HIXON FELLOWSHIP REPORT

Drawing upon the Lessons of Lead Poisoning to Build a Paradigm for Understanding Environmental Health: A Study of the History, Science and Policy of Lead Poisoning

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1 INTRODUCTION

Scientists who study environment health problems face a host of unknown factors. Asthma research, for example, is on a steep learning curve as researchers investigate all aspects of the disease, including the extent of environmental factors. The future might seem to appear uncharted. But scientists have the benefit of the experience of the investigation and subsequent regulation of lead in the environment and can draw upon this body of work to help guide the investigation of the impact of other environmental pollutants on human health.

Researchers understand the human health effects of lead exposure and the movement of lead through the environment better than any other introduced substance. (Thomas 1995) While research continues[1], scientific understanding about lead in the environment is nonetheless substantial. (Millstone 1997) The case of lead in the environment, and the years of policy and regulation that have grown from it, offer valuable insights into the human health-environment dynamic.

The concept of lead as a paradigm for the threats of other toxicants has been raised by several scientists at the forefront of lead research[2]. This essay aims to take a broader approach to address questions concerning the overall human health-environment dynamic such as the following:

- How is an environmental hazard detected?
- What are obstacles to accurate measurement of exposure and contamination?
- How does contamination vary by exposure patterns or special susceptibility of sub-populations?

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[1] Current research includes inquiries into environmental sources of lead (Cooney 1999) and threshold effects of low level dose (Needleman 1990).

- How do different environmental pathways contribute to different types and amounts of exposure?
- What happens when further research suggests tighter regulatory standards?
- At what, if any, point is low-level contamination acceptable?
- Are benefits of research, law and policy distributed equitably across society?

2 DETECTION OF LEAD POISONING: A MULTI-STAGE PROCESS

2.1 Early Evidence of Effects of Lead Poisoning: 200 B.C. and Onward

Lead is certainly humankind's longest running contaminant. The Romans, who added lead acetate to sweeten their wine, recognized the effects of substance. (Aitchinson 1960) The earliest description of the effects of lead dates back to 200 BC when Dioscerides noted that "Lead makes the mind give way." (Needleman 1990) In the eighteenth century, Ben Franklin, an astute observer of scientific and social phenomena, noted the insidious effect of lead on human health. (Hays 1992)

Anecdotal, community-based knowledge is often the first precursor to recognizing the effects of a contaminant. The history of the earliest detection of lead contamination suggests both the importance of such early signals and the need for rigorous further research. The striking effects of direct lead poisoning from drinking lead-laced wine prompted attention but also misled observers into thinking that such extreme reactions were the only possible outcome. The more insidious effects were overlooked and thus not understood for almost two milleniums. (Lin-Fu 1992)

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[2] See (Landrigan 1990; Needleman 1990; Silbergeld 1990). These essays, published together in 1990,

2.2 When the Abnormal is the Norm: Overlooking the Impact of Environmental Hazards

The history of lead research and regulation suggests a pattern of discovery coupled by broad scientific and social disinterest in these new findings. With hindsight, it is clear that scientific evidence of the dangers of environmental lead were known, but ignored, for decades.

This pattern is evident in the first research on lead poisoning on children, undertaken by two Australian physicians in the late nineteenth century. The source of the poisoning was determined to be lead paint and, over the next twenty years, the physicians pressed for regulation of the uses of lead paint.

The most striking aspect of this early research is its limited impact. The regulation was restricted to the area of Queensland region of Australian. Other nations, indeed other areas of Australia, considered the issue to be limited to Queensland. This is despite ongoing evidence over the years of the insidious effect of lead in the environment. This seminal research was not unearthed again until the 1960's. (Needleman 1988; Lin-Fu 1992). This early research and its limited impact suggests that the scientific data alone is not persuasive. It needs to be coupled with some level of public concern before a shift in perception and the subsequent research can begin.

This implies the importance of a context for human health-environmental heath dynamics. The environment literally surrounds us and changes to the larger ecosystem can be slow and subtle. The nation's rivers were highly polluted before the Cuyahoga and other rivers burned but the flaming rivers provided a seminal event for focussing attention on a clear problem that had been seen, but somehow not heard, for decades.

