Longitudinal Study to Monitor Blood Lead Level Reduction in 0 to 15 year Old Children Residing at a Large Community Near a Lead Smelter in Mexico

THESIS

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ABSTRACT

Chronic exposure to environmental lead may cause persistently high blood lead levels (Blood Lead Level) and bone lead levels with high risk to develop long-term impairments in intellectual function including reduced cognitive capacity and abnormal behavior in the absence of observable changes in brain morphology or gross neurological deficits. Therefore, the overall objective of this project was to analyze the Blood Lead Levels in children chronically exposed to environmental lead and effects of environmental remediation on it. Blood samples from children living near the smelters were analyzed over a period of 13-years, from 1999 to 2011. Approximately 65,000 children tested positive for lead with Blood Lead Level as high as 83.8 µg/dl. Throughout these years, as the environmental health and community health programs were implemented, a successful gradual reduction of Blood Lead Level was observed. However, in April 2012 approximately 367 children's Blood Lead Level remained lower than 15 µg/dl (Category II = 10 to 14.9 µg/dl), and 154 children remained in category III (Category III = 15 to 24.9 µg/dl) and these children are under medical care and environmental surveillance. A recent review of literature revealed that low Blood Lead Levels may cause neurobehavioral abnormalities in developing young. Thus continuous medical and toxicological assessment of children is recommended to detect early toxicological, neurological and behavioral abnormalities.

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FOREWORD

The present thesis is the result of a unique experience from 1999 to 2011 as toxicology consultant on children and chronic environmental exposure to lead at a community located in close proximity to the lead smelter in Mexico. I have collaborated with an extraordinary and dedicated group of professionals from diverse backgrounds, working together to protect children's health and the environment. Our primary goal were (1) to protect health and safety of children residing near the lead smelter and (2) to clean the environment within the 2 km perimeter from the lead smelter at Torreon Coahuila Mexico.

On November 1999 I was invited by the Secretary of Health of the State of Coahuila, Mexico to help them on an environmental health problem that was affecting children and their communities located near to a lead smelter at the city of Torreon Coahuila. I was asked to arrange a symposium on entitle "Lead" for the healthcare providers and government authorities, health and safety personnel from the smelter, community members, and the local media. The symposium included lectures on physicochemical characteristics of lead, environmental standards, laws and regulations, environmental pollution, exposure pathways, toxicokinetics, health effects, children and lead poisoning, epidemiology, surveillance programs, risk assessment and risk management, as well as diagnosis and treatment of lead poisoning.

In November 1999 I started working as medical toxicology consultant for the smelter, assisting the Department of Health. A new unit of Environmental Health ("Unidad de Salud Ambiental") was established to provide healthcare services and environmental protection to the children and their families, especially providing cleanup/decontamination of houses when children's blood lead concentrations exceeded 10 µg/dl. The data presented in this thesis are from children and their families living near the lead smelter.

INTRODUCTION

This is a longitudinal study on environmental lead and in children aimed to decipher the extent of lead exposure and measure the rate of reduction of blood lead levels from children residing in close proximity to the largest lead smelter in Latin America. This investigation contains 13-year follow up screening Blood Lead Levels data from 65,000 children from 1999 to 2011 from the Environmental Toxicology Program developed to protect children with chronic environmental exposure to lead at Torreon Coahuila Mexico. The problem of environmental exposure to lead at Torreon Coahuila Mexico garnered national and international attention, possibly due to the public health risk, the misinformation regarding toxicity of lead, and the large number of children exposed. (Benin, 1999) The lead-silver smelter Met Mex Peñoles, the largest lead smelter in Latin America, started smelting operations in 1901, and by 1907 was located 15 miles away from a small village known as Torreón ("Villa de Torreon"): (AGEC. 2009, History of Peñoles, 2007; UIT, 2009). By 1972, the surrounding areas near the smelter were invaded and occupied by illegal settlers (squatters), beginning the development of a new community (Peñoles, 2007). The population did not respect the buffer zone and started to get very close to the smelter.

From 1999 to 2011, blood samples were collected and analyzed data from Blood Lead Levels collected from approximately 65,000 children 0 to 15 years old residing within 5 km perimeter from the smelter's main chimney. For this purpose a unit of Unit of Environmental Health was developed, financed by Met Mex Peñoles, working in coordination with the local Department of Health of Torreon Coahuila. An active surveillance and epidemiology program was created to monitor Blood Lead Levels and Children's Health, the program included all children living within the perimeter of the smelter's main smoke stack. Blood samples were collected from approximately 65,000 children. The samples were analyzed for lead concentrations prior to and after initiation of environmental remediation. The data entered on a daily basis into an EXCEL database. In the present study, we have analyzed the data to determine the extent of lead problem and effects of remediation on Blood Lead Levels in children.

BACKGROUND INFORMATION

I. TORREON COAHUILA MEXICO

The city of Torreon in the State of Coahuila, located 550 Km from the US-Mexico Border at the center of Northern Mexico, a State bordering with the State of Texas. (Figure 1) The city of Torreon together with the neighboring cities of Gomez Palacio and Lerdo Durango form the Metropolitan area known as "La Lagunera" with an estimated population of ~1,000,000 inhabitants.

In 2005 Torreon population was 548.723 inhabitants (INEGI 2005), from which approximately 11% (61,229 people) live on the 37 colonias within 5 kilometer perimeter around the smelter (USA, 2005, Figure # 2). Torreon is considered the ninth-biggest metropolitan area in Mexico, and one of the most important economic and industrial centers of Mexico. The municipality of Torreon covers 1,947.7 km^2 including much of the rural area south of the city. The elevation is over 1,000 meters above the sea level (~3,280 ft). When the smelter Met Mex Peñoles started its operations it was located 15 miles away from the Village of Torreon, and by 1970's due to government corruption the land near the smelter was invaded developing a new community in very close proximity to the smelter (Figure # 2). The 37 Colonies were developed within the 5 Km perimeter with an estimated population of 61,183 inhabitants (Unit of Environmental Health-USA, 2006 Report, & Figure # 2). On Figure # 3 we show the map of 37 Colonias and their geographical location within the 5 kilometers perimeter around the smelter.

Figure # 1: Maps of Mexico & Coahuila: Torreon is located southern in state of Coahuila, ~ 550 Km from the US-Mexico Border on the US-Mexico border with Texas. It's considered the largest metropolitan area of Coahuila.

When the smelter Met Mex Peñoles started its operations it was located 15 miles away from the Village of Torreon, and by 1970's due to government corruption the land near the smelter was invaded developing a new community in very close proximity to the smelter. (Figure # 2).

Figure # 2.- Aerial Figure #s of the smelter Met Mex Peñoles on 1972 (left) and 1999 right). On the early 1970's the perimeter of the smelter with no communities, and by 1999 communities grew up in close proximity to the smelter

The 37 Colonias are located within the 5 Km perimeter (Figure # 3), with an estimated population of 61,183 inhabitants (Unit of Environmental Health (USA, 2006 Report). First circle is 1 Km, 2^{nd} is 2 km and 3^{rd} circle is 5 km. However, the estimated population within the 5 Km perimeter is over 100,000 inhabitants. Under Figure # 3 we show the list of Colonias and their Divisions, from Division A to Division L, and their geographical location within the 5 kilometers perimeter from smelter main smoke stack.

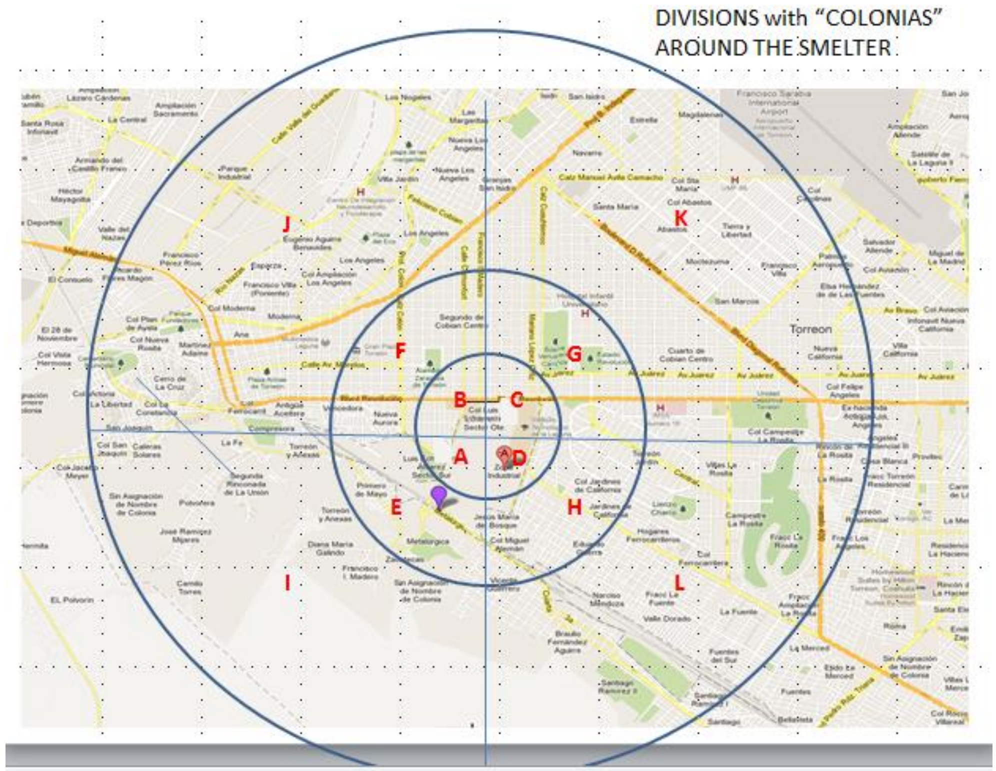


Figure # 3.- Map of Geographycal Location of Colonias: Showing the geographical location of the 37 "Colonias around the lead smelter. These areas were found to have high levels of lead in soil, and children with elevated blood lead levels. The three 3 circles represent perimeters of 1, 2 and 5 kilometers from the smelter's main smoke stack.

*There are 4 colonias located at Divisions: A,B,C, & D, within 1 Km from the smelter: Luis Echeverria 1, Luis Echeverria 2, Lucio Blanco and Miguel Alemán. There are 15 Colonias located at Divisions E, F, G & H within 2 Km radius from the smelter: Zacatecas, Nuevo México, Justo Sierra, Torreón y Anexas, Primera Rinconada, Nueva Aurora, Vencedora, Antigua Aceitera, Compresora, José Lopez. Portillo, Centro, Jardines de California, Eduardo Guerra, Vicente Guerrero & Jesús Ma. del Bosque), and 17 Colonias located in Divisions I, J, K & L.: Camilo Torres, Fsco I. Madero, Buenos Aires La Polvorera, José Ramírez , Nueva Creación, Morelos, Diana Maria Garcia, 2ª, Rinconada de la Union, La Fe, Lázaro Cárdenas Santiago Ramírez, Braulio Fernández Sierra de las Noas, Hogar Ferrocarril, Narciso Mendoza, and Ampliacion Lazaro Cárdenas.

II. HISTORY OF THE LEAD SMELTER “MET MEX PENOLES

The lead smelter Met Mex Peñoles (initially known as “Mining-Smelting and Refining Corporation of Monterrey S.A”) started its smelting operations in the early 1890’s. It was located several miles away from a small village known as Torreón near Durango Mexico. On 1908 the Figure # of urban development established the industrial area with a safety perimeter of land around the smelter, a buffer zone, (Figure # 4) to prevent human settlements near the smelter in order to prevent environmental exposure to fumes to the community.

Figure # 4: Map of Torreon from 1908 and the smelter areas showing a “buffer zone”. The smelter is located at the blue star. It was located away from the community.

In 1969 the metallurgic operations became part of the new corporation named “Met-Mex Peñoles, S.A. de C.V”, and currently Met Mex Peñoles S.A. de C.V. is still smelting and refining lead, silver and zinc. The industrial area also have plants of sulfuric acid, oleum, ammonium sulfate and liquid sulfur dioxide aimed for the fixation of sulfur to usable products, as well as to abate sulfur releases into the atmosphere. To reduce water consumption from underground aquifers, the industrial area also has two waste industrial and municipal water treatment plants.

