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# Airborne hexavalent chromium nanoparticles detected around cleanup zones for the 2025 Los Angeles wildfires



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The 2025 Eaton and Palisades fires in Los Angeles (LA) exemplify destructive wildfires that increasingly threaten cities across the globe. The dangers during the post-burn cleanup phase from major urban wildfires are still being discovered. Here we report that airborne chromium bearing nanoparticles (diameter < 56 nm) were found in the LA wildfire debris cleanup zones, a unique finding implicating the fires as a source of nanoparticle metals. The airborne chromium was predominantly in the carcinogenic +6 oxidation state two months post-fire with average concentrations of  $13.7 \pm 6.2 \text{ ng m}^{-3}$ , below the NIOSH workplace exposure limit of  $200 \text{ ng m}^{-3}$  but above the US EPA screening levels for indoor air ( $0.1 \text{ ng m}^{-3}$  for cancer;  $3 \text{ ng m}^{-3}$  for non-cancer effects). Model calculations indicate that chromium containing nanoparticles traveled 10–15 km downwind from the cleanup zone. Caution and health surveillance is warranted for nearby residents given that nanoparticles can easily cross cell membranes and circulate throughout the body.

The Eaton and Palisades wildfires that occurred in January 2025 in the Los Angeles communities of Altadena and Pacific Palisades directly killed at least 31 people and destroyed more than 16,000 structures<sup>1</sup>. The scale of the debris cleanup and reconstruction required to recover from this disaster in proximity to more than 18 M Southern California residents is unprecedented in recent decades of U.S. history. Destructive wildfires that occurred in Paradise, CA, and Lahaina, HI, in recent years had even higher direct death tolls during the active fire but far less population exposure to wildfire smoke during the fire and the dust generated by debris cleanup afterward. Initial cleanup focused on removing hazardous materials such as fuel tanks and electric vehicles from burned buildings. Later efforts recognized the hazards posed in dust contaminated with lead (Pb), arsenic (As), and other toxic metals released by the urban fires. Potential exposure to toxic dust plumes generated by debris removal and reconstruction may pose an equally serious threat to public health.

The long-term health outcomes of workers helping to recover from past disasters provides a cautionary example of unexpected exposures during recovery efforts<sup>2,3</sup>. For example, the dust plume surrounding the destroyed World Trade Center contained pulverized concrete, glass, and asbestos as well as detectable amounts of lead (Pb) and mercury (Hg)<sup>4–6</sup>. Carbon nanotubes were found in World Trade Center dust samples and in the lungs of workers exposed to that dust<sup>7</sup>. A broad range of health effects

likely related to dust exposure have been certified by the World Trade Center Health Program, including asthma, respiratory disease, chronic obstructive pulmonary disease, skin cancer, and prostate cancer<sup>8</sup>.

Dust suppression was a priority during cleanup activities after the Eaton and Palisade wildfires. Best practices included (i) wetting debris before and during transfer to trucks, (ii) covering trucks with tarps, and (iii) regularly washing streets<sup>9</sup>. We observed that these practices were common, but not universally followed, and they cannot suppress all dust, even when fully implemented. Based on our field observations, many workers in the debris cleanup zone did not wear masks despite California requirements to provide approved air purifying respirators to workers<sup>10</sup>. The large scale of the wildfires and cleanup effort along with the substantial amount of burned infrastructure – including wastes from hydrocarbon fuels, plastics, metals, and fiberglass – increased potential for many toxic exposures during the cleanup efforts.

Here we report on measured concentrations of metallic nanoparticles associated with the debris cleanup activities in Altadena and Pacific Palisades in the months following the wildfires. Of greatest health concern are hexavalent chromium nanoparticles that persisted for months after the fires were extinguished. We use a full 3D chemical transport model (CTM) for atmospheric mixing and deposition to calculate an exposure zone extending 10–15 km downwind from the cleanup sites. This analysis helps inform the

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public, workers, and government agencies about potential toxic air contaminants associated with fire recovery efforts and lays the foundation for subsequent epidemiological studies of the health-effects from the fires.

## Results

### Presence of heavy metals in airborne particles in cleanup zones

Size-resolved samples of airborne particles were collected while driving (Fig. 1) through major active debris cleanup zones associated with the Eaton (Fig. 2) and Palisades (Fig. 3) fires. Real-time particle concentration (PM<sub>10</sub>) measurements indicate elevated emissions around active debris cleanup activities and along transportation routes that are likely indicative of hot-spots for particles of all sizes.

In general, the element-specific size distributions determined from the collected particles exhibit between one and three modes, with these modes peaking in (i) the supermicron size range ( $\sim 4\ \mu\text{m}$ ), (ii) the submicron-accumulation mode range ( $\sim 0.4\ \mu\text{m}$ ), and (iii) the ultrafine size range ( $< 0.1\ \mu\text{m}$ ). The size of inhaled particles determines where they deposit in the human respiratory system<sup>11</sup>. Particle size distributions can also be used as a chemical fingerprint, since elements with similar size distributions across samples are likely to be generated by the same emissions source. Apparent in the measured profiles are signatures for crustal material and/or road dust generated by vehicles, brakewear, residue from burned biomass (e.g., K), metals from burned buildings and vehicles (including Pb and As), and even markers for flame retardants used in construction materials, consumer products and electronics (e.g., B and P). Each of these components in the dust plume generated by cleanup activities is expected and are fully discussed in Supplementary Information.

