

**Health Consultation  
CEMEX, Incorporated**

**Lyons, Boulder County, Colorado**

**EPA Facility ID: COD980957823**



**Prepared by  
U.S. Department of Health and Human Services  
Agency for Toxic Substances and Disease Registry  
Division of Health Assessment and Consultation  
Program Evaluation, Records, and Information Services Branch**



## Table of Contents

Summary and Statement of Issues .....	1
Background .....	1
Discussion of Community Health Concerns.....	1
Figure 1 .....	5
Figure 2 .....	6
Child Health Considerations .....	10
Conclusions.....	10
Recommendations.....	10
Public Health Action Plan.....	10
Authors.....	11
Technical Advisor.....	11
References.....	12
Abbreviations and Definitions .....	14
Appendices.....	16
Appendix A: Tables .....	A-1
Table 1 – Estimation of Worst-Case Metals Concentration in Leafy Vegetables .....	A-2
Table 2 – Chemicals Detected in CEMEX Stack Gases.....	A-3
Table 3 – Metals Detected in CEMEX Stack Gases.....	A-5
Table 4 – Health Evaluation of Average Ground Level Concentrations* of CEMEX Stack Emissions Exposure Concentrations for the Maximal Exposed Individual Resident (MEIR)A-6	
Table 5 – Health Evaluation of Maximum Ground Level Concentrations* of CEMEX Stack Emissions Exposure Concentrations for the Maximal Exposed Individual Resident (MEIR)A-8	
Appendix B: Calculation of Hypothetical Soil Values in Table 1 .....	B-1
Appendix C: Uptake of Environmental Contaminants by Plants .....	C-1



---

## Summary and Statement of Issues

Since the release of ATSDR's first health consultation (ATSDR 2003b) regarding the burning of tires by CEMEX, Inc., the Boulder County Public Health Department has received questions from several residents regarding that health consultation. The Health Department asked ATSDR to help address the resident's concerns.

## Background

The Boulder County Public Health Department (BCPH) asked ATSDR to review the available data on burning tires as a partial replacement for coal as a fuel in the CEMEX, Inc. cement kiln. BCPH requested help in addressing area residents' concerns about the potential health effects resulting from the change in emissions. After a review of the source emissions testing report and site-specific air dispersion modeling of the CEMEX stack gases, ATSDR concluded that burning tires in the manner employed during the November 2002 test would not result in air concentrations that would cause adverse public health effects in residents living near the plant. ATSDR provided a discussion of the data evaluation and its conclusions in a health consultation issued on July 9, 2003 (ATSDR 2003b).

The Boulder County Public Health Department presented the ATSDR health consultation and the Health Department's conclusions to the Board of Health and to the public on July 14, 2003. Additional background information is available in the earlier ATSDR health consultation (ATSDR 2003b).

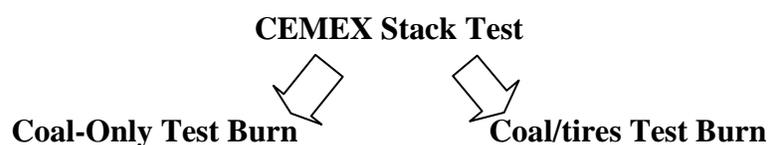
## Discussion of Community Health Concerns

This section discusses each of the community concerns. We have grouped comments on the same issue together. In some cases ATSDR summarized the comments rather than repeating them verbatim.

- 1. Why were the test burn results considered acceptable when one of the four tests (25% of the results) was discarded due to high acetone values? Doesn't it call into question the remaining stack test runs and the reliability of the testing company? How can ATSDR conclude there is no danger to the community using incomplete data?**

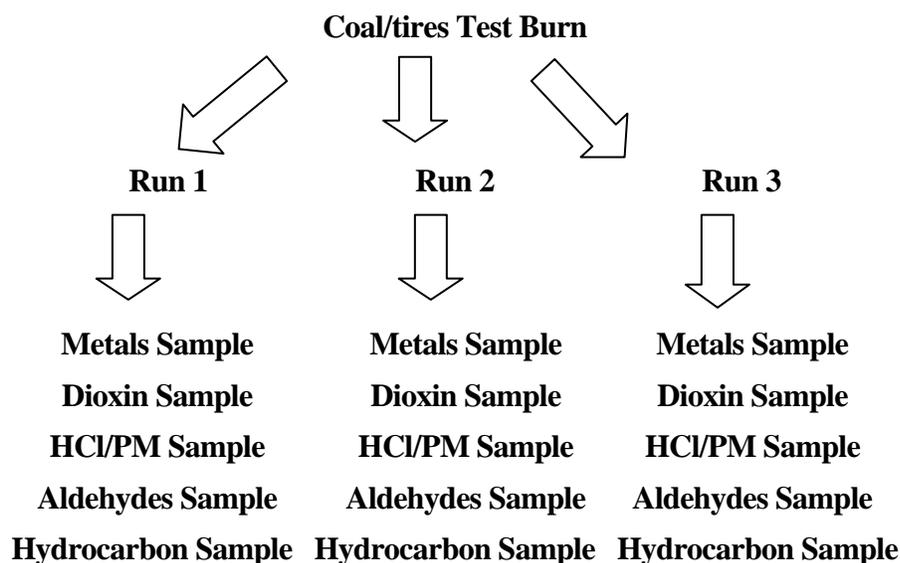
The main question ATSDR was asked to address in the July 9, 2003, CEMEX, Inc. Health Consultation was whether burning 19% tires in the cement kiln would adversely affect public health. The only data needed were the test burn data while burning tires as fuel. Since the discarded test data were two samples from the coal-only test burn, the data do not really affect our evaluation. The coal/tires test burn data were complete. Nevertheless, we will address the issues of (1) whether discarding samples if there is a problem with one or more samples is acceptable, and (2) whether discarding some samples invalidates the entire stack test.

First, an explanation of terminology. The CEMEX **stack test** consisted of **two test burns**—one test burn using coal only, and one test burn using coal and 19% tires.



A test burn consists of **three runs**. Each run is conducted under the same operating conditions with the normal fluctuations that occur during plant operations. During each test run at CEMEX, the stack sampling company collected **five samples (one of each type of sample)** as specified in the approved test plan. Therefore, the coal/tires test burn consisted of 15 samples, three of each type of sample.

The company used EPA or state-approved sampling, and used analytical methods specifying the quality control and quality assurance (QA/QC) procedures necessary to collect and analyze the samples. Each type of sample stands on its own. If there is a problem with one type of sample or analytical method, it only affects the validity of that one type of sample. It has no effect on the other types of samples taken during that test burn, or taken during other test burns.



At CEMEX, the types of samples collected during each run were (Dunmire 2003):

- **PM/multi-metals sample (Metals sample).** A sample that was analyzed for total particulate matter (PM) and multiple metals.
- **Dioxin/furan/PCB/PAH sample (Dioxin sample).** A sample that was analyzed for dioxins, furans, poly chlorinated biphenyls (PCBs), and poly aromatic hydrocarbons (PAHs).
- **HCl/PM sample.** A sample that was analyzed for hydrogen chloride (HCl) and total particulate matter (PM).
- **Aldehydes sample.** A sample that was analyzed for formaldehyde and acetaldehyde.
- **Hydrocarbon sample.** A six-liter SUMMA canister sample that was analyzed for 59 trace hydrocarbons.

The problem that appears to have occurred was that two of the hydrocarbon sample SUMMA canisters collected during the coal-only test burn were contaminated with acetone. In stack gas samples, very low detection limits are required. Thus, even a slight leak in the sampling equipment, or a small residue of solvent like acetone or methylene chloride—commonly used to

---

clean laboratory equipment—can ruin a sample. The samples were analyzed a few days after the test burn. That was when the laboratory staff discovered that two of the coal-only hydrocarbon samples were contaminated. The acetone contamination caused the detection limits for all the hydrocarbons to be so high that in those two hydrocarbon samples none of the other 58 hydrocarbons could be detected.

Thirteen of the 15 samples taken during the coal-only test burn were valid. Only two of the hydrocarbon samples (2/15 of the coal-only samples) were discarded due to acetone contamination. This invalidated only the hydrocarbon sample data for the coal-only test burn. The other types of samples taken during the coal-only test burn are valid, as are all the samples taken during the coal/tires test burn.

Tables 1A, 1B, 2, and 3 from the July 9 health consultation were revised to delete the coal-only hydrocarbon sampling data, for which there is only one data point. The revised tables are Tables 2–5 in Appendix A of this consultation.

Having problems with one or two samples does not invalidate the entire stack test, nor does it bring into question the reliability of the testing company. It certainly should not bring into question the reliability of those attending the stack test. Acetone is a commonly used solvent in laboratories, and acetone contamination in sampling equipment is not something that can be seen in the field. The purpose of quality control procedures is to detect problems such as this, i.e., sample contamination or analytical problems. The fact that the laboratory personnel detected and reported the sample contamination speaks favorably of the stack sampling company and those who analyzed the samples.

