope, fuel moisture, fuel density, fuel configuration, etc.)
- Pre-burn data: Where available, information in pre-burn vegetation/habitat will be collected, including vegetation type, fuel density, percent invasive species, fire history.
- Active-burn data: Data collected will include the number of engines and firefighters at the incident, number and frequency of other resources used (e.g. air tankers, helicopters, bulldozers, hand crews, water tenders, overhead, etc.). During the wildland fire, each firefighter will be monitored with protocols that mimic the controlled burn study as closely as practicable. The equipment and assessments will only be deployed where practicable and only when it does not interfere with operations and response.
- Observer-collected data: During the wildfire, qualified observers will be monitoring the fire ground for the rate of spread (feet per minute, and acreage per minute) and the rate of attack (production rate in feet per minute). They will also monitor the fire ground for ambient conditions, mimicking the controlled burn study as closely as possible without causing operational or response interference. This portion of the study will also attempt to document the type of material burning when involved in a WUI incident.
- Post-burn data: After the wildfire is contained the following data will be collected: total time to containment, rate of attack (feet per minute), total distance covered (including total hose layed), total area burned, and ambient CO levels on the burned area (during mop-up). Continual monitoring of the post-burn activities, firefighters, and environmental risks will be monitored until the incident is concluded. A final health assessment of firefighters will be conducted upon conclusion, including CO exposure (using a pulse oximeter and breath analysis), heart rate monitoring, and a basic health assessment.

3.0 Proposed Analyses

Statistical expertise is a prerequisite for the successful completion of this project. Statistical interpretation requires critical understanding, assessment, and interpretation of the data. Fortunately, researchers participating in this study have the necessary background and expertise in research design, statistics, and wildfires to support this proposed research effort. This includes researchers with over 17 years of scientific research design and statistical analysis experience, medical experts in firefighter safety and health, and firefighters with direct expertise in wildland fires and fire research. This expertise includes the ability to understand the complicated relationships between effects of staffing, environmental conditions, and human health risk. Data will be analyzed and graphically represented SYSTAT version 13.1. In

3.1 Exploratory Data Analysis

Data collected during this research project will be both quantitative and qualitative. Initial analysis will include basic exploratory data analysis that will help identify potential relationships between staffing and initial attack effectiveness on controlled burns. Exploratory analyses are often a critical first-look into the data collected, yet an overlooked first step to many experiments.[52] Exploratory data analysis has gained significant popularity in recent years, particularly with projects such as this one where complicated and diverse arrays of variables are collected during the experiment. This phase of the analysis will provide the following: 1) suggested hypotheses regarding the causes of observed phenomena; 2) assumptions on which statistical inference will be based; and 3) selection of appropriate statistical tools and techniques used later in the final analysis. This approach also provides an unbiased approach to data analysis, where researchers do not enter into an analysis or experiment with preconceived notions or biases that may influence the development of rigorous hypothesis testing. Analyses include box plots, histograms, and scatter plots that help describe the spread of the data and let the observer see potential patterns and relationships in the data.

3.2 Descriptive Statistics

The second phase of the analysis includes the development of basic descriptive statistics. This would include developing summary statistics such as the mean, median, and range of data. Existing national standards exist for assessing the risks associated with many of the data collected (e.g. elevated heart rates and PM, and CO exposure). We will therefore conduct basic analyses that calculate the average fireline exposure, maximum 8-hour exposures, maximum peak exposures, 5-minute maximum exposures, and 1-minute maximum exposures.

These descriptive statistics are important in providing a general summary of the results and often provide a means by which simple comparisons may be made. These descriptive statistics can also help identify outliers (e.g. a sample that is clearly outside the rest of the data that were collected). This phase of the analysis also describes the amount of variability or "spread" in the data (e.g. how consistently similar the different trials are to each other). The most common measures of variability are the range, the interquartile range (IQR), variance, and standard deviation.

3.3 Advanced Statistics

The final phase of the analysis will provide the highest level of statistical review and interpretation. The first two phases help with identifying the key variables that are significantly associated with initial attack effectiveness, CO exposure, and overall firefighter health and safety. Independent t-tests will be used to compare differences in mean values between two groups for continuous variables. Chi-square test will be used to compare categorical data and/or percentages in evaluating bivariable associations. Bivariate analysis will also include the assessment of continuous data and can be assessed through a simple linear regression. These analyses also provide an assessment of the relative strength of the relationship between the two factors. Multivariable regression methods will be used to adjust for co-variables such as age, race, and career-volunteer status between groups.

