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LEAD USE IN CALIFORNIA INDUSTRY: ITS PREVALENCE AND HEALTH IMPLICATIONS*

Dan S. Sharp[a†]
Carin Perkins[a]
Steven J. Samuels[b]
Jon Rosenberg[a]
Linda Rudolph[a]

[a]California Occupational Health Program, California Department of Health Services, 2151 Berkeley Way, Berkeley, CA 94704; [b]Division of Occupational and Environmental Medicine, University of California, Davis, CA 95616

An estimated 230 000 workers were reported to work in lead-using activities as a result of a 1986 statistical survey of employers in California. However, 68% of these workers worked in activities of relatively low hazard. This included 114 000 workers engaged in electronic soldering. Over 1800 workers were reported to work in battery manufacture, a relatively high-hazard activity, but with consistent monitoring and protection. In contrast, over 4300 workers were involved in radiator repair activities, a high-hazard activity with inconsistent monitoring and protection. Over 8% of construction workers were reported to work in lead-using processes. This sector is exempt from federal Occupational Safety and Health Administration (Fed/OSHA) and California Occupational Safety and Health (Cal/OSHA) lead standards, yet some of the most hazardous activities (welding, grinding, and cutting, etc.) occurred here. Comparison of projections from the National Occupational Hazard Survey of potential lead exposure in California with these survey results suggests consistent and reliable assessment of the major sources of potential occupational exposure to lead.

Lead is a most useful substance. Its utility has been recognized since antiquity, as have its hazards.[1–4] Determined assessment and intervention into modern lead hazards can be traced to the efforts of Legge and Oliver in the United Kingdom with the passage of the Factories Act of 1895, when lead poisoning became a notifiable disease.[5] Studies of the United States ceramics industry in the 1910s,[6] of the German lead industries in the 1920s,[7] and of the United States storage battery industry in the 1930s[8,9] represent early efforts to assess the extent and type of lead exposure in targeted working populations.

Since 1940, attempts to characterize the lead-exposed population in the United States have been sporadic. A survey of a number of industrial hazards including lead was conducted by the United States Public Health Service in 1940 in 15 states.[10] This survey suggested that 5.2% of all workers in the United States were exposed to "lead and its compounds." More recent data on the extent of occupational lead exposure is available from the National Institute for Occupational Safety and Health (NIOSH) National Occupational Hazard Survey (NOHS)[11–13] conducted between 1972 and 1974. A new survey, labeled the National Occupational Exposure Survey, is currently being completed with similar, but expanded, goals and assessments as the NOHS.

The estimated numbers of California workers reported by their employers to work in lead-using processes are presented in this paper. This study, as well as previous surveys, document an important and essential public health activity in regard to the hazards of human lead exposure. Without the ability to identify who is exposed, where they are exposed, and how they are exposed, appropriate interventions are neither feasible nor effective.

EXPERIMENTAL MATERIALS AND METHODS

The sample survey was designed specifically to estimate the number of workers reported to work in lead-using processes and those with environmental and biological monitoring. Estimates of monitoring activity have been presented in another publication.[14] All estimates are derived from a 1986 probability sample of California industrial, commercial, and governmental facilities. A detailed description of the sampling strategy and the statistical methods used in this survey are presented in the accompanying paper in this issue.[15]

Employers were identified and sampled from a list maintained by the California State Employment Development Department. Information was provided by employers responding to one or two questionnaires by mail or by telephone interview. The first questionnaire identified current lead users and asked for counts of employees working in lead-using processes. The second questionnaire, directed only to lead users, requested information on processes with lead use and on environmental and biological monitoring.

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†Address correspondence to Dr. Sharp, Amoco Corporation, 200 East Randolph Drive, Mail Code 3805, Chicago, IL 60601.

Assessment of lead use was self-reported by company representatives. The numbers reflect employees reported to work in lead-using processes by their employers. These workers are labeled "potentially exposed" because the survey did not directly assess dose of lead accumulation.

