CLAIR PATTERSON’S BATTLE AGAINST LEAD POLLUTION

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ABSTRACT

Few scientists have combined their interests in the basic sciences with their passion for social welfare and moral excellence in the same way as Clair Patterson. Although Patterson’s scientific contributions merit much attention in their own right, they have also been critical in protecting environmental and human health through the elimination of leaded gasoline, paint, food packaging, and other commercial products. His work thus exemplifies how basic science can be relevant to public policy.

Patterson risked his scientific reputation by seeking to promote his research findings, even in the face of tremendous criticism, to lead to regulatory change. His distinctive personality contributed to his ultimate success. Patterson operated as if he was immune to social pressures and expectations and refused to be inconvenienced by formality, procedure, or negative media campaigns.

Patterson’s struggle also highlights the difference between two major philosophies of how to use scientific evidence to guide new regulations and illustrates the techniques used by industry to fend against regulation of industrial chemicals. While Patterson’s research led him to believe that the risks posed by the anthropogenic disruption of the natural lead budget called for immediate, large-scale action, the lead industry, represented particularly by pathologist Robert Kehoe, insisted that no regulations should be made in the absence of a scientific consensus. The lead and oil industries also produced their own, often poorly-controlled studies, limited the release of scientific data from the research they funded, and influenced governmental agencies responsible for establishing lead emission standards, in order to manufacture confusion about what was known about lead.
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INTRODUCTION

The History of the Environmental Movement

The relationship between clean water, air, and soil and the health and prosperity of nations has been long recognized; the environmental movement, however, is recent. Modern American environmentalism is the product of changes in the way people understand the relationship between man and the environment. Only a few decades ago, the average American would not have heard of environmentalism, yet today awareness of environmental issues permeates our culture, as evident in our frequent discussions of climate change, greenhouse gas emissions, nearly universal adoption of citywide recycling programs, and widespread concern over the swift depletion of natural resources. In fact, polls suggest that approximately 86% of Americans are highly concerned with the use of natural resources and the protection of the environment.[1]

Environmentalism as we know it today developed in several major phases, beginning with a focus on conservation and preservation in the mid to late 19th century,
and succeeded by a political, social, and moral movement that began in the 1920s and 1930s and expanded and evolved over subsequent decades. Three major factors were especially important in fostering the rise of the environmental movement over the past one and a half centuries: the diffusion of post-industrial social values supportive of environmental regulation, the emergence of an ecological consciousness troubled by the uncertain impacts of many industrial practices and limited resources, and the appearance of new organizations that framed important issues and guided the movement itself in an organized fashion over several decades. [2, 3]

The modern environmental movement began in the second half of the 19th century with the development of increased interest in conservation and preservation beginning around 1850. This heightened consciousness about the environment first emerged as a complex, broadly popular political and cultural movement, based largely on a growing appreciation among Americans for the importance of nature as an economic, aesthetic, and spiritual resource. Motivated by concerns over the protection of the wilderness, early environmentalists popularized a new environmental philosophy that grew out of the Progressive movement. Progressive environmentalists, led by Gifford Pinchot,1 emphasized the importance of using the government to restrain the free market and establish appropriate programs, policies and regulations to protect the environment and ensure efficient use and conservation of natural resources. A biology-centered approach

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1 Gifford Pinchot (1865 - 1946) was appointed by President Theodore Roosevelt the first chief of the United States Forest Service in 1898 and later became appointed the Chief Forester of the United States Forest Service. Under Pinchot, the number of national forests in the country increased from 32 in 1898 to 149 in 1910 and grew to include 193 million acres. Pinchot and Roosevelt worked together to make environmental conservation part of United States domestic policy.
arose in the preservationist philosophy of John Muir\textsuperscript{2} and land ethic of Aldo Leopold, \textsuperscript{3} which together resulted in the preservation of land in the form of national parks and wilderness areas. Also, during the late 19\textsuperscript{th} century, environmental groups such as the Appalachian Mountain Club (1876)\textsuperscript{4} and the Sierra Club (1892), which served mainly as lobbying organizations, were established. These groups mainly echoed the concerns of the middle-class centering upon conservation, the protection of parks and open spaces, wildlife protection, and the potential harm to the environment that could arise from industrial pollutants.

This movement continued to gain support through the early 20\textsuperscript{th} century as more governmental agencies began to focus on environmental concerns. Scenic tourism, which began as Americans traveled to see Yellowstone and other National Parks by train and eventually by car, led to a growing recognition of its economic importance. Additionally, as the United States found itself involved in the world wars, the country echoed the importance of conservation and need to unite in order to preserve our resources to support the war effort.[3]

\textsuperscript{2} John Muir (1838–1914) was the founder of the Sierra Club and is known for his promotion of the idea that the wilderness has spiritual as well as economic value. The Sierra Club was established by John Muir based on the Alpine clubs in Germany and the Appalachian Mountain Club in Boston, representing the beginning of a grass-roots environmental movement to save the forests. To this date, the Sierra Club remains an active lobbying organization.

\textsuperscript{3} Aldo Leopold (1887–1948) a professor of wildlife management, who believed that man should be viewed as a part of nature, rather than as a supreme conqueror of the environment was pivotal in the designation of Gila National Forest in New Mexico in 1924 as America's first national wilderness area. His essays, compiled posthumously in\textit{ A Sand County Almanac} (1949), had a significant influence on later biology-centered environmentalists.

\textsuperscript{4} The Appalachian Mount Club originated in Boston, and served as a model for many other environmentalist lobbying groups.
Following the vast social and economic changes that took place in the United States subsequent to World War Two (WWII), the environmental movement began gaining momentum. As incomes and standards of living rose, values changed. The expanding middle-class, which before the 1930s valued natural resources for their short-term economic utilization, became more concerned with environmental health: the importance of clean water and air and an increasing awareness of the direct relationship between industry and pollution. Public interest in the environment rested in part on aesthetic objectives; and the concern for pollution had roots in new attitudes toward the biological environment as well as towards human health. Although there were efforts to deal with urban environmental problems and waste disposal beginning in the 19th century, it was not until the 1960s that these efforts gained widespread support and led to equally widespread action.[3]

Beginning in the 1960s, the various philosophical strands of environmentalism were given expression through the establishment of political movements as activist nongovernmental organizations or environmentalist political parties. The political goals of the modern environmentalist movement in the United States and elsewhere throughout the developed world focused on changing government policy and promoting environmental social values. The 1960s were activists and employed unusual strategies, often involving protests, to draw attention to environmentally harmful policies and practices. Other methods included public-education and media campaigns, as well as conventional lobbying of policy makers and political representatives. The movement also attempted to set public examples to increase awareness of and sensitivity to environmental issues through the establishment of large-scale communal projects
including recycling, green consumerism, and the establishment of cooperative communities. Activists and scientists wrote popular books and newspaper articles to expose the harm of various industrial practices. Rachel Carson’s *Silent Spring*, written in 1962, exposed the hazards of the pesticide DDT and is credited as setting the stage for the modern environmental movement as we know it.[3] Some have stated, that during the 1960s, ecological issues “burst into American consciousness” with “unprecedented speed and urgency” as a “miracle of public opinion.”[1] The environmental movement continued to gain support until Earth Day 1970, and then began to decline rapidly until the Reagan Administration took office in 1980. The resurgence in environmental awareness was a response in part to Reagan’s lax environmental policies and in part to the introduction of new environmental concerns, including the depletion of the ozone layer, the Exxon Valdez oil spills, contamination of water supplies, and global warming, which were all heavily covered by the news media.[1, 3]

Although environmentalists have raised concerns about industrial waste products, radiation, toxic metals, pesticides, and other harmful compounds for the past half century, the impact these local pollutants could have on the global environment or upon human health was not widely acknowledged until fairly recently. Although people may have understood that a given chemical could cause harm to an individual if there was direct contact, there was no understanding of how dangerous this chemical could be to individuals with exposure to the chemical after it was released into the environment, or of how and to what extent a given chemical would accumulate in the environment and to what effect. For the most part, the wilderness was still viewed as pristine, isolated from anthropogenic pollution. This idea was perpetuated in part by popular misconceptions,
but also through rather visible industrial campaigns that emphasized the safety and necessity of their products for both human and environmental health. While the deaths of several industrial workers in the late 19\textsuperscript{th} and early 20\textsuperscript{th} centuries called attention to the fact that some industrial compounds were toxic, the effects of these substances on the environment were generally unknown since there were no accurate scientific methods to measure trace contaminants in the environment. Although environmentalists emphasized the importance of these issues, it was impossible to show definitively that impurities in the air, water and soil were accumulating unnaturally, and environmentalists were too political and activist to be taken seriously by the media and the public. Without solid evidence, there was no way to convince anyone of their views.

For this reason, enactment of regulatory changes has often required efforts by individuals within the scientific community, not only to develop the appropriate scientific methods, but also to challenge incorrect assumptions, misunderstandings, and financially-motivated disinformation campaigns about the environmental effects of new technologies and industrialization. Even though our society extols scientific advancement, there are few examples of discoveries relevant to environmental health being quickly applied in governmental policy and few scientists working to help shape those policies. Often, scientists whose work catapults them into the policy realm are viewed as activists, or – even worse – as specialists who do not have enough common sense to mind their own business.

\textbf{Clair Patterson’s Role in the “New” Environmentalism}

Clair Cameron Patterson, a geochemist from the California Institute of
Technology, realized how difficult it was to be taken seriously by both scientists and politicians as a scientist in policy working on issues which pertained to environmental and human health. After producing the first accurate uranium-lead isotope dates for the age of the Earth and the Solar System in the 1950s,[4] Patterson became a public figure in 1965 when he published “Contaminated and Natural Lead Environments of Man” as a popular article in *Archives of Environmental Health.*[5] Patterson originally began his research on lead with the intent of compiling data to be used to formulate a better understanding of the history of the Earth by determining the age of different continental plates through his technique for measuring micro-quantities of lead isotopes in sediments. But he soon felt obligated to report his findings pertaining to the accumulation of unhealthy levels of lead in the air, water, and soil. Although Patterson was not an environmentalist, he presented evidence suggesting that four decades of adding tetra-ethyl lead to automobile fuel to reduce engine knock had produced high levels of environmental lead contamination, which he believed was harmful to human and environmental health. His goals of reducing environmental lead levels by removing lead fit within the agenda of his environmentalist contemporaries.

Following Patterson’s startling revelation that there were dangerous levels of lead in the environment, Patterson continued to investigate environmental lead levels and, after realizing the magnitude of lead contamination accumulated since the beginning of the industrial era, began to find scientific evidence of its accumulation in human beings. He also found that lead in gasoline was not the only concern. Subsequent research suggested that lead used in any public goods was harmful. As Patterson continued to pursue this work, his findings were supported by several epidemiological studies showing
that young children were at especially high risk for extensive exposure to lead from sources including food packaging, glazes on pottery, pewter dishes, pesticides, and lead in paint.[6-9] Patterson argued that widespread exposure was responsible for a thousand-fold increase in the amount of lead in the bloodstream and was becoming noticeable in the population through preliminary signs of lead poisoning.[10] Although Patterson was not a health professional, he felt obligated to inform the public about the dangers of lead and urged the government to ban the addition of lead to gasoline and to change other regulations pertaining to the use of lead in public goods.

The timing of Patterson’s scientific discoveries in the midst of the acceleration of the modern-day environmental movement, along with his fiery personality, and vehement objections to his findings, primarily from those who would be hurt by anti-lead legislation, put his work on environmental lead contamination on the front pages of newspapers all over the world. In his campaign to remove lead from gasoline, he fought tirelessly against the Ethyl Corporation, DuPont, the American Petroleum Institute, the lead additive industry, government scientists, and policy makers. Nonetheless, other scientists who disputed Patterson’s findings made it difficult to convince policy makers that changes in lead regulations were necessary. It was not enough for Patterson to present his data; he also had to demonstrate that conflicting results obtained by others were due to contamination of samples and laboratory equipment and to show that the increased levels of lead in the bloodstream were indeed a health risk. Resistance to Patterson’s findings can be attributed to politics and professional pride: Patterson’s lead data had the potential to change the lead and gasoline industry, put many people out of business, and indicated that lead measurements made over the preceding decades may
have been measurements solely of contaminants.[11] Patterson, however, was determined to continue his pursuit of truth and to disseminate accurate information to the public. He worked through official channels and through informal interactions with other scientists and governmental representatives.

The Significance of Patterson’s Work

Few scientists have combined their interests in the basic sciences with their passion for social welfare, moral excellence, and social justice in the same way as Clair Patterson. Although Patterson’s scientific contributions alone merit much attention and have had a tremendous impact on basic science, not only in geology and chemistry, but also in archeology, meteorology, oceanography, and the environmental sciences, the social consequences of his scientific work have been critical in protecting environmental and human health through the elimination of lead from gasoline and from other commercial products.[12] His scientific brilliance, persistence, and gifted research capabilities resulted in key legislation to protect us from environmental lead poisoning and eventually led to changes in the food processing industry, the Clean Air Act of 1970, removal of lead from paint in 1978, and ultimately to the removal of lead from all gasoline in the United States in 1986. Lead levels within the blood of Americans dropped by more than 80% soon after these legislative changes in 1986.[13] Now, lead has been removed from most manufacturing processes in the developed world and some parts of the developing world.

Patterson’s experience in removing lead from gasoline, paint, food packaging and other goods thus exemplifies how basic science is relevant to policy decisions and
emphasizes how difficult it can be to provide sufficient scientific evidence to change public policy. In the case of lead regulation, there was substantial evidence to support the conclusion that lead in gasoline was directly linked to elevated levels of environmental lead contamination, which was having substantial health related effects on all people. Still, no legislative action could take place without a general consensus from within the scientific community and a clear understanding of what data was meaningful and reliable. Not only were there scientists and spokespersons from the lead and petroleum industries disputing Patterson’s work, but there were also disagreements within the scientific community. These arguments mainly centered on how to make policy suggestions with imperfect information. More specifically, it was difficult for various scientists to speak about threshold levels of lead which were safe to have in the environment if they were unable to take statistically relevant measurements of quantities of lead, and there was no conceivable way to measure levels of contaminants since there was no existing, non-contaminated system to which to compare samples.

Additionally, scientists faced the challenge of having to coordinate between the incompatibilities of the research world and the policy world. Patterson found, as did many other scientists, that many of the underlying methodological concerns in developing the appropriate scientific conclusions necessary to make policy recommendations cannot be adequately discussed in National Research Council (NRC) forums. The scientific community and the political community work on different time scales. While it is acceptable for academic researchers and university affiliates to take several years to develop theories and publish findings, politicians are used to producing policy recommendations with much faster response times. The inherent incompatibility
of the scientific research world and the policy world makes it difficult, therefore, for scientists to come to an agreement on how the scientific community views these issues and their relevance in policy decisions in the course of a few days a few times a year.

The lead debacle also calls attention to the difficulties in forming uniform regulation of a single substance. In this case, the regulation of lead required several different congressional hearings, NRC committee meetings, and other focus groups and coordination through several governmental agencies including but not limited to the FDA, OSHA, HUD, CDC, and the EPA, which can not be done in short meetings scattered throughout the year to develop consensus reports. This calls attention to the necessity to know where certain data is coming from, who is participating in each meeting, what potential biases are likely to surface, which scientists are performing disinterested research and which scientists might be biased by funds received from parties with an economic stake in the decisions.

Patterson’s dedication to the issue itself also introduces crucial questions about what provokes scientists to pursue these social, political and moral issues, rather than focusing intently on their scientific pursuits alone. Surely, there are other scientists whose work could have led them to venture beyond the confines of their laboratories, but they instead chose to stay quiet and focused on their science. There is something unique about Clair Patterson and the other very few scientists who chose to adopt issues of the heart, rather than just those of the mind, yielding to no one until they find answers and get results.
It was eleven o’clock PM on December 29, 1970 and the heavy wooden door to North Mudd, the geology and planetary science building at the California Institute of Technology, swung open. Under normal circumstances, only madmen and graduate students venture away from their families and into work at such an hour, but this night was not normal. Assistant Professor Clair Cameron Patterson, known as “Pat” by friends and colleagues, wasted no time as he swiftly carried his tall, thin frame from the entryway, through the long, narrow, dimly lit hallway, up two flights of steps, in through two sets of double doors and into his soundproof office. Unfortunately for Patterson, good work needed to be done and, for him, this work was urgent and could not wait until early the following morning.

