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Elevated tungsten and cobalt in airborne particulates in Fallon, Nevada: Possible implications for the childhood leukemia cluster

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Abstract

Trace metal content was measured in airborne particulates in five towns located in west central Nevada with an emphasis on Fallon, where 16 cases of childhood leukemia were diagnosed recently. Airborne dust samples were collected using portable, high-volume particulate air samplers, and each filter was chemically analyzed by acid-dissolution, inductively coupled plasma mass spectroscopy. Tungsten was the most notable metal in Fallon dust, with cobalt of secondary but still important interest. Tungsten and cobalt were elevated in Fallon relative to comparison towns of west central Nevada, and within Fallon they co-varied closely temporally and spatially. These results were obtained and confirmed in two different collections during two different seasons of the year and using entirely different hardware and different types of filters. By weight of multiple lines of evidence, the source of tungsten and cobalt in airborne particulates in Fallon is probably not natural, but rather a hard-metal facility located in Fallon should tentatively be considered a candidate source of the airborne exposure of these metals within Fallon. Neither tungsten nor cobalt has yet to be definitively associated with childhood leukemia, but cobalt and tungsten carbide together are probably carcinogenic to humans. We concur with calls by others for more research in Fallon, and we recommend that cobalt be added into the toxicological studies, especially as an interactive factor with tungsten.

1. Introduction

Trace metal content was measured in airborne particulates in five towns located in west central Nevada with an emphasis on Fallon (Fig. 1), where 16 cases of childhood leukemia were diagnosed from 1997 to 2002, inclusive. Although childhood leukemia includes multiple, related diseases (Lilleyman, 1994), Fallon was homogeneous in that 15 of its childhood leukemia cases were of acute lymphocytic leukemia while just one case was acute myelocytic leukemia (Reno-Gazette Journal, 29 July 2002). As of the latest census, Fallon has 7526 residents (US Census, 2000), so its pediatric population up to 19 years of age is ~2400 children. Counting all 16 cases in the time span

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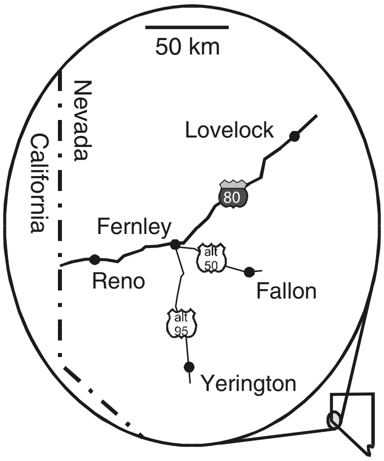

Fig. 1. Map of towns of Nevada region where airborne particulate sampling was done.

of 6 years, the rate of childhood leukemia in Fallon was many times the expected rate of 4.1 childhood leukemia cases per 100,000 children (0–19 years) per year (US NCI, 2003). This cluster had a "very small" likelihood of being a random event (Expert Panel, 2004), and Fallon has been declared "one of the most convincing clusters of childhood cancer ever reported" (Steinmaus et al., 2004).

In spite of prevailing pessimism about finding causes of illness clusters (Rothman, 1990), various hypotheses have been tested in search of a cause of Fallon's leukemia cluster. A non-environmental hypothesis known as population mixing asserts that when large numbers of non-residents arrive and/or pass through a small, rural town, residents are susceptible to infectious illnesses that can lead to leukemia (Kinlen and Doll, 2004). Fallon epitomizes this scenario, as its small resident population is often greatly outnumbered on an annual basis by large influxes of transient military personnel. Population mixing remains an active hypothesis for testing with respect to Fallon's clusters of childhood leukemia.

Many environmental hypotheses have been tested for Fallon, a rural town with an economy based primarily on agriculture (Greater Fallon Area Chamber of Commerce, 2005). Within Fallon, indoor air, play yard soil, household dust, and tap water were tested (US CDC, 2003a). Within Fallon and comparison towns of Nevada, tap water, yard soil, and floor dust were tested (US CDC, 2003b). Groundwater underlying Fallon was tested recently (Seiler, 2004) and compared to similar tests conducted in 1989 (Lico and Seiler, 1994), well before the current leukemia cluster was identified. Drinking water statistics were evaluated for arsenic exposure at the county scale throughout Nevada (Moore et al., 2002). Surface water of the watershed in which Fallon sits was tested (US ATSDR, 2003a). A fuel pipeline that runs underground through Fallon was investigated for leaks (US ASTDR, 2002). Although some of these studies have shown some metals and/or other contaminants to be elevated in Fallon, the consensus has been that no environmental characteristic of Fallon is unusual enough to lead to a cluster of childhood leukemia.

Total suspended particulates in outdoor air have also been tested in and around Fallon (US ATSDR, 2003b). However, that air testing deployed just two high-volume samplers, one in the center of town and the other several kilometers west of town. That sampling was not dense enough to determine spatial patterns of airborne particulates, and ultimately no association was found between environmental exposure to airborne particulates and childhood leukemia (US ATSDR, 2003b, p. 25).

Outdoor airborne particulates are omnipresent in air, even in rural areas where air might appear to be clear relative to urban settings (Holmes, 2001). Inhalation exposure to dust can be a health concern, and children in particular come in close contact with dust and soil when playing (US ATSDR, 2003c). Therefore, we felt that more-extensive testing of outdoor airborne dust in Fallon and in comparison towns was warranted. Our primary objective was to identify metals that are elevated in Fallon relative to comparison towns. Succeeding at that, our secondary objectives were to search for a candidate source or sources of the elevated metals and to evaluate existing scientific literature about the carcinogenicity of those metals.