A number of approaches were used in establishing exposure indicators. One approach examined special interest standard industrial classification (SIC) codes with known lead use. These were more heavily sampled and included (SIC codes in parentheses) plumbing, heating, and air conditioning (1711); secondary smelting and nonferrous metal (3341); storage battery manufacture (3691); shipbuilding and repair (3731); automotive repair (7538); radiator repair (7539); and welding repair (7692).

Two additional approaches examined the specific processes listed by respondents and reduced these into 12 categories describing a process (e.g., painting with leaded paints, dispensing leaded gasoline, etc.) and a more general exposure score for each process that was based on expert industrial hygiene ranking of exposure intensity. The ranked processes were divided into low, moderate, and high levels. The formation of these scores is described in the appendix. Reported frequency of work in listed processes was an additional dimension of exposure, reduced to three ordered levels labeled daily, weekly, and less than weekly.

The number of facilities and workers reported to be involved in some type of lead-using process in California are reported in this paper. The estimated numbers of potentially exposed workers are categorized by the general SIC code divisions (manufacturing, construction, etc.); various exposure indicators (specific lead-using SIC codes, the 12 descriptive processes, exposure score, frequency of exposure); and facility size. The estimated numbers are based on the weighted sampling scheme described in the accompanying paper[15] and are designed to be free of systematic bias. Standard errors of these estimated numbers were also determined and reflect the variability that arose from taking the sample.

RESULTS

A total of 1155 employers were sent the first questionnaire, and 1086 (93.5%) completed it. Of these, 539 reported using lead or lead-containing materials, and 521 (96.7%) of these completed the second questionnaire. All estimates presented in the following tables are rounded. Thus, they may not sum accurately to reported totals.

There are an estimated 52 700 facilities in which lead is used (Table I). With 682 600 facilities in California,[16,17] this represents about 7.7% of all facilities. Over half of the lead use is in facilities of 1 to 19 employees (33 400).

An estimated 230 000 workers work in industries and positions in which their employers reported some type of lead-using process. This represents almost 2% of the total work force of 11.8 million (Table II). The number of workers reported to work in lead-using processes decreases from 82 000 in small-sized facilities to 45 000 in facilities with more than 500 employees and to 32 000 in facilities with 100–499 employees (Table I).

Estimation of Workers Reported to Work in Lead-Using Processes

Over 85 000 workers reported to work in lead-using processes are employed in the manufacturing SIC code division (Table II). The next largest segment is in the construction division, with 42 000 workers. These 42 000 workers represent over 8% of the work force in construction, the largest proportion noted among all divisions.

Frequencies in the public administration division are markedly underestimated. This is because the California State Employment Development Department does not include all state-owned facilities on the Employer Detail File.[15]

Indexes of Lead Exposure

Special Interest SIC Codes and Type of Process

Over 22 000 workers are reported to work in lead-using processes in special interest SIC code 1711, which covers plumbing, heating, and air conditioning (Table III). The numbers of potentially exposed workers in radiator repair (SIC 7539) and welding repair (SIC 7692) are much smaller than the numbers reported in Table IV, indicating sizable radiator repair and welding activities in SIC codes outside these special interest codes.

Table IV depicts the number of workers reported to work in lead-using processes for 12 descriptive activities. Soldering activities (excluding pipe and metal sheets) accounted for almost half of potentially exposed workers. Each remaining process generally accounts for less than 10% of potentially exposed workers.

Exposure Score and Frequency of Exposure

Low exposure scores accounted for almost 68% of workers reported to work in lead-using processes and daily exposure frequency for over 50% of workers (Table V). Almost all daily contacts occurred in activities with low exposure scores and represent approximately 95 000 of 115 000 (83%) potentially exposed workers with daily contact.

TABLE I. Estimated Number of Facilities and Employees Reported to be Involved in Lead-Using Processes in California by Size of Facility[A]

	Facilities with Lead Use		Employees in Lead-Using Activity			
Facility Size	n	(SE)	n	(SE)	In Size Category (%)	(SE, %)
Total	52 700	(7800)	229 400	(21 200)	100.0	—
1–19	33 400	(7500)	81 900	(10 800)	35.7	(4.2)
20–99	12 800	(2200)	70 400	(15 500)	30.7	(5.2)
100–499	4100	(780)	32 300	(6000)	14.1	(2.6)
500 or more	2400	(400)	44 800	(8600)	19.5	(3.5)

[A]Estimates are rounded and may not sum accurately to the total.

