Wildland Firefighter Smoke Exposure and Risk of Lung and Cardiovascular disease

NORTHERN ROCKIES FIRE SCIENCE NETWORK

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Wildland firefighters are exposed to health hazards including inhaling hazardous pollutants from the combustion of live and dead vegetation (smoke) and breathe soil dust, while working long shifts with no respiratory protection. This research brief summarizes a study analyzing long-term health impacts of smoke exposure for wildland firefighters (Navarro et al. 2019). The study estimated relative risk of lung cancer and cardiovascular disease mortality from existing particulate matter (**PM**) exposure-response relationships using a measured PM concentration from smoke and breathing rates from previous wildland firefighter studies across different exposure scenarios.

Firefighters dig fire line on the 2017 Rice Ridge Fire in western Montana. Photo by Kari Greer.

Key Findings

- **Firefighters who worked both short and long seasons (49 days and 98 days per year, respectively) were exposed to increased lifetime doses of PM_4 across all career durations (5-25 years).**
- **Wildland firefighters were estimated to be at increased risk of lung cancer (8 to 43 percent) and cardiovascular disease (16 to 30 percent) mortality across season lengths and career durations.**
- **These findings suggest that wildland firefighters should reduce exposure to smoke in any way possible.**

Methods

Wildfire Smoke Exposure-Response Relationship

This study used *exposure-response* (**ER**) relationships to estimate the *relative risk* (**RR**) of lung cancer (**LC**) and cardiovascular disease (**CVD**) mortality from exposure to $PM_{2.5}$ (PM with a diameter of ≤2.5 µm) from smoke. Exposure-response relationships describe the strength of a person's response to a stressor (in this case $PM_{2.5}$) after a certain exposure time. Relative risk is used to understand the risk of an adverse health outcome from an environmental exposure compared to not having the exposure. An RR of greater than 1 suggests an increased risk of an adverse health outcome. For example, an RR of 1.2 indicates a 20% increase in risk of developing a disease from an environmental exposure. Study authors used the following equations developed from Pope III et al. (2011), which were developed for the American Cancer Prevention Study II, to calculate disease risk for wildland firefighters:

Relative Risk of LC = $1+ 0.3195 (\text{Dose of PM})^{0.7433}$

Relative Risk of CVD = $1 + 0.2685 (\text{Dose of PM})^{0.2730}$

Estimation of Lifetime Daily Dose of $PM_{2.5}$

Study authors estimated the lifetime daily dose of wildfire smoke $PM_{2.5}$ from measured concentrations of PM_4 (PM with a diameter ≤4µm). PM_4 provides a close, and likely conservative, approximation of $PM_{2.5}$. The authors estimated wildland firefighter breathing rates based on measured heart rates, daily shift duration, and frequency of exposure. They examined different frequency of exposure scenarios to examine the varied number of days spent on wildfires each year and career length. They used the following equation to estimate the lifetime daily dose of $PM_{2.5}$ from wildland fire smoke for wildland firefighters:

$$Daily\ dose\ PM_4\ (mg) = Exposure\ Concentration\ \left(\frac{mg}{m^3}\right)\ X\ Daily\ Shift\ Duration\ \left(\frac{hrs}{shift}\right)\ X\ Breathing\ Rate\ \left(\frac{L}{min}\right)\ X\ F\ X\ CF$$

$$\text{CF} - \text{Conversion Factors}\ \left(\frac{60\ min}{hr}\right)\ \text{and}\ \left(\frac{m^3}{1000\ L}\right)$$

$$\text{F} - \text{Frequency of Exposure} = \left(\frac{shift\ days\ per\ year}{365\ days\ per\ year}\right)\ X\ \left(\frac{years\ of\ firefighting\ career}{45\ years}\right)$$

The research team consisted of wildland firefighters trained by the USDA Forest Service National Technology and Development Program (NTDP) to collect exposure data and perform direct observations. The research team directly observed each subject (equipped with data recording devices) for the duration of the work shift; they recorded job task performed and daily shift duration (hours per shift). Methods for the collection of PM_4 exposure concentrations were generally consistent with National Institute for Occupational Safety and Health methodology (NIOSH 0600 and 7500). Additional data were used from a separate study, where wildland firefighter breathing rates were calculated from field-measured heart rates while firefighters performed fire operations in the western US from May through September (2013-2015). Breathing rate was calculated using heart rate across the main job tasks performed, using regression equations developed by Valli et al. (2013).

The number of days spent on wildfire assignments per fire season can vary greatly from year to year, and a good data source was lacking for this information. Authors estimated a "firefighter long season" to be 98 days spent on fire assignments (equivalent to seven 14-day assignments) and a "firefighter short season" to be 49 days spend on fire assignments (equivalent to three and a half 14-day assignments). They calculated frequency of exposure using 5, 10, 15, 20, and 25 years for wildland firefighter career duration, adjusted over 45 years, which is the average working career of an individual in the United States.

