Christine of Lorraine, he reaffirms the truth of Scripture: "Holy Scripture can never lie, provided its true meaning is understood, which—I do not think it can be denied—is often hidden and very different from what a simple interpretation of the words seems to indicate" (national edition of the works of Galileo, vol. V, p. 315). Galileo introduces a principle of interpretation of the sacred books that goes beyond the literal meaning but is in accord with the intention and type of exposition proper to each of them. It is necessary, as he affirms, that "the wise men who explain it should bring out their true meaning."

Ecclesiastical authorities admit that there is more than one way to interpret the Holy Scriptures. In fact, it was explicitly stated in the encyclical *Divino afflante Spiritu* of Pius XII that there are different literary styles in the sacred books and therefore interpretations must conform to the character of each.

The various points of agreement that I have brought to mind do not only resolve all the problems of Galileo's case, but they contribute to creating a favorable starting point for their honorable solution, a state of mind propitious for an honest and straightforward resolution of old conflicts.

The existence of the Pontifical Academy of Sciences, with which Galileo was, in a sense, associated through the old institutions that preceded the one to which eminent scientists belong today, is a visible sign that shows to the people of the world, without any form of racial or religious discrimination, the profound harmony that can exist between the truths of science and the truths of faith.

Lead in Albacore: Guide to Lead Pollution in Americans

Dorothy M. Settle and Clair C. Patterson

Summary. Lead contamination in canned tuna, exceeding natural concentrations 10,000-fold, went undiscovered for decades because of analytical error. The magnitude of this pollution effect helps explain the difference between the lead concentration in the diets of present-day Americans (0.2 part per million) and in the diets of prehistoric peoples (estimated to be less than 0.002 part per million). It also explains how skeletal concentrations of lead in typical Americans became elevated 500-fold above the natural concentrations measured in bones of Peruvians who lived in an unpolluted environment 1800 years ago. It has been tacitly assumed that natural biochemical effects of lead in human cells have been studied, but this is not so because reagents, nutrients, and controls used in laboratory and field studies have been unknowingly contaminated with lead far in excess of naturally occurring levels. An unrecognized form of poisoning caused by this excessive exposure to lead may affect most Americans because magnitudes of biochemical dysfunctions are proportional to degrees of exposure.

Tuna are the only large carnivorous fish that have been carefully analyzed for lead in academic laboratories so far. It has been found that albacore muscle fresh from the sea contains the smallest concentration of lead yet measured in any biological tissue—about 0.3 nanogram per gram of fresh tissue (*1*, *2*). The nutrient medium of food precursors of tuna fish, seawater, contains the smallest concentration of lead yet measured in any natural substance on the earth—in the North Pacific, 0.005 ng per gram of biologically productive seawater and ~ 0.001 ng per gram of deep water (*3*). Still, the surface waters of the North Pacific, including a thermocline layer 0.5 kilometer thick, are believed to contain about ten times more lead than in prehistoric times (*3*) as a consequence of atmospheric inputs from smelter fumes and exhaust from combustion of leaded gasoline. The natural concentrations of lead in fresh tuna muscle and in surface seawater are estimated to have been ~ 0.03 and 0.0005 ng/g, respectively. Even with the tenfold contamination of the sea and tuna, the relatively low concentration of lead in tuna muscle makes it possible to determine the effects of additional lead contamination from food processing operations. These effects include a 20-fold increase in lead contamination from butchering and packing in unsoldered cans, a 400-fold increase from butchering, grinding, and air-drying, and a 4000-fold increase from butchering and packing in cans soldered with lead.

Administrators in the Food and Drug Administration (FDA) disregarded the discovery, published 6 years ago (*1*), that lead concentrations in fresh albacore muscle were many orders of magnitude lower than levels commonly thought to be present in fish muscle. The discovery simply had no meaning within the context of their latest aims and procedures with respect to lead in foods, and it was devalued by the largely inconsequential or inaccurate data concerning lead pollution being issued in thousands of papers, reports, reviews, and books by applied chemical and engineering research workers. This situation reached a climax in 1978, when we found that the National Marine Fisheries Service (NMFS) laboratory in Maryland had made a serious mistake in analyzing lead in tuna muscle while studying lead in seafoods on behalf of the FDA. It reported an average lead concentration of 400 ng/g [0.4 part per million (ppm)] in fresh tuna muscle (*4*) and 700 ng/g (0.7 ppm) in canned tuna (*5*), with the first value too high by a factor of 1000. This report reinforced the erroneous belief, held by the FDA, that cans soldered with lead elevate lead levels in foods only a few times above so-called normal levels.

This was not an isolated incident. The federal surveillance laboratory mentioned above is but one of thousands that analyze lead concentrations incorrectly

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in all but the most contaminated samples. The few correct analyses of lead in fresh tuna muscle that have been reported can be corroborated only in those few ultraclean laboratories in which nuclear geochemists currently try to measure ^{204}Pb in lunar rock minerals by means of isotope dilution mass spectrometry (*6*).

We and our co-workers at the biogeochemical laboratory at the California Institute of Technology (Caltech) have checked some analyses of plant and animal materials for lead that were made by laboratories that use conventional, rapid methods of lead analysis. In virtually every case, serious errors were found. Nearly all of the thousands of analyses of lead concentrations in plants, animals, and sediments reported by the Bureau of Land Management are probably wrong (*7*). All of the many analyses of lead in old stem wood of trees (*8*, *9*) are erroneously high by a factor of 1000 (*10*, *11*). Despite more than 40 years of study and measurement of the occurrence of lead in open ocean waters, it has been found that all previous analyses of lead in such waters are wrong (*12*)—most by three orders of magnitude; correct analyses of lead in open ocean waters have been reported in only one recent study (*3*). 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 (*3*, *10*, *13*–*16*), can reveal the true magnitude of lead contamination in Americans.

We measured lead, barium, and calcium concentrations in grocery-store canned tuna and anchovies, prepared and forwarded a sample of fresh tuna muscle to the NMFS laboratory in Maryland for lead and calcium analysis, measured barium and calcium concentrations in the National Bureau of Standards (NBS) tuna muscle reference material, and used these new data in combination with our earlier values for lead, barium, and calcium in tuna to prepare this article.

Sample Characteristics

Metal concentrations that we measured in canned and fresh tuna are listed in Table 1. They were determined by stable isotope dilution measurements with a high-resolution, thermal ionization source mass spectrometer and ultraclean analytical techniques in an ultraclean laboratory. Clean laboratory techniques, cleaning of ware, preparation of reagents, and dissection of fresh tuna are discussed in (*17*). Chemical dissolution and separation of lead from tuna muscle are reported in (*2*). Mass spectrometric techniques and analytical errors are given in (*7*). In cleaning of polyethylene ware, 4*N* HNO_3 was substituted for concentrated HCl; this eliminated widespread laboratory corrosion. Pure quartz dissolution vessels were used instead of Teflon whenever possible. All ware used for chemical dissolution was cleaned and then treated by simulating reagents, temperature, and times exactly; the blank lead value for dissolution and extraction in the ware was determined during a second simulated treatment ($\sim$ 0.5 ng for a 5-g sample), and the ware was then used without further cleaning. Resin columns (blank value, $\sim$ 0.7 ng) are no longer used for analyses of albacore muscle, although they are still used for bones. Reagent-grade $CHCl_3$ is now extracted with 4*N* HCl before conventional triple distillation in pure quartz; this reduces the concentration of lead in that reagent to 0.0008 ng per gram of $CHCl_3$.

