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■ A methodology for the development of an air quality standard (AQS) for lead is presented. It is shown that the results of community studies can be used to calculate the air lead level at which the cumulative frequency distribution of blood lead values of a population will meet a biological guideline for blood lead. The procedure is illustrated by using the data on the relationship between blood lead and air lead obtained in two well-known epidemiological studies. A variety of analyses, involving different blood lead–air lead models, blood lead frequency distributions, and data bases, are included to study the sensitivity of the methodology to variations in assumptions and calculation procedures. The proposed methodology is general and can be used in the development of any AQS for which the appropriate biological guideline is expressed in the form of a cumulative frequency distribution.

1. *Introduction*

In 1974 Zielhuis (*1*) proposed a biological guideline for blood lead. This guideline provides for the protection of public health by specifying a desirable distribution of blood lead values. It is therefore proposed that the air quality standard (AQS) for lead be determined by calculating the air lead level at which Zielhuis' guideline will be met. The methodology for making these calculations and developing the AQS is described. It is shown that blood lead values from several populations can be combined to give an accurate estimate of the within-population distribution of blood lead values. The data collected by Azar et al. (*2, 3*) and Tepper and Levin (*4*) are used to illustrate the procedure and to develop an AQS for lead. These results are also compared with the standard adopted by the United States Environmental Protection Agency (*5*). The approach is general and can be used in the development of an AQS for any pollutant for which a biological guideline similar to that of Zielhuis is appropriate.

Any group of subjects exposed to a given air lead level will have a distribution of true blood level values because of biological differences between the subjects and differences in lead exposures from sources other than air lead. The distribution will be further broadened due to blood lead measurement variation. As the air lead level of the group is increased, the corresponding blood lead distribution will shift upward. This suggests that an air quality standard for lead could be determined by finding the air lead level at which the upper portion of the predicted blood lead distribution will be equal to that of Zielhuis' biological guideline distribution. A schematic of this procedure is shown in Figure 1.

In order to make the calculations described above, it is necessary to have a model for the relationship between blood lead and air lead and data on the within-population variation in blood lead values. The best available data on the blood lead–air lead relationship for adults is that published by Azar et al. (*2, 3*). In this study air lead and blood lead measurements were obtained on 150 subjects over a 2- to 4-week period. The air lead was continuously measured 24 h/day during the test period by using personal monitors. Two to eight blood samples were taken from each subject and duplicate lead determinations were made on each sample. This is the only study of nonoccupationally exposed subjects whose air lead exposure was monitored continuously by personal air monitors.

The Seven Cities survey (*4*) contains a large amount of data on within-population variation in blood lead values. The blood lead levels of 2015 subjects from 12 populations (80–219 subjects/population) were collected in this study. This study is important because a large sample size is required to get a precise estimate of the within-population distribution of blood lead values. The use of the data from the Azar study and Seven Cities survey in the development of an AQS for lead is described in the following paragraphs.

2. *Biological Guideline for Lead*

After an extensive review of the literature, Zielhuis (*1*) concluded that the following blood lead distribution was an acceptable biological guideline for the protection of public health.

percentile	blood lead, μg/dL
50	20
90	30
98	35

This guideline has been widely accepted and has been adopted by the European Economic Commission (*6*). This distribution will be used to determine an AQS for lead by first calculating blood lead levels associated with percentiles of interest and then calculating air lead levels that would raise these blood lead levels to those of the Zielhuis distribution. We concentrated on matching the 90th and 98th percentiles, since individuals at the upper end of the distribution are at greater risk. Results for the 50th percentile are included, however, for comparative purposes.