Results

Table 1 presents the parameters used to calculate lifetime daily dose of PM_4 for the two exposure scenarios: firefighter short season and firefighter long season. Based on field study observations, firefighters worked an average of 13.6 hours per shift. The mean concentrations of PM_4 and crystalline silica (indicator of dust exposure) measured on wildland firefighters was 0.53 mg m^{-3} and 0.026 mg m^{-3}, respectively. After adjusting the measured average concentration of PM_4 to exclude dust, authors determined wildland firefighters were exposed to a mean concentration of 0.51 mg m^{-3} of PM_4 from smoke exposure per shift.

For wildland firefighters, as frequency of exposure, career duration, and days on fire assignment each year (fire days) increased, the lifetime daily dose of PM_4 also increased (Table 1). Firefighters who worked a short fire season (49 days) were exposed to a lifetime daily dose of PM_4 that ranged from 0.15 mg for a 5-year career to 0.74 mg for a 25 -year career, respectively. Lifetime daily dose of PM_4 ranged from 0.30 mg to 1.49 mg for firefighters who worked 5-15 years respectively for a long fire season (98 days).

During mop-up activities, firefighters can be exposed to smoke and dust as they dig out or apply water to extinguish smoldering materials.

Across all exposure scenarios and career durations, the calculated relative risk for lung cancer and cardiovascular disease was greater than 1, indicating an increased risk of mortality from these diseases as a result of smoke exposure (Figure 1). For both firefighter exposure scenarios (short and long season), the risk of lung cancer steadily rose as career length increased. The risk of cardiovascular disease increased sharply for firefighters with 5- to 15-year careers and increased slightly over 20- and 25-year careers.

Discussion

This study estimated lifetime risk of lung cancer and cardiovascular mortality due to exposure to PM_4 from smoke. The analysis measured PM_4 concentration from smoke and estimated breathing rates from extensive field studies of wildland firefighters. Using published $PM_{2.5}$ exposure-response relationships (Pope III et al. 2011), study authors estimated that wildland firefighters had an increased risk of lung cancer and cardiovascular disease mortality, with relative risks greater than 1 across all exposure scenarios and career durations.

Measured heart rates and estimated breathing rates were lower than what might be expected based on work demands and breathing rates reported for previous studies of wildland firefighters. However, firefighters are expected to work at consistent exertion levels for the duration of a shift and are conditioned to meet the physical demands of the job. The estimated breathing rate was comparable to those measured in other studies for trained athletes performing exercise at a relatively mild level. Still, the estimated breathing rate used was lower than previously reported measurements for other wildland firefighter studies, and it likely led to an underestimation for lifetime daily dose and the overall risk calculation.

Table 1. Parameters used to calculate lifetime daily dose of PM_4 for each exposure scenario and relative risk (RR) of lung cancer and cardiovascular disease (CVD).

Exposure Scenario	Shift Duration (hours)	Shift Exposure (mg/m^3)		Breathing Rate (LPM)	Fire Days (Days/Year)	Career Duration	PM_4 Daily Dose (mg)	Lung Cancer	CVD
		Mean	95th Percentile				Mean[a] (95th percentile)	RR[b]	RR[b]
Firefighter Short Season	13.6	0.51	0.64	24	49	5	0.15(0.19)	1.08 (1.09)	1.16 (1.17)
						10	0.30 (0.37)	1.13 (1.15)	1.19 (1.21)
						15	0.45 (0.56)	1.18 (1.21)	1.22 (1.23)
						20	0.60 (0.75)	1.22 (1.26)	1.23 (1.25)
						25	0.74 (0.93)	1.26 (1.30)	1.25 (1.26)
Firefighter Long Season					98	5	0.30 (0.37)	1.13 (1.15)	1.19 (1.21)
						10	0.60 (0.75)	1.22 (1.26)	1.23 (1.25)
						15	0.89 (1.12)	1.29 (1.35)	1.26 (1.28)
						20	1.19 (1.50)	1.36 (1.43)	1.28 (1.30)
						25	1.49 (1.87)	1.43 (1.51)	1.30 (1.320

[a]Daily dose was calculated using the mean and 95th percentile shift exposure concentration.
[b]Relative risk was calculated using the mean and 95th percentile PM_4 Daily Dose.