Three different commercial brands of water-packed tuna in soldered cans were analyzed. Albacore muscle (100 to 300 mg) was taken from the periphery near the seam and from the center of each can. These portions were combined into a single composite sample because lead is distributed heterogeneously in the canned material. The entire composite was dissolved and analyzed in the same manner as for a high-lead sediment or soil. Two commercial brands of oil-packed tuna in soldered cans were analyzed in a similar fashion; one brand from an unsoldered can was also analyzed. Uncertainties in our metal concentration values (Table 1) amount to less than one part in ten, except for lead and barium in fresh albacore muscle, for which the values deviate from true values by less than three parts in ten.

Our samples are not intended to provide statistically representative lead concentrations for the canned tuna found on grocery shelves. They do provide a reliable measure of the large difference between lead concentrations in fresh and commercially processed tuna. Data for barium and calcium are given for comparison of the relative effects of industrial barium and lead contamination, and to correct for the lead in muscle that originates from bone fragments.

The reference material supplied by the NBS and analyzed by us consisted of fillets of muscle obtained from many albacore caught off the coast of southern California. The fillets were flown to a commercial food plant, where they were freeze-dried, powdered, mixed, and packaged in polyethylene bags. This reference material is not dried-and-ground whole fish, although it does contain small fragments of ray bone.

An anchovy was taken from the stomach of an albacore dissected in our clean laboratory. It was analyzed, and the data obtained were compared with data from analyses of anchovies packed in lead-soldered cans (Table 1). (The canned anchovy was from the Atlantic Ocean, and the anchovy from the tuna stomach was from the Pacific Ocean, but the significance of this geographic factor with respect to differences in lead concentrations is negligible in the face of the 4000-fold greater lead contamination of the canned anchovy muscle.) Metal concentrations for an entire albacore (Table 1) are calculated from separate analyses of major individual organs (*2*). Table 1 also lists concentrations of lead in albacore muscle that were determined for the FDA by the NMFS laboratory. The first value in this series is an average of data from analyses of fresh muscle from many tuna dissected by the NMFS laboratory (*4*). The second value is the lead concentration in a portion of albacore muscle dissected in the Caltech clean laboratory and shipped to the NMFS laboratory in special packages to prevent contamination. The third value is an average of data from many analyses of canned tuna (*5*).

Comparison of an estimated value for the concentration of lead in surface seawater of the prehistoric North Pacific with the present-day value (Table 1) shows that industrial lead contamination, originating mainly from leaded gasoline exhausts, has elevated lead levels by about an order of magnitude in those waters (*3*). Estimates of lead concentrations in prehistoric seawater are based on measurements of the output flux of authigenic lead in pelagic sediments and of the residence times of common lead and ^{210}Pb in the mixed layer (*3*, *18*). This contamination is passed along marine food chains, relatively un-

changed, to tuna (*13*), which is why we are able to estimate the concentration of lead in prehistoric fish muscle with some confidence.

Analytical Results

There is a 40,000-fold difference between the lead concentration that was present in prehistoric albacore muscle and that in tuna packed in lead-soldered cans. About 99.5 percent of this contamination originates from lead solder; albacore muscle packed in unsoldered cans contains only 7 ng of lead per gram. The layer of mucus that covers the fish's skin is contaminated by industrial lead in the refrigerant brines of fishing boats (*2*) and the thawing brines of packing plants, or by lead-containing dusts, lubricants, and alloys on machinery at the plants. This lead is transferred to meat during the first cooking step and subsequent filleting and deboning before canning. About 0.5 percent of the lead in tuna packed in lead-soldered cans, and most of the lead in tuna in unsoldered cans, originates from this source. Only about 0.01 percent of the industrial lead in tuna packed in lead-soldered cans comes from industrial lead pollution in the seas. Very little comes from the lacquered inner lining of the can, since the lead content of that lining is $\leq$ 20 ppm (*19*). The concentration of lead in tuna bone is 100-fold higher than in tuna muscle (*2*), so small bone fragments in canned tuna could contribute some lead. But as Table 1 shows, contributions of lead by bone fragments in tuna muscle are negligible because the amount of bone calcium in canned tuna is only 14 ppm (36 ppm total calcium minus 22 ppm calcium in muscle cells leaves 14 ppm bone fragment calcium in canned tuna muscle), which would contribute less than 0.0005 percent of the lead in tuna packed in lead-soldered cans.

Since other reports show an average lead concentration of 700 ng/g in tuna packed in lead-soldered cans (*5*) and of 500 ng/g in other foods in lead-soldered cans (*20, 21*), the average concentration of lead in canned tuna may be less than the 1400 ng/g reported by Caltech (Table 1). Overall the lead contamination in canned tuna is about 10,000-fold above natural levels.

The concentration of barium in albacore muscle today is not substantially higher than it was in prehistoric times (Table 1), even with the contamination introduced during drying and grinding, or butchering and packing the meat in cans soldered with and without lead and in polyethylene bags. The slightly elevated barium concentrations in albacore muscle and whole anchovies oil-packed in cans soldered with lead may be due to natural variations in the barium content of seawater and food chain precursors rather than to the oil. In any case, such twofold increases are inconsequential compared to the 10,000-fold increases in contamination caused by industrial lead.

The NBS reference material and the fish dissected at Caltech under clean laboratory conditions came from fish collected at the same time and place. Therefore, the 400-fold greater lead concentration in the NBS reference material (on a fresh-weight basis) was due to industrial lead contamination during commercial drying and pulverizing. Thus a common food-processing technique is contaminating food with industrial lead at the 400 ng/g level. The bone calcium content in the NBS reference material (96 ppm total calcium minus 22 ppm muscle calcium gives 74 ppm bone calcium) is modest compared to that in muscle (22 ppm); lead from tuna bone contributes only 0.04 percent of the lead in the reference material. It is impossible, from a mass inventory standpoint, for more than 10 percent of the lead in the NBS reference material to originate from contaminated fish skin mucus. The analysis of commercial tuna not packed in lead-soldered cans proves this.

The total lead concentration for an albacore (Table 1) shows that lead concentrations in muscle tissue are ~ 1/20 of those in the whole fish. If this factor applies to lead concentrations in fresh anchovy muscle, then, after correcting for lead contamination from bone tissue, the concentration of lead in canned anchovy muscle (~ 4000 ng/g) represents a 40,000-fold increase over the concentration of lead in anchovy muscle in prehistoric times (~ 0.1 ng/g).

