Final Project
PH 267B, Spring 2007
Jason Meggs

Worker Safety in the Berkeley BART Station: Aerosolized Metals Analysis

Introduction:

Subway environments provide an unusual microenvironment with important implications for human health. Air contaminants in subway stations are a little-studied area receiving increasing concern. Recent revelations in New York City identified high exposures to manganese, chromium and iron from steel dust for workers[1] and teenagers [2], with ongoing research [3].[1]

Subway environments collect and concentrate ambient pollutants, sometimes to much higher levels than the ambient (aboveground) air. Additionally, airborne contaminants in subways were found more genotoxic than street level particles and to induce oxidative stress in cultured human lung cells [4].

In Japan, suspended particulate matter in subways was found to vary by season, but concentrations in the size range of 0.5-5.0 μm were year-round higher than aboveground air, and contained heavy metals such as iron, lead, zinc and manganese, in that order of concentration [5]. Elevated levels of dust in train tunnels and platforms was found to be three times higher than at station entrances in Rome, Italy[6]. Respirable manganese associated with street-level gasoline combustion has been found in Montreal subway stations in concentrations twice as high as ambient levels, exceeding USA EPA limits [7]. In London, a 10-fold increase in aerosol manganese was found in the underground as compared to the ambient environment, as well as elevated exposure to aluminum and PM2.5 [8].

In Paris, the concern over elevated concentrations of airborne contaminants in the Metro, an underground rail system, prompted an investigation of a removal treatment using an electrostatic precipitator, finding that “about twenty filters placed in the top of a non mechanically ventilated station would permit to half an initial concentration in particles of 230 μg/m^3,” with the pilot device losing 15% effectiveness after one year of operation, requiring cleaning of precipitation cartridges [9].

Study Area:

Workers in the Berkeley Bikestation, an attended secure bicycle parking facility located on the underground concourse above the platform level of the Downtown Berkeley BART station, an underground rail mass transit system, have complained of health problems associated with airborne contaminants. The constant presence of fine black

---

[1] A manuscript has been submitted with the main biomarker results from the pilot study, with ongoing work on the completed real-time monitoring survey as well as additional analyses on the particulate matter.

powder with a metallic quality, was associated by workers with feelings of lung effects and ill health prompted the investigation of that dust in this study, which evidently is referred to as “brake dust” [10]. Metal aerosols found in subway microenvironments may result from brakes as well as wheel-to-rail friction. High winds caused by trains may further suspend these particles. Additional sources of airborne contaminants include street pollution, which may be sucked down stairwells into the work area.

For BART trains, “braking is supplied by DC series motors controlled by a powerful semiconductor. A hydraulic disc brake system operating on all wheels controls mechanical braking which is automatically blended with the electric brake system” [10]. An effort to determine what the brake pads consist of is ongoing. An award of Invitation for Bid No. 8789, for Bonded Brake Lining, to Railroad Friction Products Corp., for an amount of $750,375.00, was found on the BART.gov website. A call to the company did not result in specific information as to the “proprietary” materials used in the brakes. An email to the Amalgamated Transit Union (ATU) Local 1555 BART worker’s union was sent asking if they had product safety data sheets for the brakes, but no reply has been seen. The ATU Local 1555 currently consists of approximately 800 members including “Train Operators, Station Agents, Transportation Clerks, Transportation Secretaries, Foreworkers, Power Support Controllers, Communication Specialists and Education Development Specialists” [11].

Microenvironment:

Workers have two primary working environments: indoors (inside the BART station agent booth) and outdoors (inside a primarily fence-walled steel cage which air passes through). Workers pass back and forth between two primary stations (an indoor desk at a computer, and an outdoor check-in shelf) in addition to a mechanic stand similar to the check-in shelf and various work throughout the cage parking bicycles and moving materials. Dust collects heavily on all horizontal surfaces and requires constant cleaning, which is not always done. Trains cause high winds in the cage, presumably increasing suspended airborne particulate matter. Workers are supplied with disposable latex gloves which are rarely used, as well as an air filter for the indoor environment which is out of use. Dust masks are not worn.

Methods:

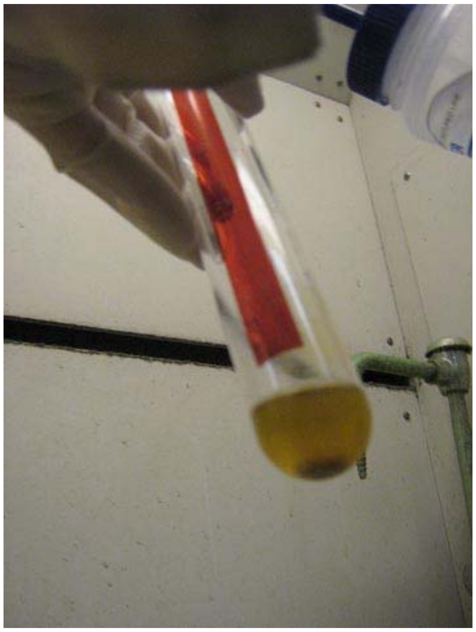
Sampling Methods

Exploratory Swipes:

Exploratory samples for metals analysis were collected by hand, by scraping dust from relatively clean stainless steel surfaces exhibiting a smooth pattern of the target dust, transported to the ICP lab where they were weighed, dissolved in 2ml nitric acid (20%), and boiled for 20 hours. One of the samples was collected on a measured piece of tissue paper and included additional dust types from a particularly dirty corner of the Bikestation cage; a blank sample of the same measurements was tested for comparison.

Because some of the samples had not fully dissolved, additional nitric acid was added where necessary and a second 20 hours of boiling was conducted. The samples were then brought "to volume" of 12.5 ml with the addition of water. Due to the suspended matter, which would clog the ICP, the samples were poured through filter paper. A blank filter paper with nitric and water was run as well for comparison purposes.