The pattern of pivotal research followed by years of silence continued when another major leap in research was greeted by decades of disinterest. A critical shift in emphasis

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focussed on lead as a model for understanding other toxic agents.

from physiological and neurological effects to cognitive and behavioral deficits was led by Byers, a pediatric neurologist who treated many cases of childhood lead intoxication. Consensus had been that if child survived poisoning they were left unimpaired but Byers noticed that many of the behavioral cases he treated were recovered lead poisoning cases. Byers and Lord, a psychologist, followed up on 20 recovered lead cases and applied psychometric, as opposed to neurological tests. Nineteen of the twenty cases indicated behavioral or cognitive deficits. (Byers 1943)

This work represented a critical shift on thinking on two levels. First, lead effects were no longer limited to physiological impacts. Second, the time frame of lead poisoning opened up to include long term, persistent effects that were not well understood at the time. Yet the implications of this work were not grasped for another 25 years.

2.3 Recognizing and Reacting to the Threat of Environmental Lead Poisoning

The next stage of lead research linked contamination and individual performance. The seminal breakthroughs in this stage of research were methodological (using children's teeth to measure long term exposure) and conceptual (relating this exposure to school performance on academic, social and emotional measures). (Needleman 1979; Needleman 1990)

This research did not follow the fate of earlier studies. The social climate had changed and the pivotal Needleman study was picked up by a host of other researchers. The reaction was not widely supportive, however. The lead industry had become quite entrenched over the past 75 years and attacked the study, and Professor Needleman, with equal venom. (Millstone 1997) The controversy continued over the next fifteen years but appears to finally have been put to rest with the research and the integrity of Needleman and his colleagues secured. (Silbergeld 1995; Silver 1995; Scarr 1996; Schoen 1996; Silbergeld 1996; Smith 1996)

The vitriolic nature of the confrontation over lead in the environment can be seen as a conflict over values and science. (Hays 1992) In this regard lead is a model, or perhaps a warning, for other human health-environment interactions. Persistent pollutants have usually been put out in the environment for a purpose and can be quite effective. Industries, coalitions and individuals all have a stake in seeing the use of a particular chemical or process continue. Researchers come to the issue with other values and goals and a clash is inevitable. Rarely, however, is the public health well served by such controversy and a more fruitful dialogue can be achieved by avoiding some of the pitfalls of the lead experience.

Many aspects of social policy had shifted in the years leading up to 1979, changes that aided in the recognition of the problem and the importance of both earlier and contemporary research. These shifts included a new focus on the environment and the problem of environmental degradation (post-Rachel Carson and post-Earth Day), a new federal regulatory agency to address such concerns (the US EPA) and an increased focus on and voice from poor, disenfranchised communities where lead poisoning was especially virulent.

Further, while much of the earlier research and controversy was conducted away from public view, the debate is now more open to scrutiny. When attacked by lead industry researchers, Needleman and others pushed for open hearings and the effect of a public forum, actual and merely potential, was immense in several aspects of later lead research and policy. (Hays 1992) Some researchers express concern that the lay public cannot understand the complexity and inherent uncertainty of science. But the last decades of lead poisoning research and regulation strongly suggest that a public engagement in environmental health issues is critical in ensuring that competing views are heard and constructive regulations implemented. The public battle over lead poisoning has been vitriolic, but this intensity has ultimately served the needs of the public and of science.

2.4 Detection Mechanisms

Most environmental toxicants cannot be seen or readily measured. Detection mechanisms are critical to enable researchers to capture the extent of the impact of introduced substances both on environment and on human beings.

Early lead studies were based upon observation of effects on people and blood samples. This captured short-term impact but could not describe accumulated impacts from lead exposure. Further, the techniques then available were slow and cumbersome, effectively limiting the number of samples that could be tested. Two key breakthroughs -- in blood lead testing and sampling of childhood teeth -- proved critical in opening up new ways of understanding and treating lead poisoning.

The blood lead testing pioneered by Piomelli in the early 1970’s vastly reduced the time and cost of monitoring and expanded the range of potential subjects. This made later studies possible. (Piomelli 1973) Scientists knew that lead was stored in human bone but could not figure out how to study bone deposits until Needleman and his colleagues looked to children’s teeth and developed an inventive use of dentine levels. (Needleman 1979)

Understanding the impact of a chemical in the environment depends, first, on determining its presence in different mediums, including the human body. A full understanding of the pathways of contamination and the effect on humans relies upon detection mechanisms, as does eventual regulation and oversight. Sometimes these mechanisms are refinements of long existing practices, such as Piomellis’s adaptation for blood lead testing. Other techniques require a new way of seeing and seeking evidence, such as Needleman’s creative use of children’s teeth as a source of evidence of the long-term storage of lead.