In summary,

- Acetone is a solvent commonly used in laboratories to clean equipment, thus traces of acetone remaining in laboratory equipment is not unusual.
- Discarding the hydrocarbon sampling data from the coal-only test burn does not invalidate the other types of samples taken during that test burn, nor does it invalidate the coal/tires test burn data.
- ATSDR’s conclusions regarding burning of tires in the cement kiln were based on the coal/tires test data—not the coal-only test burn data. Therefore, discarding the two coal-only samples does not affect ATSDR’s conclusions.

## **2. Stack tests are done under ideal operating conditions. What assurances are there that the stack emissions are the same, not higher, after the stack test is over?**

We recognize that some in the community find it difficult to accept as sufficient assurance the fact that most of the operating conditions that would affect the stack emissions would also affect the quality of the cement. That is why we discussed in the July 9 consultation (ATSDR 2003b) the important kiln design and operating conditions, and how they can affect stack emissions. These are some of the things that inspectors could look at to provide assurance to the community that the normal operation of the facility is the same as during the stack test.

The design and operating conditions listed in the discussion on pages 6 and 7 of the first health consultation fall into two categories: conditions that can affect the stack emissions which would be easy to spot during an inspection if they were changed, and things that would be more difficult to spot but can still be discovered.

Conditions that would be easy to spot if they were changed are

- The location where the fuels or raw materials are fed into the kiln.
- The temperatures in the pre-heater and kiln.
- The temperature in the baghouse(s). The company continuously monitors the temperatures in the pre-heater, kiln, and in the baghouse(s). The inspector can observe the readings on these monitors to assure that they are in the same range as they were during the stack test.
- The time that the materials are in contact with the flame and the mixing and turbulence that occur in the kiln. To change the time that the materials are in the kiln or to change the mixing and turbulence that occur in the kiln would require a major modification of the facility, e.g., the design of the kiln, its length or diameter, the angle of incline, or speed of rotation. Changes in the kiln design, e.g., its length, its diameter, or a major change in the angle of incline would be a very expensive, major construction project requiring permit modifications and prior approval. Kiln modifications would require a shut down for an extended period, and the changes would be obvious to an inspector who is familiar with the plant. With a stopwatch, an inspector can easily determine the number of revolutions per minute, i.e., the speed of rotation.

Conditions that would be more difficult to spot are

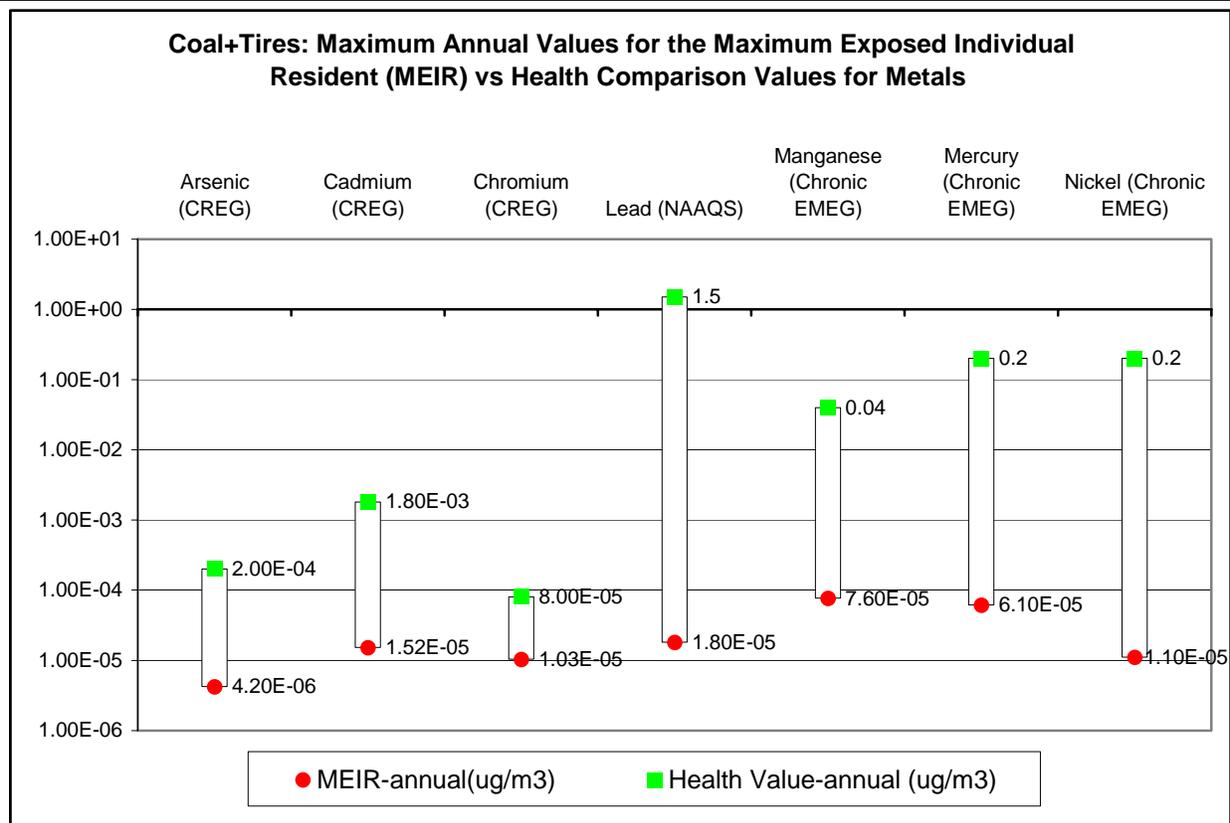
- Changes in the raw materials or fuels burned. However, the stack gases are continuously monitored for NO<sub>x</sub>, SO<sub>x</sub>, and CO and one or more of these readings should reflect a change in the nitrogen, sulfur, or hydrocarbon levels in the raw materials or fuels, a change in combustion conditions, or whether the pollution control equipment is working properly. The inspector can look at the records of these continuous monitorings to determine whether their values have fluctuated since the last visit. Changes in metal content would be more difficult to spot, because inspectors would have to look at fuel and raw material analyses to determine whether changes occurred.
- A change in the percentage of tires burned. The inspector can spot-check the tire and coal feed rates and calculate the percentage of tires fed to the cement kiln.

Looking at the quality control analyses on the raw cement and the rejected batches will also provide information to the inspectors about changes that may have occurred in the raw materials, in the fuels, or in the kiln's operating conditions.

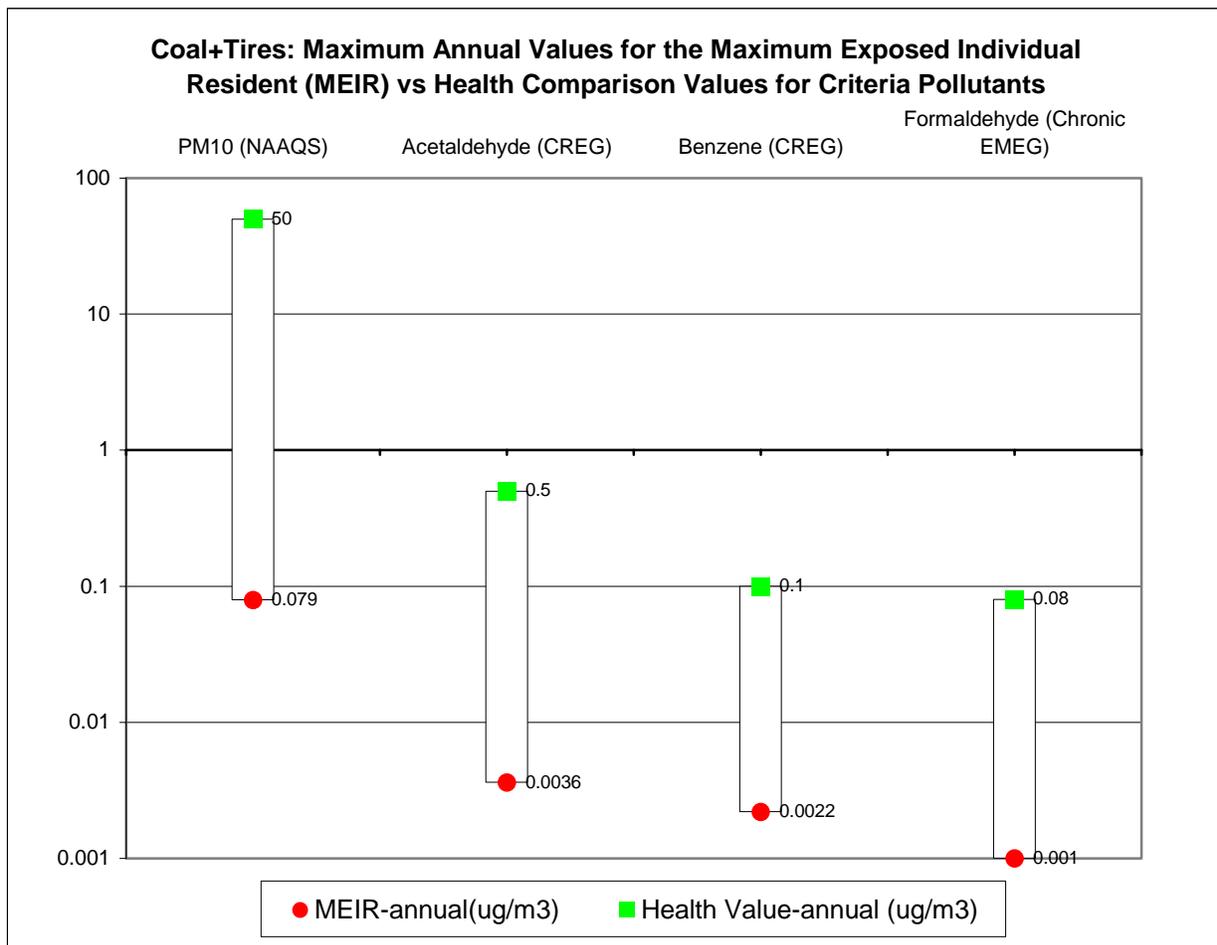
Figures 1 and 2 show the health value for each chemical and the maximum concentration to which the maximally exposed individual resident (MEIR) would be exposed under worst-case conditions. Because in this figure none of the MEIR exposure concentrations are close to their health value, even some fluctuation in the emissions would not cause adverse health effects.