There is a 1000-fold error in the lead concentration reported by the NMFS laboratory when they dissect, handle, and analyze tuna muscle. Part of the error is due to lead contamination introduced during dissection and handling in their laboratory; thus they reported a smaller concentration of lead when they analyzed muscle that had been dissected in the Caltech laboratory, sealed in ultraclean containers, and shipped with special instructions for opening the containers and transferring the samples to dissolution dishes. The magnitudes of the errors caused by improper sample preparation and improper analysis are 20-fold and 50-fold, respectively ($20 \times 50 = 1000$). The difference in lead concentra-

Table 1. Concentrations of lead, barium, and calcium (wet weight) measured in various samples by the Caltech and NMFS laboratories.

Sample	Lead (ng/g)	Barium (ng/g)	Calcium (μg/g)
Analysis by Caltech laboratory			
Surface seawater, prehistoric (estimated)	0.0005 (*3, 14*)	5 (*58*)	400
Surface seawater, modern	0.005 (*3*)	5 (*58*)	400
Albacore muscle, prehistoric (estimated)	0.03 (*3, 13*)	6	22
Albacore muscle, fresh (dissected in Caltech laboratory) (*2*)	0.3	6	22
Albacore muscle from die-punched unsoldered can*	7	8	36
Albacore muscle, NBS reference material	120 (*1*)†	5	96
Albacore muscle from lead-soldered can‡	1,400	13	
Entire albacore (*2*)	6	90	7,000
Entire anchovy from albacore stomach (*2*)	21	500	11,000
Part of anchovy from lead-soldered can	4,200	1,000	3,000
Analysis by NMFS laboratory			
Albacore muscle, fresh (dissected in NMFS laboratory)	400 (*4*)		
Albacore muscle, fresh (dissected in Caltech laboratory)	20§		24‡
Albacore muscle from lead-soldered can	700 (*5*)		

*Chicken of the Sea, Van Camp Company. †Actual concentration of lead in raw, dried, and powdered reference material is 400 ng/g. ‡Includes tuna packed both in oil and in water. §Data are from personal communication; actual concentration of lead is 0.3 ng/g (wet weight).

tions in canned tuna reported by the two laboratories is probably due to differences in types of samples or sampling techniques. The calcium concentration in tuna muscle reported by the NMFS laboratory (24 ppm) is outstandingly accurate, and differs more than tenfold from the erroneous mean of 300 ± 80 ppm derived from 12 other studies (*22*).

The concentrations of lead and barium in tuna muscle may differ by a factor of 2 or 3 among individual fish (*2*); not enough fish have been reliably analyzed to determine the range more accurately. It is improbable that calcium would vary so much. Concentrations of lead, barium, and calcium in muscle showed quite small variations between the two fresh tuna that were correctly analyzed (*2*). However, lead and barium concentrations in bone showed twofold variations between the same two fish in the face of almost no variations of potassium, rubidium, cesium, and strontium in bone (*2*). Differing amounts of lead and barium in seawater or differences in food chain precursors of tuna may give rise to the differences in concentrations of lead and barium in bone and perhaps in muscle among tuna; nevertheless, the metal concentrations in tuna muscle listed in row 4 of Table 1 define the values that are significantly useful from the chemical, oceanographic, and biological standpoints.

History of Lead Production

In order to understand the importance of lead in tuna muscle as a pollution monitor, it should be discussed in the context of the historical perturbations of natural lead distributions in the earth's biosphere. The history of world lead production (Fig. 1) provides the basis for estimating the extent of these perturbations. Old World technologies for smelting lead-silver alloys from sulfide ores and cupeling silver from the alloys were developed at least 5000 years ago. The desire for silver was the principal stimulus for lead production in early times. About 400 parts of lead were produced as a by-product for each part of silver smelted from ores, and this by-product was used in many ways. Lead mined and smelted for itself has constituted a significant portion of total lead production only during the past century. World lead production averaged 160 tons per year from 4000 years ago until ~ 2700 years ago, rose to ~ 10,000 tons with the introduction of silver coinage, and rose again to ~ 80,000 tons during the flourishing of the Roman Republic and Empire 2000 years ago. Lead production declined during medieval times, but with the onset of the industrial revolution, production increased dramatically—from 100,000 tons annually 300 years ago to 1 million tons 50 years ago. Today, about 3 million tons are produced annually worldwide (*23–25*).

Global Extent of Lead Pollution

Contamination by industrial lead appears to have occurred everywhere on the earth. The main means of dispersal of this lead are atmospheric transport of (i) aerosols from smelters and gasoline exhausts and (ii) reentrained dusts and smokes. Table 2 gives an estimated inventory of major sources of industrial lead aerosol emissions to the earth's atmosphere (*26*). Natural lead levels (the kind that existed in the prehistoric environment) can no longer be measured directly by collecting and analyzing samples from remote areas, no matter how carefully it is done, but must be estimated from current environmental data and from models of natural biogeochemical cycles of lead. Estimated natural emissions of lead aerosols to the earth's atmosphere are only about 1/100 those of industrial lead emissions (Table 2). Because there are few reliable data, only rough approximations of natural levels of lead in air, soil, water, and biota can be developed.

Contamination of the earth's atmosphere. All people in cities and towns in North America today breathe air containing 500 to 10,000 ng of lead per cubic meter. The Environmental Protection Agency (EPA) has recommended a maximum permissible level of 1500 ng/m^3 for the general population (*27*). Direct measurements and estimates from mass inventories suggest that the concentration of lead in the atmosphere in remote regions of North America is about 10 ng/m^3 (*10, 28*). These concentrations are 100 to 100,000 times higher than the natural concentration of lead in continental air (about 0.04 ng/m^3) that biogeochemists believe prevailed in prehistoric times.

In the Northern Hemisphere, records of reliably determined concentrations of air-derived lead in annual layers of polar ice show a 200-fold increase during the past 3000 years (*29*), a fourfold increase during the past century in water-laid sediments in remote ponds (*30*), and a twofold increase in rural soils during the past 50 years (*31*). These data indicate that lead in the earth's atmosphere increased with time on a hemispheric scale because the measurements were not unduly influenced by local lead emissions. It has been claimed that there was no increase of lead in polar ice prior to 1900 (*32*), but the data on which this claim is based are of questionable value because of contamination problems associated with taking core samples and performing analyses at the level of accuracy required (0.0005 ng of lead per gram of ice).

