Electrostatic Precipitator Maintenance Process Re-Engineering: Lead & Cadmium exposure control at the Hampton/NASA Steam Plant.

John S. Austin, P.E.
50 Wythe Creek Road
Hampton, Virginia

Electrostatic precipitators (ESP) collect fine particles from municipal waste combustor flue gases, which contain significant concentrations of heavy metals. In response to new OSHA standards, the Hampton/NASA Steam Plant began re-evaluating exposures during semi-annual maintenance shutdowns. A primary concern was whether the cadmium or lead standard action level were exceeded during ESP maintenance. The initial testing confirmed exposure levels were above OSHA Permissible Exposure Limits for cadmium and lead.

During the Fall of 1994, a maintenance process review was initiated to bring the process under control and to minimize exposures to these hazards. The focus for process review was to develop engineering controls that reduce worker respirable exposure below the action level for Cadmium(.0025 mg/m^3) and Lead(.025 mg/m^3). The process review lasted three years, for ESP maintenance is done only four times each year.

All of the task workers had monitoring for lead and cadmium during the review. Exposures for non-task workers were coordinated with ongoing monitoring for other shutdown tasks. During all ESP entries, the task workers were fully suited and protected with full face positive pressure air purifying respirators. Procedures were implemented to prevent flyash ash migration.

Each iteration, the process review team incorporated improvement that reduced exposures. The initial phase succeeded to reduce exposures by 86% to 0.330 (Pb) and 0.017 (Cd) mg/m^3. Personal exposures to lead and cadmium were still above OSHA Subpart Z action levels.

The process review team concluded the existing procedures needed to be abandoned. New procedures for wetting the flyash and water washing the ESP were developed. During the first trial of the new wet method, all air sampling cassettes recorded levels below the PEL.

Three more iterations optimized the process, and the procedures had substantial control over exposures. The end result of the maintenance process review was an ESP cleaning procedure that consistently reduced worker exposures to below the PEL for lead and cadmium.

Background Information

The Hampton/NASA Steam Plant is as a cooperative enterprise owned by the City of Hampton and the National Aeronautics and Space Administration. The facilities two Detroit Stoker furnaces process 240 tons per day of municipal solid waste. High pressure steam is provided to NASA Langley Research Center to power high speed wind tunnels and a variety of other process and institutional power needs. The facility is permitted to and operated by a Joint Board of Oversight who represent the owners.

The Hampton/NASA Steam Plant is an independent enterprise, much like a small business. With limited resources, Continuous Process Improvement methods are used by the employees to develop and update facility procedures and to solve problems. Regulatory programs, like respiratory protection are processes designated for continuous improvement, to help ensure continuous compliance with OSHA requirements.

New standards for cadmium exposure were issued by U.S. Occupational Safety and Health Administration during 1991. The Hampton/NASA Steam Plant began to evaluate exposures during semi-annual maintenance cycles. There was concern that the Cadmium standard action level was being exceeded during ESP cleaning and maintenance. Unlike the OSHA lead standard, rotation of employees was not allowed for compliance with the 5 microgram per cubic meter (0.005 mg/m^3) permissible exposure limit (PEL). Each of the standards set an Action Level of one half the PEL. The standard has some requirements effective when exposures exceed the Action Level. A process that reduced employees exposure to lead and cadmium in flyash would mean two less regulatory programs to incorporate into procedures. Each of the standards require employers to implement engineering controls, if possible, to remove the hazard.

ESP Maintenance Process Review

The review followed a general process used at the Hampton/ NASA Steam Plant, by employee teams, to achieve the goals of continuous process improvement.

The process review followed four distinct steps.
1) Document and review current process.
2) Implement improved procedures.
3) Evaluate results and potential improvements
4) Critical Process Decision ~ Re-Engineer?

