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The Development and Results of 1999 Lead Emission Inventory for the Greater Cairo Area

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ABSTRACT

As part of the Cairo Air Improvement Project (CAIP), 1999-lead emissions inventory has been completed for the Greater Cairo (GC) area, including the Governorates of Cairo, Giza, and Kalubia. The inventory and the associated database will assist in developing regulatory and control strategies, assessing emission trends, and conducting modeling exercises. This paper describes the results of the 1999-lead emission inventory for Greater Cairo area.

As detailed follow, it is estimated that the primary sources of lead emissions in the area emitted 2,669 metric tons of lead in 1999. The annual emissions from secondary lead smelters are estimated to be 2,177 metric tons, or approximately 81.6 percent of the total lead emissions from these sources. The annual emissions from the combustion of Mazout (Heavy Fuel Oil) in the Greater Cairo area are estimated to be 477 metric tons, or approximately 17.9 percent of the total lead emissions from these sources. Emissions estimates are also provided for other sources as shown in Table 1 below.

TABLE (1):- 1999 LEAD EMISSIONS INVENTORY SUMMARY
Estimate of Lead Emissions from the most significant Major Sources in the Greater Cairo Area 1999

Activity	Number of Facilities	1999 Production	1999 Lead Emissions (metric ton)	Percentage of Total Lead Emissions
Secondary Lead Smelting[1]	15	59,940 (metric tons lead ingot)	**2,177**	**81.6%**
Lead-Acid Battery Production[1]	33	416,600 (batteries)	**3.41**	0.13%
Secondary Copper Processing[1]	206	16,080 (metric tons)	**8.04**	0.30%
Portland Cement Manufacturing[1]	3	~13,500,000 (metric tons cement)	**3.39**	0.13%
Mazout Combustion	Not Applicable	4,180,000 (metric tons Mazout consumed)	**477**	**17.9%**
Total			**2.669**	**100%**

Introduction

Background

Pure lead is a silvery-white metal that oxidizes and turns bluish-gray when exposed to air. Its properties include a low melting point; ease of casting; high density; low strength; ease of fabrication; acid resistance; electrochemical reaction with sulfuric acid; chemical stability in air, water, and earth; and the ability to attenuate sound waves, atomic radiation, and mechanical vibration.[1] Lead in its elemental or pure form rarely occurs in nature. Lead most commonly occurs as the mineral galena (lead sulfide [PbS]), and is sometimes found in other mineral forms.[2]

For many of the uses in Cairo and elsewhere, lead must be hardened. Lead is hardened by alloying it with small amounts of arsenic, copper, antimony, or other metals. These alloys may then be used in manufacturing various lead-containing products. In addition to lead alloys, there are many lead compounds that may be used in the manufacture of lead-containing products.

Though lead has many uses, it is also a toxic material that can adversely affect the blood, nervous system, brain, and kidneys. The principal routes of human exposure are ingestion and inhalation. Manifestations of lead exposure include anemia, encephalopathy, and kidney damage. Studies that investigate the environmental health risks to Cairo residents invariably conclude that lead is one of the area's major health hazards. Several references report ambient lead levels up to 10 $\mu g/m^3$ in many areas of Cairo and in the range of 10-50 $\mu g/m^3$ in industrial areas. Studies of blood lead levels in Cairo resident's report that some children, the most sensitive receptors in the population, have blood lead concentrations up to three times the "safe" level.

Though much has been done to reduce the ambient lead concentrations, there remain further opportunities for improvement. In order to implement policies with a goal of reducing the amount of ambient airborne lead, it is necessary to have an accurate lead emissions inventory that details the primary sources of ambient lead. With this information, sources can be prioritized and corrective actions can first be taken where they will have the greatest positive effect. This document is the initial attempt at an inventory of lead emissions from the major sources of lead emissions in the greater Cairo area. The inventory and associated database will provide a foundation on which to base regulatory strategies, conduct modeling exercises, and assess emissions trends.

Air Emission Inventory Methodology

The methodology for this initial inventory can be divided into three parts; source category selection, data collection, and emissions estimation methodology.

