ORIGINAL ARTICLES

Surface soil as a potential source of lead exposure for young children

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Soil analyses revealed an elevated lead content in the surface soil of three British Columbia cities. The lead accumulations were largely attributed to dustfall from a nearby large lead–zinc smelter in Trail and to automotive traffic in Nelson and Vancouver. Although the mean concentrations of lead in the soil were relatively low at Nelson (192 parts per million [ppm]), in selected areas of Vancouver with heavy traffic they were similar to those found within 1.6 km of the large smelter at Trail (1545 and 1662 ppm respectively).

In a study conducted in 1975, children aged 1 to 6 years in Trail and Nelson were found to have higher mean blood lead levels than grade nine students. The findings of the later study support the view that particulate lead in surface soil and dust accounted for most of the greater lead absorption in the younger children.

Des analyses du sol ont révélé un contenu élevé en plomb dans la couche de surface de trois villes de Colombie-Britannique. Les accumulations de plomb ont été en grande partie attribuées aux retombées d'une importante fonderie de plomb et de zinc située à Trail et à la circulation automobile des villes de Nelson et Vancouver. Bien que les concentrations moyennes de plomb dans le sol fussent relativement faibles à Nelson (192 parties par million [ppm]), elles étaient, dans des endroits choisis de Vancouver à forte circulation, comparables à celles qui ont été retrouvées à moins de 1.6 km de l'importante fonderie de Trail (1545 et 1662 ppm respectivement).

Au cours d'une étude menée en 1975, des enfants de Trail et de Nelson âgés de 1 à 6 ans ont présenté des teneurs sanguines en plomb supérieures à celles d'étudiants de neuvième année. Les résultats de cette dernière étude soutiennent l'hypothèse que le plomb particulaire à la surface du sol et la poussière comptent pour la plus grande partie de l'absorption supérieure de plomb chez les plus jeunes enfants.

The potentially harmful effect of environmental lead exposure on the health of children has become a matter of general concern.[1,2] Elevated blood lead levels have been reported in children in the United States, not only in the vicinity of smelters and lead processing plants,[3-7] but also in urban centres.[8,9] Between 5% and 10% of children tested recently in that country showed an increase in lead absorption sufficient to cause metabolic derangement of heme synthesis but insufficient, with rare exceptions, to cause the classic symptoms of lead poisoning.[2,10] It has been suggested, however, that subclinical increases in lead absorption in preschool-aged children may be one of the factors causing minimal brain dysfunction that only becomes evident when the children are of school age.[2,11] Similar increases in lead absorption in suckling (but not older) experimental animals have been shown in some studies to be followed by the delayed appearance of subtle deficits in learning ability and aberrations in behaviour.[2,12]

Although no blood lead studies have been carried out on a national scale in Canada, a 1973–74 survey in Toronto showed that some of the people living near three lead processing plants had an elevated blood lead content.[13]

In 1975 a blood lead study of children in Trail, BC, the site of one of the continent's largest lead–zinc smelters, and the neighbouring (control) city of Nelson was conducted jointly by the University of Ottawa, the Laboratory Centre for Disease Control, Department of National Health and Welfare, and the West Kootenay and Selkirk health units of the British Columbia Ministry of Health. The findings of the study were reported elsewhere by Neri and colleagues.[14,15] Data from that report will be related to the findings of a soil survey, reported in this article, that was conducted in Trail, Nelson and Vancouver in 1977.

Soil survey

The Trail–Nelson–Vancouver soil survey, which was carried out in the summer of 1977, was designed to investigate the distribution and concentration of lead in surface soil and to determine whether there is a relation between soil lead concentrations and blood lead levels in children.

Trail (population 12 000) is situated in the semidry interior of British Columbia (average annual rainfall 630 mm) in the narrow Columbia River valley and is surrounded by high mountains. The Trail smelter, which is the only major industrial establishment in

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the area, was built at the turn of the century and has been substantially modified over the years to improve productivity and to diminish environmental contamination. Approximately 135 kg of lead is emitted daily into the atmosphere, and the annual mean concentration of suspended particulate lead in ambient air at the time of the study was about 2 $\mu g/m^3$.

A nearby city, Nelson (population 10 000), was selected as the control city. Nelson, which is situated in the Kootenay River valley, is about 41 km north of Trail. Because of its topography, its distance from Trail and the direction of the prevailing winds Nelson is not affected by the emissions from the Trail smelter. The annual mean concentration of suspended particulate lead in ambient air in Nelson at the time of the study was 0.5 $\mu g/m^3$.