The lead in small particles associated with silicates in larger aerosols in the atmosphere today is 100 times more abundant than that found naturally in soils (*29, 33*); this excess could not originate from volcanic emissions (Table 2). Analyses of sediments in the North Pacific show that excess atmospheric lead began to develop no more than 50,000 years ago; the sediments record a deposition of authigenic lead in ancient times at the annual rate of 2 ng/cm^2 (*18*) compared to a present-day atmospheric input to the ocean above its sediments of about 60 ng/cm^2 annually (nonsilicate lead) (*3*). Regional variations in the isotopic compositions of authigenic lead deposited in ocean sediments (*18*) also indicate that the atmospheric input of nonsilicate lead to the oceans was insignificant in prehistoric times because aerosol leads of different isotopic compositions are homogenized by mixing in the atmosphere.

Contamination of the earth's waters. It is commonly believed that natural concentrations of lead in rivers and lakes range from 1 to 10 ng/g (*34*). This estimate is wrong because most analytical methods for lead in water are too insensitive, and contamination controls during sample collection and analysis have been inadequate. The EPA has set a maximum permissible limit of 50 ng/g in potable water (*35*), which contrasts markedly with the estimated natural concentration of lead in riverine fresh water during prehistoric times (< 0.02 ng/g). In the Northern Hemisphere, the oceans, polar ice cap, and precipitation are demonstrably polluted by the 200,000 tons of long-lived industrial lead aerosols emitted annually into the atmosphere. In prehistoric times, the upper 50 m of the oceans in the Northern Hemisphere contained an estimated 4000 tons of natural lead from fluvial sources; today, some 80,000 tons of industrial lead originating from the atmosphere are present in these waters (*3*). The amount of natural lead in the upper 10 m of the Greenland ice cap was ~ 10 tons in prehistoric times; today, the top 10 m of ice contains ~ 4000 tons of industrial lead (*29*). On the basis of natural dust contents, it is estimated that in prehistoric times the annual precipitation over all the land in

the Northern Hemisphere contained ~ 300 tons of lead (*36*); today, this value is ~ 40,000 tons (*10*). Much of the industrial lead in precipitation is sorbed in soils, which complicates relations between lead in river waters and precipitation. In the Sierra Nevada, California, snow contains ~ 0.7 ng of industrial lead per gram and rain ~ 5 ng/g, yet streams that drain off this precipitation contain only ~ 0.015 ng/g (*10*). A few reliable measurements (0.006 to 0.05 ng of lead per gram of water) have been made in stream and river waters from remote areas in the western United States (*37*).

Contamination of the earth's biomass. Published estimates of the amount of lead in the earth's biomass (*38*) are wrong because erroneous data were considered and the extent of industrial lead pollution of the biosphere was not properly understood. Trees constitute most of the earth's biomass (*39*). In prehistoric times, the natural concentration of lead in most of the biomass was probably about 4 ng/g, since century-old portions of the stems of softwood trees have a lead concentration of only ~ 3 ng/g, and hardwood stems even less (*10, 11*). Foliage, a small fraction of a tree's mass, probably contained slightly higher concentrations of lead; pine needles in North America today are believed to contain about 10 ng/g (fresh weight) internally, of which about half is anthropogenic (*10*). In prehistoric times, lead in the biomass of the Northern Hemisphere was ~ 3000 tons, and the annual turnover in the growth cycle was only ~ 300 tons. Contamination of trees by the emission of about 200,000 tons of long-lived industrial lead aerosols to the Northern Hemisphere annually is confined mostly to bark surfaces. Years of accumulation of such lead on bark and leaf surfaces has elevated the average total lead content of trees about tenfold above natural levels in the biomass of North America (*10, 40*).

In the Southern Hemisphere, lead pollution effects in remote, nondomesticated regions are estimated to be about one-tenth of those in the Northern Hemisphere. About 90 percent of the industrial lead aerosols produced are emitted into the troposphere of the Northern Hemisphere, and since the residence time of lead aerosols in the atmosphere (~ 10 days) is short compared to the half-life of interhemispheric exchange (~ 1 to 2 years), the average amount of excess industrial lead associated with silicate aerosols in the atmosphere of the Northern Hemisphere remains about tenfold greater than in the Southern Hemisphere.

Table 2. Global lead emissions from natural and anthropogenic sources (*26*).

Source	Production (10^9 kg/year)	Emission factor (g/kg)	Lead emission (10^3 kg/year)
	Natural		
Wind-blown and volcanic dust	200	1×10^{-2}	2,000
Sea spray	1000	$< 1 \times 10^{-7}$	< 1,000
Forest foliage	100	$< 1 \times 10^{-5}$	< 100
Volcanic sulfur	6	2×10^{-4}	1
Total			2,000
	Anthropogenic		
Lead alkyls	0.4	700	280,000
Iron smelting	780	0.06	47,000
Lead smelting	4	6	24,000
Zinc and copper smelting	15	2.8	42,000
Coal burning	3300	4.5×10^{-3}	15,000
Total			400,000

Range of natural lead concentrations in the biota. The lead content of the earth's crust ranges from 12 to 20 ppm (*18, 41*). It has been implied, incorrectly, that the various amounts of lead in ore-containing rocks and in different types of igneous rocks created a wide range of lead concentrations in soils, which in turn caused a wide variation in the lead content in different parts of the biosphere (*27, 42*). In prehistoric times, areal exposure of lead ore-containing rocks to soil-forming processes was only about 10^{-6} of that of ordinary country rocks (*24*). Most soils are derived from sedimentary rock terrains in which the fourfold range of lead concentrations in igneous rocks of the gabbro-to-granite series have been homogenized by fluvial, biochemical, and diagenetic processes. Lead in mineral particles is, for the most part, biochemically inactive in soil, and, except for a small fraction on surfaces of these particles, is relatively unavailable for biological assimilation. Humus probably constitutes the principal reservoir for biological lead in soils. It is reported to contain 5 to 10 percent of the lead in soils [that is, 5 to 10 ppm in dry humus that constitutes ~ 10 percent in dry soil (*10*)]; the significant range and mean concentration of lead in humus are not known. In prehistoric times, most of the lead in the biosphere was probably derived from lead in films of moisture in the soil. Films of soil moisture collected in the field with ultraclean blotters have been found to contain lead at concentrations of about 2 ng/g in the upper 10 cm of soil (well above the water table) in remote undisturbed soils that are nevertheless probably contaminated with substantial amounts of industrial lead (*10, 14*). The significant range and typical concentration of lead in soil moisture films are not known, but it is unlikely that variations of more than tenfold in the concentration of lead in soil moisture