Peñoles is the second most important mining corporation in Mexico, it's the main producer of silver, lead, and bismuth with an annual production of silver of 1.1 million ounces, and 200,000 metric tons of lead, it's the main producer of refined gold and zinc in and lead and sulfuric acid Mexico. In the early 1970's the surrounding areas from the smelter were invaded by squatters, this illegal human settlement was supported by politicians, activist groups and civil organizations. (Figure #s 5.3 & 5.4) The community grew up and a result the government gave legal possession of the land to home owners and developed urban infrastructure, the area was divided in 37 neighborhoods known as "colonias") .

III. THE LEAD SMELTER AND CHILDREN's BLOOD LEAD LEVELS

The main priority of the Toxicology Program from the Environmental Health Unit and the Department of Health was to lower the Blood Lead Levels of children by (i) identifying and controlling all sources of emissions and sources of exposure to lead, (ii) developing strategies for environment cleanup and remediation and (iii) developing community health programs with community participation. To achieve the priority, international experts were hired by the smelter company to help on this endeavor, as well as to investigate and eliminate/reduce other important sources of exposure to lead in Mexico. However, there were a number of complications: (i) the lack of effective laws and regulations and (ii) poor to no enforcement of existing ones. Leaded Gasoline was banned in Mexico by the end of 1998, lead from gasoline remained on side roads and streets (Gleeson, 2008). Also, there was lead pottery (Azcona , 2000; FDA, 1992; Fernandez 1997; Lµgo, 2000), contaminated candies and wrapping (CDC, 2002; FDA 1995), canned food, lead paint, and folk remedies (Baer, 1998; (CDC, 1993, 2002; Krebs NF. 2001) as well as other sources of exposure (Cowan, 2006; Hurtado, 2008; Namihira, 1993; Serrato, 1996). There was a need to develop a comprehensive plan to reduce exposure by convincing the government officers to develop better regulations, educating the community to follow the laws, developing environmental cleanup programs both indoors and outdoors and implementing nutrition and hygiene improvement programs.

In 1999, Met-Mex Peñoles complied with the Mexican Law and regulation on Lead Air Emissions (NOM 199, 1993), lowering Lead air emissions to less than1.5 $\mu g/m^3$ of lead in air. Starting from 1999, the smelter company made remarkable progress improving the environmental protection, increasing safety and filtration environmental equipment, taking care of environmental control and community environmental health protection. The smelter company built several warehouses to keep the processes of lead production indoors (Figure # 5), improving handling materials, increased abatement system capacity, improving all processes of lead production and filtration capability to comply with international standards. All of these measures contributed to control all emissions to the atmosphere and lower Blood Lead Levels. An unprecedented scale of community cleanup, monitoring and health surveillance has contributed to a substantial reduction in the blood lead levels of children in the adjacent community. All sources of emissions of lead were controlled. Met Mex Peñoles showed great social responsibility to protect people and the environment (FIGURE # 5 & 6).

Figure # 5: Aerial Photo of the Smelter: Development of warehouses: > 45,000 ^{3}m were built keep all processes of lead production encapsulated to prevent fugitive emissions of lead particles to the atmosphere, keeping air emissions under control.

Environmental protection inside the smelter became a priority and all processes were reviewed and improved to include filtration capacity inside the smelter plant which was increased more than 3 million ^{3}m per hour. Also, more warehouses were built to control the process zinc concentrates preventing releases of lead at the zinc plant and at the secondary processes, increasing and improving houses of bags and electrostatic precipitator keeping dust particles and fumes inside the smelter plant (FIGURE # 6). All of these environmental protection actions inside the smelter plant concomitantly with environmental cleanup and community interventions contributed to:

i). to have a complete control of emissions of lead and other particles to the atmosphere

ii). to lower the exposure to environmental lead; and

iii). consequently to reduce Blood Lead Levels on children and the rest of the community.

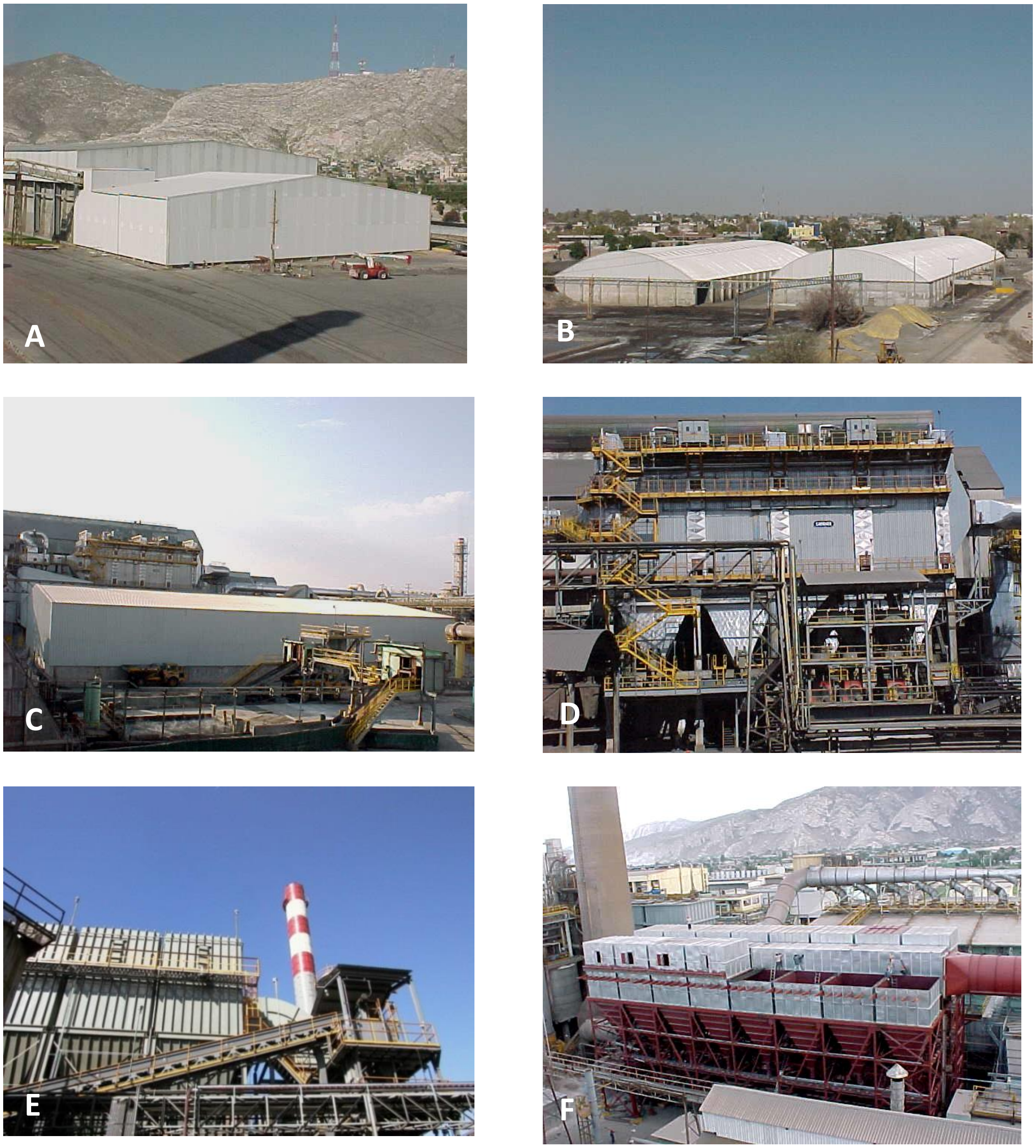


Figure # 6: Control of air emissions: New Technology implemented to control all emissions of lead from the smelter by making structural and technology changes. A: Warehouse to Process Zinc Concentrates, B: Warehouses to Process Secondary Processes, C: New Filtration Equipment at Cold Sintering Area, D: Modern Electrostatic Precipitator, E: Increasing the House of Bags to capture particles and F: House of Bags. All filtration systems filter more than 3 million^{3m} per hour.

LEAD TOXICITY

Lead is a heavy metal extensively used by industry with multiple uses and applications in our daily life (ATSDR 2007; Mindat 2008) It was one of the earliest metals discovered by humans and has been used for thousands of years because it's abundant, easy to extract and easy to work. The Roman Empire used lead to manufacture water pipes and lining baths, and the plumber who joins and mends pipes (Lewis 1985; Cramb, 2009). The name lead comes from the Latin word plumbum, meaning lead. The term Plumbum is also the origin of the terms 'plumb bob' and 'plumb line,' used in surveying, it's also the chemical symbol for lead, Pb. (Heskel, 1983, & Table # 1)

Lead has been used extensively and despite its innate toxicity lead has been an important element that has supported human civilizations through the development of tools and machinery like many other heavy metals that helped to improve the quality of life and supported the advancement of our civilization (Wikipedia 2013)

During 19^{th} and 20^{th} century up to the early 1980's there was an steady increase in production and use of lead aimed to support technical, industrial social and economic growth. This resulted in an increase exposure of humans to lead and ensuing increase in Blood Lead Levels worldwide. Emission from Industrial and automobile further polluted the environment. From 1970's to the beginning of the 21st century, the development and application of federal laws and regulations proposed by the United States Centers for Disease Control and Prevention made possible to overturn this trend. (CDC 2007) Some of the major accomplishments in reducing lead from the environment worldwide were due to the elimination of leaded gasoline, banning of the use of lead paint, banning the use of lead in food packaging and soldering, eliminating the use of lead in water pipes for human and animal consumption, and other plumbing components. (ATSDR, 2007, CDC 1993, 2007; Hilts SR, 2003; Kim, 2008; Meyer, 2003; Oyana, 2007) From 1976 to the late 1990's, there was an amazing reduction of Blood Lead Level in children in the United States demonstrating that federal laws and regulations were effective (Boreland, 2008 ;Bornschen, 1985; CDC, 2007; Ranft 2008) However, as the environmental lead concentrations declined, researchers decreased the minimum dose required to cause toxicity from 10 µg/dl to 1µg/dl. (Singh and Ashraf (1989), Singh (1993), Singh and Jiang (1997ab)

Table # 1.-: Physico-Chemical Characteristics of Lead

Atomic Symbol	Pb
Atomic Number	82
Atomic Weight	207.2
Electron Configuration	32-18-4
Melting Point	621.3°F (327.4°C)
Boiling Point	~ 3,180°F (1,749°C)
Density	11.37 g/cm^3
Physical Characteristics	Lead is a bluish-white metal of bright luster, it's very soft, highly malleable, ductile, and a poor conductor of electricity, very resistant to corrosion.
Sources	Mining is the main source and are more abundant in some regions of the planet. It's mostly obtained by a roasting process from galena (lead sulfide; PbS (86.6% lead)), anglesite (lead sulfate; $PbSO_4$), cerussite (lead carbonate $PbSO_3$), and mimetite (Arsenate of Lead: $Pb_5(Cl)AsO_4)_3$) Lead is found in combination with other elements such as zinc, silver, arsenic copper, gold and other elements. Currently 15-20% of lead comes from recycling lead batteries, and scrap metal.
Uses	Lead is used in thousands of applications. The most important is Lead Batteries (Acid-Storage Batteries). Also it's used to make bullets for fire arms, fishing sinkers, weights, lead-glass, solder, fusible alloys, radiation shields, ceramic glazes, stained glass, ballasts, electrodes, coats for electrical cords, coolant in molten lead, lead-base semiconductors, building construction, etc.
Production (Largest worldwide producers)	Australia, China, United States, Peru, Canada, Mexico, and Sweden. United States is the 3rd largest producer; with ~ 450,000 tons in 2003 (U.S. Geological Service 2004).Mexico is the 6th Largest Producer of Lead.

*Source: ATSDR; Griffit, 2002; Mindat 2008; WES 2008

The increased production and industrial use of lead during the 19th and 20th centuries resulted on increased blood lead levels worldwide and have been directly related to the industrial and economic growth (ATSDR, 2007) From the 1800's to the early 1980's Blood Lead Levels continued rising worldwide due to industrial and automobile emissions resulting on severe environmental pollution. By the early 1970's the United States Centers for Disease Control and

Prevention overturned the trend that allowed a substantial reduction in children demonstrating that federal laws and regulations were effective. Most of these regulations have been applied in other countries worldwide resulting also on a substantial reduction of Blood Lead Level in children (ATSDR, 2007).