Vancouver, a large coastal city, was selected as a second control site.

Materials and methods

The soil sampling sites in Trail and Nelson were selected randomly from a directory of residences. In Vancouver soil was collected over a 45-km^2 area from boulevards, roadside gutters and vacant lots adjacent to main streets in the downtown residential and commercial districts, where children could readily come in contact with dirt or soil.

The samples in all three cities were collected by a trained public health inspector using a standardized method and specially designed equipment, including an acid-washed, stainless steel spoon with a 2.5-cm-long digger and a plastic template exposing a 100-cm^2 area. About 250 cm^3 of material was excavated, to a uniform depth of 2.5 cm, and placed in a sterile plastic container. Large stones and vegetation were discarded. The equipment was cleaned after each sampling. In Vancouver an effort was made to ensure that each sampling site was free from nonvehicular sources of lead contamination. A second field worker independently inspected the sampling area visually to identify emissions from commercial or private sources that might contain lead.

The soil samples were analysed at the environmental laboratory of the Ministry of the Environment, Vancouver. A 1-g portion of the sample was weighed, predigested with 10 ml of concentrated nitric acid, then digested with 5.5 ml of 70% perchloric acid. The lead content of the sample was determined by atomic absorption spectrometry. The analytic technique used was flame aspiration with simultaneous background correction. The laboratory's lower limit of precision for lead analysis is 0.005 mg/g. During the 2-year interval between the collection of the blood and soil samples lead emissions from the Trail smelter were monitored; they did not change significantly.

Findings

The lead content of 245 soil samples was determined. Lead concentrations were calculated for the three cities and are shown in Table I. The mean lead concentration of the Trail soil samples, 1320 parts per million (ppm), was significantly greater ($P < 0.01$; Student's t-test) than the mean for Nelson, 192 ppm, but there was no significant difference between the means for Trail and Vancouver ($P = 0.14$).

In Trail, as is shown in Table II, the sampling sites more than 3.2 km from the smelter had a mean lead concentration of 354 ppm. At lesser distances the mean lead concentration in the soil increased sharply, and samples taken within 1.6 km of the smelter had a mean lead concentration of 1662 ppm. The Spearman rank order correlation between the lead concentration and the distance of the sampling site from the smelter was significant ($P = 0.01$).

Fig. 1 is a map of Trail showing nine residential areas and their soil lead concentrations. Table III gives the median, mean and 75th percentile soil lead concentrations for each area. It is apparent that the lead content of the soil was not uniform throughout the district, and even at sites equidistant from the smelter there were marked variations. Areas 3, 4 and 6 were all within 1.6 km of the smelter, yet areas 4 and 6 had a combined mean soil lead concentration

Table I—Lead concentration of surface soil in Trail, Nelson and Vancouver, BC in 1977

City	No. of samples	Concentration (parts per million [ppm]) Median	Mean	Standard error	75th percentile	t value*
Trail	153	800	1320	109	1687	—
Nelson	55	83	192	39	253	9.74
Vancouver (selected areas)	37	1240	1545	174	2189	−1.09
Total	245	620	1101	80	1490	—

*Student's t statistic from a comparison of the Trail mean with the means of Nelson and Vancouver.

Table II—Lead concentration of surface soil at increasing distances from the smelter in Trail in 1977

Distance from smelter (km)	No. of samples	Lead concentration (ppm) Median	Mean*	Standard error	Quartile deviation	75th percentile
< 1.6	64	1214	1662	165	1547	2245
1.6 - 3.2	65	698	1341	180	1453	1772
> 3.2	24	253	354	77	204	344
Total	153	800	1320	109	1358	1687

*The Spearman rank order correlation between the lead concentration in the surface soil and increasing distance of the sample site from the smelter was significant at the 0.01 level; the correlation coefficient was −0.5.

of 1849 ppm, whereas area 3 had a mean of 1217 ppm. Areas 2, 5, 7 and 8 were between 1.6 and 3.2 km from the smelter; the combined mean soil lead concentration in areas 7 and 8 was 1845 ppm and in areas 2 and 5 only 537 ppm. Areas 1 and 9, which were more than 3.2 km from the smelter, had relatively low soil lead concentrations, 171 and 570 ppm respectively. The lead values appeared to be higher in locations that were more exposed to smelter emissions by virtue of topography and the prevailing winds.