The review lasted three years, and was followed by a year of independent validation of the new procedures. A process review team was formed that included the Steam Plant, Operations and Maintenance Managers. Team Leaders from each maintenance team and those currently involved with the ESP maintenance also participated with the review team. Meetings of the team occurred just prior to and after each iteration of the procedures. Team members met with the industrial hygienist only on the days the tasks were being performed and monitored.

The focus goal for the review was to develop engineering controls to reduce task worker respirable exposure below the action level for Lead (.025 mg/m^3) and Cadmium (.0025 mg/m^3). All process reviews include other safety, environmental and economic goals, as did this process review. A concurrent goal was to keep the stack opacity at 0% during the ESP cleaning process. Initial attempts at induction fan ventilation control only relocated the hazard up the smokestack. Another focus goal was to ensure that the ESP containment and procedures protect the non -task employees from exposure to fugitive flyash.

Task cost impact had only small importance, for the facility's respiratory protection program already incorporates most components of a Subpart Z program. Employees have full medical surveillance, including monitoring blood lead level. Mechanics and operators are all issued powered air purifying respirators (PAPR) with high efficiency particulate and aerosol (HEPA) level protection. Possible cost effects for any contractor performed work were not considered. All contractors are required to use the procedures, and special procedures typically raise contract cost.

Initial ESP Maintenance Process Review

Initial review of the ESP cleaning included reviewing current maintenance and safety procedures, personal protection levels, OSHA regulations, and current literature and experience from similar facilities.

The two ESP units are each entered twice annually. The units are throughly cleaned, inspected and then required repairs are made. The infrequency of the tasks made a comprehensive process review challenging. Ultimately, 20 employees were involved in the process review. Five data points represent the author's own exposure while performing the tasks being reviewed.

With each trial of the procedure, improvements were made. Changes included complete mechanical cleaning prior to using air lances, air lancing top to bottom between plates and manually cleaning all wire weights. HEPA vacuums were used when opening the until, and each task worker is vacuumed upon exit of the ESP. The task was done by two or three worker teams that took turns as entrants and attendants, so to balance the workload. For some tests, a non-entrant attendant was provided so the data would reflect no employee rotation.

Improvement of the ESP maintenance process had tremendous results. Exposures were reduced by more than 86%. Increased labor and contract cost was attributed completely to industrial hygiene testing and increased team meetings. Yet two factors required that the current process be abandoned.

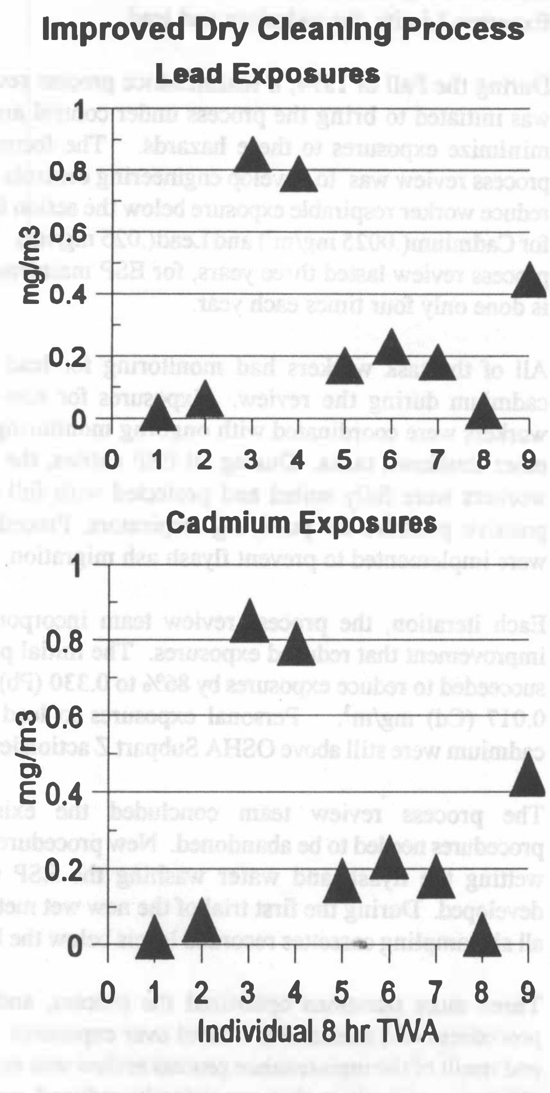


Figure 1: Worker exposure during dry cleaning ESP.

