WILDFIRES

EVALUATING THE CARDIORESPIRATORY HEALTH OF WILDLAND FIREFIGHTERS

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KEY TERMS

Chronic Obstructive Pulmonary Disease
Cytokines
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In Vitro–In Vivo
Micro-Orifice Uniform Deposit Impactor (MOUDI)
National Multi-Agency Coordinating Group
Oxidized Low-Density Lipoprotein

INTRODUCTION

Wildland fires can pose grave occupational health risks to firefighters, as well as risks to wildlife, the environment, and communities. Cardiorespiratory health effects among firefighters are of special concern, along with risks of traumatic injury or death from firefighting-associated activities, such as entrapment in the fire, and from vehicle and air transport crashes. This case study chapter provides public health students and practitioners with an introduction and overview of the increasing risks from wildfires, health issues for firefighters, firefighting organization and practices, and vignettes of experiences and lessons learned from scientific field investigations and laboratory investigations of wildland firefighter (WLFF) health conducted by researchers

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The following icons, located in the margins throughout the chapter and within the summary tables, denote essential services of public health, CEPH competencies, and leadership levels: Essential services of public health; CEPH competencies; Leadership levels.

at the National Institute for Occupational Safety and Health (NIOSH) and the Harvard School of Public Health.

THE INCREASING RISKS FROM WILDFIRES

According to wildland fire statistics collected by the U.S. government, the number and intensity of wildfires has grown over the past decades, with approximately 7.1 million acres being destroyed in an average North American wildland Fire season between 2010 and 2019 (National Interagency Fire Center [NIFC], 2020b). The year 2012 involved extremely arid conditions (i.e., the worst U.S. drought since 1934), and 9.3 million acres burned in wildfires. In 2018, the Camp Fire was the deadliest and most destructive wildfire in California history and the most expensive global natural disaster in 2018 in terms of insured losses (Reyes-Velarde, 2019). Similarly, Australia experienced one of its worst droughts in decades in 2019 and 2020, with 46.3 million acres ravaged by wildfires, killing 34 people, an estimated 1 billion animals, and destruction of over 5,900 buildings (Dickman, 2020). The growing annual extent and intensity of wildfires spurs increasing concern for the health of exposed individuals, especially the seasonal and permanent WLFFs employed each year by the U.S. federal government.

HEALTH ISSUES

Firefighters are known to have respiratory and cardiovascular problems (Adetona et al., 2016; Cascio et al., 2018; Yoo & Franke, 2009).[1] At the 1997 Consensus Conference on the Health Hazards of Smoke, WLFF health and safety experts reported that respiratory problems were common in WLFFs and accounted for 30% to 50% of visits to fire incident medical aid stations (Sharkey, 1997). Cardiovascular disease (CVD) events are the leading cause of on-duty and lifetime mortality among structural (career and volunteer) firefighters (Kales et al., 2003; Sardinas et al., 1986; Yoo & Franke, 2009). The deleterious effects of smoke exposure to structural firefighters have been extensively researched (Burgess et al., 2001; Centers for Disease Control and Prevention [CDC], 2006; Chia et al., 1990; Kales et al., 2003; Liu et al., 1992; Musk et al., 1979; Scannell & Balmes, 1995; Yoo & Franke, 2009). Exposure to particulates and other contaminants, heavy physical exertion, and cardiovascular strain have been found to be among the chief health hazards associated with structural firefighting (Delfino et al., 2009; Gaughan, Christiani, et al., 2014; Gledhill & Jamnik, 1992; Takeyama et al., 2005). Those findings, however, may not be generalizable to WLFFs for a number of reasons, including the difference in smoke composition, as well as the possible comparative younger age of WLFFs, the generally shorter career tenure of WLFFs, and the longer duration of respiratory exposures per incident (up to several weeks instead of just minutes or hours) for WLFFs as compared to structural firefighters. Additionally, structural firefighters routinely wear respiratory protection when responding to fires while WLFFs do not.

Studies examining respiratory symptoms and pulmonary function in WLFFs have found increases in symptoms, airways hyperresponsiveness, and declines

[1] Additional references of interest are Austin et al. (2001), Betchley et al. (1997), Burgess et al. (2001), Centers for Disease Control and Prevention (CDC) (2006), Chia et al. (1990), Gaughan et al. (2008), Guidotti & Clough (1992), Kales et al. (2003), Liu et al. (1992), Materna et al. (1992), Musk et al. (1979), Rothman et al. (1991), Sardinas et al. (1986), Scannel & Balmes (1995), Slaughter et al. (2004), and Takeyama et al. (2005).

in lung function cross-shift and cross-season (Betchley et al., 1997; Letts et al., 1991; Liu et al., 1992; Reh et al., 1994; Rothman et al., 1991; Sharkey, 1997; Slaughter et al., 2004). A longitudinal study conducted by NIOSH from May 2004 to May 2007 (Gaughan et al. 2008) observed significantly increased upper and lower respiratory symptoms, including cough, wheeze, sputum production, inflammatory indicators in sputum and nasal exudate, shortness of breath or chest tightness, shortness of breath while walking, and various eye, nose, and throat symptoms, postfire compared to preseason (i.e., health conditions of the firefighters after they conducted firefighting duties compared to their health conditions before they were deployed for firefighting duties in an annual firefighting season). This finding is consistent with observations made by Rothman et al. (1991), who observed a significant increase in eye irritation, nose irritation, cough, phlegm, and wheezing from preseason to late season among WLFFs, with strong associations noted for recent firefighting activity. In the longitudinal study by the NIOSH, the increased scores for lower respiratory symptoms observed postfire returned to near preseason levels during the postseason. Upper respiratory symptom scores remained significantly elevated at postseason compared to preseason, although scores were significantly lower at postseason compared to postfire. These observations suggest substantial recovery from respiratory tract effects of firefighting by the time of the authors' postseason assessment. Nevertheless, the finding in multifactor analyses that cumulative time spent fighting fires over a career was significantly associated with increased upper (but not lower) respiratory symptoms suggests that wildfire-associated exposure may produce a more sustained rhinitis/sinusitis (Gaughan et al., 2008). Conversely, Betchley et al. (1997) observed no significant increase in symptoms cross-season in their study of 53 WLFFs, but their postseason testing was done well over a month later in the season than the NIOSH study and may have allowed for more complete recovery. A practical limitation of longitudinal studies such as these is that not all crew members return to the same crew for multiple seasons. For example, in the NIOSH study, only half the members of one crew (10 out of 20) returned for the next season. The possibility that some crew members do not return because of health issues or health concerns raises the possibility that the actual magnitude of health effects may be underreported.

These previously observed increases in subjective symptoms and declines in objective measures of lung function suggest that wildland firefighting is associated with upper and lower airway inflammation and raise concern about potential risk of long-term respiratory effects, including asthma, **chronic obstructive pulmonary disease** (COPD), and upper airway conditions such as sinusitis.