TABLE II. Estimated Number of Employees Reported to Work in Lead-Using Processes in California by SIC Code Division[A]

SIC Code Division	Total Workers in California n	(%)	Workers in Lead-Using Activity n	(SE)	Total Workers in Division (%)	(SE, %)
Total	11 787 300	(100)	229 400	(21 200)	1.95	(0.18)
Agriculture, Forestry, & Fishing	423 900	(3.6)	—[B]		—	
Mining	47 100	(0.4)	990	(590)	2.1	(1.3)
Construction	518 100	(4.4)	41 700	(5700)	8.0	(1.1)
Manufacturing	2 154 900	(18.3)	85 100	(12 200)	4.0	(0.6)
Transport, Communication, & Utilities	753 600	(6.4)	32 100	(13 400)	4.3	(1.8)
Wholesale Trade	694 800	(5.9)	7900	(2200)	1.1	(0.3)
Retail Trade	2 001 800	(17.0)	27 500	(6200)	1.4	(0.3)
Finance, Insurance, & Real Estate	730 100	(6.2)	1500	(1500)	0.2	(0.2)
Services	3 744 600	(31.8)	32 800	(8200)	0.9	(0.2)
Public Administration[C]	612 300	(5.2)	—		—	
Unclassified	106 000	(0.9)	—		—	

[A]Estimates are rounded and may not sum accurately to the total.

[B]Estimated totals of 10 or less and corresponding percentages are indicated with a dash (—).

[C]Frequencies in this division were underestimated because of a failure to include all state-owned facilities on the California Employer Detail File, from which the sample was drawn.

TABLE III. Estimated Number of Employees Reported to Work in Lead-Using Processes in California by Special Interest SIC Code

Lead-Using SIC Code		Employees in Lead-Using Activity n	(SE)
1711:	Plumbing, heating, and air conditioning	22 700	(2200)
3341:	Secondary smelting, nonferrous metals	390	(130)
3691:	Storage battery manufacture	1850	(310)
3731:	Shipbuilding and repair	1090	(440)
7538:	Automotive repair shops	6560	(1590)
7539:	Radiator repair shops[A]	900	(110)
7692:	Welding repair	310	(90)

[A]This is a general automotive repair SIC code. Only facilities with the word *radiator* in their business name were included in the sampling frame.

The most common category was daily frequency/low exposure score with almost 42% of potentially exposed workers. The major activities in this category are electronic soldering and dispensing leaded gasoline. The most hazardous category, daily/high, accounted for 6400 workers.

Exposure Score by Frequency by Facility Size

Table VI depicts a further breakdown of the number of workers reported to work in lead-using processes by frequency of exposure, exposure score, and facility size. Daily/low was the most common category of exposure for all facility size levels, ranging from 28% to 68% of potentially exposed workers. Electronic soldering was the primary activity contributing to these daily/low numbers for companies with 20 or more employees (data not shown), engaging between 80% and 95% of all potentially exposed workers in this category. About 77% of potentially exposed workers in this joint level dispensed leaded gasoline in facilities with 1–19 employees.

Almost 10% of potentially exposed workers employed in facilities with 100–499 employees worked in the daily/high level. This contrasts with 1–2% in the other facility size levels. This high percentage reflects a high proportion of battery manufacturers and casting/melting lead activities in this facility size level.

DISCUSSION

About 2% of the working population in California is estimated to work in lead-using processes. This represents approximately 230 000 people. In contrast, application of NOHS data to California employment patterns suggests 164 000 potentially exposed workers. It is unlikely, then, that the survey missed major lead-using activities or large numbers of potentially exposed workers.