Major environmental regulatory and environmental health protection agencies around the world approved laws to lower Blood Lead Level during the last two decades. Some of the laws included banning the use of lead paint in households and facilities where children are present, eliminating leaded gasoline, banning the use of lead in food wrapping and packaging, children toys and furniture, and the elimination of lead soldering in water pipes, joint soldering and other plumbing components. As a result from 1976 to the early 1990's there was an amazing reduction of Blood Lead Level in children in the United States and other countries (ATSDR, 2007; CDC, 2002, 2003, 2007)

I. Lead Toxicokinetics

Lead can be absorbed through the lungs, digestive tract and skin. Dermal absorption is very poor compared to inhalation or ingestion (James, 1994; Cassarett, 2006; Goldfrank, 2008). The quantity of lead absorbed depends on individual characteristics such as age, and the physicochemical characteristics of the lead such as particle size (Ruby, 1999). Absorption in the gastrointestinal tract is higher in children than adults. Children absorb 40 to50 % of an oral dose of water-soluble lead compared to adults who absorb only 3 to 10% (ATSDR, 2007; Binns, 2007; CDC, 2007; Levin, 2008; Mahaffey, 1983). Very small particles (Nanoparticles) of lead can be almost completely absorbed throμgh the respiratory tract whereas larger particles may only be swallowed (Chamberlain 1978; Hursh 1969; James AC et al, 1994; Wells, 1975).

The main site of gastrointestinal absorption of lead is the duodenum by a saturable mechanism (James HM et al , 1985; Pocock, 1983; Sherlock, 1982, 1984, 1986). In adults and children, approximately 94% and 73%, respectively, of the total body burden is deposited in the bones. In blood lead is also deposited in erythrocytes (Cassarett 2006). Some conditions i.e. pregnancy, lactation, menopause, and osteoporosis increase bone absorption of lead. Also, lead is transferred from the maternal blood to the fetus and from the mother to infants via maternal milk.

Gastrointestinal absorption of water-soluble lead is higher in children than in adults, studies conducted in infants and children (ages 2 weeks to 8 years) indicate that ~ 40–50% of ingested lead is absorbed (Alexander, 1974; Ziegler, 1978). Children with iron deficiency have higher blood lead levels than children with normal iron serum levels. Iron deficiency result in higher absorption of lead or, possibly, other changes in lead kinetics that would contribute to lower Blood Lead Levels (Mahaffey, 1986; Marcus, 1987). Also, ingestion of dietary calcium in normal nutrition appears to affect lead absorption. An inverse relationship has been observed between dietary calcium intake and blood lead levels in children,

children who are calcium, iron-deficient may absorb more lead than calcium-and iron replete children (Mahaffey, 1986; Watson et al, 1986; Ziegler, 1978). Lead absorption in humans may be a capacity limited process, in which case, the percentage of ingested lead that is absorbed may decrease with increasing rate of lead intake. Studies to date, do not provide a firm basis for discerning if the gastrointestinal absorption of lead is limited by dose. Numerous observations of nonlinear relationships between blood lead concentration and lead intake in humans provide support for the existence of a saturable absorption mechanism or some other capacity limited process in the distribution of lead in humans (Sherlock 1984, 1986).

The amount and rate of gastrointestinal absorption of ingested inorganic lead are influenced by physiological states of the exposed individual (e.g., age, fasting, nutritional calcium and iron status, pregnancy) and physicochemical characteristics of the medium ingested (e.g., particle size, mineralogy, solubility, and lead species). Lead absorption may also vary with the amount of lead ingested. (Ziegler 1978)

Particle size influences the degree of gastrointestinal absorption (Ruby et al. 1999). In rats, an inverse relationship was found between absorption and particle size of lead in diets containing metallic lead particles that were ≤250 μm in diameter (Barltrop, 1979). Tissue lead concentration was a 2.3-fold higher when rats ingested an acute dose (37.5 mg Pb/kg) of lead particles that were <38 μm in diameter, than when rats ingested particles having diameters in the range of 150– 250 μm (Barltrop and Meek 1979; Peijnenburg et al, 2007). Dissolution kinetics experiments with lead-bearing mine waste soil suggest that surface area effects control dissolution rates for particles sizes of <90 μm diameter; however, dissolution of 90–250 μm particle size fractions appeared to be controlled more by surface morphology. (Davis,1990).

Deposition & clearance of lead from the respiratory tract have been measured in humans (Chamberlain, 1978; Hursh 1969, 1970; Morrow, 1980). Humans were exposed to lead particles with median aerodynamic diameters (MMAD) less than 1 μm. The inhaled lead particles are initially dispersed in the bronchiolar and alveolar regions of the respiratory tract and then transported, larger particles and moved out by mucociliary clearance, transported to the laryngopharynx and ingested by the gastrointestinal tract (Hursh, 1969). Approximately 95% of deposited inorganic lead that is inhaled as submicron particles is absorbed (Hursh, 1969; Wells, 1975). The rates of clearance (measured as the half- life) of inorganic lead, inhaled as submicron particles of lead oxide, or lead nitrate, were 0.8 hours (22%), 2.5 hours (34%), 9 hours (33%), and 44 hours (12%) (James et al 1994; Chamberlain, 1978). Althoμgh possible cause for variations in the results is not known, different studies have used different lead doses and experimental designs. The biological half-life of lead in blood has been estimated in ~ 28 days to 36 days (Casarett 2006, ATSDR 2005; ATSDR 2007). Approximately 99% of lead in blood is attached to red blood cells; the remaining 1% remains in blood plasma. (ATSDR, 2007; DeSilva, 1981). Bones and teeth of adults contain about 94% of their total lead body burden; in children, is approximately 73%. (Barry 1975 as cited in ATSDR 2005). Lead in mineralizing tissues is not uniformly distributed. It tends to accumulate in bone regions undergoing the most active calcification at the time of exposure, the estimated half-life in bones is ~25 years (Rabinowitz 1991, ATSDR 2007) In the body lead is metabolized with formation of complexes with proteins and non-protein ligands. Organic lead compounds are metabolized in the liver by oxidative dealkylation by P-450 enzymes. (Rabinowitz, 1973, 1974) Regardless of the route of exposure lead is excreted primarily in urine and feces. Other minor routes of excretion are sweat, saliva, hair, nails, and breast milk. Figure # 7 shows that lead distribution in body have a two compartment model: a central or blood compartment and peripheral soft-tissue an initial short half-life of approximately 28 days, followed by a long half-life of approximately 10,000 days in bones and other regions from connective tissue.

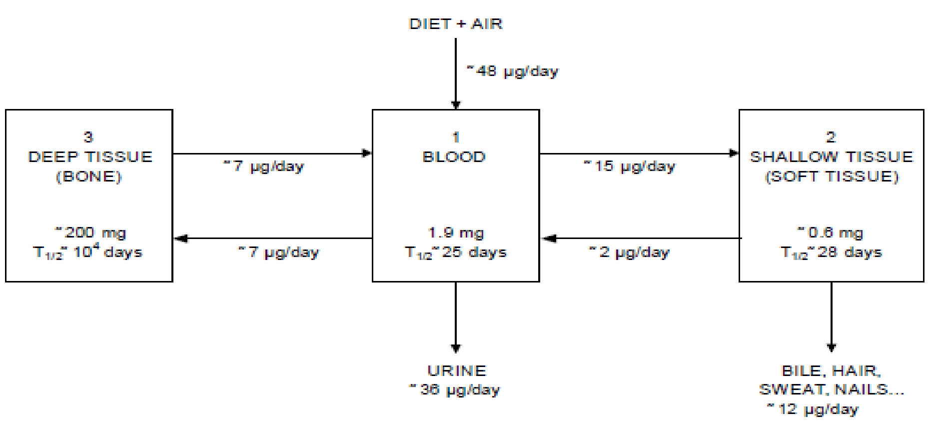


Figure # 7.- Lead Metabolism Model: Schematic model for lead kinetics.
Source: Rabinowitz et al. 1976, ATSDR Toxicological Profile for Lead, 2007.

Compartments representing different organs or groups of organs that share a similar characteristic were defined as volumes, or pools, that are kinetically homogeneous. The body could be represented by a central compartment (e.g., blood plasma), and one or two peripheral compartments, which might be “shallow” or “deep” (i.e., they may exchange relatively rapidly or relatively slowly with blood plasma) (O'Flaherty 1987). One of the first of such models was proposed by Rabinowitz in 1976 based on a study of the kinetics of ingested lead isotope tracers and lead balance data in five healthy adult males. The Rabinowitz model includes three compartments: a central compartment representing blood and other tissues and spaces in rapid equilibrium with blood (e.g., interstitial fluid); a shallow tissue compartment, representing soft tissues and rapidly exchanging pools within the skeleton; and a deep tissue compartment, representing, primarily, slowly exchanging pools of lead within bone (Jameson et al 1997; ATSDR Toxicological Profile for Lead, 2007).

II. Health Effects

Lead exposure causes multiple adverse health effects, including hematologic, neurological and neuropsychiatric problems, reproductive effects and even death (CDC, 2003; 2007; Binns, 2007). Health effects have been studied and reported in scientific journals and numerous publications on the toxic effects due to chronic exposure to lead and clinical manifestations in children exist (Baranowska-Bosiacka, 2012; Fox, 2012; Luo, 2012; Senut, 2012; Smith 1983; Some of the clinical signs most frequently reported were developmental problems, weight loss, weakness, anemia and neuroconductal deficiencies, among others (ATSDR 2007, Casarett 2006). Throughout the years many publications report that is no correlation between Blood Lead Levels and clinical effects (ATSDR 2007, CDC, 2007, Casarett 2006)

Recent publications have reported that even at low levels lead exposure may affect children's intellectual development. Since the early 1980s several studies reported that there is a direct relationship between Blood Lead Levels <10 μg/dL in children 1–5 years of age with decreased IQ and cognition, a recent study (Jusko et al 2008) reported that damages may occur at levels as low as 2 μg/dL, and the truth is that there are no threshold level values (Brent 2004; Bruening 1999; CDC 2007).

Many countries worldwide adopted the goal of reducing all exposures to lead and eliminating elevated blood lead levels greater than 10 μg/dL. The United States planned to eliminate Blood Lead Levels >10 μg/dL in children by 2010 (U.S. Department of Health and Human Services 2000) (ATSDR 2007; CDC 2007 & FIGURE # 8).

Hematological Effects: Microcytic and hypochromic anemia results primarily from both inhibition of heme synthesis and reducing the erythrocyte lifespan. Lead interferes with heme synthesis by altering the activities of δ-aminolevulinic acid dehydratase (ALAD) and ferrochelatase (Casarett 2006; ATSDR 2007). Nevertheless, anemia is also associated with low level of trace elements such as iron, zinc and copper (Hegazy 2010). In children, exposure to lead has been shown to inhibit formation of the heme-containing protein cytochrome P-450, as reflected in decreased activity of hepatic mixed-function oxygenases. (ATSDR 2007)

Cardiovascular effects may include lowering glomerular filtration rate may contribute to elevation of blood pressure (Schwartz 1995; Staessen et al. 1994) may predispose people to glomerular disease. Other cardiovascular changes include cardiac conduction and rhythm changes (ATSDR 2007)

Gastrointestinal Effects such as colic is an abdominal pain that has been reported with levels greater than100 µg/dl in occupationally exposed workers, and it's accompanied by constipation, cramps, nausea, vomiting, anorexia, and weight loss Colic is a consistent early symptom of lead poisoning in occupationally exposed cases or in individuals acutely exposed to high levels of lead. (ATSDR 2007)

Renal Effects: Lead nephrotoxicity causes proximal tubular nephropathy, glomerular sclerosis and interstitial fibrosis. Chronic exposure to lead affects kidney where it can produce lead nephropathy described as chronic interstitial nephritis. High Blood Lead Levels are reported to cause lead nephropathy which is now rare to observe, particularly in developed countries. Renal function is affected causing enzymuria, low- and high-molecular weight proteinuria, impaired transport of organic anions and glucose, and depressed glomerular filtration rate, some reports have revealed histopathological changes of renal injury in humans, including intranuclear inclusion bodies and cellular necrosis in the proximal tubule and interstitial fibrosis (Biagini et al. 1977; Wedeen et al. 1975, 1979).

Reduced glomerular filtration rate (i.e., indicated by decreases in creatinine clearance or increases in serum creatinine concentration (Cramer et al. 1974).