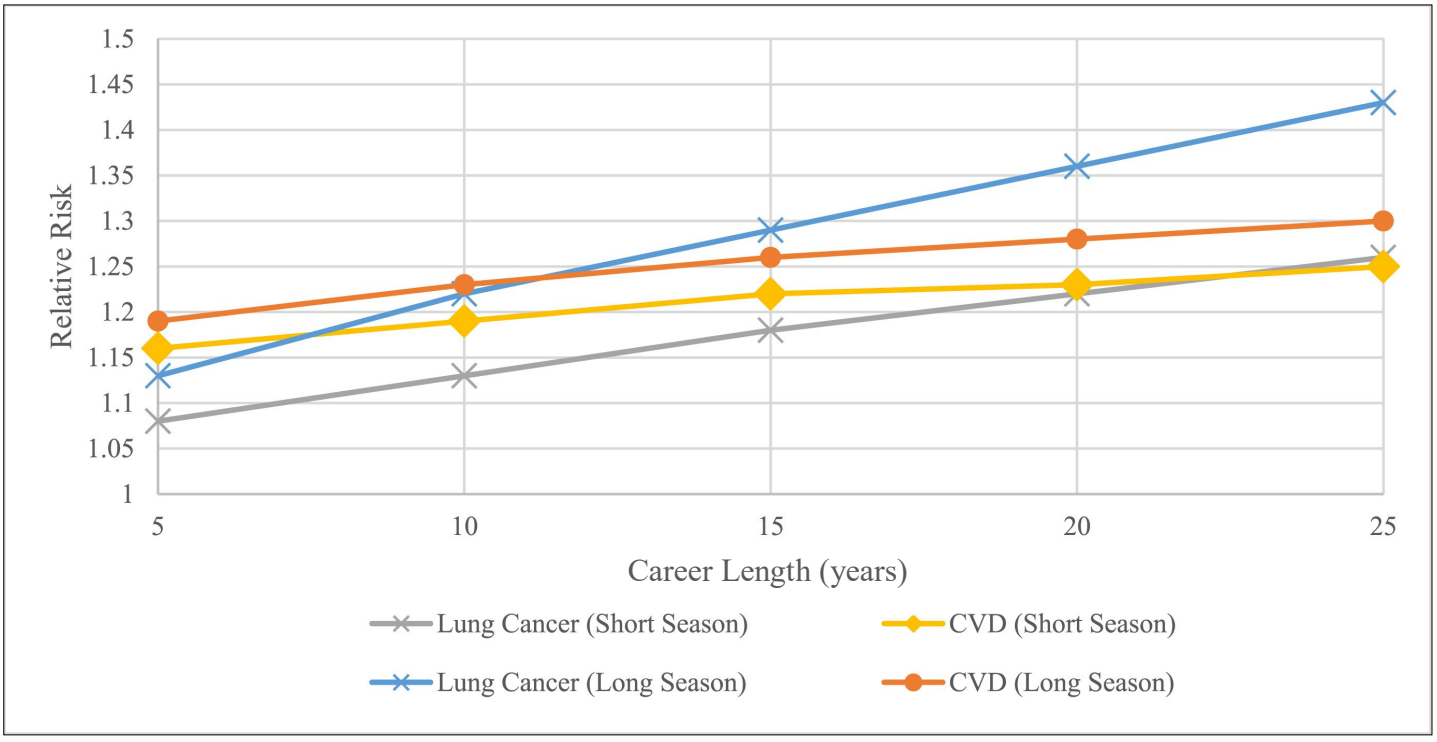

Figure 1. Relative risk of lung cancer and cardiovascular disease across career length.

Limitations of the Analysis

Although this analysis provided a unique approach for assessing long-term mortality risks for two specific diseases, a few limitations were noted by the researchers. Here we highlight two limitations to consider when interpreting these results – Long-term risks associated with PM exposures over a full working career were based on assumptions about exposure concentration, frequency, and duration used to determine a lifetime daily dose. Individual firefighters conduct many tasks and activities over their careers that may influence these assumptions. An alternative approach to provide a more realistic exposure could be to use a weighted average of exposures over the course of a career, possibly adjusted by job title. Secondly, this analysis only considered the size and concentration of PM across exposures to wood smoke, ambient air pollution, and cigarette smoke, and did not address any of the differences in chemical composition of the PM from these sources.

Reducing Smoke Exposure

Over the past 25 years, there have been recommendations to reduce firefighter exposure to smoke in various ways: minimize mop-up where appropriate on a fire line and rotate firefighters in and out of heavy smoke situations throughout a work shift; develop a medical surveillance program and occupational exposure limits specific to wildfires; and increase wildland firefighter training on the hazards of smoke. More study is needed to determine whether these recommendations would reduce exposure to smoke enough to reduce health risks.

The authors of this study believe that firefighters should reduce exposure to smoke in any way possible. For effective risk management, sound smoke exposure mitigation strategies must be developed, implemented, and enforced.

Holding line during firing operations on the 2019 Cow Fire, Malheur National Forest. Photo: Kathleen Navarro.

Citations & Additional Information

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Research brief authors – Kathleen Navarro, USDA Forest Service, and Linda Mutch, Northern Rockies Fire Science Network and National Park Service

Editing and layout— Linda Mutch, Northern Rockies Fire Science Network and National Park Service and Signe Leirfallom, Northern Rockies Fire Science Network

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