In summary, inspectors have many ways to—and routinely do—analyze plant operations to determine and verify whether stack emission levels are maintained at permitted levels. Figures 1 and 2 show that the maximum annual exposure concentrations are well below their corresponding health values for long-term exposure, i.e., the air comparison values (ACV).

The Green square dots are the health values. The Red round dots are the maximum annual exposure concentrations to which an individual would be exposed. All values are micrograms per cubic meter (µg/m<sup>3</sup>). See the Abbreviations and Definitions section for explanation of other terms used in the following figures.



**Figure 1** shows that even the maximum annual concentrations of the metals that would be in the air of the most exposed individual (based on modeling) are well below health values used to evaluate long-term exposure. This is true even when all the chromium is assumed to be hexavalent chromium, which is the worst-case assumption.



**Figure 2** shows that the maximum annual concentration of the EPA criteria pollutants that would be in the air of the most exposed individual (based on modeling) is well below values established to protect human health.

**3. Why did ATSDR only look at the Lyons population? Why didn't you include Longmont too, which is four miles east of the plant?**

Longmont and communities to the east of the CEMEX facility were not included in our analysis because the worst-case winds in the area are towards the west. The state's modeling showed that even under worst-case 24-hour weather conditions the areas most impacted are in the mountainous areas southwest of the plant. The weather conditions data used in the model were from a meteorological station that was maintained at the CEMEX plant for 12 months. Strong winds (which people tend to notice) are reported to come from the west, so local residents are likely to expect a greater impact in Longmont, which is east of the plant. However strong winds disperse the stack emissions so ground level concentrations are lower than when the winds move slowly or the air is calm. Modeling shows that calm or slow moving air allows more of the stack emissions to settle closer to the plant, thus creating the maximum ground-level concentrations. According to modeling using the local weather data, the areas that will have the highest ground-

---

level concentrations (however they are still below concentrations that cause adverse health effects) are in the mountains west of Hwy 36 and southwest of the CEMEX plant.

If the ground-level concentrations of the chemicals in the most impacted areas of the mountains are below levels expected to cause adverse health effects, then the air concentrations in Longmont, which are much lower, will not cause health effects.

**4. Why did you only consider the inhalation pathway? You should do a multi-pathway health assessment. We want the water and soil pathways tested (sampled and analyzed). We are particularly concerned about the impact on local agriculture, local markets, and home gardens due to “very small increases in bioaccumulative lead, mercury, chromium IV [probably meant VI], arsenic, and cadmium.”**

The air pathway is the primary exposure pathway to the stack emissions from CEMEX for persons living in Boulder County. We used the CEMEX stack emissions data from samples taken while the plant was burning 19.2% tires to evaluate the public’s inhalation exposure if CEMEX were to burn tires as kiln fuel.

ATSDR also considered that inhalation exposures would involve release of all of the chemicals from the stack simultaneously. This is referred to as multiple chemical exposures. As shown in Figures 1 and 2, even the maximum predicted air concentrations (the primary exposure route) are generally more than two orders of magnitude below conservative health comparison values. For years, scientists have been studying interactions of mixtures of chemicals. The results of these studies have been consistent: they suggest that as long as the components of any mixture are all below their individual No Observed Adverse Effect Level (NOAEL), exposure to the mixture is unlikely to result in adverse health effects (Feron et al. 1993; Jonker et al. 1993a; Jonker et al. 1993b; Jonker et al. 1990; Groton et al. 1991). One recent study examined exposure to PCBs, dioxins, DDT (and other pesticides), as well as heavy metals, all generally at minimal risk level (MRL) doses (and the NOAEL for dioxin). The data showed no immunologic and reproductive effects in rats, further suggesting no additive or synergistic effects at residue levels (Wade et al. 2002). Therefore, if virtually all of the individual contaminants detected at a site are present at levels below the dose levels known to produce adverse health effects, ATSDR concludes that the *combined* exposure to all of these contaminants is not likely to be of public health concern (ATSDR 2001a).

To help the community understand why a multi-pathway health assessment is not necessary we are including additional screening-level analyses of other routes of exposure.

To address the community’s question about the contamination of water in the area, we looked at aerial maps of the areas most impacted by CEMEX stack emissions (see reply to question 3). Very few waterways in this mountainous area are conducive to fishing or swimming on a consistent basis. The “Ditch and Reservoir Map Directory” prepared by the Boulder County Transportation Department (1998) shows South Ledge Ditch to be the only waterway in this area. South Ledge Ditch serves as a very junior water right and only carries water two to three weeks out of the year, the rest of the year the ditch is dry (Pam Milmoie and Chris Poule, personal communication, June 23, 2004). Because the lakes, reservoirs, and streams in the area around the CEMEX plant are not located in the areas most likely to receive air deposited pollutants from the stack, additional water analysis was deemed unnecessary.

To address community concerns about metals bioaccumulation in agricultural products, ATSDR obtained a report by the Colorado Department of Public Health and Environment published September 27, 2000, and entitled *Hygiene, Colorado PM10 Receptor Modeling Study* (CAPCD

2000). This report contains analytical data for two soil samples taken near the CEMEX plant. Table 1 in Appendix A compares the arsenic, cadmium, chromium, lead, and mercury concentrations in the Leukonen Pasture and 59<sup>th</sup> Street samples with health values and typical concentrations of these metals in Colorado soils. Data were available from only two local soil samples, so we included in Table 1 the mean and range of concentrations of these metals in Colorado soils from the extensive U.S. Geological Survey (USGS) soils database. As can be seen in Table 1, the concentrations of all the metals in the soil samples near CEMEX are at the low end of the range of concentrations of those metals in Colorado soils. All of the metals in the two local soil samples are below health values.

To address the question of how the increases in the concentrations of some metals in the stack gases might affect soil concentrations when tires are burned, we added two columns in Table 1 labeled “Hypothetical Soil” (see Appendix B for calculations). The hypothetical values are the calculated concentrations of the six metals in the soil 33 years in the future, assuming 20% of the metals currently in the soil came from 33 years of air deposition from the CEMEX plant (since the plant’s inception), and that the plant burns 19% tires for the next 33 years. The hypothetical soil concentrations are very conservative, albeit crude estimates. Nevertheless, if one assumes long-term daily exposure to the soils, even the hypothetical soil concentrations are within the normal concentrations of these metals in the soil and therefore would not cause an increased health hazard. Because we know that CEMEX is not the only source of metals in the area, we assumed that 20% of the metals were from the CEMEX plant. Other sources contributing to metals in soils include agricultural burns, emissions from auto and truck traffic, and emissions from power plants. For example, a study conducted by the Colorado Department of Public Health and Environment on air quality in the Lyons area (CAPCD 2000) determined that with respect to particles 53% of the particulates were from road dust, 20% from cement, 16% from vegetative burning, and 6% from mobile sources. While we do not have the same speciation for metals, it is clear there are other air emission sources in the area that could contribute metals to the air.

To address the question of how the increases in the concentrations of some metals in the stack gases might affect agricultural products when tires are burned, we looked at the research conducted with fruit and vegetable plants to determine whether they adsorb metals from the soil. The adsorption of metals by fruits and vegetables is called uptake of metals (ATSDR 2001; EPA 1992; EPA 1996; EPA 2001; Rieuwert JS et al 1998; Chaney RL, Ryan JA and O’Connor GA 1996).