2. Methods

Airborne particulates were collected in Fallon, Nevada, as well as in four other communities that provided a baseline for comparison with Fallon. The comparison towns are located within 100 km of Fallon (Fig. 1) and at roughly similar elevations (Table 1). The comparison communities differ from Fallon and each other by their location in different watersheds and proximity to interstate highways, factors that might affect airborne particulates (Johannesson et al., 2000; Ludwig et al., 1977). Two of the comparison communities are smaller than Fallon in population, one is about the same size, and one is considerably larger.

Table 1
West central Nevada air sampling communities and their pertinent geographical data

Community	Elevation (m)	Distance (km) and direction from Fallon	Population[a]	Watershed	Next to interstate highways
Fallon	1200		7536	Lower Carson	No
Lovelock	1220	81, NNE	2003	Humboldt	Yes
Fernley	1270	45, WNW	8543	Lower Truckee	Yes
Yerington	1340	66, SW	2883	Middle Walker	No
Reno	1500	92, W	180,480	Middle Truckee	Yes

[a] Data from US Census (2000).

Within each community, outdoor airborne dust was collected at homes of participants who were chosen from a pool of volunteers with the objective of representing each community spatially. No attempt was made to place air samplers at the homes of children with leukemia. Two separate time periods were tested during 2004, one from mid March to early April (hereafter "March") and another during mid November (hereafter "November").

Dust samples were collected using portable, high-volume particulate air samplers, a common strategy for collecting suspended particulate matter (US EPA, 1999b). The filter medium was glass-fiber, also commonly used for high-volume sampling of airborne particulates (Eadie and Bernhardt, 1976; Lee and Mukund, 2001). Filters were 510 μm thick and had 99.99% retention for particles down to 0.3 μm (HI-Q Environmental Products Company, 2003).

Based on results from March, changes in equipment and sampling strategy were made to optimize data collection during November. First, the samplers used during March had brushed motors, which could potentially auto-contaminate their filters with copper (US EPA, 1999b). Indeed, Cu concentrations in dust collected in March ranged as high as 20,000 ppm (2%), which is much higher than the typical Cu crustal abundance of 50 ppm (Krauskopf, 1995). To avoid this contamination in November, the high-volume air samplers were changed to a type with brushless motors. Accordingly, Cu concentrations in dust collected in November had a median value of only 181 ppm, much lower than during March. Second, during March the filters were of a type that contained an acrylic resin binder and waterproof coating, but for November, filters were changed to a type without the binder or waterproof coating in order to lower their element background (Lee and Mukund, 2001). Third, air sampling sessions during March lasted four days in order to collect sufficient dust to assure detection of trace quantities of metals, but during November the individual sampling sessions were shortened to the more-conventional length of one day in order to avoid saturating the filters with dust.

During sampling sessions, five samplers were deployed in Fallon while five other samplers were deployed within a comparison community. This concurrent sampling was intended to account for changing regional weather through time. Between sampling sessions, the filters of all samplers were changed and the comparison samplers were moved to the next community while the Fallon samplers were left in place. For one sampling session during March, all ten samplers were deployed within Fallon in order to maximize spatial coverage there. An unused, blank filter was carried along for each sampling session.

Within backyards of participants, air samplers were placed several meters from buildings and as far as possible from potentially confounding issues (e.g., trees, pet areas, barbecues). The open-face intake orifices (US EPA, 1999a), which were vertically oriented and 102 mm in diameter, were set at the typical breathing height of 1.5 m above the ground (US EPA, 2001) and were pointed in random directions. The samplers and intakes were sheltered from rain and settling dust by umbrellas that were attached to the samplers. During March, the air flow rate was initialized to $0.85\,\mathrm{m^3\,min^{-1}}$ ($30\,\mathrm{ft^3\,min^{-1}}$), but during November it was set to $0.45\,\mathrm{m^3\,min^{-1}}$ ($16\,\mathrm{ft^3\,min^{-1}}$), the highest rate attainable by the samplers with brushless motors. The flow rate at the end of each sampling session was recorded, and the total duration of each sampling session was measured to ±0.1 h. Total volume of air sampled was calculated as the product of the average flow rate by the duration of sampling (Eadie and Bernhardt, 1976).

Prior to deployment in the field, clean filters were weighed at room temperature and humidity to ±0.0001 g. Upon completion of each sampling session, dusty filters were folded dust side inward and stored in paper envelopes (US EPA, 1999b). Dusty filters were re-weighed after stabilizing at the same room temperature and humidity as during pre-weighing (Solomon et al., 2001). Filters were touched only while wearing dust-free, latex gloves (US EPA, 1999b).

Half of each filter was chemically analyzed by acid-dissolution, inductively coupled plasma mass spectroscopy (ICP-MS) at the University of Missouri Research Reactor Center. The filters were digested using a laboratory microwave system and a combination of high purity HNO_3 and HF acids and hydrogen peroxide. A 4% H_3BO_3 solution was used to reduce the formation of insoluble fluorides that are known to precipitate some elements (Kingston and Haswell, 1997). The digestate was spiked with internal standards and analyzed on a VG Axiom ICP-MS. Blank filters and quality control samples (NIST SRM-1648, Urban Particulate Matter) were processed the same way. Solutions were measured for beryllium, vanadium, chromium, manganese, cobalt, nickel, copper, arsenic, strontium, molybdenum, silver, cadmium, tin, antimony, cesium, tungsten, thallium, lead, and uranium. Sample values were corrected by subtracting the average value from the blank filters (Eadie and Bernhardt, 1976). Sample values less than the limit of detection or less than the average of the blank filters were set to zero. The remaining halves of the filters have been retained.