The swipes are lacking in that there is no way to know what percent of the material tested for was truly in the air at any point, let alone the size of its components

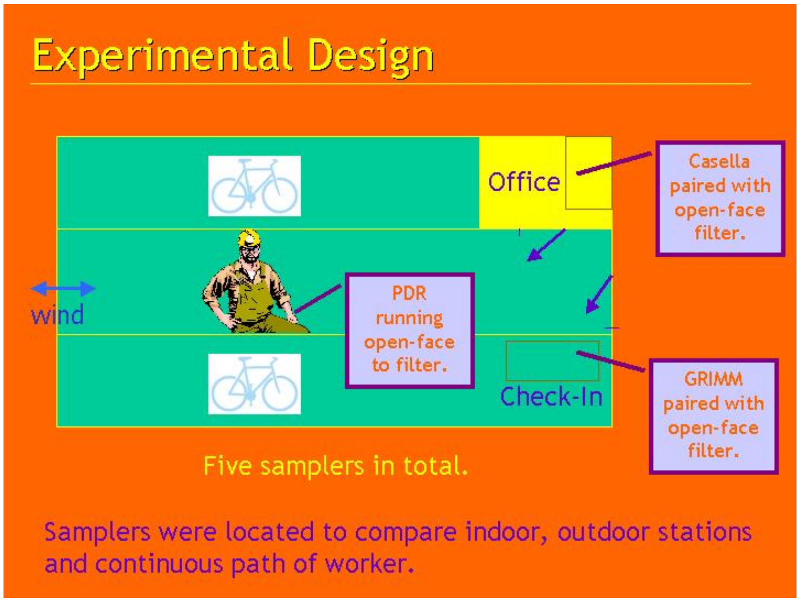


A large portion of the samples did not dissolve.

Sample solutions were filtered a second time before ICP analysis to protect the ICP. It was noticed that rust was present on the test tube holder, and rust appeared on the gloves. Gloves were changed and filters were folded with new gloves. (Iron is the primary metal observed, so contamination with iron would be perfectly awful.)

<u>Air Sampling During 7-hour shift:</u>
Air sampling was geared to analysis of metals and comparison of the characteristics of airborne particles in the indoor v. outdoor environment. The two primary stationary indoor and outdoor locations were each chosen for active sampling with a pair consisting of an open face filter ("IN" and "OUT," respectively) and a higher-detail sampler for comparison (a GRIMM sampler outdoors and a Casella indoors). Personal sampling was approximated with a Portable DataRAM (PDR) worn on the investigator (due to the barriers of human subjects requirements), who followed the worker throughout the shift. The PDR was run open face as a hybrid of the two stationary sampling strategies.

Open face sampling was chosen because the primary goal was to collect metal of all sizes. Even non-respirable/non-inhalable particles may settle in the GI tract and be swallowed.



Experimental Design

Five samplers in total.

Samplers were located to compare indoor, outdoor stations and continuous path of worker.

Principles of each Instrument:

GRIMM:

The Grimm “Dust Monitor Series 1.100” was selected for its ability to detect particles on 16 channels by size. Light refraction is used. The Grimm has its own internal pump to provide air flow through the device, and its own 47 mm filter chamber and relatively large diameter, Teflon-based filter type, for gravimetric analysis and comparison. The Grimm is specified to measure from 1 to 2,000,000 particles/liter, using a 1.2 l/min. air sampling pump with an air volume control system.

CASELLA:

The Casella “MICRODUST Pro Aerosol Monitoring System” was selected for its high accuracy at measuring concentrations. Light refraction is used against ambient air; no pump or filter are incorporated. The sensing technique uses forward light (12 to 20 degrees) using an 880 nm infra red source. Its measuring range is 0.001-2.500 mg/m3 over four ranges (0-2.5, 0-25, 0-250 mg/m3); the active range may be fixed or auto ranging. Its resolution is 0.001 mg/m3. Its zero stability is claimed to be < 2 ug/m3/degrees-Celsius [12].

PDR:

The Thermo Electron Corporation “Personal DataRAM” personal sampler (PDR) measures mass concentrations in real time using light scattering. The PDR was chosen for its portability and its ability to provide data of comparable types to the that obtained from the stationary pairs: an open face MCE filter as well as real time concentration analysis. The PDR was set to a 5-second interval for sampling average concentration. No size selection was used at the airway opening.

OPEN FACE PUMPS:

Three TSI “SidePak Personal Sampling Pump SP350” devices were employed, with airway openings connected to an open face MCE filter in front of the machine. Two were run horizontally on AC power and were calibrated horizontally on AC power; the SidePak was worn vertically on a belt on battery power and was calibrated vertically using battery power on a table, in case power source affected flow. All were set to 80% of their machine-determined capacity, on the theory that as the filters became less permeable from sampling, or batteries declined, the machines would have an additional 20% of power capacity to compensate.

It should be noted that the PDR filter is behind the machine, unlike the other two open face filters, which are open and bare to the outside. The PDR airway opening is less than 1 cm in diameter, whereas the open face filters presented closer to 4 cm in diameter, although the tube behind them is close to the size of the PDR opening. The likely result is that fewer particles will reach the PDR filter due to passing through the machine. On the other hand, it may be that larger particles were sucked into the opening due to its not being obstructed.

Analytical Methods and Analytical Instruments:

Filters:

All three open-face samplers were fitted with Mixed Cellulose Ester (MCE) filters which are "hydrophilic, autoclavable and the standard filter for fibers and metals" and "meet NIOSH and OSHA method specifications for monitoring airborne metals, asbestos and fibers" which "dissolve and clear completely" [13]. Because metals are being tested for, and fibers are also of interest, these are the best filters known for this type of task.

Problems with filter use: first and foremost, the open face filters all leaked. There were no visible dust marks on the filter, but the pads had streaks of black dust. Secondly, the filter for the interior (office) filter was torn by tweezers, although it may not have lost any material. Finally, measuring weights may have been affected by the change in relative humidity and temperature (which changed 4.2% and 3.3 degrees Celsius, respectively; it had rained the night before).