It is important to recognize that, in terms of observed and theoretical distributions of blood lead data, the 50th percentile of the Zielhuis distribution is not consistent with the 90 and 98 percentiles. If we assume that blood lead levels are lognormally distributed, then the 90th percentile of 30 and the 98th percentile of 35 μg/dL are consistent

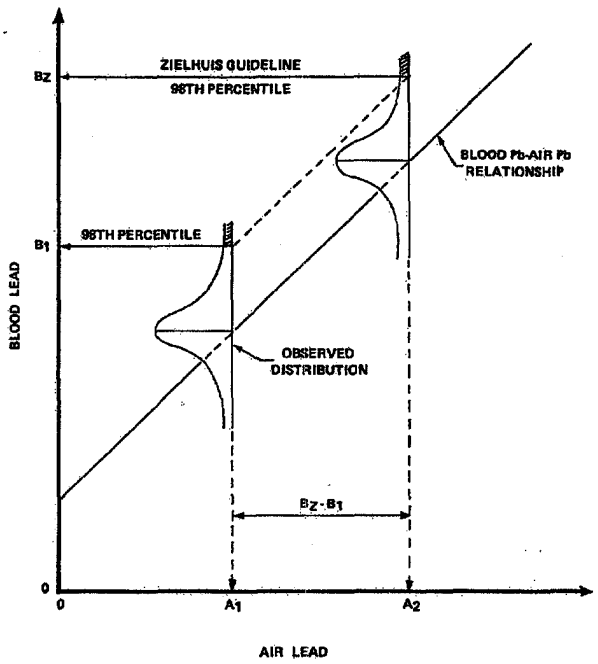

Figure 1. Schematic of calculation procedure for determining the air lead level at which a percentile of an observed distribution will be consistent with the Zielhuis guideline. Linear blood lead–air lead model and 98th percentile are shown in the figure.

with a 50th percentile of 23.2 μg/dL. In the unlikely event that blood lead levels are normally distributed, the 90th and 98th percentiles of the Zielhuis distribution are consistent with a 50th percentile of 21.7. It is concluded that the 50th percentile of the Zielhuis distribution is low by approximately 3 μg/dL.

3. *Relationship between Blood Lead and Air Lead*

To determine the air lead level at which the blood lead distribution of a normal population was consistent with the Zielhuis distribution, it was necessary to know the relationship between air lead and blood lead. Two different relationships were used. The first model was the "lead exposure" model (*7, 8*), which assumes an exponential relationship between blood lead and air lead. The second model was a linear relationship between blood lead and air lead. Both of these mathematical forms have been used widely in correlating air lead and blood lead data.

The "lead exposure" model used in this analysis was

$$\text{blood Pb} = 12.1(\text{air Pb} + B)^{0.2669} \qquad (1)$$

This model was developed from the Azar data (*7*). It relates blood lead to total lead exposure by dividing lead exposure into two parts—air lead exposure and background lead exposure (i.e., food, water, etc.). In eq 1, background lead is represented by the B coefficient, which was found to be 3.28 for the Azar data (*7, 8*). Additional details on the development of this model are given in ref *7*.

The second model used (eq 2) is a straight line blood

$$\text{blood Pb} = \text{air Pb} + B_0 \qquad (2)$$

lead–air lead relationship with a slope of 1 (i.e., an increase of 1 μg of Pb/m³ of air results in an increase of 1 μg of Pb/dL of blood). The blood lead–air lead slope of 1 was found in a combined analysis of eight epidemiological studies of the relationship between blood lead and air lead (*8*) and in the studies conducted by Chamberlain et al. (*9*).

The slope of 1 is also supported by the lead exposure model (eq 1) for the Azar data and by the analysis of the Azar data conducted by Hammond et al. (*10*), both of which indicate that the blood lead–air lead slope for the Azar data varies from approximately 1.2 to 0.6 for ambient air lead levels ≤10 μg/m³. Slopes larger than 1 have been reported (*11, 12*); however, these appear to be out of line with respect to the other studies and are based on clinical rather than epidemiological studies. The methodology described here is general and can accommodate any assumed slope or blood lead–air lead model.

4. *Blood Lead Distribution*

So that the blood lead distribution for the Azar data could be determined, a blood lead value was calculated for each subject corresponding to an air lead level of zero. Equation 1 indicates that the ratio of the blood lead B_1 at air lead A_1 to the blood lead B_2 at a second air lead A_2 is

$$\frac{B_1}{B_2} = \left[\frac{A_1 + 3.28}{A_2 + 3.28}\right]^{0.2669} \qquad (3)$$

Hence, the lead exposure model (eq 1) predicts that the blood lead of a subject at an air lead of zero will be

$$B_0 = B_A\left[\frac{3.28}{A + 3.28}\right]^{0.2669} \qquad (4)$$

where B_0 is the calculated blood lead at an air lead of zero, A is the air lead exposure of the subject, and B_A is the blood lead of the subject.