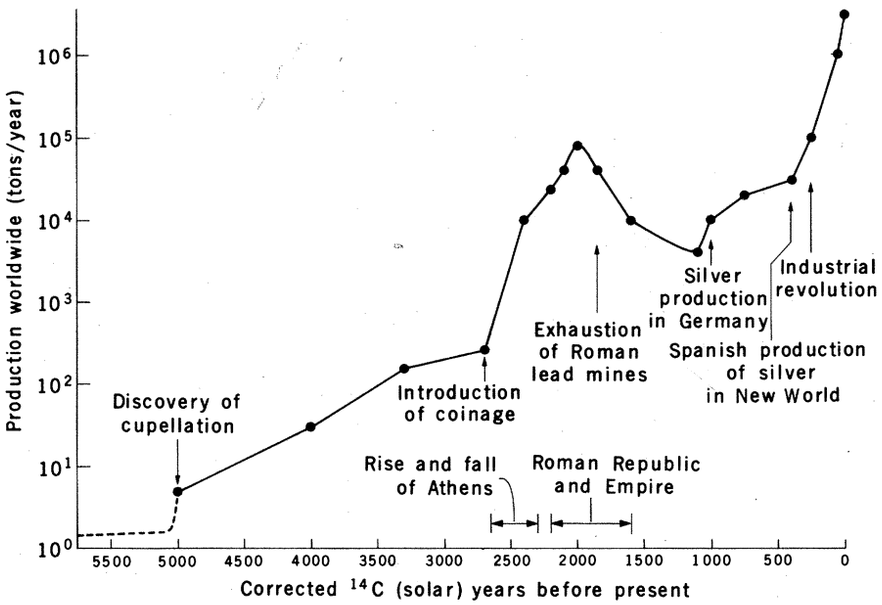

Fig. 1. World lead production during the past 5500 years (*23-25*).

films significantly influenced the lead content of the earth's biosphere in prehistoric times.

There are variations in the occurrences of barium in ores, rocks, minerals, and soils, yet there is remarkable uniformity in the skeletal Ba/Ca ratios among humans who lived at different times on different continents (atomic Ba/Ca = 1×10^{-6} in an ancient Egyptian, 2×10^{-6} in ancient Peruvians, 3×10^{-6} in present-day Americans, and 7×10^{-6} in present-day British) (*16*). This indicates that regional variations in the barium content of human diets are small and do not fluctuate widely as a consequence of regional variations in the barium content of soils or differences in the biopurification of calcium with respect to barium. Since barium and lead are covariant within organisms and consequently in food, it is unlikely that the natural lead content of human diets in prehistoric times varied greatly as a result of regional variations in lead concentrations in soils or differences in biopurification factors.

Natural Lead in Human Foods During Prehistoric Times

The average concentration of lead in the American diet is ~ 200 ng/g (0.2 ppm) (*43*); the maximum safe intake level recommended by the World Health Organization is equivalent to 300 ng/g (0.3 ppm) in the adult diet (*44*). These levels are far above the human dietary lead concentration [< 2 ng/g (0.002 ppm)] believed to have prevailed in prehistoric times.

Studies of lead in a Californian subalpine ecosystem that developed on soil derived only from local igneous rock show that, centuries ago, the input of lead from the atmosphere to that ecosystem was only about one-fifth of the input from rock weathering (*10*). Today, the atmospheric input of lead to the same ecosystem has been elevated by anthropogenic lead-rich aerosols to about 20 times the input of lead by rock weathering. Virtually none of this recently introduced lead leaves the ecosystem by stream runoff. Although the excess industrial lead collects in soil humus, and by root uptake increases lead concentrations in plants and their consumers, new and more predominant entry routes for industrial lead into food chains have been established by dry deposition on foliage and fur surfaces. These new reservoirs of industrial lead in terrestrial ecosystems, although short-lived and of relatively small mass, elevate lead levels in consumers in great disproportion to the effects caused by larger masses of industrial lead collected in soil humus, and bypass so-called biopurification processes that formerly diminished lead levels in higher organisms under natural conditions. As a result of these new reservoirs, concentrations of lead are elevated from ~ 20 to 300 ng/g (wet weight) in plant leaves and from ~ 20 to 900 ng/g (wet weight) in carnivore bones by annual lead inputs of ~ 270 ng/cm^2 by dry deposition (on the basis of projected map area of ecosystem) and ~ 130 ng/cm^2 by precipitation in the Sierra Nevada, where the atmospheric lead concentration is ~ 10 ng/m^3 (*10, 28*).

Biopurification of calcium with respect to lead and barium. In organisms, lead belongs to the calcium, strontium, and barium family of metals with respect to uptake, internal distribution, and excretion (*3, 10, 13-16, 45*). Apparently, lead and barium are processed inadvertently along with calcium by virtually all organisms, and are stored in major reservoirs of calcium. Biochemical mechanisms seem to regulate calcium directly, but operate passively on lead and barium as a consequence of trace occurrences and less efficiently as a result of small differences in chemical properties. Calcium is purified of these trace metals during its ingestion by plants and animals because relatively less lead and barium are absorbed. Major reservoirs of calcium in most organisms generally reflect this purification process in terms of reduced Pb/Ca (*15, 45*) and Ba/Ca (*46*) ratios compared to those in nutrient media. This process is called biopurification of calcium with respect to lead and barium. In food chains, stepwise 5- to 20-fold biopurifications of calcium with respect to lead and barium are multiplicative through successive consumer stages, so organisms at the highest ends of food chains possess calcium reservoirs with extremely low Pb/Ca and Ba/Ca ratios compared to initial values for rock. Proteins in some tissues possess such great affinities for lead, relative to calcium, that Pb/Ca ratios in these tissues are sometimes greater than those in nutrient media. However, the masses of lead in these tissues are such small fractions of the total lead in organisms that biopurification of calcium with respect to lead holds for entire organisms. Biopurification factors are numbers that remain relatively fixed, independent of increases of trace lead concentrations in nutrient media due to contamination. Thus higher levels of lead in nutrients result in elevated lead concentrations in consumers.

In North America, the average atomic Ba/Ca ratio in crustal rocks (*47*) is 3000×10^{-6}, whereas this ratio in the skeletons of Americans, British, and ancient Peruvians (*16*) ranges from 2×10^{-6} to 7×10^{-6}. The 1000-fold difference is the result of consecutive biopurifications of calcium with respect to barium in the food chains of humans. Field measurements in the subalpine ecosystem in California show that the initial Ba/Ca ratio of rocks is reduced at four successive trophic levels in a stepwise manner by an overall factor of 1000 in a food chain leading from rock to carnivore (*10, 14*). Measurements of these factors have not been affected by contamination with industrial barium. Such contamination in remote ecosystems and in human foods is relatively minor, even though world industrial production of barium is nearly the same as that for lead (barium is mainly used in drilling oil wells, making paint and smoke depressants, and refining sugar). There is an enormous contrast between the small contamination effects of industrial barium and the large contamination effects of industrial lead in tuna (Table 1).