TABLE IV. Estimated Number of Employees Reported to Work in Lead-Using Processes in California by Type of Lead-Using Process[A]

Lead-Using Process	Employees Exposed to Lead	Percent of Exposed (%)	(SE, %)
Total	229 400	100.0	
Soldering, except pipe & sheets	114 100	49.7	(4.7)
Dispensing leaded gasoline	31 000	13.5	(3.0)
Soldering pipes & sheets	22 300	9.7	(1.5)
Cable cutting and splicing	13 800	6.0	(4.8)
Painting with leaded paints	12 700	5.5	(2.9)
Printing with lead-based inks	7500	3.3	(2.6)
Casting or melting lead, or jointing	4500	2.0	(0.5)
Radiator repair	4300	1.9	(0.7)
Welding metal alloys or lead-painted surfaces	4100	1.8	(0.4)
Machining, grinding, or sanding alloys, or lead-painted surfaces	3200	1.4	(1.0)
Battery manufacture	1900	0.8	(0.1)
Other processes	10 100	4.4	(1.2)

[A]Estimates are rounded and may not sum accurately to the total.

TABLE V. Estimated Number of Employees Reported to Work in Lead-Using Processes in California by Frequency of Exposure and Exposure Score[A]

Exposure Frequency	Exposure Score[B] High	Moderate	Low	Unclassified	Total
Daily					
N exposed	6400	13 100	95 500	100	115 000
% of exposed	2.8	5.7	41.6	0.04	50.1
(SE, %)	(0.65)	(1.0)	(4.6)	(0.05)	(4.8)
Weekly					
N exposed	3500	20 900	25 300	—[C]	49 700
% of exposed	1.5	9.1	11.0	—	21.7
(SE, %)	(0.6)	(4.7)	(3.4)		(5.2)
Less than weekly					
N exposed	6500	23 000	34 100	1040	64 700
% of exposed	2.8	10.0	14.9	0.4	28.2
(SE, %)	(1.1)	(3.0)	(2.7)	(0.4)	(4.1)
Total					
N exposed	16 400	57 000	154 900	1150	229 400
% of exposed	7.1	24.8	67.5	0.5	100.00
(SE, %)	(1.4)	(4.9)	(4.8)	(0.4)	

[A]Estimates are rounded and may not sum accurately to the total.

[B]Refer to Appendix for explanation of exposure score.

[C]Estimated totals of 10 or less and corresponding percentages are indicated with a dash (—).

Methodological Limitations

The numbers determined in this survey were subject to error. Two kinds of error can occur: random sampling error as reflected in the standard error of estimate and nonsampling errors that produce biases. The authors have rigorously attempted to control the sources of sampling error by following a strict statistical design. Caveats relating to both types of error are discussed in the accompanying paper.[15]

The assessment of exposure relied upon the self-reported activities of knowledgeable representatives of the company. Respondents often called study staff for guidance, and staff queried questionable or unusual responses. The survey could not determine the actual lead dose workers accumulated from the various activities; this would have required observation of the work site and recording of systematic industrial hygiene and biological monitoring data, which was not feasible.

Thus, the authors cannot directly infer that employees reported to be working in processes involving lead were actually accumulating lead; they can only infer a potential for such accumulation. Therefore, the results of this survey reflect the number of employees reported by their employers to work in a lead-using process without regard to their actual accumulation of lead from that process. Indirect indicators reflecting increased risk of accumulation, or a range of risk, are reflected in the special interest SIC codes, the 12 processes, and the exposure score (appendix).

The exposure score represents an attempt to generalize about the risk of actual exposure by using the experienced judgment of industrial hygienists. The high reliability among the hygienists in scoring the lead-using processes suggests the score to be a valid, although indirect, indicator of such risk.

Pathophysiological and Public Health Implications

With only 2% of the working population potentially exposed to lead, it appears that occupational exposure in the general population of California would be a small contribution to the total population's lead accumulation. The level of exposure would appear to be quite low compared to occupational exposure levels of the past half-century. Indeed, even in the traditionally

hazardous industry of battery manufacture, current practices result in much less frequent lead toxicity than characteristically seen only a few decades ago.