The process was still out of control. Individual task worker exposure varied greatly; standard deviation of the samples for both lead an cadmium were greater then the PEL's. Exposures were reduced 86% to 0.330 mg/m^3 of lead and 0.017 mg/m^3 of cadmium, these exposures were still above OSHA Subpart Z action levels.

ESP Maintenance Process Re-Engineering

The critical decision to abandon a current set of procedures, and to start from scratch, is never taken lightly. A work environment of continuous process improvement can easily become chaotic with never-ending trials of "new & improved" procedures. If a current procedure has had some success, why risk a radical change. If a new procedure was worth trying, it also should be worth improving on.

At the Hampton/NASA facility wet methods and HEPA vacuum procedures have worked successfully with others ash related tasks, but the ESP flyash has much higher concentrations of lead and cadmium. Vacuuming the large surface areas within the ESP would have been difficult. Vacuum cleaning methods move dust in the air, but the focus goal was to get the dust out of the air.

The review team quickly explored the idea of wet cleaning. Many team members thought this was a bad idea. Information was gathered from literature the ESP original equipment manufacturer and experience at other power plants. While some coal combustor plants had been successfully using wet cleaning, many facilities experienced problems and equipment failure. Most waste to energy plants used mechanical or air cleaning.

Wet cleaning weighted wire ESP units similar to these had caused serious problems with wire weight alignment and guide corrosion. There were also some concerns about the corrosion reconditioning of the ESP's corten steel housing. Then there is the lesson we all seem to have to relearn: if you are going to get the ash wet, you better wash it all out. Otherwise, it will fuse and harden.

ESP Wet Cleaning Procedure

The employee team prepared a draft wet cleaning procedure that required only minor improvements over the first three iterations. Task workers use a 11/2 inch fire hose to wash their way from top to bottom, and from inlet to outlet. During initial trials water wash effluent was pumped to a tanker truck for analysis and off-site disposal. The wash down water is now allowed to flow to the wet trench system and then pumped to the wastewater storage tank for future system make-up water. The cleaning process continues through the flyash system to the wet trench. The entire ESP and flyash conveyer maintenance processes are now done in a single 12 hour day. The mechanic labor for the combined maintenance process has been cut in half; an annual savings of $6000.

The process review team met with task workers before each time the ESP maintenance procedure was done. Industrial hygiene services were provided by LabCorp Analytical, of Richmond Virginia. Personal exposure data was taken for Lead and Cadmium. Only one data point was affected by the water washing.

The result of the re-engineered process was tremendous. After the first procedure trial all cadmium test cassettes have been collecting less than the analytic detecting limit (ND). For the second entry, it is decided to hose through the man way prior to entering. The instant results were amazing. The ESP environment previously was very dusty; a flashlight beam would disappear into the dust. After a brief misting of water, the air inside the ESP was visibly clean. Light traveled to far corners, and no dust particles were seen in the air.

After one wet cleaning the ESP wire weights froze in their guides, causing the procedure to be repeated. Great detail is now focused on ensuring all ash is washed out of the wire guides. That is now done with a garden hose, for the force of the fire hose would bend the guides leading to additional work.

During all of 1996, wet cleaning exposures were monitored, and exposures were consistently below the lead and cadmium action levels (see Table I). The procedure proved very repeatable. Total labor time for the wet cleaning procedure was half of the previous dry-cleaning method. Inspection and repairs after the wet cleaning procedure also became less hazardous. A more thorough inspection can be made after wet cleaning.

