Fifty-one apartments in twenty buildings (random sample) from sections of Manhattan, Bronx, and Brooklyn having a high incidence of lead poisoning were surveyed using a portable, direct reading, non-destructive lead detection apparatus based on X-ray fluorescence. The results show that 100% of the apartments surveyed have lead levels of 0.26 mg/cm² (approximately 3% in a single coat of paint). However, the results also indicate a marked decrease in frequency of contaminated surfaces as levels increase. These results suggest that an effective program of lead paint decontamination, planned to correct sequentially the worst hazards first, may be economically feasible.

The Distribution of Lead Paint in New York City Tenement Buildings

Gerard R. Laurer, Ph.D.; Roy E. Albert, M.D.; Theodore J. Kneip, Ph.D.; Bernard Pasternack, Ph.D.; Clifford Strehlow, Ph.D.; Norton Nelson, Ph.D.; and Frederick S. Kent, B.S., M.P.H.

Introduction

In the last few years there has been a rapidly growing public concern over the need to eliminate lead poisoning in teething children living in the city slums. About two years ago, the problem was brought to the attention of this Institute by the New York City Department of Health with particular regard to the nature of the hazard and methods for its control. The salient facts about the hazard which emerged from these discussions were the following: there are perhaps 30,000 dilapidated tenements (each containing on the average some ten apartments) in which the risk of childhood lead poisoning is high. The cost of wholesale decontamination in all these apartments, either by removal of the paint or by covering with cladding material, was estimated at several billion dollars, and consequently economically unfeasible. However, it was noted that low lead levels (less than 1% by weight) were encountered in the majority of paint samples, collected and analyzed by the New York City Health Department from apartments in which lead poisoning cases had occurred. This finding raised the possibility that a more detailed and systematic study of lead paint in slum tenements might show a sufficiently spotty distribution pattern to make selective decontamination effective and economically feasible. The success of such an approach clearly depended on the availability of a suitable survey instrument for measuring lead in painted surfaces. Because of the pressing nature of the problem, this Institute undertook a program to develop such a survey instrument and to carry out a limited study of the distribution of lead paint in the slum tenements as the first step in assessment of the feasibility of selective decontamination. The survey instrument developed has been reported elsewhere.[1] This paper describes the distribution pattern of lead in a randomly selected sample of 51 apartments in 20 tenement buildings within areas of New York City having a high incidence of lead poisoning.

Materials and Methods

1.0 Lead Detector

The instrument operates by detecting and counting the number of K-shell X rays in the energy range characteristic of the Kß line of lead excited by irradiation with gamma rays from a ^{109}Cd-^{109}Ag source. The detector is a lithium-drifted, germanium diode cooled by liquid nitrogen. Pulses from the preamplifier within the detector housing are conducted by cable to a module consisting of an amplifier, single-channel analyzer and pulse counter. The two components of the prototype detector (cryostat and electronics module) each weighed approximately twenty pounds. The instrument was calibrated in terms of mg Pb/cm² using mock wall panels constructed with metal lathe, wood lathe and gypsum board covered with plaster and painted with a single coat of known lead content paint and several coats of non-lead base paint. The use of this instrument provides a specific, rapid, in situ, non-destructive method for detection of lead paint with sensitivity for small amounts of contamination. The detection limit for the prototype instrument used in the survey was 0.26 mg/Pb/cm² (approximately equivalent to one layer of paint with 3% lead content). A fixed detector-surface distance of five centimeters was used for all measurements. The effective measured area was a circle of five cm in diameter.