Although the traditional toxicologic consequences of occupational lead exposure may be a major public health problem of the past, two concerns remain. These are continued serious hazards in poorly monitored or regulated sectors and the consequences of chronic low-level lead accumulation, which has become a focus of current scientific interest.

There is particular concern that radiator repair activities represent a serious source of high lead exposure and that they are not adequately monitored by regulatory activities.[18,19] Similarly, the data from this survey and from surveillance activities recently established in California[20] are consistent in suggesting that a serious and continuing exposure problem exists in the construction trades. These industries have been exempt from the lead monitoring requirements of Fed/OSHA and Cal/OSHA. Indeed, the permissible exposure limit in construction trades is four times that of all other industrial segments (200 versus 50 $\mu g/m^3$). There are sizable numbers (41 700) and proportions (8.0%) of construction workers potentially exposed to lead in California, they are inadequately monitored,[14] and serious accumulations of lead and clinical toxicity are being noted among them.[20]

An additional concern relates to work activities acting as a source of lead contamination and accumulation in the worker's home and family. Radiator repair, smelter, and battery workers can bring home enough lead debris on their clothing and person to place their children and spouses at substantial risk.[21-23] The results of this survey estimate that no more than 6600 workers may act as vehicles of exposure to their homes and families. The actual potential is probably much less, given the stringent hygiene practices of most battery manufacturers.

New concern regarding lead exposure has developed in the past few years. Subtle, but biologically plausible, effects have been noted in the function of a number of organ systems at blood lead concentrations recently considered "acceptable."[24] These include hematological,[25] cardiovascular,[26] and cognitive/neurological effects from prenatal exposure.[27]

The levels of lead accumulation in these studies have been exceedingly low. In some cases, adverse effects have been associated with blood lead concentrations of less than 25 $\mu g/dL$.[27,28] These findings place the relationship between lead exposure and health risk in a different perspective.

More than 114 000 workers (almost 50% of all potentially exposed workers) are reported to work in electronic soldering activities. Do these workers accumulate sufficient lead over a prolonged period of time to place them at risk for developing these more subtle, but nonetheless significant, health effects?

Courtney and Meekin[29] demonstrated air lead levels of 2 $\mu g/m^3$ at the soldering tip and 1 $\mu g/m^3$ in the breathing zone. These are 2% to 4% of the OSHA permissible exposure limit for lead. However, significant decreases in blood lead concentrations of 4 $\mu g/dL$ were noted when smoking and food consumption were prohibited in the soldering work area.[29] Are such reductions in accumulation pathophysiologically important?

Although a sizable proportion of companies in California that engage in electronic soldering activities have done some type of monitoring,[14] few publications have described the results of such activities. In particular, there appears to be little investigation into the actual accumulation of lead derived from

TABLE VI. Estimated Number of Employees Reported to Work in Lead-Using Processes in California by Frequency of Exposure, by Exposure Score, and by Facility Size[A]

Facility Size and Exposure Frequency	*Exposure Score[B]*			*Unclassified*	*Total*
	High	*Moderate*	*Low*		
1–19 Employees					
Daily	840	4100	29 400	—[C]	34 300
Weekly	2900	5500	5800	—	14 100
Less than weekly	4500	15 100	13 700	—	33 400
Subtotal	8300	24 700	48 900	—	81 900
20–99 Employees					
Daily	1390	5800	19 500	—	26 700
Weekly	220	13 600	16 300	—	30 100
Less than weekly	560	4200	8800	—	13 600
Subtotal	2200	23 600	44 600	—	70 400
100–499 Employees					
Daily	3200	2000	16 000	—	21 200
Weekly	160	1140	1820	—	3100
Less than weekly	730	1320	6000	—	8000
Subtotal	4100	4500	23 800	—	32 300
500 + Employees					
Daily	970	1070	30 600	100	32 800
Weekly	230	720	1360	—	2300
Less than weekly	710	2400	5600	1040	9700
Subtotal	1910	4100	37 600	1140	44 800
Total	16 400	57 000	154 900	1150	229 400

[A]Estimates are rounded and may not sum accurately to the total.