Table IV shows the lead concentration of soil and blood samples collected at increasing distances from the Trail smelter. There was a positive correlation between the mean soil lead concentrations for each distance and the corresponding blood lead concentrations in the 1- to 3-year-olds and the grade one children. Both values increased with decreasing distance from the smelter. However, there was no similar relation between the soil and blood lead concentrations in the grade nine students, who had relatively low and uniform blood lead levels throughout the city. Table V compares the soil and blood lead concentrations of the younger children by residential area; this comparison also showed a positive correlation between the soil and blood lead values.

Discussion

The importance of dirt and dust as a cause of elevated blood lead levels in children has received increasing attention in recent years.[16-22] It is thought that young children are particularly likely to ingest contaminated dust particles because they are more inclined to play in the dirt and put things in their mouths. Thus, they may substantially augment their daily lead intake by the accidental ingestion of dirt in the course of their play.[23] The transfer of lead-

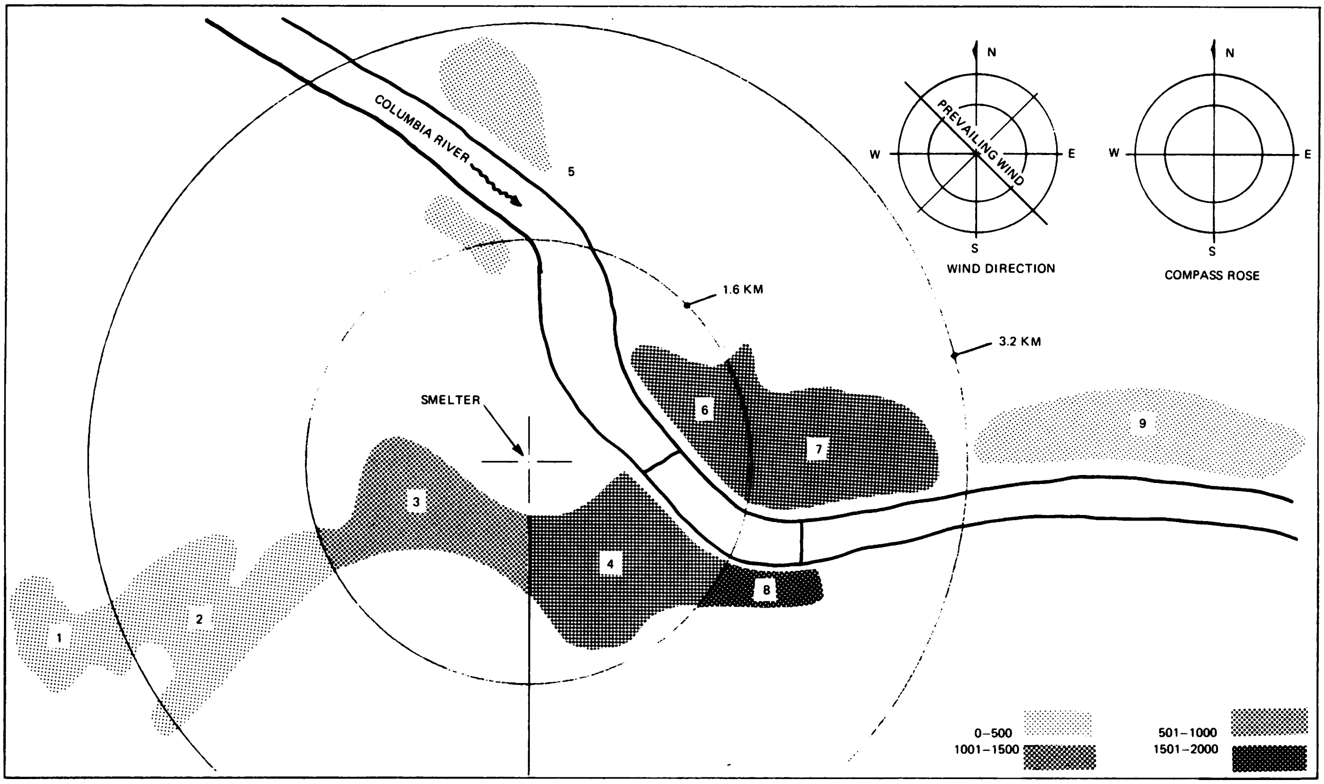

FIG. 1—Map of Trail, BC indicating soil sampling areas and soil lead concentrations in parts per million.