Navarro et al. (2019) used a number of assumptions about smoke concentration levels, frequencies and durations of exposures per year, number of years in the career of a firefighter, and health effects of a given smoke exposure to estimate the relative risk of CVD mortality based on existing PM2.5 exposure–response relationships. An example of their assessment is that the lifetime risk of mortality from CVD for a firefighter who was exposed for 98 days per year for a career duration of 25 years would be 30% higher than the lifetime risk to someone who was not exposed in that manner.

Health risks to firefighters also include traumatic physical injury and even death. The fire with the greatest toll of deaths prior to 1950 was the Mann Gulch Fire in 1949, which occurred north of Helena, Montana, at the Gates of the Mountains area along the Missouri River. Thirteen firefighters died. This disaster directly led to the establishment of safety standards, some of which are still used today by all WLFFs. On July 6, 1994, nine members of a firefighting crew based in Prineville, Oregon, died after being overtaken by the fast-moving Storm King Fire west of Glenwood Springs, Colorado. Five other firefighters also died in the fire. On June 30, 2013, the 19 members of the Prescott Fire Department's wildfire fighting crew (known as the Granite Mountain Hotshots) perished in the Yarnell Hill Fire near Yarnell, Arizona, when their escape route was cut off by the approaching fire.

Health risks to firefighters also include exposures to infectious diseases. In 2020, in response to the COVID-19 pandemic, the **National Multi-Agency Coordinating Group** established three regional Area Command Teams that, along with partners at all levels of the fire community, developed protocols which were integrated into nine Wildland Fire Response Plans (WFRP; www.nifc.gov/fireInfo/covid-19.htm). Topics include: Fire Personnel Readiness; Modifying Strategies, Tactics, and Logistics; Drawdown Projections and Contingency Opportunities; and Leveraging Best Available Information Management and Technology. Tactical information is intended for local area fire managers, Incident Management Organizations, and the "boots on the ground" in the format of Best Management Practices. These region-specific WRFPs provide guidance and considerations for strategic and tactical information for maintaining continuity of wildland fire response in the presence of the COVID-19 virus for all levels of wildland fire response—from national level, regional level, and local level to module level.

WILDLAND FIREFIGHTING ORGANIZATION AND PRACTICES

The North American wildland fire season typically runs from May through November. The National Interagency Coordination Center (n.d.) mobilizes local, regional, and national firefighting resources. Firefighter assignments to specific fire incidents can be for up to 14 consecutive days, followed by two obligate days off. In some situations, assignments may be extended to 21 days; however, this is somewhat rare. While at a fire, the shift duration can vary, depending on the nature of the fire, the terrain and weather, and the available number of firefighters. Some shifts may extend to 12 hours or more. Thus, sleep deprivation may be reported as a pervasive concern among these workers. Moreover, resultant stress from sleep restriction may be an independent risk factor for cardiovascular morbidity (Austin et al., 2001).

The other demands of wildland firefighting can also be profound. Some crews may work from camps in remote areas, eating prepackaged food, with limited access to sanitation or shower facilities during their assignment. On larger fires, crews may be assigned to fire camps with hundreds if not thousands of other firefighters where hot meals, showers, and handwashing stations may be available under crowded conditions.

Additionally, a person's daily caloric consumption to maintain work performance and cognitive abilities at a wildland fire operation routinely can be quite high (e.g., 4,000 to 6,000 calories during arduous duty activities on the fireline; NWCC, 2020). The high level of duty activities is important to note because prolonged, intense exercise may amplify **oxidized low-density lipoprotein** generation, which is associated with atherosclerotic plaque (Ashley & Kannel, 1974), and because changes in body composition (defined as the ratio of fat to lean muscle) may hasten the development of CVD (Higgins et al., 1993; Lissner et al., 1991).

Examples of Firefighting Crew Types

As described in the following, firefighting crews are differentiated based on increasing levels of experience, leadership, and availability. Categories of federal WLFF crew types per the 2020 edition of the *Interagency Standards for Fire and Fire Aviation Operations* (commonly referred to as the Interagency Redbook) are Type 1, Type 2 IA (Initial Attack Capable), and Type 2 (NIFC, 2020a). Crews typically comprise 18 to 20 men and women, including a crew boss and squad bosses who supervise the crew's actual work. Duties may involve serving as "lead" workers, the individuals who oversee all crew operations; "line" workers, those who construct the fire line; "sawyers," the chain-saw operators who clear the way for fire line construction; and "swampers," who shadow the sawyers, removing the fallen debris. Fire line construction is defined as clearing vegetation and exposing bare soil by cutting, scraping, or digging to create a break in fuel availability. Mop-up operations involve extinguishing or removing burning material along or near a fire line after the fire has been controlled. When not on wildland fire assignments, crews are stationed at their home unit, and they perform project work such as collecting samples of vegetation, identifying plant species, documenting wildland fuel loading, and conducting prescribed burning and other fuel-reduction activities.

Smoke Jumpers

Smoke jumpers are specially trained Type 1 WLFFs who provide an initial attack response on remote wildland fires. They are transported by plane or helicopter and descend by parachute to the site of the fire. In addition to performing the initial attack on wildfires, and like other qualified WLFF professionals, they may also provide leadership for extended attacks on wildland fires. Shortly after smoke jumpers touch ground, they are supplied by parachute with food, water, and firefighting tools, making them self-sufficient for 48 hours. Today, nine smoke jumper crews operate in the United States. Seven are operated by the U.S. Forest Service (USFS), and two are operated by the Bureau of Land Management (BLM).

The minimum required physical fitness standards for smoke jumpers set by the National Wildfire Coordinating Group are carry a pack loaded with 110 lb for three miles within 90 minutes; run 1.5 miles in 11 or fewer minutes; and perform 25 push-ups in 60 seconds, 45 sit-ups in 60 seconds, and seven pull-ups.

Interagency Hotshot Crews

Type 1 Interagency Hotshot Crews (IHCs) are elite crews who often construct fire lines using hand tools during the most dangerous phases of wildland fire suppression. Type 1 crews often comprise 20 members. In the United States, hotshot crews are organized by agencies such as the USFS, the National Park Service, the Bureau of Indian Affairs, the BLM, and state/county agencies. The NIFC in Boise, Idaho, coordinates hotshot crews on the national level.

All IHC crew members are expected to strive to meet the fitness criteria developed by the National Wildfire Coordinating Group (Sharkey & Gaskill, 2009). These criteria include the ability to perform the following: 1.5 mile run in a time of 10:35 or less, 40 sit-ups in 60 seconds, 25 push-ups in 60 seconds, and chin-ups based on body weight as follows: four chin-ups for body weight more than 170 lb, five chin-ups for 135 to 170 lb, six chin-ups for 110 to 135 lb, and seven chin-ups for less than 110 lb.

Engine, Helitack, and Air Tanker Crews

Engine crews are generally made up of 3 to 5 WLFFs. A typical wildland fire engine is an off-road vehicle able to carry water for use in firefighting. Many wildland fire engines also carry foam to use on wildland fuels to help extend the use of the limited water supply they have. Engine crews are used in initial response to a fire, sometimes providing structure protection, holding burnout operations, patrolling, providing structure protection, and conducting mop-up activities.