Regardless of the specific method, some consistent and widely supported detection method is critical to the study and regulation of environmental health hazards. In the study of air pollution, for example, the current debate over the impact of different particulate sizes (PM_{10}, $PM_{2.5}$, etc) is part of the larger issue of what is detectable and by what means.

Detection is critical in understanding human health-environment dynamics. New methodologies and approaches are vital in determining what hazards are in the environment, where they accumulate and where and how they are stored in the human body.

3 VARIATION IN LEAD POISONING CONTAMINATION

Not all groups or individuals have the same susceptibility to environmental pollutants. Lead poisoning offers a dramatic example of how susceptibility to a toxicant can vary tremendously. This section considers lead poisoning variability by age, gender, genetic disposition, demographics and geography and offers a framework for considering variability in the effects of other environmental hazards.

3.1 Lead Poisoning and Children

The special vulnerability of children to environmental hazards has been well documented. (CDC 1991; Wargo 1998) Children are especially vulnerable to lead poisoning due to physiological and behavioral factors. Physiologically, children's growth patterns can lead to increased storage of lead in the body. More critically, children's behavior and stature makes them especially vulnerable to lead poisoning.[3]

The ways in which children's bodies function and the ways that children behave thus has a profound effect on their susceptibility. Such unique susceptibility patterns are evident in

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[3] Lead dust (from leaded paint or leaded gas released into the air) and lead paint chips are found at ground level, right where young children play and crawl. The tendency of very young children to put their hands in their mouths results in a steady transfer of contaminants into the body. Outdoor play can result in the stirring up of contaminated dust and dirt, leading to further exposure.

the case of lead poisoning and can provide guidance in understanding the impact of other toxicants on children. Children essentially move through the world differently than adults. In many ways the physical experience of children is vastly different than adults and the history of lead poisoning indicates that these differences have impact on their susceptibility to disease. In terms of asthma, for example, the physiology of children's respiratory systems many differ significantly from adults. The air at ground level may have significantly higher levels of particulates, dust, pollens or other irritants. The case of children and lead poisoning, and later the case of children and pesticide poisoning, strongly suggest that a child's susceptibility to other environmental hazards, such as air pollutants will differ significantly from adults.

3.2 Effects on Other Vulnerable Populations: Gender Variability

The steady focus on children over the past 25 years has partly obscured other vulnerable populations. For example women, who experience changes in bone density (due to pregnancy and/ or menopause) may have elevated blood lead levels as lead previously stored in bone becomes free within the body. The implications for women's health and the health of affected fetuses are quite serious. (Silbergeld 1990)

The experience of lead poisoning research and regulation points to how even a successful campaign to address human health-environment hazards can, through its very success, overlook other vulnerable populations. The tremendous focus on children led researchers away from examining other populations for several years.

Kids' health is a great unifier. Usually contentious adults can almost miraculously let go of their fiefdom struggles when confronted with the problems of our children. An air quality researcher recently looked across a room packed with researchers and advocates concerned about childhood asthma and mused how this topic, air quality, which has been his passion for 30 years, now commands widespread attention because asthma has "put a face" on the problem of air quality. There is clearly effectiveness to this strategy, as well as danger.

3.3 Role of Genetics in Variability of Susceptibility to Lead Poisoning

Genetic susceptibility to lead poisoning has only recently been investigated, since much of early lead research poisoning predates modern gene therapy discoveries. This is in contrast to the timeline of later environmental health research, such as the study of asthma, which has been concurrent with the recent advantages in gene research. (Onalaja AO 2000)

In this regard, lead does not offer much of a template for understanding how genetic variability can influence an individual's susceptibility to environmental hazards. Current research on lead poisoning, asthma and other environmental health diseases will almost certainly provide clues to how genetic predisposition can influence an individual's, or a sub-population's, reaction to an environmental contaminant.