Table I: Wet Cleaning Exposures

	Cadmium	Lead
Average (mg/cm)	.0008	.0035
High Exposure	.0035	.014
95% Confidence	.001	.005
Standard Deviation	.0003	.0013
% of PEL	20%	10%

Equipment performance after wet cleaning was exceptional; the automatic ESP controls ramped to full power with a low spark rate for days after cleaning. No notable repairs have been caused by wet cleaning the units except for the rework due to the weights not being cleaned completely. Corrosion deposits left after wetting has seemed to reduce the wear of some components.

By the Spring of 1997, the hazard was under control with one exception. Even after wet cleaning, metal grinding in the ESP still caused exposures above the PEL. The review team developed a wet grinding procedure, and it now reduces exposures below the PEL. Grinding and welding tasks are generally done by contractors, but facility staff took on the tasks, so to improve the process.

Changes to the Respiratory Protection Program

Initially several enhancements were made to the procedure to increase employee protection and awareness. All mechanics were issued powered air purifying respirators. Stricter control and specification of tedlar disposable coveralls were implemented. Task workers are cleaned with HEPA vacuums as they exit the ESP manway. Procedures were established for use and cleaning of HEPA vacuum equipment. Several types of vacuums were purchased, including small shoulder strap HEPA vacuums that were perfect for top end entries.

The lessons learned during the process review led to major changes to the 29CFR 1910.134 respiratory protection program that the facility had. The program now incorporates many aspects of the OSHA Lead and Cadmium standards. The employee hazardous substance notification appendices have been incorporated into the Safety Manual for Lead and Cadmium. Substance data sheets have been included with other material safety data information. The wet cleaning method was included as a safety procedure. Updating was also needed to reflect changes to personal protective equipment.

The newly designated Fly-Ash Hazard also had to be incorporated into policy and procedure. All points of probable exposure are clearly marked with bright orange signs directing workers to special procedures. Training now emphasizes lead and cadmium information, and "wash your hands" awareness has been included for maintenance shutdowns. Since the respiratory hazard has been reduced, additional focus is now being placed on other multi-path exposures.

Disposable tedlar suits have been problematic, and are no longer required under rain coats during wash down itself. The facility now intends to establish a dirty coverall program. With special procedures Medlar suits are now HEPA vacuumed, prior to disrobing in clear bags immediately upon disrobing and are delivered directly to the refuse feed hoppers.

The certified Industrial Hygienist who validated the wet cleaning procedure recommended task testing as follows: annual re-testing of the wet procedure, and testing for Lead ash grinding task until more data is available to evaluate exposures. Industrial Hygiene testing will be included with the Semi-annual maintenance shutdowns to gather data on many other "infrequent tasks." Costs for these services have doubled to about $4000 each year. Testing also increases time and difficulty of the tasks.

Summary of Analysis and Results

All exposure data was collected and reduced to Time Weighted Averages (TWA) using approved industrial hygiene methods and calculations. During the initial dry cleaning task workers had to change filter cassettes over a twelve hour procedure. Data was combined and corrected to an 8 hour TWA with a 95% confidence levels. The reported results are representative of a single worker's exposure over 8 hours, 95% confidence. Exposure data was reported and all calculations were done in micrograms per cubic meter.

The following formulas and constants were used:

$$TWA = \frac{\sum_{i=1}^{n} T_i C_i}{8hrs}\left(\frac{T_{Task}}{8hrs}\right)$$

Monitoring was done typically for a minimum eight hour period, and the value use for T_{task} was always eight hours or greater. The dry cleaning task took 10 to 12 hours, and this formula compensates for the longer exposures.