In the case of the linear model, the blood lead at zero air lead is given by eq 5,

$$B_0 = B_A - A \qquad (5)$$

where B_0, B_A, and A are defined as in eq 4.

After the blood lead values were obtained for the zero air lead level, the next step was to determine the distribution of blood lead levels calculated from eq 4 and 5. The blood lead levels corresponding to selected percentiles were obtained from the best fitting distribution of the Pearson system (*13, 14*) because the frequently used lognormal distribution was found to give an inadequate fit in several instances.

The Pearson system encompasses a wide variety of frequency distribution forms and does not require an assumption concerning the specific mathematical form of the distribution to which the data conform. Many of the distributions that are frequently used in the analysis of air quality data (i.e., normal, lognormal, gamma, beta, and Weibull) are special cases of the Pearson system. This family of models selects that distribution whose first four moments (i.e., average, standard deviation, skewness, kurtosis) are the same as those of the observed distribution. The lognormal distribution will be fit when it is the appropriate distribution; hence, the fit of the Pearson system will be equal to or better than that of the lognormal distribution.

It is shown in section 8 that the Azar data and some of the data in the Seven Cities survey are not lognormally distributed. It is well-known that the lognormal distribution is adequate for estimating geometric mean relationships among air pollution variables such as that described by eq 1. We will see later that, in the case of the 50th percentile, there is no practical difference between the air lead levels developed from the lognormal and Pearson distributions. In the case of the Azar Study and Seven Cities survey, however, the lognormal distribution

Table I. Air Lead Levels Associated with Zielhuis Biological Guideline for Lead Based on the Analysis of Azar Data

	percentile	blood Pb,[a] μg/dL	air Pb, μg/m³
lead exposure model, Pearson system	50	15.8	4.2
	90	22.4	6.5
	97.5	26.9	5.5
lead exposure model, normal distribution[b]	50	15.7	4.8
	90	22.6	6.2
	97.5	27.1	5.3
	98	27.8	4.5
linear model, Pearson system	50	15.7	4.3
	90	23.2	6.8
	97.5	28.5	6.5
linear model, normal distribution[b]	50	15.6	4.4
	90	23.5	6.5
	97.5	28.6	6.4
	98	29.4	5.6

[a] At air Pb = 0. [b] The normal distribution gave an adequate description of the variation in (blood Pb)$^{0.3}$.

does not provide an adequate description of the upper percentiles of the blood lead distribution. It is very important to get accurate estimates of these values because the Zielhuis distribution and the associated air quality standard are based on the upper percentiles. The Pearson system is able to better address this accuracy because of its rich family of models and its use of four moments to select the best fitting distribution. Results for the lognormal distribution have been included, however, for comparative purposes.

An alternative procedure to the Pearson system is to transform blood lead data to another scale such that the distribution of the transformed values is closely matched by a normal distribution. As noted earlier, the Azar blood lead data at zero air lead were not lognormally distributed; however, blood lead raised to the 0.3 power, (blood lead)$^{0.3}$, was found to be approximately normally distributed. The blood lead values calculated from the Azar data with use of the Pearson system are summarized in Table I. The corresponding values calculated from a normal distribution approximation to the transformed data ((blood lead)$^{0.3}$) are also included in Table I. In each instance, the results obtained from the Pearson system are in close agreement with those obtained from the normal distribution, indicating the Pearson system gave a good description of the observed data. The 97.5th rather than the 98th percentile, is used in the Pearson system. This slight deviation from the Zielhuis distribution was necessary because published tabulations of the Pearson system contain the 97.5th rather than the 98th percentile.

After the blood lead values corresponding to zero air lead were calculated, it was then possible to compute the air lead at which the blood lead distribution was equivalent to that of the Zielhuis distribution at the higher percentiles. In the case of the lead exposure model (eq 1), this air lead is given by eq 6, where B_0 is the blood lead at zero air lead

$$A_Z = 3.28[(B_Z/B_0)^{1/0.2669} - 1] \quad (6)$$

and A_Z is the air lead associated with the corresponding blood lead (B_Z) of the Zielhuis distribution. In the case of the linear air lead–blood lead model, the air lead level that equates the two distributions is given by eq 7, where

$$A_Z = B_Z - B_0 \quad (7)$$

A_Z, B_Z, and B_0 have the same definition as in eq 6.