Occupational studies provide evidence for an association between high exposures to lead and changes in thyroid, pituitary, and testicular hormones (ATSDR 2007). Some data, mainly results of tests of hormonal stimulation suggest that the changes in thyroid and testicular hormones are secondary to effects of lead on pituitary function. Decreases in serum T4 were found in studies of workers with very high PbB (Cullen, 1984). Decreases in serum T4 were found in studies of workers with very high PbB (Cullen, 1984). No significant effects of lead on thyroid function have been found in children, but the number and/or quality of the available studies do not allow drawing firm conclusions.

III. Neurotoxicity and Neurocognitive Damage

High Blood Lead Levels causes neurological and developmental effects in children (ATSDR, 2007; Bellinger D, 1988; Al-Saleh, 2008; Cleveland, 2008; Ernhart T, 1992; Ernhart CB 1992 & 2005, Greene et al , 1991; Kotok 1997; Ruff et al, 1996). During the past 30 years there have been numerous studies regarding children and chronic environmental exposure to lead explaining that Blood Lead Levels greater than 10 µcg/dl were harmful for children (CDC 2007). Recently, studies reviewed the probability that low environmental exposure to lead cause neurological, neurocognitive and intellectual damage to children (Lanphear BP, 2005; Jusko TA, 2008). Low level lead is not safe for children and may be harmful enough to cause neurological damage and other and neurocognitive effects. These studies proposed that a Blood Lead Level<10 μg/dl is not safe for children particularly in during early stages of development such as embryonic and fetal stages, to neonates, lactants and children younger than 5 years old. (Al-Saleh 2008; Cleveland 2008; Ernhart 1992; Ernhart 1990,1992; Kaiser 2008)

Neurobehavioral effects in children have been studies extensively. Recent studies suggest that there may be no threshold for the effects of lead on intellectual function. (Koller et al. 2004; Needleman 2004). Asymptomatic children with long-term lead exposures and average maximum PbB of 68 μg/dL (average PbB level, 51–56 μg/dL versus 21 μg/dL in the control group) had an average decrement of 5 IQ points on the McCarthy General Cognitive Index.

Low lead level may also impair the intellectual function; Some studies that have reported cognitive impairments associated with low lead exposure include Al-Saleh et al. (2001), Bellinger and Needleman (2003), Carta et al. (2003), Emory et al. (2003), and Shen et al. (1998). Although individually all of these studies have limitations, collectively, they support the association between low blood lead and intellectual impairment in children. Recent studies support the view that there is no apparent threshold in the relationship between lead and neurobehavioral functions (ATSDR 2007). No threshold for the association is evident in the range of routinely measured blood lead levels. On the basis of this review, the working group concluded that the inverse association between children's blood lead levels and children's cognitive function that has been observed in populations of children with higher blood lead levels is also present in populations of children with measured blood lead levels less than 10 µg/dL. (CDC 2007)

IV. Laws and Regulations on Lead control in Mexico

By 1999 there were no regulations on Blood Lead Levels in Mexico. Since 1971 Mexico followed the Center for Disease Control (CDC) guidelines and matched, adapted and applied the laws and regulations approved by the CDC (Mexican Official Norms) but without enforcing them. After 1999 new regulations were created to limit Blood Lead Levels and reduce the non-occupational exposure to lead aimed to protect children and pregnant women (NOMs 016; 147, 199 & 231). The regulations were aimed to prevent, reduce and eliminate exposure to lead in order to prevent adverse health effects in children (Mexican Official Norm # 199, NOM-199-SSA1-2002). This law states the maximum "acceptable as normal" Blood Lead Level to be lower than the 10 µg/dl.

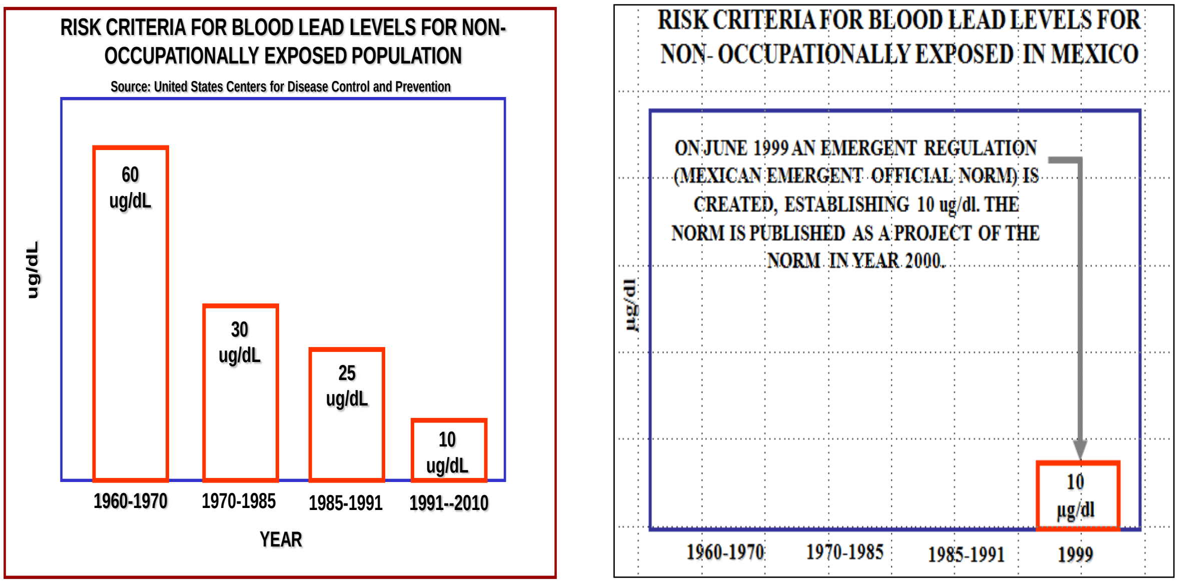


Figure # 8.- Blood Lead Levels Reference Criteria (1960's to 2010) from CDC to show evolution of acceptable Blood Lead Levels in USA and Mexico. In Mexico there was no standard or laws until year 1999 when Mexico established a law matching the CDC criteria for Blood Lead Levels (NOM 199, 2002). Until 1999 Mexico adopted the CDC criteria of acceptable NORMAL" Blood Lead Level of 10 µg/dl

V. Lead Toxicity Studies Performed in Mexico

Numerous studies describing the sources of exposure to lead and its health effects have been published in Mexico (Hernandez 2003, Serrato 1996, Azcona 2000, Borja 1999, Flores 2004, Hernandez 2003, Kordas 2007, Namihira 1993, Romieu 1994, Rothemberg 1993, Schnaas 2004, Fernandez 1997, Carrisales 2005, Yáñez 2003, Albalak 2003, Albert 1991, Benin 1999, Garcia 2001, Lµgo 2000, Mendez 2008, Pineda 2004, Alvarez 1997, Cowan 2006, and Diaz-Barriga 1997). Environmental exposure to lead has continued in Mexico due to deficiencies in human capacity and enoµgh technical and logistic support to enforce the laws and regulations. In addition, poverty in many areas of the country, poor social conditions and lack of education allows exposure to lead and other heavy metals (Borja-Aburto et al 1999, Bornschein 1985, & Bornschein et al 1985; Levin R, 2008; Ortega-Ceseña 1993; Scchnaas, 2004).

Althoμgh Mexico banned the use of leaded gasoline during the early 1990s, it was not until 1998 when leaded-gasoline was completely removed from the market (Glesson, 2008), decreasing 90% of airborne lead concentrations in Mexico City (Schnaas, 2004). However, the lead-glazed pottery remained a significant source of population exposure (Azcona, 2000; Calderón-Salinas 1996, Hernandez-Serrato et al, 2003; Romieu, 1994). Previous studies have described presence of lead in non-occupationally exposed groups, including children, in the Mexico City metropolitan area.

Most of these studies were performed in children exposed to lead in urban communities due to leaded gasoline from automobile emissions, from glazed pottery, and via contaminated air near lead smelters (Carrizales, 2005; Diaz Barriga, 1997, Garcia 2001; Lugo, 2000; Manzanares et al 2006 Méndez-Gómez et al 2008;). The major pathways of lead exposure among the Mexican population are gasoline emissions, lead-glazed ceramics, leaded paint, lead in canned foods and beverages (Romieu, 1994; FDA, 1992; 1995), and Mexican folk remedies (Baer, 1988; CDC 1993). Most currently environmental lead exposure is related to inadequately controlled sources including ethnic remedies (i.e. azarcon & greta containing 80-90% lead oxide used to treat bad digestion in children), goods and consumer products, and food-related items such as ceramics (Levin R, 2008). In addition, lead also comes from historic contamination of soils from leaded gasoline, and industrial emissions, paint dust, and food packaging (ATSDR, 2007; EckeL 2001; Elhelu, 1995).

In Mexico, there was no regulation or standards for blood lead levels until 1999. During many years, there was very little to no awareness of chronic environmental exposure to lead and health risks for children at the community living near the lead smelter at Torreon, Mexico. The World Health Organization and the U.S. Centers for Disease Control and Prevention have established 10 µg/dl as the threshold level of concern in children (CDC 1991; WHO, 1998) However recent studies suggest that there is no safe level of exposure, speculating on the possibility that some health effects such as intellectual impairment could occur at Blood Lead Level < 10 µg/dL. According to the CDC Advisory Committee on Childhood Lead Poisoning Prevention these effects were very small, most likely, were influenced by residual confounding factors (CDC, 2002, 2003, 2004)

HYPOTHESIS, SPECIFIC AIMS AND OVERALL APPROACH

This longitudinal study on environmental lead and children is designed to understand the rate of Blood Lead Level reduction in children residing in close proximity to the lead smelter. This investigation contains a 13-year follow up screening of Blood Lead Levels data from an Environmental Toxicology Program developed to protect children 0 to 15 years old with chronic environmental exposure to lead at Torreon Coahuila Mexico. The overall objective of the present work was to analyze and study the trend of reduction of Blood Lead Level in children with chronic environmental exposure to lead and describe environmental health community interventions and environmental remediation/cleanup contributed to lower Blood Lead Levels in thousands of Children from these communities.

I. Hypothesis: Rate of reduction in Blood Lead Levels in children 0 to 5 years old is different compared with the rate for older children, 6 to 10 or 15 years old.

II. Specific Aims: This study consists of two specific aims described below.

1. To analyze the time-course of change in blood lead levels in children living near a lead smelter during 13-year follow up period. The pattern of change in Blood Lead Level will be determined in children of different age groups: new-born to 5, 6 to 10, and 11 to 15 years old.

2. To determine how environmental remediation and community environmental health programs helped to lower Blood Lead Levels in children residing near a lead smelter.

EXPERIMENTAL DESIGN

This is an observational and longitudinal cross-sectional study to measure Blood Lead Levels (Blood Lead Levels) and then compare the remediation-mediated rate of reduction of Blood Lead Level in children from 0 to 5, 6 to 10 and 11 to 15 years old residing near a lead smelter Met Mex Peñoles. The analysis was performed at different age groups and gender, i.e.: small children 0 to 5 years old, vs. 6 to 10 years old, 11 to 15 years old and older than 16 years old.

Human Subjects Safety: According with the federal regulations and NIH (National Institutes of Health) guidelines for the use of human subjects in health research, this study will comply with the specifications. This is not a clinical research, we analyzed numeric data related to Blood Lead Levels, no personal identifiers were used (no names, and no address) only numeric identification numbers were used for each individual. Also, because this study was performed in a population living in Mexico, we complied with the Mexican criteria of the Ethics Committee for Research (CEI: Comite de Etica en Investigacion - Secretaria de Salud).

The Overall Experimental Approach: For studying Blood Lead Levels in children over time, we selected children living in communities located within 5 kilometer perimeter from the smelter (considering the main lead smelter smoke stack). We also collected and analyzed environmental samples to assess efficacy of the environmental remediation and community education programs for both indoors and outdoors. The Environmental Health Unit (USA - Unidad de Salud Ambiental), developed and operated by the smelter Met Mex Peñoles is on charge of the epidemiological and screening programs reporting the State and Local Department of Health, reporting results every month, health education, health interventions on all children with Blood Lead Levels greater than 10μg/dl. The program is still on-going.

Data Collection: At the beginning of the program, we found many difficulties listed below.

(i) At the beginning there was low community participation because of their animosity against the Smelter Corporation, as well as against their local government and authorities due to corruption.

(ii) Political parties and activist groups involved were pursuing different social, economic and political interests.