Helitack crews are specially trained in the tactical and logistical use of helicopters for fire suppression. These crews can be rapidly deployed and are often the first to respond to a wildland fire. Some helitack crews are also trained to "rappel" from a hovering helicopter in areas where the terrain or vegetation does not allow the helicopter to land. Others are trained in operations for rescue missions on fires. Other helitack duties may be loading and unloading thousands of pounds of equipment and supplies needed for firefighting, commonly called "cargo," and manifesting and loading and unloading firefighters headed to the fireline (USFS, 2017). Air tanker crews use fixed-wing aircraft to apply water or other fire suppressants to the fire area.

The Incident Command System

The Incident Command System (ICS) is part of the National Incident Management System and was created in response to a series of destructive wildfires in southern California in 1970 (FEMA, 2020). National, state, and local emergency responders required a tool to effectively provide command and control functions while coordinating the efforts of many individual agencies and departments working together to stabilize a disaster while protecting life, property, and the environment. The ICS is used by emergency responders across the nation as well as by local governments and agencies. ICS is successful because it uses a common organizational structure with standardized management principles. The ICS is a management system designed to enable effective and efficient domestic incident management by integrating a combination of facilities, equipment, personnel, procedures, and communications operating within a common organizational structure. ICS is normally structured to facilitate activities in five major functional areas: command, operations, planning, logistics, and finance/administration. The incident commander typically is supported by a public information officer, a liaison officer, and a safety officer. The ICS is a scalable structure, and it may also include intelligence and investigations, as well as epidemiology. It is a fundamental form of management, with the purpose of enabling incident managers to identify the key concerns associated with the incident—often under urgent conditions—without sacrificing attention to any component of the command system.

Emergency Responder Health Monitoring and Surveillance

A plan for monitoring emergency responder health and conducting surveillance for diseases and health conditions associated with emergency responders is essential to ensure the health and safety of the responders. The NIOSH has worked with the U.S. National Response Team (NRT, www.nrt.org), and a number of federal agencies, state health departments, labor unions, and volunteer emergency responder groups to develop the Emergency Responder Health Monitoring and Surveillance™ (ERHMS™) framework (NIOSH, 2020a). The ERHMS™ framework provides recommendations for protecting emergency responders during small and large emergencies in any setting. It may be used by all who are involved in the deployment and protection of emergency responders, including incident command staff; response organization leadership; health, safety, and medical personnel; and emergency responders. ERHMS™ training is available online (CDC, 2020). The application of ERHMS™ in wildland firefighting situations could be a useful augmentation to the ICS.

VIGNETTES ON EVALUATING THE CARDIOVASCULAR HEALTH OF WILDLAND FIREFIGHTERS

Within the many areas of knowledge, skills, and abilities that public health practitioners require to understand, communicate, and manage the health risks associated with wildland fires, an area of special expertise involves the harnessing of the multiple disciplines of exposure assessment, field and laboratory methodologies, medicine, and epidemiology and biostatistics. The following sections present examples of how the integration of these disciplines was carried out for the field portion and for the laboratory portion of longitudinally designed NIOSH and the Harvard School of Public Health studies of the cardiorespiratory effects of particulate exposures in two IHCs (Gaughan et al., 2008; Gaughan, Piacitelli, et al., 2014; Gaughan, Siegel, et al., 2014; Leonard et al., 2007).

Field Issues for Evaluating the Cardiorespiratory Health of Wildland Firefighters

To successfully design and implement an epidemiological study in the organizationally and logistically complex wildfire environment, a number of field issues had to be anticipated, communicated, and managed. From 2004 through 2006, NIOSH public health practitioners applied epidemiological methods to monitor the respiratory health status of affected firefighters by collecting medical and exposure data preseason, during a wildfire or prescribed fire setting, and postseason (in October, a minimum of 2 weeks' postfire exposure) consisting of all members of two Type 1 IHCs employed by the National Park Service. The Alpine IHC of Rocky Mountain National Park was studied preseason; for 7 days while fighting the Boundary Fire (Fox, AK, July 2004), which was a very large and intense wildfire; for 7 days while working the Tuolumne Grove Fire (Yosemite National Park, CA, October 2005), a less intense prescribed burn; and for 6 days while fighting the Red Eagle Fire (Glacier National Park, MT, August 2006), a large wildfire.

In addition, the Arrowhead IHC of Sequoia and Kings Canyon National Parks was studied preseason and for 3 days while fighting the South Sundance Fire Complex (Sundance, WY, July 2005), a smaller wildfire that was nearly completely contained during the period of testing. Preseason participation was 100% for both crews in all years. In May 2011, a follow-up study of the Alpine IHC was conducted by the Harvard School of Public Health and NIOSH. This cross-sectional survey expanded the medical data collection to include measures of arterial stiffness and oxidative stress.

Consistent with the essential public health service of communicating effectively and the essential public health service of strengthening, supporting, and mobilizing communities and partnerships to improve health, members of the wildfire research team made formal presentations and question-and-answer sessions to each crew at the beginning of each fire season detailing the proposed health study methods. Written informed consent was obtained from each crew member. End-of-season presentations about the study results to date were made to each crew at the conclusion of each fire season. Similar presentations were made as well to the NIFC, the DOI, and the USFS stakeholders at various times during the study. In addition, a daylong workshop of stakeholder experts was held in March 2005 at the NIOSH to discuss the first-year results and future study plans in detail.

In addition, consistent with the essential public health service to build and support a diverse and skilled public health workforce, the NIOSH trained the occupational health technicians who conducted lung function testing on federal WLFFs. This was part of the larger medical standards program to ensure safety that has been established by the DOI (see www.nifc.gov/medical_standards/Program/index.html). The technicians received the 16-hour NIOSH spirometry certification at no cost. Following training, the technicians were provided with the spirometry equipment and supplies. The technicians submitted spirometry test results (tracings) for quality review by the NIOSH for 1 year. Feedback from trained NIOSH experts was then provided back to technicians.

As public health practitioners who were external partners to the formal wildland fire ICS, the NIOSH investigators undertook a number of steps to become familiar with, and to become qualified to participate in, the details and procedures of wildland firefighting. These actions are consistent with the essential public health service to build and support a diverse and skilled public health workforce and can serve as an example to other public health practitioners who may want or need to become directly involved in emergency response involving specialized situations. NIOSH technicians began by becoming certified in Basic Firefighter Training and Wildland Fire Behavior (S130/190) and Introduction to the Incident Command System (ICS-100) at the Arizona Wildfire Academy, Prescott, Arizona; the Colorado Wildfire Fire and Incident Management Academy, Alamosa, Colorado; the Utah Fire and Rescue Academy, Orem, Utah; and the local USFS, Morgantown, West Virginia. The National Fire Academy S130/190 and the ICS-100 courses are also now available online (U.S. Fire Administration, n.d.). Field technicians were also fitness-rated at the moderate level in what is known as the Work Capacity Field Test (WCFT; Figure 9.1). This test involves walking two miles in 30 minutes wearing a 25-lb weight vest and is an annual requirement of the National Wildfire Coordinating Group (2021). The WCFT was administered in the spring by the local USFS preceding preseason data collection.

Figure 9.1 NIOSH wildland fire research team members preparing for participation in wildfire field activities by taking the U.S. Forest Service's annual Work Capacity Field Test, Morgantown, West Virginia.