5. *Air Quality Value Developed from Azar Data*

The air lead at which the Azar blood lead distribution was equivalent to the Zielhuis blood lead distribution was calculated from eq 6 and 7 (Table I). The availability of two different air lead–blood lead models (linear, lead exposure), two different blood lead distribution models (Pearson system, normal-power transformation), and three different percentile levels (50, 90, 97.5) made it possible to analyze the Azar data in a variety of different ways. This enables a determination of the sensitivity of the resulting air lead levels to the calculation procedure used. In Table I we see that in all cases the calculated air lead levels are greater than 4 μg/m³. In the case of the upper (90, 97.5) percentiles all the air lead levels are greater than 5 μg/m³ except for the lead exposure model, normal-power transformation case.

6. *Air Quality Value Developed from Seven Cities Survey Data*

The calculational methods used in the analysis of the Azar data were applied to the data obtained in the seven cities survey. This is important because the seven cities survey included blood samples obtained from 2015 subjects in 11 different locations. This large data base enables one to obtain an accurate estimate of the upper percentiles of the distribution of blood lead values. The air lead exposures were obtained from stationary samplers located in the areas where the subjects lived and are thus less specifically related to individual blood lead than was the case in the Azar study.

In this analysis, the lead exposure and linear blood lead–air lead models were both used. In view of the close agreement of the results of the Pearson system and the normal-power transformation, only the Pearson system was used to describe the blood lead distribution. The air lead levels and the associated 50th, 90th and 97.5th blood lead percentiles calculated from the Seven Cities survey data are summarized in Table II. The air lead values used were the annual average air lead results obtained at each site. The air lead levels needed to make the observed blood lead distributions equivalent to the upper end of the Zielhuis distribution were calculated from eq 8, where A_7 is the

$$A_Z = (A_7 + 3.28)[(B_Z/B_7)^{1/0.2669} - 3.28] \quad (8)$$

annual average air lead associated with the observed blood lead B_7 obtained from the Pearson system and A_Z is the air lead associated with the blood lead B_Z of the Zielhuis distribution.

In the case of the linear model, excluding the Rittenhouse location, the calculated air lead levels are greater than 5 μg/m³ in 28 out of 33 instances and greater than 4 μg/m³ in 30 out of 33 instances. Each of the five instances where the air lead level was less than 5 μg/m³ was associated with matching of the 50th percentile. The United States Environmental Protection Agency (*15*) has pointed out that Rittenhouse is an old section of Philadelphia in which many of the houses contain lead plumbing, which probably contributed to the relatively high blood lead values.

The lead exposure model calculations showed similar results. Excluding Rittenhouse, the air lead values were greater than 5 μg/m³ in 26 out of 33 instances and greater than 4 μg/m³ in 30 out of 33 instances. Three of the seven instances where the air lead level was less than 5 μg/m³ were associated with matching of the 50th percentile.

We also see in Table II that there is a wide variation in the air lead values calculated for the different locations. This reflects variations in exposures to lead other than that

Table II. Air Lead Levels Associated with the Zielhuis Biological Guideline for Lead Based on Analysis of Seven Cities Survey Data