[B]Refer to Appendix.

[C]Estimated totals of 10 or less are indicated with a dash (—).

soldering activities. Such investigations could be quite challenging because the concern is accumulation attributable solely to soldering activity and the degree of that accumulation is likely to be comparable to, if not smaller than, other environmental sources.

CONCLUSIONS AND RECOMMENDATIONS

Substantial numbers of California workers (230 000) are reported to work in lead-using processes. The level of exposure would appear to be much less than that of the past. This is not to say, however, that serious exposures no longer exist. In spite of marked improvements in exposure control in well-monitored industries such as battery manufacture, serious lead exposures still occur. Serious exposure potential appears to exist in such activities as radiator repair and the construction trades, in which there appears to be room for improvement in exposure control and monitoring activities.

The results of this survey, coupled with the results of recently instituted surveillance of laboratory blood lead concentrations in the state of California,[20] strongly indicate that workers in the construction trades are significantly exposed to lead, are inadequately monitored, and are sustaining serious illnesses from exposure. Exposure and monitoring standards and regulatory activities directed toward this sector need to be reevaluated.[14]

Efficient and targeted public health intervention into the control of lead exposure and hazards is possible only by development of accurate profiles. Identification of exposure and monitoring[14] profiles based on such indicators as the exposure score, frequency of exposure, and facility size appear to contribute to such efficiency. However, the methods used in this survey cannot be considered ideal. Attempting to assess exposure risk was particularly challenging and only partially successful in that the authors were unable to bring to bear already established and specific measuring techniques available to industrial hygienists. Similarly, concern regarding health effects from exceedingly low levels of lead exposure places interesting and novel demands upon public health assessment and intervention.

In spite of these limitations, this survey represents one of the most thorough and least biased estimations of lead use in a definable population.