(iii) Low educational levels, poverty, deficient urban services (potable water, trash recollection, some dirt roads and streets), scarce healthcare resources, cultural habits, poor hygiene and nutritional deficiencies contributed to the difficulties.

These problems were resolved gradually by communicating the goals of the study, especially by informing them of the benefits the children will have. Since 1999, data were collected in Excel. The purpose was to keep records from the Blood Lead Level (Blood Lead Level) screening program developed to monitor Blood Lead in all children residing within the 37 Colonias. A total of 215,540 blood lead levels were obtained, some individuals have only one test and very few have up to ~70 Blood Lead Level tests. Due to the complexity or the way data base was collected throughout 13-years, it was time consuming to cleanup of the database removing incomplete data (i.e. no age, no date of birth, no address, etc…). To analyze the rate of reduction of Blood Lead Level' we selected all children who had 4 or more years of follow Blood Lead Levels and were residents in one of the 37 neighborhoods (colonias) .

<u>Study Population</u>: The study population is children 0 to 15 years old residing within one of the 37 "Colonias". The total number of children included in this analysis is 13,197 children who started the Blood Lead Levels screening tests from 1999 to 2003. To do the calculation of rate of reduction per year we selected children who were followed for a minimum of 4 years and had at least four blood screening test during the period of follow up until 2011. Children were followed up until when they reached 15 years of age. The total number of blood

lead level samples from these 65,000 children range from 4 up to 74 tests per child and were followed from 4 up to 13-years. The average number of blood screening tests per child was 9.35 and the average time of follow up was 7.86 years.

Analytical Method: Blood was obtained following CDC standard method for Blood Lead Level testing (CDC. 2013 Guidelines for Collecting Blood). All blood lead levels were obtained from venous blood and analyzed with Graphite furnace atomic absorption spectrometry (GFAAS) PerkinElmer Model AANALYST 600. The Laboratory is certified by WSLH Proficiency Testing, and NMX-EC-IMNC-2006 / ISO 15189-2003 / Clinical Laboratories. Certificate No. 06CL0001.

Statistical Analysis of the data: The analysis of data was performed using SPSS Statistics Gradpack for windows. The initial part of the analysis of data was to remove records with errors (i.e. no age, no date, no address, etc.), then to select all children 0 to 15 years old residing within the 5 km perimeter from the smelter (living in one of the 37 neighborhoods ("colonias"), and select all children who had at least 4 years of follow up and had at least one Blood Lead Level test per year. Applying these selection criteria we ended up with 13,197 children, from which I have a total of 84,792 Blood Lead Levels. About 63.9% of children who were included in the study started when they were 5 years old or younger, 32.2% of children were 6 to 10 years old and 3.8 % started when they were 10 years and older. 51.1% were female and 48.1 were males (Table # 2).

Table # 2.- Gender of Study Population: 51.1 % of these children were females and 48.9% males, children younger than 15 years old from the total population residents from the 37 Colonias. 51.1% of children were females and 48.9 % males.

	Frequency	Percent	Valid Percent	Cumulative Percent
Female	6748	51.1	51.1	51.1
Male	6449	48.9	48.9	100.0
Total	13197	100.0	100.0	

During the 13 years period we had 13,197 children, 8439 children were 0 to 5 years old (63.9%), 4252 children 6 to 10 years old (32.2%), and 506 children 11 to 15 years old (3.8%). (Table # 3)

Table # 3.- Age when the FIRST blood lead level was obtained; 23.4% of Blood Lead Levels screening tests started in children at 1 years of age or less. And only 7.5 % of children less than 1 year old started Blood Lead Levels monitoring tests. The great majority, 92.6% of the first Blood Lead Levels test was performed in children from 0 to 8 to 9 years old.

Age	Frequency	Percentage	Valid Percent	Cumulative Percent
0	990	7.5	7.5	7.5
1	2102	15.9	15.9	23.4
2	1609	12.2	12.2	35.6
3	1367	10.4	10.4	46.0
4	1179	8.9	8.9	54.9
5	1192	9.0	9.0	63.9
6	1122	8.5	8.5	72.4
7	1080	8.2	8.2	80.6
8	898	6.8	6.8	87.4
9	680	5.2	5.2	92.6
10	472	3.6	3.6	96.2
11	285	2.2	2.2	98.3
12	128	1.0	1.0	99.3
13	43	0.3	0.3	99.6
14	35	0.3	0.3	99.9
15	15	0.1	0.1	100.0
Total	13,197	100.0	100.0	100.0

The reason why the small number of older children is because when children's Blood Lead Levels fell below 10 µg/dl they were removed from the

Blood Lead Levels screening program and were followed by the local department of health.

To compare rate of reduction of small children vs. older children I divided all children into three age groups as follow 0 to 5 years old, 6 to 11 years old and 11 to 15 years old (Table # 4).

Table # 4.- Age groups of children were divided into three groups from 0 to 5 years old, 6 to 10 years old and 11 to 15 years old. We observed that 63.9% of children started their first blood test were from 0 to 5 years old.

	Frequency	Percent	Valid Percent	Cumulative Percent
0-5	8439	63.9	63.9	63.9
6-10	4252	32.2	32.2	96.2
11-15	506	3.8	3.8	100.0
Total	13197	100.0	100.0	

Table # 5.- Age Group at 1st Sample * Gender Cross tabulation. The distribution by gender and age groups is very similar for children 6 to 10 years old. There were a little bit more males than females on children 0 to 5 years old. There were less males than females on children 11 to 15 years old 6.1% females vs. 1.5 % males.

			Gender		Total
			Female	Male	
Age Group at 1st Sample	0-5	Count	4136	4303	8439
		% within Gender	61.3%	66.7%	63.9%
	6-10	Count	2200	2052	4252
		% within Gender	32.6%	31.8%	32.2%
	11-15	Count	412	94	506
		% within Gender	6.1%	1.5%	3.8%
Total	Count		6748	6449	13197
	% within Gender		100.0%	100.0%	100.0%

During the 13-year study period we included all children who had at least 4 Blood Lead Levels tests during 4 years and were followed from 4 up to 13-years. We found that the number of Blood Lead Levels tests range from 4 up to 74 tests, and 9 tests were the average number of tests (Table # 6).

Table # 6.- Number of Blood Lead Level (Blood Lead Level) tests or samples and the number of years followed. The number of blood lead level samples range from 4 up to 74 tests and were followed from 4 up to 13-years. The average number of blood screening tests per child was 9.35 and the average time of follow up was 7.86 years

	N	Minimum	Maximum	Mean	Std. Deviation
# Total of Samples per Person	13197	4	74	9.35	5.916
Years Followed per Person	13197	4	12	7.86	2.177
Valid N (list wise)	13197				

The number of children followed during the 13-years period are as follows; 18% of children were followed 9 years, 17.4% followed 8 years, most children were followed during 6 to 10 years. The greatest number of years following children's Blood Lead Levels was between 6 to 10 years (Table # 7).

Table # 7.- Years Followed per Person. The majority of children were followed during a period from 4 to 10 consecutive years.

	Frequency	Percent	Valid Percent	Cumulative Percent
4	990	7.5	7.5	7.5
5	1126	8.5	8.5	16.0
6	1834	13.9	13.9	29.9
7	1550	11.7	11.7	41.7
8	2289	17.3	17.3	59.0
9	2428	18.4	18.4	77.4
10	1442	10.9	10.9	88.3
11	696	5.3	5.3	93.6
12	842	6.4	6.4	100.0
Total	13197	100.0	100.0	

In 1991 the Centers for Disease Control (USA-CDC) defined the blood lead level (Blood Lead Level) that should prompt public health actions as 10 µg/dL. Concurrently, CDC also recognized that a Blood Lead Level of 10 µg/dL did not define a threshold for the harmful effects of lead (5). Research conducted since 1991 has strengthened the evidence that children's physical and mental development can be affected at Blood Lead Levels <10 µg/Dl. (CDC, 1991, 2002).

The criteria in Mexico to classify Blood Lead Levels (Blood Lead Level) were established by the Mexican Law # NOM-199. 2002. This law was established following the Centers for Disease Control and Prevention (CDC, 1993) criteria from 1991. The acceptable as “safe” Blood Lead Level was established up to 9.9 µg/dl and the categories I to VI are described in Table # 12.

Table # 8.- Categories of Blood Lead Levels in Mexico (NORMA Oficial Mexicana NOM-199-SSA1-2000).

Category	Blood Lead Level (µg/dl)
I	0 a 9.9
II	10 a 14.9
III	15 a 24.9
IV	25 a 44.9
V	45 a 69.9
VI	>70

On the first Blood Lead Level test we observed the number of children with Blood Lead Levels Category I, lower than 10 µg/dl, was 4669, 35.4%, this number was substantially increased over the period of the study to 12,096, 91.7% (Table # 9). On the last Blood Lead Level test we observed how the number of children from categories II to VI was reduced increasing the number of children with < 10 ug/dl (Category I). This was a very positive result showing the effectiveness of all community intervention programs, environmental cleanup, remediation and environmental controls inside the smelter plant aimed to lower Blood Lead Levels.

Table # 9.- Number of children in each category group at their first Blood Lead Level test.

Category	Frequency	Percent	Cumulative Percent
I	4669	35.4	35.4
II	2996	22.7	58.1
III	3477	26.3	84.4
IV	1829	13.9	98.3
V	221	1.7	100.0
VI	5	.0	100.0
Total	13197	100.0	

Table # 10.- Last Blood Lead Levels by category group.

Category	Frequency	Percent	Cumulative Percent
I	12096	91.7	91.7
II	840	6.4	98.0
III	241	1.8	99.8
IV	20	0.2	100.0
Total	13197	100.0	

Table # 11.- Number of children by zone of residence; 58.8% of the population resided at the south from the smelter plant and 18% on the northern part. The prevailing wing is South-West. On approximately 23.5% of the study population we couldn't establish the area of residence, the reason is because there were many changes of addresses on many people due to relocation during these period of time.

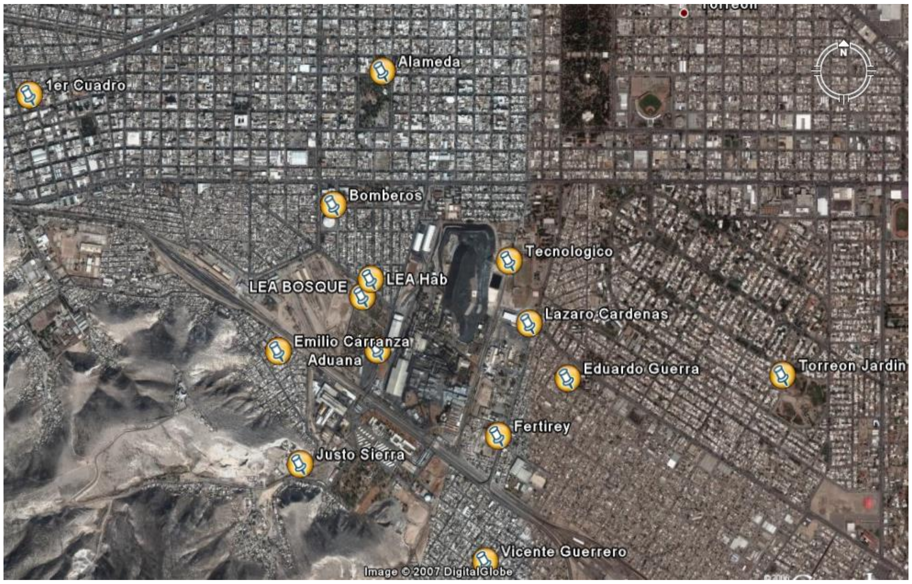
Zone of Residence	Frequency	Percent	Cumulative Percent
Unknown	3106	23.5	23.5
NW 2Km	1992	15.1	38.6
NE 2Km	379	2.9	41.5
SW 2Km	1036	7.9	49.4
SE 2Km	2890	21.9	71.3
SW 4.5Km	1177	8.9	80.2
SE 4.5Km	2617	19.8	100.0
Total	13197	100.0	

By the end of the follow up children 0 to 5 years old had mean Blood Lead Level as low as 4.19 µg/dl, (on 1999 it was 23.61 µg/dl), and children 6 to 10 and 11 to 15 had 3.37 µg/dl and 3.21 µg/dl, respectively (it was 21.34 & 19.57 respectively). During the 13-year follow up period, from 1999 to 2011, we observed the group of children 0 to 5 years a total reduction on the annual average of Blood Lead Level of 19.42 µg/dl, we observed an annual reduction of 1.44 µg/dl. This reduction is statistically significant with an R^2 value of 0.9. A similar behavior was observed on the other two groups of children with average annual Blood Lead Level reduction of 1.38 µg/dl., and 1.20 µg/dl., both also statistically significant.

