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Variation of Exposure Between Workers in Homogeneous Exposure Groups

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It is generally assumed that workers employed in the same job at a given location are uniformly exposed, i.e., that they have the same long-term mean exposure. This assumption has led to observational schemes for classifying workers into homogeneous exposure groups (HEGs), based on job title, location, and other identifiable features of the work environment. This paper presents results from analysis of 183 HEGs (comprised of 15 495 personal measurements) in which it was possible to determine the between-worker component of variance in exposure. The results indicate that, contrary to popular belief, only about one fifth of the HEGs were uniformly exposed (less than a two-fold difference among 95% of individual mean exposures) while an equal number showed a high degree of variation between workers (more than 15-fold differences among 95% of individuals). Further analyses indicate that the identifiable features of the work environment, which are typically used to establish HEGs, are only marginally related to the between-person variation (accounting for only 13% of this variance component). It is concluded that industrial hygienists should not rely on observational schemes to guarantee that groups of workers are uniformly exposed. Rather, they should adopt methods of statistical sampling and analysis that allow the variance components to be estimated so that decisions regarding the evaluation of hazard and selection of controls will be appropriate.

The assessment of occupational exposure has traditionally focused on groups of workers who share identifiable characteristics related to the industrial process. In most such applications, rather broad characteristics have been used, notably those related to the job title and the location (e.g., factory, building, or room) where work was performed. More detailed assessments have occasionally taken into account the differences in tasks among workers in a given job title. But regardless of the rigor of the exercise, the method of classification has relied entirely on observation of the individuals and their work and, therefore, has been referred to as the "observational approach."[1] Various terms have been used to denote observational groups including "hazard class,"[2] "occupational-title group,"[3] "workplace exposure zone,"[4] and "homogeneous exposure group."[5] As will be seen, the last term (homogeneous exposure group or HEG) most clearly denotes the philosophical basis of the observational approach and will be used subsequently in this paper.

By defining an HEG as " . . . a group of workers with identical probabilities of exposure," Hawkins et al. have stated what had previously been implicit, namely that all individuals in a group are assumed to have the same exposure.[5] This notion of uniform exposure across a group is extremely important to the traditional practice of industrial hygiene. Indeed, Hawkins et al. described the HEG as " . . . the central philosophical construct for detailed workplace exposure assessments."[5] Such a strong statement suggests that the HEG is the cornerstone of many health-surveillance programs in large industries. Published schemes for prospectively evaluating occupational exposures tend to reinforce this conjecture.[5–6]

It is important to keep in mind that traditional practices provide no means for ensuring that a group is homogeneous (because repeated measurements are rarely collected from the same workers); rather, uniform exposure is accepted on faith. Yet, it makes sense that some HEGs would be less homogeneous than others because of differences in tasks and work practices that were not observed, or simply because those who assigned some groups were less knowledgeable or rigorous than others. After analyzing 31 HEGs, Rappaport[1] concluded that substantial differences in exposure were common; indeed, in some cases the range of exposures among workers in a given HEG was greater than 100-fold. Since heterogeneity of this magnitude pierces the very heart of the observational approach, it is important to investigate a

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much larger cross section of industries, agents, and processes to determine the extent of the problem.

This paper reports the results of analyses of 183 HEGs. The database, which is described in detail elsewhere,[7] consists of groups from which multiple personal measurements were obtained from representative workers. By employing an analysis-of-variance (ANOVA) model, we used these data to estimate the between-worker (within-HEG) component of variance for each group. A description of the ANOVA model and its application in this context will be reported separately.[8] By investigating the distribution of between-worker variances in this paper the validity of the observational approach for assessing occupational exposures in general will be addressed.