Upon entering his cave, Patterson made his way to his chair and sat behind his desk, surrounded by an avalanche of papers, lab notes, maps, and books, pen in hand, while he toiled away, tormented by the painful reality that he may have been the only one
to recognize the danger introduced by increasing levels of lead in the environment. He collected his thoughts and etched his ideas onto his notepad. Patterson had been excluded from a National Review Council (NRC) committee on Biological Effects of Atmospheric Pollutants meeting on lead, and after being overlooked in favor of industrial toxicologists, it was easy for him to believe that, if it were up to anyone but himself, the lead industry would continue to compromise social welfare by allowing lead to gradually contaminate the environment. Although Patterson was a scientist, he had absolutely no intention of standing by, quiet and useless waiting for policies, founded on misconceptions of lead in the environment, to change miraculously through conventional methods. He continued to transfer his thoughts to paper, “Lawyers are not scientists and neither are government bureaucrats— and when the bureaucrats are elected by people, the majority of whom believe in astrology and do not believe in evolution, then this sort of thing can be expected. My government still does not understand what the lead exposure situation is. They are still concerned with shaded area, and still believe in thresholds.” [14]

When it came to important matters, Patterson planned out every move with extraordinary detail, and knew exactly how he wanted things done, often exhibiting his brilliance and caring nature while also being driven, uncompromising and rather unorthodox. At this point, as far as Patterson was concerned, there were only a few options: 1) run for Congress 2) convince a friend to run for Congress or 3) to write his former mentor, Harrison Brown, a member of the National Academy of Sciences, who may be able to convince others that he, as a geochemical expert on lead, should be included in the NRC meeting. Patterson was not a politician, he knew he was not a politician, and did he have a particular longing to be one; however, nothing could amount
to the dissatisfaction he felt with the way things were being handled in Washington, D.C. Since the first option was doomed to failure from the start, he began a letter to Brown[15] and began to think of how he would convince another science minded fellow, like himself, to run for political office. Bruce Murray, a Caltech professor of planetary science and geology, recalls Patterson rushing into his office, exclaiming, “Bruce, you’ve got to run for congress!” He proceeded to rant about the problems in Washington pertaining to science and technology policy and expressed his desire for change.[16]

Patterson’s unique, over-the-top, character contributed to his being greatly misunderstood both within the political arena and within academic circles. His persistence and tireless dedication to doing the right thing and pursuing scientific truth were appreciated by almost everyone that knew him. His distinctive personality has been eloquently portrayed in Saul Bellow’s novel *The Dean's December*, in which Patterson is the model for the character Sam Beech, an eccentric professor who goes to great lengths to warn people of the imminent dangers of lead.[17] The name Sam Beech was derived from the phrase “son of a bitch,” which, according to his friends and colleagues, including Bellow himself, fit Patterson well.[18] Indeed, it took a persistent “son of a bitch” to confront well respected scientists and prominent policy makers aggressively for over twenty years, and to continuously respond to letters-to-the-editors from newspapers, scientific journals, and popular magazines. These qualities took years to fully develop but were evidenced in his behavior as a young child and throughout his early adulthood, and undoubtedly contributed to his success.

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5 Saul Bellow and Patterson were good friends. Bellow was a visiting professor at Caltech and the two met each other when Patterson sat in on one of Bellow’s classes on the early 20th century novel. Pat had a lasting impact on Bellow and the two often had lunch together at the Athenaeum, Caltech’s Faculty Club.
Clair Patterson was born on June 2, 1922 in Mitchellville, Iowa, a small, traditional, rural Midwestern town. Both of his parents were liberal, college educated, and had reliable jobs: his father was a postal worker, and his mother frequently helped out at his school and was on the school’s board of directors. His parents instilled in their three children a strong work ethic, which contributed to the unusual rigor with which Patterson pursued his academic studies, and a deep sense of morality which undoubtedly aided him in the altruistic focus of his later work.[18] Patterson and his brother and sister, along with the other neighborhood children, established a sort of “tribal society”[19] in which none of the children were without other youngsters with whom to play. This close-knit interaction between the children was promoted further by schooling of all children, grades K-12, at a single school with no more than 100 students.[19, 20]

Patterson’s affinity for science and mathematics was evident at an early age and presented itself through his social and educational experiences. He enjoyed learning about plants, animals, and the geography of the areas which surrounded his home and frequently wandered off into the wilderness to navigate the great outdoors, go fishing, hunting, swimming, or to learn about the natural sciences by putting together animal bones.[19] His interest in chemistry was fostered by Patterson’s parents and teachers. His mother purchased a chemistry set for him when he was in elementary school, and by the time he was in 7th or 8th grade, he set up a lab in his basement with chemicals purchased for him by the superintendent of his school, who was also his math teacher. Beginning in 9th grade, he took an interest in learning college chemistry from some textbooks and laboratory manuals given to him by an uncle who had been a chemistry student at Iowa State College. There was no doubt he was gifted: Patterson was a top ten
finalist among high school algebra and geometry students in state-wide early tests given by the University of Iowa.[19]

His unique academic talents allowed him to take on a mentoring role in the classroom, offering explanations to other students and teachers on how the world worked scientifically. The students, teachers and parents accepted Patterson’s outspokenness and there was, according to Patterson, “no retribution for being outspoken or a dissident—if there was quality in what you were doing . . . my parents always allowed me to go off in any wild direction I wanted to go, provided it had a sound basis—if it could be demonstrated to be a worthy thing. . . I was always different from most youth.”[19]

Following his graduation from high school at the age of sixteen in 1939, Patterson went to Grinnell College. He remembered it as being “a very small, excellent college, also in Iowa. There the faculty treated us just like they were parents. There was a close interaction between the faculty and the students.”[19] The intimacy of the school, with a total of 800 students, encouraged Patterson to channel his non-conformist energy positively to his studies. While he was rather lackadaisical about mathematics, homework, and studying, he excelled in chemistry and physics. The Grinnell faculty recognized Patterson’s brilliance and allowed him to function again as a renegade, giving him the freedom to move ahead on labs and explore his passions with excitement.

At Grinnell, Patterson met his future wife, Lorna McClearly (Laurie). Although their mothers had grown up together in a small town in Iowa, they had never heard of each other prior to becoming lab partners in Chemistry. The two worked well together as a team, and Patterson’s superior scientific reasoning and advanced laboratory skills helped Laurie to receive top grades. Patterson, on the other hand, never had particularly
exceptional formal grades due to his rebellious behavior and failure to turn in many assignments, which he viewed as busy work; however, his close relationship with his chemistry professors enhanced his scientific skills and led to much academic and personal growth during this stage of his life. His chemistry professors, Leo Sherman and Bill Oelke, encouraged him to continue studying after obtaining his bachelor’s degree.[18]

Although many of Patterson’s professors recognized and embraced Patterson’s uniqueness, senior school administrators wanted to break his mold, so to speak, to prevent his non-conformist attitude from holding him back later in his life. The dean, however, was hesitant to take disciplinary action too early for fear that Patterson would rebel against punishment and drop out of college. For this reason, he waited until Patterson was close to meeting graduation requirements, and had already applied and committed to attending a masters programs, before expelling him for a few weeks.[18] Although this punishment was meant to teach Patterson the importance of respecting authority and following rules, Patterson’s future behavior shows us that this punishment was rather ineffective.

Immediately after graduating from Grinnell, Patterson began a masters program at the University of Iowa at Iowa City under the mentorship of George Glockler, a molecular spectroscopist. In keeping with his interests in physical chemistry, Patterson undertook a project pertaining to the extent of depolarization of certain modes of molecular vibration in halogenated organics using Raman spectroscopy.[12] Though he spent a great deal of time working as a teaching assistant, he managed to obtain his masters degree and complete his thesis in under nine months. There, he and Laurie
married and the couple began to be heavily focused on joining the war effort like so many of their peers. [12, 18, 19]

Patterson’s masters research, along with his strong chemistry and physics background, prepared him well to contribute to the Manhattan Project, which was being conducted at three locations: Oak Ridge in Tennessee, University of Chicago in Illinois, and Los Alamos Laboratories in New Mexico. In 1944, both Patterson and Laurie moved into an apartment in Chicago, and Patterson began doing work as an atomic spectroscopist in an analytical laboratory at the University of Chicago.[19] Patterson’s major responsibility was to run studies of trans-uranic and fission product elements, which were related to finding information concerning nuclear fission. Although they were originally excited about their ability to help the nation, they were quite “unhappy in the city, doing work we thought would ‘let the genie out of the bottle’ much too soon,”[19] and disliked the fact that they were among the youngest scientists working on this project in Chicago. After just a few months, the newlyweds returned to Iowa for just long enough for Patterson to enlist in the U.S. Army. Lorna applied for the WAVES, Women Accepted for Volunteer Emergency Service. Patterson had applied once before to the Army during his senior year of college, but was rejected because of near-sightedness. By 1944, however, the physical requirements had been lowered, and he felt he would be accepted. Three days later the draft board reported they could not draft Patterson because of his high security rating, and that he must return to the University of Chicago.[18]

The colonel in charge of the Manhattan Project at Chicago suggested Patterson and Laurie go to Oak Ridge for the duration of the war, where there were plenty of young
scientists working on electromagnetic separation of uranium, in particular the production of $^{235}$U atomic bomb fuel. Laurie had not turned in all of her required papers to join the WAVES, so they went together to Oak Ridge and began working at the Tennessee Eastman Y-12 segment of the Oak Ridge plant. Both worked in analytical labs measuring the purities of the materials used in the project. Patterson soon changed assignments and began maintaining small mass spectrometers to check isotopic purities of the enriched bomb fuel at different stages of its production.[12] These mass spectrometers were also used in analytical laboratories in academic research and would be the machine Patterson used for measurements later in his scientific career.

Following the war, many scientists who worked on the Manhattan Project, including Patterson, felt a sense of regret for the Japanese lives lost as a result of their work; however, for the most part, scientists believed what they did was imperative to protecting democracy and avoiding the loss of even more American lives in an invasion of Japan.[7] Having so many American scientists working on the Manhattan Project restored a sense of enthusiasm about physical chemistry and, as scientists returned to academia, the University of Chicago benefited greatly. Indeed, it managed to entice

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6 $^{235}$U atomic bomb fuel was produced by using large mass spectrometers with uranium hexafluoride sources, milliamp ion currents, and collector boxes of slotted graphite. These huge machines, which were called calutrons, were so enormous that their coils had to be made from the US Government’s supply of silver supplied by the treasury. The vacuum beam path of each machine was in a 15 X 20 foot plane isolated in separate steel boxes placed approximately ten feet apart from each other. The beams were wrapped, wound magnets connected in a magnetic loop approximately the size of a football field perimeter. By repeating this process multiple times, common uranium was purified and the $^{235}$U was collected between each stage of enrichment. Davidson, C.I., *Clean hands: Clair Patterson's crusade against environmental lead contamination*. 1999, Commack, N.Y.: Nova Science Publishers. xlii, 162.

7 For the rest of his life, Patterson felt deep regret for his involvement in working on “that damn bomb” and considered himself “a murderer.” Settle, D.M., *Interview with Dorothy Settle*, R. Adler, Editor. 2006: Pasadena, CA.
some of the strongest geochemists in the world, including Harold Urey,\(^8\) William Libby,\(^9\) Mark Inghram\(^10\) and Harrison Brown. Patterson and Laurie were also drawn to Chicago, where Patterson began work towards his Ph.D. under the guidance of Harrison Brown, and Laurie obtained a position as research infrared spectroscopist at the Illinois Institute of Technology to support their family while Patterson pursued his degree. \([18, 19]\)

In the 1950s, Linus Pauling suggested that the geology division offer Harrison Brown a position as a Caltech associate professor to help build up a more competitive geology program. Brown agreed to make the move from the University of Chicago and brought Patterson, Sam Epstein and Chuck McKinney along with him.\([18]\) At the time, the geology division had forgotten most of what they had learned of isotopes in elementary chemistry courses. They did not know the new students, but were willing to

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\(^8\) Harold Urey (1893-1981) is known for his research concerning the entropy of diatomic gases and problems of atomic structure, absorption spectra and the structure of molecules. In 1931 he devised a method for the concentration of any possible heavy hydrogen isotopes by the fractional distillation of liquid hydrogen: this led to the discovery of deuterium. Together with the late Dr. E.W. Washburn, he developed the electrolytic method for the separation of hydrogen isotopes and he carried out thorough investigations of their properties, in particular the vapor pressure of hydrogen and deuterium, and the equilibrium constants of exchange reactions. He later worked on the separation of uranium isotopes and the measurement of paleo-temperatures, investigations into the origin of the planets, and the chemical problems of the origin of the Earth.

\(^9\) Willard Libby (1908-1980) is known for his development of the C14 radiocarbon dating method in 1947. He tested his process on artifacts with known ages, and it was proven to be reliable for dating objects up to 70,000 years. This work not only served as a valuable tool for geologists and anthropologists to date the age of organic matter, but also won Libby the Nobel Prize for Chemistry in 1960. In 1954, while at Chicago, Libby became the first chemist appointed to the Atomic Energy Commission where he headed Eisenhower’s international ‘Atoms for Peace’ project and studied the effects of radioactive fallout.

\(^10\) Mark Inghram is known for helping to determine the age of the Earth, helping to determine the half life of radioactive carbon, but most of all for his experimental work and an inventor and developer of mass spectrometers. Of particular relevance to Clair Patterson is the fact that he permitted Patterson to use his mass spectrometer.
take risks and give them a chance. It was with great enthusiasm that these young scientists pursued their goals and made efforts to fit in, both academically and socially with the other Earth scientists. Patterson enrolled in field camp, took great interest in the departmental activities, and made extraordinary efforts to stay in shape so that he could stay healthy and participate in the various outdoor activities.\textsuperscript{11} In time, both Patterson and Epstein began to direct renovations to North Mudd into real geochemical laboratories by building their own equipment and overseeing the construction and renovation of new facilities. Robert Sharp, a Caltech geologist, recalled:

\begin{quote}
Pat’s lab was particularly difficult as he needed an ULTRA CLEAN environment in which to work. His PhD thesis at Chicago had dealt with lead-isotope ratios in iron meteorites. That work suffered lead contamination from various extraneous sources. From it Pat learned that he had to have a totally lead-free environment in order to get reliable measurements of the very small quantities of the different lead isotopes in iron meteorites. Very precise rigorous chemistry was required and no contamination could be tolerated... It was during construction of this laboratory that we all learned what a no-compromise\textsuperscript{[sic]}, intense, dedicated, demanding, zealous character we had on our hands in the person of Clair C. Patterson: a satisfactory laboratory would never have been completed without his total dedication to the task.\textsuperscript{[18]}
\end{quote}

Patterson’s work in creating the clean lab was well worth it, and since Brown did not do much laboratory work himself, the space became his entirely. With the help of Harrison Brown and Robert Sharp, Patterson secured adequate funding for his work, and he was able to conduct the experiments, obtain the data, and write the publications. Patterson\textsuperscript{11} Patterson cared a great deal about his health throughout his lifetime. He ran around a track near his home every morning, and even in his middle age, competed against high school students. He was so intense about his exercise regimen that he gave himself foot problems. He also watched what he ate. Despite his thin frame, he ate healthy portions and refrained from eating deserts and other processed foods as much as possible.
never had any great desire to package his work in a way to get funding, which made this cooperative relationship with others in his department was crucial to his success.

In 1953, Patterson was officially hired as research associate and he became not only a tremendous asset to the institute, but also somewhat of a liability.[16] His brilliant scientific contributions, which will be discussed in detail in the later sections, drew world-wide publicity from the scientific community as well as the news media. Over the course of his career, he acquired several honors, prizes, and awards including honorary degrees from Grinnell College in 1973 and the University of Paris in 1975, the J. Lawrence Smith Medal of the National Academy of Sciences in 1973, the Goldschmidt Medal of the Geochemical Society in 1980, the Professional Achievement Award from the University of Chicago in 1983. Additionally, an asteroid (2511) and a peak in the Queen Maude Mountains, Antarctica, were named for Patterson early on in his career. Patterson was elected to the National Academy of Sciences in 1987. The last and most meaningful award, the Tyler Prize for Environmental Achievement, was granted 1995, just months before his death.