The ICP-MS data were examined in multiple ways. First, element loadings (ng element m^{-3} air) of each measured element were compared between Fallon and each concurrently sampled community using the non-parametric Mann–Whitney test of medians (Sokal and Rohlf, 1981). Analyzing medians instead of means was considered a conservative approach as medians are less vulnerable to the influence of outlying values. These tests were set as one-tailed with the alternative hypothesis implying that Fallon values were greater than values of comparison towns. To take full advantage of the entire data set, element loadings were grouped within each collection period into all-Fallon and all-comparison towns for an additional test of medians with larger sample sizes.

Second, element loadings were evaluated sequentially in order to assess temporal variability within elements as well as synchroneity across elements. Because wind is an important determinant in temporal variability in dust (Ludwig et al., 1977), wind rose diagrams and average wind speeds for each sampling session were compared to the metal loadings. Hourly wind directions and speeds recorded at Fallon Naval Air Station (~12 km southeast of central Fallon) were obtained from the National Climatic Data Center, National Oceanic and Atmospheric Administration. For the wind rose diagrams, light winds were considered unimportant, so the threshold for "calm" was set at 4 m s^{-1}, approximately the upper limit for "light breezes" on the Beaufort scale (WMO, 1970).

3. Results

3.1. March collection

During March, most of the 19 elements measured showed no consistent differences or patterns between Fallon and the comparison towns. In sharp contrast to this background of no elevated exposures of most metals, tungsten and cobalt were elevated in Fallon relative to comparison towns of west central Nevada during March (Fig. 2(a)). Tungsten and cobalt loadings were higher in Fallon than in all comparison towns separately, and when grouped to improve sample sizes, tungsten and cobalt were significantly higher in Fallon than in the comparison towns together.

Temporal variability of tungsten and cobalt was high within Fallon, with median values ranging from 0.57 to 8.56 ng m^{-3} for tungsten and from 0.66 to 1.68 ng m^{-3} for cobalt (Fig. 2(a)). Across the comparison towns, variability in these elements was low, ranging from 0.12 to 0.16 ng m^{-3} for tungsten and from 0.37 to 0.58 ng m^{-3} for cobalt. This low variability in the comparison towns is notable given the fact that those towns differ from one another by population, watershed, and proximity to interstate highways and various local industries. Within Fallon, tungsten and cobalt loadings co-varied closely through time, with low values co-occurring during the Fallon-Yerington session and high values during the Fallon-Fernley and Fallon-Reno sessions. Tungsten and cobalt loadings also varied across sampling locations within Fallon. Coefficients of variation, a conservative measure of standard deviation relativized for different mean values (Sokal and Rohlf, 1981), were usually at or greater than 100% within Fallon for both metals (Fig. 2(b)). Conversely, coefficients of variation were usually at or below 50% within the comparison towns.

For the March collection period, 50% of surface winds in Fallon were either calm or light breezes, and the stronger winds were predominantly westerlies or southwesterlies (Fig. 3(a)). Four of the five sampling sessions also had ~50% calm or light

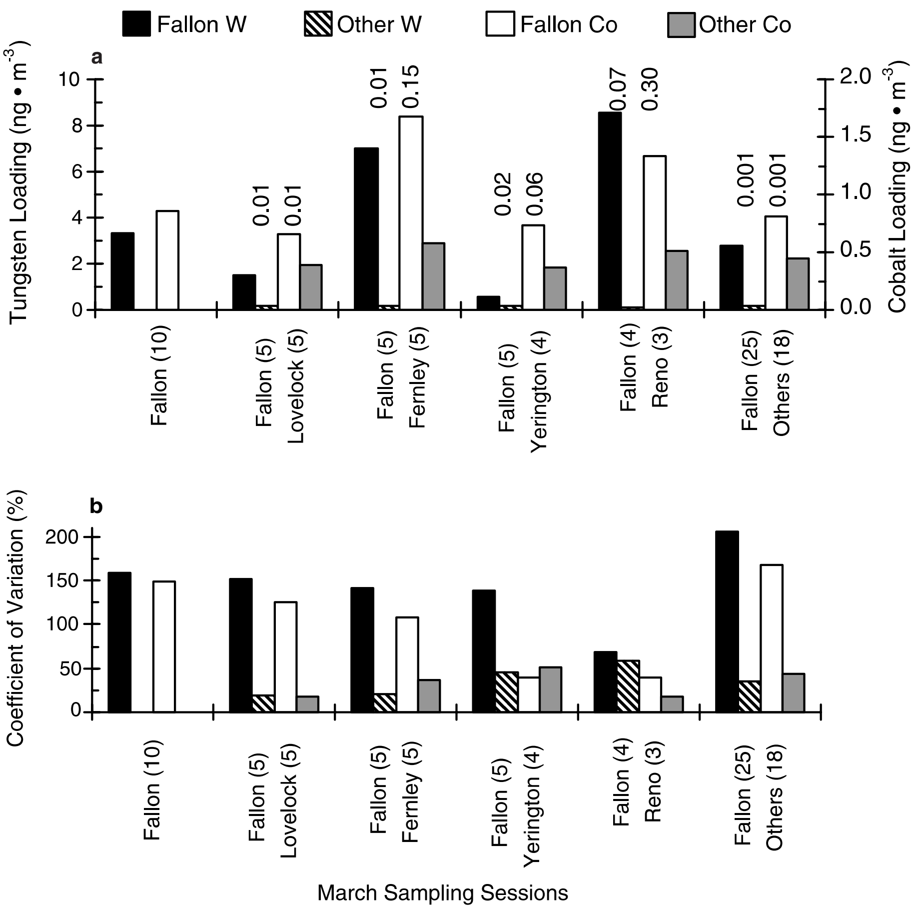

Fig. 2. Tungsten and cobalt results for the March collection period: (a) airborne loadings within Fallon and comparison (other) towns for each sampling session. Significance levels (unadjusted for multiple testing) for the Mann–Whitney test of medians between Fallon and its respective comparison town are given above the bars; (b) coefficients of variation of airborne loadings within each town for each sampling session. In both graphs, sample sizes for each session-town are given in parentheses.