### Hexavalent chromium in airborne nanoparticles in cleanup zones

Of all the trace elements detected in the ambient particles within the cleanup zones, Cr and Ag display the most surprising size distributions since they were found almost exclusively in nanoparticles with diameter less than 56 nm at much higher concentrations inside the cleanup zone (Figs. 2–3, Supplementary Figs. S3–S7) compared to the background site at the upwind edge of the cleanup zone (Supplementary Fig. S2). The background sampling location experienced the same regional concentrations but was upwind of the debris cleanup activities. These differences emphasize the presence of a unique nanoparticle source associated with debris removal. Nanoparticles can be generated by the combustion of fuels such as natural gas<sup>12</sup>, or they can nucleate from gas-phase precursors such as sulfuric acid + ammonia (followed by condensation of organic compounds)<sup>13</sup>. Neither of these nanoparticle generation mechanisms would produce Cr or Ag. Measured Cr-containing nanoparticle concentrations are approximately 10x higher than measured Ag-containing nanoparticle concentrations on a molar basis, suggesting that these particles are not derived from the

combustion of silver chromate ( $\text{Ag}_2\text{CrO}_4$ ) that may be present in black and white photographs.

One possible source of Cr- and Ag-containing nanoparticles is combusted consumer and industrial products that were originally manufactured with nanoparticle technology<sup>14</sup>. Cr nanoparticles are used in pigments found in paints and in coatings used for improved wear and corrosion resistance in electronics and automotive applications. Ag nanoparticles are used in antimicrobial applications such as clothing and may also be found in electronics. Transmission electron microscopy combined with energy dispersive X-ray spectroscopy analysis of ash from structures and vehicles that burned during fires at the wildland-urban interface of cities in northern California in 2020 found that Cr-containing particles had diameters between 90–140 nm and 180–270 nm<sup>14</sup>, consistent with some of the minor size-distribution modes observed in the current study (Supplementary Figs. S2–S7). While the aerodynamic diameter measured by cascade impactors may modestly differ from the physical diameter measured by transmission electron microscopy, the dominance of Cr-containing particles with much smaller size (diameter  $< 56\ \text{nm}$ ) across all debris cleanup locations in the current study suggests a new or previously unrecognized source other than structures or vehicles.

Corrosion inhibitors added to fire suppressants to protect aluminum storage tanks on aircraft are known to contain a variety of metals<sup>15</sup>. In particular, the LC95W variant of Phos-Chek (Perimeter Solutions) contains more than  $70,000\ \mu\text{g L}^{-1}$  of Cr but this variant was phased out of use in California prior to 2024<sup>15</sup>. The MVP-Fx variant of Phos-Chek was the primary flame retardant dropped on the Eaton and Palisades fires<sup>16</sup>. MVP-Fx testing commissioned by a media outlet and carried out by the same lab that tested LC95W found that MVP-Fx contains approximately  $300\ \mu\text{g L}^{-1}$  of Cr<sup>16</sup>. Ag was not measured in this analysis, and the degree to which Cr exists as nanoparticle in the MVP-Fx was not determined. Media reports<sup>17</sup> and CALFIRE records indicate that more than 2,000,000 L of flame retardant was dropped over the region, making a more detailed analysis of MVP-Fx and its potential to generate Cr-containing nanoparticles a key priority.

Hexavalent chromium analysis of the PM<sub>10</sub> samples collected in parallel with the size-resolved samples indicates that 60–97% of the Cr contained in airborne particles existed as hexavalent chromium in March 2025 (Table 1). The hexavalent chromium concentrations measured within the burn zones during March 2025 are substantially higher than concentrations measured at central Los Angeles during the same time period (Supplementary Fig. S8). The Cr size distributions (Figs. 2, 3, and Supplementary Figs. S2–S7) illustrate the size of particles collected on the PM<sub>10</sub> filter. Given the dominance of chrome in particles smaller than 56 nm, these combined findings almost certainly indicate the presence of hexavalent chromium-containing nanoparticles in the atmosphere around the Eaton fire and Palisades fire cleanup zones. Wildfires can transform Cr found in soils to