Contamination by industrial lead does affect direct measurements of biopurification factors for lead. When corrections are made for the effects of industrial lead contamination in soil humus, on surfaces of plant leaves and animal fur, and within contaminated precursors in this same subalpine ecosystem, the Pb/Ca ratio is reduced about 15,000-fold by means of biopurification from rock to carnivore, a reduction that is an order of magnitude greater than that for barium (*10*). The biopurification factor for short-lived carnivores should be reduced to correct for lead accumulation in humans. The tentative correction reduces the biopurification factor for humans to about 3000. When this factor is applied to the atomic Pb/Ca ratio in crustal rocks of 6400×10^{-8}, a natural skeletal Pb/Ca ratio of about 2×10^{-8} is predicted (*10, 16*). This value compares favorably with a value of 6×10^{-8} in bones of adult Peruvians who lived 1800 years ago in an unpolluted environment (*16*), indicating that the biopurification concept for lead is valid.

The biopurification factor for calcium with respect to lead in marine food chains leading from seawater to albacore is different from that in terrestrial food chains; the Pb/Ca ratio in algae at the first trophic level is about 1000-fold greater than in seawater. This is due to preferential passive sorption of lead relative to calcium on surfaces of marine algae (*13*). The Pb/Ca ratios are sub-

sequently diminished through biopurification at successive stages in marine food chains, so tuna have approximately the same estimated natural Pb/Ca ratio as terrestrial carnivores after corrections are made for industrial lead contamination (*13*).

Natural lead in foods. During prehistoric times, biopurification reduced the Pb/Ca ratio in rocks from about 6400 $\times 10^{-8}$ to a mean of about 1.3 $\times 10^{-8}$ (atomic ratios) in herbivores and carnivores. Lead concentrations in bone are about 100 times higher than those in muscle, a ratio that is rather constant for a wide range of skeletal lead concentrations among different species of relatively long-lived animals (*10*). By assigning the content of calcium in living bone at 17 percent, the mean lead concentration in terrestrial herbivore and carnivore flesh during prehistoric times is estimated to have been ~0.1 ng/g (wet weight), or 0.0001 ppm. Concentrations of lead in marine animal flesh during prehistoric times can be estimated more directly from reliable observations that show lead concentrations of 0.3 ng/g (wet weight) in tuna muscle (*2*) and 6 ng/g (wet weight) in abalone muscle (*13*). These values must be reduced tenfold to correct for a reasonably firm open-ocean pollution factor (*3*). Herbivorous shellfish are contaminated by additional lead from the more intense pollution near shore. Thus a diet of marine herbivore and carnivore flesh in prehistoric times probably contained lead at ~0.1 ng/g (wet weight). Data are not available to permit estimates of lead concentrations in edible portions of plants during those times. The total biopurification of calcium with respect to lead observed for plants in the subalpine ecosystem in California was less than that observed for animals, which suggests that lead concentrations in vegetables were probably about 50-fold higher than in meat. The average concentration of lead in a mixture of meat and vegetables in the human diet during prehistoric times may have been ~ 2 ng/g (wet weight).

Exposure of Humans to Lead: Prehistoric and Contemporary

A comparison of the daily absorption of lead into the systemic blood of prehistoric humans (210 ng/day) with that of adult Americans (29,000 ng/day) (Table 3) shows a greater than 100-fold increase. The fraction of ingested lead absorbed by humans in prehistoric times was probably similar to that absorbed today, despite the large difference in lead concentration between the two diets. Tracer studies indicate that substantial amounts of lead are cycled through the human portal blood-liver-bile system (*48*), but the fraction of lead in food that enters the systemic blood does not include this lead, so the overall biopurification factor for calcium with respect to lead transferred from diet to skeleton is about sevenfold (50 percent absorption for calcium divided by 7 percent absorption for lead).

Table 3. Inventory of estimated average daily amounts of lead (in nanograms) absorbed into blood of adult humans in prehistoric and modern times.

Source	Prehistoric (natural)*	Contemporary (urban American)†
Air	0.3	6,400
Water	< 2	1,500
Food	< 210	21,000
Total	< 210	29,000

*Lead in air, 0.04 ng/m³ at 20 m³/day × 0.4; in water, < 20 ng/kg at 1 kg/day × 0.1; in food, <2 ng/g at 1.5 kg/day × 0.07. †Lead in air, 800 ng/m³ at 20 m³/day × 0.4; in water, 15,000 ng/kg at 1 kg/day × 0.1; in food, 200 ng/g at 1.5 kg/day × 0.07.

Biopurification factors provide reliable estimates of natural concentrations of lead in food in prehistoric times because an internal consistency can be demonstrated in relations among Pb/Ca ratios in diets, biopurification factors, and skeletal Pb/Ca ratios. The estimated atomic Pb/Ca ratio in natural diets (~ 8 $\times 10^{-7}$) was probably reduced sevenfold through biopurification to a predicted value of ~10 $\times 10^{-8}$ in human skeletons, which agrees well with the skeletal value of 6 $\times 10^{-8}$ in ancient Peruvian adults. The observed Pb/Ca ratio in American diets of 8 $\times 10^{-5}$, when reduced through biopurification, yields a predicted skeletal Pb/Ca ratio of 10 $\times 10^{-6}$, which compares favorably with the measured skeletal ratio of 35 $\times 10^{-6}$ (contributions from inhaled and other nondietary sources of industrial lead are included in the latter value). This internal consistency constitutes strong evidence that the fraction of ingested lead absorbed by prehistoric humans from their diets did not differ appreciably from the fraction absorbed today.

The estimated natural concentration of lead in food is confirmed by direct measurements of very low lead concentrations in old stem wood of trees, which show that the atomic Pb/Ca ratio in the main mass of the earth's biosphere (calcium concentration, ~ 1000 ppm) was ~ 8 $\times 10^{-7}$. It is unlikely that the atomic Pb/Ca ratio in the diet (8 $\times 10^{-5}$ for Americans) would exceed the Pb/Ca ratio in most of the biosphere. On the contrary, since many dietary components are at higher trophic levels than are trees, the dietary Pb/Ca ratio should be reduced through biopurification. Therefore, the natural atomic Pb/Ca ratio in human diets was definitely less than 8 $\times 10^{-7}$, which requires that the average natural concentration of lead in these diets was < 2 ng/g.

The most forceful confirmation of low lead concentrations in the diets of prehistoric humans is made by direct measurement of the lead concentration in fresh tuna muscle (0.3 ng/g). This value stands as a benchmark that correctly orients scientific views of the natural concentration of lead in human diets. It is concordant with similarly low theoretical values in dietary components calculated from measured biopurification factors in marine and terrestrial ecosystems. The value is exeedingly low in comparison with measured levels of lead in present-day human diets. Yet we know that it is still an order of magnitude too high, because the seas are contaminated about tenfold with industrial lead.