Categorical data may require specialized statistical analyses. Because these non-parametric alternative analyses make fewer assumptions (because they use generalized categories), their applicability and robustness is much wider than other statistical alternatives. However, caution must be used in their interpretation, largely due to the over-generalization of the relationships and limited statistical power.

Finally, it may be that multiple factors are all involved in producing an outcome. For example, it may be that the temperature, wind speed, and fuel density are all related in how quickly a fire spreads and the time it takes different levels of firefighters to extinguish a wildfire. In that case, a multivariate analysis would be the most appropriate approach to understanding and describing that relationship. The advantage of a multivariate analysis can address multiple

[52] See generally Tukey, J. 1977. Exploratory Data Analysis. Addison-Wesley Series in Behavioral Science - Quantitative Methods.

relationships simultaneously, and can also identify which factors have the most influence on the outcome (ideal for complex, data-intensive projects such as this one). We will use an Analysis of Variance (ANOVA) and Multivariate Analysis of Variance (MANOVA) to compare differences between multiple groups. If appropriate, we may use a binomial and multinomial logistic regression to develop a more thorough understanding and predictive models for comparing exposure levels to physiological impacts.

Overall, our approach to analyzing these data will result in more scientific rigor and epidemiologic power than previous purely descriptive analyses of these factors.

3.4 Human Protocols and Protection

During all phases of the research involving firefighters, the highest level of care and concern will be given to the safety and health of the participants. If at any time the health or safety of a firefighter is in question, they will be immediately removed from the study and given proper medical care. Firefighter safety is also a top priority. We will prepare an incident action plan (IAP) for each controlled burn. Line emergency medical technicians (EMTs) or paramedics will be onsite. Three engines will be assigned to the controlled burn, with an additional holding force of two to three engines, hand crews, water tenders and a CAL FIRE helicopter.

The approval for studies involving human test subjects is also strictly supervised and approved. The Institutional Review Board (IRB) at the SDSU Research Foundation is a standing committee of the University Research Council. Their purpose is to review research involving human subjects to determine and certify that all projects conform to the federal and institutional regulations and policies. An existing IRB approval exists for prior research, and will be amended and updated for this project. All information collected will be carefully protected. No information will be available that can be cross-walked back to the identity of a particular individual. Firefighters involved in the study will be identified only by a unique number rather than by name.

3.5 Scientific Review and Expert Evaluation

All research publications go through a rigorous internal peer review process. This includes participants of the research program, as well as independent experts within the University, CAL FIRE, IAFF, USFS, NIST, and CDF Firefighters that are not directly involved in the research program. These members will be part of a technical advisory committee that is created specifically for this research program. Independent external reviewers will also participate in the final phase of the project review. Additional scientific peer review will occur upon submittal of the report for final publication.

3.6 Proposed Timeline

As described above, initial studies were conducted in 2009-2012. Based on these findings, the project partners are seeking funding support for this large-scale research program. Given the timing and opportunities to conduct controlled burns in California, the proposed research program will begin Fall 2013. Live fire assessments will occur during the peak fire season of that same year and summer 2014. Data analysis will be conducted periodically throughout the study. A final report will be produced in by the end of Fall 2014.

4.0 Resources: People and Facilities

Key to the success of the research, education and outreach program is the participation and cooperation of essential agencies and individuals. Fortunately, we already have a demonstrated history of successful research and outreach programs. This proposed research program continues to build on a strong foundation of prior wildfire research that is comprised of a partnership between researchers, firefighters, state agencies, and medical professionals. Dr. Rahn will be leading the research team, and is the current Director of the SDSU Wildfire Research Center. He has nearly two decades of experience in the applied sciences and policy, with an emphasis on statistics, research design, environmental science, and public policy and law. He has been working on projects related to wildfires since 1999, on topics such as communications, wildfire detection technology, environmental impacts, habitat restoration, endangered species impacts, economic analyses, community planning, staffing studies, and initial attack effectiveness.

The project team includes experts in wildland firefighting, structural firefighting, and logistics. The team has performed in various Incident Command System positions on some of the largest fires recorded in history, such as the Cedar and Witch fires in San Diego County. They hold various teaching credentials and are California State certified instructors. They are also certified instructors for the National Wildlife Coordinating Group courses. All have significant experience in predicting, measuring, and recording burn and staffing characteristics, and providing analysis and findings as it relates to the wildland-urban-interface. We have also recruited the medical director from CAL FIRE to assist in data analysis and interpretation. Finally, we are working with specialists in communication and outreach programs, with decades of experience working in the interface between wildfires, public education, community outreach, training, and policy.