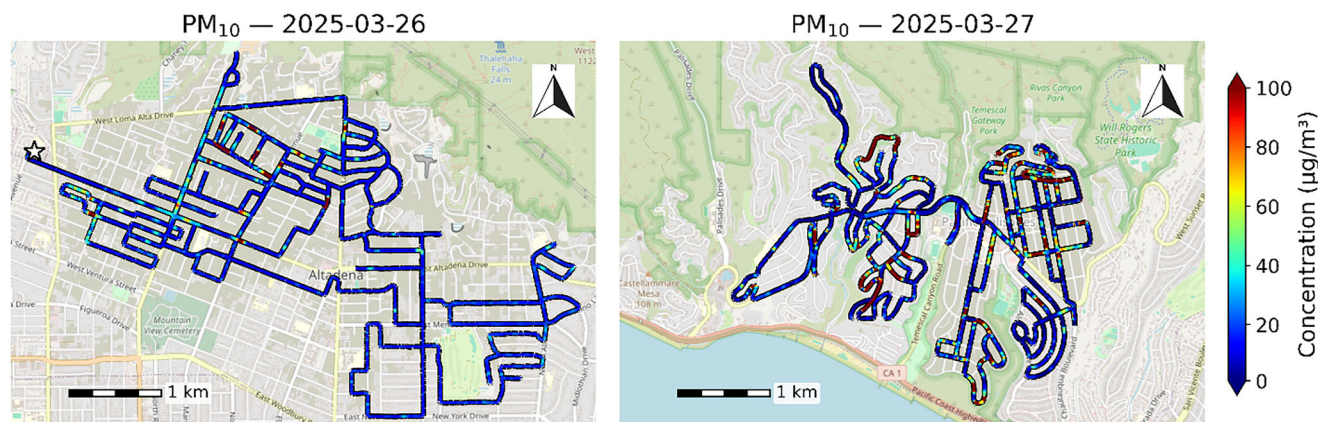


**Fig. 1 | Examples of driving route through fire debris cleanup zones.** Altadena (left panel) on March 26, 2025, and Pacific Palisades (right panel) on March 27, 2025. Color scale indicates PM<sub>10</sub> concentration ( $\mu\text{g m}^{-3}$ ) measured with a QuantAQ

MODULAIR-PM optical particle counter. Star in left panel indicates the location of stationary background site at the western (upwind) edge of cleanup zone. Higher concentrations occur at active cleanup locations.

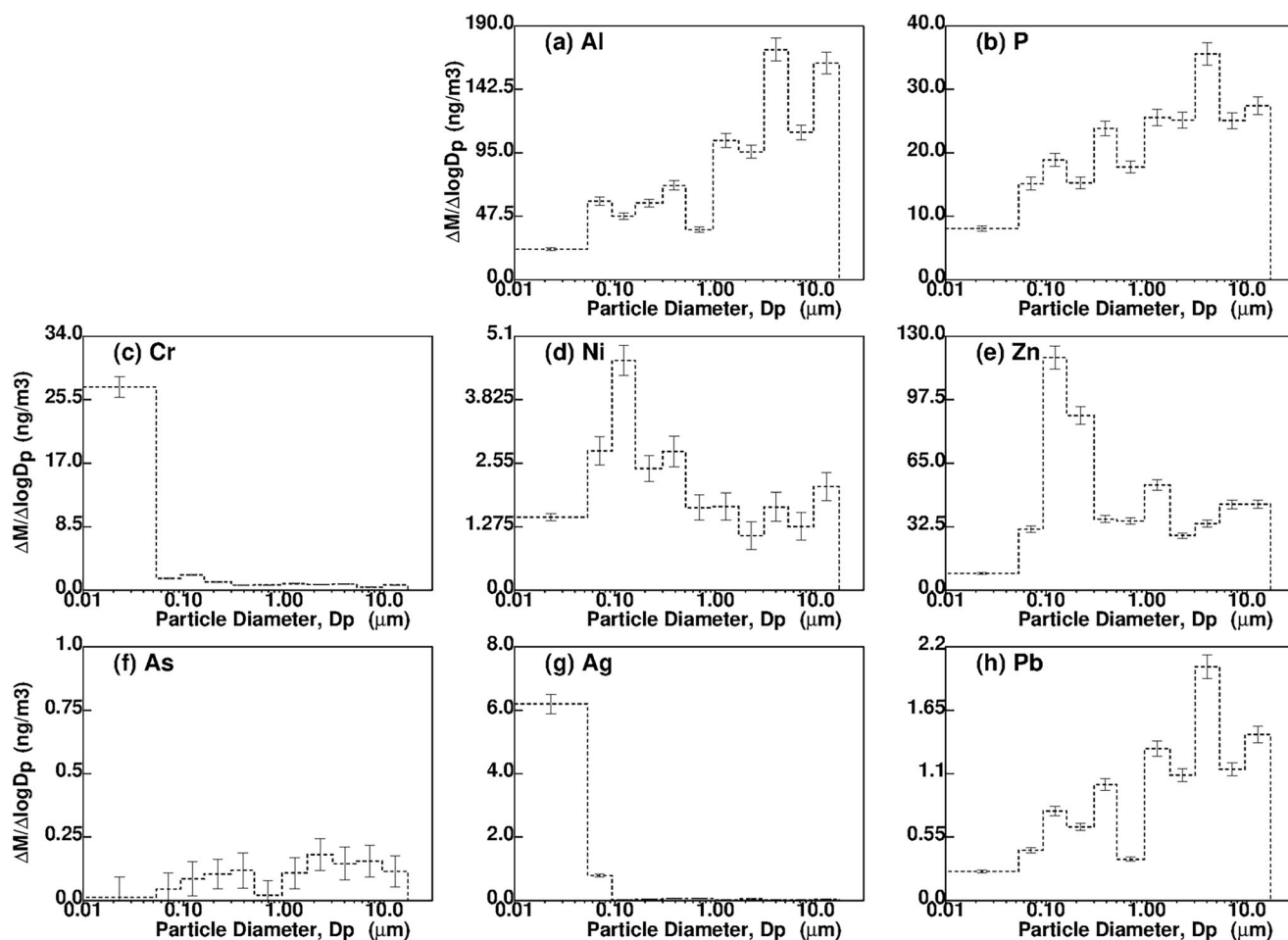


**Fig. 2 | Size distribution of particle-phase elements measured in Eaton fire debris cleanup zone.** Select elements shown for March 25, 2025: aluminum (a), phosphorus (b), chromium (c), nickel (d), zinc (e), arsenic (f), silver (g), and lead (h).