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REFERENCES

1. **Aub, J.C., L.T. Fairhall, A.S. Minot, and P. Reznikoff:** Lead Poisoning. *Medicine 4*:1–250 (1925).
2. **Gilfillan, S.C.:** Lead Poisoning and the Fall of Rome. *J. Occup. Med. 7*:53–60 (1965).
3. **Nriagu, J.O.:** Saturnine Gout among Roman Aristocrats: Did Lead Poisoning Contribute to the Fall of the Empire? *N. Engl. J. Med. 308*:660–663 (1983).
4. **Nriagu, J.O.:** *Lead and Lead Poisoning in Antiquity.* New York: John Wiley & Sons, 1983. pp. 309–424.
5. **Lane, R.E.:** The Care of the Lead Worker. *Br. J. Ind. Med. 6*:125–143 (1949).
6. **Hamilton, A.:** *Lead Poisoning in Potteries, Tile Works, and Porcelain Enameled Sanitary Ware Factories.* Bulletin of the United States Bureau of Labor, Industrial Accidents and Hygiene Series, No. 104. Washington, D.C.: Government Printing Office, 1912.
7. **Engel, H.:** *Uber die Gesundheitsgefahrdung bei der Verarbeitung von metallischem Blei mit besonderer Berucksichtigung der Bleiloterei* [Concerning the Health Dangers of Working with Metallic Lead with Particular Consideration of Lead Soldering]. Schriften Aus Dem Gesamtgebiet Der Gewerbehygiene. Vol. 13. Der Deutschen Gesellschaft fur Gewerhehygiene. Berlin, Germany: J. Springer, 1925. [German].
8. **Dreesen, W.C., T.I. Edwards, W.H. Reinhart, R.T. Page, S.H. Webster, D.W. Armstrong, and R.R. Sayers:** *The Control of the Lead Hazard in the Storage Battery Industry.* Public Health Bulletin No. 262. Washington, D.C.: Government Printing Office, 1941.
9. **Dreessen, W.C.:** Health of Lead-Exposed Storage Battery Workers. *J. Ind. Hyg. Toxicol. 25*:60–70 (1943).
10. **Bloomfield, J.J., M. Trasko, R.R. Sayers, R.T. Page, and M.F. Peyton:** *Preliminary Survey of the Industrial Hygiene Problem in the United States.* Public Health Bulletin No. 259. Washington, D.C.: Government Printing Office, 1940.
11. **National Institute for Occupational Safety and Health:** *National Occupational Hazard Survey, Volume 1: Survey Manual* (DHEW/NIOSH Pub. No. 74-127). Washington, D.C.: Government Printing Office, 1974.
12. **National Institute for Occupational Safety and Health:** *National Occupational Hazard Survey, Volume 2: Data Editing and Data Base Development* (DHEW/NIOSH Pub. No. 77-213). Washington, D.C.: Government Printing Office, 1977.
13. **National Institute for Occupational Safety and Health:** *National Occupational Hazard Survey, Volume 3: Survey Analysis and Supplemental Tables* (DHEW/NIOSH Pub. No. 78-114). Washington, D.C.: Government Printing Office, 1978.
14. **Rudolph, L., D.S. Sharp, S.J. Samuels, K. Perkins, and J. Rosenberg:** Environmental and Biological Monitoring for Lead Exposure in California Workplaces. *Am. J. Public Health 80*:921–925 (1990).
15. **Samuels, S.J., C. Perkins, D.S. Sharp, J. Rosenberg, and L. Rudolph:** Occupational Lead Use and Monitoring in California: Survey Design Methods. *Am. Ind. Hyg. Assoc. J. 52(10)*:403–408 (1991).
16. **California State Employment Development Department:** *Employment and Payrolls (Report 127), July–September 1985.* Sacramento, Calif.: California State Development Department, November 1986. pp. 1, 6.
17. **United States Bureau of the Census:** *County Business Patterns, 1985, California.* Washington, D.C.: Government Printing Office, 1987. p. 1.
18. **Goldman, R.H., E.L. Baker, M. Hannan, and D.B. Kamerow:** Lead Poisoning in Automobile Radiator Mechanics. *N. Engl. J. Med. 317*:214–218 (1987).
19. **Centers for Disease Control:** Control of Excessive Lead Exposure in Radiator Repair Workers. *Morb. Mort. Wkly. Rep. 40*:139–141 (1991).
20. **Maizlish, N., L. Rudolph, P. Sutton, J.R. Jones, and K.W. Kizer:** Elevated Blood Lead in California Adults, 1987: Results of a Statewide Surveillance Program Based on Laboratory Report. *Am. J. Public Health 80*:931–934 (1990).

21. **Dolcourt, J.L., H.J. Hamrick, L.A. O'Tuama, J. Wooten, and E.L. Barker:** Increased Lead Burden in Children of Battery Workers: Asymptomatic Exposure Resulting from Contaminated Work Clothing. *Pediatrics 62*:563–566 (1978).
22. **Garrettson, L.K.:** Childhood Lead Poisoning in Radiator Mechanics' Children. *Vet. Hum. Toxicol. 30*:112 (1988).
23. **Wilson, D., A. Esterman, M. Lewis, D. Roder, and I. Calder:** Children's Blood Lead Levels in the Lead Smelting Town of Port Pirie, South Australia. *Arch. Environ. Health 41*:245-250 (1986).
24. **Landrigan, P.J.:** Toxicity of Lead at Low Dose. *Br. J. Ind. Med. 46:593–596 (1989).*
25. **Poulos, L., S. Qammaz, S. Athanaselis, C. Maravelias, and A. Koutselinis:** Statistically Significant Hematopoietic Effects of Low Blood Lead Levels. *Arch. Environ. Health 41*:384–386 (1986).
26. **Sharp, D.S., C.E. Becker, and A.H. Smith:** Chronic Low-Level Lead Exposure: Its Role in the Pathogenesis of Hypertension. *Med. Toxicol. 2*:210–232 (1987).
27. Bellinger, D., A. Leviton, C. Waternaux, H. Needleman, and M. **Rabinowitz: Longitudinal Analyses of Prenatal and Postnatal Lead** Exposure and Early Cognitive Development. N. Engl. J. Med. *316:1037–1043 (1987).*
28. **Sharp, D.S., J. Osterloh, C.E. Becker, B. Bernard, A.H. Smith, J.M. Fisher, S.L. Syme, B.L. Holman, and T. Johnston:** Blood Pressure and Blood Lead Concentration in Bus Drivers. *Environ. Health Perspect. 78*:131–137 (1988).
29. **Courtney, D. and S.R. Meekin:** Changes in Blood Lead Levels of Solderers Following the Introduction of the Control of Lead at Work Regulations (1980). *J. Soc. Occup. Med. 35*:128–130 (1985).