Medical Data of Interest

Medical field technicians on the wildland fire research team collected questionnaire data, blood pressure, spirometry, bronchial hyperresponsiveness, exhaled breath carbon monoxide (CO), blood, urine, pulse wave velocity for arterial stiffness assessment, and sputum and nasal lavage for markers of inflammation (Figure 9.2).

Additionally, to diagnose and investigate public health problems associated with affected firefighters, spirometry and exhaled breath CO were collected pre- and post-shift (Figure 9.3). Samples were placed on dry ice and shipped overnight to the NIOSH in Morgantown, West Virginia, for processing. Technicians collecting spirometry had completed the NIOSH 16-hour spirometry certification training course (NIOSH, 2020b), and all were trained in their designated procedures following standard manual of procedures (MOPs).

Environmental Data of Interest

To understand the concentrations and composition of smoke to which the firefighters were exposed, personal and area sampling devices were provided to

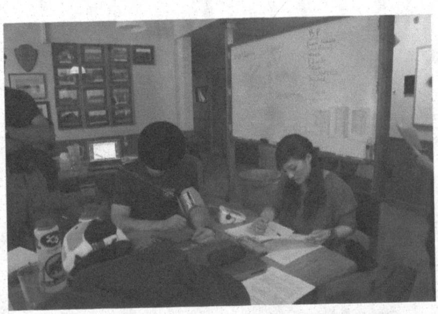

Figure 9.2 A wildland fire research team member applies epidemiology skills by collecting preseason medical data from an IHC crewmember at the Alpine IHC home base, Rocky Mountain National Park, Estes Park, Colorado.

Figure 9.3 A wildfire research team member meets with IHC crewmembers to conduct pre-shift exhaled breath CO testing at the Boundary Fire, Fox, Alaska.

the crews by the NIOSH investigators. Figure 9.4 shows research team members packing field equipment into the fire area.

Environmental field technicians collected sets of aerodynamically size-selected aerosol samples using the **Micro-Orifice Uniform Deposit Impactor (MOUDI)** model 110 with rotator (MSP, Inc., Minneapolis, MN) for area samples. Each Hotshot agreed to wear a personal real-time (RT) personal breathing zone CO monitor (Industrial Scientific Corporation, Oakdale, PA); and one of the following: a filter cassette with a 10-mm nylon respirable cyclone to measure respirable particulate concentration and either a respirable levoglucosan (LG, an indicator of burning biomass) concentration or a respirable crystalline silica concentration; a personal cascade impactor to measure particle size distribution, total concentrations of particulates and LG, and respirable concentrations of particulates and LG; or a personal DataRAM monitor (Thermo Scientific Corporation, Franklin, MA) to measure RT particulate in the size range of 0.1 to 10 µm. NIOSH environmental field technicians shadowed the crews, periodically checking the personal and area samplers for the duration of the shift. At the conclusion of the work shift, the samplers would be returned to a technician

Figure 9.4. Wildfire research team members packing field equipment into the fire area at the Boundary Fire, Fox, Alaska.

Figure 9.5 View of the Alpine IHC approaching the fire line at the Tuolumne Grove Fire, Yosemite National Park, California.

staying at a local hotel who would charge the pumps and place the filters on nitrogen or dry ice for shipment back to the NIOSH in Morgantown, West Virginia, for processing. Figure 9.5 shows sampler-equipped firefighter crew members approaching a fire line.

Laboratory Issues for Evaluating the Cardiorespiratory Health of Wildland Firefighters

To successfully design and implement an epidemiological study in the organizationally and logistically complex wildfire environment, a number of laboratory issues had to be anticipated, communicated, and managed. The following sections describe both general and specific thought processes and actions that were taken in the NIOSH respiratory studies. These can serve as an example for public health practitioners who may be faced with the coordination of laboratory issues in their own areas of emergency response practice. Planning and cooperation between the principal investigators, the team leaders of the laboratory, and the skilled technicians who carry out the research are crucial for the success of the project. As part of the laboratory team's goals they must keep in mind the 10 essential public health services. Assessment and monitoring of the health status of WLFF populations are performed by the field team. Investigation, diagnosing, and identifying hazards affecting the WLFF population are performed through literature searches and epidemiology studies. Communicating effectively to inform and educate people about the hazards will come through the publication of findings in scientific journals and presentations of data at conferences. Strengthening, supporting, and mobilizing communities and partnerships to improve health will be a result of information and data the laboratory investigation provides. While the laboratory cannot create and implement policies and laws, the data and findings are used to establish these through recommended exposure limits and hazard identification. The laboratory findings and publications will provide a basis for legal and regulatory actions designed to improve and protect the public's health. The identification of specific hazards and biological pathways involved can help assure an effective system of individual services and healthcare. Up-to-date training and the use of standard operating procedures as well as good laboratory practice will build and support a diverse and skilled public health workforce. Providing ongoing training, attending relevant conferences, and staying abreast of other scientific research will improve and innovate public health functions resulting in continuous quality improvement. Effective interactions and communication between the field team and the laboratory team can build and maintain a strong organizational infrastructure for public health.

Project Planning for Sample Collection and Analysis

The first questions that need to be addressed in any occupational health study are, why are we doing this study, what questions do we hope to answer, and what strategy will we implement to accomplish our goals? The strategy to answer these questions will help determine the biological and toxicological endpoints to be measured and must be developed by the principal investigator or team leader. The laboratory must also look at the assets they have; personnel, equipment, instruments, and laboratory skill sets will all be used in assessing possible endpoints. Once the goals, strategy, and endpoints have been determined it is important for the laboratory team and field team to meet. Encouraging all personnel involved to see not just their individual responsibilities but also the "big picture" is essential for idea exchange, independent thinking and maximizing individual contributions to the project.

Communication is the most important aspect in any situation where field teams and laboratory teams are working together. It is vital that both groups work together and prepare for the study as thoroughly as possible prior to its start. The field team must understand what sample types the laboratory will need and how they will be treated, handled, and shipped back to the laboratory. The laboratory must recognize that the field team will be working in difficult, even dangerous, conditions, and once on-site they may have very limited access to electrical power, refrigeration, or any supplies or materials that they may run short of. Communication starts with both teams, or team representatives, meeting and discussing the sampling strategy and requirements. The laboratory team should present a prioritized "wish list" of analysis endpoints, and together both teams can access what they can realistically collect. Items to be considered include samplers, collection materials, sample volume, sample storage, and sample shipment back to the laboratory. Samplers can be heavy and may require batteries or generators to take collections. The field team may also only be able to deploy a limited number of these samplers. Personal samplers are smaller but also require batteries, time, and a trained individual to place them on the firefighters (Figure 9.6).