2.0 Selection of Buildings and Apartments for Survey

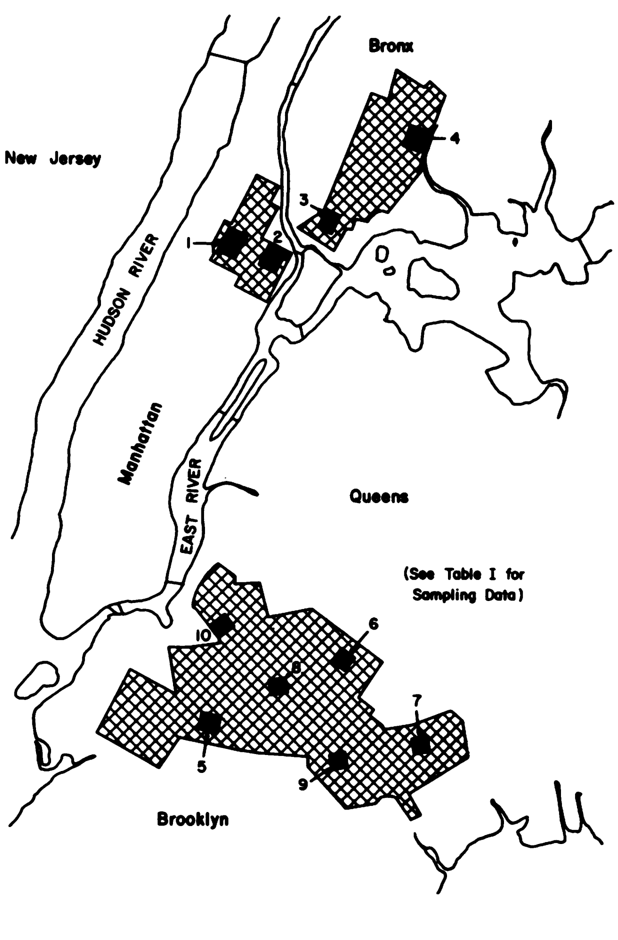
In recent years almost all lead poisoning cases occurred in the three regions of New York City shown in Figure 1, which are located in south Bronx, upper Manhattan, and sections of Brooklyn. In each of the three areas, ten randomly located sites, 10-15 blocks square, were chosen as shown in Figure 1. The number of sites per borough was roughly proportioned to the area in which the lead poisoning cases occurred, i.e., two each in the Bronx and Manhattan and six in Brooklyn. A table of random numbers was used to select two blocks within each of the ten sites and one building to be surveyed from each block. In case of failure to gain access to the selected building, the same process of random selection was repeated until a building on the same block was located in which the survey could be carried out. In this way a total of twenty buildings were selected for study.

In each selected building, all accessible apartments were surveyed, i.e., 51 of a possible 151. Entry was refused in about one-third of the non-surveyed apartments; the occupants were unavailable in the remainder. The number of apartments and children of various ages in each of the surveyed buildings is tabulated in Table 1.

3.0 Lead Measurements

In each apartment lead measurements were made in every room, as well as the interior halls. In each room measurements were made on two walls and one of the doors and window frames. Doorframes and baseboards were also measured when the paint was different from that on the doors. All measurements were of one-minute duration and were made with the instrument on a tripod, at a distance of 2.5 feet from the floor. Instrument performance was checked against a lead calibration surface before use in each room.

Figure 1—Sampling Regions Used in New York City. Crosshatched sections are the regions of high incidence of lead poisoning. Numbered, dark areas are sampling locations



The two walls selected for measurement in each room were determined largely by ready access for positioning of the detector. Duplicate measurements were made at all wall sites where readings were in excess of 20 cpm (equivalent to 1.0 mg Pb/cm^2). A second site on the same wall was measured when the initial reading was less than 20 cpm. The first step assessed the reproducibility of measurements and the second the variability of lead levels on a given wall. For 142 duplicate measurements on one point on a wall, the data, when divided into four ranges of 20-100 cpm, 100-200 cpm, 200-300 cpm, and 300-400 cpm, yielded coefficients of variation of 15%, 7.3%, 7.8% and 7.0% respectively. The larger deviation in the lower count rate ranges is expected because of the lower counts recorded. Only two out of 112 duplicate measurements at different points on the same wall (1.8%), resulted in significant differences between the values. Single measurements were made on doors and/or doorframes and window frames.

Results

The combined data for all 51 apartments are presented in Figure 2 in terms of the frequency distributions of maximum lead levels according to apartment, room, wall, door, doorframe and window frame. The maximum measured lead levels in mg/cm^2 have been classified according to the following intervals: less than 0.255, 0.255-0.99, 1.0-4.99, 5.0-9.99, 10.0-14.99, 15.0-19.99, 20.0-24.99, 25.0-29.99, 30.0 and higher. The detection limit of 0.255 mg Pb/cm^2 is roughly equivalent to 3% lead in a single layer of paint.