site	air Pb	percentile	blood Pb[a]	air Pb[b] lead exposure model	air Pb[b] linear model
Okeana	0.32	50	15.9	5.2	4.4
		90	23.0	6.5	7.3
		97.5	27.6	5.5	7.7
Ardmore	1.15	50	18.8	2.3	2.4
		90	26.1	4.2	5.1
		97.5	29.8	4.8	6.4
Rittenhouse	1.67	50	20.4	1.3	1.3
		90	29.5	2.0	2.2
		97.5	35.6	1.4	1.2
Pasadena	3.39	50	17.5	7.7	5.9
		90	25.0	9.9	8.4
		97.5	29.9	8.8	8.5
Los Alamos, male	0.17	50	17.0	3.1	3.2
		90	23.5	5.3	6.7
		97.5	28.2	4.5	7.0
Los Alamos, female	0.17	50	15.2	6.4	5.0
		90	20.3	11.6	9.9
		97.5	23.8	11.4	11.4
Washington, D.C.	1.19	50	19.2	1.9	2.0
		90	26.0	4.4	5.2
		97.5	29.6	5.1	6.6
Port Washington	1.13	50	15.2	9.1	5.9
		90	21.4	12.4	9.7
		97.5	25.4	11.4	10.7
Greenwich Village	2.08	50	16.4	8.0	5.7
		90	22.9	11.5	9.2
		97.5	27.5	10.0	9.6
Lombard	1.18 (7 mo)	50	14.0	13.7	7.2
		90	19.0	21.4	12.2
		97.5	22.9	18.6	13.3
Bridgeport	1.76	50	17.2	5.6	4.6
		90	24.2	8.0	7.6
		97.5	29.8	5.9	7.0
Houston	0.85	50	12.7	19.4	8.1
		90	17.8	25.9	13.0
		97.5	20.8	25.7	15.0

[a] Blood Pb value (μg/dL) estimated by fitting the Pearson System to the observed frequency distribution. [b] Air Pb level (μg/m³) at which the upper portion of the observed blood Pb distribution would be equal to the Zielhuis guideline.

Table III. Air Lead Levels Associated with Zielhuis Biological Guideline for Lead Based on the Analysis of the Combined Azar and Seven Cities Studies

	percentile	dev from av[a]	blood Pb,[b] μg/dL	air Pb, μg/m³
lead exposure model, Pearson system	50	0.0000	15.8	4.2
	90	0.0738	21.7[c]	7.8
	97.5	0.1188	26.1	6.6
lead exposure model, normal distribution	50	0.0000	15.8	4.2
	90	0.0766	21.9	7.4
	97.5	0.1170	25.9	6.8
	98	0.1226	26.5	6.0
linear model, Pearson system	50	0.0000	15.8	4.2
	90	0.0738	21.7	8.3
	97.5	0.1188	26.1	8.9
linear model, normal distribution	50	0.0000	15.8	4.2
	90	0.0766	21.9	8.1
	97.5	0.1170	25.9	9.1
	98	0.1226	26.5	8.4

[a] Distribution of (blood Pb)$^{0.15}$: average = 0, standard deviation = 0.0597, skewness = −0.02, kurtosis = 3.81. The normal distribution has skewness = 0 and kurtosis = 3.0. [b] At air Pb = 0. [c] Blood Pb = $((15.77)^{0.15} + 0.0738)^{1/0.15} = 21.7$.

in the air and to variations arising from analytical uncertainties in the data.

7. *Air Quality Value Developed from the Analysis of the Combined Azar and Seven Cities Survey Studies*

The combination of the Azar study with its excellent estimate of the blood lead–air lead relationship and the Seven Cities survey with the large number of subjects provided the best basis for establishing an air quality value for lead. So that this could be done, the blood lead values for the 2015 subjects in the Seven Cities survey were used to establish a blood lead distribution. This distribution was constructed by subtracting the average blood lead for each site from each of the blood leads collected at that site. Next, these deviations from the site average were combined into a single distribution. The standard deviation of this distribution was the pooled within-site standard deviation and was a measure of the blood lead variation in the normal population. Since the blood lead standard deviation typically increases with increasing blood lead level, it was necessary to transform the blood lead levels before the combined distribution was constructed. The objective was to make a symmetrical distribution. It was found that the power transformation (blood lead)$^{0.15}$ resulted in a symmetrical distribution; however, the tails of the distribution were longer than those of the normal distribution (kurtosis = 3.81, whereas for a normal distribution kurtosis = 3.0). For this reason, the percentiles were estimated by both the Pearson system and the normal distribution (Table III). In the Azar data, the blood lead equivalent to the 50th percentile point at air lead = 0 μg/m³ (lead exposure model calculation) was 15.77 μg/dL. The blood lead values associated with the upper percentiles of the blood lead distribution were obtained by adding the corresponding values of the "deviation from site average" distribution to the blood lead 50th percentile of the Azar data at zero air lead. A sample calculation using the Pearson system for the 90th percentile is shown in eq 9

$$\text{blood Pb} = [(15.77^{0.15} + \text{dev from site av})]^{1/0.15}$$

$$= [(15.77)^{0.15} + 0.0738]^{1/0.15} = 21.7 \qquad (9)$$

The air lead levels that equate these blood lead values to those of the Zielhuis distribution are summarized in Table III.