Source Category Selection

Given the number of uses for lead and its compounds, it can be correctly deduced that there are a large number of industries that may emit lead into the air. The USEPA has researched the subject and publishes a list of the industries, activities and practices that emit or may emit lead. The stationary (i.e., excluding mobile) sources found from the USEPA research are listed in Table 2 below.

An important step in reducing health risks due to lead exposure was taken when a lead additive was removed from gasoline sold in the greater Cairo area. This action reduced the exposure of the general public to lead emitted from mobile sources. Thus, stationary sources are thought to be the major remaining sources of lead emissions and are the focus of this inventory.

TABLE 2: STATIONARY SOURCE ACTIVITIES THAT MAY EMIT LEAD

List of Stationary Sources, Industries, and Practices that May Emit Lead and Lead Compounds[c]
Secondary Lead Smelting
Primary Copper Production
Secondary Copper Production
Primary Lead Smelting
Primary Zinc Smelting
Secondary Aluminum Operations

TABLE 2: STATIONARY SOURCE ACTIVITIES THAT MAY EMIT LEAD
List of Stationary Sources, Industries, and Practices that May Emit Lead and Lead Compounds[c]
Iron and Steel Foundries
Ore Mining, Crushing, and Grinding
Brass and Bronze Processing
Stationary External Combustion Sources
Stationary Internal Combustion Sources
Municipal Waste Incineration
Industrial and Commercial Waste Incineration
Sewage Sludge Incineration
Medical Waste Incineration
Hazardous Waste Incineration
Drum and Barrel Reclamation
Burning of Scrap Tires
Crematories
Pulp and Paper Industry
Portland Cement Manufacturing
Pressed and Blown Glass Manufacturing
Lead-Acid Battery Production
Lead-Oxides in Pigments
Lead Cable Coating
Frit Manufacturing
Ceramics and Glazes
Solder Manufacturing
Electroplating
Stabilizers in Resins
Asphalt Concrete
Application of Paints
Shooting Ranges

Though these activities may each emit lead, it is beyond the scope of an initial emissions inventory to include every potential source of emissions. Rather, this emissions inventory will focus on the industries and activities that are felt to be most significant in the greater Cairo area. Based on monitoring data, preliminary emissions investigations, and the experience of the USEPA and local environmental professionals, it was felt that the most significant remaining sources of ambient lead emissions in Cairo are given in Table 3 below. As the inventory is updated in the future, it can be refined by including additional activities.

TABLE 3: STATIONARY SOURCES INCLUDED IN THIS EMISSIONS INVENTORY

List of Lead-Emitting Stationary Sources, Industries, and Activities Included in this Emissions Inventory
Secondary Lead Smelting
Lead-Acid Battery Production
Secondary Copper Production (including brass and bronze)
Portland Cement Manufacturing
Mazout Combustion

Data Collection

The development of an emission inventory for lead (or any other pollutant) in Egypt is confounded by the lack of data and resources to identify relevant facilities and obtain accurate, current process and production data. Some information on identification and characteristics of licensed facilities was obtained from the General Organization for Industrialization (GOFI), the Central Agency for Planning, Mobilization, and Statistics (CAPMAS), and the Environmental Map of Egypt prepared by the EEAA.[3] However, the most productive approach to data collection was facility-to-facility surveys. Many unlicensed facilities exist that can only be identified by this approach as there are no official records of their presence. Though the facility surveys are time consuming, they are an indispensable means of obtaining accurate, current, and comprehensive source data. The secondary lead smelting, lead-acid battery, copper, and Portland cement production data given in this report were obtained using facility surveys. Mazout usage data was obtained from the Ministry of Petroleum.

Emissions Estimation Methodology

An emission factor is a representative value that relates the quantity of a pollutant released to the atmosphere with an activity associated with the release of that pollutant. These factors are usually expressed as the weight of pollutant divided by a unit weight, volume, distance, or duration of the activity emitting the pollutant (e.g., kilograms of lead emitted per metric ton of Mazout burned). Such factors facilitate estimation of emissions from various sources of air pollution. In most cases, these factors are simply averages of the available data of acceptable quality, and are generally assumed to be representative of long-term averages for all facilities in the source category (i.e., a population average). In the absence of continuous emissions data, emission factors are frequently the best or only method available for estimating emissions, in spite of their limitations.