Table 2 presents a breakdown of the data for various types of rooms and surfaces according to the observed and minimum-expected percentages which exceeded 0.255 mg/cm^2, 1.0 mg/cm^2 and 5.0 mg/cm^2. The basis for the statistical estimate of the minimum-expected percentages (i.e., the lower limit of a one-sided 95% confidence interval for the "true" population percentage) is given in Appendix I. All of the 51 apartments had some contamination and 84% had at least one measurement exceeding 5.0 mg Pb/cm^2, approximately equivalent to one layer of 50% lead paint. All of the measured surfaces (window and doorframes, walls and doors) had similar levels of contamination. For all surfaces, the observed percentages exceeding the levels of 0.255 mg/cm^2, 1.0 mg/cm^2 and 5.0 mg/cm^2 were 87%, 60% and 35% respectively. The window frames tended to be the most contaminated and the doors the least contaminated surfaces, but the differences were not large; e.g., 44% of the window frames exceeded lead levels of 5.0 mg/cm^2 compared to 31% for doors.

All of the rooms regardless of type showed some measurable contamination; however, there were appreciable differences in the frequency of relatively heavy contamination. The observed proportion of kitchens with maximum levels exceeding 5.0 mg/cm^2 was 72%; while bathrooms, dining rooms and bedrooms all had comparable values of 56%-57%; the lowest frequencies were found in halls and living rooms with 48% and 39% respectively.

Table 1—Number of Apartments and Children of Various Ages in Surveyed Buildings

Borough	Site	No. Surveyed Apartments/Building	Number of children in the indicated age range <1	1-4	>4	Total
Manhattan	1	5	2	2	13	17
		2	0	1	0	1
	2	1	0	2	1	3
		4	0	1	14	15
Subtotal		12	2	6	28	36
Bronx	3	1	0	2	0	2
		6	0	2	5	7
	4	5	1	6	4	11
		2	0	1	8	9
Subtotal		14	1	11	17	29
Brooklyn	5	4	1	1	8	10
		3	0	0	0	0
	6	1	0	1	1	2
		2	0	0	7	7
	7	1	0	0	0	0
		4	0	2	5	7
	8	1	0	0	1	1
		2	0	2	5	7
	9	1	0	0	1	1
		2	0	0	0	0
	10	2	2	2	6	9
		2	1	2	6	9
Subtotal		25	4	10	40	54
Grand Total		51	7	27	85	119

Table 2—Lead Contamination According to Apartment, and Type of Room, and Painted Surface: The Observed and Minimum Expected Percentages* in Excess of the Indicated Levels of Contamination

	Total No.	>0.255 mgPb/cm²	Obs. %	Minimum Expected %	>1.0 mgPb/cm²	Obs. %	Minimum Expected %	>5.0 mgPb/cm²	Obs. %	Minimum Expected %
Apartments	51	51	100	94.3	51	100	94.3	43	84.3	71.7
Rooms	280	280	100	98.9	245	87.5	83.4	158	56.4	50.5
Walls	556	487	87.6	84.8	325	58.5	54.3	182	32.7	28.8
Doors	166	129	77.7	70.7	94	56.6	47.9	51	30.7	23.6
Doorframes	102	91	89.2	82.2	64	62.7	51.7	43	42.2	28.1
Window frames	159	146	91.8	87.0	111	69.8	61.6	70	44.0	36.1
Kitchens	50	50	100	94.2	49	98.0	90.5	36	72.0	56.2
Bathrooms	47	47	100	93.8	41	87.2	74.7	27	57.4	38.2
Dining rooms	9	9	100	71.7	9	100	71.7	5	55.6	26.0
Living rooms	44	44	100	93.4	33	75.0	58.5	17	38.6	15.3
Halls	23	23	100	87.8	17	73.9	48.5	11	47.8	15.2
Bedrooms	101	101	100	97.7	90	89.1	81.9	58	57.4	45.1

* See Appendix I for explanation

The frequency distributions of the contamination levels in apartments, rooms and on surfaces, when classified by borough, are given in Table 3. It can be seen that the apartments, rooms and walls in the Bronx are somewhat less severely contaminated than those in Brooklyn and Manhattan when compared at the 5.0 mg Pb/cm^2 level. This difference is consonant with the ages of the buildings in the Bronx as compared to the other boroughs.