With the Grimm, one issue noticed was the collection of black sooty particulates on the interior of the filter chamber, evidently from previous users who took it to the foundry. The chamber was wiped with kim-wipes, but this raises questions as to how much particulate matter actually makes it to the filter. Given the difference between the machine's claim of the total mass seen, different from the filter (evidently 55.87 times more), some quantity presumably is lost within the sampler. Other explanations include the disparity between actual sample size and reading, particularly for larger samples; there is a big step between possible values for the largest particles (>20ug) of 22.9 ug/m3, and for the next largest size (15.0-20.0 um), the step is 7.9 ug/m3. But if anything, it seems that should make the filter seem heavier than the measurements, if lower values don't trigger any response (not sure what the range is/where the cut-offs are, for triggering a value).

Extrapolating filter pad results:

Metals Analysis:

Analysis of metals was conducted using the Inductively Coupled Spectroscopy (ICP) facility at UC Berkeley's College of Natural Resources (CNR). "An ICP uses a high temperature Argon plasma to analyze element concentrations in liquid solutions. The CNR ICP is an optical emission (OES) system and uses the light emission from the high temperature excitation of the atoms to determine their concentration. Applications include plant elemental analysis, soil extracts, silicon chip analysis, nanoparticles, rock fusions to name just a few. The instrument used is a Perkin Elmer 5300 DV optical emission ICP with auto sampler. The ICP has a standard nebulizer system. For certain applications a flow injection system with hydride generation ability, and an ultrasonic nebulizer for enhanced detection limits are available"[14].

Metals of interest must be chosen before using the ICP. A standard solution is made with known concentrations of the target metals, for comparison with the sample. Metals for standard were chosen based on NYC study and various metals of concern: Iron, Manganese, and Chromium; with Cadmium, Cobalt, Copper, Lead, Mercury, Nickel, and Scandium added to the list.

The filters were very difficult to insert into the test tubes; they cracked, and seemed to cling to gloves and glass. The first sample's filter (MCE from inside the booth) was the hardest, and it is possible small particles of the filter were lost. A method of folding the filter as it cracked was developed and employed for the remaining filters. The Grimm filter was folded tightly in this way, however, the Grimm filter, being made of Teflon, did not dissolve, leaving a tightly balled hunk of Teflon. Is it possible that metals did not dissolve into the nitric acid as a result of being so encapsulated? This would help explain why levels on the Grimm are low or comparable to the pads which leaked.

Results and Discussions:

Data and Observations:

Exploratory Swipes:

Very high concentrations of iron were found, as well as indication that there was manganese, cadmium, chromium, cobalt, lead and copper. Scandium was not evident and the test for mercury was unusable as it no standard was made for it and the ICP machine is not reliable for mercury to begin with.

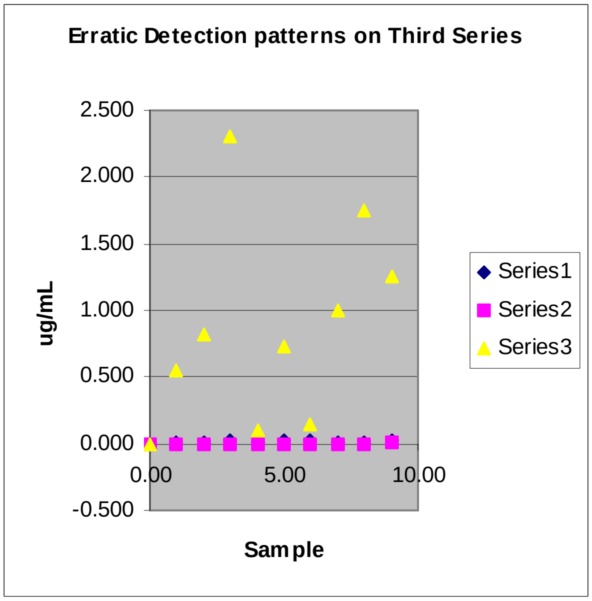
Also present was a high percentage of material that would not dissolve. This suggests a strong possibility of minerals, such as asbestos, which do not dissolve in the nitric solution (asbestos is a known component of many brake pads).

Metals Collected by Air Sampling During Morning Work Shift:

It is most important to recognize that any detection of metals found in this exploratory project are minimums, not maximums. This is due primarily to the uncertainty of the digestion method (not all the sample dissolves for analysis), the leakage around filters, and limits of detection being set too high on the ICP.

The primary metal detected was, as expected, iron. There is reason to further investigate levels of nickel and manganese. Other components may indeed be present in smaller concentrations than could be detected during the sampling period. Given the unusually clear day, the leakage on the filters, and the fact that the ICP had not been calibrated low enough to reliably describe the levels that may be present, the test must be repeated.

There appeared to be a repetitive pattern underlying all results, suggesting the machine was not appropriately calibrated. Scandium is a good element for these types of correction, as it is almost certainly zero, making it a good baseline test element.



The pattern shown in series 3 (here, for lead, on emission line "Pb 261.418") is replicated in other tests, suggesting a problem with the tuning of the ICP. This could be corrected for if necessary.

In general, there appeared to bee an approximately 4% drift upward in results from beginning to end of each run, indicated by readings of the standard solution. The results which are usable were credible due to their consistency across various emission lines (elements emit various light waves in the ICP; these do not indicate isotope, but rather are different views of the presence of the same element).

Although there was a lack of detection, this does not indicate a lack of concern regarding all the metals tested (and others yet to be tested, such as aluminum).

Digestion:

Because the digestion method (nitric acid) is presumably not completely digesting all particulate present, given the large portion undigested in the swipe samples, any metals found are but a lower limit. An EPA-rated digestion method is necessary to be more certain about the metals present. It may be possible to increase the concentration of nitric acid used, or to use perchloric acid instead. Unfortunately, perchloric acid requires very special care due to its high danger, and a separate facility would be required.

Quantities Collected and Limits of Detection:

Furthermore, because there was leakage, and only a 6-7 hour sampling window, and the ICP was not set to low enough levels to detect what may or may not be present, the experiment must be repeated while correcting for those errors.