The general equation for emission estimation using an emission factor is:

$$E = A \times EF \times \left(\frac{1 - ER}{100} \right)$$

where:

E = Emissions EF = Emission Factor
A = Activity Rate ER = Overall Emission Reduction Efficiency, %

The emissions reduction efficiency can be accounted for either using the ER term in the equation above or by developing emission factors that incorporate the emissions reduction (as is done for Portland cement kilns). Note that, although there are a small number of air pollution control devices installed at the facilities surveyed, these are by and large ineffective or inoperable. Thus, for most facilities, no emissions reduction efficiency has been used in estimating emissions. The one exception is the Portland cement industry, which has efficient and operational control devices. Emissions reductions due to the use of this equipment has been accounted for in this industry, although it is not clear that the emissions control equipment is operated continuously.

Emissions of lead were calculated for each source using emission factors from three sources:

- *Compilation of Air Pollutant Emission Factors, Fifth Edition*, AP-42, U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards, Research Triangle Park, North Carolina.
- Source tests performed in Cairo by the Cairo Air Improvement Project for the express purpose of developing emission factors.
- Mass balance using materials information.

It should be noted that emissions estimates rely not only upon the emission factors, but also upon reliable and accurate production data ("activity rate" in the equation above). The production data used to estimate emissions for this inventory comes primarily from the facility surveys. The survey requested actual production data for 1999. Where possible, this data was confirmed, however, it is not unreasonable to assume that some facility owners have under-reported the production from their facilities out of fear of additional taxation. Future refinements of this inventory may include additional checks of the accuracy of the reported production

Stationary Source Emissions

Secondary Lead Smelting

The secondary lead smelting industry produces elemental lead and lead alloys by reclaiming lead. The primary source of the reclaimed lead is scrap automobile and truck batteries. Smelting is the reduction of lead compounds to elemental lead and requires a higher temperature than that required for melting lead. Rotary furnaces are typically used for smelting scrap lead and producing secondary lead. After processing in the rotary furnace, the secondary lead is typically refined in a kettle to produce soft lead, or refined and alloyed to produce hard lead. The typical sequence of operations at an Egyptian secondary lead smelting operation includes scrap receiving and preparation, rotary furnace smelting, lead refining and alloying, and casting. Battery breaking is also performed at a number of facilities (primarily the Awadallah

facilities) and is undoubtedly a source of lead emissions. However, because of the variable nature of emissions from battery breaking, USEPA has elected not to develop an emission factor for this process. Given the relatively minor amount of emissions from battery breaking, the lead emissions from this process are not accounted for in this report. However, in the future it may be helpful to perform testing at an Awadallah facility and develop an emission factor. As battery breaking is performed primarily at the Awadallah facilities, an emission factor may be appropriate in Egypt while it may not be in the United States. A summary of 1999 emissions from this industry is provided in Table 5.

Activity	Governorate	No. of facilities	Total No. in Greater Cairo
Secondary lead Smelter	Cairo	7	15
	Giza	3	
	Kalubia	5	
Secondary Copper Process	Cairo	184	206
	Giza	8	
	Kalubia	14	
Lead -Acid Battery Production	Cairo	23	33
	Giza	10	
	Kalubia		
Portland Cement Magnification	Cairo	3	3
	Giza		
	Kalubia		

Table (4) : - The most significant activities which have high lead emissions in greater Cairo area (Cairo, Giza and Kalubia), and the relating total number of facilities respect to each activity and each governorates of greater Cairo

* Production Data Source: - CAIP Data

Rotary Furnace Smelting

A rotary furnace is typically a refractory-lined steel drum mounted on rollers with an electric motor to rotate the drum. Fuel is injected at one end of the drum, and the connection to the exhaust stack (if applicable) is often located at the same end. The furnaces are operated on a batch basis.