3.4 Variation by Demographics and Geography

The successful campaign to remove leaded gasoline from the U.S. market resulted in a dramatic decline in blood lead levels, declines matched in other countries during and following a phase-out of leaded gas. (Thomas 1997) As lead in gas, and its release into the atmosphere and deposition on the ground became less of an issue, other sources of lead became primary sources of contamination and the lead poisoning issue became more geographically and demographically focussed. (Mahaffey 1982; Brody, Pirkle et al. 1994; Pirkle 1994; Millstone 1997; Pirkle 1998)

3.4.1 Higher Blood Lead Levels in Urban Communities

Lead paint from older homes has proven to be the most persistent source of lead poisoning in the U.S. environment. These homes are located predominately in older cities, making such areas prime areas of lead poisoning. The Second and Third National Health and Nutrition Examination Surveys (NHANES II and III) provide critical information into the skewed distribution of the disease. An analysis of the NHANES II data, presented in the New England Journal of Medicine in 1982, noted that:

> "Mean levels of blood lead were higher in blacks than whites among children and adults… Young children from families (both white and black) whose incomes were under $6,000 had a significantly higher prevalence of elevated lead levels than those with incomes of $6,000 or more…. NHANES II data indicated that in the general population, blood lead values were highest among urban dwellers, especially those living in central cities, and became progressively lower as the degree of urbanization declined." (Mahaffey 1982)

A decade later, an analysis of the NHANES III data demonstrated that:

> "… the risk for lead exposure is not spread evenly throughout the pediatric population. Rather, lead hazards can be localized within neighborhoods, largely due to such factors as housing conditions, industrial emissions, or dust and soil contamination." (Pirkle 1998)

3.4.2 Impact of Diet in Elevated Blood Lead Levels

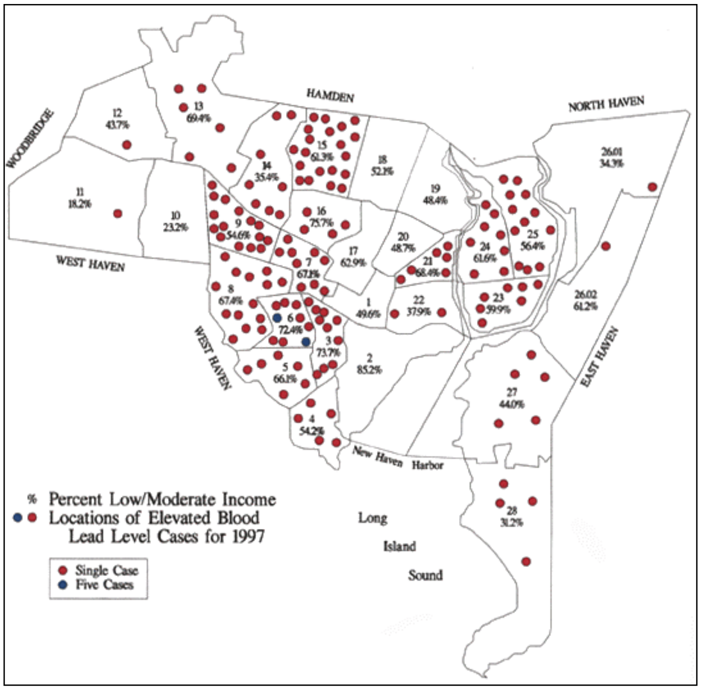
The concentration of elevated blood lead levels in minority populations living in low-income inner city communities is partly due to the increased presence of lead paint. Issues of diet further complicate lead poisoning, as low levels of iron and calcium in children's diet can increase the body's uptake of lead. As noted in an analysis of NHANES III data:

> The concentration of elevated blood lead levels in minority populations living in low-income inner city communities is partly due to the increased presence of lead paint. In addition, inadequate nutrition can further complicate lead poisoning, as low levels of iron and calcium in children's diet can increase the body's uptake of lead. (Mahaffey KR 1986; Mahaffey 1995)

3.4.3 Example of Concentrations of Elevated Blood Lead Levels in An Inner City Neighborhood

The skewed distribution of lead poisoning is illustrated by overlaying information about elevated blood lead levels with socioeconomic data. Modern census and mapping capabilities make such overlays possible, as shown in the following example which details of the concentration of lead poisoning cases in New Haven, CT. This map (see below) reveals that in every census tract but two, the areas where over 50% of families have low or moderate incomes also have, by several orders of magnitude, the greatest number of cases of elevated blood lead levels.[4]