Iron:

Because relatively high concentrations of iron are the most certain of the measurements, iron is described more fully here.

Sampler	ug/m3
IN	3.9627
OUT	6.9220
PDR	18.0708
BLANK MCE	
GRIMM	5.2873
BLANK PAD	
PAD IN	7.0609
PAD OUT	14.6116
PDR PAD	9.8908

Air concentration of iron found using various filters and pads, in ug/m3.

Based on the flow rates of the specific machines, average air concentration is calculated using the amounts indicated by the ICP, in the table above.

Locating occupational exposure limits for iron aerosols was difficult; OSHA and EPA do not appear to have any clear web page describing this. In addition, the term "aerosol" is defined narrowly at the EPA[2]. No chronic exposure limit for iron was listed at the OEHHA site as of February 2005.[3] Pages describing various types of iron oxides and dicyclopentadienyl iron dust were found at various agency sites, but it was not clear how they relate to the iron found in these samples. The closest summary of regulations was here:

Chemical Name	TLV ppm	PEL ppm	STEL/Ceiling ppm	IDLH ppm
Iron oxide fume	5 mg/m3	10 mg/m3	-	2500 mg/m3

Table of Regulations Regarding Iron

Clearly, the levels measured are roughly three orders of magnitude safer than the TLV value. Even given all the errors (leakage, etc.), it seems unlikely, based on this, that the iron levels violate any regulation. We can better approximate those levels by attempting to include the levels on the filter pad, which was also digested and analyzed. However, the pad is not designed to be free of metal, and appeared to contain iron. This was also adjusted for in the following table:

---

[2] "Aerosols are substances stored under pressure and then released as a suspension of particles in air." http://www.epa.gov/ozone/snap/aerosol/index.html

[3] http://www.oehha.ca.gov/air/chronic_rels/AllChrels.html

Sampler	Filter	Pad	Sum
IN	3.9627	7.0609	11.0236
OUT	6.9220	14.6116	21.5335
PDR	18.0708	9.8908	27.9616

Table of Iron Content on Filters and Pads, and their Combined implications (ug/m3). No correction for content within the filter is made here.

Based on the lowest values, one can estimate a lower limit for the total human exposure during an 8-hour shift while breathing moderately at 2 LPM, for a total of 0.96 m3.

Sampler	ug/m3	Human 8 hr
IN	3.9627	3.8042
OUT	6.9220	6.6451
PDR	18.0708	17.3479

Estimation of total ingestion of a human during an 8-hour shift (lower limit).

Manganese:

Although the levels for manganese are not reliable, we can take a similar look at how much higher they would have to be to amount to a violation:

Chemical Name	TLV ppm	PEL ppm	STEL/Ceiling ppm	IDLH ppm
Manganese compounds (as Mn)	0.2 mg/m3	-	5 mg/m3+	500 mg/m3
Manganese fume (as Mn)	-	-	5 mg/m3+	500 mg/m3

Manganese regulators limits.

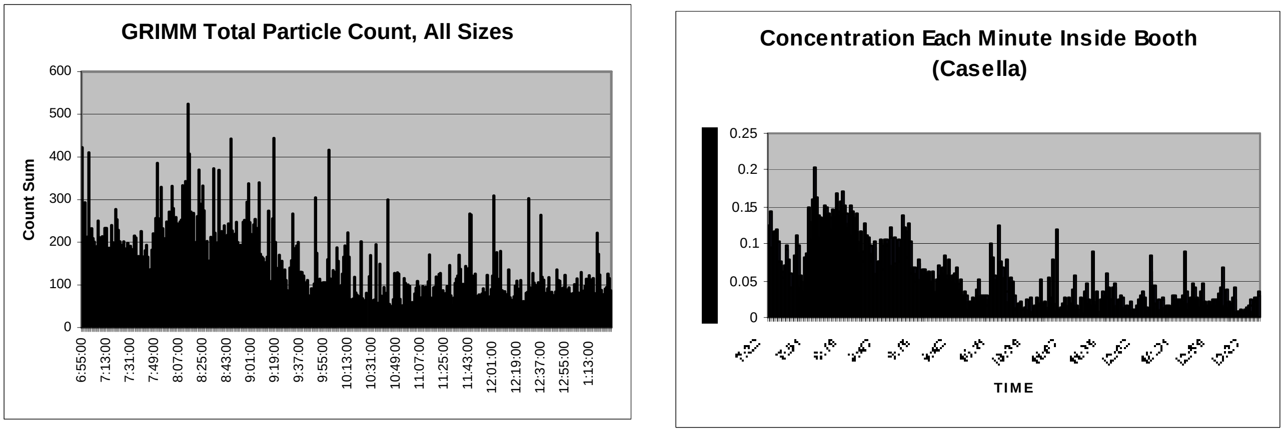
Sampler	ug/m3
IN	0.0322
OUT	0.0451
PDR	0.1378
BLANK MCE	
GRIMM	0.0940
BLANK PAD	
PAD IN	0.0583
PAD OUT	0.1507
PDR PAD	0.0138

Sampler	ug/m3	Human 8-hr
IN	0.0322	0.0309
OUT	0.0451	0.0433
PDR	0.1378	0.1323

The Reference Concentration (RfC) for manganese is 0.00005 mg/m^3 based on impairment of neurobehavioral function in humans [15]. Given that, the levels in the Bikestation are six orders of magnitude higher than the RfC (making me wonder if I have made a mistake; perhaps my manganese levels are too high to think properly as a result of visiting the Bikestation). But the EPA further explains that the RfC is “an estimate (with uncertainty spanning perhaps an order of magnitude) of a continuous inhalation exposure to the human population (including sensitive subgroups) that is likely to be without appreciable risk of deleterious noncancer effects during a lifetime. It is not a direct estimator of risk but rather a reference point to gauge the potential effects. At exposures increasingly greater than the RfC, the potential for adverse health effects increases. Lifetime exposure above the RfC does not imply that an adverse health effect would necessarily occur.”