We have created an advisory board for the research program that consists of members of the fire services industry, wildfire agencies, and key collaborators from the private sector. This will ensure that the goals and agenda are part of the short- and long-term objectives of the actual parties involved in the wildfire arena, and can be directly integrated into workshops, outreach programs, education, and training. The advisors include the research and development officer from CAL FIRE, members of the Technology and Development Center with the USDA Forest Service (from Missoula and San Dimas), and the leader of the Wildland Urban Interface Fire Group, of the Engineering Laboratory (EL) at the National Institute of Standards and Technology (NIST).

4.1 About SDSU

Founded in service, SDSU continues to be a leader in analyzing and resolving complex community problems, ranked as the number one small research university in the United States. The proposed research initiative continues this legacy by advancing science in an area that is fundamentally consequential to California and the region. San Diego is one of the highest fire-risk regions in the nation, with SDSU's 4,500 acre Santa Margarita Ecological Reserve located in the center of an extreme fire hazard zone; an opportune location for a wildfire research program. Our collaborative relationship with the CSU and UC system provides us with thousands of additional acres throughout the state that conduct regular controlled burns and fuel management programs – an ideal situation for wildland fire research at dozens of "outdoor laboratories."

SDSU and our College of Sciences also have a strong tradition of innovative community programs. As a leader in wildfire research, SDSU opened the Wildfire Research Center in 2012. The Wildlife Research Center is working in collaboration with our departments and programs, including strong ties to the Environmental Sciences Program and our program in Homeland Security. Through this center, we can provide an outreach program that takes the important results of this research and conveys them to the firefighters, community members, and other key agencies and organizations. In addition, SDSU is a recognized leader in advanced education programs. A future ambition of this initiative is to develop training and education programs for firefighters. We will ultimately provide programs to educate the next generation of "firefighter-scientists" that have a deeper understanding of the field, going beyond traditional firefighter education and training programs. This could create an unparalleled synergistic relationship between research and education that would simultaneously advance the firefighting industry and improve research. The overall value of this new Center is that the sustainability of this research, and future endeavors is maintained through a strong foundation of applied research and institutional commitment to this area of study.

The SDSU Research Foundation has been operating for over seventy years as an auxiliary organization of San Diego State University. SDSU has been consistently recognized as the number one small research university in the United States. Our purpose is to further the educational, research, and community service mission in California. We have a proven track record of success, and have consistently provided timely project completion in other state and federal grant programs.

5.0 Partners

We are teaming up with CAL FIRE and the US Forest Service for this project. As leading wildfire agencies in the United States, they will be actively involved in all stages of this research, and will provide expert analysis and review of the results. These agencies will also participate in identifying and discussing and identifying potential solutions to the more serious implications from the study regarding exposure, risk, and health and safety. It will be through these agencies that the information will be disseminated and deployed.

The firefighters themselves are also key partners in this research. We will be working side-by-side with them in order to understand how to accurately measure exposure and risk in the field. Their input into the design, use, and implementation of the equipment is critical is developing a monitoring and assessment platform that is compatible with their PPE and does not interfere with their duties or activities. It will also be important to understand what information they are personally interested in, so that they can also have a better understanding of the environmental conditions they are working in, and how they are responding physiologically to those situations.

Our partnership with CDF Firefighters and the International Association of Firefighters will provide us with state and national opportunities for presenting these results at conferences and conventions. These collective venues provide an opportunity to foster continued discussion and expert involvement in understanding the research results and identifying ways to improve firefighter health and safety.

San Diego State University has also teamed up with the Wildland-Urban Interface Fire Group at the National Institute of Standards and Technology (NIST) to provide additional technical resources. NIST engineers and researchers will assist in planning, instrumentation, and analysis of controlled field burns. NIST has developed a standardized field data collection system that utilizes geographic information systems (GIS) linked technology. NIST has successfully responded to fires including Witch Creek/Guejito, CA (2009)[53] and Amarillo, TX (2011)[54] to collect post fire data.

Letters of support and collaboration from our collaborators and partners are provided in the included Appendix, along with the experience and expertise of key personnel.

[53] Maranghides, A., and Mell, W., April 2009. A Case Study of a Community Affected by the Wich and Guejito Fires. NIST Technical Note 1635. National Institute of Standards and Technology, Gaithersburg, MD.