New Haven, CT: Locations of Elevated Blood Lead Levels for 1997 by census tract



Source: New Haven Health Department

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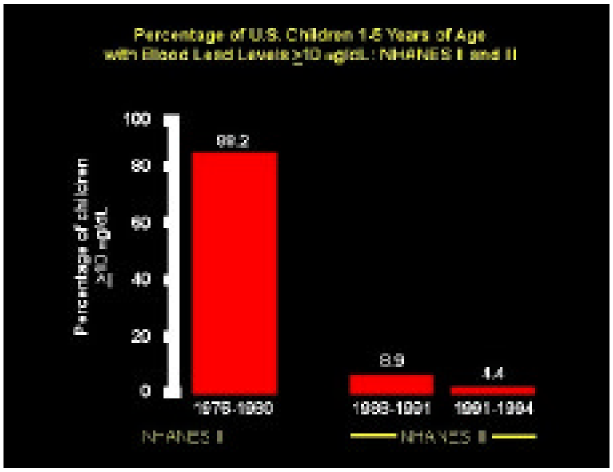
[4] Of the two low-moderate income census tracts which due not have an increased number of cases of elevated blood lead levels, one is home to a large number of Yale graduate students (poor but healthy) and the other is almost exclusively an area of heavy industry with few residential units.

The extent of the inequitable distribution of lead poisoning in the late 1990's raises questions about the nature of the supposed success of the nation's lead campaign. The past twenty years have seen a dramatic reduction children's blood lead levels (see chart below – *source: Centers for Disease Control*). At the same time, lead poisoning remains a primary health concern in low-income inner city neighborhoods. (CTDPH 1999) These high rates of localized lead poisoning are partially due to technical obstacles: it is more difficult to regulate and actually remove lead from old buildings, site by site, than it is to regulate and enforce the removal of lead from gasoline. This disparity in lead poisoning also suggests a lack of the political will and/ or moral imperative to ensure the same level of health for all children. The persistence of lead poisoning among the nation's poor, urban children points to the failure of lead policy to meet the needs of all children and as such offers a warning for future environmental health problems, including the current crisis in childhood asthma.



4 LEAD: ONE SUBSTANCE BUT MANY DIFFERENT ENVIRONMENTAL PATHWAYS

The tremendous range and persistence of lead pollution illustrates a key aspect of environmental hazards: the tendency of toxicants to enter the environment through multiple pathways and take on multiple forms of contamination. The section below will examine some of the different pathways lead can take in the environment and their subsequent impact on human health as an example of how a single pollutant can manifest itself in strikingly different ways which then necessitates different scientific and regulatory responses.

4.1 Three Key Pathways: Air, Soil and Water

Any one hazardous material can take multiple pathways in the environment. The source of airborne lead comes mostly from leaded gas. Numerous studies show a dramatic parallel in declining levels of leaded gas and blood lead levels. (USEPA 1986) (Thomas, Socolow et al. 1999) More localized airborne lead can be found near lead smelters as seen in such areas as the Superfund site near Kellogg, Idaho.

Lead in soil is related to airborne lead since lead in the air settles onto soil. This causes areas near highways to have increased levels of lead in soil, due to historic use of leaded gasoline. Leaded paint, in the form of paint chips and dust, is another source of lead in soil. (Rabin 1989; USHUD 1990) Both of these lead sources create higher levels of lead-contaminated soil in inner city communities. (Weitzman, Aschengrau et al. 1993)

The source of water-borne lead comes from leaded pipes and/ or lead solder in plumbing. To a lesser extent, plumbing fixtures can contribute lead as well (notably brass fixtures). (ATSDR 1988)

The range of pathways that lead takes through the environment has forced researchers, regulators and activists to take a broad approach to studying and controlling lead in the environment. The comprehensive aspect of lead method will be a useful model is tackling the environmental aspects of the asthma crisis. Recent research indicates that asthma has multiple triggers (Eggleston, Buckley et al. 1999), which suggests that there are multiple pathways by which air pollutants can affect respiratory health.

4.2 Lead and Mixtures

Lead poisoning does not work in isolation. There are mixture issues, as there are with many environmental health hazards. This mixture factor becomes essentially another pathway along which lead interacts with and poisons the human body. Numerous studies indicate that depletion of calcium and/ or iron can enhance uptake of lead. (Mahaffey KR

1986; Bogden JD 1992; Bruening, Kemp et al. 1999) (Cheng, Willett et al. 1997) (Quarterman J 1978) Such a mixture dynamic should be considered when examining other environmental health dynamics. An exposure to tobacco smoke may, for example, increase the susceptibility of a child's respiratory system to pollutants such as particulate matter.