Table 3—The Observed and Minimum Expected Percentages in Excess of the Indicated Levels of Lead Contamination According to Apartments, Rooms, Painted Surfaces of Various Types, and Borough

	No. Obs.	Greater than 0.255mg/cm²	Obs. %	Minimum expected %	Greater than 1.0mg/cm²	Obs. %	Minimum expected %	Greater than 5.0mg/cm²	Obs. %	Minimum expected %
Manhattan										
Apartments	12	12	100	77.9	12	100	77.9	12*	100	77.9
Rooms	68	68	100	95.7	57	83.8	73.2	40*	58.8	43.5
Walls	134	124	92.5	87.3	80	59.7	49.4	55*	41.0	28.9
Doors	45	37	82.2	67.9	24	53.3	32.8	12*	26.7	15.7
Doorframes	17	15	88.2	67.0	12	70.6	47.5	5*	29.4	12.5
Window frames	34	32	94.1	81.5	23	67.6	46.3	14*	41.2	14.5
Bronx										
Apartments	14	14	100	80.7	14	100	80.7	8†	57.1	32.0
Rooms	74	74	100	96.0	60	81.1	70.3	26‡	35.1	17.5
Walls	148	128	86.5	80.4	75	50.7	40.1	30‡	20.3	13.7
Doors	39	32	82.1	66.3	21	53.8	31.4	9*	23.1	11.6
Doorframes	25	20	80.0	58.0	9	36.0	20.2	4‡	16.0	5.7
Window frames	50	41	82.0	68.5	28	56.0	37.1	15*	30.0	15.0
Brooklyn										
Apartments	25	25	100	88.7	25	100	88.7	23	92.0	74.8
Rooms	138	138	100	97.9	128	92.8	87.7	92	66.6	57.4
Walls	274	235	85.8	83.5	170	62.0	56.2	97	35.4	29.6
Doors	82	60	73.2	61.6	49	59.8	46.2	30	36.6	20.1
Doorframes	60	56	93.3	84.7	43	71.7	57.4	32	53.3	35.9
Window frames	75	73	97.3	91.6	60	80.0	69.2	41	54.6	39.6

* Not significantly different from Brooklyn at the 0.05 probability level.
† Significantly different from Brooklyn at the 0.05 probability level.
‡ Significantly different from Brooklyn at the 0.01 probability level.

No significant association was found between the ages of the children living in a given apartment and the level of lead contamination.

Discussion

The survey reported here, although limited in scope, was done on a carefully randomized basis and is adequate to give a general picture of the distribution characteristics of lead in the tenement buildings.

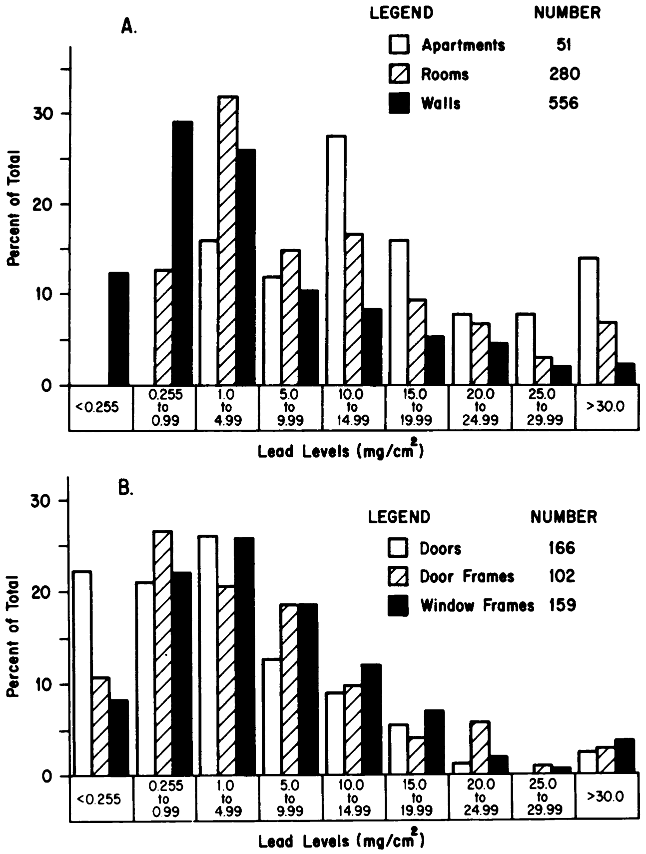
The survey results show that only a small proportion of the painted surfaces have a negligible lead content (i.e., <0.26 mg/cm², equivalent to about 3% lead in a single layer of paint). However, it is encouraging to note that while the lead paint is widespread throughout these old buildings, it is not found on all surfaces. The number of surfaces to be decontaminated would depend strongly on the choice of acceptable contamination limits. For example, the minimum expected percentage of contaminated walls decreases from 84.8% at a level of 0.255 mg/cm² to 28.8% at a level of 5.0 mg/cm². (See Table 2 and Figure 2). Although the number of apartments requiring decontamination is not appreciably affected by these considerations, the number of rooms requiring decontamination falls rapidly with increasing levels of acceptable contamination. The minimum expected percentage of contaminated living rooms, for example, drops from 93.4% at 0.255 mg/cm² to 15.2% at 5.0 mg/cm².