The fact that Patterson was not a recluse, however, did stir up some commotion in Caltech politics and even upset a member of the board of trustees affiliated with one of the large oil corporations.[18] Patterson was intense and principled, and he was not affected by the political consequences of his actions, nor was he interested in being subtle about issues he felt were important. For this reason, he was regarded as a “loose cannon” or as “a little bit crazy”[22] by those in the department who did not completely understand him. In particular, Patterson refused to become a tenured professor out of principle, and although he received many of the benefits of being a full professor with the
exception of the higher salary, he was excused from many of the major responsibilities such as teaching classes. He believed that the people who really needed the job security were the young scientists who needed some flexibility and understanding to allow for them to make naive, creative mistakes, and that the older professors, with their wisdom and experience, should be the most productive. In accordance with these views, he underwent periodic review by the department, filing what many would consider unnecessary, annoying paperwork and actively searched for other professors who would join him in attempting to abolish the tradition of tenured jobs within the academic community.

Patterson was as dedicated to his family as he was to his science. Together, he and Laurie had four children: Cameron, Claire, Charles, and Susan.[23]
"True scientific discovery renders the brain incapable at such moments of shouting vigorously to the world “Look at what I’ve done! Now I will reap the benefits of recognition and wealth.” Instead such discovery instinctively forces the brain to thunder “We did it” in a voice no one else can hear, within its sacred, but lonely, chapel of scientific thought.”

Clair C. Patterson [24]

Clair Patterson made several seminal discoveries during his half-century long scientific career. He is widely known for having determined that the Earth is 4.55 billion years old and for recognizing that lead from anthropogenic sources had been accumulating in the environment, in some cases to toxic levels, since the Industrial Revolution. These two contributions are not independent. Instead, they form part of a progression of accomplishments that begins with Patterson’s graduate research, alongside George Tilton, Harrison Brown and Mark Inghram, developing accurate methods to measure the abundance and isotopic composition of minuscule quantities of lead in samples, which he then applied as a post-doctoral researcher to date the Earth and, during much of the remainder of his career, to study how lead emitted from anthropogenic activities affects environment and human health.
In this chapter, I will discuss four phases of Patterson’s scientific accomplishments:

**Stage 1**: Basic work in nuclear chemistry developing accurate techniques for isotopic and elemental analyses.

**Stage 2**: The refinement of the uranium-lead dating method and the application of isotope geochronology to the determination of the age of meteorites and the Earth.

**Stage 3**: The application of his analytical techniques to the measurement of lead in sediments and the development of the lead isotope system as a tracer of sediment provenance.

**Stage 4**: The examination of lead in recent environments, which led to the development of his hypothesis that anthropogenic activities were increasing environmental lead concentrations and human exposures by orders of magnitude since the Industrial Revolution.

Although Patterson’s work can be divided into four major stages, these built upon each other and were not entirely separate. Each phase of his career built upon and grew out of his previous research.

**A Brief History of Scientific Research to Determine the Age of the Earth**

The currently accepted age of the Earth stems directly from Clair Patterson’s work on radiochronometry, using radioisotopes to determine the ages of rocks. The evidence and logic that led scientists to conclude that the Earth and other parts of the
solar system are indeed 4.55 billion years old, however, grew out of a discussion that is at least as ancient as the written word.

The popular understanding of the age of the Earth originated from religious accounts of creation, popularized through various texts, many of which arrived at dramatically different conclusions. For example, the Western understanding of the age of the Earth stemmed from the creation story set forth in Genesis. In 1654, Archbishop James Ussher used a literal interpretation of Biblical chronology, combined with counting of astronomical cycles, historical accounts and numerology to calculate that God created the Earth on “the entrance of the night preceding the twenty third day of October in the year of the Julian Calendar Callendar 710,”[25] that is to say October 23, 4004 BC, thus indicating that the Earth is approximately 6,000 years old.12 According to Hindu cosmology, the Earth is measured in relation to the birth and re-birth cycle of Brahma, the creator god, and the universe is understood to be timeless. The current creation, according to this view, is believed to be in its 51st year of the present Brahma, implying that the Universe is about 155 trillion years old. By the beginning of the 18th century, however, natural scientists started to question these religious views and began to develop scientific methods to measure the age of the Earth based upon experimentation, observation, and scientifically based reasoning.

In the mid to late 1700s, the age of the Earth became “one of the most hotly debated subjects of science.”[27] Scientists interested in this question could largely be

separated into two major categories: 1) physicists who sought to calculate the age of the Earth based upon a set of initial conditions, including the cooling of the Earth and the accumulation of salt in the ocean, and 2) geologists and biologists who attempted to draw conclusions about the Earth’s age based upon observations of the rock and fossil record. The age of the Earth as calculated by physicists in the 18th and early 19th centuries varied dramatically from thousands of years\(^ {13}\) to several millions of years. Uniformitarian geologists extrapolated the Earth’s age from the vast number of different layers of rock they observed and concluded that the Earth must be millions, if not billions, of years old.\(^ {14}\) James Hutton, the founder of uniformitarianism, famously wrote that he observed “no vestige of a beginning, no prospect of an end.”\(^ {28}\)

There was no single estimate of the Earth’s age in the mid 1800’s and there was certainly no good way to arrive at one. Various attempts were made to estimate the Earth’s age, from sedimentation rates and other geological phenomena. The attempts produced estimates from about 100 million years up to several billion years. There were two major problems with such efforts: the first is that geological history was incomplete, the second is variability and incomplete knowledge of the rates of geological processes.

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\(^{13}\) Comte du Buffon, a French naturalist, pioneered the first attempt to calculate the age of the Earth in 1779. Using the assumption that the Earth was created from a solid ball of molten material, he attempted to measure the age of the Earth by calculating rate of cooling of Earth-like material, using this to infer creation taking place approximately 75,000 years ago.

\(^{14}\) Building upon Steno’s Principle of Superposition, which states that younger layers of rocks are laid down atop older rocks, William Smith of England suggested that two layers of rocks located in two different geographical locations containing the same fossilized remains were likely from the same geological time period. Using this major concept to compare various fossil remains from different locations, Smith’s student, John Phillips, calculated that the Earth was at least 96 million years old.
In 1862, British physicist William Thompson, later Lord Kelvin, estimated that the Earth was 98 million years based upon its rate of cooling. In 1897 he revised his estimate downwards to between 20 and 40 million years. Geologists were stumped by how the observed diversity of Earth’s stratigraphy could have been produced in such a short period of time. Similarly, contemporary biologists, including Charles Darwin and Thomas Huxley, were mystified by how evolution by natural selection could have possibly occurred in such a short time frame.[27]

In 1895, however, German physicist Wilhelm Roentgen observed energy being emitted from a cathode-ray tube that caused paper coated with barium platinocyanide to luminesce, even when the paper had been separated from the tube with a layer of cardboard. These invisible rays, which Roentgen called x-rays, inspired a French chemist, Henri Becquerel, to study rays emitted from uranium salts. In 1896 Becquerel found that the radiation darkened a wrapped photographic plate and induced electrical conductivity in gasses. Two years later, in 1898, Marie and Pierre Curie discovered that similar radiation was emitted from thorium, coined the phrase “radioactivity,” and determined that radioactivity was a property of specific elements. The discovery meant that a key assumption on which calculations of the age of the Earth were based, specifically that the Earth and the Sun were created at some point in the past and have

15 William Thompson, also known as Lord Kelvin, was an extremely productive scientist and over his scientific career he published more than 600 scientific papers and books on a wide range of subjects including electricity, magnetism, thermodynamics, hydrodynamics, atmospheric electricity, geomagnetism, tidal theory, and the age of the Earth. His work on dating the age of the Earth inspired primarily through his research in thermodynamics and a natural extension of his work to determine the age of the sun based upon the dissipation of heat from one body to another. His studies were largely controversial and were contested by numerous prominent geologists and physicists of the time.
been steadily cooling ever since, was incorrect. Based upon their observation that elements, like thorium, could in some circumstances release heat in the form of radiation, the Earth’s temperature now is warmer than it would be without the radiation. In this sense, a temperature calculated based upon steady cooling would produce a drastic underestimate for the age of the Earth. [27, 29]

Within a few years of the initial discovery of radioactivity, Ernest Rutherford began to characterize radioactive elements and to study their decay patterns. Through these studies and his collaboration with Fredrick Soddy, a paper was produced in 1902 which introduced a new model for rates of radioactive change by observing the exponential decay in radioactive gas emitted by thorium. This decay of the atoms in radioactive material, they concluded, occurs as an unstable parent element spontaneously degrades into a daughter element, releasing radiation in the form of alpha or beta particles. In 1903, Rutherford and Soddy published another paper suggesting that the decay products may be helium atoms. Subsequently, in 1905, Rutherford suggested that radioactivity could be used as a way to measure time in the geological record:

The helium observed in the radioactive minerals is almost certainly due to its production from the radium and other radioactive substances contained therein. If the rate of production of helium from know weights of the different radio elements were experimentally known, it should thus be possible to determine the interval required for the production of the amount of helium observed in radioactive minerals, or, in other words, to determine the age of the mineral.[27, 30]
The first attempts to use radiometric dating to measure the age of the Earth occurred shortly after the initial discovery of radioactivity; however, these efforts were futile since many of the methods and tools necessary to calculate the age of the Earth had not yet been discovered or invented and it would be several decades before radioactivity would be understood sufficiently to be useful for this purpose. These failed attempts, however, fueled even more curiosity about the stable products of the decay series of uranium, thorium, and radium and determining their abundances and half-lives.[27]

Each particular radioactive isotope of an element decays into an isotope of another element at a specific rate. The characteristic time it takes for half of a given isotope to decay is known as its half-life. As Rutherford and other scientists began to characterize the radioactive isotopes, they found that some have relatively short half-lives while others have relatively long ones. Additionally, each isotope has a characteristic

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16 The first attempt to use radioactivity to date the Earth was made by Bertram Boltwood and Rutherford in 1904. Their experiment relied on the idea that alpha particles released in the decay of radium would be trapped in the Earth’s sediments as helium atoms and not released over time. According to this thought, measuring the concentration of helium in any given sample would reveal its age. Using this technique and the half-life, they dated an Earth rock to 40 million years.

40 In 1905, Bolwood suggested lead was the final stable product of the decay of radium, and also an intermediate product from the decay of uranium. Using what he knew about radium-lead decay, he aged rocks from 250 million to 1.3 billion years old. Although his estimate of the Earth’s age was inaccurate, his paper, published in 1907 made clear that sediments from the same layers had similar uranium-lead ratios and that generally, samples from younger layers had a lower proportion of lead.

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decay series, which is a series of unstable and stable isotopes of other elements into which each radioactive isotope decays. This observation was promising for geologists who sought to use these radioactive isotopes to measure the age of the Earth. Elements like uranium and thorium were known to have half-lives long enough so that both parent and daughter isotopes remain in the Earth crust. The proportion of the parent isotope to the daughter isotope would be directly related to the Earth’s age.

Scientists continued to study and characterize the decay patterns of radioactive isotopes over the next several years. The new fields of nuclear physics and nuclear chemistry grew out of studies of radioactivity, the structure of the atom, and the measurement of isotopic abundances using sophisticated machinery including mass spectrometers and spectrographs. Leading up to World War II, there was an increased interest in learning more about the structure of the atom, subatomic particles, and the applications of the new knowledge. In 1942, the Manhattan Project began, and the nation’s physical scientists began working furiously, not only to understand more about physical chemistry, but also to employ it in new, different ways. World War II brought about a sense of unity among young scientists, and many, including Patterson, became increasingly familiar with mass spectrometry and radioactivity.
A. α radiation occurs when a nucleus of an unstable isotope emits an α particle, which is composed of two protons and two neutrons and is also equivalent to the nucleus of a helium atom. B. β radiation occurs when an unstable nucleus emits an electron. As the emission occurs, a neutron turns into a proton. According to the quantum-mechanical model of the atom, an electron's probability is zero in the nucleus, so the electron will be emitted as soon as it forms. γ radiation occurs when an unstable nucleus emits electromagnetic radiation. The radiation has no mass, so its emission does not change the element. However, gamma radiation often accompanies α and β emission (picture not shown).
<table>
<thead>
<tr>
<th>Radioactive Isotope (parent)</th>
<th>Stable Isotope (daughter)</th>
<th>Half-Life (ma)</th>
<th>Decay Constant, $\lambda$ ($\text{yr}^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{238}\text{U}$</td>
<td>$^{206}\text{Pb}$</td>
<td>4,470</td>
<td>$1.55125 \times 10^{-10}$</td>
</tr>
<tr>
<td>$^{235}\text{U}$</td>
<td>$^{207}\text{Pb}$</td>
<td>704</td>
<td>$9.8485 \times 10^{-10}$</td>
</tr>
<tr>
<td>$^{87}\text{Rb}$</td>
<td>$^{87}\text{Sr}$</td>
<td>48,800</td>
<td>$1.42 \times 10^{-11}$</td>
</tr>
<tr>
<td>$^{40}\text{K}$</td>
<td>$^{40}\text{Ca}$</td>
<td>1,250</td>
<td>$5.81 \times 10^{-11}$</td>
</tr>
<tr>
<td>$^{147}\text{Sm}$</td>
<td>$^{144}\text{Nd}$</td>
<td>106,000</td>
<td>$6.54 \times 10^{-12}$</td>
</tr>
<tr>
<td>$^{187}\text{Re}$</td>
<td>$^{187}\text{Os}$</td>
<td>43,000</td>
<td>$1.612 \times 10^{-11}$</td>
</tr>
<tr>
<td>$^{232}\text{Th}$</td>
<td>$^{208}\text{Pb}$</td>
<td>14,000</td>
<td>$4.948 \times 10^{-11}$</td>
</tr>
<tr>
<td>$^{176}\text{Lu}$</td>
<td>$^{176}\text{Hf}$</td>
<td>35,900</td>
<td>$1.93 \times 10^{-11}$</td>
</tr>
</tbody>
</table>

**Table 1: Common radioactive isotopes used in radiochronometry:** In the above table are common radioactive isotopes used in radiochronometry, their stable isotopes, and the corresponding half life. Notice the half lives and decay constants have a wide range. (ma is used to denote million years.)[27]
Figure 2: Pictorial representation of uranium-lead decay over time: Consider a rock that solidified containing both \(^{238}\text{U}\) and \(^{235}\text{U}\). \(^{238}\text{U}\) decays with a half-life of 4.47 Gyr, ending up eventually as \(^{206}\text{Pb}\), a stable lead isotope while \(^{235}\text{U}\) decays with a half-life of 710 (704) Myr, ending up eventually as \(^{207}\text{Pb}\), a different stable lead isotope. Over time, in the rock, there will be less \(^{238}\text{U}\) and even less \(^{235}\text{U}\) since it has a smaller half-life. There will also be more lead of both isotopes, but in different isotopic proportions because of the different radioactive decay rates of the parent uranium isotopes.

**Clair Patterson’s Science**

**Stage 1- Basic Work in Nuclear Chemistry**

Towards the end of the war, geochemists and geophysicists began once again to investigate aggressively the age of the Earth. Few radiometric ages of common rocks had been determined. Alfred Nier, having established quantitative relationships between various lead and uranium isotope abundances and decay rates, had measured the ages of a few uranium-ore deposits from the elemental composition of large zircon crystals, which
are rich in uranium and poor in non-radiogenic lead.[18] Although the concept of using uranium and lead isotopes to date common igneous rocks and meteorites seemed straightforward, a problem arose because there were only trace quantities of uranium and radiogenic lead in small zircon samples and there were no known methods able to measure their isotopic composition accurately.

After World War II, Harrison Brown was interested in measuring trace elemental and isotopic abundances using new, spectroscopic techniques developed during the war. As a doctoral student at Johns Hopkins University before the war, Brown had pioneered the use of the mass spectrometer in cosmochemistry for work on cobalt isotopes in the context of nuclear formation of elements in stars. This investigation led him to think about how he could use the measurements of isotopes to determine the age of the Earth from measurements of meteorites.