The calculated air lead level for the 50th percentile is greater than 4.2 μg/m³ for all cases. The ten air lead values associated with the 90th and 97.5th percentiles ranged from 6.0 to 8.9 μg/m³. It is thus apparent that an air lead level of 4 μg/m³ is consistent with all parts of the Zielhuis guideline and that the upper percentiles (90 and 97.5) of the blood lead distribution of a population exposed to an air lead level of 5 μg/m³ would be within the Zielhuis guideline.

8. *Log Blood Lead Distribution*

The lognormal distribution has been widely used in the analysis of blood lead data. For this reason it is appropriate to consider what air lead levels would be obtained if the lognormal distribution is used to describe the blood lead distribution rather than the more general Pearson system. The resulting air lead levels are summarized in Tables IV and V. It is important to understand that these

Table IV. Azar Study: Estimation of an Air Quality Standard for Lead Assuming Blood Lead Levels Are Lognormally Distributed

	lead exposure model		linear model	
lognormal percentile	blood Pb[a]	AQS[b]	blood Pb[a]	AQS[b]
50	15.5	5.2	15.3	4.7
90	22.9	5.7	23.8	6.2
97.5	28.2	4.1	30.1	4.9
98	29.0	3.4	31.0	4.0

[a] Blood Pb (μg/dL) at air Pb = 0 (lognormal distribution). [b] Air quality standard – air Pb levels (μg/m^3) at which the upper portion of the observed blood lead distribution would be equal to the Zielhuis biological guideline for lead.

results are representative only if the lognormal is the correct distribution to apply.

We tested the adequacy of the lognormal distribution by computing the skewness and kurtosis statistics for the log blood lead data sets in the Azar study and the Seven Cities survey and comparing these results with the corresponding parameters of the normal distribution. Using the statistical tests discussed by Pearson and Hartley (*13*) we found that at least 7 of the 13 observed distributions (Azar's plus 12 sites in the Seven Cities survey) were significantly different from the lognormal distribution (Table VI). It is important to note that the direction of the skewness of the log blood lead distribution is reflected in how the resulting AQS compares to that computed by using the Pearson system. Negative skewness results in lower values than the Pearson system while positive skewness results in higher values (compare Table I with Table IV and Table II with Table V). On the log scale the lognormal distribution has no skewness; hence, when the skewness of the data is negative, the blood lead levels predicted by the lognormal distribution will be higher than those of the observed data and will result in lower air lead levels. The opposite effect occurs when the skewness is positive.

As noted earlier, the Pearson system has the flexibility to describe a wide variety of distributions, including the lognormal. It is concluded that, in the case of the Azar study and the Seven Cities survey, the Pearson system provides a more accurate characterization of the blood lead distribution than the lognormal.

9. *Discussion*

A methodology for determining an air quality standard for lead from epidemiological studies has been described and illustrated by using the best available data on blood lead–air lead relationships and within-population variation in blood lead values. The Azar study and the Seven Cities survey include a wide variety of different adult population groups that provide a firm basis for the determination of an air quality standard for lead. The standards developed from these studies using a variety of models and assumptions are summarized as follows:

	calculated air quality standard, μg/m^3	
study	average	range
Azar	5.5	4.2–6.8
Seven Cities survey	8.0	1.2–25.9
combined Azar and Seven Cities survey	6.5	4.2–8.9

With a few exceptions in the Seven Cities survey (Rittenhouse and the 50th percentiles for Ardmore, Los Alamos (male), Washington, D.C.) all of these air lead levels are greater than 4 μg/m^3. The air quality standard of 4 μg/m^3 is considerably higher than the 1.5 μg/m^3 promulgated by the U.S. Environmental Protection Agency (*5*) and the value of 2 μg/m^3 proposed by Yankel et al. (*16*). In the development of their standard, the EPA used a different and more stringent risk level than the Zielhuis guideline used in this work. They identified children as the high-risk population, assumed blood lead values were