Biochemical Dysfunctions Caused by Lead

Industrial lead is distributed so widely and excessively that it masquerades as natural lead in foods before they are processed. Medical authorities, unaware of this, mistakenly believe that typical concentrations of lead in many foods are close to the natural concentrations. On the basis of definitions of classical lead poisoning set forth in 1839 (*49*), with minor recent modifications (*27*), they have recommended maximum allowable daily ingestion rates for lead (300 ng/g) in food that, biochemically, are grossly excessive. Such levels should have been considered unjustifiably high simply on the grounds that they do not allow a sufficient margin of safety from lead levels that cause overt deleterious effects. A lead concentration of 500 ng/g in the American diet is, because of additions from atmospheric input, equivalent to about 700 ng/g in the diet of persons breathing pure air. Dietary intake of lead at this level will, within 4 years, double the lead burden of the body and elevate blood lead to 650 ng/g and urinary lead to 900 ng/g (*50*); this last characteristic borders on the urinary lead-excretion levels of industrial workers who have classical lead poisoning (*50*).

Regulatory agencies charged with monitoring lead pollution effects have focused their research aims and the analyt-

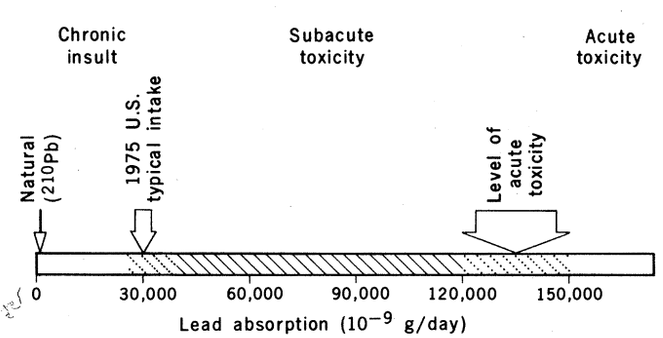

Fig. 2 (left). Range of lead intakes into systemic blood of adult humans on a linear scale.

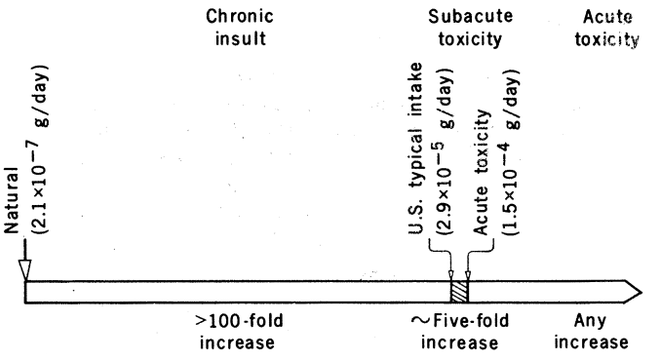

Fig. 3 (right). Incremental increases of lead absorption above natural intakes by typical and by classically poisoned Americans on a multiplication factor scale.

ical capabilities of their surveillance laboratories exclusively on deleterious effects of lead in the small fraction of the population whose intake exceeds the norm. For the past 15 years, interest has leaned heavily toward the subtle, subclinical effects from so-called low-level lead exposures that are above typical exposures and below those that cause easily recognized, clinical symptoms. The low-level range of exposures, shown in Fig. 2, appeared to be important to investigators, who questioned the existence of a threshold for harmful exposures to lead after the basis for this concept, established in 1933 (*51*), was undermined in 1965 (*45*). Low level is a term that has originated from the widespread medical attitude today that present "normal" lead intakes are safe; indeed, on a linear scale they do not appear to be displaced very far from the zero point (Fig. 2). It is not generally understood that these intakes are typical instead of normal, and that they are displaced from natural intakes by enormous factors.

Priorities become different, however, if it is recognized that a lead pollution factor of 100 or more applies to the lead intakes of most Americans. If incremental increases rather than absolute amounts are arranged on a multiplication factor scale (Fig. 3), overtly poisonous intakes (two to five times greater than typical intakes) appear only as a small extension at the upper end of a range of very large exposures. This correctly indicates the seriousness of industrial lead pollution in most Americans. The difference between lead concentrations in skeletons of Peruvians who lived 1800 years ago and in skeletons of modern humans is five times greater than the chronic insult interval, based on differences between dietary lead concentrations, that Fig. 3 shows. The natural concentration of lead in prehistoric diets (< 2 ng/g) may be overestimated by this factor. There can be no doubt that exposure of Americans to industrial lead today is two or three orders of magnitude greater than exposure of humans to natural lead in prehistoric times.

Reagents, nutrients, and controls used in biochemical laboratories are highly contaminated with industrial lead because proper precautions are not taken (*17, 52*). The fact that correct handling of samples and analyses of lead in tuna muscle, tree stem wood, or seawater cannot be carried out in most laboratories confirms this. To our knowledge, no one has yet studied natural interactions of lead in living cells or determined how present excessive lead exposures have perturbed natural processes in so-called normal (control) cells. Because magnitudes of biochemical dysfunctions have been observed to be proportional to the extent of lead overexposure (*27*), it is probable that some biochemical processes within cells in Americans have been altered, perhaps deleteriously. At present we are constrained to extrapolate downward through the enormous long-term overexposures to lead illustrated in Fig. 3 in order to consider how, on a molecular basis, natural biochemical processes within cells might differ from those existing today.

In cells, there must be background levels of trace constituents that serve no useful purpose and that are ignored by biochemical processes (*53*). Contemporary levels of lead in biochemical systems in cells are so excessive for most Americans compared to natural levels that it is probable that numerous perturbations of cellular biochemical processes are being caused by excess lead. Since divalent lead masquerades as calcium, biochemical reactions involving calcium are most likely perturbed. The problem arises of distinguishing between biochemical adaptations that may be relatively harmless and biochemical dysfunctions that probably cause harm.

Relatively modest elevations of lead exposures above typical levels perturb biochemical processes in the heme biosynthetic pathway (*27*). Typical levels of lead may cause far more serious perturbations within this system, but these have been unsuspected because of ignorance of the true extent of industrial lead pollution. It is not generally recognized that most of the nutrient calcium and trace toxic barium in whole blood is contained in plasma and not in red blood cells; this same distribution should hold for lead because a strong covariance exists between the distributions of barium and lead among different tissues in many organisms (*3, 10, 13-16, 45*). Most of the lead in the blood of highly contaminated mammals (the only organisms examined so far) is contained in red cells, and it appears that this distribution is highly anomalous. Hemopoietic systems in mammals exposed to typical inputs of industrial lead may be so badly perturbed that most of what is probably an overwhelming excess of lead in the blood has been transferred to red cells as a result of the overloading and breaking down of natural biochemical processes. Rather than monitor lead exposures by blood lead concentrations in what may be highly perturbed biochemical systems, we might better monitor lead exposures by the shift in the distribution of lead from plasma to red cells. Mitochondrial and neurotransmitter biological systems are highly sensitive to perturbation by lead (*27*). These effects have been studied for lead exposures above the normative control levels which exist in biochemical laboratories; however, such control levels actually represent lead exposures that are about 1000-fold above natural levels. It is probable that at natural lead levels, these biochemical systems would operate differently in many respects because this would represent a very large change in the concentration of a reactant.