In 1947, Brown and Patterson published a paper which outlined the abundance of light elements: sodium, magnesium, aluminum, silicon, potassium, calcium and titanium and others, based upon the analysis of 107 separate stony meteorites. In this paper, they discussed the distribution of elements among three major phases of meteorites: 1) the silicate phase, composed of silicon, magnesium and iron oxides, 2) the metallic phase, composed primarily of iron and nickel and 3) the troilite phase, composed of iron sulfide. Although the concentration of an element could be determined in a single phase of the meteorite, the relative abundance in the entire meteorite was difficult to determine. By using the lithophile elements, which include oxygen, magnesium, calcium, sodium, potassium and titanium, which are found only in the silicate phase, they were able to calculate the abundances for individual species of light elements.[31]
After successfully determining meteorite composition, Brown suggested Patterson work with George Tilton, another graduate student, to develop new measurement techniques to analyze the isotopic composition of the minuscule quantities of uranium and lead in meteorites. Tilton was measuring uranium using alpha counting, and Patterson worked to develop chemical and mass spectrometric techniques for measuring both the abundance and isotopic compositions of trace amounts of lead in the rocks. Combining these uranium and lead data with Nier’s previous macro-scale studies and a correction factor for lead contamination would yield ages of the rocks.[12]

Patterson’s work measuring lead concentrations began in 1948 in the University of Chicago’s Kent Hall, which was overly dusty, did not have laminar air flow and air filtration, and lacked Teflon containers.[12] Nonetheless, he reduced his sample blank to 0.1 microgram per gram, which was impressive by the standards of the time. By 1950, working with milligrams of minerals separated from kilograms of rocks, Tilton and Patterson devised techniques measuring micrograms of uranium and lead that provided the first accurate radiometric ages of a ubiquitous type of igneous rock. In parallel with the lead work, Patterson participated in an experiment to determine the branching ratio for the decay of $^{40}$K to $^{40}$Ar and $^{40}$Ca. Patterson measured $^{40}$Ca within 4% of the accepted value.[32] Although most of Patterson’s future work relied upon uranium-lead and lead-lead data, he did in some of his earlier work verify his methods by looking at the ratio of $^{40}$Ar/$^{40}$K.[12]

In 1951, Patterson submitted his dissertation, which presented lead isotopic compositions for minerals separated from a billion year-old Precambrian granite. This project was inspired years earlier by Brown’s visit to the United States Geological
Society (USGS) to meet with Esper Larsen, Jr. Larsen was working on a method for
dating zircon in granite using both the alpha-lead method, which was a measure of
uranium and thorium content, and emission spectroscopy to measure the decay of
uranium and thorium.[12] Although Larsen obtained reasonable dates on rocks using this
method, Brown thought they could do better, and therefore arranged for Paterson to study
one of Larsen's rocks. Patterson obtained uranium-lead data on all of the major minerals
from the rock and found highly radiogenic lead in zircon, which showed that a common
accessory mineral in granites could be used for measuring accurate ages.

Stage 2 – Refinement of U-Pb Dating

At Caltech, Patterson continued work with Brown and hoped to determine the age
of the Earth. To measure the age of the Earth correctly, he and Brown realized they
could not rely on measurements of uranium and lead in Earth rocks alone. They believed
the constant recycling of the Earth’s crust, through plate tectonics, weathering and
erosion, adversely affected isotopic dating mechanisms. For this reason, conventional
isotopic dating methods, applied directly on samples of the Earth’s soil or rocks, would
not produce accurate measurements of the age of the Earth itself. Rather, these would
yield a measurement of that sediment’s age. To circumvent this problem, Patterson made
the assumption that the Earth was formed at the same time as the rest of the solar system.
Meteorites formed at the same time as the Earth, existed in a closed system since their
creation and contained lead and uranium of the same isotopic composition as that on
Earth. Meteorites could therefore be used to make the appropriate measurement for the
age of the Earth and the solar system.[4, 12, 19]
In 1953, Patterson began a study of the troilite phase of the Canyon Diablo iron meteorite, hoping to use the age of the meteorites to determine the age of the Earth. He chose the Canyon Diablo meteorite because it contained sulfide minerals in three distinct phases.[33] Three distinct separations between troilite, metallic nickel-iron alloys, along with silicate minerals would allow for investigation of Pb-isotopic composition and the uranium and lead concentrations. Patterson’s measurements of the meteorite were based on lead-lead dating techniques, which are rooted in the decay of the uranium isotopes $^{238}\text{U}$ and $^{235}\text{U}$, to lead isotopes, $^{206}\text{Pb}$ and $^{207}\text{Pb}$, respectively. Since the two decay processes occur at two different rates, their ratios can be used to come to a robust conclusion about a particular rock’s age.[18]

The Canyon Diablo troilite had the lowest lead ratios that had ever been measured and had extremely low concentrations of uranium. These findings indicated that its lead composition must not have changed significantly since the meteorite came to Earth, and supported the idea that Canyon Diablo could be used as an indicator of primordial lead at the creation of the solar system. Based upon this information and measurements taken later from the Columbia River Basalt and oceanic sediments, Patterson presented at a conference calculations of the Earth’s age as 4.51-4.56 billion years old.[4]

Following this success, Patterson began to focus on dating meteorites directly instead of inferring their ages from the Canyon Diablo troilite initial lead ratios. This was accomplished by measuring lead isotope ratios in two stony meteorites with spherical chondrules, which are called chondrites, and a third stony meteorites without chondrules, called achondrites.[4] To do this, Patterson sought to develop a generic connection between meteorites and the Earth by deriving the following equations:
\[ \frac{\text{Pb}^{206}}{\text{Pb}^{207}} = 9.5 + 1.014 \times \frac{\text{U}^{238}}{\text{Pb}^{204}} \]

\[ \frac{\text{Pb}^{207}}{\text{Pb}^{204}} = 10.41 + 0.601 \times \frac{\text{U}^{238}}{\text{Pb}^{204}} \]

Measurements from any two of the unknown quantities in these equations from a modern lead sample would satisfy these equations if the sample belonged to the meteoritic system. In other words, if modern Earth lead falls on the meteoritic isochron, it must have evolved in a closed system at the same time. He also sought to determine whether or not Earth sediment would satisfy the two equations by analyzing pelagic sediments, samples from the deep sea. These samples are useful since they are like “an Earth in a blender” by containing sediments from a large volume of starting material and thus may present average lead in the crust.

By using five samples, instead of one, he refined his measurement of the Earth’s age to be 4.55 ± 0.07 billion years. The co-linearity from this data set representing such a wide range of isotopic compositions indicated that the assumptions of the Pb-Pb dating method were correct and that the slope of the isochron represents the initial formation and differentiation of the meteorites and the universe (Figure 3). The isotopic ratio of common Earth leads was on the same isochron as the meteors, which supported the conclusions that “the time since the Earth attained its present mass is 4.55 ±0.07 billion years.”[4]
Stage 3 – Measurement of Lead in Sediments

After Patterson dated the Earth to 4.55 billion years, he sought to use his isotopic methods to learn more about the Earth’s history, in particular how the concentration of lead has changed through geologic time. Although he had used the uranium-lead dating method to determine the age of sediments, a problem remained. He had not yet devised a method to determine what happened to the lead on Earth over time. In 1955, he began to measure quantities of lead in various sediments from around the United States, as well as from pelagic sediments, which are marine sediments from the deep ocean.

One paper which characterizes Patterson’s work during this period was published in 1962 and discussed the occurrence and significance of lead isotopes in pelagic
Considered “encyclopedic” by some,[12] “The occurrence and significance of lead isotopes in pelagic sediments” introduced Patterson’s concern with anthropogenic lead pollution as he presented isotopic data collected from sediment samples from several locations on the sea floors of the Pacific and Atlantic using standard gravity and piston coring techniques. According to Patterson and Chow, “The aim of this study [was to] establish the mean isotopic composition of lead today in the Earth’s crust.”[34] What was more important than the average value, however, was the variability. They found a difference between lead isotopes in ocean water,\(^{18}\) as measured from manganese nodules, and lead measured directly in the pelagic sediments. Specifically, far more mechanically deposited lead accumulated in pelagic sections during the past million years than in marine sections, whereas there is more particulate lead entering marine sections than pelagic sections. Measurements published in this paper also showed that current influx of dissolved lead in pelagic areas is currently seven times greater than the input of lead into the oceanic environment one million years ago. Additionally, the consistency in variation between different sites over the course of the last million years suggested that ocean circulation patterns have been somewhat stable and that the difference in the levels of dissolved lead from the upper to lower waters results from a change in lead emission over time.[35]

Another key observation included in Chow and Patterson 1962, although not a major focus, pertained to the influx of lead resulting from industrial activities over the past several hundred years. They stated in the middle of the paper, as they are discussing the patterns of influx and efflux of lead, in the world’s oceans that:

\(^{18}\) Sections of ocean water on which isotope measurements are taken are also known as “marine sections.”
The rate at which dissolved lead is removed cannot be readily compared with the rate at which it is introduced into the oceans because of the effects of industrial contamination and large uncertainties in available analytical data... We believe that present soluble denudation is distinctly abnormal compared to the average for the last one my years.[34]

They also suggested that a large portion of the lead in young ocean water may be contaminated by mined lead. Towards the end of the paper, more information is included about the importance of investigating the specific effects of industrialization in regard to lead emission. In notes seven and eight, Patterson and Chow include rates of lead currently released into the environment and suggest “the increase in soluble lead emissions could potentially establish tracer conditions for investigating mechanisms in the weathering and marine cycles and the disadvantage of obscuring measurements of true magnitudes in these cycles.”[36] These assertions, tucked away in the midst of 46 pages of text and included as an aside in the end notes, became the focus of Patterson’s work, and motivated him to embark upon studying the impact of lead on our modern environment.

Beginning in 1963, Patterson began to closely investigate the concentration of common lead in the ocean. First, Patterson and Mitsunobu Tatsumoto from the USGS in Denver, Colorado, measured the concentration of lead collected off the coast of Southern California using isotopic dilution methods, and found that there was an abrupt decrease in lead concentrations as one moved from the surface of the ocean to the deep sea.[37] This difference, they proposed, resulted primarily from industrial contamination, the bulk of which could be attributed to the tetraethyl lead (TEL) included in gasoline.
Figure 4: Lead concentration profiles in the Atlantic and Mediterranean Oceans: At the Mediterranean and Pacific stations, lead concentrations are high in surface waters and uniformly low in deeper waters. At the Atlantic stations, the concentrations do not follow a uniform trend with depth. In general, lead concentrations at the Atlantic stations appear to increase from surface to intermediate or deep waters and decrease again in deep waters. The length of the horizontal bar at each point denotes estimated analytical uncertainty.[38]

This study was continued during the same year as Patterson and Tatsumoto collected more data to measure the influx of lead to the oceans in the Mediterranean and in the Atlantic. This time, measurements were taken to better insure the accuracy of the data and to look into some of the uncertainties that previously existed in analytical techniques and sample preparation. To establish that the increased concentration of lead at the surface of the ocean water was from TEL aerosols and not dust, snow from three separate falls was collected and analyzed from an isolated meadow near Mount Lassen Volcanic National Park. The lead in the snow samples was analyzed for silica as well as for lead, and results were normalized. They wrote, “The lead concentration in snow was found to
be 10-100 times larger than those measured in sea-water, so that only a small number of years of such precipitation are required to provide the amount of lead now present in the surface waters of the oceans of the northern hemisphere.”[39]

Results from the oceanic samples indicate that water from the past few decades in the Pacific, Atlantic and in the Mediterranean contained three to ten times more lead than older water (see figure 5). The Atlantic values, however, increases towards the mid-ocean depths for multiple reasons. First and foremost, the stations in the Atlantic were located thousands of miles away from industrial centers, thus resulting in less industrial lead contamination. Secondly, the ocean current patterns vary in different parts of the world which results in younger water towards the surface of the Mediterranean and Pacific Oceans, while the younger waters in the Atlantic are located in the intermediate and deep Atlantic.[38] This provided new evidence for disturbance in the balance of the natural geochemical cycle for lead by anthropogenic lead input and emphasized that the effects of lead contamination in the environment were not local.

Stage 4 – Measurement of Lead in the Modern Environment

Patterson’s dedication to reducing unnatural lead contamination in the environment is eloquently expressed in his first popular article, “Contaminated and Natural Lead Environments of Man,” published in 1965.[5] In this paper, he explains that the current industrial level of lead is much greater than people think by explaining the difference between natural lead levels and increased or contaminated levels. In the
process, he refuted popular misconceptions about safe levels of lead in the human blood stream. He wrote:

A prevailing belief is that industrial and natural sources contribute more or less equal amounts of lead to the body burdens of the general population. It is also commonly believed that the significant range of natural lead concentrations in the blood is not much displaced from the interval between an average natural level and the average toxic level. A new approach to this matter suggests that the average resident of the United States is being subjected to severe chronic lead insult. [40]

Patterson continued by explaining the degree to which lead was being used in industrial processing, and emphasized that the air people breathe in the northern hemisphere contains approximately 1000 times the natural level of lead. He also explained why lead is dramatically different than “other kinds of industrial filth” in that lead not only has the potential to shorten human lives, but also has a great probability of leading to “intellectual irritability and dysfunction” in those that live in large American cities.[41]

The poignant phrase “severe chronic lead insult,” which is repeated multiple times throughout the paper, along with the introduction of startling statistics and powerful descriptions of a lead filled future, clearly communicate the urgency of reducing lead in the environment. In a laundry list format at the conclusion of the paper, Patterson prioritized some issues he felt deserve consideration and support. These include:

Defining natural and toxic lead levels with greater care than in the past; investigating deleterious effects of severe chronic lead insult; investigating the dispersion of industrial lead into food chains; elimination of some of the most serious sources of lead pollution such as lead alkyls,
insecticides, food can solder, water service pipes, kitchenware glazes, and paints; and a reevaluation by persons in positions of responsibility in the field of public health of their role in the matter.[42]

It is not coincidental that these activities were, in fact, what Patterson himself ended up pursuing throughout the rest of his scientific career. This paper presents an outline for his future scientific contributions and serves as evidence that Patterson’s scientific endeavors did not change significantly over time, despite the opposition he encountered.

Following Patterson’s powerful 1965 paper, he began to publish concrete evidence to suggest that anthropogenic lead had measurable consequences. These papers, in combination, help to establish a lead budget. In one paper, “Skeletal Concentrations of Lead in Ancient Peruvians,” written with Jonathon Ericson and Hiroshi Shirahata, Patterson measured the concentration of lead in the human body introduced through anthropogenic lead pollution by comparing lead concentrations in the bones of modern humans to those in six ancient Peruvians, dated to 4900-5300 years ago.[43] The Peruvian skeletons came from arid deserts, where there was minimal lead contamination from soil moisture. Although other scientists had reported increased lead concentrations in human bones following the industrial revolution, Patterson claimed that their studies underreported the changes because they did not choose appropriate comparison specimens. He wrote, “Bones of people who lived since 4500 years bp19 in the Old World should not be analyzed for natural lead values because about 200 tons of lead per year were produced after that date.”[44] Therefore, although other authors found a difference between current and former lead levels, their data were not accurate.

19 BP, which stands for “before physics” or “before present,” is used to denote years before 1950.
After thoroughly cleaning the bones of remaining soil and potential contaminants added during the collection and transportation of the specimens, Patterson and colleagues measured lead concentration within them. The lead came from two sources: 1) lead accumulated from diet and 2) lead accumulated from soil moisture absorbed during burial. To subtract the non-biological lead sources from measurements, they measured the barium to calcium ratio as well as the lead to calcium ratio in the tooth enamel and in the bone. In natural samples, the Ba/Ca and Pb/Ca ratios are known to be approximately equal. Additionally, the ratio of lead to calcium increases with age in human skeletons. Taking these two facts into consideration, Patterson determined that the lead concentration in modern man is one hundred times greater than the lead concentrations in ancient Peruvians.