ENVIRONMENTAL CLEANUP

Since 1999, the magnitude of the environmental contamination was tested by analyzing soil samples from the streets, schools, parks, churches, playing grounds and public buildings for the pm on some areas (Benin, 1999, Albalak 2003; Torreon Department of Health 2003). Many environmental remediation methods were developed to clean up the environment, particularly soil contamination inside and outside the smelter. Inside the plant, all processes were examined and significant structural and engineering changes were made within a very short period that controlled the lead emissions. Air monitoring network (Figure # 9) was installed inside the smelter plant and around the smelter on the community. (EPA, 1986, Profepa Federal Environmental Agency of Mexico 2001, 2003, Met Mex Peñoles 2003). Overall, lead emissions to the atmosphere decreased to permissible air concentration of 1.5 $\mu g/m^3$.

Figure # 9.- Air quality monitoring network was implemented around the smelter. Air Monitoring stations report on-real time air levels of suspended particles, SO_2, and lead were placed around the smelter.



SOIL CONTAMINATION: Due to the nature of the contamination process it was estimated that the contamination was affecting a perimeter of 2 kilometers from the smelter main smoke stack, lead soil testing was performed by a computer model and confirmed by soil testing performed by the Mexican environmental agency known as PROFEPA, it was found that lead in soil was unevenly distributed. Soil samples were collected and tested according to international standards for soil collection and analysis to measure lead in soil within the 2 kilometer perimeter from Met Mex Peñoles and were compared with basal levels obtained from areas away from the smelter or any other industrial sources of lead. Table # 13 shows reference soil lead levels. Total lead levels higher than 1000 ppm are legally hazardous.

Table # 12.- Criteria for Soil Lead Levels in Mexico. Reference level 400 ppm.

Lead Level (ppm)	Extracted Lead (ppm)	Estimated Total Lead
Low	less than 43	less than 500*
Medium	43 to 126	500 to 1000
High	126 to 480	1000 to 3000
Very High	greater than 480	greater than 3000

*If estimated total soil lead levels are above 400 ppm, however, young children and pregnant women should avoid soil contact. (NOM)

Also, there are other sources of soil contamination in Mexico such as tetraethyl lead used as an anti-knock ingredient in gasoline used until the late 1990's. Other sources of lead are use of lead glazed pottery, candy and food wrappers, folk remedies, and pesticides containing lead arsenate used in fruit orchards until late 1990's. Automotive lead emissions and lead pesticide are no longer in use and have effectively ceased with the phasing out of leaded fuels, and the development of more effective pesticides. Unfortunately lead persists in soil many hundreds of years, so the past use of these products continues to present problems in some areas.

SOIL ANALYSIS

A study was conducted to measure Pb concentrations in soil samples from selected areas near Met Mex Peñoles, analyzed by atomic absorption spectrometer (Drexler J, 2001), Lead Sulfate, Lead Arsenate, Lead Carbonate and Lead Oxide were the most prevalent forms or lead found in soil (Table 13).

Table # 13.- Natural Soil Composition at Torreon Mexico, study Performed by Dr. Drexler on 2002, from the University of Colorado, on 3 areas near the smelter.

Phase	%Frequency	%RM-Pb	%RM-As	%E-95
Anglesite	1.4%	3.1%	0.0%	1.8%
Arsenopyrite	0.5%	0.0%	12.8%	1.1%
Cerussite	7.6%	20.3%	0.0%	4.1%
FeOOH	35.8%	2.4%	0.1%	7.5%
Galena	1.1%	3.6%	0.0%	1.6%
PbAsO	8.0%	19.1%	33.9%	4.3%
PbMO	10.2%	11.2%	36.3%	4.7%
PbMOS4	13.3%	24.4%	12.1%	5.3%
PbO	0.9%	4.4%	0.0%	1.5%
PbSbO	1.2%	1.6%	0.1%	1.7%
PbSbS	0.5%	0.6%	0.0%	1.1%
PbSiO4	1.4%	2.2%	0.0%	1.9%
Phosphates	6.2%	5.6%	3.0%	3.8%
FeSO4	5.0%	1.3%	0.9%	3.4%

%F = Frequency percent, %RM-Pb = Percentage Relative Mass Lead ; %RM-As = Percentage Relative Mass Arsenic; %E-95 = Counting Error at 95th percent confidence interval,; *The "M" in phase name stands for other elements (Zn,As, Sb, or Cu)

OUTDOOR REMEDIATIONS

Outdoor environmental cleanup interventions included vacuuming streets, sidewalks and roofs, as well as removing all debris and trash from backyards removing contaminated soil and dust (Figures # 10 & 11). To support these interventions several environmental monitoring and surveillance programs of air and soil were implemented to keep environmental lead levels under control. It has been a continuous program that still being applied up to today, indoor and outdoor cleanup and remediation is performed periodically on every house within the 2 kilometer perimeter particularly when Blood Lead Levels remain higher than 10 µg/dl, or when lead concentration in soil or dust is above 400 ppm. Also, all possible sources of lead were investigated to reduce any exposure to lead from pottery, candy wrapping, folk remedies, etc.

Figure # 10.- Outdoor Remediation: Vacuuming streets, sidewalks and roofs, as well as removing all debris and trash from households streets and all public areas helped to substantially reduce the amount of environmental led. These actions are performed periodically, followed by screening programs to monitor lead in soil and dust, particularly on areas where Blood Lead Level are above 10 µg/dl.

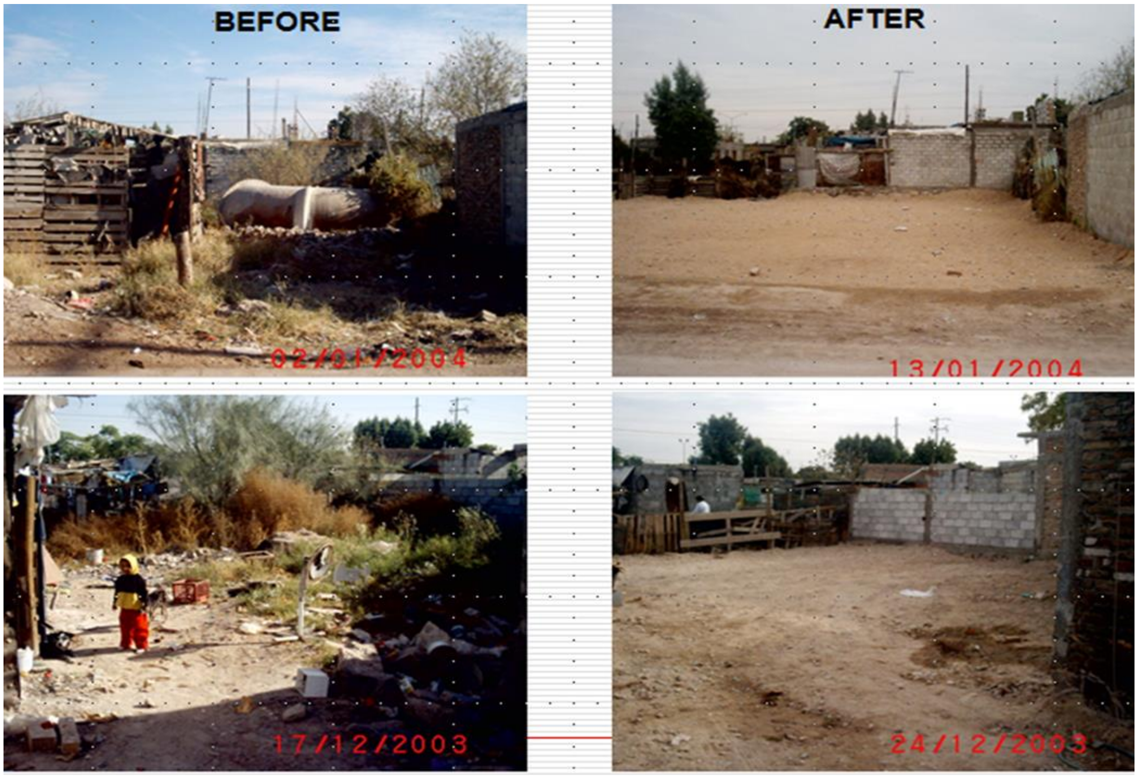


Figure # 11- All Debris/Trash Removed from Backyards & Front Yards, soil replacement, replacing ~10 centimeters with lead-free soil. Also: other forms of soil remediation such as with phosphates, or replacement with concrete floors.

Due to historic contamination of soil around the smelter, a program was developed together with the municipal government to clean up the environment by paving dirt-roads and streets to reduce the exposure to lead This program was aimed to lower lead exposure from streets and sidewalks. More than 400,000 m^2 of the unpaved roads and streets were paved in communities located within the 2 km perimeter from the smelter. (Figure 12). These actions substantially improve quality of life, public transportation and reduction of lead levels in the environment; circulating traffic on those streets contributed to dispersion of dust and lead particles into the air and contributed to outdoor and indoor exposure to lead. (Figure # 13)

Figure # 12.- Pavement of the Streets and Roads: Aerial Figure # and Streets around the smelter. More than 400,00 m2 of pavement were placed on unpaved roads and streets around the smelter. These included the pavement on the following neighborhoods (Colonias) E. Guerra 155,021 m^2, 1^o de Mayo 19,608 m^2, V. Guerrero 68,806 m^2, L. Echeverria 36,032 m^2, Cañon del Marmol 27, 271 m^2, , M Aleman 16,429 m^2 & Other Colonias 36,032 m^2.

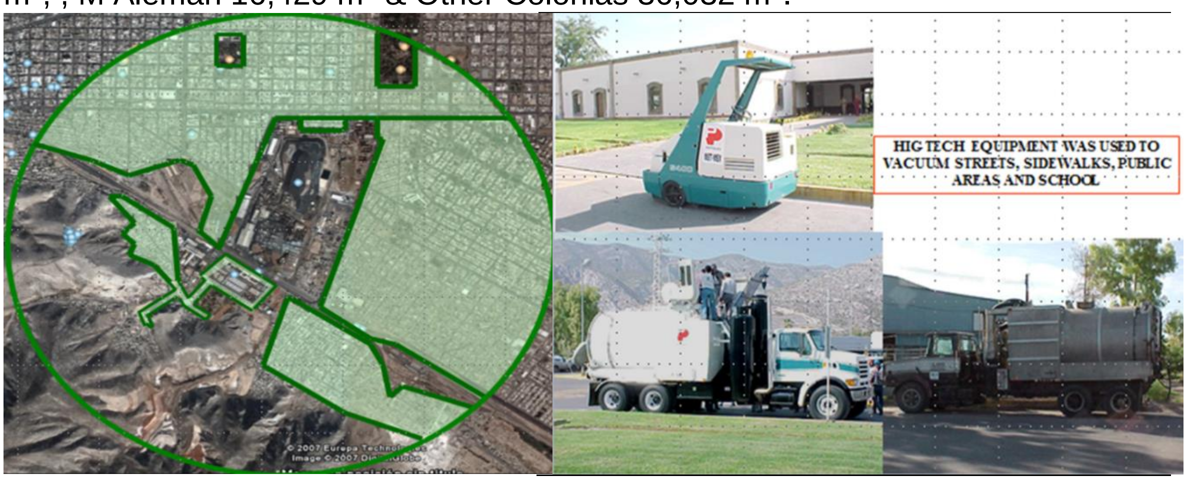


Figure # 13.- Cleaning Streets.- Year 2007, Aerial Figure # showing the areas that has been swept and part of the Equipment acquired to vacuum the 2 km. perimeter from the smelter; Streets, sidewalks, public areas, playground areas and all public and private schools.

The environmental cleanup of back and front yards was accomplished using the indoor lead screening programs. The cleanup strategies used were wet-cleaning methods, vacuuming indoors roofs and all exterior structures of each house. The cleanup remediation was performed once a month until Blood Lead Level from the household children fell off below 10 µg/dl. These environmental interventions were supported together with community health education programs aimed to educate parents, teachers and all community members toxicity of lead, lead and children, lead and pregnancy, and environmental hazards, as well as to improve personal and household hygiene, and nutrition. By 2007 more than 201,804 household actions /interventions (93,798 indoor, and 108,066 outdoor) were performed to clean up inside and outside homes, elementary schools, kinder-garden schools, middle schools and other schools aimed to remove soil, dirt and dust.