Error bars represent uncertainty (one standard deviation) in analytical measurements. Missing elements were below detection limits or failed QA/QC checks.

hexavalent chromium, with increased production rates observed for soils that are rich in Cr content and in more severe (high temperature) fires<sup>18</sup>. The soil types in the cities of Altadena and Pacific Palisades are not known for their high Cr content<sup>19,20</sup>. Furthermore, the small size of the hexavalent chromium nanoparticles (diameter < 56 nm) suggests an anthropogenic source that could be related to the combination fuel type and fire behavior. Significantly, the urban structures that burned in the Eaton and Palisades fires had much higher equivalent fuel loads than surrounding vegetation<sup>21</sup>, likely producing higher combustion temperatures that could have increased the oxidation of metals in the burn zone. Previous studies have measured increased concentrations of hexavalent chromium in the ash from burned residential areas compared to non-residential forested areas but the size of particles containing hexavalent chromium was not measured<sup>22</sup>.

### Comparison to reference levels

PM<sub>10</sub> concentrations of hexavalent chromium in March 2025 averaged  $13.7 \pm 6.2 \text{ ng m}^{-3}$  with the majority of this material in particles smaller than 56 nm. This concentration falls well below the 8-h exposure workplace action level set by the Occupational Health and Safety Administration (OSHA)<sup>23</sup> of  $2500 \text{ ng m}^{-3}$  and the exposure limit of  $200 \text{ ng m}^{-3}$  recommended by the National Institute for Occupational Safety and Health (NIOSH)<sup>24</sup>. While this rules out the need for immediate workplace action, it is noteworthy that the PM<sub>10</sub> hexavalent chromium concentration in March 2025 exceeded the United States Environmental Protection Agency (US EPA) screening level<sup>25</sup> for cancer and non-cancer risk in workplace air ( $13 \text{ ng m}^{-3}$  and  $1.1 \text{ ng m}^{-3}$ , respectively), suggesting that further study is

warranted. US EPA screening levels for airborne hexavalent chromium in any indoor environment, including homes where vulnerable populations such as children may be present for prolonged periods, are  $<0.1 \text{ ng m}^{-3}$  to maintain cancer risk below one in a million. While our measurements were made in outdoor air, all homes have some level of air exchange with the outdoor environment that leads to infiltration of pollutants indoors. Nanoparticles (diameter < 100 nm) are no exception, with multiple studies documenting outdoor nanoparticle infiltration factors of approximately 0.3 to indoor environments<sup>26,27</sup>. It is also important to note that EPA limits for lifetime exposures (70 years), and screening levels are used to trigger a more detailed investigation, not to act as a signal for immediate protective measures. Nevertheless, the potential for hotspot concentrations within the debris cleanup zone that exceed the city-wide averages reported here (Fig. 1), the proximity of the debris cleanup zone to a large population, and the nanoparticle form of the hexavalent chromium (Figs. 2, 3, Supplementary Figs. S2–S7) may warrant extra caution when interpreting these standards. Inhaled nanoparticles can easily cross cell membranes and circulate throughout the body and the health consequences for unique events that expose a large population to low levels of high toxicity nanoparticles are highly uncertain.

### Cr(6+) reduction to Cr(3+) over time

Cr(6+) generated at high temperatures in fires can transform back to less toxic Cr(3+) when exposed to the post-fire environment, especially in wetter environments<sup>18</sup>. This aging process involves redox reactions with a wide variety of elements<sup>28</sup>. Measurements in March, May, and September