Table V. Seven Cities Survey: Estimation of an Air Quality Standard for Lead Assuming Blood Lead Values Are Lognormally Distributed

				AQS[b]	
site	air Pb	percentile	blood Pb[a]	lead exposure model	linear model
Okeana	0.32	50	15.6	5.9	4.7
		90	23.6	5.6	6.7
		97.5	29.3	3.7	6.0
		98	30.2	3.0	5.1
Ardmore	1.15	50	18.0	3.3	3.2
		90	27.1	3.2	4.1
		97.5	33.6	1.9	2.6
		98	34.6	1.3	1.6
Rittenhouse	1.67	50	20.5	1.2	1.2
		90	29.3	2.1	2.4
		97.5	35.4	1.5	1.3
		98	36.4	1.0	0.3
Pasadena	3.39	50	17.5	7.7	5.9
		90	24.9	10.1	8.5
		97.5	30.0	8.6	8.4
		98	30.8	7.5	7.6
Los Alamos, male	0.17	50	17.2	2.8	3.0
		90	23.2	5.8	7.0
		97.5	27.2	5.6	8.0
		98	27.8	4.9	7.4
Los Alamos, female	0.17	50	15.0	6.9	5.2
		90	20.6	10.8	9.6
		97.5	24.3	10.3	10.9
		98	24.9	9.1	10.3
Washington, D.C.	1.19	50	19.1	2.0	2.1
		90	25.7	4.7	5.5
		97.5	30.1	4.6	6.1
		98	30.7	4.0	5.5
Port Washington	1.13	50	15.4	8.5	4.6
		90	21.1	13.2	10.0
		97.5	25.5	12.5	11.2
		98	25.5	11.2	10.6
Greenwich Village	2.08	50	16.6	7.5	5.5
		90	22.7	12.0	9.4
		97.5	26.8	11.3	10.3
		98	27.5	10.0	9.6
Lombard	1.18	50	14.0	13.7	7.2
		90	19.1	20.9	12.1
		97.5	22.5	20.1	13.7
		98	23.0	18.2	13.2
Bridgeport	1.76	50	17.6	4.9	4.2
		90	23.9	11.8	7.9
		97.5	28.0	8.3	8.8
		98	28.7	7.3	8.1
Houston	0.85	50	12.6	20.0	8.2
		90	17.8	25.9	13.0
		97.5	21.5	22.4	14.3
		98	22.1	19.8	13.7

[a] Blood Pb value (μg/dL) estimated from a lognormal distribution. [b] Air quality standard: air Pb levels (μg/m^3) at which the upper portion of the observed blood Pb distribution would be equal to the Zielhuis biological guideline for Pb.

Table VI. Summary Statistics for Log Blood Lead Distributions from Azar and Seven Cities Studies

data set	n	log blood Pb, av	std dev	skewness[a]	kurtosis[a]
Azar data[b]					
linear	149	1.186	0.149	−0.35[d]	3.27
lead exposure	149	1.189	0.133	−0.31[e]	2.90
linear-power[c]	149	2.281	0.232	−0.01	3.17
lead exposure[c]	149	2.283	0.208	−0.05	3.00
Okeana	162	1.194	0.139	−0.81[f]	6.47[f]
Ardmore	150	1.256	0.138	−0.76[f]	3.87[f]
Rittenhouse	136	1.312	0.121	0.10	2.84
Pasadena	193	1.244	0.119	−0.06	3.42[e]
Los Alamos, male	80	1.236	0.101	0.44[d]	3.05
Los Alamos, female	191	1.176	0.107	−0.34[d]	3.95[d]
Washington, D.C.	219	1.282	0.100	0.06	2.42
Port Washington	198	1.188	0.106	0.20	3.09
Greenwich Village	140	1.219	0.107	0.21	3.28
Lombard	208	1.147	0.105	−0.13	4.92[f]
Bridgeport	147	1.246	0.103	0.55[f]	3.59[e]
Houston	191	1.099	0.119	−0.09	2.59