breezes with stronger winds predominantly as westerlies (Fig. 3(b)–(d) and (f)). However, the session with anomalously low metal loadings in Fallon had strong winds that were predominantly northerlies (Fig. 3(e)), possibly indicating a wind direction and/or speed effect on metal loadings in dust of Fallon. Wind speed did play a role in controlling metal loadings in dust of Fallon: at the temporal scale of sampling sessions, median tungsten loadings correlated inversely with average wind speed, showing a negative-exponential relationship with wind velocity with an R^2 of 0.78 using all five data points (Fig. 4(a)).

3.2. November collection

As with March, during November most of the 19 elements measured showed no consistent differences or patterns between Fallon and the comparison towns. However, copper concentrations during November were informative for this research. Yerington, which sits at the base of an open pit and tailings piles of a now-defunct copper mine, had a median concentration of 2250 ppm copper in its airborne dust, which was over an order of magnitude higher than the median copper content of 153 ppm for the other towns of north central Nevada. High atmospheric deposition of copper has been found near a copper mine elsewhere (Zschau et al., 2003), so it is logical for Yerington dust to be elevated in copper relative to the comparison towns, which are not near copper mining or ore processing facilities. This result validates the strategy of this research of sampling airborne particulates to identify unusual exposures of metals in dust as well as indicate candidate source areas of those metals.

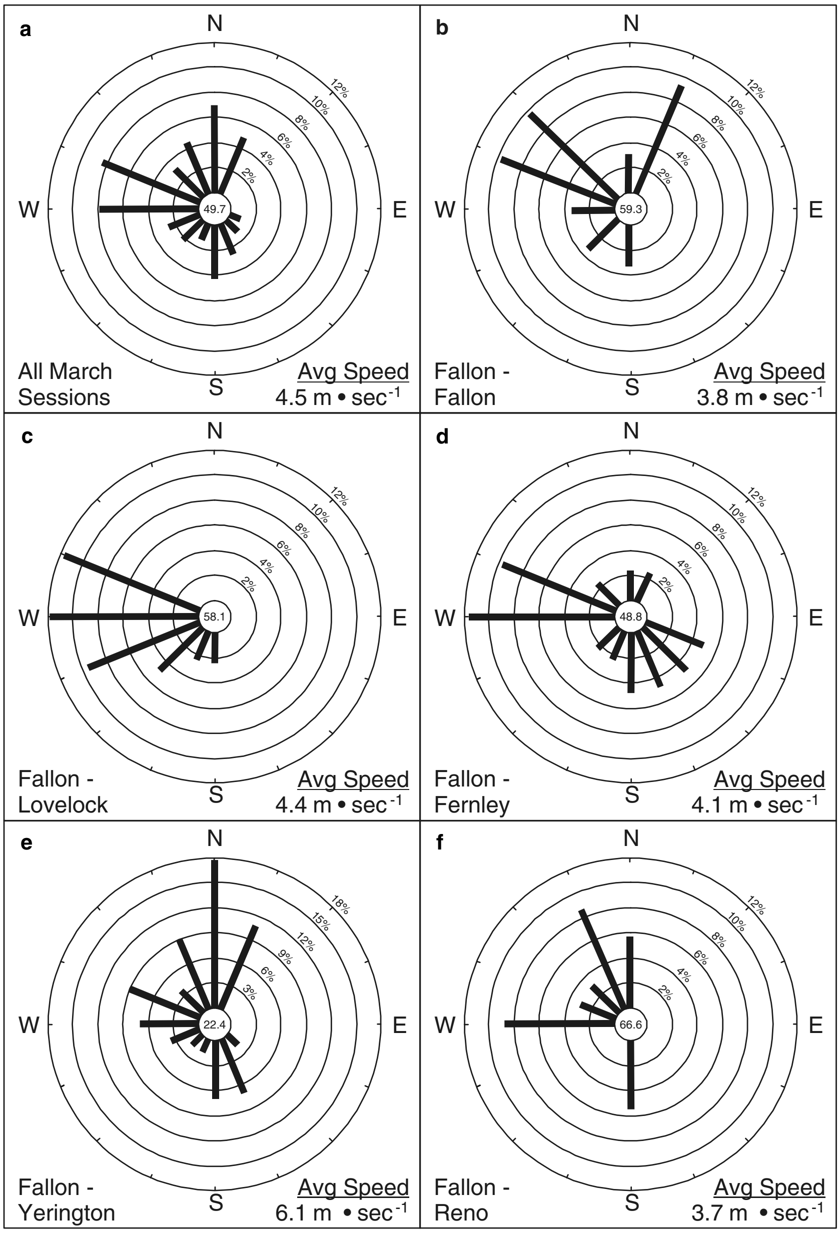

Fig. 3. Wind rose diagrams for the entire March collection period (a) as well as for the individual sampling sessions (b)–(f). Numbers inside the center circles are percent calm winds, including winds up to 4 m s^{-1}. Hourly wind data from NCDC, NOAA; wind roses generated using software of the Western Regional Climate Center.

As for tungsten and cobalt, their loadings during November were again elevated in Fallon relative to comparison towns during November (Fig. 5(a)). Tungsten and cobalt loadings were higher in Fallon than in Fernley, Yerington, and Reno. Tungsten and cobalt were anomalously low in Fallon during the Lovelock session such that no differences between those towns were found during that session. When grouped, tungsten and cobalt were significantly higher in Fallon than in the comparison towns together.