All samplers require some sort of filter and replacement filters, which require proper storage and handling to prevent contamination before use, as well as proper installation into the sampler. The laboratory and field teams need to agree on the volumes to be collected based on the time on-site and materials present. This will allow the laboratory team to determine number and types of endpoints they can measure and prioritize them. Handling and storage of samples will be a challenge in the field environment. Will the samples need to be refrigerated, frozen, or stored under a special head gas? These needs may necessitate coolers, blue ice, dry ice, and special gas tanks. The research team must ask the field team if these needs can be met. Shipping of the samples must also be considered. What kind of access to shipping points does the field team have,

Figure 9.6 Wildfire research team member installing a personal air sampler on a wildland firefighter at the Red Eagle Fire, Glacier National Park, Montana.

or will they directly carry the collected samples back to the laboratory when they return from the site? Labeling is paramount for effective communication between field and laboratory teams. Both teams must agree on a simple, clear method for labeling the samples in order to avoid any confusion and assist in a smooth transition from field to laboratory. Filters, tubes, bottles, or any other collection vessels should be pre-labeled before going into the field to avoid mistakes. Sitting on a mountainside in 90-degree heat with your eyes watering from smoke exposure may make a simple task in the laboratory difficult in the field.

Skills needed for this area of the project are leadership, strategic planning, interpersonal communication, and organizational management.

Goals of the Laboratory Research Team

Determining the research strategy generates a selection of productive endpoints. The chosen endpoints then dictate sample types and sample volumes to possibly be collected by the research team. Beyond the physical dangers, WLFFs are exposed to a variety of inhaled hazards (Broyles, 2013). These inhaled hazards can vary depending on location, material of burn, temperature of burn, and weather conditions (EPA, 2021). Wildfire smoke particle toxicity depends on volume, size of particles, and chemical makeup. Important characteristics of inhaled particle toxicity are particle size and aerodynamic diameter, which together determine how far into the respiratory tract a particle can penetrate and be deposited. Different locations in the respiratory tract have different methods of dealing with and clearing particles as well as various sensitivities to their effects. The chemical characteristics of a particle are also important in determining its toxicity once it is deposited in the respiratory tract (Cheng et al., 1999). Is it soluble, insoluble, or persistent? Soluble particles may transmit their components into the bloodstream or other areas of the respiratory tract, while persistent particles may cause chronic conditions (Tarlo, 2012). As shown in Figure 9.7, there are three basic regions in the respiratory tract: nasopharyngeal (nose, sinuses, pharynx), tracheobronchial (trachea, upper bronchus), and pulmonary (bronchioles, alveoli).

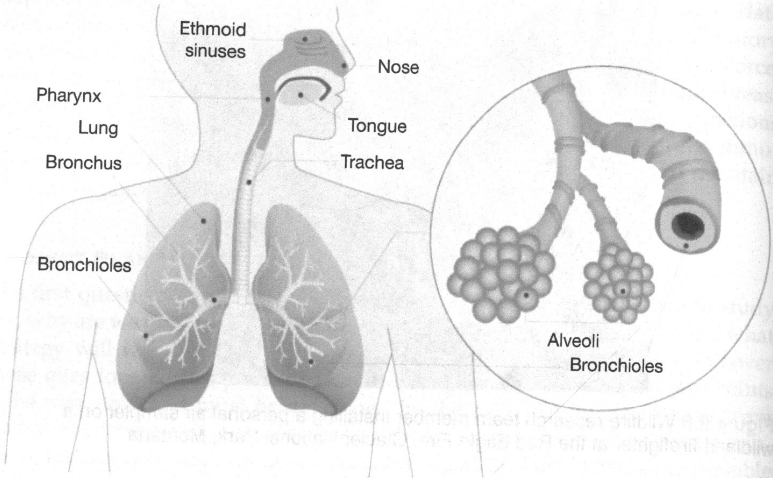

Figure 9.7 Respiratory tract showing major areas of possible exposure.

Clearing particles from these areas takes different forms. The mucociliary escalator covers most of the bronchi and bronchioles. It is composed of mucus-producing goblet cells and ciliated epithelium particles that are trapped in the mucus; cilia movement directs the particles into the pharynx, where they are swallowed and cleared (Stuart, 1984). If a particle is inhaled and deposited in the pulmonary region, which is composed of the lung's small bronchioles and alveolar sacs, the particle encounters a sensitive, high surface area environment specifically designed to absorb. The alveolar sacs are made up of a thin layer of cells and therefore it is relatively easy for toxins to cross into the bloodstream. This area is defended by macrophages that engulf and destroy most particles and bacteria; however, persistent particles can remain in the alveolar sacs and may cause chronic toxic conditions (Oberdörster et al., 1994). These physical and chemical characteristics of the particles are factors that the laboratory must consider when planning their analysis.

Skills needed for this part of the study are a comprehension of physics and a grasp of how surface area influences particle behavior in the respiratory tract, of the chemistry of particles and how this can impact their toxicity, and of basic human physiology and structure of the bronchopulmonary zone.

Type of Exposure Model

An important part of the particle analysis and testing is deciding whether to use either **in vitro or in vivo** testing. In vitro assays include those performed or taking place in a test tube, culture dish, or elsewhere outside a living organism. These can include chemical, enzymatic, cellular, and ex vivo organ systems. In vitro systems can provide good models of reaction systems if properly used. They provide testing for determination of initial toxicity and dosages without using animals. In vitro assays can also provide valuable mechanistic information of biological pathways involved in reactions. When using in vitro cellular systems there are many choices available. Cell lines provide relatively durable cells which can be grown in media and used in exposure assessments (D. D. Allen et al., 2005).

One disadvantage of cell lines is that they are transformed cells and may not provide an accurate model of cells in living systems. Primary cells are cells that are taken directly from living tissue and established for growth in vitro (Roggen, 2011). This increases their relevance as a model of living systems, but they are more challenging to culture. Both cell lines and primary cells have advantages and drawbacks, so the selection of an in vitro cellular system is dependent on experimental conditions. In addition to different cellular systems, cells themselves can be grown and maintained in a variety of ways. Cells can be grown in a suspension of media, on the surface of culture plates while immersed in liquid media, or even in an air–liquid interface, where the top surface of the cell is exposed to the atmosphere while the base of the cell is bathed in media (Lacroix et al., 2018). Air–liquid interface cell culture allows direct access to the cells for vapor, gas, and small particle exposures.

In vivo animal models can provide a "whole system" approach to test exposures, and the interaction of multiple biological pathways can be measured at once (Nemmar, 2013). Crosstalk between various biological systems through signaling can influence modulation of an organism's response. In vivo systems can also provide information for short-term, long-term, and repeated exposures as well as chronic outcomes, none of which may be an option with in vitro systems. Exposures can be accomplished through inhaled material, intratracheal instillation, dermal exposures, injection, and ingestion. The use of animals in research carries tremendous ethical responsibility for their proper care, handling, and use. When animal exposures are used, the researcher must try to maximize the number of useful endpoints that can be obtained from each animal. Before any animals are ordered, the researcher must also provide a protocol to their Institutional Animal Care and Use Committee (IACUC), which will review the plan. In addition, the researcher must establish the reasoning behind the study, need for the study, novelty of the study, and statistical justification for the number of animals requested. This is usually a multi-step procedure with the IACUC adding refinements and clarifications throughout the process. Only once the researcher has shown animal use justification and proper animal handling techniques are they permitted to use animals in the project. The in vitro or in vivo system that the laboratory uses depends on the skills and instrumentation laboratory members possess, as well as the experimental model and specific aims of the study.