The upper confidence limits were calculated as a percentage of the PEL with the following formula and a normal statistic Z value of 1.645. The coefficient of variation (CV_{Total}) for lead and cadmium sampling were 0.06 and 0.07 respectively.

$$UCL(95\%) = \frac{X_{mean}}{PEL} + 1.645\frac{CV_{total}}{\sqrt{n}}$$

The results of wet methods were procedures that consistently reduce exposures during and after cleaning to below the action levels. The wet grinding procedure reduces lead levels to below the PEL, but above the action level. ESP grinding tasks are very infrequent, so it may take years to accurately quantify exposures. The summary of results are presented in Figures 2 and 3.

Figure 2: Lead Exposures

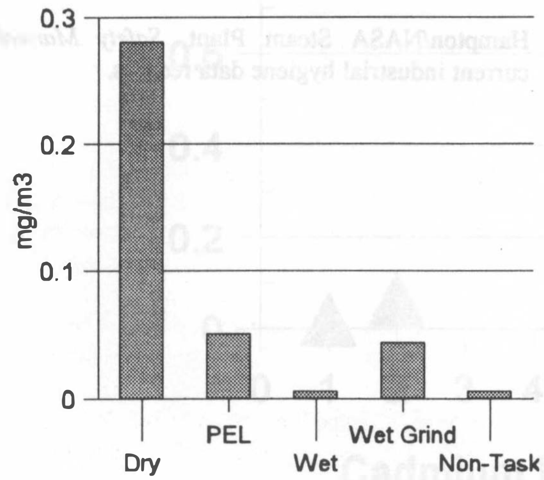
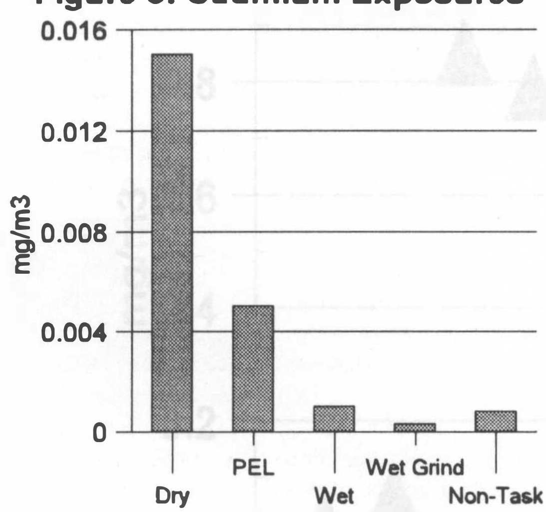


Figure 3: Cadmium Exposures



Most cadmium samples for the wet methods and the non-task incidental exposures were reported at a non-detect level. Time weighted averages for these varied based upon the sampling and task durations. The wet grinding procedure controls cadmium, but the lead absorbed into the metal causes lead exposure above the action level.

Non-task workers were performing there regular tasks while the ESP cleaning was occurring. These samples were all taken during planned maintenance shutdown periods. Two samples were taken from mechanics that were engaged in flyash conveyer repairs. Those workers that served only as attendants for the ESP procedure were included with the non-task worker data (see Table III). The results indicate the ESP containment in conjunction with exit vacuuming does prevent fugitive ash migration.

Table II
Incidental Exposures

	Cadmium	Lead
Average (mg/cm)	.00065	.0035
High Exposure	.0028	.012
95% Confidence	.0008	.0053
% of PEL	**16%**	**11%**

To better understand the hazard, ESP flyash composite grab samples were taken and analyzed for total toxic metal content. Lead and cadmium were found in significant amounts. Arsenic was not detected in the flyash samples. The results indicated lead varied more than cadmium, and lead was found in concentrations of forty times that of cadmium 9 (see Table III).

Table III
Lead & Cadmium in the Flyash

Lead	**7055 mg/kg**
Cadmium	**160 mg/kg**

The wash water effluent wash also tested prior to disposal. The water was washed to an idle wet trench then pumped up to the tank truck, so some contamination was expected. The results was opposite of the dry sample, for concentrations of Cadmium (13 mg/l) were higher than for Lead (3.2 mg/l). The levels of these two metals in the effluent were not problematic. However, Zinc levels of 137 mg/l required the waste water to be shipped out of the region for processing.