THE DATABASE

Data were obtained from 45 studies, most of which had been carried out by industrial hygienists from academic institutions. Sources of these data are cited with the detailed description of the database.[7] Some of the studies (about 9%) were conducted by private companies, often in collaboration with professional associations. The database used for this analysis contains 15 495 personal measurements (minimum duration = 4 hours) mostly from the chemical industry (83% of measurements and 58% of groups). Each entry includes the measured exposure, the chemical name and type of contaminant (gaseous, particulate, or dermal), and identifiers for the worker, his or her job title, and the primary location where work was performed. If the industrial hygienists who conducted the surveys had preassigned workers into HEGs (referred to herein as "job class"), these designations were also entered. Several additional features of the workplace and the nature of the process were coded as dichotomous variables (by job title but not by job class). These included the following: environment (indoor vs. outdoor), process (continuous vs. intermittent), type of source (general vs. local), presence of local-exhaust ventilation (yes or no), and the mobilities of the worker and the source (mobile vs. stationary).

ASSIGNMENT OF GROUPS

The majority of the HEGs (65%) were assigned by the authors of this study based on job title and location. The remaining groups (35%) were those established *a priori* by the industrial hygienists who performed the original surveys. In the latter cases several job titles at a given location had been combined into a single job class (HEG), because the industrial hygienist considered the potential for exposure of a particular contaminant to be the same for all job titles. This practice of collapsing several small groups, each represented by a job title, into a single HEG is commonly employed by industrial hygienists.[4–6]

Each HEG was subjected to ad hoc tests to determine whether the ANOVA model (described in the next section) could reasonably be used to estimate the components of variance.[8] Analysis was restricted to the 183 HEGs deemed to adequately fit the model. Data obtained from these groups included personal measurements from 2045 workers (minimum of 2 measurements per worker). The median number of measurements per HEG was 28 with a range of 11–5076. The median number of workers per HEG was 8 with a range of 5–62. Exposures included a vast assortment of chemical agents and mixtures that were present as particulate matter (89 HEGs), gases and vapors (68 HEGs), and dermal contaminants (25 HEGs); one additional case involved exposure to a mixture of gaseous and particulate contaminants. A complete listing of the chemical agents and the industries that comprise the data sets is given in the Appendix.

COMPONENTS OF VARIANCE

Components of the total variance in exposure were estimated by employing the random-effects ANOVA model from Proc NESTED of the SAS System Software (SAS Institute, Cary, NC). Briefly, this model is specified by the following expression,

$$Y_{ij} = \ln(X_{ij}) = \mu_y + \beta_i + \epsilon_{ij}, \text{ for } (i = 1, 2, \ldots, k) \text{ and } (j = 1, 2, \ldots, n_i) \qquad (1)$$

where,

X_{ij} = the exposure concentration of the i-th worker on the j-th day,

Y_{ij} = $\ln(X_{ij})$,

μ_y = mean of Y_{ij},

β_i = the random deviation of the i-th worker's true exposure from μ_y, and

ϵ_{ij} = the random deviation of the i-th worker's exposure on the j-th day from his or her true exposure, $\mu_{y,i}$.

The structure of the model defined in Equation 1, as well as the inherent assumptions and the methods for estimating parameters, are well known.[9] It is assumed under the model that both persons and days are randomly selected for monitoring. Furthermore, it is assumed that β_i and ϵ_{ij} are normally distributed; i.e., $\beta_i \sim N(0,\sigma_B^2)$, and $\epsilon_{ij} \sim N(0,\sigma_w^2)$. Thus, the underlying distribution of exposures (X_{ij}) is assumed to be lognormal, consistent with earlier work (reviewed by Rappaport[1]). Finally, β_i and ϵ_{ij}, are assumed to be statistically independent of each other. Thus, the parameters σ_B^2 and σ_w^2 are referred to as the components of the total variance $\sigma_y^2 = \sigma_B^2 + \sigma_w^2$, and $Y_{ij} \sim N(\mu_y, \sigma_y^2)$.