INDOOR REMEDIATION

All houses located within the 2-km perimeter were included into the program of indoor lead screening and cleanup using wet-cleaning methods. Also all houses from children with Blood Lead Level greater than 10 µg/dl were screened and decontaminated, vacuuming indoors, roofs and all exterior structures of each house (Figure # 16). Indoor cleanup remediation was performed periodically until children's Blood Lead Level fell off below the 10 µg/dl. These environmental interventions were supported together with community health education programs aimed to educate parents, teachers and all community members on toxicity of lead, lead and children, lead and pregnancy, and environmental hazards, as well as to improve personal and household hygiene, and nutrition.

Figure # 14.- Indoor Environmental Remediation: A large number of people from these communities received training on lead hazards & decontamination then were hired to work full-time performing environmental cleanup and remediation of households: Thorough cleaning inside houses by wet-cleaning methods, vacuuming indoors to include windows and door edges, all furniture, floors, roofs and all exterior structures of each house. Indoor cleanup remediation was performed periodically at each household until Blood Lead Levels from household children with high Blood Lead Levels fell off below 10 µg/.

Several community outreach programs were developed to improve quality of life on communities affected by lead contamination. These programs helped to improve access to healthcare, hygiene, environmental health education aimed to reduce environmental exposure to lead. Community health education focused on improving community awareness on toxicity of lead and lead hazards, improvement personal care and household hygiene, how to protect children from exposure to lead and nutrition intervention programs providing calcium, iron and vitamin supplements to all children together with screening of Blood Lead Levels and pediatric healthcare services (Figure # 15)

Figure # 15.- Community healthcare services were developed and operated by Met Mex Peñoles with approval of municipal and state health care services aimed to provide healthcare to children and pregnant women. These community clinics were attended by medical do8ctors and nurses taking care of community health problems. Together with Blood Lead Levels screening program on all children and pregnant women, as well as members of the community who asked for the service and were residents within the 2 km perimeter.

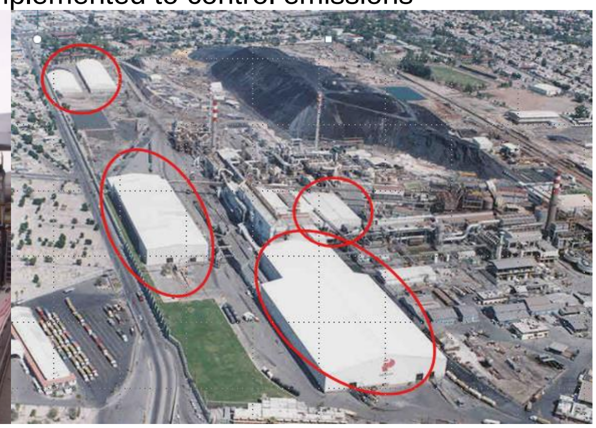
CHANGES MADE INSIDE THE SMELTER PLANT

To lower all kind of particulate emissions, including metals, Peñoles made important changes and improvements in all environmental protection methods inside the plant. Some of these changes are depicted below. (Figure # 20)

1. The filtration capacity of all air emissions to the atmosphere was doubled, by installing bag-houses and an electrostatic precipitator which increased the filtration capacity from 2 to 4 million cubic meters per hour, and by installing bags with Teflon membrane to prevent any releases to the atmosphere.
2. All operations of handling and storing raw materials and recycled materials were confined. Several giant warehouses were built with a total surface of 45,000 m^2.
3. A lot of the equipment was replaced by modern technology, and all processes were optimized.
4. A 4 car / truck-wash stations were built inside of the smelter to prevent the transportation of contaminated materials to the exterior.
5. All roads, streets and ground areas within the smelter were paved with hydraulic cement and are kept clean around the clock. Soils from open areas were remediated and transformed into green ecologic areas.
6. A lot of the equipment was replaced by modern technology, and all processes were optimized.

Modern Filtration systems were implemented to control emissions

Filtration Equipment: House of Bags increasing the filtration capacity to more than 3.5 million m^3 /Hour.



45,000 m^2 Warehouses were built to keep all proceeses indoors and prevent fugitive lead emissions to the atmosphere

Truck and Euipment washing to control dusts transported outside the plant

A park was constructed where Col. Luis Echeverria III was located, and residents were relocated away from the smelter

Figure # 16: Environmental protection equipment and technology inside the smelter plant.

RESULTS AND DISCUSSION

By the end of the follow up children 0 to 5 years old had a mean Blood Lead Level of 4.19 µg/dl, and children 6 to 10 and 11 to 15 had 3.37 µg/dl and 3.21 µg/dl, respectively. We observed the group of children 0 to 5 years a total reduction on the annual average of Blood Lead Level of 19.42 µg/dl, we observed an annual reduction of 1.44 µg/dl. This reduction is statistically significant with an R^2 value of 0.9. A similar behavior was observed on the other two groups of children with average annual Blood Lead Level reduction of 1.38 µg/dl., and 1.20 µg/dl., both also statistically significant.

Inside the smelter plant, important structural changes and manufacturing processes were developed to control all sources of emissions of lead to the atmosphere. Outside on the community several programs were developed to clean up the environment indoors and outdoors, as well as healthcare and epidemiological surveillance programs were implemented to screen children for Blood Lead Levels together with. Amongst the community programs were community intervention programs to improve health, hygiene and nutrition.

The scope and scale of the actions taken by the company within such a relatively short time period have been extraordinary. Programs and actions included community outdoor and indoor remediation and cleanup of all households with the implementation of all methods and technologies available. These included purchasing 448 houses a community known as Col. Luis

Echeverria III, located in very close proximity to the smelter with levels of lead contamination that required this type of intervention to protect children by relocating this community away from the smelter, together with important changes inside the smelter plant. By 2007, more than 201,804 household (93,798 indoor, and 108,066 outdoor) were cleaned inside and outside homes, elementary schools, kinder-garden schools, middle schools and other schools. Each one of these measures played important part in lowering blood lead levels on the children from this community. Substantial cleanup of the environment was achieved from cleaning streets, homes, public areas, healthcare for children as well as cleaning the streets. Outdoor, Indoor and environmental remediation of streets, schools and public areas were performed (See sections on indoor and outdoor remediation). The Smelter Company Met-Mex Peñoles financed all cleanups and got the approval from the Municipal Government, Community Organizations and the local community.

One of the most important programs was an Epidemiological Surveillance System to monitor Blood Lead Levels in children 0 to 15 years old, supported by other programs developed concomitantly to include community health education, nutrition and hygiene and several comprehensive environmental cleanup programs described below. A reduction in Blood Lead Level was observed in children from all 37 neighborhoods (Colonias). In addition to environmental remediation both indoors and outdoors many community education programs were also implemented. These programs were aimed to lower environmental lead and lower Blood Lead Levels to protect children's health.

Tables # 15 and 16 show the First and Last Blood Lead Levels obtained from all children from 1999 to 2003, new children were included each year, in order to have a minimum of 4 years of follow up Blood Lead Levels the last test was performed from 2003 up to 2011.

Table # 14,- All children's first Blood Lead Level test was obtained from 1999 to 2003. Children continued follow up Blood Lead Level monitoring tests up to 2011. The greatest number of children's first Blood Lead Level test, 34.2%, was obtained on 1999.

	Frequency	Percent	Cumulative Percent
1999	4515	34.2	34.2
2000	1287	9.8	44.0
2001	1912	14.5	58.5
2002	3426	26.0	84.4
2003	2057	15.6	100.0
Total	13197	100.0	

Table # 15.- Last Blood Lead Level Test 28.5 % of children were followed up to 2011.. The last Blood Lead Level test was obtained from 2003 up to 2011.

	Frequency	Percent	Cumulative Percent
2003	457	3.5	3.5
2004	293	2.2	5.7
2005	617	4.7	10.4
2006	640	4.8	15.2
2007	1216	9.2	24.4
2008	2608	19.8	44.2
2009	2056	15.6	59.8
2010	1550	11.7	71.5
2011	3760	28.5	100.0
Total	13197	100.0	

Table # 16.- The time-course of change in Blood Lead Levels. The values ranged from *0.0 to 83.8 µg/dl with geometric mean Blood Lead Level of 15.44 µg/dl. At the end of the follow up period, the Blood Lead Levels ranged from 0.1 to38.4, with geometric mean Blood Lead Level of 5.4 µg/dl. We observed a significant reduction of Blood Lead Level during the follow up period. (* Was the level reported by the laboratory)

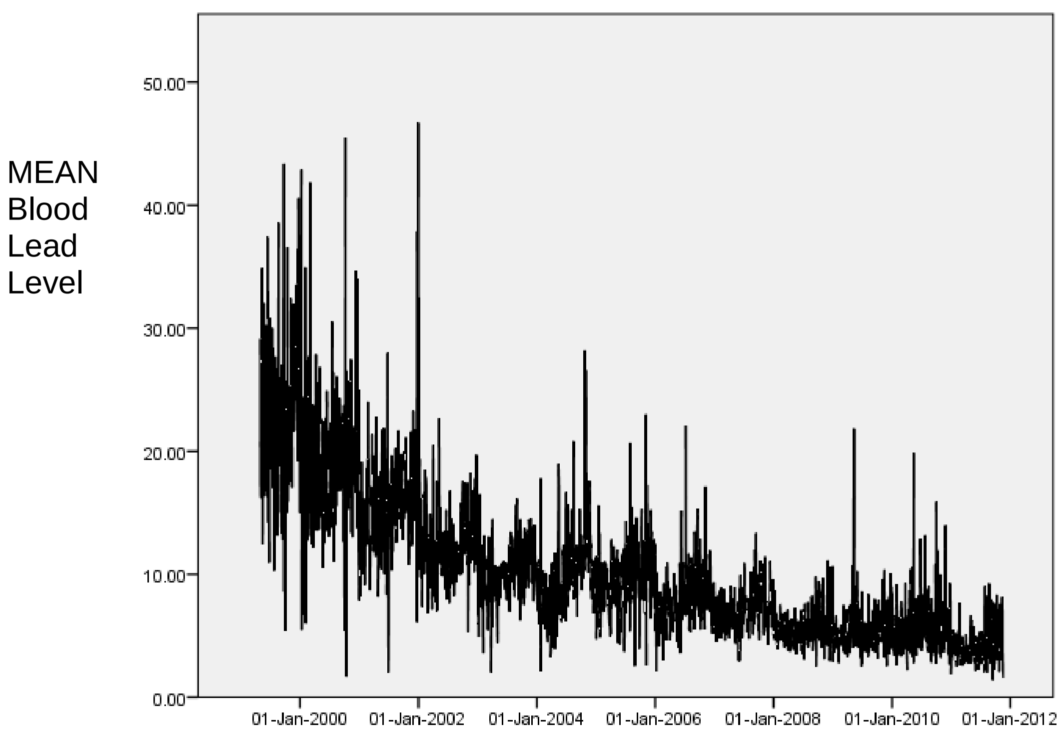
	N	Minimum	Maximum	Mean	Std. Deviation
Blood Lead Level 1st Sample	13197	0.00	83.80	15.4470	10.18732
Blood Lead Level Last Sample	13197	0.10	38.40	5.4080	3.51580

Table # 17.- Mean Blood Lead Levels differences between first and last Blood Lead Level; Throµghout the follow up period we observed an average reduction on Blood Lead Levels of 11.06 µg/dl.

	N	Mean	Std. Deviation
Diff First Sample & Average Last Sample	13197	10.0389	9.09362
Diff First Sample & Average Last Sample	13197	11.0628	10.91732

We observed a continuous reduction of Blood Lead Levels from all children residing within the 5 kilometers perimeter from the lead smelter (Figure 17). These reductions were the result of comprehensive environmental cleanup and remediation programs implemented inside the smelter and outside at the community together with the application of community environmental health intervention programs aimed to improve quality of life of families and the whole community.

Figure # 17.- Histogram: Mean Blood Lead Levels were substantially reduced.



During 1999 Blood Lead Levels collected from 7512 people from all ages living near the lead smelter. Venous blood samples were collected from April to November showing that 86.6% had Blood Lead Levels greater than 10 µg/dl, and a geometric mean Blood Lead Levels of 24.113 µg/dl (Table # 20).