Skills needed include cell culture techniques, sterile method, dilution calculations, IACUC-certified courses on specific animals used, and animal anatomy knowledge.

Sample Characterization

Particles and fumes that penetrate into the respiratory system may have multiple effects and potentially cause varied types of toxicity and damage. The following is an example of the sample analysis plan we developed for wildfire smoke; however, this is not meant to be an all-encompassing strategy. Each situation will need to have a unique sampling and analysis plan developed by the research team.

For our wildfire study, airborne particles were collected and separated into discrete sizes using an MOUDI, including using a specialized nano-MOUDI device to collect particles in the ultrafine (smaller than 100 nm) size range

(Leonard et al., 2010; Figure 9.8). The MOUDI separates particles based on their size, which allows the researchers to understand which particles may penetrate to different depths in the respiratory system.

The MOUDI impactors are used for collecting size-fractionated particle samples in the 0.056 to 10 μm aerodynamic diameter range, which can be used for the collection of particles for gravimetric and/or chemical analyses. The different MOUDI models can hold different numbers of size stages, and the classic MOUDIs hold various impaction stages and cut sizes. Particle deposits are collected on standard 47-mm substrates that can be analyzed to determine mass or examined via chemical analysis or microscopy. Nano-MOUDIs increase the size range and number of fractions that can be captured. Personal cascade impactors are smaller devices that can be worn on an individual. Figure 9.9 illustrates the value of using particle size–selective sampling to characterize the wildfire aerosols.

An additional important aspect of the sample collection is the type of filter used in the aerosol impactors. Filter types should be compatible with both the collected material and the endpoint analysis to ensure there is no chemical interference from the filters themselves.

Wildfire smoke contains many different elements and characteristics. Because no two smoke samples are identical, we wanted to develop a broad analysis plan to investigate wildfire smoke's possible effects. Potential methods in particle characterization include mass spectrometry, x-ray diffraction, the

Figure 9.8 MOUDI particle collector (left) and MOUDI being set up by wildfire research team members in the field (right).

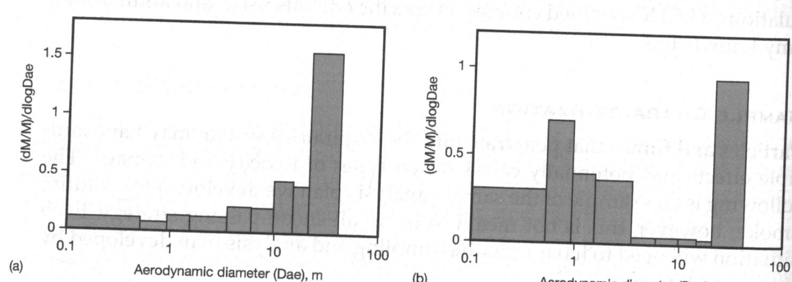

Figure 9.9 Normalized personal cascade impactor particle size distributions for (A) airborne particle mass and (B) airborne levoglucosan. Note that airborne particle mass is mostly associated with larger particles, while airborne levoglucosan is bimodally distributed.

Brunauer–Emmett–Teller (BET) method, and dynamic light scattering (DLS). Mass spectrometry separates isotopes, molecules, and molecular fragments according to mass (El-Aneed et al., 2009). The sample is vaporized and ionized, and the ions are accelerated in an electric field, deflected by a magnetic field, and launched into a curved trajectory yielding a distinctive mass spectrum. This can be matched to known samples, and the elemental profile of the sample can be determined. X-ray diffraction scatters x-rays through the regularly spaced atoms of a crystal, which obtains data about the structure of the crystal (Ameh, 2019). The BET method uses the physical adsorption of gas molecules on a solid surface for the measurement of materials, specific surface area (Gelb & Gubbins, 1998). DLS can be used to measure particle size down to the nanometer (Stetefeld et al., 2016).

In our wildfire study we first investigated the smoke's basic reactivity. When a smoke particle interacts with the lung, how could it react? Many particles were found to contain Fe2+ or other transition metals that can generate **free radicals** upon exposure to cells (Leonard et al., 2007). The high heat and freshly generated nature of wildfire smoke potentially make it likely to contain reactive materials. Therefore, a free radical analysis on the samples was performed using several methods: electron paramagnetic resonance (EPR; Davies, 2016), measurement of intracellular reactive oxygen species (ROS; Halliwell & Gutteridge, 2015), and the comet assay (Glei et al., 2016). A free radical is an uncharged molecule, typically highly reactive and short-lived, having an unpaired valence electron. In biology, a primary interest is the hydroxyl and superoxide radicals. It is important to note that radicals play an important role in a healthy biological system and are not always damaging. Hydroxyl radicals are an important part of the cellular defense system and superoxide radicals are integral to the mitochondrial electron transport chain, which is essential for generating cellular energy (Cogliati et al., 2018). Balancing these radicals in cellular systems is important. If the redox state is out of balance then the cells can accrue damage (Figure 9.10).

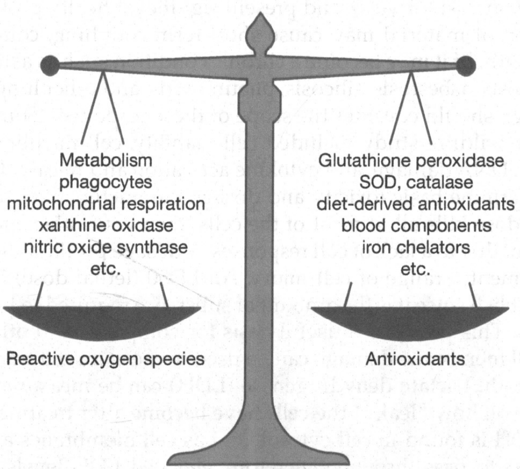

Figure 9.10 Illustration of how the ability of the body to balance radical generators and radical scavengers is important to overall health.

SOD, superoxide dismutase.

Free radicals can be detected by EPR in chemical, enzymatic, cellular, organ, and whole-body systems. As part of our wildfire study we used EPR in chemical and cellular systems. We first reacted wildfire smoke with hydrogen peroxide and macrophage cells to measure the basic reactivity of the smoke (Leonard et al., 2007). The wildfire smoke may react with the hydrogen peroxide to generate hydroxyl radicals. With the addition of a "spin trap," in this case 5,5-dimethyl-1-pyrroline N-oxide (DMPO), we can trap and measure the radicals. If the smoke does generate hydroxyl radicals, then we can determine its relative reactivity and ability to produce damaging radicals. Other assays and spin traps can measure superoxide radicals and nitroxide radicals. Superoxide radicals can be measured using EPR with the spin trap 5-(diethoxyphosphoryl)-5-methyl-1-pyrroline-N-oxide (Halliwell & Gutteridge, 2015) or by using various cell-staining methods. Nitroxide radicals can be measured using EPR and using light emissions such as luminescence and fluorescence. Depending on the study goals and laboratory capabilities, these assays may be used in your study.

Skills needed include a background in chemistry and physics and knowledge of chemical analysis, particle-sizing techniques, and materials testing.