[54] Maranghides, A., Mell, W., Ridenour, K, and McNamara, D., July 2011. Initial Reconnaissance of the 2011 Wildland-Urban Interface Fires in Amarillo, Texas. NIST Technical Note 1708. National Institute of Standards and Technology, Gaithersburg, MD.

5.0 Dissemination and Implementation

The second phase of this proposed project is the dissemination and integration of the results into an outreach and education program. The first step will be to integrate our research into a program that describes the preliminary findings and provides a forum for discussion and dissemination. This will be done through a strategic partnership with professionals who are actively engaged in wildfire policy, communications, and public relations. As our research and analysis advances our understanding, our communications forum provided by the Wildlife Research Center will become an increasingly vital tool in disseminating the research results, and fostering discussion within the firefighting community.

We will host approximately two workshops in California (depending on location and participation), targeting agencies and municipalities that have a risk and responsibility for wildland fires. At least two additional workshops will be held at national venues, including Colorado and Washington DC. We will be targeting audiences from state, local, federal, and tribal agencies. We will develop a series of documents (brochures and technical reports) summarizing our research results that will be distributed to workshop participants. Information will also be provided through a variety of social media and online services, including a project website with the research and results, and an online discussion forum.

The second step is to determine which factors influence initial attack effectiveness of wildland firefighting and firefighter health and safety, and develop recommendations on how this information can be integrated into new policies and procedures. This requires the continued involvement of the firefighting community as well as those involved in creating policy. We will conduct a series of targeted workshops designed to evaluate the methods and tools that can be integrated into new protocols and training. We will seek the most cost effective and technically proficient equipment and methods, which increases the likelihood of successful integration into firefighting practices.

The final phase of this program will involve the development of recommendations, risk reduction strategies, and remediation measures that may increase initial attack effectiveness and decrease the possibility of wildland firefighter morbidity and mortality. This may include the identification of hazard awareness programs, fire ground monitoring and assessment protocols. We will involve firefighters, managers, and regulators in developing the monitoring, assessment, and exposure management strategies. We will host a working group meeting to provide policy makers and municipalities an opportunity to understand and discuss the research results and evaluate methods for improving initial attack effectiveness and firefighter health and safety. The results of this forum will be used in the development and implementation of an education and training programs for wildland fire personnel. These strategies are particularly important for the development of practical and accurate firefighter health assessment protocols, since the symptoms for CO exposure are often identical to those associated with heatstroke, exhaustion, dehydration, and heat exposure. We will also work with our advisory board in identifying potential solutions that may include hazard awareness training and protocols for routine air monitoring. Finally, the scientific and research community will also be invited to participate in all phases of this education and outreach program, targeting those individuals and institutions with a particular interest and emphasis on wildland fires and firefighter health and safety. Additional materials will be prepared for the scientific audience, including the submittal of the final research results into an appropriate peer reviewed scientific publication.

The initial results will be disseminated to our research collaborative with CAL FIRE, CDF Firefighters, US Forest Service, and NIST. This is the first step in understanding what factors may be contributing to firefighter morbidity and mortality. The results of this study will be presented at a formal workshop hosted at SDSU, where our advisory board and research collaborators will discuss the outcomes and propose potential solutions. At the end of this study we will provide the following deliverables:

1) Testing of Methods Used to Monitor Firefighter Health and Safety at Controlled Burns
2) Development of Firefighter Exposure and Physiological Monitoring Protocols for Actual Wildland Fire Events (compatible with PPE)
3) Results of Data Collected and Statistical Analysis of Firefigher Health and Safety/Exposure Study
4) Dissemination of Results and Discussion at two Workshops Hosted by SDSU (San Diego, CA) and NIST (Boulder, CO).
5) Final Report on Research Results and Recommendations from Workshops
6) Print Collateral for Distribution to the Wildland Firefighter Community and Presentation at the IAFF Redmond Symposium for Occupational Health and Hazards of the Fire Service
7) Proposed Recommendations for Future Research

6.0 Cost / Benefit Analysis

The concept of cost effectiveness is applied to the planning, management, and implementation of our research programs. A cost study is used to determine how the results and findings can be integrated into modern wildfire practices and protocols. It is important to describe how changes (e.g. in engine staffing, or CO mitigation protocols) can be effectively implemented, taking into account the benefits of improving initial attack effectiveness and firefighter health and safety. Although it is difficult to quantify the economic value of firefighter safety, training, and health, the purpose of this analysis is to ensure that research findings can be integrated into a long-term sustainable program or policy with an accurate assessment of costs and benefits. We will also track how these findings are integrated into longer-term education/outreach program and training seminars.

