

Carbon monoxide exposures in wildland firefighters in the United States and targets for exposure reduction: Supplementary Appendix

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1. Wildland fire term definitions

- a. **Job task categories:** Groupings of similar individual duties and responsibilities carried out by wildland firefighters during a given work shift. Sixty-four pre-defined individual tasks were collapsed into 8 categories of job tasks based on similar requirements and conditions involved in each task.
- **Hiking:** Walking over terrain to get to the area of the fire or other location a crew is assigned, return to vehicles during or after shift, or move positions on a fire. Individual tasks include: hiking.
 - **Lighting:** Utilizing some type of hand-held device for igniting fire by applying flaming liquid fuel to the materials to be burned. Individual tasks include: prescribed burn (RX) lighter, suppression lighter
 - **Holding:** Patrolling a section of direct or indirect fireline and using various tactics to ensure that fire does not cross the fireline. If fire crosses the fireline, other tactics are employed to control the fire that has crossed. Individual tasks include: holding direct line, holding indirect line, holding firefighter, holding squad leader, holding engine operator, suppression holder, prescribed burn (RX) holder, grid the green
 - **Indirect suppression:** Various suppression tasks conducted in locations where the constructed or natural fireline is not directly adjacent to the active fire edge. Individual tasks include: improving indirect line, handline indirect scratch, handline indirect sawyer, handline indirect swamper, handline indirect squad leader, handline indirect firefighter, line preparation, structure protection
 - **Direct suppression:** Various suppression tasks conducted in locations where the constructed or natural fireline is directly adjacent to the active fire edge. Individual tasks include: improving direct line, handline direct scratch, handline direct sawyer, handline direct swamper, felling sawyer, felling swamper, handline direct squad leader, handline direct firefighter
 - **Mop-up:** Extinguishing, removing, or securing burning material near the fireline to prevent the fire from escaping control lines after an area has burned, to make a fire safe and secure, or to reduce residual smoke. Individual tasks include: mop-up, colding trailing, grid the black
 - **Staging/operational or rest break:** Various types of tactical pauses. Staging is where crews can be assigned to await a tactical assignment on a three-minute available basis for multiple reasons, including

upon initial arrival at an incident or after completing a previous tactical assignment. Operational breaks are pauses in operations for reasons other than a scheduled or rest break. Reasons may include waiting in a safety zone until fire behavior decreases or waiting to engage until supervisors have scouted for hazards. Rest breaks are a break from job tasks to rest. Individual tasks include: initial attack, ICP stationary, ICP Supply, ICP other, lunch break, rest break, operational break, staging

- **Other:** Job tasks that do not fit within a category or are not otherwise specified. Individual tasks include: dozer operator direct, dozer operator indirect, engine pump operator, holding pump operator, handline indirect dozer boss, prescribed burn (RX) boss, suppression burn boss, PT, project saw, project stacking, briefing, driving, refurb tools, working with aviation, scouting hazard trees, medical, station work, tool up/tool down, hose work, patrolling

b. Incident type: For this study, the incident type is the type work shift that wildland firefighter study participants were assigned to for their study period. Except for station day, the other 4 incident types indicate different classifications of wildland fire incidents based on their objectives and complexities, that participants were formally assigned to.