Table # 18.- Blood Lead Levels (Blood Lead Level) reported by the Local Department of Health, Sanitary Jurisdiction No l, Torreon, Coahuila, up to November 30th 1999. This Table # included data from total population.

Blood Lead Level µg/dl

Blood Lead Level (µg/dl)	0 to 9	10 to 24	25 to 44	45 to 69	> 70	Total
No. of Patients	1007	3732	2073	671	29	7512
Percentage	13.4 %	49.6 %	27.6 %	8.99 %	0.4 %	100 %
Total		6812 Patients			700 Patients	7512

Source: Secretaria de Salud, Jurisdiccion Sanitaria 1. Torreon Coahuila. Nov, 1999.

To respond to this alarming situation the smelter company in coordination with health and environmental authorities developed and financed all programs to protect children's health and clean up the environment. Within a relatively short period of remediation, reduction in Blood Lead Levels was observed. By 2002, we observed 51.8 % reduction of Blood Lead Levels with a geometric mean Blood Lead Level of 11.621 %. The reduction of Blood Lead Levels continued and, in 2011, we observed a geometric mean Blood Lead Level of 5.6%, a reduction of 76.8% (Table # 10). At the end of the study (2011), 76.3% of children with Blood Lead Levels greater than 10 µg/dl are in category II (10 µg/dl to 14.9 µg/dl).

The implementation of comprehensive environmental cleanup and remediation inside the smelter plant and outside on the community together with community intervention programs aimed to improve health, hygiene and nutrition were key factors in lowering Blood Lead Levels in Children. Reduction of Blood Lead Levels was continuous, with important reduction measured since the first year (Figure # 9). Reduction of Blood Lead Levels was very similar in all three age groups, we didn't observe a significant difference in lowering Blood Lead Levels. From all 13,197 children, 102 showed an elevation of Blood Lead Levels above 5 µg/dl at the end of the follow up period compared with their initial Blood Lead Level. Up to 2011 Blood Lead Levels from 91.7% of children 0 to 15 years old were reduced below 10 µg/dl, and only 8.3% of these children are in Category II and few in III (10-14.9 & 15-24.9 µg/dl). In Mexico, the criteria to classify Blood Lead Levels were established according to the Mexican Law # NOM-199 (2002). The acceptable "safe" Blood Lead Level was 9.9 µg/dl, and the categories I to VI are described in Table # 13. However, in the USA, the safe dose of 1 µg/dl.

By the end of the follow up, children 0 to 5 years old had mean Blood Lead Level as low as 4.19 µg/dl, and children 6 to 10 and 11 to 15 had 3.37 µg/dl and 3.21 µ.g/dl, respectively. During the 13-year follow up period, from 1999 to 2011, we observed the group of children 0 to 5 years a total reduction on the annual average of Blood Lead Level of 19.42 µg/dl, we observed an annual reduction of 1.44 µg/dl. This reduction is statistically significant with an R^2 value of 0.9. A similar behavior was observe don the other two groups of children with average annual Blood Lead Level reduction of 1.38 µg/dl., and 1.20 µg/dl., with an R^2 value of 0.88 & 0.80 respectively both also statistically significant (Table 19 and Figure 18).

Table # 19.- Annual mean Blood Lead Levels by Age Group.

YEAR	0 to 5 y.o.	6 to 10 y.o.	11 to 15 y.o.
1999	23.61	21.34	19.57
2000	19.87	18.28	16.62
2001	16.86	15.01	13.23
2002	13.02	11.30	9.47
2003	11.21	9.33	7.51
2004	10.97	8.75	6.45
2005	10.80	8.47	6.40
2006	8.72	6.55	4.59
2007	7.65	6.00	5.05
2008	6.19	4.53	4.52
2009	5.64	4.21	4.22
2010	5.67	4.24	4.00
2011	4.19	3.37	3.21
Difference 1999-2011	19.42	17.96	16.36
Slope	-1.44	-1.38	-1.20
R^2	0.90	0.88	0.80

ANNUAL MEAN BLOOD LEAD LEVEL BY AGE GROUP 1999-2011

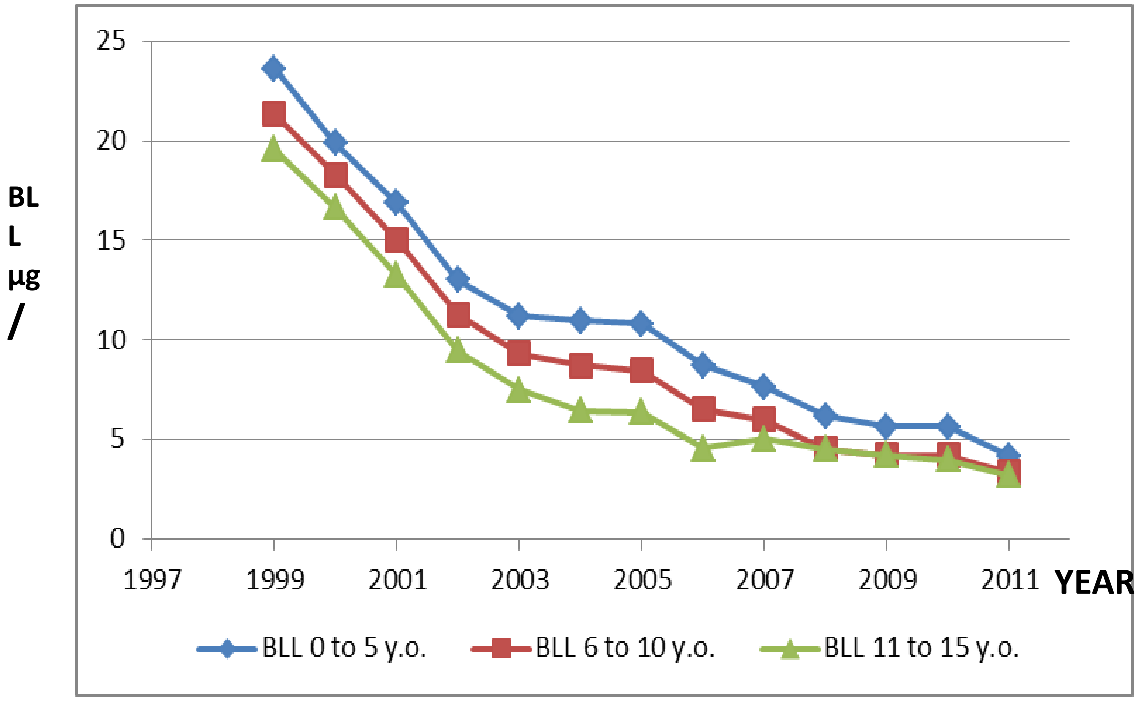


FIGURE # 18.- Annual mean blood lead level from 1999 to 2011. We observe that Blood Lead Level were similarly lowered on all three age groups of children 0 to 5, 6 to 10 and 11 to 15 years old.. On this graphic we observe the change in Blood Lead Levels (dependent variable, axe Y)-throughout a follow up from 1999 to 2011 (independent variable, axe X). We observed a very similar reduction of Blood Lead Levels in younger children than older children. Blood Lead Levels from these three age groups of children 0 to 5, 6 to 10 and 11 to 15 years old show an statistical significant reduction of Blood Lead Levels over the time. We observe that in 1999 children 0 to 5 years old had mean Blood Lead Level of 23.61 µg/dl, and children 6 to 10 and 11 to 15 had mean Blood Lead Level of 21.34 µg/dl and 19.57 µg/dl respectively.

CONCLUSIONS

The implementation of comprehensive Clinical & Environmental Toxicology Programs is essential to protect children from exposure to lead and other environmental contaminants. These programs include medical toxicology and environmental assessment, screening of Blood Lead Levels supported with basic clinical laboratory tests, together with health education aimed to improve nutrition and personal hygiene and improvement access to healthcare are essential to protect their health. Concomitantly it's necessary to implement comprehensive environmental cleanup methodologies to remove all sources of exposure to lead.

The environmental cleanup methods included, but are not limited to, environmental control of all lead emissions inside the smelter plant improving all processes of handling materials and the implementation of modern technologies to prevent the release of lead and other particulates to the atmosphere by improving filtration systems and bag houses to keep dusts and fumes inside the smelter plant during sintering and smelting heavy metals, as well as controlling other potential sources of lead emissions during all processes from storing and handling lead concentrates, transportation inside and outside the plant, mixing, and processing heavy metals keeping fumes and dusts inside the smelter plant. Besides controlling the main source of exposure to lead it was necessary to investigate and detect other potential sources of exposure to lead such as occupational exposures to lead, workshops, soldering, car batteries and other community business that could be handling lead. Also, we ruled out exposure to lead from ceramics and cookware, food and water contamination, use of folk remedies, candy wrapping, toys and furniture contaminated with lead paint.

The environmental cleanup also included indoor decontamination of homes, schools, and all public areas where children spend time while playing and developing their activities. Household cleanup was fundamental to clean up children's most closest environment by using wet-methods to remove dust and soil inside their homes with exhaustive cleaning of every single space and areas inside their homes, vacuuming furniture and every place and corner of the house, cleaning their toys, many times replacing mattresses and some pieces of furniture that adsorb dust and particles (i.e. pillows). If the house has dirt backyard and/or front yards it was necessary to cleanup and remove all debris and trash and replace soil surface, approximately 10 to 15 centimeters of dirt-soil with lead-free dirt and encapsulate the upper layer covering it with grass, bricks, gravel or concrete. Indoor cleanup was accompanied by concomitant outdoor environmental cleanup to remove contaminated soil and dirt from streets, sidewalks, playground areas, schools and all community areas by removing trash and debris, vacuuming streets with special vacuum trucks and equipment, recycling hundreds of metric tons of dirt and dust. Also it was necessary pavement of streets and dirt roads, and remediation of soil from playground areas with encapsulation of contaminated areas with lead-free soil, bricks, gravel or concrete. A continuous monitoring of air and soil must be established to assure that the community is lead-free and well kept.

At the beginning of our participation on the environmental health problem 86.6% of children had Blood Lead Levels (Blood Lead Levels) greater than 10 µg/dl, with a geometric mean Blood Lead Levels of 24.113 µg/dl, and with the implementation of all of the above mentioned programs we achieved the continuous reduction of Blood Lead Levels to < than 10 µg/dl on more than 90% of children 0 to 15 years old living near the lead smelter at Torreon Coahuila Mexico. The remaining number of children with high Blood Lead Levels are between 10 to 15 µg/dl. Currently there is an on-going environmental health program coordinated by the Unit of Environmental Health (Unidad de Salud Ambiental) operated by Met Mex Peñoles working in coordination with the local Department of Health to monitor environmental lead from indoors, Blood Lead Levels from Children 0 to 15 years old, providing healthcare services to all children residing near the smelter.

All, and each one of these environmental remediations played important part in lowering blood lead levels on the great majority of children from this community, as well as achieve a substantial cleanup of the environment by reducing lead from all sources and emissions to include the implementation of all available environmental remediation methods from cleaning streets, homes, public areas, healthcare for children as well as cleaning the streets, All cleanup interventions were developed and financed by the Smelter Company Met-Mex Peñoles with participation and support of the Municipal Government, Community Organizations as well as the community participation.

FUTURE RESEARCH

Absolute environmental control of lead emissions from primary and secondary sources are necessary to protect children and their the communities, as well as the investigation to discover every potential source of exposure to lead such as food and water contamination, cooking tools, candies, folk remedies and every potential source of lead are essential to protect pregnant women and developing children who are more sensitive to suffer neurocognitive damage and other health effects. Environmental cleanup and remediation are only effective if all sources of lead are controlled and concomitant application of comprehensive community intervention programs such as education on personal and household hygiene, improvement of nutrition, healthcare with community participation are developed. It's necessary further research to measure the effectiveness of each one of the intervention programs and environmental remediation. This type of environmental cleanup intervention is recommended to communities around the world, particularly at poor and developing countries. Also, further research is necessary to identify biomarkers of health effects in children at very low Blood Lead Levels to propose new laws and regulations to protect children from lead poisoning. Also, it's recommended to investigate how soil composition rich in calcium, phosphates, zinc and sulfates may play an important role affecting bio-availability of lead, interfering with lead absorption, as well as altering its metabolism, distribution and elimination due to the presence of calcium, zinc, phosphates and sulfates competing with lead and most probably reducing the toxicity of lead.

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