The long-term benefit of this research program depends on whether the results are integrated into existing programs and policies. If, for example, we determine that CO is indeed a serious risk on the fire ground, the ultimate measure of success would be the integration of this information into new policies, procedures and training programs which limit CO exposure and damage in active duty firefighters. This requires the participation of key agencies, many of which are already involved in the development of this research program. Our research collaboration and successes over the past several years demonstrates a need and an interest in advanced wildfire research. Recognizing the need for additional scholarship in this arena, we are working together to advance our understanding and fill critical gaps in information regarding wildland fires. We are dedicated to supporting the fire services community through applied research, education, interaction with policy makers, and outreach programs focused on understanding and improving firefighter safety and health, emergency response services, and firefighting effectiveness.

According to the Center for Disease Control (CDC) unintentional CO exposure accounts for an estimated 15,000 ER visits and 500 unintentional deaths in the United States each year (statistics current through 2004). Firefighters are put in situations where CO exposure is more prevalent. The fire service has made great strides in protecting firefighters from CO exposure in identified IDLH atmospheres (i.e. structure fires), however this same awareness has not been carried over to wildfire scenarios. "These findings suggest that heart damage caused by carbon monoxide may have long-lasting effects even after its been eliminated from the blood, making the diagnosis of carbon monoxide poisoning even more critical," said lead author Selim Suner, M.D., M.S., Director of Emergency Preparedness and Disaster Medicine at Rhode Island Hospital. However, many studies have focused on these factors as individual contaminants. Wildland firefighters are exposed to several factors, which may interact and have synergistic effects. While carbon monoxide is the number one cause of poisoning deaths in the United States and worldwide, we do not understand how this, combined with HAPs, PM, stress, temperature, and other factors affects humans.

A 2004 study found that nearly 50% of all injuries to firefighters were the result of muscle injuries (strains and sprains); overexertion was a primary causative factor for these injuries.[55] Additionally, roughly 12% of the injuries were related to smoke, respiratory issues, heart attack/stroke, and thermal stress. Based on methods applied from two of the more relevant economic studies discussed in that report, the estimated cost of addressing firefighter injuries and of efforts to prevent them is $2.8 to $7.8 billion per year. According to the report, the cost elements that comprised those two studies were based on workers compensation payments and other insured medical expenses, including long-term care; lost productivity; administrative costs of insurance; and others. Significant financial and health benefits can be derived if even a fraction of the injuries and fatalities can be reduced through advancing our understanding of the exposure and stress of wildland firefighters. The costs for research and understanding this phenomenon are far outweighed by the thousands of firefighters that can benefit from a better understanding of the issue, and improved protocols and rehabilitation procedures.

7.0 Financial Need

We are keenly aware of the need to maximize funds and provide economical and effective research programs. Given our prior history, accomplishments, and initial studies, we strive to maximize the level of funding that goes directly into the delivery of the research project (with funds devoted to implementation rather than planning). This also ensures that the proposed research program has a high probability of success, that the proposed research is reasonable, and that there are potentially high benefits derived from a reasonable investment in grant funds.

Encouraged by our past success and the benefit that our research has conferred on our region, we have agreed to expand this promising partnership. Unfortunately, the costs associated with this advanced program are substantially higher than our previous research efforts. The proposed research program requires a significant increase in support, firefighter resources, and expertise. We are also proposing to develop new outreach, education, and implementation programs, which also requires increased resources and support.

While this next step in research and education is collective priority, funding through our project partnership is considerably inadequate; we are unable to jointly provide the level of funding and support necessary. Our historic research costs were covered through our collective financial and in-kind contributions. However, current budgets dedicated to wildfire agencies, state universities, and other project partners are now severely limited in scope, with research becoming an unfunded mandate. Additionally, external funding for wildfire research of this type is extremely limited. We have worked diligently to identify and secure additional funding through other federal agencies, including the Department if Interior, National Science Foundation, and NASA. However, funding available for this particular type of research is not generally available. Support from the DHS/FEMA FP&S program is vital to continuing this critical research, and advance our understanding of wildfire impacts, initial attack effectiveness, and firefighter health and safety.

[55] NIST. 2004. The Economic Consequences of Firefighter Injuries and Their Prevention. Final Report. NIST GCR 05-874.