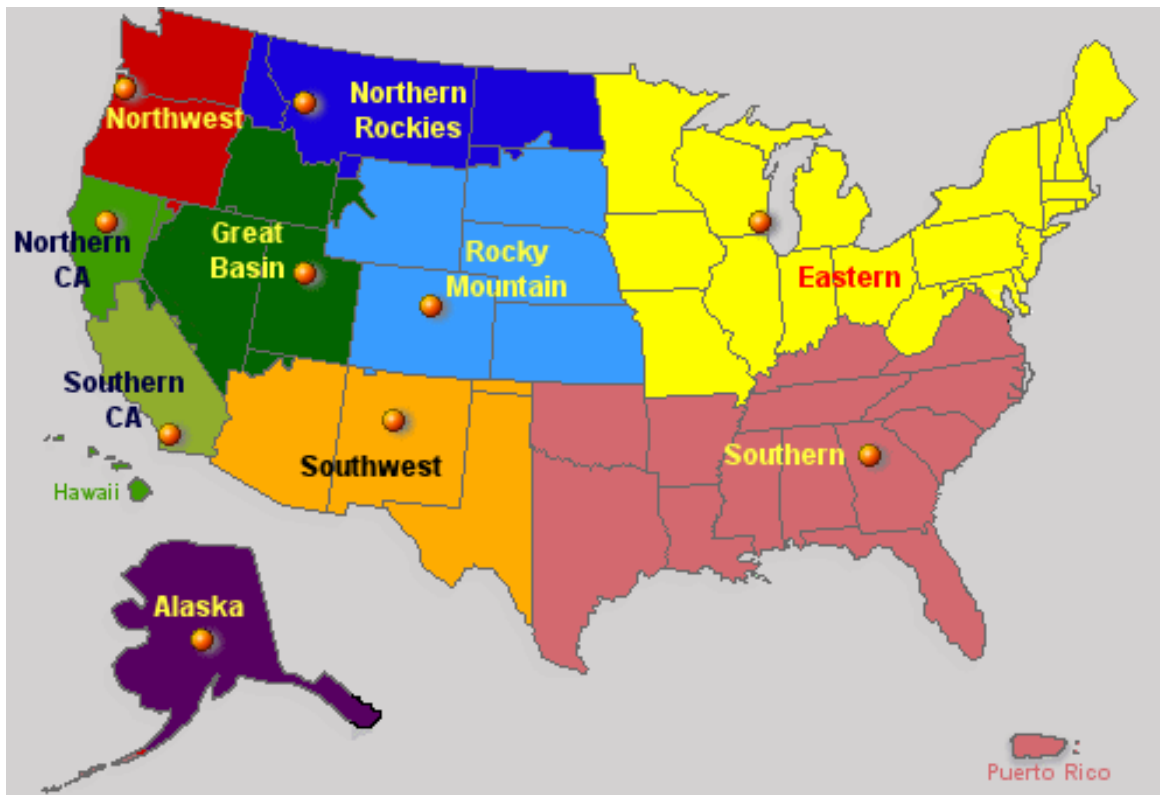
- **Station day:** This shift encompasses any assigned job tasks while wildland firefighters report to their regularly assigned duty station. Tasks can include training and physical training, refurbing tools and equipment, project work, and preparedness for a fire assignment.
- **Initial attack:** A new wildfire incident where full control by the first crews dispatched is expected within the first burning period. When assigned to an initial attack, the fire is usually small in size, and few resources are initially assigned. Initial actions can include size-up of the fire and direct and indirect suppression actions to attempt to prevent further extension of the fire.
- **Managed fire:** Also referred to as wildland fire use. A naturally ignited wildland fire that is designated to be managed for resource benefits in particular geographic areas. Wildland firefighters use the full range of job tasks to check, direct, or delay the spread of fire to protect safety, property, and keep fire within the determined management area.