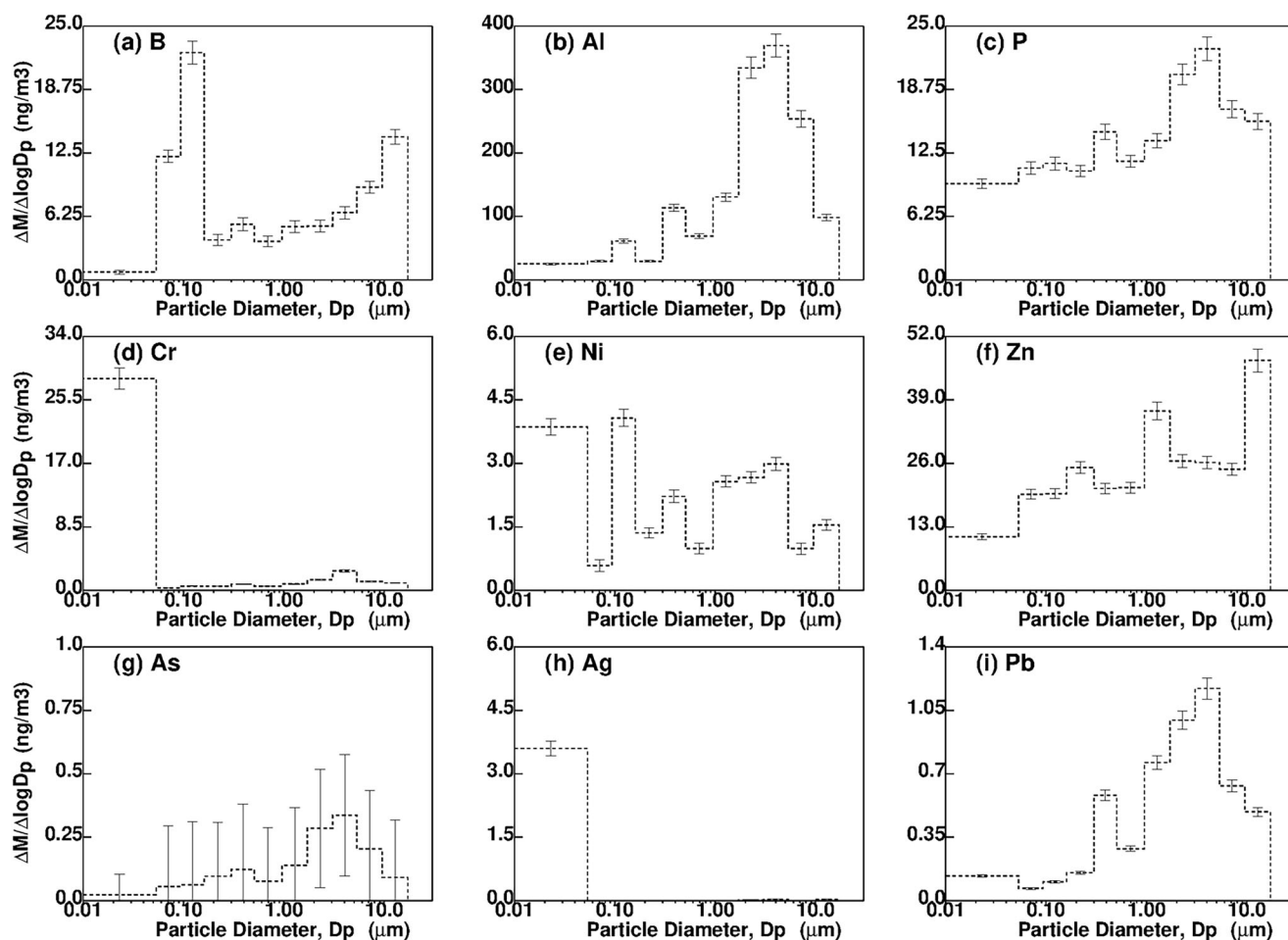


**Fig. 3 | Size distribution of particle-phase elements measured in Palisades fire debris cleanup zone.** Select elements shown for March 27, 2025: boron (a), aluminum (b), phosphorus (c), chromium (d), nickel (e), zinc (f), arsenic (g), silver (h), lead (i). Error bars represent uncertainty (one standard deviation) in analytical measurements.

2025 show a decreasing fraction of total  $PM_{10}$  Cr in the  $Cr(6+)$  form (Fig. 4). The exponential decay trend suggests that  $Cr(6+)$  was reduced back to  $Cr(3+)$  during the cleanup period, with the implication that exposure risk to  $Cr(6+)$  nanoparticles decreased over time.

### Exposure distance

The presence of toxic metals such as Pb and As in soils around the wildfire zone caused considerable anxiety for nearby residents and contributed to the public debate about appropriate levels of mitigation<sup>29</sup>. We have found that Cr- and Ag-containing nanoparticles are also metals of concern in the aftermath of the 2025 Los Angeles wildfires. Ground-level concentrations of Cr and Ag will decay with downwind distance due to surface deposition and dilution. A full 3D CTM<sup>30</sup> was applied to the region for March 2025 to predict zones of potential population exposure to  $PM_{0.1}$  Cr. CTM calculations successfully predict the spatial variation of  $PM_{10}$   $Cr(6+)$  concentrations measured around the burn area as a quality control check (Supplementary Fig. S8). Focusing on the nanoparticle size fraction, enhanced  $PM_{0.1}$  Cr concentrations are predicted to extend 10–15 km downwind of the debris removal zone (Fig. 5). These findings are consistent with simple dispersion calculations summarized in SI. The majority of the 100 zip codes with the greatest population exposure are located southeast of the Palisades Fire (Fig. 5).  $PM_{0.1}$  Cr concentrations in these zip codes are predicted to exceed  $0.3 \text{ ng m}^{-3}$ . As a reference point, the most protective screening level for long-term exposure to  $Cr(6+)$  contained in airborne particles of any size is  $0.1 \text{ ng m}^{-3}$ . Health protective levels for nanoparticle  $PM_{0.1}$   $Cr(6+)$  over a one month exposure time have not been established. The population in the 100 zip codes with the highest  $PM_{0.1}$  Cr

concentrations in March 2025 is approximately 3.3 M people. Note that monthly-average  $PM_{0.1}$  Cr concentrations inside the debris cleanup zones exceed  $10 \text{ ng m}^{-3}$ . Workers in these zones are predicted to have experienced substantially higher  $PM_{0.1}$  Cr concentrations than the surrounding population, with the  $Cr(6+)$  proportion decaying over time due to aging (Fig. 4).