Temporal variability of tungsten and cobalt was again high within Fallon, with median values ranging from 0.10 to 40.9 ng m^{-3} for tungsten and from 0.04 to 7.5 ng m^{-3} for cobalt (Fig. 5(a)). Across the comparison towns, variability in these elements was low, ranging from 0.02 to 0.09 ng m^{-3} for tungsten and from

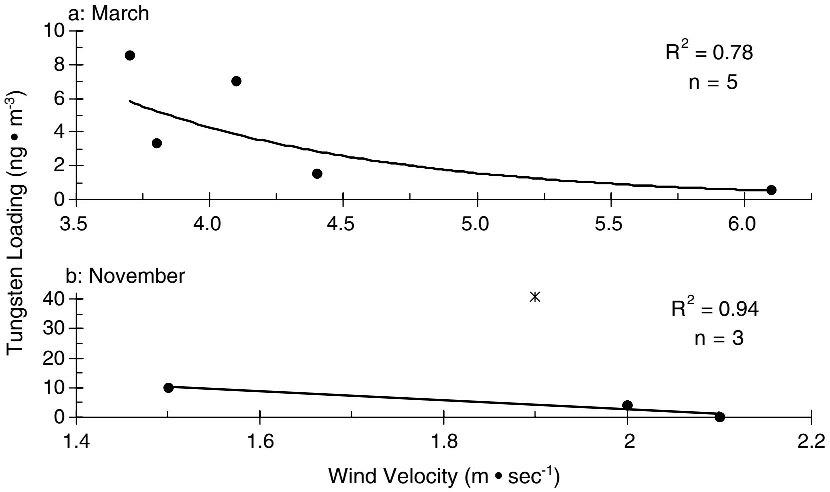

Fig. 4. Median airborne tungsten loading as a function of average wind velocity during sampling for the March (a) and November (b) collection periods. The fit line for March used all five data points, but the fit line for November excluded the high outlying value (asterisk symbol).

0.04 to 0.13 ng m^{-3} for cobalt. Within Fallon, tungsten and cobalt loadings again co-varied closely through time, with low values co-occurring during the Fallon-Lovelock session and very high values during the Fallon-Fernley session. Tungsten and cobalt loadings also varied across sampling locations within Fallon. Coefficients of variation were usually at or greater than 100% within Fallon for both metals (Fig. 5(b)). Conversely, coefficients of variation were usually at or below 50% within the comparison towns.

For the November collection period, almost all surface winds in Fallon were either calm or light breezes (Fig. 6(a)). All of the daily sampling sessions had mostly calm or light breezes, including two sessions with no winds measured stronger than light breezes (Fig. 6(b)–(e)). These results indicate that during the November collection period the effect of wind direction on metal loadings in dust of Fallon was not as important as it seemed during March. At the temporal scale of sampling sessions, median tungsten loadings correlated inversely with average wind speed, showing a linear relationship (Fig. 4(b)). The R^2 of 0.94 is calculated without the high outlying value, and with a sample size of only three, this relationship is weaker than during March.

4. Discussion

4.1. The distinguishing environmental characteristic of Fallon dust

Tungsten was the most notable metal in Fallon dust, with cobalt of secondary but still important interest. Even at their lowest median loadings, tungsten and cobalt were typically higher in Fallon than elsewhere, and at their highest median loadings, tungsten and cobalt were significantly elevated within Fallon. Tungsten loading in Fallon was up to an order of magnitude higher than the typical ambient atmospheric loading of tungsten of 0.5–1.0 ng m^{-3} (Kazantzis, 1986; US ATSDR, 2004a). Tungsten loading in comparison towns was never higher than this ambient standard. Similarly, cobalt loadings in Fallon were above the typical ambient loading of 1 ng m^{-3} (Hamilton, 1994), but they were never higher than this ambient standard in comparison towns. Cobalt was high in Fallon even when compared to cobalt loadings in major US cities prior to enactment of laws regulating pollution output (Tabor and Warren, 1958). These results were obtained and confirmed in many sampling sessions of two different collection periods during two different seasons of the year as well as using entirely different hardware and different types of filters. In short, this finding of elevated airborne exposure of tungsten and cobalt in dust of Fallon is replicated at multiple levels using different sampling equipment.

4.2. Candidate source areas for tungsten and cobalt in Fallon dust

A natural source could potentially account for Fallon's elevated tungsten. Tungsten occurs naturally in mineable concentrations throughout northern Nevada (Stager and Tingley, 1988), including at locations within 100 km of Fallon. For example,