In this paper, as in the past, Patterson not only presented his scientific findings, but also emphasized the importance of acting upon the scientific knowledge in a responsible manner. In particular, he emphasized the impact of industrial lead contamination on the scientific community’s ability to measure controls, stating:

no one has yet studied natural interactions of lead in human cells, because all reagents and nutrients used in laboratory and field studies, as well as controls, have been excessively contaminated with industrial lead. Therefore, lead interactions observed now in typical human cells are probably unnatural because biochemical dysfunctions are proportional to variations in the degree of lead exposure, and present-day man is subjected to exposures that elevate concentrations of lead in skeletons about 500-fold above natural levels.[45]
He encouraged other scientists and health professionals to “deal with” and “accept” that there is a vast difference between natural concentrations of lead in humans and the current high level of lead in humans and to work to develop solutions.[45]

In 1980, Patterson wrote a key paper with Dorothy Settle called “Lead in Albacore: Guide to Lead Pollution in Americans,” which investigated one factor contributing to the dramatic difference in the amount of lead consumed by modern Americans and ancient Peruvians.[46] Patterson and Settle measured muscle from tuna, a large carnivorous fish with the smallest concentration of lead measured in biological tissue, ranging from 0.0005 to 0.03 ng/g in fish dwelling in surface sea water. They found that three different commercial brands of water-packed canned tuna and two varieties of oil packed canned tuna contained approximately 10,000 times this amount due to food handling, processing, and packaging.
Figure 5 – World lead production during the past 5500 years. The increase in lead production approximately 5000 years ago in the Old World suggests using specimens from these regions after 5000bp will result in inaccurate comparisons between ancient and current levels of lead.[47]

This information affirmed Patterson’s suspicions about lead in food packaging, and he began to urge that lead-soldered cans for food be eliminated. Although government regulatory agencies had previously measured lead in food before and after packaging, there was a poor conception of how much lead leached into the food because of other labs’ poor measurement techniques and high analytical errors, as well as a gross overestimation of safe levels of lead in the human diet. In re-doing measurements taken on plant and animal tissue in government labs, Patterson found “serious errors” in almost every case resulting in measurements of lead that were off by a factor of 1000. This led him to the conclusion that:
Clearly the regulatory agencies lack the ability to correctly monitor the extent of lead pollution. The recent decline in the quality of most lead analyses (which is correlated with the increased volume of reported data) has been caused by a failure of investigators to recognize that proper acquisition of these data in meaningful samples is a challenging research problem that cannot be dealt with merely by using sophisticated instruments that reduce sample size and increase data output. The unusual sensitivity of tuna muscle to lead pollution can be used as a monitor that, combined with reliable new knowledge of the occurrences of lead and barium in wild plant and animal ecosystems and in bones of ancient humans can reveal the true magnitude of lead contamination in Americans.[48]

Additionally, he asserted that the governmental agencies such as the Food and Drug Administration and the Environmental Protection Agency were not dealing adequately with this problem “because they cannot accommodate this knowledge within their present aims and obligations. This article places their obligations within a new context and requires that they modify their aims. Regulatory agencies must understand that an unrecognized form of lead poisoning may be affecting most Americans and a major portion of the world’s population.”[49] Given the complexities of measuring lead and the demonstrated lack of trained scientists in national laboratories and in other highly respected universities, Patterson and Settle concluded the paper with a reminder about how important it is in making measurements of lead to work in “ultraclean sanctuaries to see whether natural biochemical processes differ from those in environments excessively contaminated with industrial lead.” [50]

Patterson also conducted a number of studies looking at natural and current concentrations of lead in ice and snow packs in the Arctic and Antarctic with the aim of creating a lead budget by reconstructing the “natural, pre-human atmospheric fluxes of
this toxic heavy metal” [51] and measuring the fluxes today. [52, 53] In 1969, Murozumi et al. reported measurements taken from Greenland recent snow and ancient ice that revealed an increase in lead concentration from 1 to 200pg/g during the past 3,000 years. [54] Additionally, there was a 100-fold increase in the lead to silicate dust ratio over the same time interval. On this basis, they claimed that in the past, most lead in the troposphere came from wind-entrained soil dust naturally, while in modern times, over 99% of the lead the troposphere originates from human activities.

Following the initial proposal of this model in 1969, no other investigators had been able to control lead contamination during sample collection or laboratory analysis to confirm or duplicate the Greenland data upon which the pollution claim was based. Instead, other scientists proposed that the increased lead concentrations in the environment were produced by various large-scale natural sources of lead, including volcanoes, vegetation and rock volatilization, together with mechanisms which concentrate lead in sea spray or precipitation relative to air. In 1981, however, Ng and Patterson confirmed the original characterization of the ancient end of the Greenland temporal lead curve by Murozumi et al. through the use of improved “ultra-clean techniques.” [55] Ng and Patterson also modified the dust model to include approximately equal contribution from volcanic fumes based upon measurements of volcanic Pb/S ratios and global volcanic sulfur fluxes. By 1986, Boutron and Patterson successfully used 10-14 Antarctic ice cores to confirm the lead contribution from volcanic ash, dust, and sea salts from ocean spray using aluminum concentrations in the ice over time. Analysis of the data showed that before humans began to mine lead, there was no significant lead contribution by soil dust and volcanoes. [56]
Moving Forward

Patterson’s new measurement techniques, along with his astuteness and ability to ask the right questions, enabled him to measure levels of lead in the environment and to show definitively how substantial the anthropogenic lead contribution really was following the Industrial Revolution. Having made his claim that TEL in gasoline was a serious hazard in the 1960s, Patterson felt obligated not only to show scientifically the difference between natural and typical levels of lead in our environment, but also to work towards making changes within the scientific and political communities about how to address these quantities, as will be discussed in the next chapter.
CHAPTER 3: CAMPAIGN AGAINST LEAD

Best scientists lack the comfort of peers
Their science is always at first incredible,
Event though later it teaches more. . . .
Why do they struggle so?

Because in each discovery of new knowledge
Lies an awareness of the beauty and worth of human life,
Which enslaves them as guardians of human destiny.
-Clair Patterson August 23, 1981[57]

Lead possesses many unique properties that have contributed to its widespread use since ancient times. Because lead is non-corrosive in water, malleable, and readily available, it has been used extensively in large scale plumbing systems, architecture, construction of ships, and writing tablets. Its density and malleability make it useful for making sinkers and weights, and its low melting point make it ideal as an ingredient of solder. Its atomic configuration and color variability make it a good dye and opacifier in glass. It has been used as a pigment in makeup and paints from as early as the late Paleolithic period.[58]

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20 It is unclear when lead was first utilized since ancient texts often used words for lead, tin, zinc, arsenic, and antimony interchangeably; however, there is considerable evidence that lead was used during the pre-Hellenistic period, and was certainly referenced in ancient Hebrew and Arabic writings.

21 Lead minerals come in a variety of colors. For example, galena (PbS) is silver in color, whereas niello (an alloy of sulfur, lead, copper, or silver) is black, litharge (PbO) is yellow, grayish yellow, yellowish white, greenish yellow, bright yellow, reddish yellow or red, minium (Pb₃O₄) is bright red, and cerussite (PbCO₃) is white. Nriagu, J.O.,
Despite lead’s undeniable utility, it has not been particularly alluring; its early applications were often a byproduct of silver mining and smelting. It is suspected, with good reason, that the toxic properties of lead detracted greatly from its utility. In fact, “the first person to commercialize metallic lead was probably poisoned by the lead fumes from his or her kiln or furnace, and undoubtedly generations of artisans thorough antiquity who worked with this dangerous metal received the same rude treatment.”[59][22] Nonetheless, the economic use of lead persisted from ancient times into the modern era, and even grew substantially during the Industrial era, when it was used on a large scale in paints as a pigment, as an additive in gasoline, in food processing, and in packaging and was glamorized through aggressive advertising campaigns.

In this chapter, I will discuss the primary industrial uses of lead throughout the 20th century and how, over the course of several decades, the use of lead transitioned from being a symbol of American success and strength, to being understood as a serious hazard. This was facilitated by the scientific work of Clair Patterson following 1963, discussed in chapter two, and his extraordinary efforts to compel political figures and other prominent scientists to move away from the perception of lead as a solution to large-scale industrial problems toward a new understanding of lead as a widespread environmental and human health problem. As Patterson worked hard to affect public policy changes, he fought vehemently against coordinated efforts to thwart his studies. Patterson faced opposition not only from industry, but also from other scientists, and

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22 Lead is a neurotoxin which has the potential to cause damage to the peripheral nervous system, to blood forming organs, and to the gastrointestinal tract. Lead has been shown to decrease productivity and cause insanity and death. See Needleman’s work for more details.
encountered difficulties in regulating substances through governmental policy. Armed with knowledge and persistence, Patterson rose above these challenges.

**Lead’s Use in the 20th Century**

Following World War I, the consumer economy in the United States experienced dramatic growth. As Americans started to work fewer hours and earn higher salaries, they began to invest in the stock market, in new household items, and in some cases family vehicles, like the Ford Models A and T. Rapid technological growth, increased demand for modern conveniences, and a new sense of pride in American workmanship, transformed American society and increased economic productivity.

By the 1920s, as it became more common for families to own automobiles, the American auto industry struggled to solve a problem of engine knock.[60] 23 Engine knock, which was named after its characteristic “ping” sound, often accompanied by clanging and intense vibration of the engine’s valves and gears, was the sudden loss of engine power that occurred when the pistons in the internal combustion engine reached peak efficiency. If knock persisted for extended periods of time, or if it happened too regularly, the engine would be destroyed. Solving the problem would allow the

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23 Engine knock occurs only in engines with high compression ratios. The heat from the compression stroke is enough to detonate the fuel before the piston reaches the appropriate point.
manufacture of more powerful engines that would be able to run more efficiently on the available fuel.²⁴

In 1921, Thomas Midgley, Jr., a mechanical engineer and inventor, began working with Charles Kettering²⁵ at Dayton Engineering, where he was told to solve the knock problem.[61] As an engineer, he began learning more about the knock problem by photographing the engine as it functioned. He determined that the knock problem was caused by gasoline that was prematurely combusting in the engine cylinder. As he described, “When a spark occurs in a cylinder, a wall of flame spread out from this point. . .[However,] when any gas is heated either it must expand or its pressure must rise. They layer of gas just in the front of the flame is so intensely heated that it rises to a very high pressure, and in some cases. . .the gas in front of the flame wall is subjected to such a high pressure that it goes off with a bang—that is detonation.”[61] He began an aggressive experimental program to find a solution to the knock problem, and decided to add a dark, oil-soluble dye to gasoline, hoping that there would be a noticeable effect. Although he was unable to locate a dye that met his specifications, a stock room attendant suggested he use iodine. Much to his surprise, the iodine solution cured engine knock.

Iodine produced a foul odor and was much too expensive to serve as a marketable solution to engine knock; however, this success led Midgley to experiment with other oil-

²⁴ Knock also became a significant concern to the U.S. government since it affected cars and airplanes used by the military and therefore compromised security.
²⁵ Charles Kettering was a well known mechanical engineer and inventor who held more than 300 patents. As the inventor of the all-electric starting, ignition and lighting system for automobiles, he established himself as an important figure in the development of the auto industry and became the Vice President of General Motors Research Corporation in 1920.
soluble dyes and odorless iodine compounds.[61] In 1922, Tabby Boyd, Midgley’s assistant, synthesized a small amount of tetraethyl lead (TEL), Pb(CH₂H₅)₄, a toxin originally discovered in 1852 by a German chemist, and determined that it was a suitable solution to the knock problem.⁴ When added in quantities as small as one-twentieth of one percent, it guaranteed efficient combustion of gasoline. The resistance to premature detonation is measured by the rated octane number of the fuel. Adding TEL to gasoline raised the octane rating of the fuel, thus allowing the manufacturers to successfully use higher compression ratios, increasing the power and fuel economy.

Health authorities, however, were alarmed about the potential for wide-spread lead poisoning of workers in the gasoline refining industry, as well as members of the general public who would be exposed to exhaust from the fuel. [13, 61, 62] Midgley, Kettering and Boyd were aware of the potential problem. Boyd recalled:

> From the outset it was appreciated that putting lead in gasoline might possibly introduce a health hazard. . .The first opinions of the doctors who were consulted were full of such frightening phrases as ‘grave fevers,’ ‘distinct risk,’ ‘widespread lead poisoning’ and the like. The source of the possible hazard to health thought of at first was not so much that from the tetraethyl lead itself as that from finely divided lead dust in engine exhaust.[60]

Midgley, concerned that there were no required tests to ensure safety of the TEL by the National Institute of Occupational Safety and Health (NIOSH), sought advice from Harvard and Columbia medical schools, promising there would be “no strings attached”[63] about what would be published in scientific journals. He also attempted to

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⁴ It is called the octane number because the hydrocarbon octane was used as the standard, and pure octane has an octane rating of 100.
gather information from the U.S. Bureau of Mines, the agency that at the time was responsible for regulating automobile exhaust fumes and could investigate the exhaust of fuel with TEL as compared to fuel without it and compare toxicity.[61] The universities did not conduct studies, and industry had a direct influence on the US Bureau of Mines, which subsequently approved the use of TEL. When the Surgeon General expressed concern, Midgley responded by saying health had been “given very serious consideration . . . although no actual experimental data has been taken.”[63] He and his co-workers assumed that the harmful particles would be filtered out of the exhausted during the combustion process.

Midgley and Boyd continued to research why TEL was an efficient additive to fuel and received the first auto industry sponsored research funds not directly related to product development.[61] They discovered that TEL itself was not the chemical responsible for curing engine knock; rather, the TEL combusted in the engine with the gasoline to produce a byproduct that stopped the clanging. Midgley also conducted his own studies on leaded-fuel exhaust and concluded that there was no lead in the end product. Using these results, which later proved to be faulty, he convinced scientists and executives that there was not a significant health risk associated with the use of TEL in gasoline. He served as an advocate for the use of TEL and the new manufacturing processes that he developed.

In 1923, Midgley was contacted by a German scientist, whose identity is not known, who warned him that TEL and similar compounds were directly associated with negative health effects and, in some cases, death.[61] Though he ignored this warning,
by 1923 Migdley himself began to show signs of lead poisoning. Yet Midgley remained confident that lead, when handled correctly, could be perfectly safe. In 1924, General Motors (GM) and Standard Oil of New Jersey formed the Ethyl Corporation, which Kettering and Migdley headed as President and Vice President, respectively.\textsuperscript{27} In the spring, there were several deaths and severe illnesses among DuPont employees who worked with TEL. These cases were not publicized and leaded gasoline began to be sold under the name “Ethyl” to distance TEL from the negative connotation of lead.\textsuperscript{28}

Leaded gasoline, which was sold for \textasciitilde $0.04 more than unleaded gasoline, had immediate market success, as drivers noticed the disappearance of knock when they added the leaded fuel to their tanks.\textsuperscript{[64, 65]} By the middle of 1924, “Ethyl” in leaded gasoline had been transformed into a symbol of American prosperity, strength, and stability (See Figure 6). Realizing the potential for profit, the nascent lead industry began to exercise their political power to prevent the government from studying exhaust from leaded fuel.

\textsuperscript{27} There was a complicated “web” of corporate relationships which led to the production and sale of TEL gasoline. Du Pont, which was responsible for the production of leaded gasoline, was partially owned by GM until 1957.