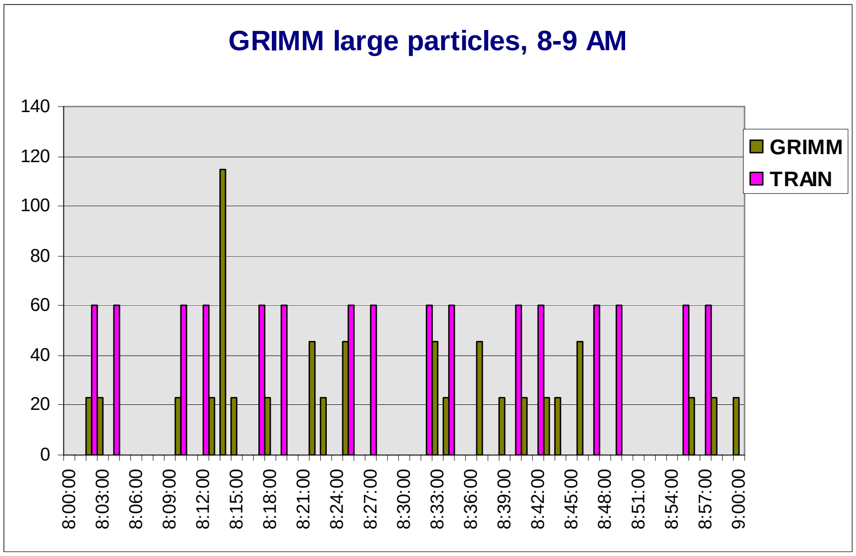
Particle Concentrations:

There was a clear peak during the peak travel period shown on all three sampling instruments (see graphs, below). To what degree this is due to longer and more frequent trains, versus other possible sources such as increased traffic aboveground and increased patron presence and activity, is not yet clear.



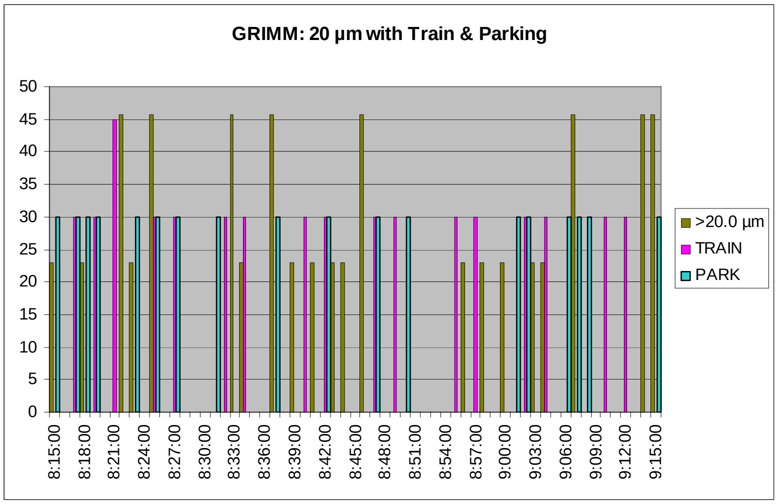
Comparison of GRIMM and Casella particle Concentrations. Both show a clear peak period.

An attempt was made to associate particles with train activity (wind and generation of brake and steel dust) to help give an answer to this question. There does appear to be some association seen, for instance in this graph:

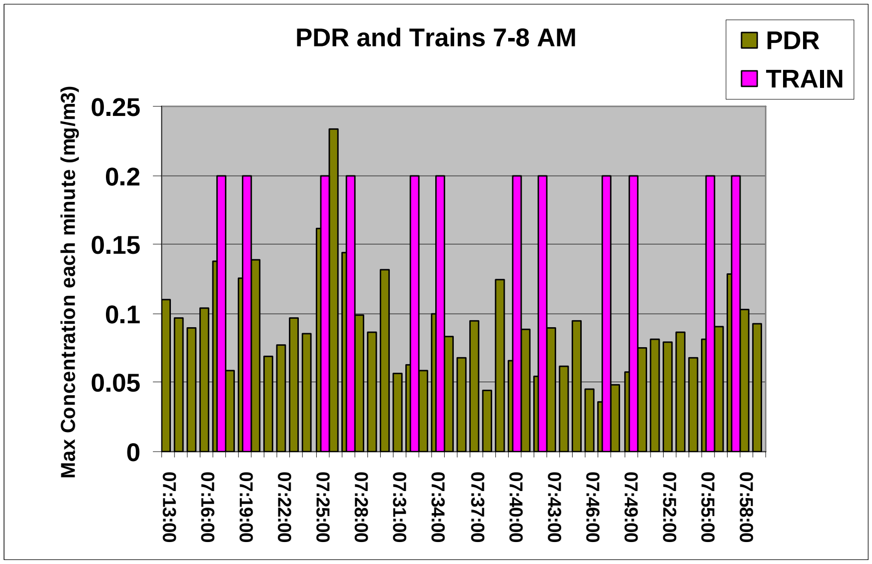


Association of train activity with large particle concentrations in the BART station during the peak period.

An effort was also made to look at the effect of bicycle parking with trains, to see if that might help explain the high peaks (parking results in opening of the mostly solid station door adjacent to the Grimm location, which would allow more air flow). A graph of this is below:



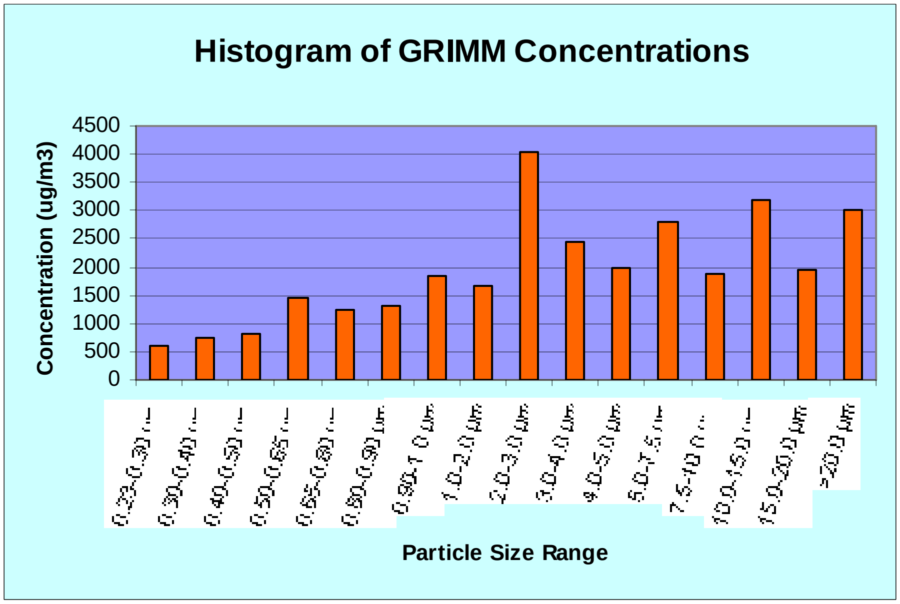
Association of train activity and bicycle parking with large particle concentrations in the BART station during the peak period (8:15 – 9:15).



Association of PDR concentrations seen with trains (personal sampling for worker exposure) in the BART station during the peak period (7– 8 AM).

GRIMM:

Data clean-up for the Grimm was done by interpolating between adjacent datapoints to replace values which were clearly "electronic errors," e.g., extremely high values orders of magnitude out of range. They comprised approximately 7/6320 (0.11%) of all datapoints. What causes these? Is it possible that extra large particles, or particles of a particular type (charged? metallic? magnetic?) are causing them? Are these important datapoints? Interpolation did not appear inconsistent with the patterns of data.



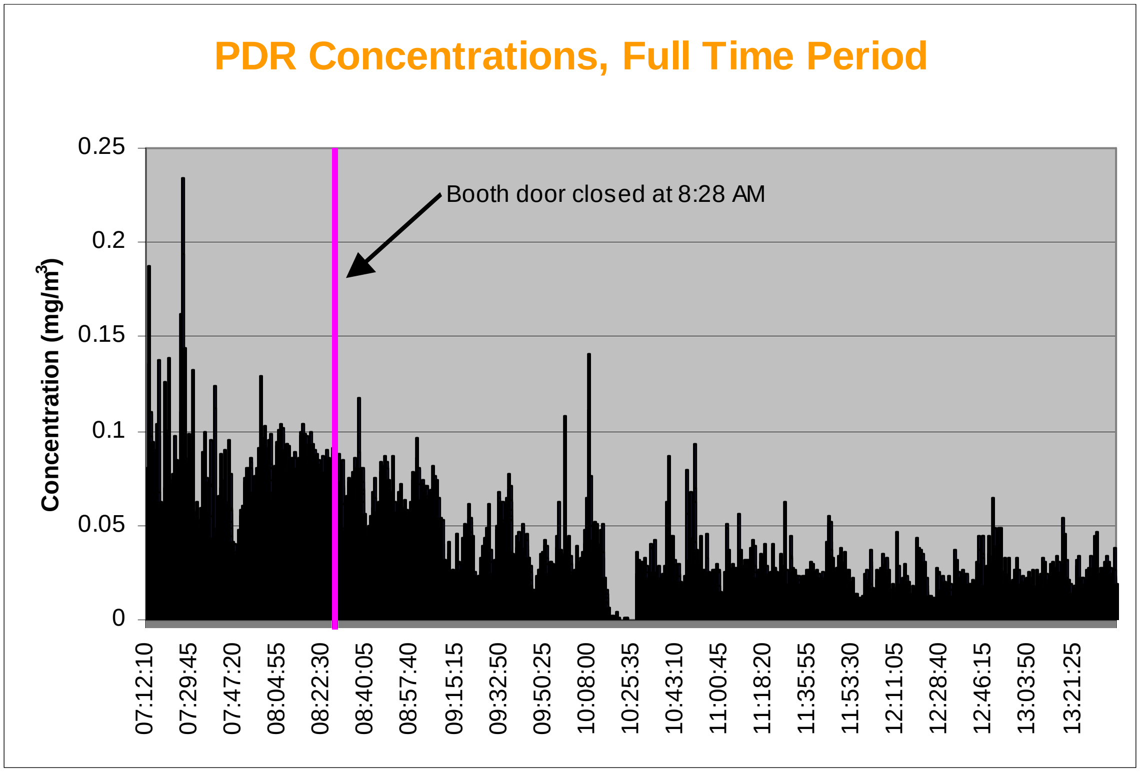
Histogram of Particle Bandwidths Detected by the Grimm.

CASELLA:

The Casella did not appear to have any aberrant datapoints.

PDR:

A similar data clean-up was done as for the Grimm, but in this case, the two 5-second intervals which were modified occurred due to operator behavior; to test the pump as it seemed to be failing or off, the operator placed a finger over the air intake briefly. The pump soared and ultrahigh datapoints were generated. These comprised less than 1:2247 (0.044%) of all datapoints. Interpolation did appeared consistent with the pattern of data.



Personal (PDR) Sampling. Note that the booth door closed at 8:28 AM as marked, which might result in lower concentrations seen while in the booth. Note also the blank period around 10:15-10:30 resulting from battery failure.

OPEN FACE:

No runtime data was generated for the open face filters, except for the number of minutes of operation. Calibration was done the afternoon/evening before (approx. 13-14 hours before) operation, and recalibration was done five hours after sampling.

	FLOW RATE IN CC/MIN			
Filter	BEFORE	AFTER	AVERAGE	% CHANGE
PDR	3456.00	3473.00	3464.50	0.49%
OUT	3504.00	3207.50	2255.75	-8.46%
IN	3698.50	3648.00	3673.25	-1.37%

Comparison of Before and After Calibrations of Pumps

Filter	ml
PDR	1297743.958
OUT	1248339
IN	1447260.5
Grimm	480000.000

Filter	Liters
PDR	1297.74396
OUT	1248.339
IN	1447.2605
Grimm	480.000

Filter	m3
PDR	1.29774396
OUT	1.248339
IN	1.4472605
Grimm	0.48

Flow Rates in ml, L, m3 for the four samplers.