[a] For a normal distribution, skewness = 0, kurtosis = 3.0 (skewness < 0 indicates the distribution is skewed to the left). [b] Blood Pb at air Pb = 0. [c] Results of power transformation – (blood Pb)$^{0.3}$. [d] Distribution not normal ($p < 0.05$). [e] Deviation from normality significant ($p < 0.10$). [f] Distribution not normal ($p < 0.01$).

lognormally distributed with a geometric standard deviation of 1.3, and calculated the air lead level at which a blood lead 99.5th percentile of 30 μg/dL would be obtained. In making this calculation, the EPA used a blood lead–air lead slope of 2.0, which they estimated from the data reported by Yankel et al. (*16*), who studied a single population of children that lived close to a lead smelter. The control population in this study had an average blood lead level of approximately 30 μg/100 mL, which is considerably higher than that of typical nonoccupationally exposed populations.

The authors of the Yankel study have concluded from more recent analysis that the appropriate blood lead–air lead slope for this study is approximately 1.0 (*17*). Our analyses (*8*) of the Yankel data and other children studies reported in the literature suggest that the blood lead–air lead slope for children is approximately 1.0 and not significantly different from that of adults.

Since the EPA has identified young children as a high-risk population, it is appropriate to perform the analysis described in this paper for child populations when the appropriate data become available. It is also recommended that the proposed methodology be used in the development of an air quality standard for any pollutant for which the appropriate biological guideline is expressed in the form of a cumulative frequency distribution.

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Literature Cited

(1) Zielhuis, R. L. *Int. Arch. Arbeitsmed.* **1974**, *32*, 103–127.
(2) Azar, A.; Snee, R. D.; Habibi, K. *Comm. Eur. Communities, [Rep.] EUR* **1973**, *EUR-5004*, 581–594.
(3) Azar, A.; Snee, R. D.; Habibi, K. *Environ. Qual. Saf.* **1975**, *2*, 254–290.
(4) Tepper, L. B.; Levin, L. S. *Environ. Qual. Saf.* **1975**, *2*, 152–197.
(5) *U.S. Environ. Prot. Agency, Fed. Regist.* **1978**, *43*, No. 194.
(6) Commission of European Communities, Council Directive of March 19, 1977, on Biological Screening of the Population for Lead, *Off. J. Eur. Communities*, **1977**, *20*, No. L105, 10–17, Brussels.
(7) Snee, R. D. Report PLMR-10-78; E. I. du Pont de Nemours and Co., Petroleum Laboratory: Wilmington, Delaware, unpublished data.
(8) Snee, R. D. *Int. Arch. Occup. Environ. Health* **1981**, *48*, 219–242.
(9) Chamberlain, A. C.; Heard, M. J.; Scott, A. B. N.; Clough, W. S.; Newton, D.; Wells, A. C. *Postgrad. Med. J.* **1975**, *51*, 790–794.
(10) Hammond, P. B.; O'Flaherty, E. J.; Gartside, P. S. *Food Cosmet. Toxicol.* **1981**, *19*, 631–638.
(11) Chamberlain, A. C.; Heard, M. J.; Little, P.; Newton, D.; Wells, A. C.; Wiffen, R. D. *U.K. At. Energy Auth. Rep. AERE-9198*, **1978**.
(12) Rabinowitz, M. B.; Wetherill, G. W.; Kopple, J. D. *J. Clin. Invest.* **1976**, *58*, 260–270.
(13) Pearson, E. S.; Hartley, H. O. "Biometrika Tables for Statisticians"; Cambridge University Press: London, 1972; Vol. II.
(14) Hahn, G. J.; Shapiro, S. S. "Statistical Models in Engineering"; Wiley: New York, 1976.
(15) United States Environmental Protection Agency, Office of Research and Development, Washington, D.C., November 1976.
(16) Yankel, A. J.; von Lindern, I. H.; Walter, S. D. *J. Air Pollut. Control Assoc.* **1977**, *27*, 763–767.
(17) Walter, S. D.; Yankel, A. J.; von Lindern, I. H. *Arch. Environ. Health* **1980**, *35*, 53–58.

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