Emission factors were developed by CAIP through source testing at several facilities in Cairo. Two emission factors have been developed for this process. One is applicable at the Awadallah facilities, and the other is applicable at all other facilities. The Awadallah facilities produced nearly 75% of the total lead ingot in 1999 and consistently showed lower emissions from their rotary furnaces. It was felt that the most accurate portrayal of emissions from this process would result from separating the Awadallah facilities from the others. The emission factor for lead emissions from rotary furnaces at secondary lead smelters was applied directly to the annual production throughput to calculate annual emissions, as shown below. The production throughput for rotary furnaces is the amount of lead ingot produced.

Awadallah Facilities:

$$44{,}400\frac{\text{metric tons ingots}}{\text{year}}\times 21.4\frac{\text{kg lead emitted}}{\text{metric ton ingots}}=950{,}160\frac{\text{kg lead emitted}}{\text{year}}$$

Other Facilities:

$$15{,}540\frac{\text{metric tons ingots}}{\text{year}}\times 76.8\frac{\text{kg lead emitted}}{\text{metric ton ingots}}=1{,}193{,}472\frac{\text{kg lead emitted}}{\text{year}}$$

Kettle Refining Operations

After the secondary lead is produced from the rotary furnace it is typically cooled into bars that are then used as the feed stream for the kettle refining process. In this process, large, open-top, heated kettles are used to melt and refine the secondary lead. In some cases, smaller cauldrons are used in lieu of kettles, but the principal of operation is the same. This is also the step in the process where other metals such as antimony can be added to produce a desired lead alloy.

Emission factors were developed by CAIP through source testing at several facilities in Cairo. See Appendix B for more detail on the emission factor development. The emission factor for lead emissions from kettle refining operations at secondary lead smelters was applied directly to the annual production throughput to calculate annual emissions, as shown below. The production throughput for refining kettles is equivalent to the amount of refined lead ingots produced. One facility does not use refining kettles, but only rotary furnaces, which is why the throughput for this process is lower than that for the rotary furnace.

$$51{,}540\frac{\text{metric ton ingots}}{\text{year}}\times 0.63\frac{\text{kg lead emitted}}{\text{metric ton ingots}}=32{,}470\frac{\text{kg lead emitted}}{\text{year}}$$

Casting

After the lead is refined in the refining/alloying kettles, it is typically poured into molds and allowed to cool. The pouring process is usually done by hand with one operator dipping a ladle into the refining kettle and pouring the molten lead into the mold. Another operator skims any impurities from the top of the molten lead as it cools and removes the

hardened lead after the cooling process is complete. This is the often the final product from a secondary lead smelter.

The USEPA believes that casting of lead is a small, but not insignificant, source of lead emissions because the temperature of molten lead is well below the fuming temperature of lead. Visual inspection of select casting operations in Cairo confirmed that only a negligible amount of lead fumes was visible during the casting operation. Thus, it was felt that the AP-42 emission factor for lead casting was appropriate for use in Cairo.

The emission factor for lead emissions from casting processes at secondary lead smelters was applied directly to the annual production throughput to calculate annual emissions, as shown below. The production throughput for casting operations is equivalent to the amount of lead ingots produced.

$$59{,}940\frac{\text{metric ton ingots}}{\text{year}}\times 0.0074\frac{\text{kg lead emitted}}{\text{metric ton ingots}}=444\frac{\text{kg lead emitted}}{\text{year}}$$

TABLE 5: SUMMARY OF LEAD EMISSIONS FROM SECONDARY LEAD SMELTING

Estimate of 1999 Lead Emissions from Secondary Lead Smelting Processes in the Greater Cairo Area

Process	**Annual Throughput** (metric ton ingot)	**1999 Lead Emissions** (metric ton)
Rotary Furnace Smelting	59,940	2,144
Kettle Refining Operations	51,540	32.5
Casting	59,940	0.44
Total		**2,177**

Lead-Acid Battery Production

TABLE 6: SUMMARY OF LEAD EMISSIONS FROM LEAD-ACID BATTERY PRODUCTION

Estimate of 1999 Lead Emissions from Lead-Acid Battery Production in the Greater Cairo Area