The New York City health code specifies a limit of 1% of lead by weight in the non-volatile solids, in paints for indoor use. This is also the limit specified for paint already on indoor surfaces. An early publication[2] specifically stated that the recommendation of the Committee on Hazards for Children, on which the code is based, did not apply to multiple layers of paint in old, deteriorating housing. Thus, despite meeting a 1% Pb by weight limit, multiple layers of paint could contain excessive amounts of lead in very small flakes. The need therefore is to define the limit in terms of mass per unit area, as has been done in this report.

The definition of a "safe" amount of lead which may be ingested is extremely difficult. A study group of the Federal Public Health Service has been appointed to provide an estimate of such a limit using units of mg/cm².[3]

Chisolm[4] has reported mean fecal outputs of 0.13 mg Pb/24 hours (range 0.012-0.175) for non-exposed controls, 0.832 (0.087-1.93) mg Pb/24 hours for exposed controls, and 2.16 (0.116-9.6) mg Pb/24 hours for children with blood leads over 0.06 mg% classed as "asymptomatic, increased lead absorption." These would correspond approximately to mean intakes of 0.15, 0.92 and 2.4 mg Pb/24 hours. Thus even "exposed normals" exceed the unexposed controls by about a factor of 6. It appears that a "safe" limit might be between 0.1 and 1.0 mg/24 hours. Assuming that ingestion of as little as 1 cm² per day should not be harmful, this amounts to contamination limits on the order of 0.1 to 1.0 mg/cm². These estimates are clearly based on very in-

Figure 2—Lead Paint Distribution



complete information and serve primarily to indicate the need for more reliable information.

In any event, it is apparent the most severe hazards should be dealt with first and a very substantial gain would be achieved by correcting sequentially the worst hazards first, then proceeding to lesser levels of contamination and accessibility. The proper use of the survey instrument will depend on the priorities chosen and the economics of the cleanup operation at the several stages. For example, a strategy of decontaminating first all walls and woodwork in apartments with lead contamination of 20 mg/cm^2 or higher would require the correction of about 8% of the walls and about 10% of the woodwork in about 17% of the rooms, these in approximately 28% of the apartments. This would represent a very significant gain in safety. The identification of the contaminated surfaces can be quickly and accurately achieved with an instrument such as the one described. Cost estimates for decontamination at graded levels of completeness are clearly required; the effectiveness in reducing the overexposure of children to lead by such graded levels of decontamination might profitably be examined in a carefully planned demonstration program.

The current practice of testing and repairing only damaged or deteriorated areas in a room fails to remove many potential sources of exposure. Since the buildings involved are in generally poor condition, any intact surface may be a deteriorating source of paint flakes in the foreseeable future. Thus location and removal of all potential sources is a critical factor in preventing re-exposure of once-exposed children or exposures of additional children.

Appendix I

Estimation of Minimum Expected Contamination Levels

The minimum expected percentage is determined as follows: Let p denote the probability that an apartment is not contaminated (based on an arbitrarily selected level, 0.255, 1.0 or 5.0 mg Pb/cm^2, e.g., contamination—at least one measurement is greater than 0.255 mg/cm^2) and q, the probability that an apartment is contaminated. Then the probability that k out of n randomly selected apartments will not be contaminated can be obtained from the binomial distribution,

$$P(k) = \frac{n!}{(n-k)!k!} p^k q^{n-k}$$

where $p + q = 1$.