- **Prescribed fire:** Any fire intentionally ignited by management actions in accordance with applicable laws, policies, and regulations as part of an approved fire plan. The prescribed fire is intended to meet specific management objectives such as fuel reduction and resource benefit.
 - **Large incident:** A large and complex unplanned wildland fire, either naturally or human ignited, where the objective is to put the fire out. Fires where a large amount of personnel and equipment are assigned to the incident for an extended period.
 - **Project fire:** A particularly prolonged large incident.
- c. **Crew type:** A type of wildland fire resource. An organized group of firefighters under the leadership of a crew boss or other designated official that have been trained primarily for operational assignments on wildland fire incidents. Crew types provide information on resource size, capabilities, equipment, and capacity. Crew typing provides managers with additional information in selecting the best resource for the task.
- **Engine crew:** Firefighters assigned to a fire engine that provides specified levels of pumping, water, and hose capacity. Firefighters that specialize in the use of engines for tactical operations. The Fireline Handbook (<https://www.nifc.gov/PUBLICATIONS/redbook/2019/RedBookAll.pdf>) defines the minimum crew makeup by engine type. An engine is usually accompanied by a crew of 2-6 personnel.
 - **Type I crew:** Also called Interagency Hot Shot Crews (IHCs). A hand crew consisting of 20-22 wildland firefighters who must as a collective crew possess specific qualifications as required by the Standards for Interagency Hotshot Crew Operations or agency policy. IHCs are safe, professional, mobile, and highly skilled hand crews for all phases of fire management and incident operations. Hand crews, such as Type I crews, specialize in the use of hand tools, chainsaws, ignition devices, and other tools for tactical operations and to build fireline by hand.
 - **Type II or Type II Initial Attack (IA) crew:** A hand crew consisting of 7-20 individuals that have been organized and trained and are supervised principally for operational assignments on an incident. Training, experience, and management qualifications are less than for Type I crews. Hand crews, such as Type II

and Type II IA crews specialize in the use of hand tools, chainsaws, ignition devices, and other tools for tactical operations and to build fireline by hand.

- d. Geographic Area Coordination Centers (GACC):** Geographic regions with boundaries designated by government agencies (wildland fire protection agencies) that coincide with a geographic area boundary within which they work together coordinating, for the effective mobilization and demobilization of emergency management resources within their area. Listings of geographic coordinating areas can be found in the National Interagency Mobilization Guide, Chapter 20, Section 21.1. (https://www.nifc.gov/nicc/mobguide/Mobilization_Guide.pdf). There are currently 9 GACCs (see figure S1).

Figure S1: A map of each Geographic Area Coordination Center. The colored outline indicates the geographic boundary of each area. The pins indicate the office location of the physical coordination center staff for that region. Map from: <https://gacc.nifc.gov/>



e. Other wildfire-related terms

- **Incident command post:** Incident location at which coordination and administration of the primary logistics functions occur.
- **Spike camp:** A location away from base camp more proximal to the fire for suppression activities.

References for Wildland Fire Terminology:

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3. Redbook 2021: Interagency Standards for Fire and Fire Aviation Operations 2021. Boise, ID: Interagency Standards for Fire and Fire Aviation Operations Group, National Interagency Fire Center; 2021.
4. Fire Terminology. West Glacier, MT: Glacier National Park, National Park Service. Kallispell, MT: Flathead National Forest, USDA Forest Service. <https://www.fs.fed.us/nwacfire/home/terminology.html#M>. Accessed February 26, 2021.
5. NWCG Glossary of Wildland Fire, PMS 205. Boise, ID: National Wildland Fire Coordinating Group. April 2018. <https://www.nwcg.gov/glossary/a-z>. Accessed February 26, 2021.

2. Sensitivity analyses

Table S1. Predictors of geometric mean CO and 25 ppm threshold exceedance with adjustment for smoking status.