### Discussion

Debris removal and cleanup operations associated with the Eaton and Palisades fires generated dust plumes that contained a mixture of natural and anthropogenic material. Elements associated with windblown crustal material had mean diameters between 1.0 and  $5.0 \mu\text{m}$ , which is typical for particles generated by mechanical abrasion. A substantial fraction of the Pb contained in airborne particles was found in this coarse particle size fraction (diameter larger than 2.5 microns). Particle-phase components related to combustion of anthropogenic materials (including flame retardants) often had a peak between 0.1 and  $1.0 \mu\text{m}$  particle diameter in Figs. 2, 3, and Supplementary Figs. S2–S7, which is more representative of direct emissions from the fire without agglomeration to larger particles. Approximately 17–37% of the Pb and 24–55% of the As was found in these smaller particles. Most surprisingly, Cr and Ag content was found most concentrated in nanoparticles with diameters less than 56 nm that can easily cross cell membranes in the lung and circulate throughout the body. Previous studies of ash generated by burned buildings and vehicles from fires in 2020 did not detect such small Cr- and Ag-containing nanoparticles, possibly indicating a new or previously unrecognized source for fires in 2025 to the best of our knowledge. Corrosion inhibitors added to reformulated aerial fire suppressants are one possible new or previously unrecognized source of this

**Table 1 | Summary of airborne particulate matter sample collection and Cr concentrations**

| Date/Time                                                  | Location                                      | Collection devices                          | Conc. (ng m <sup>-3</sup> )                                           |
|------------------------------------------------------------|-----------------------------------------------|---------------------------------------------|-----------------------------------------------------------------------|
| Stationary background sample on edge of Eaton cleanup zone |                                               |                                             |                                                                       |
| 3/24/2025 11:00am–3/26/2025 4:30 pm                        | 725 Altadena Dr, Altadena CA (Odyssey School) | MOUDI-foil; MOUDI-Teflon                    | Total Cr = 1.5<br>Cr(6+) = not measured                               |
| Mobile sample throughout indicated zone <sup>a</sup>       |                                               |                                             |                                                                       |
| 3/24/2025 1:00 pm–3/24/2025 6:00 pm                        | Altadena                                      | MOUDI-foil; MOUDI-Teflon; PM10-filter       | Total Cr = 22.2<br>Cr(6+) = 21.6                                      |
| 3/25/2025 8:15am–3/25/2025 5:45 pm                         | Altadena                                      | MOUDI-foil; MOUDI-Teflon; PM10-filter       | Total Cr = 11.6<br>Cr(6+) = 9.5                                       |
| 3/26/2025 9:14am–3/26/2025 4:30 pm                         | Altadena                                      | MOUDI-foil; MOUDI-Teflon; PM10-filter       | Total Cr = 13.4<br>Cr(6+) = 8.1                                       |
| 3/27/2025 12:45 pm–3/27/2025 4:45 pm                       | Pacific Palisades                             | MOUDI-foil; MOUDI-Teflon; PM10-filter       | Total Cr = 23.1<br>Cr(6+) = 15.4                                      |
| 4/9/2025 8:23am–4/9/2025 3:27 pm                           | Altadena                                      | MOUDI-foil; MOUDI-Teflon                    | Total Cr = 11.8<br>Cr(6+) = not measured                              |
| 5/14/2025                                                  | Altadena                                      | MOUDI-foil; MOUDI-Teflon<br>PM10-filter     | Total Cr = 3.8<br>Cr(6+) = 0.7                                        |
| 5/15/2025                                                  | Pacific Palisades                             | MOUDI-foil; MOUDI-Teflon<br>PM10-filter     | Total Cr = 11.6<br>Cr(6+) = 0.6                                       |
| 9/4/2025 10:42am<br>9/4/2025 6:04 pm                       | Altadena                                      | MOUDI-foil; MOUDI-Teflon<br>PM10-filter x 2 | Total Cr = 27.8<br>Cr(6+) < MDL                                       |
| 9/5/2025 8:36am<br>9/5/2025 2:38 pm                        | Pacific Palisades                             | MOUDI-foil; MOUDI-Teflon<br>PM10-filter x 2 | Total Cr = 41.3<br>Cr(6+) < MDL                                       |
| 9/7/2025 12:05 pm<br>9/7/2025 5:02 pm                      | Davis                                         | MOUDI-foil; MOUDI-Teflon<br>PM10-filter x 2 | Total Cr = 125.8<br>Cr(6+) < MDL                                      |
| Stationary Sampling at Palisades Fire Station              |                                               |                                             |                                                                       |
| 9/16/2025 12am–9/16/2025 11:59 pm                          | 15045 Sunset Blvd, Pacific Palisades          | PM10 filter                                 | Total Cr = not measured<br>Cr(6+) = 0.25 (UC)<br>Cr(6+) = 0.15 (AQMD) |
| 9/19/2025 12am–<br>9/19/2025 11:59 pm                      | 15045 Sunset Blvd, Pacific Palisades          | PM10 filter                                 | Total Cr = not measured<br>Cr(6+) = 0.04 (UC)<br>Cr(6+) = 0.08 (AQMD) |
| 9/22/2025 12am–<br>9/22/2025 11:59 pm                      | 15045 Sunset Blvd, Pacific Palisades          | PM10 filter                                 | Total Cr = not measured<br>Cr(6+) < MDL (UC)<br>Cr(6+) = 0.09 (AQMD)  |

<sup>a</sup>All mobile measurements included SMPS, APS, and QuantAQ MODULAIR-PM measurements but these are not the focus of the current analysis. MDL is method detection limit.