Research shows that each plant species has different transport mechanisms, and that metals bioavailability is dependent on many factors and on specific growing conditions. Without more information on the fruits and vegetables grown in the areas potentially impacted by metals deposition, the rates and distribution of metals deposition, the soil pH, and organic content it is not possible to predict accurately the concentration of each metal in “agricultural products” or vegetables grown in home gardens. However, ATSDR staff assumed a worst-case scenario to estimate in Table 1 the concentration in vegetables of the metals of community concern.

EPA developed guidance on how to calculate the metals uptake by various fruits and vegetables when developing regulations on the use of sewage sludge as fertilizer (EPA 1992) and while developing the Superfund soil clean-up guidance (EPA 1996; EPA 2001). Research has shown that (1) only small amounts of metals are taken up by fruits and vegetables, and (2) the metals are phytotoxic to the plants (i.e., would kill the plants) at concentrations lower than the metals adsorbed by the plants would cause adverse health affects. EPA concluded in the Superfund *Soil*

---

*Screening Guidance* that “The data suggest that, for cadmium, mercury, nickel, and selenium, toxicity to plants will be observed at levels well below those estimated to elicit adverse effects in humans.”(EPA 2001). Arsenic concentrations in samples of leafy vegetables (primarily lettuce) have been found at concentrations that could cause health effects. Studies have shown that this is primarily due to soil splashing on and adhering to the plants and the difficulty of thoroughly washing all the soil off leafy vegetables like lettuces. It is common to find 1% to 2% soil in washed leafy vegetables. Because leafy vegetables have the highest bio-concentration factors, we used leafy vegetables in the worst-case scenario (ATSDR 2001, EPA 2001). The bio-concentration factor for a metal is the milligrams (mg) of that metal per kilogram (kg) of plant per mg of the metal in a kg of soil. The EPA Superfund *Soil Screening Guidance* did not have bio-concentration factors for chromium and lead, so in Table 1 we used the highest mean bio-concentration factor (0.364) for estimating the concentration of chromium and lead in leafy vegetables.

Where a hypothetical value could not be calculated (cadmium and mercury), Table 1 uses the detection limit for those metals. Table 1 also contains the estimated metal concentration in leafy vegetables grown in the mean Colorado soils. Note that the mean Colorado metals concentrations in leafy vegetables are below health values.

Research has shown and ATSDR toxicologists generally agree that “if the soil does not pose a risk for direct ingestion, it will not pose a risk for plant uptake” (ATSDR 2004). Fruits and vegetables do not bio-accumulate metals from the soil, (i.e., they are not “hyperaccumulators”) (ATSDR 2001b). See Appendix C for additional discussion of the uptake of environmental contaminants by plants.

In summary, research to date shows that crops do not absorb metals in concentrations that are toxic to humans when the crops are raised under typical farming practices in the United States, (i.e., fertilizing with phosphates and micronutrients, maintaining soil pH in proper range to enhance production, and watering or irrigating). In general, people will have greater potential for ingesting, inhaling, or absorbing (via dermal contact) metals and other contaminants from the deposition of soil onto plants than from the actual uptake of these contaminants from the soil into the plants. The public can reduce its exposure to all types of contaminants, both man-made and naturally occurring, by thoroughly washing and peeling (when possible) fruits and vegetables.

**5. Please explain this statement on page 5, “Seventeen of the chemicals detected in the stack gases were over one or more comparison values in the stack, i.e., if someone stuck their head in the stack and breathed in, these chemicals might cause health effects.”**

The quoted statement was only intended to illustrate the difference between concentrations at the source (stack exit) and at ground level, where one could be exposed. The statement means that the concentrations of most of the chemicals present in the stack gas were so low they would not cause health effects, even if people were directly exposed to the undiluted gases. That said, however, 17 of the chemicals were present in concentrations at the stack exit that indicated a more realistic exposure analysis was needed—because no one is breathing the undiluted stack gases. Those were the 17 chemicals for which ATSDR determined the concentrations at ground level, where people might breathe them. The worst-case, ground-level concentrations were calculated and provided in Table 5. This table shows that the highest ground level concentrations of these chemicals will not cause adverse health effects. The revised tables are in Appendix A of this document as discussed in the reply to Comment 1, above.

## **Child Health Considerations**

In communities faced with air, water, or food contamination, the many physical differences between children and adults demand special emphasis. Children could be at greater risk than adults from certain kinds of exposure to hazardous substances. Children play outdoors and sometimes engage in hand-to-mouth behaviors that increase their exposure potential. Children are shorter than adults are; this means they breathe dust, soil, and vapors close to the ground. A child's lower body weight and higher intake rate results in a greater dose of hazardous substance per unit of body weight. If toxic exposure levels are high enough during critical growth stages, the developing body systems of children can sustain permanent damage. Finally, children are dependent on adults for access to housing, for access to medical care, and for risk identification. Thus, adults need as much information as possible to make informed decisions regarding their children's health.

ATSDR has taken into account the unique vulnerabilities of infants and children to environmental contaminants during the evaluation of these public health issues and the preparation of this health consultation.

## **Conclusions**

- Inhaling the combination of multiple chemicals released from the cement kiln stack while burning a fuel mixture of coal and 19% tires will not result in adverse health effects.
- Eating agricultural food products grown near the CEMEX facility will not cause adverse health effects. Agricultural food products are not expected to bioaccumulate metals (or other contaminants detected in the stack gases) in sufficient concentrations to cause adverse health effects.
- ATSDR classifies the inhalation, ingestion, and skin contact routes of exposure to stack emissions from the Boulder County cement kiln resulting from burning a fuel mixture containing coal and 19% tires as "no public health hazard."

## **Recommendations**

- Although eating fruits and vegetables grown near the CEMEX plant will not cause adverse health effects, to minimize public exposures to contaminants ATSDR recommends that everyone thoroughly wash and peel, if possible, all fruits and vegetables—no matter where they are grown or purchased.

## **Public Health Action Plan**

- If additional data or new information becomes available that would affect our conclusions regarding the public's exposure to stack gases from the CEMEX plant, ATSDR will provide review and consultation on the new data and information, if requested and if deemed appropriate at that time.

## **Authors**

Betty C. Willis, MS

Environmental Health Scientist/Combustion Specialist  
Program Evaluation, Records, and Information Services Branch  
Division of Health Assessment and Consultation  
Atlanta, GA

Chris Poulet, MS

Environmental Health Scientist  
Regional Representative  
ATSDR Region VIII  
Denver, CO

## **Technical Advisor**

Allan S. Susten, PhD, DBAT

Associate Director of Science  
Division of Health Assessment and Consultation  
Atlanta, GA

## References

- [ACGIH] American Conference of Government Industrial Hygienists. 2002. Two thousand two threshold limit values for chemical substances & biological exposure indices. Cincinnati.
- [ATSDR] Agency for Toxic Substances and Disease Registry. 2001a. Draft guidance for the assessment of joint toxic action of chemical mixtures. February 2001. Atlanta: US Department of Health and Human Services.
- [ATSDR] Agency for Toxic Substances and Disease Registry. 2001b. Tribal exposures to environmental contaminants in plants. March 23, 2001. Atlanta: US Department of Health and Human Services.
- [ATSDR] Agency for Toxic Substances and Disease Registry. 2003a. Air comparison values. June 30, 2003. Atlanta: US Department of Health and Human Services.
- [ATSDR] Agency for Toxic Substances and Disease Registry. 2003b. Revised CEMEX, Incorporated health consultation. July 9, 2003. Atlanta: US Department of Health and Human Services.
- [ATSDR] Agency for Toxic Substances and Disease Registry. 2004. Electronic mail from Dr. Kenneth G. Orloff regarding assessing the hazard posed by garden vegetable uptake of contaminants from soil. May 10, 2004. Atlanta: US Department of Health and Human Services.
- Boerngen JG and Shacklette HT. 1981. Chemical analyses of soils and other surficial materials of the conterminous United States: US Geological Survey open-file report 81-197. Denver: US Geological Survey.
- Chaney RL, Ryan JA and O'Connor GA. 1996. Organic contaminants in municipal biosolids: risk assessment, quantitative pathways analysis, and current research priorities. The Science of the Total Environment 185: 187-216.
- [CAPCD] Colorado Air Pollution Control Division. 2000. Hygiene, Colorado PM10 receptor modeling study. Denver: Colorado Department of Public Health and Environment.
- Dunmire JM. 2003. Source emissions testing report, CEMEX – TDF/Coal demonstration tests, Lyons, Colorado cement plant. Denver: Air Pollution Testing, Inc.
- [EPA] US Environmental Protection Agency. 1992. Technical support document for the land application of sewage sludge, volume I and II. EPA822/R-93-001a. Washington: US Environmental Protection Agency.
- [EPA] US Environmental Protection Agency. 1996. Soil screening guidance: user's guide. EPA540/R-96/018. July 1996. Washington: US Environmental Protection Agency.
- [EPA] US Environmental Protection Agency. 2001. Supplemental guidance for developing soil screening levels for Superfund sites (peer review draft). March 2001. Washington: US Environmental Protection Agency.
- Feron VJ, Jonker D, Groten JP, Horbach GJMJ, Cassee FR, Schoen ED, Opdam JJG. 1993. Combination technology: From challenge to reality. Toxicol Trib 14:1-3.
- Jonker D, Woutersen RA, van Bladeren PJ, Til HP, Feron VJ. 1990. 4-week oral toxicity study of a combination of eight chemicals in rats: comparison with the toxicity of the individual compounds. Food and Chemical Toxicology 28: 623-631.