The current application will report only the ANOVA estimate of σ_B^2, which will be designated as ${}_BS_y^2$. The method of computation of ${}_BS_y^2$ under the random-effects model is well

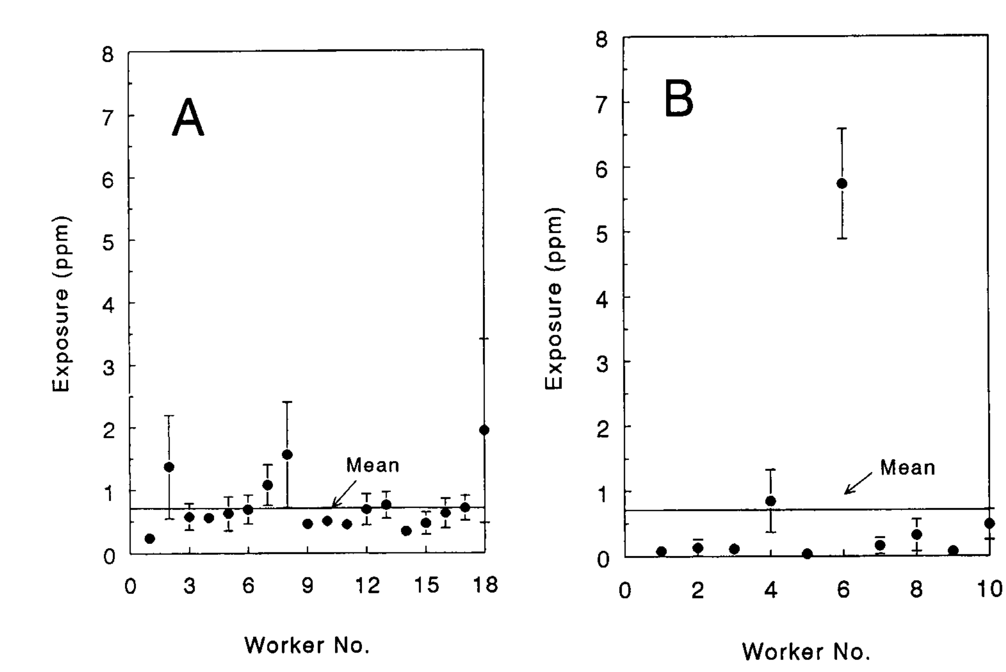

FIGURE 1. Exposures to benzene received by two groups of operators in petroleum refineries; individual means and standard errors are shown. A—Data from Group 147 (see Appendix); 2–7 measurements per worker, ${}_BS_y = 0.193$ and ${}_B\hat{R}_{.95} = 1.8$; B—Data from Group 153 (see Appendix); 2–13 measurements per worker, ${}_BS_y = 0.824$ and ${}_B\hat{R}_{.95} = 25.3$.

documented.[9] As an additional aid to interpretation of results, we will follow the earlier convention of Rappaport[1] and define a scale-independent measure of the range of exposures within a group, ${}_BR_{.95} = \exp[3.92\sigma_B]$, which represents the ratio of the (arithmetic) mean exposures received by the 97.5th and 2.5th percentile workers. A value of ${}_BR_{.95} = 10$, for example, would indicate that the mean exposures of 95% of the individuals in the group lie within a 10-fold range; this occurs when $\sigma_B^2 = 0.5874$. The estimates of ${}_BR_{.95}$, designated as ${}_B\hat{R}_{.95} = \exp[3.92{}_BS_y]$, and of ${}_B\sigma_y$ are listed in the Appendix for all HEGs that fit the random-effects model.