Task ^c	% difference (95% CI) GM CO		Above 16 ppm, OR (95% CI)		At or above 25 ppm, OR (95% CI)	
	Adjusted ^a	Adjusted ^b	Adjusted ^a	Adjusted ^b	Adjusted ^a	Adjusted ^b
Hiking	4 (0, 8)	5 (1, 9)	1.29 (1.05, 1.60)	1.31 (1.06, 1.64)	1.32 (1.02, 1.72)	1.39 (1.05, 1.84)
Other	5 (1, 8)	6 (3, 10)	1.72 (1.45, 2.03)	1.77 (1.48, 2.10)	1.76 (1.43, 2.17)	1.89 (1.52, 2.35)
Lighting	27 (15, 39)	36 (23, 51)	3.65 (2.90, 4.61)	4.01 (3.15, 5.10)	4.00 (3.09, 5.18)	4.64 (3.56, 6.06)
Holding	27 (21, 33)	40 (33, 48)	3.32 (2.88, 3.83)	3.93 (3.38, 4.58)	4.08 (3.46, 4.81)	5.14 (4.32, 6.13)
Indirect suppression	20 (14, 26)	25 (18, 33)	2.46 (2.05, 2.96)	2.73 (2.23, 3.34)	2.96 (2.39, 3.66)	3.53 (2.80, 4.45)
Direct suppression	56 (47, 65)	53 (43, 64)	6.10 (5.15, 7.21)	5.35 (4.37, 6.56)	7.72 (6.37, 9.36)	7.42 (5.91, 9.32)
Mop-up	22 (16, 28)	28 (21, 35)	3.99 (3.39, 4.69)	4.66 (3.90, 5.57)	4.54 (3.75, 5.49)	5.45 (4.43, 6.72)
Incident type^c						
Initial attack	13 (-4, 32)	13 (-3, 32)	1.68 (0.82, 3.43)	1.70 (0.83, 3.49)	0.61 (0.13, 2.92)	0.62 (0.13, 2.91)
Managed fire	69 (45, 97)	61 (38, 88)	7.25 (4.04, 13.0)	6.25 (3.46, 11.3)	16.2 (6.50, 40.5)	13.9 (5.62, 34.5)
Prescribed fire	233 (175, 305)	155 (110, 211)	13.2 (7.25, 24.0)	6.73 (3.65, 12.4)	41.8 (16.6, 105)	21.0 (8.38, 52.5)
Large incident	35 (20, 52)	30 (15, 46)	3.11 (1.78, 5.42)	2.72 (1.55, 4.78)	6.55 (2.67, 16.1)	5.78 (2.38, 14.0)
Crew type^c						
Type I	24 (15, 34)	34 (24, 45)	1.75 (1.46, 2.09)	2.13 (1.76, 2.59)	1.64 (1.35, 2.00)	1.93 (1.57, 2.37)
Type II / IA	-2 (-9, 5)	3 (-4, 11)	1.06 (0.88, 1.27)	1.26 (1.04, 1.54)	1.03 (0.84, 1.25)	1.20 (0.98, 1.48)
Fire location^c						
Northern CA	17 (6, 28)	21 (10, 34)	1.58 (1.23, 2.07)	1.58 (1.23, 2.04)	1.62 (1.24, 2.12)	1.63 (1.24, 2.15)
Northern Rockies	21 (10, 34)	49 (33, 67)	2.16 (1.69, 2.76)	3.25 (2.50, 4.24)	2.10 (1.60, 2.76)	3.18 (2.39, 4.23)
Northwest	19 (6, 33)	-	1.24 (0.95, 1.62)	-	1.28 (0.96, 1.70)	-
Rocky Mountains	23 (12, 35)	24 (13, 37)	1.68 (1.30, 2.16)	1.65 (1.28, 2.12)	1.77 (1.34, 2.34)	1.76 (1.34, 2.32)
Southern	207 (119, 332)	217 (127, 344)	13.3 (8.14, 21.9)	14.6 (8.84, 24.2)	17.1 (10.6, 27.8)	18.3 (11.3, 29.8)
Southern CA	75 (54, 98)	96 (72, 123)	4.69 (3.50, 6.28)	5.82 (4.25, 7.96)	5.01 (3.65, 6.88)	6.03 (4.31, 8.44)
Southwest	24 (13, 35)	22 (12, 34)	1.92 (1.50, 2.46)	1.77 (1.38, 2.28)	2.03 (1.55, 2.67)	1.86 (1.42, 2.45)
Smoke^c	-	29 (19, 39)	-	1.72 (1.46, 2.03)	-	1.82 (1.54, 2.16)

Abbreviations: GM, geometric mean; OR, odds ratio; CI, confidence interval

^a Analyses adjusted for job task, incident type, crew type, and fire location. Sample included 246 WFFs and 142,109 minutes of observation.

^b Analyses adjusted for job task, incident type, crew type, fire location, and smoking status. Sample included 211 WFFs and 119,897 minutes of observation.

^c Reference groups were as follows: staging/operational/rest break for job task; station day for incident type; engine for crew type; and Great Basin for fire location.