APPENDIX

A total of 28 categories of lead-using processes were identified by the consulting industrial hygienist from processes reported by companies on the second questionnaire. An additional miscellaneous category included such activities as measuring trace quantities of lead in waste water, shredding currency, and installing lead counterweights in machinery. Over 99.5% of potentially exposed workers fell into the 28 identified categories. All processes reported by lead-using facilities on the second questionnaire were grouped into one of the 28 + 1 categories.

These 28 categories were reduced or limited to 12 groups to be used as categories within which to summarize the number of employees in California who were potentially exposed to various lead-using processes with common descriptive features. These 12 groupings are indicated as part of Table IV of the text. A more general reduction of categories was accomplished with the assistance of additional consulting industrial hygienists.

Eight industrial hygienists with at least 6 yr of experience independently scored the 28 categories (the miscellaneous category was not scored) on a scale of 1 to 10 (1 = low, 10 = high) as to potential for hazard based on the intensity (i.e., concentration) of exposure. These scores were grouped into three ordered levels by examining the distribution of average scores of each of the 28 categories for natural groupings. Cut points at scale scores of 4 and 7 were made.

Levels were labeled low (score 1 to <4), moderate (4 to <7), and high (7 to 10). This grouping of scores is denoted as the exposure score.

A description of these categories, the average of the eight industrial hygienists' scores for each process category, and the grouping of these scores into the three levels of exposure score are presented in Table I-A. These scores were then

TABLE I-A. The Exposure Intensity Score of 28 Lead-Using Processes Based on the Average Scores of Eight Industrial Hygienists Categorized into Three Exposure Score Levels

Process	*Average IH Score*	*Exposure Score*
Roll-on or brushed lead-based paints	1.50	low
Dispensing leaded gasoline	1.75	
Dip tanks/baths	2.25	
Printing (leaded inks)	2.50	
Developing metal films (organic lead pastes)	2.75	
Refining gasoline	2.88	
Plastics manufacturing	3.25	
Soldering/electronics industry	3.63	
Pipe machining	4.13	moderate
Lead type printing	4.13	
Cable cutting or splicing	4.13	
Electroplating with lead solutions	4.25	
Paint and ink manufacture	4.38	
Rubber manufacture (lead pastes)	4.50	
Firing ammunition	4.50	
Soldering pipes and sheets	5.00	
Making lead joints/babbitt	5.25	
Maintenance	5.38	
Spray painting with lead-based paints	6.13	
Glaze manufacture	7.00	high
Grinding/cutting lead alloys	7.75	
Scrap metal recovery	7.88	
Sanding/abrading lead-painted surfaces	8.00	
Casting or smelting lead	8.38	
Radiator repair	8.38	
Welding/cutting lead-painted surfaces	9.25	
Battery manufacture	9.25	
Welding/cutting lead alloys	9.38	

associated with each process reported by each employer on the second questionnaire.

The agreement of scoring among raters was analyzed by two-way analysis of variance (process by rater), as described by Winer.[1] The average reliability coefficient, or intraclass correlation, of a single rater was 0.63. The mean score for all eight raters had an estimated reliability coefficient of 0.93. A reliability coefficient can range between zero (no concordance) and one (complete concordance). The authors' findings indicate excellent agreement between raters.

REFERENCES

1. **Winer, B.J.:** *Statistical Principles in Experimental Design.* 2d ed. New York: McGraw-Hill, 1971. pp. 283–296.