Conclusions

The project presents hard industrial hygiene data and a possible solution to the lead and cadmium headache that most municipal waste combustors are experiencing. It also serves as a good example of how employee teams using Continuous Process Improvement methods can help solve some of our most challenging problems.

The incumbent procedure, mechanical and air cleaning of the electrostatic precipitators, did cause exposures above the PEL for lead and cadmium. The process was out of control: some personnel had less exposure during ESP cleaning, but others would get very high exposure. The current procedures had to be abandoned, and the process was re-engineered.

Wet cleaning methods effectively control respirable exposures to lead and cadmium. The procedures validated during this process review repeatedly lowered exposures to non-detect for cadmium, even during follow-up repairs and grinding. The procedures lowered lead exposures to below the Action Levels with the exception of during grinding tasks inside the ESP.

Task workers will continue to be afforded full personal protective equipment, and many aspects of the OSHA Subpart Z standards are incorporated into the facility's respiratory protection program. Annual re-testing will be done for the ESP wet cleaning procedure and during grinding tasks inside the ESP.

The process review did not try to reduce costs, but the re-engineered task requires about half of the time to complete. Employee involvement had several benefits. Training for the new procedure was con-current with development. Employee ownership of the procedures enhances our ability to ensure procedures are being complied with. The procedures will be monitored and improved on as needed. Process reviews of operating and maintenance tasks procedures are continuing at the Hampton/NASA Steam Plant, and we expect critical goals to be achieved and costs reduced from those efforts.

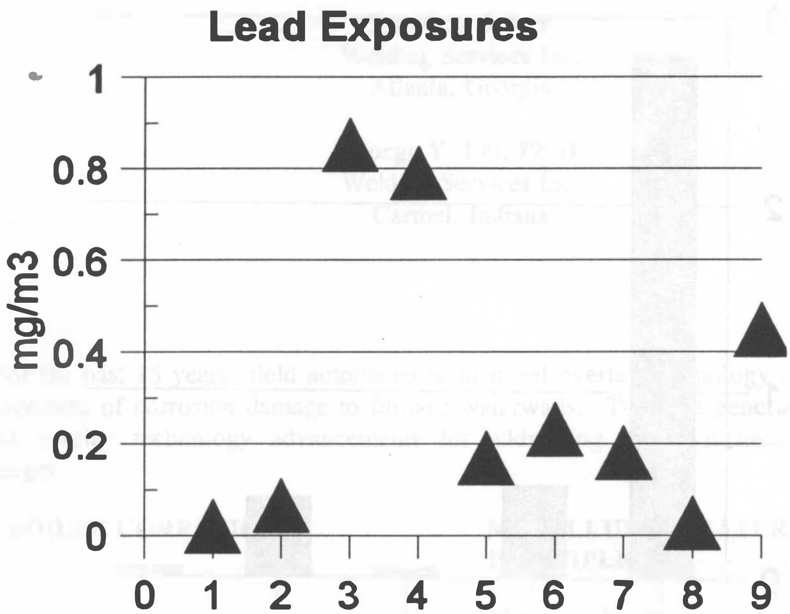
References

Plog, Barbara A. et. al., *Fundamentals of Industrial Hygiene,* 4th Edition, 1996, National Safety Council, Itasca, Illinois

Code of Federal Regulations, *29 CFR Part 1910, 1910.135, 1910.1025, 1910.1027.*, current, United States Occupational Safety and Health Administration, Washington, DC.

Hampton/NASA Steam Plant, *Safety Manual* and current industrial hygiene data records.