UNIFORMITY OF EXPOSURE WITHIN HEGS

The random-effects model clarifies the major assumption of the observational approach, namely that all individuals in an HEG have the same mean value of their (log-transformed) exposures, μ_y. If this is the case, then all variation occurs within workers over time (e.g., from day to day), $\sigma_B^2 = 0$ and $\sigma_y^2 = \sigma_W^2$. Then, the group is truly "homogeneous" and the mean value estimated from a small sample of workers can be safely assigned to all individuals in the group. This appears to be the case for the group illustrated in Figure 1A, representing 18 operators exposed to benzene in a petroleum refinery, since the value of ${}_BS_y = 0.193$ is small (${}_B\hat{R}_{.95} = 1.8$) (Group 147 of Appendix). However, as σ_B^2 becomes large, the mean exposures of the individuals differ more and more so that exposure is no longer "homogeneous." This situation is illustrated in Figure 1B, which depicts the benzene exposures of 10 operators from another petroleum refinery (group 153 of Appendix). Note that the mean exposure of Worker No. 6 is much greater than that of the group as a whole, suggesting that the population of workers (represented by this small sample) is extremely heterogeneous. In this case designation of the group as an HEG becomes problematic because ${}_BS_y = 0.824$ is large (${}_B\hat{R}_{.95} = 25.3$) and assignment of the same mean level to all members seems inappropriate.

The groups shown in Figure 1 illustrate the problem inherent in the observational approach. Both groups are legitimate HEGs in the sense that all members of each group share the identifiable characteristics of process, job title, and location. In fact, both groups experienced exposures to the same gaseous species (benzene) at about the same overall air level in similar workplaces. Yet, the distributions of exposures within the two groups were very different; exposure in the first HEG could reasonably be characterized as homogeneous but could not in the second HEG.

These conceptual (and semantic) difficulties have motivated the introduction of additional terms to clarify distinctions between groups.[1] Specifically, a "monomorphic group" has been defined as a group in which the (arithmetic) mean exposures of the individual workers can be described by a lognormal distribution and a "uniformly exposed group" as one where the (arithmetic) mean exposure is the same for all individuals. In the context of the random-effects model used in this analysis, a monomorphic group is one where the logarithms of the individual (arithmetic) mean exposures are normally distributed with mean ($\mu_y + 0.5\,\sigma_W^2$) and variance σ_B^2,[8] and a uniformly exposed group is a monomorphic group in which σ_B^2 approaches zero. Since it is unrealistic to expect σ_B^2 to be zero, Rappaport[1] suggested further that a uniformly exposed group be designated whenever $\sigma_B^2 \leq 0.0313$ (${}_BR_{.95} \leq 2$). The individual (arithmetic) mean exposures from such a distribution would be very similar, since 95% of the values would lie within a factor of two. Referring again to Figure 1, and using the estimated values of ${}_BR_{.95}$ to represent the true values, the first group of refinery workers would be uniformly exposed, but the second group would not. Since all of the HEGs reported in this paper adequately fit the random-effects model, each HEG would be a monomorphic group but not necessarily a uniformly exposed group.

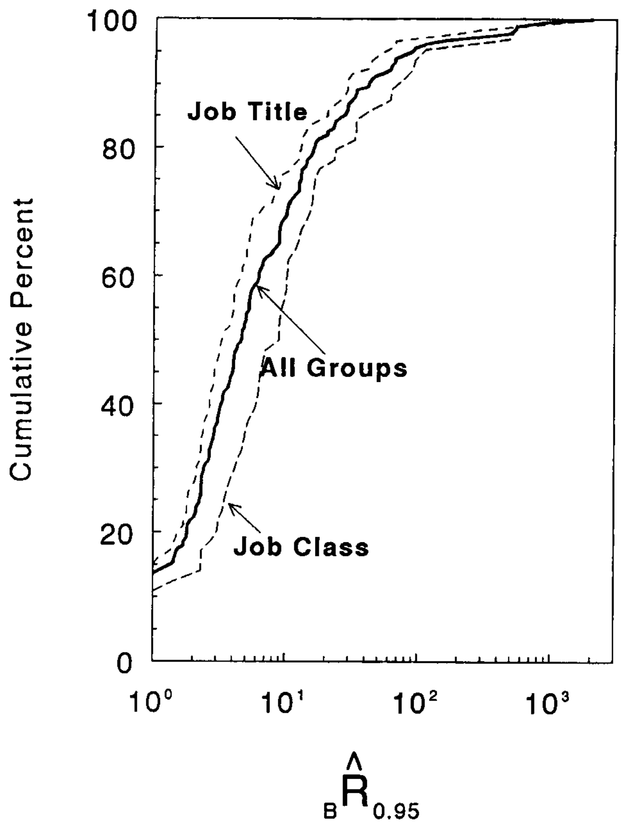

FIGURE 2. The solid curve depicts cumulative distributions of $_B\hat{R}_{.95}$ for all 183 groups of workers. The dashed curves represent distributions of groups that had been designated either a priori (job class, n = 64) by industrial hygienists who performed the original surveys or a posteriori (job title; n = 119) by the current authors.