Process	**Annual Production**	**1999 Lead Emissions** (metric ton)
Grid Casting	421.4 (1,000 bat./yr)	0.169
Paste Mixing	416.6 (1,000 bat./yr)	0.471
3-Process Operation	416.6 (1,000 bat./yr)	2.75
Small Parts Casting	142.8 (metric ton/yr)	0.020
Total		**3.41**

Secondary Copper Processing

TABLE 7: SUMMARY OF LEAD EMISSIONS FROM SECONDAY COPPER PROCESSING

Estimate of 1999 Lead Emissions from Secondary Copper Processing in the Greater Cairo Area

Process	**Annual Production** (metric ton)	**1999 Lead Emissions** (metric ton)
Tilting Furnaces	1,320	0.66
Crucible Furnaces	14,760	7.38
Total	16,080	**8.04**

Portland Cement Manufacturing

TABLE 8: SUMMARY OF LEAD EMISSIONS FROM PORTLAND CEMENT MANUFACTURING

Estimate of 1999 Lead Emissions from Portland Cement Manufacturing in the Greater Cairo Area

Process	**Annual Production** (metric tons cement per year)	**1999 Lead Emissions** (metric ton)
Cement Kiln	~13,500,000	3.39
Total		**3.39**

Mazout Combustion

TABLE 9: SUMMARY OF LEAD EMISSIONS FROM MAZOUT COMBUSTION

Estimate of 1999 Lead Emissions from Mazout Combustion in the Greater Cairo Area

Process	**Annual Production** (metric tons mazout)	**1999 Lead Emissions** (metric ton)
Mazout Combustion	4,180,000	477
Total		**477**

Conclusions

The work described in this paper is the initial lead emissions inventory for the greater Cairo area. The study has developed the most comprehensive database of lead-emissions, related process data, and production data available at this time. The results of the study clearly show that secondary lead smelters, and in particular rotary furnaces at these facilities, are very significant sources of lead emissions within the area. Future updates to the emissions inventory will show the effects of ongoing efforts to reduce lead emissions in the greater Cairo area.

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Dr. Ibrahiem Abdel Gelil and Dr. Ahmed Gamal are responsible for administration of the CAIP within the EEAA. Mr. Glenn Whaley is the USAID technical representative for the project.

Acronyms and Abbreviations

μg	Micrograms
AP-42	A collection of emission factor data published by the USEPA that provides average emission factors for various pollutants from various sources. The AP-42 emission factors are frequently used to estimate emissions when site-specific emission data is not available.
CAIP	Cairo Air Improvement Project
CAPMAS	Central Agency for Planning, Mobilization, and Statistics
Cu	Copper
EEAA	Egyptian Environmental Affairs Agency
FIRE	Factor Information Retrieval System
GOE	Government of Egypt
GOFI	General Organization for Industrialization
hr	Hour
kg	Kilogram
l	Liter
m, m^3	Meter, cubic meters
mg	milligram
OEP	Organization for Energy Planning
Pb	Lead
Sec.	Secondary
USAID	United States Agency for International Development
USEPA	United States Environmental Protection Agency

References

[1-] The Merck Index*: An Encyclopedia of Chemicals, Drugs, and Biologicals*, 10th ed. Rathway, New Jersey: Merck and Company, Inc., 1976. p. 776.

[2-] Greninger, D., V. Kollonotsch, and C. H. Kline (Charles H. Kline & Co., Inc.). *Lead Chemicals*. New York, New York: International Lead Zinc Research Organization, Inc. (ILZRO), 1975.

[3-] Office of Air Quality Planning and Standards, Office of Air and Radiation, U.S. Environmental Protection Agency, *Locating and Estimating Air Emissions from Sources of Lead and Lead Compounds*. Research Triangle Park, North Carolina. May, 1998.

4- Cabinet of Ministers, Egyptian Environmental Affairs Agency, Technical Cooperation Office for the Environment, *Lead Smelting in Egypt-Baseline Study (Private Lead Smelters in Greater Cairo)*. Cairo, 1996.