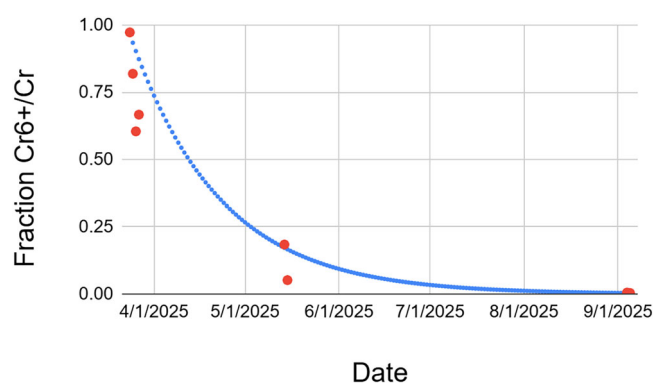


**Fig. 4 | Fraction of PM<sub>10</sub> Cr present in the Cr(6+) oxidation state.** Red dots are measurements, blue dots are exponential curve fit.

material, but more study is needed to test this hypothesis. Most of the Cr was found to be in the toxic 6+ oxidation state (hexavalent chromium) that is classified as a human carcinogen by the International Agency for Research on Cancer (IARC), the National Toxicology Program (NTP), and the US EPA. Although the concentrations of total suspended hexavalent chromium are well below Occupational Safety and Health Administration (OSHA) and NIOSH workplace limits, they exceed the US EPA screening levels for

cancer and non-cancer risks in both workplace air and residential air. Screening levels are used to determine when a more in-depth investigation is warranted. Full 3D CTM calculations indicate that hexavalent chromium nanoparticle concentrations may persist at concentrations above the US EPA screening levels for 10–15 km downwind of the cleanup zone. Monitoring near wildfire cleanup zones is warranted to ensure that concentrations decay to background levels over time, and residents living adjacent to wildfire cleanup zones should take steps to reduce hexavalent chromium exposure by using indoor air filters (HEPA or +MERV13) and limiting outdoor exercise in the fire zones until conditions return to safe levels.

## Methods Measurements

Cascade impactors were used to collect size-resolved samples of airborne particulate matter that were then analyzed for elemental composition using Inductively Coupled Plasma Mass Spectrometry (ICP-MS). In parallel, filter samples collected with a size-selective inlet were analyzed for hexavalent chromium, a known carcinogen. Supplemental measurements were made with a Scanning Mobility Particle Sizer (SMPS) (TSI Corp) and a QuantAQ MODULAIR-PM optical particle counter. These supplemental measurements will be discussed in greater detail in a future manuscript and are only included here as support for the impactor and filter measurements.

Samples of airborne particulate matter were collected over fourteen days on the schedule summarized in Table 1. Stationary samples were

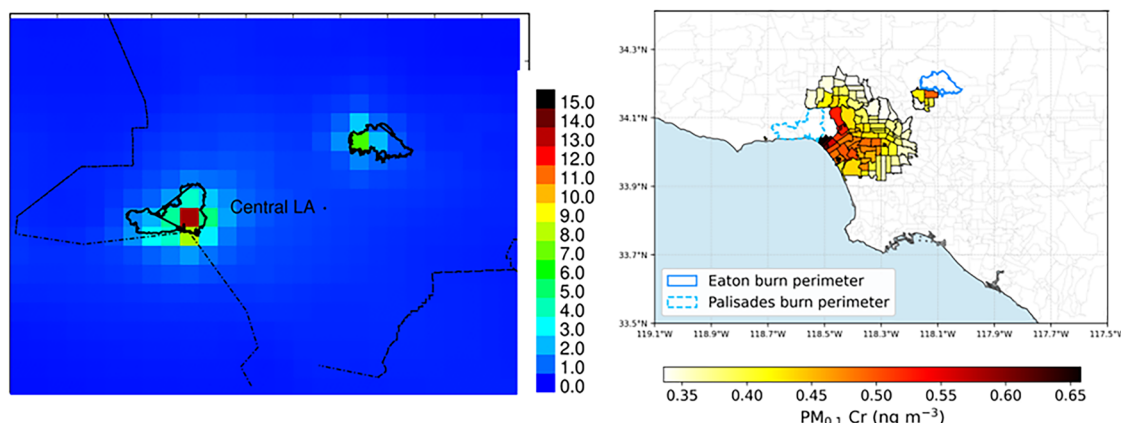


**Fig. 5 | Predicted  $PM_{0.1}$  Cr exposure field in March 2025.** Cr concentrations ( $ng\ m^{-3}$ ) (left) and location of 100 zip codes with the highest  $PM_{0.1}$  Cr concentrations (right).

collected at a background site on the edge of the Eaton fire debris cleanup zone over a continuous period lasting 2.3 days and inside the Palisades debris cleanup zone during three separate sampling periods lasting 24 h each. All other samples were collected using samplers mounted on the bed of an EV truck (1 m above ground) moving at a speed of  $20\text{--}30\ km\ h^{-1}$  (Supplementary Fig. S12). The open bed design of the truck allowed instruments to directly sample ambient air without the need for a specialized inlet. The driving pattern in both Altadena and Pacific Palisades covered the entire cleanup zone multiple times over the indicated collection time period to build a robust average concentration profile. Example driving patterns are shown in Fig. 1. Samples were collected in Davis, CA, to verify the absence of Cr nanoparticles in a location without fire impacts.