VARIATION OF EXPOSURE WITHIN HEGS

The values of $_BS_y$ and $_B\hat{R}_{.95}$ for the 183 HEGs that adequately fit the random-effects model are listed in the Appendix. The distributions of $_B\hat{R}_{.95}$ across the 183 HEGs are shown in Figure 2. The two dashed curves in Figure 2 indicate the cumulative distributions of HEGs that were based either on *a priori* classification (job class) by the industrial hygienists who performed the original surveys or on *a posteriori* classification by the current authors on the basis of job titles. Although one should be cautious in comparing these two distributions of HEGs, owing to the fact that they reflect exposures to different chemical agents in different industries, Figure 2 suggests that the groups formed *a priori* (job class) tend to be more heterogeneous than those based simply on job title (about a two-fold difference in $_B\hat{R}_{.95}$). This may reflect the fact that most of the job classes were developed by combining several small groups into a single HEG.

Referring to the solid curve in Figure 2, which includes all 183 groups, the range of $_B\hat{R}_{.95}$ varied between 1 and 2000 with a median value of 4.6. This indicates that workers in a typical HEG experienced significant (about 5-fold) differences in their average exposures. Twenty-two percent of all HEGs had values of $_B\hat{R}_{.95} \leq 2$, suggesting that they were uniformly exposed, and an equal percentage had values of $_B\hat{R}_{.95} \geq 15$. Thus, there was about one chance in five that a given HEG would be either very homogeneous or very heterogeneous. A significant proportion of HEGs had extreme within-group variation since 9% had values of $_B\hat{R}_{.95} \geq 50$.

The reasons for the extreme range of $_B\hat{R}_{.95}$, indicated in Figure 2 can be only partially gleaned from the database. Some shift towards larger values appears to be associated with the type of exposure (gaseous, particulate, or dermal). As shown in Table I, the variation between workers exposed to particulate and dermal contaminants was marginally greater than that observed for gaseous agents. Of those HEGs with extreme variation ($_B\hat{R}_{.95} \geq 50$) only 2/68 gaseous exposures (3%) were included, but 12/89 particulate exposures (13%) and 2/25 exposures to dermal agents (8%) were included.

Effects of the dichotomous variables on the between-worker component of variance were analyzed using multivariate procedures from Proc GLM of SAS.[7] (Because these variables could only be coded by job title, this analysis excluded HEGs based on job class and is described elsewhere as part of the more general investigation of the database).[7] Of the six variables coded in the database, only "type of process" (continuous vs. intermittent) had a significant effect on the between-worker component of variance. However, the fit of the model was very poor and only explained 13% of the variation.[7] This suggests that although some identifiable features of the working environment can marginally affect the variation in exposure between workers in an HEG, most of the variation (87%) remains locked in specific features of particular jobs, notably in the mix of tasks and work practices of the individuals comprising the group. This result is in stark contrast to the situation regarding the within-worker component of variance (σ^2_w), where 41% of the total variation in exposure was explained by these same dichotomous variables.[7]

DISCUSSION

This investigation of approximately 200 HEGs indicates that four-fifths of the groups were not uniformly exposed. Indeed, groups may be even more heterogeneous than observed herein, because most were not randomly sampled as is assumed by the ANOVA model. In elaborating the results from this database, Kromhout et al.[7] showed that σ^2_B is

TABLE I. Within-Group Variation of HEGs for Different Types of Exposure (Percentages of Each Type of Exposure Shown in Parentheses)