---

Jonker D, Jones MA, van Bladeren PJ, Woutersen RA, Til HP, Feron VJ. 1993a. Acute 24-hour toxicity of a combination of four nephrotoxicants in rats compared with the toxicity of the individual compounds. Food Chem Toxicol 31: 45–52.

Jonker D, Woutersen RA, van Bladeren PJ, Til HP, Feron VJ. 1993b. Subacute (4-week) oral toxicity of a combination of four nephrotoxicants in rats: comparison with the toxicity of the individual compounds. Food Chem Toxicol 31: 125–136.

Groton JP, Sinkeldam EJ, Luten JB, van Bladeren PJ. 1991. Interaction of dietary calcium, potassium, magnesium, manganese, copper, iron, zinc, and selenium with the accumulation and oral toxicity of cadmium in rats. Food Chem Toxicol 4: 249–258.

Klingensmith JS. 2003. Human health evaluation of cement kiln emissions from coal supplemented with natural gas and coal supplemented with tires CEMEX, Inc. cement plant Lyons, Colorado. Boulder: Flatirons Toxicology, Inc.

Rieuwert JS et al. 1998. Factors influencing metal bioavailability in soils: preliminary investigations for the development of a critical loads approach for metals. Chem Spec Bioavail 10(2): 61–75.

Wade MG et al. 2002. Effects of subchronic exposure to a complex mixture of persistent contaminants in male rats: systemic, immune, and reproductive effects. Toxicol Sci 67: 131–43.

## Abbreviations and Definitions

ACGIH = American Conference of Government Industrial Hygienists

ACV = Air comparison value (ATSDR)

Acute = Exposure for less than 14 days

ATSDR = Agency for Toxic Substances and Disease Registry

ave. = average

B(a)P = benzo(a)pyrene

BCPH = Boulder County Public Health

Chronic = Exposure for greater than 365 days

cpd = compound

CREG = Cancer risk evaluation guide for  $1 \times 10^{-6}$  excess cancer risk (ATSDR)

Cancer Classes:

A = Human carcinogen (EPA)

B1 = Probable human carcinogen—limited human, sufficient animal studies (EPA)

B2 = Probable human carcinogen—inadequate human, sufficient animal studies (EPA)

2A = Probably carcinogenic to humans—limited human evidence, sufficient evidence in animals (IARC)

CV = comparison value

dscf = dry standard cubic feet

dscm = dry standard cubic meters

EMEG = Environmental media evaluation guide (ATSDR)

EPA = US Environmental Protection Agency

FR = (stack gas) flow rate

ft<sup>3</sup> = cubic feet

g = grams

gr = grains

IARC = International Agency for Research on Cancer

Intermediate = Exposure for 14 to 364 days

lb/hr = pounds per hour

m<sup>3</sup> = cubic meters

MEIR = maximally exposed individual resident

mg/m<sup>3</sup> = milligrams (of chemical) per cubic meter (of air or stack gas)

min = minutes

MW = Molecular weight

NA = Not analyzed for

NAAQS = National Ambient Air Quality Standard (EPA)

NAAQS quarterly = NAAQS average for the quarter

ND = Not detected

NESHAP = National Emission Standard for Hazardous Air Pollutants (EPA)

ng = nanograms

NO<sub>2</sub> = nitrogen dioxide

NO<sub>x</sub> = nitrogen oxides

PAH = polycyclic aromatic hydrocarbon

PCB = polychlorinated biphenyl

PM<sub>10</sub> = particulate matter that is 10 microns or less in diameter

ppb = parts per billion

ppm = parts per million

QA/QC = quality assurance and quality control

RfC = Reference concentration (EPA)

SO<sub>2</sub> = sulfur dioxide

SO<sub>x</sub> = sulfur oxides

STEL = Short-term exposure limit

TDF = tire derived fuel

TWA = 8-hour, time weighted average

µg/m<sup>3</sup> = micrograms per cubic meter

> = greater than

< = less than

< # = Not detected at this detection limit – in calculating averages ½ the detection limit was used

## **Appendices**

## **Appendix A: Tables**

**Table 1 – Estimation of Worst-Case Metals Concentration in Leafy Vegetables**

Sample	Bioconcentration Factor*	Colorado† (ppm)			59 <sup>th</sup> Street (ppm)				Leukonen Pasture (ppm)				Chronic Health Values (ppm)	
		Range	Mean	Leafy	Soil Sample	Leafy	Hypothetical		Soil Sample	Leafy	Hypothetical			Soil EMEGs
							Soil	Leafy			Soil	Leafy		
Arsenic	0.036	<0.7-1200	29	1	4.3	0.2	6.6	0.2	6.1	0.2	9	0.3	Child: 20 Adult: 200 EPA Soil Screening: 39	
Cadmium	0.364	<0.1-50	20	7	<10	<4	{10}	4	<10	<4	{10}	4	Child: 10 Adult: 100	
Chromium	[0.364]	<5-1500	106	39	50	18	64	23	60	22	77	28	Child: 200‡ Adult: 2000‡ EPA Soil Screening: 390	
Lead	[0.364]	<10-2400	91	33	20	7	27	10	20	7	27	10	EPA Soil Screening: 400	
Mercury	0.008	<0.01-8.0	0.2	0.02	<0.1	<0.0008	{0.1}	0.0008	<0.1	<0.0008	{0.1}	0.0008	EPA Soil Screening: 23	

\* U.S. Environmental Protection Agency (EPA 2001, Appendix G)  
 [ ] Assumed value to be maximum value for leafy vegetables.  
 { } Assumed soil concentration is at detection limit.  
 † U.S. Geological Survey data (Boerngen J and Shacklette H 1981). Nondetects were included in the mean as the detection limit.  
 ‡ RMEG = Environmental media evaluation guideline - based on EPA reference dose for hexavalent chromium  
 ppm = parts per million  
 EMEG = Environmental media evaluation guideline – based on ATSDR health values

**Table 2 – Chemicals Detected in CEMEX Stack Gases**

Chemical	Average without Tires	Average with 19.2% Tires	Air Comparison Values		Evaluation
	ppb*	ppb*	ppb*	Source	
NO <sub>x</sub>	517,700	391,200	NO <sub>2</sub> 53 3,000 5,000	NAAQS annual ave. TWA STEL	Further evaluation is needed. See Table 4.
SO <sub>x</sub>	26,200	15,700	SO <sub>2</sub> 10 30 500 5,000 2,000	Acute EMEG NAAQS annual ave. NAAQS 3-hour STEL TWA	Further evaluation is needed. See Table 4.
Particulate (lb/ton of feed) <sup>†</sup>	1,600 µg/m <sup>3</sup>	1,600 µg/m <sup>3</sup>	50 µg/m <sup>3</sup> 150 µg/m <sup>3</sup> 10,000 µg/m <sup>3</sup>	NAAQS annual PM10 NAAQS 24-hr PM10	Further evaluation is needed. See Table 4.
	0.09 <sup>†</sup>	0.10 <sup>†</sup>	0.275 <sup>†</sup>	EPA NESHAP	Below EPA standard
Carbon Monoxide	50,300	120,200	35,000 25,000	NAAQS 1-hour ave. TWA	Further evaluation is needed. See Table 4.
Hydrogen Chloride	1,800	1,200	20 µg/m <sup>3</sup> 5,000	RfC Intermediate STEL ceiling	Further evaluation is needed. See Table 4.
Acetaldehyde	68.4	300	0.5 µg/m <sup>3</sup> 5 µg/m <sup>3</sup> 25,000	CREG (B2) RfC Intermediate STEL ceiling	Further evaluation is needed. See Table 4.
Acetone	110	133	13,000 13,000 26,000	Chronic EMEG Intermediate EMEG Acute EMEG	Not a health hazard
Benzene	Not available	55.5	0.1 µg/m <sup>3</sup> 4 50	CREG (A) Intermediate EMEG Acute EMEG	Further evaluation is needed. See Table 4
Bromomethane	Not available	2.7	5 50 50 5 µg/m <sup>3</sup>	Chronic EMEG Intermediate EMEG Acute EMEG RfC Intermediate	Not a health hazard
Carbon Disulfide	Not available	<7	300 700 µg/m <sup>3</sup>	Chronic EMEG RfC Intermediate	Not a health hazard
Chloromethane	<1.2	<4.5	50 200 500 90 µg/m <sup>3</sup>	Chronic EMEG Intermediate EMEG Acute EMEG RfC Intermediate	Not a health hazard
1,4-Dioxane	Not available	<4.4	20,000	TWA B2 carcinogen	Not a health hazard
Dioxins/Furans TEQ	0.016 E-3 µg/m <sup>3</sup>	<0.016 E-3 µg/m <sup>3</sup>	0.2 E-3 µg/m <sup>3</sup>	EPA NESHAP 2B carcinogen	Not a health hazard
Ethanol	Not available	<4.4	1,000,000	TWA	Not a health hazard