Table III—Lead concentration of surface soil in nine residential areas of Trail in 1977

Residential area (as shown in Fig. 1)	No. of samples	Lead concentration (ppm) Median	Mean	Standard error	75th percentile	Range
1	13	210	171	24	228	56- 304
2	13	225	281	74	264	55-1124
3	19	806	1217	264	1328	170-4055
4	23	1215	1783	271	2297	200-4960
5	12	518	777	239	620	105-2917
6	22	1321	1919	307	2489	453-4989
7	29	1184	1711	295	2654	113-5514
8	11	1772	2237	471	3086	443-4832
9	11	389	570	143	594	154-1877
Total	153	800	1320	109	1687	55-5514

Table IV—Lead concentration of surface soil and children's blood at increasing distances from the Trail smelter

Distance from smelter (km)	Mean soil lead concentration (ppm) in 1977	Blood lead concentration (μg/dl), mean ± standard deviation (and no. of children)*		
		1- to 3-year-olds	Grade one children	Grade nine children
< 1.6	1662	28.8 ± 7.1 (9)	25.1 ± 7.2 (16)	10.4 ± 0.8 (14)
1.6 - 3.2	1341	26.6 ± 11.5 (33)	24.6 ± 7.3 (42)	11.8 ± 4.7 (52)
> 3.2	354	18.7 ± 6.5 (50)	17.8 ± 5.1 (42)	11.5 ± 5.0 (62)
Total	1320	22.5 ± 9.5 (92)	22.0 ± 7.3 (100)	11.5 ± 4.4 (128)

*Unpublished data from L.C. Neri, H.L. Johansen, N. Schmitt, et al, 1975.

bearing house dust to the hands of young children living in inner city homes has also been demonstrated.[17] Weathered lead-based house paint has long been considered a major source of soil contamination, and lead from motor vehicle exhaust has been found to contribute significantly to the lead content of soil near roadways.[16] Street dust, too, has frequently been found to contain high concentrations of lead. Using data from 77 midwestern cities in the United States Hunt and colleagues[24] calculated that the concentration of lead averaged 1636 ppm in residential areas, 2413 ppm in commercial areas and 1512 ppm in industrial areas.[24] Soil lead concentrations in areas remote from human activity usually range from 5 to 25 ppm.[25]

The presence of high concentrations of lead in the soil is apparently not always hazardous: children in England living in areas where the soil lead concentration was as high as 8000 ppm were found to have only minimally elevated blood lead levels.[26] On the other hand, in Smeltertown, Texas, where it is extremely dry and dusty, more than 50% of the children 1 to 9 years of age living within 1.6 km of a smelter were found to have abnormal blood lead levels (40 μg/dl or higher).[3] The mean concentration of lead in surface soil near that smelter was 3457 ppm, and dust samples had mean values as high as 22 191 ppm. Because older children showed lower blood lead levels and adults showed normal levels it was concluded that the main source of lead absorption by the young children was particulate lead in dust and air. Similar conclusions were reached in the Toronto study.[13,22] When the homes of workers in primary and secondary lead industries became contaminated with lead from work clothes, increased lead absorption was found among the workers' children.[27,28]

Table V—Lead concentration of surface soil and children's blood by residential area of Trail

Residential area(s)	Soil lead concentration (ppm), mean ± standard error (and no. of samples)	Blood lead concentration (μg/dl), mean ± standard error (and no. of children)*	
		1- to 3-year-olds	Grade one children
1 and 2	225 ± 39 (26)	17.2 ± 1.1 (27)	18.0 ± 1.9 (18)
5	777 ± 239 (12)	19.7 ± 1.5 (11)	18.7 ± 2.3 (12)
9	570 ± 143 (11)	20.7 ± 1.6 (19)	19.1 ± 1.0 (16)
3, 4 and 8	1674 ± 183 (53)	27.7 ± 1.8 (14)	23.8 ± 1.3 (31)
6 and 7	1800 ± 212 (51)	30.2 ± 3.0 (16)	25.6 ± 1.5 (26)
Total	1320 ± 109 (153)	22.4 ± 1.0 (87)	21.9 ± 0.7 (103)

*Unpublished data from L.C. Neri, H.L. Johansen, N. Schmitt, et al, 1975.