TYPE	n	$_B\hat{R}_{.95}$ ≤2	≥10	≥50
Gaseous	68	18 (26)	15 (22)	2 (3)
Particulate	89	16 (18)	31 (35)	12 (13)
Dermal	25	6 (24)	11 (44)	2 (8)
Total	182	40 (22)	57 (31)	16 (9)

significantly larger when either workers or days are randomly sampled. But, in any case, the range of variation between workers in HEGs was so vast ($1 \leq {}_{B}\hat{R}_{.95} \leq 2000$) as to suggest that one cannot determine *a priori* which groups are likely to be uniformly exposed and which are likely to have extreme between-worker variation. It is possible that somewhat different results would be obtained from a larger database, one comprised of an even greater cross section of industries and jobs. However, we suspect that any such differences would be small provided that the usual observational methods (based on job title or class and location) were used as the primary means of classification.

Since traditional testing schemes assume that all individuals within an HEG have the same average exposure,[1] these results present two disturbing implications. First, they suggest that some workers may not be adequately protected because their average exposures are much larger than those observed in the samples on which decisions regarding overexposure were based. Even if a large shift-long exposure were observed, the HEG tenet that all variation occurs within workers, encourages the belief that any such high level represents an "unusual" work shift that is counterbalanced over time by many low exposures. Our results suggest, to the contrary, that some workers are consistently exposed to much greater concentrations than their coworkers.

The second implication of our work relates to the mechanism for selecting among options for controls that can be applied to reduce exposures. Since uniform exposure is assumed for each HEG, any evidence of overexposure must be dealt with by reducing the exposures of everyone, typically through application of engineering principles. Yet, a major component of the variation in exposure generally relates to differences in tasks or work practices that do not lend themselves to engineering solutions. Thus, the usual methods are inadequate for determining the effectiveness of controls and we suspect that many controls currently in place may be either inappropriate or ineffective or both.

Since industrial hygienists cannot accept on faith that their HEGs are uniformly exposed, they must either improve their observational methods or seek a different model for exposure, one which explicitly allows for variation between workers. Although the first course of action offers the short-term security of the status quo, it may be unworkable in the long run. This study demonstrated that the characteristics routinely used to establish HEGs (job title and location) as well as other information readily at hand (type of contaminant, nature of the process, environment and source, mobility) are only marginally related to the between-worker component of variance. Thus, observational schemes can only be improved by investigating job-specific tasks and practices. Regrettably, this is an open-ended process because there is simply no convenient point where one can stop "observing" an increasingly subtle array of tasks. It follows that more rigorous observational methods will be much more expensive, owing to the amount of professional time required to carefully investigate the tasks and, indeed, the exposures of a large number of very small groups (continued application of the observational approach to tasks and practices ultimately leads to "groups" that contain only one person).

The alternative to rigorously pursuing the observational approach is to adopt a model of occupational exposure that allows for variation to exist between workers in a given group. In the context of the ANOVA model defined in Equation 1, it is possible to define a monomorphic group where exposure can vary both within and between individuals. With knowledge of μ_Y, σ_B^2, and σ_W^2 (and the underlying distribution functions), this model allows a full range of questions to be investigated concerning not only the magnitude of exposure relative to the OEL but also the selection of controls that would be optimal in particular circumstances.[1] Indeed, by removing biases and by explicitly recognizing σ_B^2, data can be confidently used by epidemiologists and others who wish to assess the long-term risks of disease with a minimum error due to misclassification of exposure.

Even if the monomorphic group is used rather than the HEG as the paradigm for future classification of the population, it would still be necessary to employ simple observational schemes to establish *a priori* groups. However, under the new model of exposure, one would devote minimal effort to *a priori* classification so that monitoring can be maximized. In point of fact, *a priori* grouping could still be based on such broad features as job title and location. Tasks and practices would only be investigated after analysis of exposure data indicated both that controls were needed and that the *a priori* group was not uniformly exposed.[1] It should also be understood that any monitoring strategy would require that multiple measurements be collected at random from representative workers in each *a priori* group to allow estimation of the within- and between-worker components of variance.