Comparison of Instruments' Measurements:

Filter	(mg)
PDR	0.256
OUT	0.284
IN	0.249
Grimm	0.263
Average:	0.263

Quantity by weight (mg) present on filters after sampling.

It is interesting that the weight of material on the Grimm is exactly the average.

Because so much visible leakage was found on the pads, they were also digested and analyzed for metals in the ICP. However, the filter pads contain some metals, in contrast to the MCE filters which are designed to have minimal metal content.

Sampler	Total Dissolved (µg)	% Weight on Filter
IN	26.4751	10.63%
OUT	64.7129	22.79%
PDR	143.9616	56.24%
BLANK MCE	21.8794	8.31%
GRIMM	40.6336	15.44%
BL PAD	33.8862	12.88%
OF PAD IN	71.0595	28.54%
OF PAD OUT	134.4948	47.36%
PDR PAD	119.0364	46.50%

Difference between dissolved ug on filter and the total weight recorded on the filter.

ICP sums of the weights of all components, which can not be considered accurate, were used to be able to generate some kind of data for the Pads, which were not weighed. If true, this shows a large portion of the materials in the air are as yet unidentified.

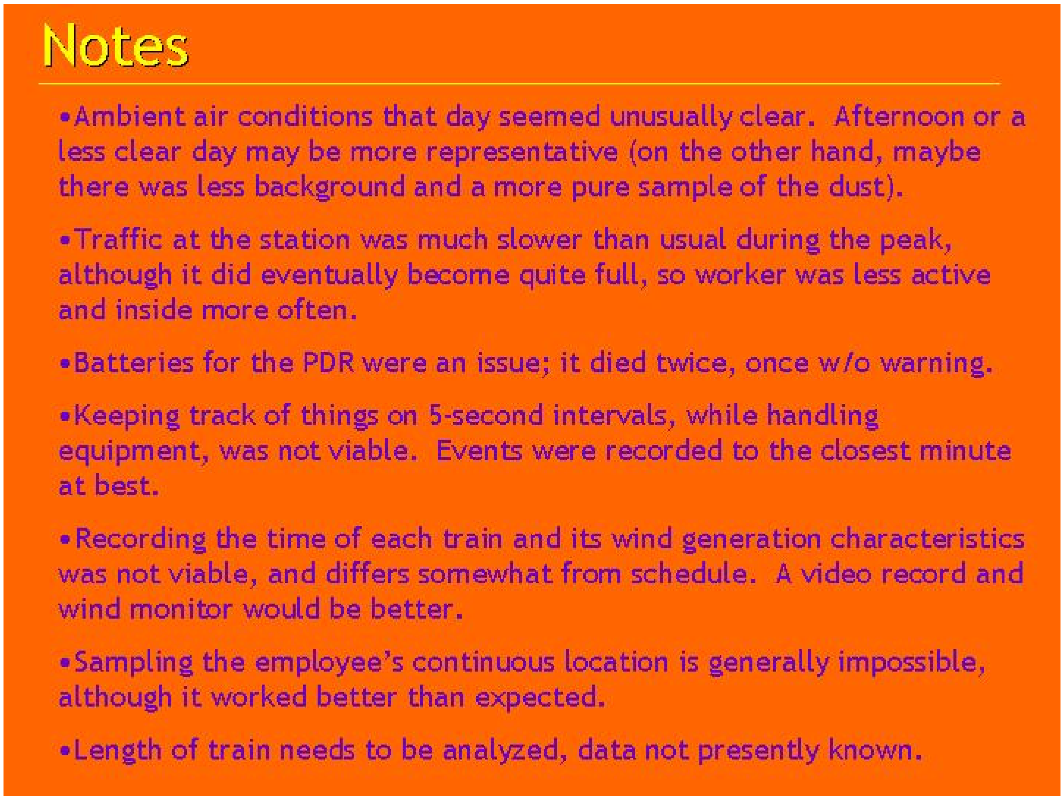
The differences in concentration on the filters and pads might be explained by several differences between the sampling methods. The PDR has the lowest estimated total collected. This might be because of the constrained nozzle and collisions that likely happen on the way to the filter (the hole is much smaller than an open face filter, and the filter is behind the instrument). The Grimm having a smaller concentration may be explained by similar reasoning (indeed, the Grimm ran with a size selector insert at the airway entrance to block larger particles) and the lower LPM, which may mean fewer large particles were attracted into the unit.

Conc.	mg/liter	Filter pad estimate	TOTAL
PDR	0.000197265	0.000163111	0.000360377
OUT	0.00022750	0.000472825	0.00070033
IN	0.000172049	0.000461783	0.000633832
Grimm	0.00054826		0.00054826
		Average:	**0.0005607**

Strengths and Limitations of Analysis:

This analysis suffers for lack of dependable data and other issues described above and below. As a first pass to explore the need for further experiments, it is a good start. No statistical analyses were attempted given the poor quality of data in this first pass, and the amount of work to time available for getting to this point in the effort.

Overall problems with experiment:



Notes

- Ambient air conditions that day seemed unusually clear. Afternoon or a less clear day may be more representative (on the other hand, maybe there was less background and a more pure sample of the dust).
- Traffic at the station was much slower than usual during the peak, although it did eventually become quite full, so worker was less active and inside more often.
- Batteries for the PDR were an issue; it died twice, once w/o warning.
- Keeping track of things on 5-second intervals, while handling equipment, was not viable. Events were recorded to the closest minute at best.
- Recording the time of each train and its wind generation characteristics was not viable, and differs somewhat from schedule. A video record and wind monitor would be better.
- Sampling the employee’s continuous location is generally impossible, although it worked better than expected.
- Length of train needs to be analyzed, data not presently known.

In addition to problems mentioned elsewhere, the above box describes a number of issues around sampling methodology.