Recommendations

The 10,000-fold lead pollution factor for tuna packed in lead-soldered cans is largely ignored by the FDA (*54*), the EPA (*55*), the NBS (*56*), and Ralph Nader's Public Citizen's Health Research Group (*57*) 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.

Lead-soldered cans should be eliminated immediately because they constitute a major source of lead in foods. The true magnitude of the lead contamination of food by lead-soldered cans has been underestimated because contamination effects have been obscured by high positive errors in analyses of lead in foods before canning. Although it was noted that foods in glass jars generally contain lead concentrations of about 50 ng/g (0.05 ppm) compared to 600 ng/g for foods in lead-soldered cans, and that bulk milk contains only 40 ng/g compared to 200 ng/g in milk packed in lead-soldered cans (*20*), the view favored by U.S. agencies is that the average effect of lead solder is more modest because only a severalfold difference is observed between the center of the can and the lead seam (*21*). The FDA considers a lead concentration of 100 ng/g in canned baby milk a reasonably low practical limit (*20*). But it is apparent that lead solder can elevate concentrations of lead in canned foods by 500 to 1000 ng/g regardless of the initial concentration [most studies (*20*) show an average concentration of 500 ng/g]. The concentration of lead in most foods packaged in containers other than lead-soldered cans may be ≤ 100 ng/g. Half the lead in the American diet probably originates from lead-soldered cans, since these containers contaminate their contents about tenfold and canned foods comprise about 20 percent of the diet. If lead-soldered cans were eliminated, the average dietary lead intake of most Americans would be reduced by about half.

Lead-soldered cans are not the only significant source of industrial lead in foods. Large quantities of lead may originate from processed foods containing dried powders. As was noted previously, commercial drying and pulverizing of albacore muscle in a food factory can increase lead contamination by 7 to 400 ng/g. This matter should be investigated immediately because the American diet contains a significant portion of materials that have undergone a drying and grinding process.

Investigators who measure lead concentrations in plant and animal tissues and water bodies must understand that the NBS orchard leaf, bovine liver, and tuna muscle reference materials are unsuitable and misleading for standardization purposes. These materials contain 100 to 10,000 times more lead than should a standard that would properly evaluate their abilities to determine lead concentrations correctly in scientifically significant environmental samples. Materials containing levels of lead that have been standardized by ultraclean isotope dilution mass spectrometry are (i) seawater in the open ocean below 2000 m (0.001 to 0.006 ng/g), (ii) fresh tuna muscle (0.2 to 0.4 ng/g), and (iii) century-old stem wood from trees (1 to 3 ng/g). Investigators must not refuse to use such materials as standards on the grounds that they are impractical in the context of their present analytical abilities and unrelated to lead levels encountered by them in their studies. Rather, they should consider whether their studies are futile exercises that waste time and funds that should be spent productively on investigations of lead pollution. They should resolve to improve their abilities to control lead contamination during sample collection and analysis.

The discovery of extremely low lead concentrations in albacore, combined with other recent discoveries concerning the natural biogeochemistry of lead, shows that previously unrecognized systems of natural biochemical processes within cells may underlie recognized systems that are probably perturbed and unnatural. Experiments should be carried out in ultraclean sanctuaries to see whether natural biochemical processes differ from those in environments excessively contaminated with industrial lead. However, most investigators cannot even correctly determine lead in water, which casts doubt on their ability to carry out the much more difficult task of growing living organisms in ultraclean conditions. The problem can be relieved somewhat by performing conventional biochemical assays outside ultraclean laboratories on extracts of organisms prepared in such laboratories. We believe that in time some investigators will develop the ability to properly monitor lead at extremely low concentrations in nutrients and growing organisms, and that this will then permit studies of natural biochemical processes to be carried out in ultraclean sanctuaries.

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26. Anthropogenic lead emission data are from a review by J. O. Nriagu [in (*9*), p. 137]. About half of these emissions can be attributed to long-lived aerosols with diameters < 5 μm and residence times in the atmosphere of about 10 days. Nriagu's estimates of natural lead emissions from silicate dusts are excessive because his estimate of natural lead concentrations in the dust is too high by a factor of 3 and he uses the highest estimate for dust in the air. The latter estimate is excessive; it is biased by measurements of dusts in rain and snow that are erroneously high due to dust contamination during sample collection. The natural emission of wind-blown silicate lead in aerosols characterized by a natural Pb/(Ca + K) ratio is modified from estimates by E. D. Goldberg [*Comments Earth Sci. Geophys.* **1**, 117 (1971)]; J. T. Peterson and C. E. Junge [in *Man's Impact on Climate*, W. H. Matthews, W. Kellog, G. Robinson, Eds. (MIT Press, Cambridge, Mass., 1971), p. 310]; E. Robinson and J. Prospero [in *The Tropospheric Transport of Pollutants and Other Substances to the Oceans* (National Academy of Sciences-National Research Council, Washington, D.C., 1978), pp. 124–145]; and from background papers for this report. Sea-spray emissions are believed (J. L. Fasching, paper presented at the Northeast Regional Meeting of the American Chemical Society, Boston, 1978) to contain lead enriched no more than 100 times above the natural concentration in surface seawater in prehistoric times (about 0.0005 ng/g). See also A. W. Elzerman and M. P. Bacon [*Eos* **60**, 276 (abstr.) (1979)] and S. R. Piotrowicz, R. A. Duce, J. L. Fasching, and C. P. Weisel (*ibid.*, p. 276). High lead concentrations reported in foliage forest emissions [G. C. Curtin, H. D. King, E. L. Mosier, *J. Chem. Exp.* **3**, 245 (1974)] are erroneous because of lead contamination during collection and analysis and failure to correct for anthropogenic lead deposited by dry deposition on foliage surfaces. Lead emissions from foliage measured with ^{210}Pb tracers [W. Beauford, J. Barber, A. R. Barringer, *Science* **195**, 571 (1977)] are reported to be less than lead deposited by dry deposition, although the emission data are erroneous because of errors in common and radioactive lead contamination control. If an upper limit of 0.1 ppm is assigned to these organic emissions, the natural lead emission can be estimated from this source. Experimental measurements of volcanic lead emissions in volcanic gases have been seriously compromised by failure to exclude lead contamination during sample collection and by use of improper flux models. Recent measurements of the Pb/S ratios in fumarolic gases from volcanoes that emit halogens in high amounts [P. Buat-Menard and M. Arnold, *Geophys. Res. Lett.* **5**, 245 (1978)] and low amounts [C. K. Unni, W. Fitzgerald, D. Settle, G. Gill, B. Ray, R. A. Duce, C. C. Patterson, paper presented at the American Geophysical Union Annual Meeting, Section on Volcanology, Geochemistry, and Petrology, San Francisco, 1978] suggest that the average Pb/S ratio in volcanic gas is about 2×10^{-7} g/g. Other natural sources of lead emissions to the atmosphere are insignificant compared to those listed in Table 2.
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