Exposure Endpoints of Interest

As part of your initial proposal, it is critical to determine the endpoints that you wish to measure as part of your specific aims. These depend on the lab's abilities and the scope of the project. How many personnel do you have available for the study? How much sample do you have to work with? Are you looking at acute, chronic, or both types of endpoints? Are you using an in vitro or in vivo model? What is the timeline for obtaining finished results? All these questions will help you devise your endpoints and the data you will gather to address your specific aims.

The effects of inhaled material may be acute, eliciting a quick response, or chronic, either persistent for a long time or constantly recurring. Acute effects may exist only for a short duration, and recovery time may be brief, whereas chronic effects may last for years and present significant health problems (Tarlo, 2012). Inhalation of material may cause short-term coughing, congestion, and shortness of breath, or it may become a chronic condition such as asthma, COPD, pulmonary fibrosis, asbestosis, silicosis, pneumonitis, and other lung conditions. The study design should consider the scope of these responses. Some endpoints we used in our wildfire study included cell viability, cell membrane damage, redox reactions, DNA damage, and cytokine activation and release. Cell viability is useful to determine basic toxicity and dosage parameters (Stoddart, 2011). If your intended dose kills all or most of the cells, then your other measurements will be irrelevant due to a lack of cell responses. A dosage profile should be determined to document a range of cell injury. An LD50 (lethal dose) is a valuable measure to establish since it is the amount of substance required to kill 50% of the test population. This provides a useful basis for comparison to other exposure substances. Cell membrane damage can be used to measure cell trauma that did not result in death. Lactate dehydrogenase (LDH) can be measured in exposed cells as a gauge on how "leaky" the cells have become after treatment (M. Allen et al., 1994). LDH is found in cell cytosol, and as cell membranes are damaged, they allow LDH to pass through. Therefore, elevated LDH levels indicate cell membrane damage. Redox reactions and measurement of a cell's redox state can give information of the health of a cell as well as what it may be responding to and signaling to other cells. As mentioned earlier, EPR is one method we used in our study for measuring free radicals in cells; however, others included hydrogen peroxide and intracellular ROS determination. Hydrogen peroxide, while not a radical, is considered an ROS and provides a precursor for the hydroxyl radical. Elevated levels of hydrogen peroxide can indicate the activation of cellular defenses and an increased redox potential. Measurement of intracellular ROS utilizes the stain dichlorofluorescein (DCFH). This stain is a probe that can penetrate cell membranes and is easily oxidized to fluorescent dichlorofluorescein (DCF)(Aranda et al., 2013). Measurement of this fluorescence can be used to determine the redox state of the exposed cells. The ability of wildfire smoke to cause cellular DNA damage was measured utilizing the comet assay (Glei et al., 2016). The comet assay uses a layer of gel which the cellular DNA is drawn through by applying an electric charge. The electric charge causes material to migrate through the gel, and the smaller a component is, the less resistance present, and the faster it will move through the gel layer. Undamaged DNA will remain in one continuous ribbon and move as one mass. Damaged DNA will be broken up into sections of various sizes that will be viewed as a smearing of broken DNA as it is drawn through the gel at various rates. As shown in Figure 9.11, this results in undamaged DNA appearing as a ball while damaged DNA looks like a comet possessing a tail of DNA pieces smearing behind the central mass.

Our wildfire study also included measurement of cytokines. **Cytokines** are any number of substances, such as interferons, interleukins, and growth factors, which are secreted by cells and influence other cells (Dinarello, 2000). There are many types of cytokines with various functions. Cytokines can be induced by oxidative stress and subsequently trigger the release of other cytokines. This may lead to increased oxidative stress and gives them an important role in chronic inflammation, as well as other immunoresponses. In contrast, cytokines can also play a role in anti-inflammatory pathways and are possible therapeutic treatments for pathological inflammation or peripheral nerve injury. There are both pro-inflammatory and anti-inflammatory cytokines which regulate these pathways, and an imbalance in these cytokines can lead to cell and tissue injury. Cytokines are usually measured using an **enzyme-linked immunosorbant assay (ELISA)**. ELISAs use a capture antibody on a solid support, generally one well of a 96-well plate (Figure 9.12), that pulls cytokines out of a biological fluid and permits the measurement using a colorimetric, chemiluminescent, or fluorescent signal. When examining oxidative stress, useful cytokines to measure are IL-1β, IL-6, IL-8, and TNF-α. IL-1β is an important mediator of inflammatory response, and it is involved in a variety of cellular activities, including cell proliferation, differentiation, and apoptosis. IL-6 can act as both a pro-inflammatory cytokine and an anti-inflammatory myokine. IL-8 has two primary functions. First, it

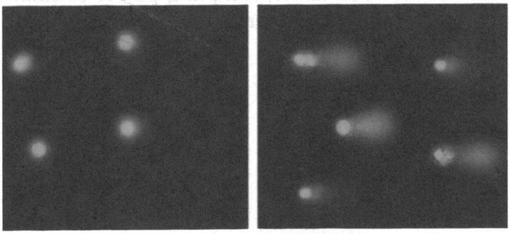

Figure 9.11 Comet assay control DNA (left) and wildfire smoke-exposed DNA (right).

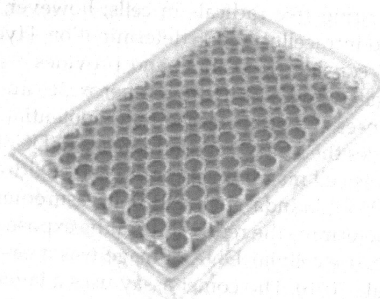

Figure 9.12 An example of a 96-well plate.

induces chemotaxis in cells, causing them to migrate, and second, it stimulates phagocytosis. TNF-α is involved in systemic inflammation and is one of the cytokines that make up the acute phase reaction. Our wildfire study plan is just an example of how different assays can be assembled to form research goals. In addition to what was mentioned, there are many other assays and methods that can be used for sample analysis and toxic response determination.

Skills needed include biology, chemistry, biochemistry, cell physiology, physiology, specific instrumentation knowledge, and specific assay protocols.

Data Analysis and Presentation of Finding

As part of your initial study plan, the statistician will help you determine the proper number and layout of samples you will need in order to provide statistical power to your results. Data analysis will include statistical models that allow you to determine the significance of differences in your results. Observing a difference in raw data isn't adequate to produce a statement about the research, so the data must be statistically analyzed to determine significance.

At the end of your study you will need to communicate your findings to other scientists, academic institutions, government agencies, occupational organizations, and the people directly involved with the exposures. Communication methods for your findings include presenting a poster at a meeting, giving an oral presentation, or publishing a paper. Posters and oral presentations permit for interaction between the presenter and audience, allowing follow-up issues to be addressed. Published papers undergo a peer-review process before release and allow a wide audience to view your results.

Skills needed include math, statistics, sampling power calculation, scientific writing, graphical presentation, oral presentation, and communication.