Improved Dry Cleaning Process



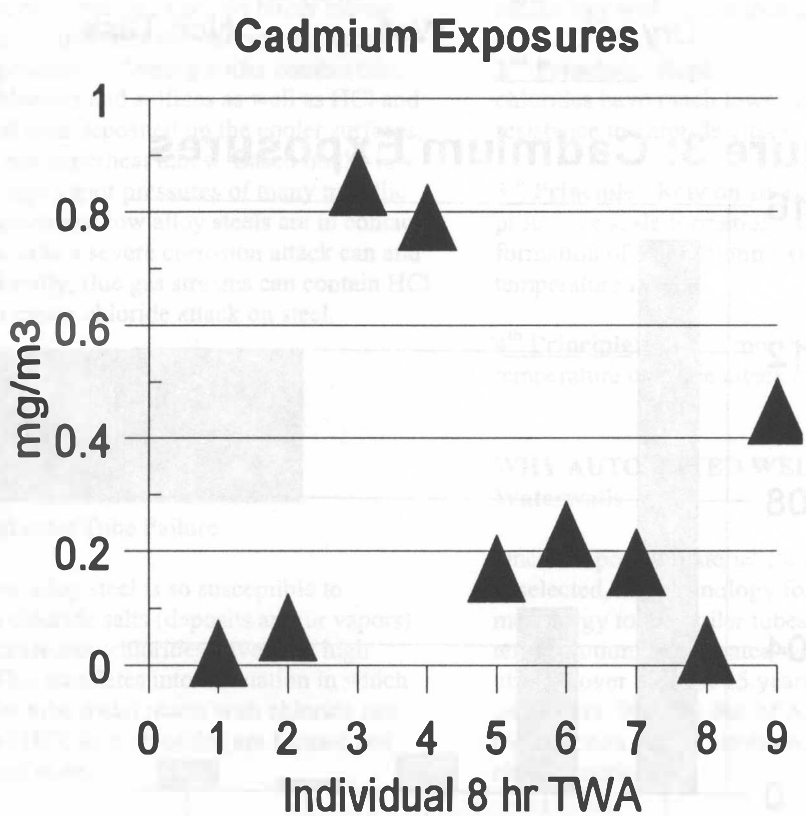


Figure 2: Lead Exposures

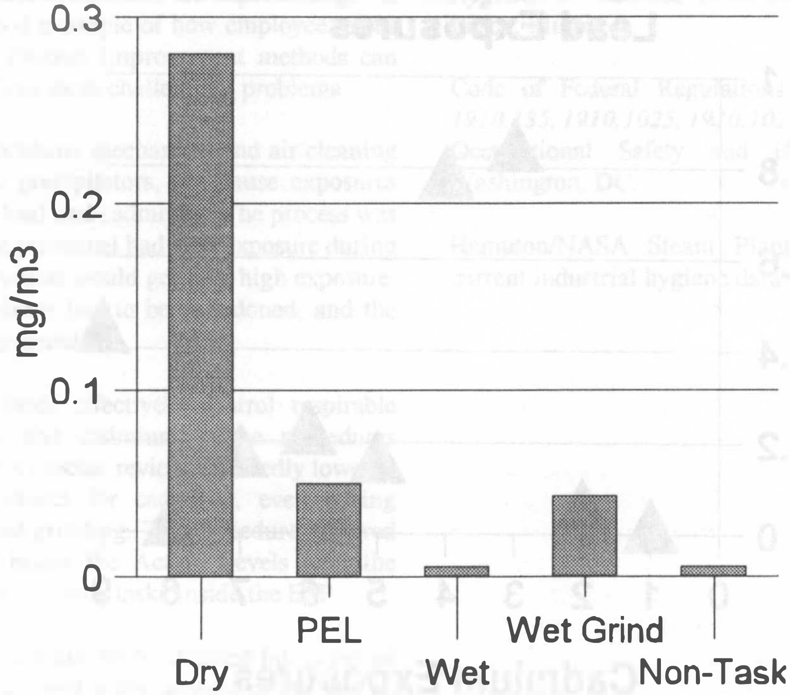


Figure 3: Cadmium Exposures