Our study revealed elevated soil lead concentrations in all three communities studied. Near the large lead–zinc smelter at Trail the soil lead concentrations were inversely related to the distance of the sampling sites from the smelter and were higher in areas with greater exposure to emissions. Similar geographic trends were noted for the blood lead levels in younger but not older children. Grade nine students had relatively low and similar blood lead levels throughout the city. It is therefore concluded that particulate lead in surface soil and dust, largely accumulated from smelter emissions, played an important role in the greater lead absorption by the younger children. If inhalation of airborne (suspended) lead had been a major factor it seems reasonable to assume that the older children would have been similarly affected and that the blood lead levels in the three age groups would have been more uniform.

Besides transferring dirt directly from hand to mouth, young children may be exposed to high particulate concentrations from dust raised during their play or by the transit of foot or vehicular traffic (or aerosolization). Mouth breathing is common among young children, and dust can be drawn into the oral cavity and ingested. Particles too large to be breathed by the nasal route could be inhaled through the mouth. During reaerosolization particulate concentrations in the air fall rapidly with height, so that older children and adults would be exposed to a considerably lower lead concentration than 1- to 6-year-olds. Although the exact mechanism is not understood, young children are known to absorb lead more readily than older people,[25] and it has been indicated that their metabolic exposure (micrograms of lead per kilogram of body weight) may be twice that of adults for inhaled lead and three times for ingested lead.[29] For these reasons, the effect on the lead burden of young children of relatively low suspended particulate concentrations in air must not be ignored.

In 1969 soil lead concentrations in areas remote from the Trail smelter were reported to be as low as 22 ppm.[30] It has been suggested that observable increases in the blood lead levels of young children occur when soil or dust lead concentrations reach 500 to 1000 ppm.[31] Our study revealed minimal elevations in the soil lead concentration at Nelson (mean level

192 ppm), yet in that city children aged 1 to 6 years had slightly higher mean blood lead values (14 μg/dl) than grade nine students (10 μg/dl).[14,15]

Soil lead concentrations at sites bordering on streets with heavy traffic in Vancouver were markedly elevated and very similar to those found within 1.6 km of the Trail smelter. A blood lead study is being considered for Vancouver. Meanwhile, the findings of this survey suggest that environmental exposure to lead in Canada is not limited to the neighbourhood of lead processing plants but may also be found in urban centres, particularly those near streets with heavy traffic.

None of the Trail or Nelson children tested in 1975 had excessive blood lead levels (70 μg/dl or higher). Two percent of the Trail children tested had elevated values (40 μg/dl or higher);[14,15] however, detailed clinical examination of these children by their family physicians did not reveal any evidence of ill health.

Conclusion

While the findings of this study are reassuring in that they do not reveal the existence of a serious health hazard, the evidence of an accumulation of lead in the surface soil of three British Columbia cities is hardly cause for complacency. It would seem prudent to carry out detailed epidemiologic studies to determine the extent and degree of current urban lead exposure and to assess the contribution of soil and dust to the lead burden of children. Meanwhile, as a preventive measure, unnecessary lead exposure from stationary and automotive sources should be reduced to a minimum.