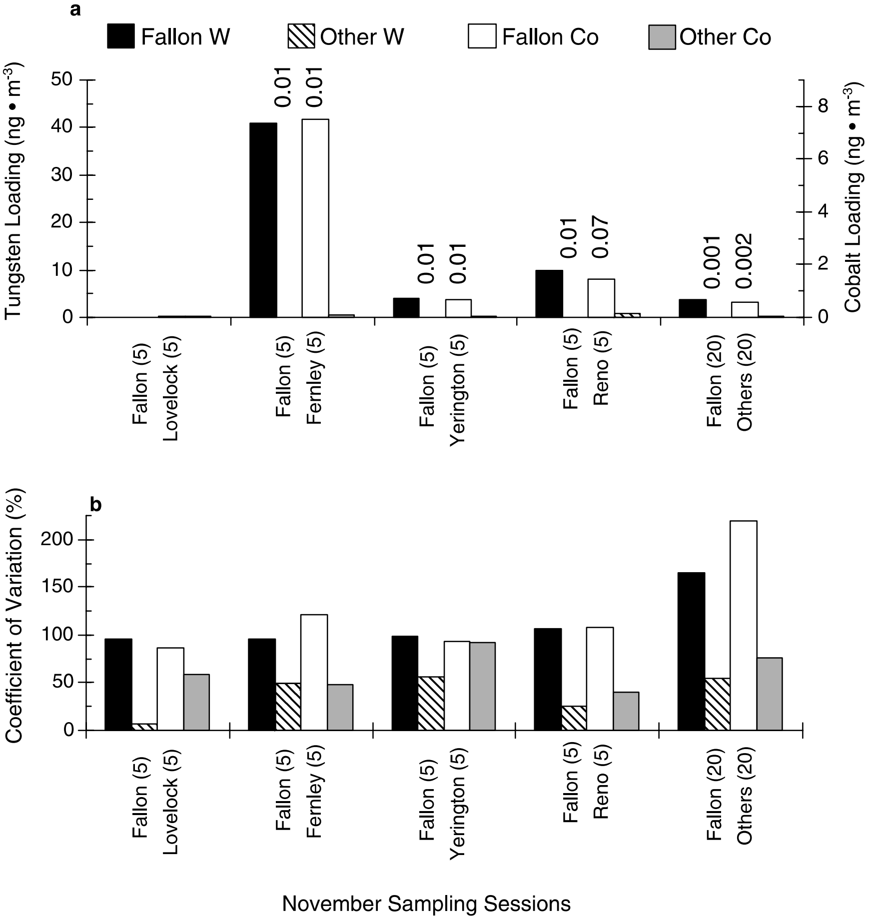

Fig. 5. Tungsten and cobalt results for the November collection period: (a) airborne loadings within Fallon and comparison (other) towns for each sampling session. Significance levels (unadjusted for multiple testing) for the Mann–Whitney test of medians between Fallon and its respective comparison town are given above the bars; (b) coefficients of variation of airborne loadings within each town for each sampling session. In both graphs, sample sizes for each session-town are given in parentheses.

surface concentrations of up to 0.5% WO_3 have been reported for Fort Churchill, 35 km west-southwest of Fallon (Stager and Tingley, 1988, p. 112).

On the other hand, at least three lines of reasoning from this research argue against the source of Fallon's airborne tungsten being natural. First, if the source of tungsten in Fallon were a natural deposit, presumably widespread and outside the city limits of Fallon, then other towns in addition to Fallon should also be affected by it. However, airborne tungsten was not elevated in any comparison town. Second, the temporal similarity of airborne tungsten and cobalt suggests a single source for these two metals. However, cobalt is not abundant naturally in west central Nevada (Peterson, 1984), and no specific deposits of both tungsten and cobalt are known near Fallon (Beal, 1964). Third, if the source were a natural deposit, then high winds that kick up dust would likely elevate tungsten loading in that dust. However, results in Fallon were exactly opposite this: high winds resulted in lower tungsten loading in Fallon dust, suggesting that the source is within Fallon. Accordingly, in spite of the fact that tungsten occurs naturally throughout northern Nevada (US CDC, 2003b) as well as in groundwater of the Fallon area due to natural geohydrological processes (Seiler et al., 2005), by weight of multiple lines of evidence, the primary source of tungsten in airborne particulates in Fallon is probably neither general nor natural.

When airborne cobalt is higher than 1 ng m^{-3}, it is often associated with cobalt-related industry (Elinder and Friberg, 1986; Barceloux, 1999; US ATSDR, 2004b). A cobalt-related industry known