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APPENDIX

Characteristics of 183 Groups (HEGs) That Fit the Random-Effects Model

(Note: k and N represent, respectively, the number of workers and of measurements in the sample while G, P, and D refer to gaseous, particulate, and dermal contaminants)

Group	*Basis*	*k*	*N*	${}_BS_y$	${}_B\hat{R}_{.95}$	*Chemical Agent*	*Industry*	*Type*
1	Job Class	18	36	0.214	2.3	Inspirable Dust	Non-woven Fabrics	P
2	Job Class	9	19	0.8	23.0	Inspirable Dust	Non-woven Fabrics	P
3	Job Title	5	25	0.213	2.3	Perchloroethylene	Dry Cleaning	G
4	Job Title	5	35	0.952	41.8	Inspirable Dust	Wood Mill	P
5	Job Title	5	23	0.189	2.1	Inspirable Dust	Wood Mill	P
6	Job Class	9	18	0.588	10.0	Inspirable Dust	Vehicle Manuf.	P
7	Job Class	26	52	0.409	5.0	Inspirable Dust	Vehicle Manuf.	P
8	Job Class	8	16	0.359	4.1	Inspirable Iron	Vehicle Manuf.	P
9	Job Class	26	52	0.328	3.6	Inspirable Iron	Vehicle Manuf.	P
10	Job Class	9	18	0.34	3.8	Inspirable Zinc	Vehicle Manuf.	P
11	Job Class	26	52	0.961	43.3	Inspirable Zinc	Vehicle Manuf.	P
12	Job Class	9	18	0.89	32.7	Inspirable Copper	Vehicle Manuf.	P
13	Job Class	26	52	0.557	8.9	Inspirable Copper	Vehicle Manuf.	P
14	Job Class	18	73	0.446	5.7	Inspirable Dust	Vehicle Manuf.	P
15	Job Class	9	43	0.466	6.2	Inspirable Dust	Vehicle Manuf.	P
16	Job Class	18	79	0.288	3.1	Inspirable Dust	Vehicle Manuf.	P
17	Job Class	18	73	0.46	6.1	Inspirable Zinc	Vehicle Manuf.	P
18	Job Class	9	43	0.475	6.4	Inspirable Zinc	Vehicle Manuf.	P
19	Job Class	18	79	0.423	5.2	Inspirable Zinc	Vehicle Manuf.	P
20	Job Class	5	25	0	1.0	Trichloroethylene	Optical Equip. Manuf.	G
21	Job Class	5	25	0	1.0	Perchloroethylene	Optical Equip. Manuf.	G
22	Job Title	9	36	0	1.0	Resp Zinc	Brass Foundry	P
23	Job Title	5	15	0	1.0	Resp Zinc	Brass Foundry	P
24	Job Class	11	50	0.589	10.1	Inspirable Dust	Animal Feed Prod.	P
25	Job Class	7	30	0.285	3.1	Inspirable Dust	Animal Feed Prod.	P
26	Job Class	5	18	0.676	14.2	Inspirable Dust	Animal Feed Prod.	P
27	Job Class	7	36	0.487	6.7	Inspirable Dust	Animal Feed Prod.	P
28	Job Class	21	83	0.898	33.8	Inspirable Dust	Animal Feed Prod.	P
29	Job Class	12	50	1.596	521.3	Inspirable Dust	Animal Feed Prod.	P
30	Job Class	6	26	0.496	7.0	Inspirable Dust	Animal Feed Prod.	P
31	Job Class	5	18	0	1.0	Inspirable Dust	Animal Feed Prod.	P
32	Job Class	12	41	0	1.0	Inspirable Dust	Animal Feed Prod.	P
33	Job Class	12	24	0.695	15.2	Inspirable Dust	Animal Feed Prod.	P
34	Job Class	11	49	1.052	61.8	Endotoxin Dust	Animal Feed Prod.	P
35	Job Class	7	27	0.212	2.3	Endotoxin Dust	Animal Feed Prod.	P
36	Job Class	5	17	0.556	8.8	Endotoxin Dust	Animal Feed Prod.	P
37	Job Class	7	33	0.595	10.3	Endotoxin Dust	Animal Feed Prod.	P
38	Job Class	20	77	1.153	91.8	Endotoxin Dust	Animal Feed Prod.	P
39	Job Class	12	49	1.605	540.0	Endotoxin Dust	Animal Feed Prod.	P
40	Job Class	6	26	0.307	3.3	Endotoxin Dust	Animal Feed Prod.	P
41	Job Class	5	17	0	1.0	Endotoxin Dust	Animal Feed Prod.	P