5 OUTCOMES AND FURTHER QUESTIONS FROM LEAD POISONING RESEARCH AND POLICY

5.1 Trend of Decreasing Standards

Perhaps the most striking aspect of the regulation of lead is the steady decrease in acceptable blood lead levels over the past thirty-five years. Between 1965 and 1995, the standard for acceptable blood lead levels decreased from 65 mg/dL to10mg/dL. (CDC 1991) Such a dramatic decrease indicates a massive shift in both scientific understanding and public perception. The case of lead reminds us both that such shifts are possible in a relatively short time but also that our society can permit an environmental hazard to persist for years before coherent research and policy is pursued.

The current status of air pollution regulation seems to lie in the pre-1965 mindset: a hazard is detected but the extent of the problem, and the level of public will to confront it, is still untested.

5.2 Lead Poisoning and the Regulatory Process

The history of lead in the environment indicates how certain factors influence the regulatory process. With lead poisoning, a critical aspect lay in the focus on children. It was our nation's children who were being affected in ways that could haunt them the rest of their lives. This created a strong call to action.

Further, the toxicity studies for lead have been done on people, not animals, and this makes for a more compelling study. Typically, toxicological studies are carried out on laboratory animals and while this is a vital aspect of science, it nonetheless blunts the impact of research, as arguments can always be made that the reaction of a laboratory animal to a controlled dose of a substance bears only passing resemblance to the effects of chronic exposure to humans over a long time period. The clever use of human teeth and other detection breakthroughs enables lead researchers to make strong claims on the human health effects of lead exposure. (Millstone 1997)

There are also important limits to regulation. Given the distribution patterns of lead poisoning, the regulations to eliminate leaded gas and paint were laudable but elimination of lead for all industrial uses is not warranted.[5] Different use patterns create different environmental pathways with different contamination rates and regulators must consider the impact of the actual pathway in the environment.

5.3 What, if any, are acceptable dose levels?

The trend of decreasing standards raises the question of acceptable dose levels. Some would argue, as Needleman does, that there is no safe blood lead level. (Needleman 1992) Others would question the necessity or practicality of zero blood lead levels. The question hovers in any consideration of environmental health dynamics. What would be the benefit of zero exposure levels and, in our techno-industrial age, are such goals even possible? Overall, Needleman asks the right questions for his bold assertions force researchers and policy makers to confront the essential ethical, technical and social issues of the intersection of the modern global environment and the billions of people who function within it.

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[5] Analyses of the life cycle of lead batteries, for example, reveals an almost perfectly closed loop with little to no damage to the environment. (Socolow 1997; Thomas 1997)

6 LESSONS FROM LEAD

Lead is a substance with many unique properties that influence both its movement through the environment and its effect on humans. It is neither advisable nor recommended to use lead as a template for assessing the toxicology of other environmental health hazards. Air pollution, for example, involves different chemistry and different patterns of use and, correspondingly, different environmental pathways.

But a study of the science, history and policy of lead in the environment over the past millennia, with a focus on the last century, can be very informative in understanding the biases and assumptions that our society brings to the study and regulation of potential environmental hazards. The history of humankind's use, study and regulation of lead can teach us about what may lie ahead as we address the magnitude and complexity of the massive chemical and industrial revolutions of the past 100 years.

This study of lead indicates that detection is pivotal and problematic. The problems are both mechanistic, such as the need for accurate and economical detection methods, and social, such as the critical role of context and public persuasion that was needed to push lead regulation forward.

Contamination rates vary in according to attributes that we now know (age, race, gender, genetics, geography, socio-economic status) and others that we have yet to discover. Averaging contamination rates or key responses can obscure spikes that may indicate affected groups or individuals. Scale matters. Geography matters. For environmental health, it is always wise to watch which way the winds are blowing. This includes political winds, which do not uniformly consider at-risk groups.

Pollutants are hard to track as they twist and veer along different chemical pathways. The study of environmental pollutants must be creative and comprehensive in order to consider the multiple routes and forms that a pollutant can take as it moves through the environment.

The above pitfalls and problems are daunting but, as this study indicates, they are not uncharted. Humankind’s long association with lead -- marked by initial innocence, followed by serious poisonings and pain and later intensive research and ultimate regulation -- offer both warning and guidance, if we are willing to listen. This discussion of the history, science and policy of lead poisoning can offer guidance for investigation of other environmental pollutants. Air pollution, for example, is a different kind of pollutant than lead, and asthma is surely a different environmental health hazard than lead poisoning. But if we are able to look past these obvious differences, the lessons of lead become clear and can mark the foundation of a paradigm for understanding and responding to environmental health hazards now and into the future.

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