Conclusions and Recommendations for Future Studies:

Implications of findings:

Metals detected on open-face MCE filters during a 7-hour shift included iron, with a possibility that chromium, manganese and others are present as well. These metals have numerous potential health risks, and the manganese levels seen are five orders of magnitude above the EPA's RfC level. While it is too early to tell what metals are present in what concentrations, the fact that these can be considered the lowest possible limits of true exposure, is of true concern. Long-term exposure to metals has many health implications; for instance, chronic exposure to lead and copper appear to be a risk factor for Parkinson's disease [16].

The fact that the metals detected on the swipe were not able to be reliably described in the air sampling demands that further testing be completed. The data collected were only lower limits due to the incomplete digestion, inadequate levels of detection on the ICP, and leakage at the filters, in addition to

The finding that a large portion of material collected is unable to be digested with nitric acid on 20-hour boil, even after a second run, raises serious concerns as to what types of substances may be present. Asbestos is one candidate which must be investigated, and is certainly not the only possibility with dire implications for human health given a chronic exposure.

Mitigation Options

How can the contaminants be controlled for? Numerous safety concerns including brake dust, falling onto the tracks, and noise hazards would be greatly mitigated with the addition of a barrier between the platform and the tracks, and should be seriously considered. Air filtering of the type investigated in Paris should be considered as well.

Next Steps:

The experiment should be repeated, correcting for the problems seen in the first:

- Better personal sampling (have worker wear device)
- Note taking to the second (use video if necessary)
- Sample on days more representative of the range of ambient air quality
- Wind analysis: correlate to particles
- No wind obstruction for Grimm
- Avoid battery problems for pump
- Avoid problems with filters breaking, clinging, and leaking
- Somehow determine length of trains (wind analysis may suffice)

- Determine whether actions of BART modify results seen (e.g., replacement schedule for brake pads and cleaning schedules)
- Lower the limits of detection on the ICP at least one order of magnitude (with a 1/100 standard in addition to the 1:1 and 1/10).
- Investigate a more certain method of digestion. Is there a higher concentration of nitric acid which can be used? Should the very dangerous method of using perchloric acid be attempted?

A cascade impactor would provide a resolution of what metals are found at different size ranges; filters from different size ranges would be analyzed in the ICP.

Fiber analysis is an important next step due to the possibility of asbestos content and other as yet unknown materials which may be associated with human injury and disease. This would include visual identification and counting of fibers as well as further chemical analysis.

Analysis of additional air contamination concerns, such as volatile organic compounds, would help complete the picture of air quality present.

Product safety sheets for the brakes might be available through the union and continued pursuit may reveal them.

A look at what happens at the station-street interface. What is entering from outdoors? What is leaving? Personal observation suggests that brake dust does not appreciably leave the station into the underground stairwells to the outdoors, and winds from outdoors entering the station become strong with train movements.

Consider testing for additional metals such as aluminum, which was suggested but was not included in the standard. Again, aluminum was reported in one study [8].

References:

References

1. Chillrud, Steven N Epstein, David Ross, James M Sax, Sonja N Pederson, Dee Spengler, John D Kinney,Patrick L. 2004. Elevated airborne exposures of teenagers to manganese, chromium, and iron from steel dust and New York City's subway system. *Environmental science technology* 38:732.

2. Chillrud, Steven N Grass, David Ross, James M Coulibaly, Drissa Slavkovich, Vesna Epstein, David Sax, Sonja N Pederson, Dee Johnson, David Spengler, John D Kinney, Patrick L Simpson, H James Brandt-Rauf,Paul. 2005. Steel dust in the New York City subway system as a source of manganese, chromium, and iron exposures for transit workers. *Journal of urban health* 82:33.

3. Chillrud S. Re: Steel Dust in Underground Subway Systems? .

4. Karlsson, Hanna L Nilsson, Lennart Möller,Lennart. 2005. Subway particles are more genotoxic than street particles and induce oxidative stress in cultured human lung cells. *Chemical research in toxicology* 18:19.

5. Furuya, Keiichi, Kudo, Yoshiyuki, Okinaga, Kiyo, Yamuki, Maho, Takahashi, Sentaro, Araki, Yoichi and Hisamatsu, Yoshiharu. 2007. SEASONAL VARIATION AND THEIR CHARACTERIZATION OF SUSPENDED PARTICULATE MATTER IN THE AIR OF SUBWAY STATIONS. *Journal of Trace and Microprobe* 19:469--485.

6. Ripanucci, G Grana, M Vicentini, L Magrini, A Bergamaschi,A. 2006. Dust in the underground railway tunnels of an Italian town. *Journal of occupational and environmental hygiene* 3:16.

7. Boudia, Nacéra Halley, Renée Kennedy, Greg Lambert, Jean Gareau, Lise Zayed,Joseph. 2006. Manganese concentrations in the air of the Montreal (Canada) subway in relation to surface automobile traffic density. *The Science of the total environment* 366:143.

8. Pfeifer, G D Harrison, R M Lynam,D R. 1999. Personal exposures to airborne metals in London taxi drivers and office workers in 1995 and 1996. *The Science of the total environment* 235:253.

9. Tokarek SB,A. 2006. An exemple of particle concentration reduction in Parisian subway stations by electrostatic precipitation. *Environmental technology* 27:1279.

10. BART Office of Public Affairs. 1996. BART - History and Facts, BART cars. 2007.

11. Amalgamated Transit Union. 2007. Amalgamated Transit Union Local 1555. 2007.

12. Casella Corporation. MICRODUST Pro Aerosol Montoring System. 2007.

13. [Anonymous]. Mixed Cellulose Ester (MCE) Air Sampling Filters. 2007.

14. The Inductively Coupled Spectroscopy Lab, UC Berkeley. 2007.

15. U.S. EPA. 2006. Manganese Compounds. 2007.

16. Gorell, Jay M Peterson, Edward L Rybicki, Benjamin A Johnson,Christine Cole. 2004. Multiple risk factors for Parkinson's disease. *Journal of the Neurological Sciences* 217:169.