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References

1. *Preventing Lead Poisoning in Young Children; a Statement by the Center for Disease Control*, publ 00-2629, Center for Disease Control, US Public Health Service, Atlanta, Ga, 1978
2. CHISOLM JJ JR: Is lead poisoning still a problem? *Clin Chem* 23: 252, 1977
3. LANDRIGAN PJ, GEHLBACH SH, ROSENBLUM BF, et al: Epidemic lead absorption near an ore smelter: the role of particulate lead. *N Engl J Med* 292: 123, 1975
4. ASHLEY JT, BOX JA, MATHER JA, et al: Follow-up on increased lead absorption — Idaho. *Morb Mortal Wkly Rep* 2: 1, 1976
5. *Helena Valley, Montana Area Environmental Pollution Study*, publ AP-91, office of air programs, US Environmental Protection Agency, Research Triangle Park, NC, 1972
6. BAKER EL, HAYES CG, LANDRIGAN PJ, et al: Nationwide survey of heavy metal absorption in children living near primary copper, lead, and zinc smelters. *Am J Epidemiol* 106: 261, 1977
7. ROELS HA, BUCHET J-P, LAUWERYS R, et al: Lead and cadmium absorption among children near a nonferrous metal plant: a follow-up study of a test case. *Environ Res* 15: 290, 1978
8. LIN-FU JS: Undue absorption of lead among children — a new look at an old problem. *N Engl J Med* 286: 702, 1972
9. GUINEE VF: Lead poisoning. *Am J Med* 52: 283, 1972
10. Surveillance of childhood lead poisoning — United States. *Morb Mortal Wkly Rep* 28: 117, 1979
11. NEEDLEMAN HL, GUNNOE C, LEVITON A, et al: Deficits in psychologic and classroom performance of children with elevated dentine lead levels. *N Engl J Med* 300: 689, 1979
12. LAPORTE RE, TALBOTT EE: Effects of low levels of lead exposure on cognitive function — a review. *Arch Environ Health* 33: 236, 1978
13. *Report of the Lead Data Analysis Task Force*, Ontario Ministry of the Environment, Toronto, 1975, p xvii
14. NERI LC, JOHANSEN HL, SCHMITT N, et al: A comparative survey of blood and hair levels for certain trace metals in Trail and Nelson, B.C., Canada: a preliminary report. Presented at the 68th Annual Conference of the Canadian Public Health Association, Vancouver, June 29, 1977
15. NERI LC, JOHANSEN HL, SCHMITT N, et al: Blood levels of children in two British Columbia communities, in *Trace Substances in Environmental Health — XII*; Proceedings of the University of Missouri's 12th Annual Conference on Trace Substances in Environmental Health, Columbia, Missouri, June 6–8, 1978, HEMPHILL DD (ed), U of Missouri, Columbia, 1978, p 403
16. TER HARR GL, ARONOW R: New information on lead in dirt and dust as related to the childhood lead problem. *Environ Health Perspect* 7: 83, 1974
17. SAYRE JW, CHARNEY E, VOSTAL J, et al: House and hand dust as a potential source of childhood lead exposure. *Am J Dis Child* 127: 167, 1974
18. FAIREY FS, GREY JW III: Soil lead and pediatric lead poisoning in Charleston, S.C. *J SC Med Assoc* 66: 79, 1970
19. ANGLE CR, MCINTIRE MS, VEST G: Blood lead of Omaha school children — topographic correlation with industry, traffic and housing. *Nebr Med J* 60: 97, 1975
20. YU WL, VISLAY SA, EDWARDS RE: Is airborne lead from combustion of leaded gasoline a possible health hazard? Observations on 277 Fontana (California) area residents. *Clin Pediatr (Phila)* 16: 791, 1977
21. LEPOW ML, BRUCHMAN L, RUBINO RA, et al: Role of airborne lead in increased body burden of lead in Hartford children. *Environ Health Perspect* 7: 99, 1974
22. ROBERTS TM, HUTCHINSON TC, PACIGA J, et al: Lead contamination around secondary smelters: estimation of dispersal and accumulation by humans. *Science* 186: 1120, 1974
23. DAY JP, HART M, ROBINSON MS: Lead in urban street dust. *Nature* 253: 342, 1975
24. HUNT WF, PINKERTON C, MCNULTY O, et al: A study in trace element pollution in 77 mid-western cities, in *Trace Substances in Environmental Health — IV*; Proceedings of the University of Missouri's 4th Annual Conference on Trace Substances in Environmental Health, Columbia, Missouri, 23–24 June, 1970, HEMPHILL DD (ed), U of Missouri, Columbia, 1971, p 56
25. *Environmental Health Criteria 3: Lead*, World Health Organization, Geneva, 1976, pp 30, 57-58, 124
26. BARLTROP D, STREHLOW CD, THORTON I, et al: Significance of high soil lead concentrations for childhood lead burdens. *Environ Health Perspect* 7: 75, 1974
27. LOVEJOY G, TAYLOR TA, FRANK M, et al: Lead poisoning — Tennessee. *Morb Mortal Wkly Rep* 25: 85, 1976
28. GIGUERE CG, HOWES AB, MCBEAN M, et al: Increased lead absorption in children of lead workers — Vermont. *Morb Mortal Wkly Rep* 26: 61, 1977
29. DARROW DK, SCHROEDER HA: Childhood exposure to environmental lead. *Adv Exp Med Biol* 48: 425, 1974
30. SCHMITT N, BROWN G, DEVLIN EL, et al: Lead poisoning in horses. *Arch Environ Health* 23: 185, 1971
31. *Air Quality Criteria for Lead*, EPA-600/8-77-017, health effects research laboratory, special studies office, US Environmental Protection Agency, Research Triangle Park, NC, 1977, pp 12-31