DISCUSSION QUESTIONS

1. Are wildfires related to climate change? Defend your position.
2. Discuss other ways to protect firefighter health.
3. Laboratory professionals provide vital services in public health. Discuss some of the ways laboratory professionals work behind the scenes.
4. Explore and research laboratories in your geographic area as a class project. Where are they located? What services do they provide? How do they communicate with public health departments? What disease is most frequently reported at labs in your area?

SUMMARY

TABLE 9.1 Select Essential Services of Public Health Demonstrated in the Wildfire Response

Essential Service # and Definition	Context in Chapter Case	Competency # It Ties to	Importance for Emergency Preparedness, Response, or Recovery
1. Assess and monitor population health status, factors that influence health, and community needs and assets (Assessment)	Assessment and monitoring the health status of wildland firefighter (WLFF) populations.	2, 3, 4	The health and well-being of firefighters must be considered in any community's preparedness and response plans. Firefighters provide direct services in emergencies. Jurisdictions should have comprehensive plans to assess fire exposure hazards and complications in its firefighter workforce.
2. Investigate, diagnose, and address health problems and hazards affecting the population (Assessment)	Investigating, diagnosing, and identifying hazards affecting the WLFF population via literature searches and epidemiology studies	1, 2, 3, 4	Based on previous studies and evaluation data, communities must anticipate and plan for treating firefighters on the front line of an event. In addition, epidemiologists and health scientists can report findings in presentations and publications to inform public health policies.
3. Communicate effectively to inform and educate people about health, factors that influence it, and how to improve it (Policy Development)	Communicating effectively to inform and educate people about the hazards	18, 19	Advance warning of the imminent threat of an advancing wild fire is essential for protecting communities in its path. Public health officials must also provide education to their constituents on how to protect themselves in the event of wildfires. Appropriate messages must be developed in advance and be ready to disseminate.
5. Create, champion, and implement policies, plans, and laws that impact health (Policy Development)	Data and findings are used to establish policies through recommended exposure limits and hazard identification.	4, 5	Policies, plans, and laws in place before a wildfire event can aid in a rapid response, reducing bureaucratic delays in decision-making. Knowledge of who is in charge of specific activities and required approvals can eliminate time wasted when boots on the ground are necessary.
8. Build and support a diverse and skilled public health workforce (Assurance)	Up-to-date training and use of standard operating procedures as well as good laboratory practice	21, 22	Laboratory technicians are in demand in public health. Jurisdictions are often short of the laboratory professionals they require for rapid processing of samples to detect disease outbreaks and identify trends. In addition, many schools of public health have eliminated or reduced training programs. Building laboratory capacity should be a priority for public health.
9. Improve and innovate public health functions through ongoing evaluation, research, and continuous quality improvement (Assurance)	Providing ongoing training, attendance at relevant conferences, and staying abreast of other scientific research	1, 2, 3, 4	Public health professionals interested in wildfire response can contribute by conducting evaluations of events using data from responses to inform program and policy improvement. Long-term research could be conducted on related issues, such as erosion and mudslide, in appropriate areas. Causes of wildfires is another area of inquiry that could be undertaken by health scientists.
10. Build and maintain a strong organizational infrastructure for public health (Assurance)	Effective interactions and communication between the field team and the laboratory team	21	Building laboratory capacity should be a high priority in all jurisdictions. Laboratory technology is changing rapidly with computer applications and diagnostic tests based on DNA analysis. Constant review and upgrades to laboratory processes are essential efforts to maintain quality.

TABLE 9.2 Select CEPH Competencies Needed for Frontline Health Workers, Managers, and Leaders for Wildfire Emergency Preparedness, Response, and Recovery

Competency # and Definition	Context in Case/Chapter	Level	Importance for Emergency preparedness, response, or recovery
2. Select quantitative and qualitative data collection methods appropriate for a given public health context.	Medical field technicians collect questionnaire data, blood pressure, spirometry, bronchial hyperresponsiveness, exhaled breath carbon monoxide (CO), blood, urine, pulse wave velocity, and sputum and nasal lavage.	Level 1	Frontline data and specimen collectors provide the basic units of analysis for all biological tests. These public health professionals are indispensable for all scientific inquiries. They are skilled in medical procedures. Frontline scientists, who collect data through surveys, are equally important for gathering information for surveillance and decision-making.
4. Interpret results of data analysis for public health research, policy, or practice.	Local U.S. Forest Service administered Work Capacity Field Test to field technicians for fitness rating.	Level 2	Midlevel managers and supervisors partner with staff at Level 1 to ensure quality of methodologies is maintained, offer day-to-day guidance and oversight to teams, and use collected and analyzed data for decision-making.
7. Assess population needs, assets, and capacities that affect communities' health.	Occupational health technicians trained by the NIOSH to conduct lung function testing on Federal WLFF	Level 1	Skilled professionals at this level interact with affected populations to administer vital assessments to address public health problems.
13. Propose strategies to identify stakeholders and build coalitions and partnerships for influencing public health outcomes.	A day-long workshop of stakeholder experts was held in March 2005 at the NIOSH to discuss the first-year results and future study plans in detail.	Level 2	Managers and supervisors plan strategies to collaborate with stakeholders and create opportunities for communities and public health professionals to meet and share knowledge and concerns.
16. Apply leadership and/or management principles to address a relevant health issue.	NIOSH worked with the U.S. National Response Team and federal agencies, state health departments, labor unions, and volunteer emergency responder groups to develop the Emergency Responder Health Monitoring and Surveillance™ framework.	Level 3	Public health agency leaders collaborate with other agency level leaders and make the decisions and policies, based on the ground work and data results provided by Levels 1 and 2, to advocate for policies and practices to benefit the public's health.
19. Communicate audience-appropriate (i.e., non-academic, non-peer audience) public health content, both in writing and through oral presentation.	Members of the wildfire research team made formal presentations and question-and-answer sessions to each crew at the beginning of each fire season detailing proposed study methods.	Levels 1, 2, 3	All levels communicate in their respective audiences and have important roles for conveying health security information to the public, to community collaborators, to the media, to agency partners, and to others. Each level crafts messages appropriate for the recipient audience.

Key: Essential services of public health; CEPH competencies; Leadership levels.

WLFF, wildland firefighters

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We dedicate this chapter to the memory of all WLFF who have been injured or lost their lives in the line of duty.

DISCLAIMER

The findings and conclusions in this report are those of the authors and do not necessarily represent the views of the National Institute for Occupational Safety and Health, Centers for Disease Control and Prevention, the NIH, or the USDA. Mention of any company or product does not constitute endorsement.

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Dedicated to the courageous public health professionals, healthcare personnel, and frontline workers who have tirelessly and sacrificially worked to combat the pandemic of COVID-19 at local, state, national, and international levels to save lives, alleviate suffering, and prevent disability.

Dedicated with love to my daughter . . . Lois J. Sharpe, Summa Cum Laude and Phi Beta Kappa graduate of Agnes Scott College and currently a third-year medical student at the Morehouse School of Medicine. You are truly my inspiration!
—Tanya Telfair LeBlanc, PhD, MS

Dedicated to my wife, Han Ju, for her always kind support and encouragement for my coediting of this book amid the pandemic of COVID-19. What a bounty!
—Robert Kim-Farley, MD, MPH