Now, for example, if $k = 0$ and $n = 51$, the resultant probability is

$$P(0) = \frac{(51)!}{(51-0)!0!} p^0 q^{51}$$

$$= q^{51}$$

Hence, the smallest value of q such that q^{51} is greater than or equal to 0.05 represents the lower limit of a 95% one-sided confidence interval for the "true" population percentage of contaminated apartments which we have called the "minimum expected percentage." In this instance ($n = 51$, $k = 0$) the value of q obtained from statistical tables of the binomial distribution is 0.943. Therefore, it may be stated, with 95% confidence, that *at least* 94.3% of all apartments in the population are contaminated at a level of 0.255 mg Pb/cm^2 or above (See Table 2). This estimate is independent of the size of the population, as long as the random sample is representative of that population.

Thus, if there are 100,000 apartments in the "lead belt" areas, at least 94,300 are expected to be contaminated at this level or above. Similarly, if there are 300,000 apartments in the population, a minimum of 0.943 times 300,000 or 282,900 are expected to be contaminated at this level or above.

As another illustration, consider an instance where, for example, two out of six dining room walls are found not to be contaminated or, stated otherwise, four out of the six are found to be contaminated, i.e. at least one measurement was found to be greater than 0.255 mg/cm^2. Here we select the smallest value of q consistent with

$$\sum_{k=0}^{2} \frac{6!}{(6-k)!k!} p^k q^{6-k} > 0.05$$

For this example, the value of q is 0.27. Thus we can state, with 95% confidence, that *at least* 27% of the population of dining room walls in the lead belt areas of New York City are contaminated. In general, then, if r out of n units (apartments, rooms, walls, etc.) are not contaminated, the "minimum expected percentage" of contaminated units in the population is taken to be q (100%) where q is the smallest value consistent with

$$\sum_{k=0}^{r} \frac{n!}{(n-k)!k!} p^k q^{n-k} > 0.05$$

where $p + q = 1$.

The values of q were obtained from tables of the cumulative binomial distribution when possible; otherwise the Poisson approximation to the binomial was used.

It should be noted, of course, that the calculated percentages depend strongly upon the total number of observations, since the same confidence level of 95% is used for all. Hence, while all bedrooms and all dining rooms were found to be contaminated, the calculated minimum expected percentages for the entire population are 97.7% for bedrooms and 71.7% for dining rooms because of the differences in sample size, i.e., 101 bedrooms versus only 9 dining rooms.

It must be emphasized that these are minimum expected percentages for the entire population and actual determined values could easily be greater.

ACKNOWLEDGMENTS

We thank the students at New York University, Heights Engineering Campus, who helped in performing the survey, viz., S. Dworkin, A. Feldman, S. Finkel, S. Fisher, A. Imakyura, A. Kalnin, Z. Kanai, S. Kantrowitz, B. Kramer, P. Lax, R. Leddy, M. Merksamer, E. Reibstein, A. Rosenberg, J. Sapan, and D. Platt; also the members of the Heights placement service, especially Mrs. Charles and Miss Unander, for their help in recruiting the students. This work was supported by Grant U-2078 from the Health Research Council of New York City and is part of a Center program supported by the National Institute of Environmental Health Sciences, Grant No. ES-00260.

References

1. Laurer, G. R., et. al. X-ray Fluorescence: Detection of Lead in Wall Paint. Science 172:466, April 30, 1971.
2. Chisolm, J. Julian, Jr. and Harrison, Harold E. The Exposure of Children to Lead. Pediatrics, Vol. 18, No. 6, pp 943-958, December 1956.
3. King, Barry. Bureau of Community Environmental Management, U.S. Public Health Service. Private Communication.
4. Chisolm, J. Julian, Jr. and Harrison, Harold E.; ibid.

Dr. Laurer, Dr. Albert, Dr. Kneip, Dr. Pasternack, Dr. Strehlow, and Dr. Nelson are affiliated with the Institute of Environmental Medicine, New York University Medical Center, New York, New York 10016. Mr. Kent was formerly with the Environmental Health Service, New York City Department of Health. His current affiliation is the Office of International Health, Department of Health, Education and Welfare, Washington, D.C.

This paper was submitted for publication in September, 1971.