\textsuperscript{28} This name was coined by Kettering, who at this point, was well aware of the health risks introduced by TEL.
Figure 6: Ethyl Controls the Giant Power of Gasoline – This advertisement from November 1924 was part of a campaign by the Ethyl Corporation to emphasize the superior strength, speed, and stability associated with the addition of “ethyl” to gasoline. At no point was it visible on advertisements that “ethyl” is tetra ethyl lead.[66]
In 1924, GM officials commissioned the U.S. Bureau of Mines, part of the Department of the Interior, to conduct a study of the effects of leaded fuel exhaust on public health. The research grant gave the Ethyl Corporation effective veto power over what could be published and publicly distributed.[67] Rather than study the effect of exhaust on the general public, the Bureau of Mines agreed to study the effects of the exposure of DuPont employees to the liquid fuel and its vapors, framing TEL as an occupational health issue rather than a more general environmental issue. GM added the stipulation that “all manuscripts, before publication, will be submitted to the Company for comment and criticism.” Two months later, the company added the word “approval” to the clause, effectively giving Ethyl Gasoline Corporation veto power over the Bureau of Mines research.[68]

Kettering and GM hired Dr. Robert A. Kehoe, a pathologist at the medical school of the University of Cincinnati, to defend the use of TEL in gasoline.[12, 62, 65] Kehoe insisted that TEL was not a health hazard and that, with the proper procedures, it

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29 Kehoe formed a long term relationship with the Ethyl Corporation and had a very successful career. Shortly after being hired by Kettering, he became the Medical Director of Ethyl Corporation. He gained scientific prominence in the mid-1920s and became the most vocal and outspoken American scientist on lead poisoning. He was very influential in the development of industrial hygiene and public health in the United States, and he became a Fellow of the American Medical Association (Vice Chairman, Council on Industrial Health); Member of the Governing Council, American Public Health Association; President of the American Academy of Occupational Medicine; Director of the Industrial Medical Association; Director and then President of the American Industrial Hygiene Association; Vice President of the Ohio Academy of Sciences; Vice President of Sigma Xi; and a recipient of many prestigious awards. Robert Kehoe and the lead industry were very closely entwined in more ways than just the theory and practice of occupational health protection—the lead industry built and equipped a laboratory for him, paid his salary (minus the $1.00 per year he received from the University of Cincinnati) Nriagu, J.O., Clair Patterson and Robert Kehoe's paradigm of "show me the data" on environmental lead poisoning. Environmental Research, 1998. 78(2): p. 71-78.
posed no harm. After instituting new procedures in Ethyl facilities, the number of DuPont employees with lead poisoning dropped by 18%, which Kehoe considered a success. Kehoe conducted numerous elaborate, dangerous and poorly controlled studies to show lead does not accumulate in the body. In one particular study, Kehoe exposed several men to lead through the air and in their food for up to five years, while exposing a control group to no non-environmental lead. During this time period, he measured the lead in their bodily fluids, including blood, feces, and urine. Since all of his subjects showed similar levels of lead, he concluded that there were significant levels of lead that were “natural” in everyone. Kehoe did not, however, measure the amount of lead in the bone, where lead accumulates. Moreover, his control group consisted of men who worked in the TEL plants and therefore had high amounts of absorbed lead in their bodies, as well as Mexican immigrants who ate from lead-glazed pottery. [69] Therefore, these studies were meaningless. Kehoe, however, proclaimed that “these necessarily extensive studies should not be repeated at present, at public expense, but that they should be continued at the expense of the industry most concerned.” [70]

Beginning in 1924, Kehoe and other members of the lead and oil industries, proposed that lead would be completely removed from gasoline if it were scientifically proven that lead was responsible for damaging human health. Those who wanted to err on the side of caution by implementing regulations on lead were painted as irrational and emotionally-driven. The table was turned against the public health experts and the Kehoe paradigm was affirmed. This way of thinking became known as the Kehoe “Show me the data” paradigm, as defined by Nriagu. [62] Dr. Kehoe was the lead industry’s right hand
man. Nearly half a century later, he would become one of Clair Patterson’s greatest opponents.

The domestic use of lead also became popular during the end of the 19th century and the beginning of the 20th century. As more families moved out of apartments and into single family homes, the production of paint and other domestic items shifted away from small, local plants to become a large-scale national industry. The train network provided a simple way to transport copious amounts of raw materials, including lead, necessary to supply the nation’s demand for plumbing, washing machines, irons, vacuums, food packaging, and most significantly paint, all of which contained large amounts of lead. In the late 19th century, the means of producing lead-based pigments, which remained the predominant basis for paints until the 1930s, was substantially improved as faster, cheaper methods for producing lead carbonate through the so-called “Dutch Process” were perfected.[64]

The new marketing schemes utilized by the United States Lead Industries Association were rather aggressive: beginning as early as 1904, but particularly in the 1920s and 1930s, they launched advertising campaigns in popular magazines promoting the use of leaded paint on interior walls, woodwork, and children’s toys, as well the use of lead in plumbing, food packaging, and solder.[64] Typically, these advertisements emphasized the health benefits of using lead in every day items. Many of the advertisements were aimed towards children. Although lead was a known neurotoxin, the lead industry worked to convince the public that lead was safe, clean, and healthy.30

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30 The campaign is discussed in great detail in the book *Deceit and Denial*. Medical research done on lead was conducted by a number of people. Most noteworthy is Herbert Needleman who conducted behavioral and medical studies at the same time as Patterson.
One particular advertising campaign spearheaded by the National Lead Company argued that “lead helps to guard your health” by making available many modern conveniences. One advertisement states, “You wouldn’t live in a house without an adequate plumbing system. For without modern plumbing, sickness might endanger your life. Lead concealed in the walls and under the floors of many modern buildings helps to give the best sanitation,”[71] (Figure 7).

Needleman and Patterson got along very well and both supported the removal of gasoline from goods.
Figure 7 – Lead helps to guard your health: This add shows the variety of ways lead is used with the home, emphasizing the importance of lead in plumbing to contribute to “health, comfort, and convenience.” This was originally published ca. 1923 in National Geographic.[71]
Figure 8- Lead Industries Association Magazine Cover: This advertisement from January, 1936 shows a stereotypical 1930s home. Here, the white walls and woodwork along with the happy men and woman in the picture place an emphasis of purity, and cleanliness and the centrality of lead in the American home.[66]
Figure 9- The drop of solder: In this advertisement, the national lead company advertises to parents emphasizing lead in cans is healthy, even in products like evaporated milk meant for young children. This particular add was published in *Saturday Evening Post* on February 23, 1946.[72]
Patterson’s Battle Begins

Lead continued to be used heavily through the middle of the twentieth century, and by the 1960s, America was inundated with lead. Leaded paint covered the walls of over 2 million homes in America and over 500,000 apartments in New York City alone.[73] Leaded gasoline accounted for 90% of all fuel sold in the US and worldwide.[74] Children’s toys were coated in lead paint, produce was grown with the use of lead-based pesticides, electronics and food packaging employed lead solder, many people ate off lead-glazed dishes were prevalent, and a significant amount of water was delivered through lead pipes. In total, over 500,000 pounds of lead was released into the atmosphere each year, and Americans in total consumed over three tons of lead annually through food. The lead industry and its affiliates had literally succeeded in creating a lead-fueled economy, and American consumers were willingly eating off their plates.

Starting in 1963, driven by his scientific findings, Patterson sought to call attention to the dangers posed by lead. He faced a great deal of opposition. Over the next three decades, his opposition came mainly in four forms: 1) direct political pressure from the lead and oil industries, 2) media bias, 3) opposition within the scientific community, and 4) difficulties inherent in the political process.

Patterson’s 1963 paper “Concentrations of Common Lead in Some Atlantic and Mediterranean Waters and in Snow,”[38] which provided evidence for disturbance of the natural geochemical cycle of lead by anthropogenic lead input and emphasized that the effects of lead contamination in the environment were non-local, caught the attention of the American public and the lead and oil industry. A footnote to this particular article
cited the American Petroleum Institute as Patterson’s funding source. They would not remain a funding source for long.\[75\] Three days after the paper’s publication, four “white shirts and ties” from the lead industry, including representatives of the Ethyl Corporation, and the petroleum industry, came to at Caltech and were waiting in Patterson’s office as he arrived. Patterson was first optimistic about their visit, assuming they were interested in the findings of his paper; however, he quickly realized he was incorrect. Patterson recalled years later that they first presented a brief resumé of their operations with the apparent aim of working out with me some way to buy me out through research support that would yield results favorable to their cause. I sat them down before a lectern and explained in principle how some future scientists would obtain explicit data showing how their operations were poisoning the environment and people with lead. I explained how this information would be used in the future to shut down their operations. They thanked me and left. Soon thereafter, the following things happened: 1) The U.S. Public Health Service\[31\] refused to renew my research contract with them. 2) The American Petroleum Institute refused to continue a substantial contract that had supported my research for years. . .They . . .not only stopped funding me, they tried to get the Atomic Energy commission to stop giving me anything—they were still giving me some money. They went around and tried to block all my funding. But I’m so stupid that I didn’t even know.\[76\]

The petroleum industry also convinced a member of the Caltech Board of Trustees, who was a vice president of the petroleum company that used TEL in gasoline, to call the President of Caltech, Lee DuBridge, about “that nut at Caltech.” DuBridge promptly called Robert Sharp, the chair of the geology division, and urged Sharp to silence

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31 which later became the FDA
Patterson. Sharp, appreciating the significance of Patterson’s work, resisted, and Patterson kept his job without any limitations.[18, 76]

In addition to canceling his grants and attempting to prevent his work from receiving public attention, the lead industry also worked aggressively to destroy Patterson’s credibility through the news media.[77] Beginning in 1963, several newspapers discounted Patterson’s work by focusing on Dr. Robert Kehoe and other lead industry allies in an attempt to create uncertainty about the effects of lead in the environment.[78-84] Herbert E. Stockinger, chief of toxicology with the U.S. Public Health Service (USPHS) in Cincinnati, Ohio, had just conducted studies and presented data which suggested there had not been increases in environmental lead levels or in the amount of lead in human blood or urine over the past several decades. Rather than address scientific concerns relating to Patterson’s studies, the lead industry attacked Patterson personally and sought to tie him to political activists of the environmental movement. Stockinger himself claimed Patterson’s conclusions were “rabble rousing . . . science fiction” and accused Patterson of “trying to be a second Rachel Carson.”[65] Multiple newspaper articles discussed Patterson’s research in the context of several contrary government and industry reports that claimed lead in the environment was not a major problem and was not created through exhaust emissions, but rather through other industrial wastes. Although these studies were scientifically unsound, they were given equal weight in the media.

32 In looking through the Archives collection, there is a noticeable pattern of U.S. Petroleum having news releases 1-2 days following a Caltech news release, geared specifically to discount the validity of Patterson’s research.
Within months of Patterson’s 1965 paper in the *Archives of Environmental Health*, Kehoe was officially re-hired out of retirement by the Lead Industry and wrote an official response to Patterson’s article, referring to Patterson as a zealot, far removed from his field and completely incompetent to address issues related to public health. Kehoe argued that Patterson was an irresponsible alarmist. He denied that the atmosphere had increased levels of lead and stated that lead concentrations in human blood are well within safe levels. [85] [77] In an interview conducted with Don G. Fowler, Director of Health and Safety for the Lead Industries Association, Kehoe said that Patterson’s results “. . . contradict all reliable medical and public health data on lead as a health hazard . . . the existing body of medical data establishes that the amount of lead consumed and retained by the public is well below the toxic levels. Furthermore, lead is not a significant factor in air pollution and represents no public health problem.”[86] In many cases, these types of statements were presented in the press without any opposing statements or chance for rebuttal. Sometimes, they were incorporation by journalists as background information in factually-inaccurate stories.

In December 1965, the USPHS sponsored a technical symposium on Environmental Lead Contamination. Over half of the participants in this symposium were from industry and included representatives from DuPont, Ethyl Corporation and the American Petroleum Institute. Several non-industry participants in the conference expressed suspicions that much of the information in support of industry was produced by Robert Kehoe and other scientists working for the Cincinnati Medical School Research Center. Dr. Harry Heimann, a physiologist at Harvard University School of Public Health stood up and said, “It is extremely unusual in medical research that there is
only one small group and one place in the country in which research in a specific area of knowledge is exclusively done.” He also expressed his disbelief of Kehoe’s use of a threshold. “To use a single figure as the safe one beyond which all poisoning will probably occur—and below which poisoning will not occur—is a most unusual kind of a situation in Public Health and in Medicine.” The conclusion of the conference did not hurt the Ethyl Corporation.

Despite the opposition, Patterson stuck firm to his course and was “driven to . . . prove [his] theoretical points unequivocally with solid experimental data.” His motivation, however, was not to prove himself right and to gain public approval, but rather to work towards a lead-free society in which health and productivity could be maximized, rather than compromised. As a follow-up to his 1965 paper, Patterson began a letter writing campaign urging state and national public officials to work towards greater regulation of lead. To change the regulation of lead, he needed to speak with as many people as possible who could potentially make a difference in lead legislation. He began his campaign in October by writing to California’s Governor, Pat Brown warning him of the dangers of lead. Stating his dissatisfaction with the way lead was being handled by the state, he wrote, “one cannot distinguish between the view of the California State Department of Public Health and the views of the Ethyl Corporation.”[87] Patterson also shared his thoughts about the treatment of environmental issues in the United States as compared to Europe. While many European countries had established ministries focused on environmental issues, the United States still relied too heavily upon local and regional approaches. He urged the governor to have the state of California act as a leader in lead legislation as it had with smog. He got no response, but would write again on
March 24, 1966.[88] 33 The second letter would lead to a July 6, 1966 bill instructing the State Department of Public Health to develop air standards for California by February 1, 1967.

On October 7, 1965, Patterson wrote a letter to Democratic Senator Edmund Muskie of Maine, chairman of the Senate Subcommittee on Air and Water Pollution.[89] Muskie had spent the previous two years holding public hearings about air quality in the United States and was a prominent figure in the Democratic Party. 34 Patterson confided in Muskie and spoke of Kehoe’s unjustified attacks on his work and his outdated belief that lead in the atmosphere was from natural sources. Subsequently, Patterson agreed to participate in the senate special subcommittee on air and water pollution held in Washington D.C. on June 15, 1966. As in the past, Ethyl depended upon Kehoe to defend them at the hearing. Unexpectedly, however, Patterson was a powerful critic.[62]

Kehoe was eloquent, concise, well spoken, and prepared. At the beginning of the hearing, he spoke, emphasizing his credentials and the fact that he “knows more about lead than anyone else in the world.”[65] After outlining his own credentials, he spoke about lead in the atmosphere, insisting there is no harm in small quantities of lead. Five days later, Patterson arrived in Washington. He had been warned ahead of time by Muskie’s aides to prepare a 15 minute statement about lead in the environment. Unfortunately, Patterson was not a good speaker and often had trouble delivering short, compelling, and direct speeches.[16] He abhorred summarizing his work and often had

33 Patterson’s second letter to CA governor got through because his secretary called Caltech to verify that Patterson was not a “nut.”
34 Muskie, who served in the Senate from 1959 to 1980, was the Democratic vice presidential candidate in 1968 and a candidate for the Democratic Presidential nomination in 1972. He served as the Secretary of State under President Jimmy Carter from May 8, 1980 until January 20, 1981.
trouble adhering to time limits when speaking at scientific conferences.[18] Prior to saying anything, he apologized to the committee saying that his statement was not “in very good shape.” He began his speech, which was densely packed with scientific facts. After Patterson spoke for 15 minutes, Muskie re-emphasized a statement made by Patterson, that “it is possible that deleterious effects to the health of large number of people are being caused by these high levels of exposure,” and through directed questioning, helped Patterson summarize his key points, specifically the difference between “natural” levels of lead and “typical” levels of lead, why this distinction had not been made by others, and why an American Medical Association committee had concluded the public does not face a health hazard due to TEL. Additionally, Patterson emphasized that the industry was attempting to disguise bad data as science in an attempt to continue the use of lead and make profit. He said:

It is clear, from the history of development of the lead pollution problem in the United States that responsible and regulatory persons and organizations concerned in this matter have failed to distinguish between scientific activity and the utilization of observations for a material purpose. [such utilization] is not science it is the defense and promotion of industrial activity. This utilization is not done objectively. It is done subjectively. It is not just a mistake for public health agencies to cooperate and collaborate with industries in investigating and deciding whether public health is endangered—it is a direct abrogation and violation of the duties and responsibilities of those public

[35] At scientific conferences, there are often red lights used to signal speakers when their time is over. Patterson was known to walk over to the light, unscrew the bulb and continue talking. (Davidson)

[36] He spoke about the extremely high levels of lead being emitted into the environment from industry and claimed that it has increased the level of lead in humans by 100-fold. He emphasized that most officials failed to understand the difference between “natural” and “normal” lead levels and cited his Greenland work showing increases of lead in snow starting with the he industrial revolution and expressed his views that it was wrong for public health agencies to work so closely with lead industries because of bias.
health organizations. In the past, these bodies have acted as though their own activities and those of lead industries in health matters were science, and they could be considered objectively in that sense.[65, 90]