CEMEX, Incorporated, Lyons, Boulder County, Colorado  
Health Consultation

Chemical	Average without Tires	Average with 19.2% Tires	Air Comparison Values		Evaluation
	ppb*	ppb*	ppb*	Source	
Formaldehyde	75.3	200	8 30 40 0.08 µg/m3	Chronic EMEG Intermediate EMEG Acute EMEG CREG (B1)	Further evaluation is needed. See Table 4.
Methylene Chloride	Not available	6.7	300 300 600 3 µg/m3	Chronic EMEG Intermediate EMEG Acute EMEG CREG (B2)	Not a health hazard
Naphthalene (Highest concentration PAH)	0.166	0.776	2 3 µg/m3 10,000 15,000	Chronic EMEG RfC Intermediate TWA STEL	Not a health hazard
PAH as B(a)P Equivalents	0.000039	0.00018		B2 carcinogen	No values
PCB Total	<0.00901 µg/m3	<0.0095 µg/m3	0.01 µg/m3 1 µg/m3 0.0001 µg/m3	CREG (B2) TWA Unit Risk – Acute	Not a health hazard
Propylene	<4.7	<7.6	200,000	TWA proposed	Not a health hazard
Tetrachloroethene	<1.2	<3.6	40 200	Chronic EMEG Acute EMEG 2A carcinogen	Not a health hazard
Toluene	<1.2	<4.2	80 1000 400 µg/m3	Chronic EMEG Acute EMEG RfC	Not a health hazard

\* Units are in parts per billion (ppb) unless other units are specified for that number.

† Units are in pounds (lb) per ton of feed.

Data Sources: ACGIH 2002; ATSDR 2003a; Dunmire 2003;  gensmith 2003.

**Table 3 – Metals Detected in CEMEX Stack Gases**

Chemical	Average Without Tires	Average With 19.2% Tires	Air Comparison Values		Evaluation
	mg/m3	mg/m3	mg/m3	Source	
Arsenic	0.000465	0.00147	0.0000002 0.0000043 0.01	CREG (A) Unit Risk – Acute TWA	Further evaluation is needed. See Table 4
Barium	0.0244	0.0334	0.5	TWA	Not a health hazard
Beryllium	<0.0000433	0.0000343	0.0000004 0.00002 0.0000024 0.002 0.01	CREG (B1) RfC Intermediate Unit Risk - Acute TWA STEL	Further evaluation is needed. See Table 4
Cadmium	0.00188	0.00502	0.0000006 0.0000018 0.01	CREG (B1) Unit Risk – Acute TWA	Further evaluation is needed. See Table 4
Chromium	0.00209	0.00358	0.5	TWA	Further evaluation is needed. See Table 4
Chromium 6	Not available	Not available	0.001 0.00000008 0.0001 0.000012	Intermediate EMEG CREG (A) RfC Intermediate Unit Risk	Further evaluation is needed. See Table 4
Copper	0.00195	0.00467	0.2 1	Fume TWA Dust/mist TWA	Not a health hazard
Cobalt	0.00085	0.000684	0.0001 0.02	Chronic EMEG TWA	Further evaluation is needed. See Table 4
Lead	0.0029	0.00597	0.0015 0.05	NAAQS quarterly TWA B2 carcinogen	Further evaluation is needed. See Table 4
Manganese	0.0191	0.0266	0.00004 0.00005 0.2	Chronic EMEG RfC Intermediate TWA	Further evaluation is needed. See Table 4
Mercury	0.0175	0.0225	0.0002 0.0003 0.025	Chronic EMEG RfC Intermediate TWA	Further evaluation is needed. See Table 4
Nickel	0.00231	0.00371	0.0002 1.5-0.1	Chronic EMEG TWA varies w/ cpd.	Further evaluation is needed. See Table 4
Selenium	0.00464	0.0121	0.2	TWA	Not a health hazard
Silver	0.000424	0.000373	0.1-0.01	TWA varies w/ cpd.	Not a health hazard
Thallium	0.009	0.0166	0.1	TWA	Not a health hazard
Zinc	0.0248	0.0363	5 10 10	Fume TWA Fume STEL Dust TWA	Not a health hazard

Data Sources: ACGIH 2002; ATSDR 2003a; Dunmire 2003; Klingensmith 2003.

**Table 4 – Health Evaluation of Average Ground Level Concentrations\* of CEMEX Stack Emissions Exposure Concentrations for the Maximal Exposed Individual Resident (MEIR)**

Chemical	Average Without Tires		Average With 19.2% Tires		Air Comparison Value			
	lb/hr Stack	µg/m3 MEIR	lb/hr Stack	µg/m3 MEIR	µg/m3	Source		
NO <sub>x</sub> NO <sub>2</sub> MW = 46.01	5116	Annual 43	3866	Annual 32	NO <sub>2</sub> 100	NAAQS annual ave.		
		24-Hour 606		24-Hour 458			5645 9409	TWA STEL
		8-Hour 1379		8-Hour 1042				
		1-Hour 6230		1-Hour 4708				
SO <sub>x</sub> SO <sub>2</sub> MW = 64.07	360.7	Annual 3	216	Annual 2	SO <sub>2</sub> 80	NAAQS annual ave.		
		24-Hour 43		24-Hour 26			1300 26	NAAQS 3-hour ave. Acute EMEG
		1-Hour 439		1-Hour 263				
Particulate	9.2		9.4	Annual 0.079 24-Hour 1.1	PM10 50 150	NAAQS annual ave. NAAQS 24-hour ave.		
Carbon Monoxide MW = 28.01	302.6		723	Annual 6 1-Hour 880			40,000	NAAQS 1-hour ave.
Hydrogen Chloride MW = 36.47	0.66	Annual 0.0056 1-Hour 0.77	0.63	Annual 0.0053	20 7458	RfC Intermediate STEL ceiling		
Acetaldehyde MW = 44.05	0.0694		0.26	Annual 0.0022	0.5	CREG		
				1-Hour 0.32	5 45,041	RfC Intermediate STEL ceiling		
Benzene MW = 78.11	Not available		0.101	Annual 0.0008	0.1	CREG		
				24-Hour 0.012	13	Intermediate EMEG Acute EMEG		
				1-Hour 0.12	160			
Formaldehyde MW = 30.03	0.0515		0.10	Annual 0.0008	10 0.08	Chronic EMEG CREG		
				24-Hour 0.012	37	Intermediate EMEG Acute EMEG		
				1-Hour 0.12	49			

(Table 4 continued)

METALS						
Chemical	Average Without Tires		Average With 19.2% Tires		Air Comparison Value	
	lb/hr Stack	µg/m3 MEIR	lb/hr Stack	µg/m3 MEIR	µg/m3	Source
Arsenic	1.77E-4		4.69E-4	Annual 3.9E-6	200E-6	CREG
				24-Hour 0.56E-4 1-Hour 5.7E-4	43E-4	Unit Risk – Acute
Beryllium	11.1E-6	Annual 0.094E-6	11.0E-6	Annual 0.093E-6	400E-6	CREG
		24-Hour 1.3E-6		24-Hour 1.3E-6	0.02	RfC Intermediate
		1-Hour 14E-6		1-Hour 14E-6	0.0024	Unit Risk - Acute
Cadmium	7.17E-4		16.1E-4	Annual 13.5E-6	600E-6	CREG
				24-Hour 0.19E-3 1-Hour 1.96E-3	1.8E-3	Unit Risk – Acute
Chromium	0.796E-3		1.15E-3	Annual 9.6E-6 24-Hour 0.00014 1-Hour 0.0014	Assume all Cr is Cr+6	Compare to Cr+6 values below
Chromium 6	Not available		Not available	Annual 9.6E-6	80E-6	CREG
				24-Hour 1.4E-4 1-Hour 14E-4	1 0.1 0.012	Intermediate EMEG RfC Intermediate Unit Risk
Cobalt	3.25E-4	Annual 2.7E-6	2.2E-4	Annual 1.8E-6	100,000E-6	Chronic EMEG
		1-Hour 3.96E-4		1-Hour 2.7E-4	20	TWA
Lead	1.11E-3		1.92E-3	Annual 16E-6 1-Hour 0.0023	1.5	NAAQS quarterly
Manganese	7.3E-3		8.56E-3	Annual 72E-6	0.04	Chronic EMEG
				1-Hour 0.010	0.05	RfC Intermediate
Mercury	6.69E-3		7.23E-3	Annual 61E-6	0.2	Chronic EMEG
				1-Hour 0.0088	0.3	RfC Intermediate
Nickel	0.882E-3		1.19E-3	Annual 10E-6	0.2	Chronic EMEG
				1-Hour 0.0014	100-1500	TWA varies w/ cpd

\* Ground level concentrations calculated for the higher stack emission concentration for each chemical, whether or not tires were being burned.