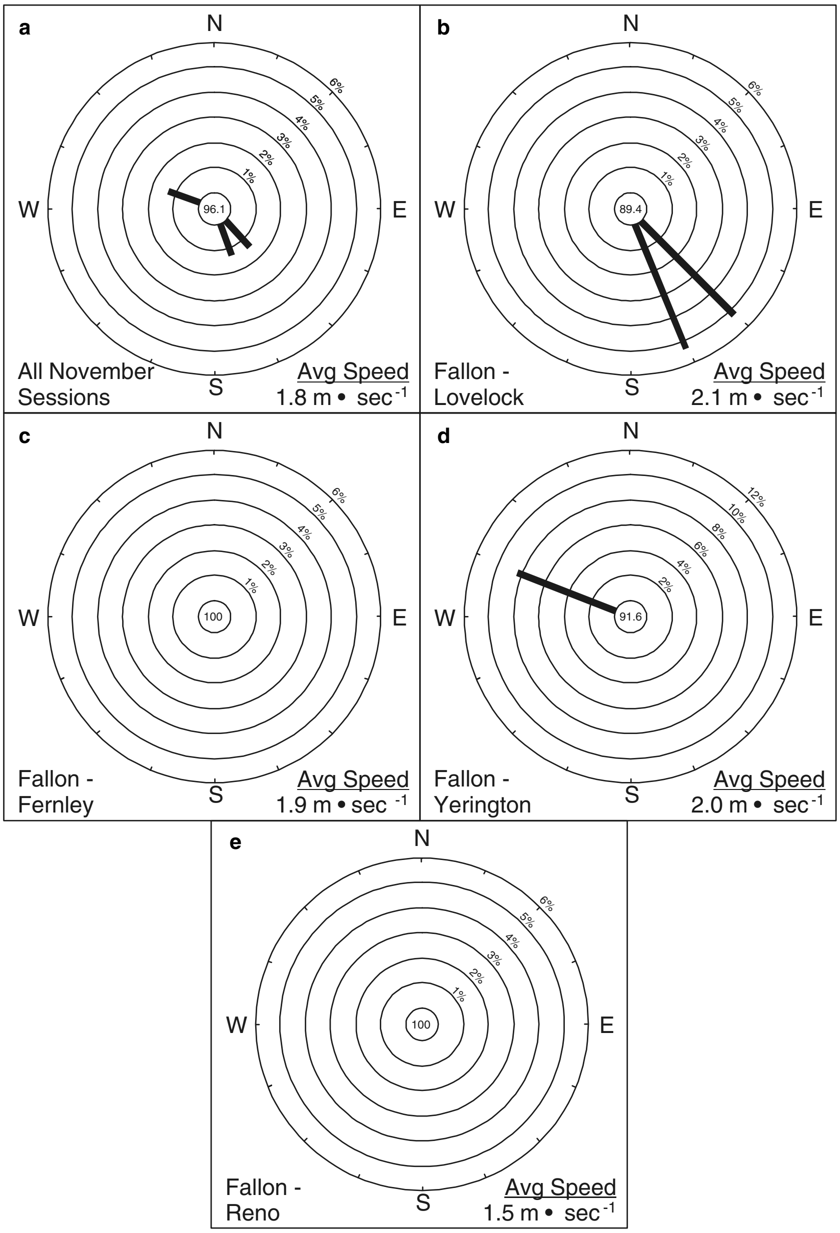

Fig. 6. Wind rose diagrams for the entire November collection period (a) as well as for the individual sampling sessions (b)–(e). Numbers inside the center circles are percent calm winds, including winds up to 4 m s^{-1}. Hourly wind data from NCDC, NOAA; wind rose software from Western Regional Climate Center.

as "hard-metal" uses various metals, including especially tungsten carbide and cobalt, to produce alloys for tools and equipment (Harris and Humphreys, 1983). A hard-metal facility is located in north central Fallon, where tungsten carbide and cobalt have been processed since the 1960s. This facility emits airborne tungsten and cobalt particles for which it is under regulatory oversight by Nevada (US ATSDR, 2003b).

Within Fallon, tungsten and cobalt showed the same spatial pattern: both had their maximum loading at the sampling location located nearest to the hard-metal facility, and they both decreased in loading with distance away from the hard-metal facility. If, for the sake of argument, the hard-metal facility in Fallon were assumed to be the source of airborne tungsten and cobalt in Fallon, then a consistent inverse relationship with distance from that facility

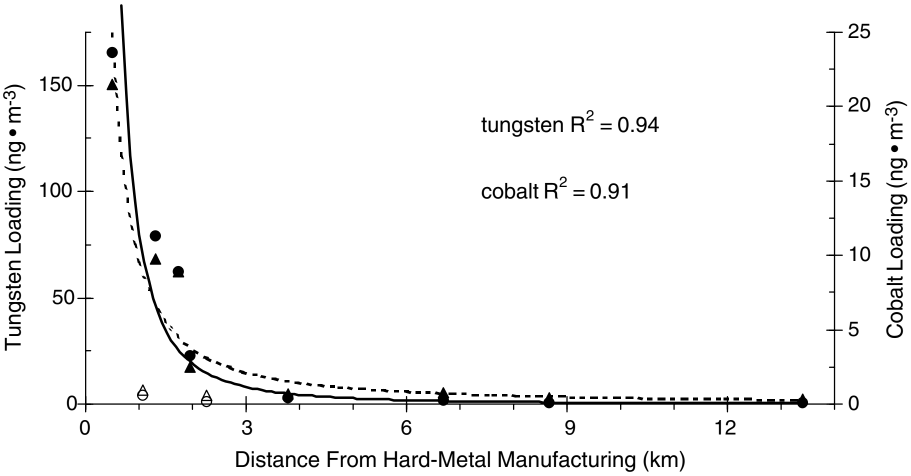

Fig. 7. Tungsten (filled circles) and cobalt (filled triangles) loadings within Fallon as a function of distance from the hard-metal facility. Fit lines (solid for tungsten, dashed for cobalt) were calculated excluding the two outlying low values (open circles for tungsten, open triangles for cobalt), which are from sample locations southwest of the hard-metal facility.

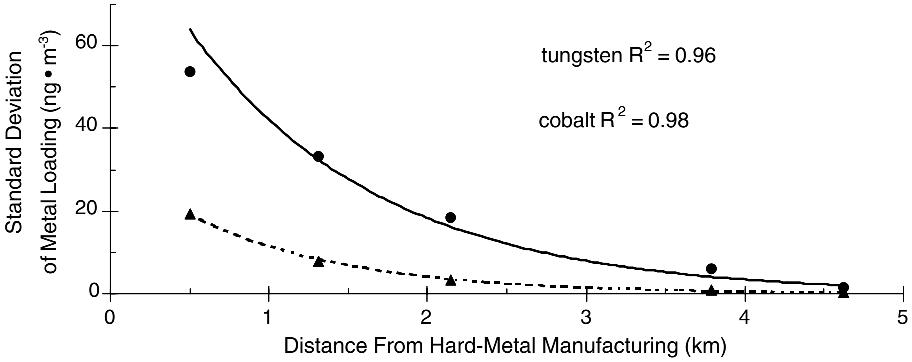

Fig. 8. Standard deviation of airborne loadings of tungsten (filled circles) and cobalt (filled triangles) during the November collection period as a function of distance from the hard-metal facility. Fit lines (solid for tungsten, dashed for cobalt) were calculated using all data points.

should emerge. Considering eight of the ten sampling locations in Fallon during March as a homogeneous group, loadings of both tungsten and cobalt dropped off steeply out to three km away from the hard-metal facility and then slowly beyond three km (Fig. 7). Two outlying values underfit this relationship for both metals (Fig. 7, open symbols), but these two sampling locations are southwest, or predominantly upwind, of the hard-metal facility, causing them to have lower loadings of airborne tungsten and cobalt. This power-function decay with distance conforms with expected patterns of airborne plumes from a point source (Seinfeld and Pandis, 1998).