Although the lead industry was satisfied with the outcome of the Senate committee hearings and Kehoe had managed to stall harmful legislation, Patterson’s testimony was able to gain public favor by painting the lead industry and associates as villains. The hearings also revealed that $480,000 of petroleum industry funds were financing a Bureau of Mines study of antiknock compounds. The newspapers reported that all the medical knowledge in favor of the lead industry had actually been provided by doctors who had been paid by the Ethyl Corporation. The fact that the lead industry had been limiting the studies that were being conducted on TEL surfaced, which led to an end of cooperation between the lead industry and universities and state and federal health agencies. These public revelations came at a critical time for the Ethyl Corporation, for the company was in the midst of a financial crisis. Not only had the patent on TEL use in gasoline expired in 1947, resulting in a substantial decrease in their market share from 100% in 1947 to 55% in 1960, but the company had just been sold in what was Wall Street’s largest leveraged buyout.37

Following the Muskie hearings, Patterson contacted other officials, including John T. Middleton, the Commissioner of the National Center for Air Pollution Control, and President Richard Nixon,[91] to advocate the use of ethanol instead of lead as a fuel

37 General Motors and Standard Oil Company of New Jersey sold Ethyl to a Virginia paper bag company a fifth Ethyl’s size in 1962. The Albemarle Paper Manufacturing Company of Richmond, Virginia borrowed the entire purchase price of $200 million from Stanford, Yale, the University of California, the Teachers Insurance and Annuity Association, and the Ford Foundation. To pay off its enormous debt, Albemarle desperately needed to continue selling TEL for ten more years.
additive. He also contacted numerous state representatives from Oregon. In a letter to Oregon State Senator Gail Holzapsal, he argued, “Lead additives in automobile gasoline serve as a crutch or a second choice economic stopgap to boost the performance of poor quality fuel, and a better solution to the problem of inadequate fuel, and one that would provide long-range economic benefits, would be to alter the refineries so as to produce high-quality fuel in the first place. . . . ethyl alcohol is a feasible substitute for lead tetraethyl as anti-knock in automotive fuels and is approximately competitive on a cost basis.”[92]

In 1970, Congress passed the Clean Air Act. Although this act did not ban lead additives from gasoline, it was the first national measure taken to empower a federal agency, the newly-created Environmental Protection Agency, to regulate fuel additives found to be harmful to the environment. Additionally, the Clean Air Act mandated the reduction of NOx emissions. One official of the Ethyl Corporation worried that the image of the company was changing from “the good guy that made engines run smoothly to the bad guy that must be eliminated if the nation wants to clean up its air.”[93]

In compliance with the Clean Air Act, General Motors and other car manufacturers began equipping cars with catalytic converters. Although the role of the catalytic converter was to reduce nitrogen oxides to nitrogen and oxygen, thus lowering NOx emissions, they also made the engines incompatible with leaded fuel. The catalytic converters used platinum as a catalyst. If lead were present in the exhaust, it would coat

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38 Oregon officials were contacted since Patterson’s campaign to remove lead from gasoline favored many of the farmers in Oregon who wished to promote the use of ethanol in fuel instead.
the platinum and render the converter ineffective.\textsuperscript{39} The development of unleaded fuel for use with catalytic converters and its widespread distribution would made it easier to ban leaded fuel, since there was already an alternative fuel.

Patterson was in high demand. Many governmental officials, medical doctors, and other scientists began soliciting his expertise. His character was an asset: people knew he would be honest with them, appealing to scientific evidence rather than emotion. This is evident in a request from George Wittenstein of the Santa Barbara Medical Society to have Patterson speak at a symposium he was organizing. He wrote:

\begin{quote}
In planning this symposium, our committee has discovered that there is a great of information, at least in the medical literature, on the long range effects of pollution on man. As you well know, a lot has been said and written by conservationists and ecologists, especially since “The Silent Spring,” but most of this has dealt only with direct and immediate effects or represented mostly speculation... We are not interested in arbitrary or emotional appeals, such as we hear form misguided conservationists, nor continuous denials, as is practiced by so much of the industry. We are instead interested in learning the facts, what is not known about the long range effects of pollution of any kind on man.[94]
\end{quote}

In November of 1970, Patterson was invited to the Food and Agricultural Organization of the United Nations to speak about the impact of lead on the health of the World’s Oceans.

The fight against the use of lead in gasoline and other common goods was not finished. Although Patterson’s position was gaining ground, there were still several areas of disagreement that existed within the scientific community. Before lead could be fully

\textsuperscript{39} The problem of knock in cars with catalytic converters was dealt with by lowering the compression ratios in the engine, which is the main reason early “smog equipped” cars ran so badly compared to others. The Japanese, notably Honda's CCV engine, solved this problem by changing the shape of the combustion chambers to reduce premature detonation, thus allowing higher compression ratios again.

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removed from all public goods, some of these issues needed to be addressed. In 1970, the National Academies assembled a panel of scientists to put together an NRC report about airborne lead to guide the EPA’s policies on lead pollution. Although Patterson had published the premier research papers about lead in the environment, he was not asked to join for fear that he was too extreme and unwilling to compromise; instead, a group including six industrial toxicologists dominated the committee.[12, 18, 75] Patterson wrote a letter to Harrison Brown expressing his frustrations with the committee chair for excluding him. He said:

I am writing to you, an officer in the National Academy of Sciences, a letter concerning the members on the Panel on Lead which is a subdivision of the Committee on Biological Effects of Atmospheric Pollutants in the Division of Medical Sciences, national Research Council. . . .The National Academy should consider that it might be a good thing to have a specialist in the geochemistry of lead on the panel. Such a person would be most likely to be aware of the nature and extent of dislocations between natural and contaminated levels of lead in the environment and thus to perhaps be more sensitive to possible deleterious effects of lead pollution. . . .I would appreciate your forwarding this letter to the appropriate person in the Academy for consideration. Thank you.[15]

Brown was unable to secure Patterson a position on the committee. As could be expected, in their evaluation of the scientific data, the committee was less forceful than Patterson wished in recognizing the dangers of lead.[75] Patterson’s work was excluded from discussion in the committee meetings and the conclusion of the committee was that environmental levels of lead were slowly increasing.[73]

Beginning in the summer of 1971, local leadership began to reduce lead levels in the environment. San Diego became the national leader in this aspect as they drafted
legislation which proposed to phase out the use of leaded gasoline in the state of California by 1974.[95] The legislation had the full support of the State Air Resources Board and partial support from the EPA but was strongly opposed by the lead industry. Although the efforts to phase out leaded gasoline were supported at the state and local level, strong lobbying efforts led by industry stalled legislation significantly. In December 1973, the EPA announced a program to reduce lead in gasoline by 60-65% in phased steps throughout the United States, and in 1974, California had phased out leaded gasoline in its entirety.
1978-1980 NRC Committee

In 1978 and 1979, a second NRC committee held hearings on lead in the human environment, and this time, Patterson was invited. The committee was empanelled to study a wide sweep of issues related to lead. These included determining the importance of various routes of human exposure, such as ingestion of lead-based paint, inhalation of airborne lead, and ingestion of lead in foods and water. The committee also was to attempt to quantify the contributions of different sources to total exposure and to potential toxic effects, to identify techniques and strategies for reducing significant lead exposures, and assess the costs and benefits of potential approaches to prevention or mitigation of the hazards of lead poisoning were to be assessed and compared.

Finally, the committee was charged with assessing research programs: identifying areas of incomplete knowledge and research needs, and reviewing the current lead related research programs of the Department of Housing and Urban Development (HUD) and other agencies of the federal government. Questions to be addressed included whether critical research needs were being pursued, and what, if any, improvements in organizational and managerial strategies were needed to enhance the value of research for the prevention of lead poisoning.

Under the leadership of Ben Ewing from the University of Illinois, Institute for Environmental Studies, the committee was to prepare a final report within 18 months, which would be used to determine whether HUD would continue to receive government funding to research lead poisoning resulting from leaded paint. Although the non-governmental representatives on the committee were prominent scientists, several of
them were directly linked to the lead and oil industries. Their influence was reflected in the way Patterson was received throughout the committee meetings.

In his opening statement, Patterson emphasized the importance of conquering five major misconceptions used to evaluate lead in the environment and used to form the basis for policy pertaining to lead emissions. Paterson told the committee that:

1) Scientific work had shown that lead in humans was concentrated at 1000 times the natural levels, elevated levels which were not healthy;
2) Lead occurs over the entire Earth and is not localized;
3) The natural biochemistry of lead was not well understood;
4) Because all cells and tissues had been subjected to pervasive environmental contamination by lead, there was no natural situation to be studied to help us learn about lead biochemistry; and
5) Lead could not be analyzed properly by most laboratories.[73]

Patterson also shared a summary of his scientific findings and identified the major source of lead in people as auto exhaust, which was worse in urban areas than in rural ones, but a global problem nonetheless. Patterson therefore proposed that studies be conducted to find the natural lead content of foods and the degree of lead contamination in them, the natural movement and distribution of lead in the ecosystem and the natural biochemical interaction of lead in the cells.

Many members of the committee disagreed with Patterson’s remarks and thought that it was unimportant to trace lead in the environment unless the “background levels are actually hazardous.”[73] Patterson said that contemporary ambient levels constituted an enormous overexposure to lead, which had clear medical implications and could have
mutagenic effects, as well as influence the immune system and intellectual functions, but was interrupted by another committee member, who argued that Patterson, as a geochemist, had no basis to draw conclusions about biology and human health. Incensed, Patterson argued that the scientific community could not know about the biochemical interactions in the human body since there are no examples of cells without lead exposure. Since there appeared to be a gradational physiological response to lead, not a threshold response, high background exposures must cause some effect. Each time Patterson spoke, he was met with a great deal of criticism, or his ideas were ignored and the meeting was dismissed. Without recognizing the real facts, he claimed, any policies or reports would be harmful to the formation of policy.

The final committee report was written as if Patterson had not participated in the meeting. Ewing, the committee chair, could not understand why Patterson was being so contrary, and argued that the forum of the committee was not appropriate for the discussions of the major methodological issues which Patterson believed were so crucial to understanding the differences between his data and those of other groups. [96] The majority report cited the need to reduce lead hazards for urban children. It stated that, while “it is well established that lead is toxic to humans at high doses,” the presence of lead does not affect all populations but instead “some members of the population.”[97] The majority report concluded that the margin between toxic and typical levels for lead in adults needs better definition and that typical atmospheric lead concentrations were 10 to 100 times the natural backgrounds for average populations and 1,000 to 10,000 times greater for urban populations. The report called for further research on these subjects, as well as on relationships between lead ingestion and intellectual ability; however, in their
synopsis of the state of lead research, they discount the differentiation made between natural and normal exposure set forth by Patterson and supported by Patterson’s work. The report states, “Further control of human exposures to lead is needed. Scientific evidence is persuasive that levels of lead in urban environments pose a significant hazard to health of some children. Other evidences suggested, less convincingly, that some risk of biological effects is associated with ‘normal’ exposures to lead from some members of the general adult population.” The report also emphasized the need for improved analytical work.

**Figure 10 – Body Burden of Lead over time:** Above is a figure illustrating the increase in lead concentration in ancient versus modern man. On the left is an illustration of Ancient Man uncontaminated by industrial lead, in the middle is modern man and on the right is an illustration of man with clinical lead poisoning. Each dot represents 40 μg of lead.[10, 98]

More infuriating to Patterson than direct references in the report discounting Patterson’s scientific data was the report’s somewhat relaxed stance on industrial uses of lead. Rather than advocating for the outright elimination of lead in all products,
including gasoline, the committee suggested a “reduction of emissions from gasoline combustion, and reduction of lead levels in food.”

Frustrated with the dismissal of the severity of the problem and the lack of concrete suggestions for how to improve air quality and reduce lead in the environment, Patterson submitted a minority report that reflects his viewpoint and his interpretation of the scientific work done on lead in the human environment. Patterson emphasized that lead in the environment was a global problem, not a local problem, and summarized his scientific evidence to support the claims. Patterson’s treatment of lead in the environment was more strongly worded than the majority report, emphasized the need for immediate, large-scale action, and criticized the notion that there can be a real threshold for lead poisoning. Patterson argued that lead needed to be removed completely from public goods to reduce environmental lead as much as possible.

Patterson’s summarized his frustrations with the outcome of the committee meeting in:

What happened there was industrial toxicologists were allowed to operate this committee through the sanction of the National Academy. I used to put in [my opinions] to this committee but was refused because the people in power had friends in industry . . . My government still does not understand what the Pb exposure situation is. They are still concerned with shaded area, and still believe in thresholds. They now believe there are lower and lower thresholds for various effects. In behavior thresholds, the threshold diminishes with the sensitivities of the test. How sensitive must the best be to detect a person who was spoiled from becoming a Curie or Einstein and only became a lawyer or political instead? The use of thresholds to detect effects is basically failed because it involves circular reasoning. Present evidence suggests that enzyme inhibition is graduation with increasing exposure and that a proper way to approach the question if harm is to describe
the biochemical process of Pb interaction at the molecular level.[99]
It is difficult to get someone to get a man to understand something when his salary depends upon his not understanding it.

Upton Sinclair

Solve the small problem before it becomes big.
The most involved fact in the world
Could have been faced when it was simple
The biggest problem in the world
Could have been solved when it was small

Lao Tzu, *The Way Of Life*

In his battle against the industrial use of lead, Clair Patterson faced two forms of intellectual opposition. The first stemmed from difficulties in obtaining a scientific consensus on facts, such as the abundance of lead in the environment and its environmental and health effects. In Patterson’s case, this opposition came because he was pioneering innovative techniques for measuring lead abundances, and also because he argued that there was no threshold level necessary for lead to have toxic effects. The second intellectual opposition stemmed from Patterson’s view of how basic scientific data should be applied in policy making. One viewpoint, which Patterson favored, is akin to the legal standard of “probable cause” and is now known by the name of the “precautionary principle.” It holds that, where there are threats of serious harm, incomplete scientific knowledge should not stand in the way of cost-effective preventative measures. An opposing viewpoint, advocated by Robert Kehoe and the oil and lead industries, holds that government action should only be taken when harm has
been proven beyond a reasonable doubt. When this was applied to lead, this approach became known as the Kehoe “Show Me the Data” Paradigm.[62] Much of the intellectual opposition is fostered by conflicts of values between science and industry evidenced by Patterson’s battle against lead. While scientists strive to acquire knowledge through logic and experimentation to find truth, businessmen and others in industry strive to make a profit by providing desired goods and services. Those organizations that benefit economically from the use of a particular substance almost always fight against its regulation.

**Difficulties in obtaining a scientific consensus**

Beginning in 1963, Patterson began to show that the increased levels of lead in the environment were associated with increases of lead in human blood, which caused negative behavioral changes and decreased cognition.40 The difference in methodology between Patterson and other scientists made it difficult to establish a scientific consensus that there was a causal relationship between lead and negative health and environmental effects. The fact that most other scientists, in university, national, and industrial laboratories, were unable to keep samples from being contaminated by high levels of background environmental lead produced unreliable data that differed from Patterson’s measurements. The poor understanding of lead biochemistry, potential sources of lead exposure and emission, and the fact that many scientists were still unsure about what levels of lead exposure could lead to deleterious effects also made it difficult to come to a consensus. Although Patterson argued that tends to occur at low levels and have cumulative effects over time, thus often rendering harm from environmental toxins

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40 Many of the behavior studies were conducted by Herbert Needleman.
difficult to observe or prove, others believed that harm resulting from lead exposure could only happen once a threshold value of lead was reached and that the effects were dramatic and all at once.[62, 80, 98]

Patterson understood that low level adverse effects pose several difficulties in scientific studies. For example, monitoring and control of industrial emissions at very low exposure levels is technically difficult and subject to wide uncertainties.[18] Taking this into account, and the fact that there is no threshold level of lead that will begin to cause health risks and that even trace amounts of lead in the environment can cause a difference in the concentration of lead in human blood and in bones, Patterson devised methods to compare the level of lead in our modern environment to the “natural” state prior to the industrial revolution.[43, 100] The recognition that there was no basis of comparison in our modern environment, however, was crucial to the creation of properly controlled studies and separated Patterson’s science from that of others.