In calculating averages, ½ the detection limit was used for non-detected values.

Data Sources: ACGIH 2002; ATSDR 2003a; Dunmire 2003; Klingsmith 2003.

**Table 5 – Health Evaluation of Maximum Ground Level Concentrations\* of CEMEX Stack Emissions Exposure Concentrations for the Maximal Exposed Individual Resident (MEIR)**

Chemical	Maximum Without Tires		Maximum With 19.2% Tires		Air Comparison Value	
	lb/hr Stack	µg/m3 MEIR	lb/hr Stack	µg/m3 MEIR	µg/m3	Source
NOx†	Not available		Not available		NO <sub>2</sub> 100	NAAQS annual ave.
					5645 9409	TWA STEL
SOx†	Not available		Not available		SO <sub>2</sub> 80	NAAQS annual ave.
					1300 26	NAAQS 3-hour ave. Acute EMEG
Particulate	10.2	Annual 0.086 24-Hour 1.2	9.4	Annual 0.079 24-Hour 1.1	PM10 50 150	NAAQS annual ave. NAAQS 24-hour ave.
Carbon Monoxide†	Not available		Not available		40,000	NAAQS 1-hour ave.
Hydrogen Chloride MW = 36.47	0.98	Annual 0.008 1-Hour 1.2	0.79		20 7458	RfC Intermediate STEL ceiling
Acetaldehyde MW = 44.05	0.2		0.43	Annual 0.0036	0.5	CREG
				1-Hour 0.52	5 45,041	RfC Intermediate STEL ceiling
Benzene MW = 78.11	Not available		0.258	Annual 0.0022	0.1	CREG
				24-Hour 0.03 1-Hour 0.31	13 160	Intermediate EMEG Acute EMEG
Formaldehyde MW = 30.03	0.0588		0.12	Annual 0.001	10 0.08	Chronic EMEG CREG
				24-Hour 0.014 1-Hour 0.15	37 49	Intermediate EMEG Acute EMEG

(Table 5 continued)

METALS								
Chemical	Maximum Without Tires		Maximum With 19.2% Tires		Air Comparison Values			
	lb/hr Stack	µg/m3 MEIR	lb/hr Stack	µg/m3 MEIR	µg/m3	Source		
Arsenic	2.18E-4		4.96E-4	Annual	4.2E-6	200E-6	CREG	
				24-Hour	0.59E-4	43E-4	Unit Risk – Acute	
Beryllium	1.68E-5	Annual	1.65E-5			400E-6	CREG	
		24-Hour				2E-6	20,000E-6	RfC Intermediate
		1-Hour				20E-6	2400E-6	Unit Risk - Acute
Cadmium	8.55E-4		1.8E-3	Annual	15.2E-6	600E-6	CREG	
				24-Hour	0.2E-3	1.8E-3	Unit Risk - Acute	
				1-Hour	2.2E-3			
Chromium	8.98E-4		12.2E-4	Annual	10.3E-6	Assume all Cr is Cr+6	Compare to Cr+6 values below	
			24-Hour	1.4E-4				
			1-Hour	14.9E-4				
Chromium 6	Not available		Not available	Annual	10.3E-6	80E-6	CREG	
				24-Hour	1.4E-4	1	Intermediate EMEG	
				1-Hour	14.9E-4	0.1	RfC Intermediate	
						0.012	Unit Risk	
Cobalt	5.44E-4	Annual	2.31E-4			100,000E-6	Chronic EMEG	
		1-Hour				6.6E-4	20	TWA
Lead	1.26E-3		2.14E-3	Annual	18E-6	1.5	NAAQS quarterly	
				1-Hour	2.6E-3			
Manganese	7.71E-3		9.05E-3	Annual	76E-6	0.04	Chronic EMEG	
				1-Hour	0.011	0.05	RfC Intermediate	
Mercury	7.09E-3		7.27E-3	Annual	61E-6	0.2	Chronic EMEG	
				1-Hour	0.0089	0.3	RfC Intermediate	
Nickel	1.08E-3		1.34E-3	Annual	11E-6	0.2	Chronic EMEG	
				1-Hour	0.0016	100-1500	TWA varies w/ cpd	

\* Ground level concentrations were calculated for the highest stack concentration for each chemical in any stack sample without regard to whether tires were being burned.

† NO<sub>x</sub>, SO<sub>x</sub>, and carbon monoxide values in Table 4 are from continuous emissions monitors. Only rolling averages were reported; maximum values were not available.

Data Sources: ACGIH 2002; ATSDR 2003a; Dunmire 2003; Klingensmith 2003.



## Appendix B: Calculation of Hypothetical Soil Values in Table 1

### Assumptions and Calculations

X = The hypothetical increase in the concentration of the five metals of concern—if tires are burned for the next 33 years and if 20% of the metals currently in the soil are due to deposition of CEMEX stack emissions. The 20% assumption is based on the state air study that found 20% of the particulates in local ambient air samples were from the CEMEX plant (CAPD 2000).

Soil Sample = Concentration detected in soil samples from 59<sup>th</sup> Street and Leukonen Pasture by Hazen Research, Inc. (CAPD 2000).

Hypothetical Soil = Soil Sample + X (The estimated metal concentrations in the soil in 33 years if 19% tires are burned, assuming 20% of the metals in the soil come from CEMEX.)

$$\frac{\text{Metal in coal only stack test}}{20\%(\text{Soil Sample})} = \frac{\text{Metal in coal + tires stack test}}{X}$$

$$\text{Example: Arsenic in Leukonen Pasture} \quad \frac{1.77 \text{ E-}04 \text{ lb/hr}}{0.2(6.1 \text{ ppm})} = \frac{4.69 \text{ E-}04 \text{ lb/hr}}{X}$$

$$X = 3.2 \text{ ppm}$$

$$\text{Hypothetical soil} = 6.1 + 3.2 = 9.3$$

Metal	59 <sup>th</sup> Street*				Leukonen Pasture*			
	No Tires		19% Tires		No Tires		19% Tires	
	Stack† lb/hr	Soil ppm*	Stack† lb/hr	Hypothetical Soil ppm	Stack† lb/hr	Soil ppm*	Stack† lb/hr	Hypothetical Soil ppm
Arsenic	1.77E-4	4.3	4.69E-4	6.6	1.77E-4	6.1	4.69E-4	9.3
Cadmium	7.17E-4	<10	16.1E-4	N.A.	7.17E-4	<10	16.1E-4	N.A.
Chromium	0.796E-3	50	1.15E-3	64	0.796E-3	60	1.15E-3	77
Lead	1.11E-3	20	1.92E-3	27	1.11E-3	20	1.92E-3	27
Mercury	6.69E-3	<0.1	7.23E-3	N.A.	6.69E-3	<0.1	7.23E-3	N.A.

\* Hygiene, Colorado PM10 Receptor Modeling Study, page 22  
† Dunmire JM 2003  
N.A. = Not appropriate to calculate a ratio using a < value.



---

## Appendix C: Uptake of Environmental Contaminants by Plants

To help staff address the issue of whether plants uptake contaminants from the soil in quantities that would make the plants a public health concern, on December 4 and 5, 2000, ATSDR convened an expert panel to discuss the potential for plants to uptake metals and other contaminants that could contribute to human exposure. The panel's key findings and conclusions are listed below. The page numbers in brackets [ ] refer to pages in the ATSDR panel report *Tribal Exposures to Environmental Contaminants in Plants* (ATSDR 2001b).

The panel discussion focused on the relative importance of plant uptake of metals as a route of human exposure compared with exposure from aerosol deposition and soil splash onto plants. The plant experts on the panel agreed that people, in general, would have a greater potential for exposure to metals and other contaminants from the deposition of soil onto plants rather than the actual uptake of these contaminants from the soil into the plants. Experts noted that the potential for soil to adhere to plant surfaces is very high and it is very difficult to wash all soil particles from the plant materials before preparing and ingesting the foods. Root crops and portions of plants growing close to the soil pose a greater risk of exposure to metals or other contaminants than the aerial portions of plants, such as fruits and berries. The experts emphasized that the potential for contamination is generally only a concern if plants are collected from areas where heavy contamination is present. ...The most important factors that affect the uptake of metals by plants ... are [page iv]:

*The "soil-plant barrier."* The soil-plant barrier involves processes that prevent excessive plant uptake of potentially toxic elements. The extent to which this barrier prevents the uptake of metals is dependent on the solubility of the element that is present in the soil [page iv].

**Heavy metals such as lead and arsenic** generally are not absorbed at all or may be absorbed into the roots but do not move through the plant body. These elements are so insoluble that under most conditions they do not get taken up into the edible parts of the plant, especially the leaves, berries, or fruits. Some elements such as **iron, tin, silver, and fluoride** may be absorbed at low concentrations, but usually do not enter the shoots of plants at levels that would be harmful to people [page 5-1].