Additionally, the temporal variability in tungsten and cobalt loadings at the continuously sampled locations within Fallon also dropped off with distance from the hard-metal facility (Fig. 8). The effect of wind speed on regulating airborne loadings of these two metals within Fallon is greatest for locations within a kilometer or two of the hard-metal facility, but then that wind effect diminishes beyond just a few kilometers from the facility.

Based on these temporal and spatial patterns of tungsten and cobalt in dust of Fallon, the hard-metal facility located in Fallon could tentatively be considered a candidate source of the airborne exposure of these metals within Fallon. This would corroborate a previous suggestion that this facility be considered a potential source of environmental tungsten in Fallon (Nevada Department of Environmental Protection, as reported by the Reno Gazette-Journal, 5 February 2003). However, it is not yet appropriate to conclude that the hard-metal facility is the source of the tungsten and cobalt exposure in dust of Fallon. Our data show more temporal variability in these airborne metals than can be accounted for by wind speed alone. We do not know if emissions from the hard-metal facility vary through time or, if they do, whether or not they covary with metal loadings in airborne dust. Additional research is warranted to directly measure emissions and simultaneously compare them to metal loadings in airborne dust.

4.3. Toxicological role of metals in childhood leukemia

Tungsten has been a metal of recent interest in childhood leukemia because tungsten has been found to be elevated in children and in drinking water of Fallon relative to national standards as well as to comparison towns (US CDC, 2003a,b). Tungsten exposure has been linked to non-cancer occupational illnesses (US NIOSH, 1977), but few studies have been published on the carcinogenicity of tungsten. Among such studies, tungsten in drinking water has induced a significant increase in mammary carcinoma in rats (Wei et al., 1985); heavy metal tungsten alloys have transformed human osteoblast cells to the tumorigenic phenotype, perhaps due to direct damage to genetic material in the form of increased DNA breakage or chromosomal aberrations (Miller et al., 2001); and tungsten pellets embedded intramuscularly into rats have caused tumors, including rhabdomyosarcoma (Kalinich et al., 2005). Tungsten has yet to be definitively associated with childhood leukemia (US CDC, 2003a), but tungsten ore administered to human leukemia cells in the laboratory has increased growth of pre-existing leukemia cells by 170% compared to control samples over a 72-h culture period (Sun et al., 2003).

Although tungsten metal is low in solubility, tungsten carbide is bioavailable (Kraus et al., 2001). Indeed, Fallon residents have tested ~15× higher in tungsten than the national background concentration, and children consistently tested higher than adults for tungsten (US CDC, 2003b). Although the majority of tungsten ingested by mammals is eliminated within 72 h in urine and feces (Reilly, 2002), the tungsten that is retained is predominantly stored in the bones (Kaye, 1968; Edel et al., 1990). Given the major role that bone marrow plays in leukemia (Lilleyman, 1994), accumulation of tungsten in the bones could link environmental exposure to tungsten with childhood leukemia.

As for cobalt, even though it is an essential element and a component of vitamin B_{12}, excessive cobalt exposure can be unhealthy (Lauwerys and Lison, 1994). The primary occupational health issue related to exposure to airborne cobalt has been respiratory illness (Edel et al., 1990; Lison, 1998; Fedan and Cutler, 2001), but lung and other cancers have also been noted (Elinder and Friberg, 1986; Jensen and Tüchsen, 1990; Wild et al., 2000).

More importantly, simultaneous exposure to cobalt and tungsten carbide, which might occur as a by-product of hard-metal manufacturing (Lombaert et al., 2004), appears to have a synergistic carcinogenic effect (Lison and Lauwerys, 1990, 1992; Lasfargues et al., 1992; Anard et al., 1997; Van Goethem et al., 1997). For example, the simultaneous exposure of tungsten and cobalt has synergistically activated carcinoma cells in the lab more than individual exposures of each metal (Miller et al., 2004). Indeed, the International Agency for Research on Cancer has declared cobalt and tungsten carbide together to be a probable carcinogen to humans based on sufficient evidence (IARC, 2003). This allows for a possible linkage between childhood leukemia and concurrent exposure to both tungsten and cobalt.

5. Conclusions

Fallon can be distinguished from other Nevada towns by its high airborne exposures of tungsten and cobalt particulates. Tungsten and cobalt loadings in particulate dust can be many times higher in Fallon than is found in nearby comparison towns. Additionally, these high airborne tungsten and cobalt exposures in Fallon are probably anthropogenic in origin. The close co-variance of tungsten and cobalt, both temporally and spatially, rules out a natural source. A hard-metal facility located within Fallon works with tungsten and cobalt, and it should be considered a candidate source for the high airborne exposures of these two metals in parts of Fallon.

Tungsten has not been shown definitively to cause childhood leukemia, and environmental data cannot make this connection directly. Additional research has been called for to interpret the high levels of tungsten in urine of residents of Fallon (Expert Panel, 2004), and the US National Institute of Environmental Health Sciences has been requested to conduct toxicological studies of tungsten (US ATSDR, 2004c). Biomedical research has also concluded that further study of the health effects of tungsten and tungsten alloys is needed (Kalinich et al., 2005). We concur with these calls for more research in Fallon, including to confirm the current airborne exposures and to definitively identify their source, to reconstruct past airborne exposures back in time predating the recent cluster of childhood leukemia, and to continue evaluating the link between childhood leukemia and exposure to both tungsten and cobalt.

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