Size-resolved particulate matter samples were collected with Micro Orifice Uniform Deposit Impactors (MOUDIs, TSI Corp Model 110). Two MOUDIs were used to collect particles on different substrates suitable for a range of chemical analysis. The current study focuses on samples collected using Teflon membrane filter substrates (Pall Cor Model R2PJ047). Ten size-resolved samples were collected with 50% cut diameters of 18, 10, 5.6, 3.2, 1.8, 1, 0.56, 0.32, 0.16, 0.1, and  $0.056\ \mu m$ . The  $0.056\ \mu m$  stage was followed by an after-filter that collected particles with diameter less than 56 nm. Filters were uncoated to reduce interference in the downstream chemical analysis. Measurements of particle size distributions made using a Scanning Mobility Particle Sizer (SMPS) were in good agreement with MOUDI measurements, building confidence that particle bounce was not a dominant factor in the analysis (Supplementary Fig. S1).

Size-resolved particle samples were microwave digested in 1 mL of trace metals grade nitric acid at  $180\ ^\circ C$  for 15 min followed by dilution with MilliQ water to a final volume of 10 mL. Samples were analyzed using quadrupole ICP-MS (Agilent Technologies Model 8900) for 30 elements: Li, Be, B, Na, Mg, Al, Si, K, Ca, Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, As, Se, Sr, Mo, Ag, Cd, Sn, Sb, Ba, Tl, Pb, and U. Results were quantified using multipoint calibration curves derived from certified standards (SPEX Certiprep) diluted at different levels. Independent quality control checks with known concentrations derived from NIST 2711 A, NIST 2709 A, and NIST 1643 F were analyzed alongside the airborne PM samples. Detection limits were estimated based on the variability of the calibration curves at the lowest measured concentrations and were generally lower than  $0.05\ ppb\ (ng\ mL^{-1})$  for most elements with the notable exceptions of B ( $0.39\ ppb$ ), Mg ( $\sim 0.35\ ppb$ ), Si ( $3.9\ ppb$ ), K ( $0.9\ ppb$ ), and Ca ( $0.14\ ppb$ ). Measurement uncertainty was estimated as twice the detection limit or 5% of the measured concentration, whichever was greater. Particle size distributions with uncertainty larger than mean measured values were removed from the analysis.

Airborne particulate matter with diameter less than  $10\ \mu m\ (PM_{10})$  was collected with a size-selective inlet head operated at 17 lpm.  $PM_{10}$  samples were collected on cellulose filters (Sterlitech CA1247100) coated with sodium bicarbonate to maintain high pH in order to stabilize the oxidation

state of Cr between  $Cr(3+)$  and  $Cr(6+)$  (hexavalent chromium)<sup>31</sup>.  $PM_{10}$  samples were sealed in sterile petri dishes and refrigerated immediately after collection. Samples were extracted in 10 mL of pH-buffered solution and analyzed for hexavalent chromium using US EPA Method 218.6. Detection limits for the hexavalent chromium analysis were  $0.024\ ppb\ (ng\ mL^{-1})$  and reporting limits were 1.0 ppb.

### Chemical transport modeling

CTM calculations were performed using the UCD/CIT air quality model<sup>30</sup> with a horizontal spatial resolution of 4 km. Sixteen telescoping vertical levels were used up to a total height of 5 km. Numerous previous studies have demonstrated the ability of this model configuration to predict ground level pollutant concentrations across California, including in the Southern California region<sup>30,32–34</sup>. Meteorological fields were generated with the Weather Research & Forecast (WRF) model v4.3 operating with 3 nested domains with spatial resolution of 36 km, 12 km, and 4 km. Initial and boundary conditions for these calculations were taken from the North American Regional Reanalysis (NARR) dataset<sup>35</sup>. Mean fractional error averaged  $1.46\ m\ s^{-1}$  for wind speed during March 2025, meeting standards necessary to support accurate CTM calculations<sup>36</sup>. Emissions for wildfire debris cleanup were based on the GIS dataset of burned buildings created to estimate emissions during the active fire period<sup>21</sup>. The amount of debris generated was assumed to be proportional to the mass of fuel in the original structures. Total cleanup activity was assumed to be completed in 120 working days across the period March through August 2025. Debris removal activity was assumed to take place during working hours of 8 am and 6 pm on each working day. Cleanup locations were assigned randomly since detailed records of address-specific cleanup dates were not available. Emissions from all other air pollution sources were obtained from the datasets maintained by the California Air Resources Board.

The UCD/CIT CTM represents airborne particles using 16 size bins spanning the diameter range from 10 nm to  $10\ \mu m$ . Particles generated from the debris cleanup activity were assumed to have a size distribution corresponding to the average of the MOUDI measurements summarized in Table 1.  $PM_{10}$ ,  $PM_{2.5}$ , and  $PM_{0.1}$  concentrations were generated and used to estimate exposures and/or to compare with available measurements. Further simplistic dispersion calculations summarized in SI have order of magnitude agreement with the more accurate CTM calculations building confidence in these results.

### Data availability

Measurement data and predicted Cr exposure data can be downloaded at <https://doi.org/10.5281/zenodo.19543938>.

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## Author contributions

M.J.K. Conceived of the study, performed sample collection, performed CTM analysis, analyzed data, wrote first draft of manuscript; C.D.C. provided instrumentation and revised manuscript; P.G.G. supported ICPMS analysis and revised manuscript; Y.Zhou. supported ICPMS analysis and revised manuscript; M.A. analyzed data, created figures, and revised manuscript; S.K. performed meteorological modeling in support of CTM analysis and revised manuscript; Y.Zhu. revised manuscript; M.J. revised manuscript.

## Competing interests

The authors declare no competing interests.

## Additional information

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