**The use of basic science in policy**

Patterson’s second major form of intellectual opposition came in an objection to his ideas of how scientific data should be used to form policy. Patterson emphasized that, despite the absence of a scientific consensus about lead in the environment and human health, the risks were sufficiently large to require urgently changing lead regulation to eliminate the use of lead in public goods. According to Patterson, the world could not wait for other scientists to get things right before corrective action was taken.[5, 90] This
idea stood in direct contrast with Kehoe’s “Show me the data” paradigm, championed by other members of the industrial community, which argued that action should be taken to limit lead use in products if and only if there was a scientific consensus to indicate that lead caused a measurable negative impact on human health. In this way, Patterson’s approach, akin to what is now called the “precautionary principle,” can be likened to environmental policy motivated by probable cause, while the Kehoe paradigm suggests that environmental policy should be changed in response to harm being caused beyond a shadow of a doubt.

Clair Patterson was the first person to see through the ramifications of the Kehoe paradigm and to challenge them publicly.[62] Beginning in 1965, Patterson presented data to turn the tables on proponents of the Kehoe paradigm. An important cornerstone of Kehoe’s theoretical edifice was the threshold concept of lead exposure and lead toxicity. Kehoe introduced the methodological innovation of using the safe workplace concentration level of exposure as a hazard management tool in the lead industry. Within the framework of the paradigm, such quantitative estimates of acceptable exposure levels were presented as the wisdom of scientific specialists and served to discourage further inquiry by the untrained or less specialized individuals.

During the Muskie hearings, Patterson charged that the best interest of public health had not been served by having public health agencies work jointly with representatives of lead alkyl industries in evaluating the hazards of automotive lead to public health. He challenged the scientific objectivity of this cooperative studies, and scientific objectivity was key in the Kehoe paradigm. Patterson contended that voluntary
self-regulation according to the paradigm served the interest of the industry and did not protect human health.

He also challenged most of the theoretical framework developed by Kehoe and the industrial establishment in support of their position. Kehoe had maintained that lead was a natural constituent of the environment and that a certain level of lead absorption was “normal.” The concept of a “toxic limit” was another important tenet of the physiological basis for the Kehoe paradigm. Using lead content of blood as a bio-indicator of exposure, Kehoe had concluded that there was a definitive level at which point lead became a hazard. In contrast, Patterson argued that classical lead poisoning represents but one extreme of a continuum of reaction of an organism or human body to various levels of lead exposure and that there was no threshold concentration that could be detected.

Through his writings, lectures, testimonies, and appearances before congressional hearings Patterson countered the “show me the data” mentality which clouded much of the Kehoe-era work on environmental lead poisoning. Patterson’s successful challenge of the Kehoe paradigm marked the upsurge of activity and attention in the United States to the potential harm to the general public from contamination of the air with lead from industries and the automobile. Kehoe’s continuing assurance that lead poisoning was not an urgent issue began to fade away.

**The conflict between science and industry**

The intellectual challenges Patterson faced during his battle against lead highlighted pre-existing conflicts between science and industry. Given the differences in
the guiding principals between science and industry, it is no surprise as to why there is a conflict between the two when it comes to the regulation of substances. In the case of lead regulation, industry attempted to tilt scientific findings in favor of industry and increase uncertainty about the relationship among lead, human health, and environmental health. One major tool was industrial funding of scientific research pertaining to lead in the environment and human health. Through this mechanism, the industry was able to limit what data was published and the way in which studies were conducted.

Since all studies must be taken into account to obtain a scientific consensus for the basis of policy decision making, the influx of poorly designed experiments along with “cooked” data weighted the available science in favor of the industry. This problem is evident in the conflict between Patterson and the industrial scientists who were funded by the lead and oil industries with the hope that they would produce data that would foster debate and postpone a scientific consensus and subsequent regulation. Kehoe, for example, produced data that contradicted Patterson’s results; however, this was not because lead in gasoline exhaust was healthy, but rather because he was conducting poorly controlled studies. Numerous other studies funded by industry were either not published, since they produced results harmful to industry, or had data that was crafted to support a favorable outcome. When asked about this during the Muskie hearings, Patterson explained that “you can use the data to justify your purposes. If your purpose is to sell lead alkyls, then you look at these data one way. If your purpose is to guard public health, you will look at this data in another way, and you will reach different conclusions.”[101]
The financial cost of conducting scientific studies on chemical additives is often high. For this reason, industry is often a major funding source; however, although they have sufficient funds to support such studies, they are not suitable to produce data which can be used to form the basis of policy since they are able to benefit from certain results. By supporting these studies and paying scientists, the consensus obtained at NRC meetings and in the literature is essentially determined by majority vote. Allowing industrial scientists with research funded by the industry to present alongside other scientists at symposia, to participate with equal weight as others in the NRC meetings, or to carry on debates in news media furthers the impression that there is not scientific consensus among independent scientists, when, often times, this is not the case.

Additionally, it is difficult to establish blanket criteria to distinguish between valid and invalid scientific results. Further research and consulting for industry are appropriate, in their place; but any such advocacy roles should be openly acknowledged, and scientific judgments related to policy issues still need to be made. Lead legislation in particular is difficult to handle since lead was added so such a variety of products, many of which are regulated through different governmental agencies. This disjointedness means that there is no single policy-making body that is empowered to deal with total exposure in an integrated fashion. As a result, policies to protect people from excessive exposure to lead are and have been fragmented and sometimes inconsistent.\[102\] The policies that do exist are uncoordinated, and was not done with urgency, but rather because it dawned on someone to look into it.
Scientific Impact

The brilliant scientific work of Clair Patterson influenced basic science, not only in geology and chemistry, but also in archeology, meteoritics, oceanography, and the environmental sciences. Patterson’s methods for measuring minuscule quantities of lead have become one of the fundamental techniques used to decipher the Earth’s history through the application of radioactive dating. During his lifetime, Patterson invited many scholars to his own “ultraclean” laboratory to teach them his sterile techniques. These same techniques are currently being used to measure other heavy metals.

Patterson’s introduction of new methodological ideas pertaining to the measurement of environmental pollutants has also been widely accepted. When Patterson began his work, it was not well understood that the “typical” levels and the “natural” levels of lead in the environment were so different. Now, governmental agencies as well as scientists working in the geological and environmental sciences have...
adopted this idea. This is particularly evident in the report from the 1996 NRC meeting on lead.\[103\] Patterson’s ideas had to be included in a dissenting opinion in 1980; however, the 1996 report echoes Patterson’s concerns as those of the majority.

**Lead legislation**

Clair Patterson’s scientific brilliance, gifted research capabilities, and determination to continue his pursuit of truth and to disseminate accurate information to the public eventually resulted in key legislation to protect the American public from the hazards of environmental lead poisoning. These efforts not only led to changes in the food processing industry, the Clean Air Act of 1970, removal of lead from paint in 1978, and ultimately to the removal of lead from all gasoline in the United States in 1986. Lead levels within the blood of Americans dropped by more than 80% soon after these legislative changes took full effect in 1986.\[13\]

Although much of the world continued to sell leaded gasoline beyond this point, significant progress has been made to reducing the amount of lead in gasoline worldwide. While leaded gasoline once dominated the world market, leaded fuel now makes up less than 10% of sales. Figure 11 illustrates this transformation. It is important to note that not all the countries on the 2005 map including several countries in central Europe and Africa have completely implemented their regulations. As of 1999, forty countries had phased out the use of leaded gasoline.\[104\] By the end of 2005, according to the United National Environment Programme, only twenty-five countries were without official bans on leaded gasoline.\[105\]
Figure 11 – Average lead concentration in petrol in 1995 versus 2005: In this figure, the forward progress in the removal of lead from gasoline is evident. On the top, the status of leaded fuel availability from 1995 is shown.[105] On the bottom, the status of leaded fuel availability from 2005 is shown.[106] One can see that about half the world was still selling gasoline that contained lead in 1995, whereas in 2005, most countries had phased it out entirely. It is important to note, however, that some countries which are shown to sell unleaded fuel only some have not been able to successfully implement already existing legislation to ban leaded fuel. It is fair to conclude that of the countries using leaded fuel, many are in the process of transitioning to lead-free fuel.
Lead legislation is making headlines. The European Union (EU) recently banned lead’s use in the solder used on common electronics, along with mercury, cadmium, hexavalent chromium and two types of brominated flame retardants, PBB and PBDE, with enforcement to begin on July 1, 2006. China is in the process of approving similar legislation, and California is close behind, hoping to have regulations in place by January 2007. These laws have prompted electronics manufacturers to change their manufacturing processes, moving towards a new global standard. The Senate considered restrictions on lead in solder in 1991 and 1993, but the U.S. electronics industry lobbied against legislation and now, U.S. manufacturers are behind in lead-free technologies. Japanese companies are in the vanguard, closely followed by their European counterparts. [107]

Recently, there was news of a lead-scare in the U.S. caused by leaded paint used on labels for soda bottles. PepsiCo had been using leaded paint Pepsi labels on soda bottle sold in Mexico, which contained as much as 45% lead. Although these bottles, which were intended to be sold in Mexico only, many businesses sell the bottles north of the California-Mexico border. According to Proposition 65, by failing to warn consumers that the labels contained lead, PepsiCo was in violation of state law. Settling a lawsuit by the city of Los Angeles and the state of California, PepsiCo., Inc. has agreed to eliminate lead-tainted labels on bottled soft drinks imported from Mexico and will pay a $1 million civil penalty, in addition to facing an additional 4.25 million dollar fine if they fail to phase out lead-tainted labels on new bottles for products in Mexico and will take existing bottles out of circulation. PepsiCo also will pay $500,000 to a fund to monitor
whether Mexican Pepsi bottles are coming into California and to other programs on lead abatement in food. Similar to the lead and oil industries, PepsiCo officials insist that the settlement does not involve any product made in the U.S. and that the lead-labels did not compromise the safety and quality of their product, nor did they violate U.S. or Mexican safety standards. [108]

**What happened to the Lead Industry?**

Today, the National Lead Company is known as NL Industries, Inc., and, despite the decrease in the use of lead in consumer items, their business remains extremely lucrative and has a net worth well over a billion dollars.[109] They have diversified their business, and now sell a wide variety of paints through their subsidiary Kronos Worldwide, which uses titanium dioxide as an opacifier. Additionally, they specialize in ball bearings, office furniture and locks. Despite all the work by Patterson and other scientists in the latter part of the 20th century, however, the lead industry as NL Industries remains strong in their conviction that lead is not harmful to human health or the environment. In required reports submitted to the Securities and Exchange Commission (SEC), NL Industries lists several pages of legal complaints and litigation against them. After promoting, selling, and profiting from leaded paint for decades, “the Company believes that the pending lead pigment and lead-based paint litigation is without merit.”[110]

Presently, NL Industries is controlled by Harold C. Simmons, who has been found guilty of violating federal campaign contribution laws on multiple occasions.[66] “In
1993 the Federal Election Commission found Simmons guilty of violating federal campaign contribution laws. Specifically, in 1988 and 1989 Simmons exceeded the yearly $25,000 contribution limit. Simmons was fined $19,800, hardly a deterrent to someone whose estimated worth tops $1.8 billion.”[111] After being found guilty the first time, Simmons continued to break the law and on May 4, 1997, after reviewing Federal Election Commission records, Susan Feeney of the *Dallas Morning News* reported that the Simmons family and others closely affiliated with Simmons had donated at least 1.5 million dollars to Republicans since 1980. The problem, however, rests in the fact that “Two daughters, Andrea Swanson, 33, and Scheryle Patigian, 44, claim in a lawsuit over control of the family trust that Mr. Simmons made hundreds of thousands of dollars of contributions in their names without their permission in violation of federal campaign law.” Additionally, Simmons gave considerable funding to Swift Boat Veterans for Truth, which attacked Senator John Kerry’s war record in the 2004 Presidential Election.
APPENDIX:

Biographical Timeline for Clair Cameron Patterson


- Born: June 2 in Mitchville, Iowa
- M.S. in Physical Chemistry
- B.S. from Grinell College
- Goes to Grinell College
- Marries Lorna McCleary
- Begins Ph.D. at U of Chicago
- Moves to Caltech as a research fellow
- Obtains Ph.D.
- J. Lawrence Smith Medal of the National Academy of Sciences
- Goldschmidt Medal of the Geochemical Society, assistant professor
- National Academy of Sciences
- Becomes a Full Professor
- Tyler Prize
- Dies: December 5
### Clair Patterson’s Biographical Timeline

<table>
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<tr>
<th>Year</th>
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<tr>
<td>1922</td>
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<tr>
<td>1939</td>
<td>Goes to Grinnell College</td>
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<tr>
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<td>Obtains Ph.D.</td>
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<tr>
<td>1952</td>
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</tr>
<tr>
<td>1973</td>
<td>J. Lawrence Smith Medal of the National Academy of Sciences</td>
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<tr>
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<td>1995</td>
<td>Dies: December 5</td>
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### Clair Patterson’s Political Timeline

<table>
<thead>
<tr>
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<tr>
<td>1963</td>
<td>“Concentrations of Common Lead in Some Atlantic and Mediterranean Waters and in Snow”</td>
</tr>
<tr>
<td>1965</td>
<td>&quot;Contaminated and Natural Lead Environments of Man&quot;</td>
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<tr>
<td>1966</td>
<td>Muskie Hearings</td>
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<td>1970</td>
<td>Clean Air Act</td>
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<tr>
<td>1971</td>
<td>GM manufactures catalytic converter</td>
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<tr>
<td>1974</td>
<td>CA bans leaded gasoline</td>
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<tr>
<td>1978</td>
<td>NRC Committee on Lead in the Human Environment</td>
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<tr>
<td>1979</td>
<td>&quot;Skeletal Concentrations of Lead in Ancient Peruvians&quot;</td>
</tr>
<tr>
<td>1979</td>
<td>Lead paint banned in U.S.</td>
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<tr>
<td>1980</td>
<td>&quot;Lead in Albacore: Guide to Lead Pollution in Americans&quot;</td>
</tr>
<tr>
<td>1981</td>
<td>Lead food packaging banned in U.S.</td>
</tr>
<tr>
<td>1986</td>
<td>Leaded Gasoline banned in U.S.</td>
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Timeline of Clair Patterson’s Major Political Contributions Regarding Lead Legislation

1960

- Muskie Hearings
- "Concentrations of Common Lead in Some Atlantic and Mediterranean Waters and in Snow"

1965

- CA bans leaded gasoline
- "Contaminated and Natural Lead Environments of Man"

1970

- GM manufactures catalytic converter
- Clean Air Act

1975

- NRC Committee on Lead in the Human Environment
- "Lead in Albacore: Guide to Lead Pollution in Americans"

1980

- "Skeletal Concentrations of Lead in Ancient Peruvians"

1985

- Lead food packaging banned in U.S.

1990

- Leaded Gasoline banned in U.S.
- Lead paint banned in U.S.
Photographs of Clair Patterson
Left: Clair and Laurie enjoyed escaping to the Cumberlands from nearby Oak Ridge, Tennessee (1945). [23]

Middle: The University of Chicago wasn't all work and no play. Here Patterson sails on Lake Michigan (1947).[23]

Right: Right: Patterson and his family Charles, Cameron, Claire, and, in front, Susan. (1955).[23]
Above: Patterson uses a distillation apparatus to purify reagents in his Caltech lab in 1957. He didn’t trust the purity of commercial chemicals, so he produced his own. (1957)[23, 75]
Bottom Left: This was a newspaper clipping which was taped on Patterson’s monitor for years which reads: “The man who fights for his ideals is the man who is alive.” This is indicative of his character and surely, by this standard, Patterson had more life than most. [112]

Others: Photographs of Patterson in Dabney Gardens on the first commencement at Caltech after he received his honorary degree from the University of Paris. This statue was one of his favorites. (1974)[112]
Top: Patterson and Settle at Three Dollar Beach in American Somoa for a beach party for SEAREX participants before returning home to California.[112]

Bottom: Patterson in front of the mass spectrometer in the basement of North Mudd. [112]
Patterson at the Tyler Prize Ceremony: Top – Patterson with Dorothy Settle and Hirao, a Japanese post-doc  Bottom: Patterson and Settle speaking with Pierre Mennard [112]
Patterson’s family all grown up: on the front left, Susan, Charles, Cameron, Claire. In the middle, Laurie and the family dog, Tera. [112]
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