*Exceptions to soil-plant barrier.* Without phosphates plants can take up certain elements (e.g., lead) into their tissues [page 5-3]. Phosphates keep lead from moving beyond a plant's roots [page 5-6]. All plants, however, need phosphates to grow properly and it is unlikely that under normal growing conditions a plant will be depleted enough in phosphates to uptake lead at levels of concern to humans. ... Therefore, stressed vegetation could be a signal that conditions may be more favorable for the uptake of metals or other contaminants. ...The two principal metals that can be taken up by plants under certain conditions are **selenium and cadmium**. If sufficient amounts of these contaminants were available in soil, it would be possible for certain plants to accumulate high enough concentrations to be harmful to people. In the case of cadmium, normal soil conditions (e.g., those with adequate concentrations of zinc in the soil) usually prevent excess uptake of cadmium by plants [page 5-2]. ...With respect to **cadmium**, as long as people have a proper diet (i.e., adequate levels of zinc, iron,

and calcium), this will usually prevent the absorption of harmful levels of cadmium [page 5–3].

*Plant-specific characteristics.* Some plant species, referred to as “hyperaccumulators,” (e.g., milkvetch or locoweed [*Astragalus*] and prince’s plume [*Stanleya*]) can accumulate some elements such as **selenium or nickel** much more readily than other plants [page iv], ...but they are rare [page 5–2]. ...Certain trees with deep roots can accumulate **cesium**, but not vegetables such as lettuce or cabbage. It was also noted that for some reason **barium** (which is rarely accumulated in plants) is readily accumulated by brazil nuts. [page 7–2].

*Portion of the plant that is harvested.* In general, fruits and berries are less likely to accumulate soil metals and other contaminants because of plant processes. Plants have physiological barriers in their structure that prevent contaminants from getting to the tops of the plants [page 5–4].

*Soil Properties.* The uptake of elements such as **zinc, cadmium, and manganese** are all very dependent on soil pH. As the soil becomes more acidic, the potential for metals to be adsorbed by the roots of the plant increases [page iv]. ...With few exceptions (e.g., cadmium), however, the concentrations of the elements would not be harmful to humans and animals without first killing the plants (i.e., soils with pH <5.2 can prevent the growth of most plants). ...It was noted that in dry land or in land irrigated with high chloride waters, elevated chloride levels result in increased rates of cadmium uptake by plants [page 5–4].

*Phytoavailability.* Many elements may be present in soil, but are not freely available for uptake by plants unless there is some deficiency (e.g., zinc) in the plant that allows the metal to be taken up more readily than usual [page iv].

*Bioavailability.* Some plants uptake metals (e.g., **mercury**), however they tie them up in a form that is not readily bioavailable to animals and humans [page v]. ...although some wetland plants uptake metals (e.g., mercury), they store them in a form that is not readily bioavailable to animals and humans ...the greatest potential for human exposure to mercury via plant materials is through the vaporization of the mercury and the deposition of the aerosol onto the leaves and shoots of the plant rather than through the uptake of mercury [pages 5–4 and 5–5].

*Indicators of contaminated or stressed environments.* Unusual changes in the coloring or growth pattern of plants may be a signal of phytotoxicity (e.g., arsenic poisoning) or a stressful growth environment (e.g., drought) resulting in plants potentially accumulating metals more readily than they would under normal non-stressful situations [page v]. ...Several elements can be phytotoxic (harmful to the plant) at levels well below those that would be toxic to people. Elements such as **zinc, copper, nickel, and arsenic** at high enough concentrations will kill the plant before it can be of harm to animals or humans consuming such plants [page 5–2].

*Potential for plant uptake of non-metal organic chemicals (e.g., PCBs and DDE).* The deposition and adsorption onto plants is the most important route of exposure rather than the uptake by the roots and translocation into the other portions of the plant. ...Many organic contaminants are soluble in the waxy layer of the cuticle. Even after washing the plant materials with the intent to remove the contaminants, substantial contamination often remains. ...However, it is unlikely that people are being exposed to volatile organic compounds (VOCs) through this route because

---

in the natural environment there will be very limited aerial deposition of VOCs. Exceptions to this conclusion exist in the northern most latitudes close to the arctic [pages 7–1 and 7–2].

...in general, people will have greater potential for ingesting, inhaling, or absorbing (via dermal contact) metals and other contaminants from the deposition of soil onto plants than from the actual uptake of these contaminants from the soil into the plants (Chaney 1985; Chaney et al. 1998; Chaney et al. 1999a; Chaney et al. 1999b) [page 5–1]. ...For example, the risk from contaminants taken up by garden vegetables is about one-fifth as high as the risk from exposure to the soil that is brought into the house from being outside in the field harvesting crops or gardening [page 5–3].

Specifically, for heavy metals such as **lead, cadmium, and arsenic**, one should be primarily concerned about the roots and about soil contamination of the lower portion of the fruits or leaves that may be used. Low lying plants (e.g., strawberries), leafy vegetables (e.g., spinach and lettuce), and root crops (e.g., potatoes and carrots) are particularly likely to contribute to human exposure to metals because soil can adhere to these plant surfaces quite readily. Since heavy metals are tightly bound to soil particles, soil is the primary vehicle for heavy metal exposure – not the uptake and translocation of metals from the root to the top of the plant. ...For example, it is common for washed spinach leaves to contain 1-2% soil. ...Peeling the skin of certain plants used for food, however, can remove much of the contaminated soil [page 5–3].

Even though the community was concerned about metals uptake by agricultural plants, the public is often also concerned about the uptake of persistent organic compounds such as lipophilic compounds like PCBs, DDT, etc. Rufus L. Chaney et al did a lot of research on the plant uptake of PCBs and other organics from biosolids-amended soil (soil to which sewage treatment sludge was applied). In the article *Organic contaminants in municipal biosolids: risk assessment, quantitative pathways analysis, and current research priorities* he summarized the key findings which are presented below (Chaney et al 1996).

Transfer of PCBs from biosolids-amended soil to edible parts of crops is quite low for the persistent lipophilic compounds which could require regulation. ... By study of <sup>14</sup>C-labelled compounds applied to the surface soil, or to the subsurface soil below the volatilization barrier previous researchers showed that the more strongly adsorbed lipophilic compounds (e.g. DDT) were transferred essentially only by volatilization, while more water soluble compounds such as dieldrin were transferred both by volatilization and by actual plant uptake and translocation. ...

All reports since their work have confirmed that volatilization is the major mechanism of transfer of PCBs both from soil to above-ground parts of plants, and movement within the soil and to subsurface roots such as carrot. ... If the main path for PCB transfer from soil to crops is volatile transfer, the soil properties which control volatilization will control plant uptake. The dominant site of PCB binding in soils is the humic materials (organic matter), so increased organic matter concentration in a soil reduces PCB volatilization. ...

Transfer of soil PCBs...to feed crops has been found to be very low in a number of studies. When reasonable concentrations of PCBs, dioxins, PBBs [poly

brominated biphenyls], DDT, etc. Were added to soils, and transfer to crops in the field...were examined, non-detectable residues were found. ...

Carrot has been identified as the highest PCB uptake crop in human diets. The peel from carrots had been found to adsorb or accumulate the lipophilic pesticides (e.g. DDT). ... Other root crops do not accumulate compounds such as PCBs nearly as well as carrots. For example, sugarbeet accumulated less than one-tenth the PCB residue of carrot in the same test soil. ... Even carrots accumulate only very small amounts of lipophilic organics when the compound involved has lower vapour pressure, such as the PBBs which were not measurable in carrot roots or other crops. ...

[In a] study of PCB uptake from soils amended with biosolids, carrot had measurable levels of PCBs while other crops had non-detectable levels (O'Connor et al. 1990). O'Connor et al. (1990) found little PCB entry to carrot deeper than the normal peel depth. ... It is clear that consumers have great protection from PCBs entering the food-chain as a result of use of biosolids on cropland. ...

The research todate shows that food crops do not uptake metals or organic compounds in concentrations that will cause adverse health effects. However, it is good public health practice to thoroughly washed and peeled (were possible) all food crops to minimize any potential for exposure. Rufus L. Chaney ends his article with advice on how to more effectively biodegrade xenobiotics (a chemical, such as a drug, pesticide, or carcinogen, that is foreign to that locale). He suggests:

Composts provide balanced soil fertility and microbial nutrition. ... And the organic matter in composts can sorb the xenobiotics, thereby reducing their volatilization, leaching, or toxicity in contaminated soils yet allowing the microbes in the amended soil to biodegrade the compounds. ... Studies have shown that application of mature compost is much more effective in biodegradation of soil xenobiotics than addition of microbial inocula or fertilizers. The combination of factors noted above show the present theory of why composts are so effective in biodegrading xenobiotics in soil.