APPENDIX. Continued

Group	Basis	k	N	$_BS_y$	$_B\hat{R}_{.95}$	Chemical Agent	Industry	Type
42	Job Class	12	40	0.392	4.6	Endotoxin Dust	Animal Feed Prod.	P
43	Job Class	5	20	0.401	4.8	Inspirable Dust	Grain Mill	P
44	Job Class	11	30	0.713	16.4	Inspirable Dust	Grain Mill	P
45	Job Class	30	101	0.703	15.7	Inspirable Dust	Grain Mill	P
46	Job Class	5	20	0.374	4.3	Endotoxin Dust	Grain Mill	P
47	Job Class	11	28	0	1.0	Endotoxin Dust	Grain Mill	P
48	Job Class	30	100	0.732	17.6	Endotoxin Dust	Grain Mill	P
49	Job Class	25	50	0.559	8.9	Inspirable Dust	Grain Elevator	P
50	Job Class	7	14	1.572	474.5	Inspirable Dust	Grain Elevator	P
51	Job Class	19	38	1.101	74.9	Inspirable Dust	Grain Elevator	P
52	Job Class	24	48	1.201	110.8	Inspirable Dust	Grain Elevator	P
53	Job Title	8	24	0.277	3.0	Inspirable Dust	Tobacco Products	P
54	Job Title	5	15	0.422	5.2	Inspirable Dust	Tobacco Products	P
55	Job Title	10	29	0.295	3.2	Inspirable Dust	Tobacco Products	P
56	Job Title	7	21	0.255	2.7	Inspirable Dust	Tobacco Products	P
57	Job Title	8	24	0	1.0	Inspirable Nicotine	Tobacco Products	P
58	Job Title	5	15	0.224	2.4	Inspirable Nicotine	Tobacco Products	P
59	Job Title	10	28	0.102	1.5	Inspirable Nicotine	Tobacco Products	P
60	Job Title	7	21	0	1.0	Inspirable Nicotine	Tobacco Products	P
61	Job Title	6	17	0.979	46.4	Inspirable Dust	Rubber Manuf.	P
62	Job Title	18	36	0.369	4.2	Inspirable Dust	Rubber Manuf.	P
63	Job Title	5	14	0.18	2.0	Inspirable Dust	Rubber Manuf.	P
64	Job Title	6	18	0.768	20.3	Inspirable Dust	Rubber Manuf.	P
65	Job Title	8	22	0.465	6.2	Inspirable Dust	Rubber Manuf.	P
66	Job Title	6	18	0.268	2.9	Inspirable Dust	Rubber Manuf.	P
67	Job Title	5	13	0.155	1.8	Inspirable Dust	Rubber Manuf.	P
68	Job Title	5	11	0.767	20.2	Inspirable Dust	Rubber Manuf.	P
69	Job Title	5	14	0.653	12.9	Inspirable Dust	Rubber Manuf.	P
70	Job Title	5	12	0.855	28.5	Inspirable Dust	Rubber Manuf.	P
71	Job Title	6	18	0.335	3.7	Inspirable Dust	Rubber Manuf.	P
72	Job Title	6	13	0.293	3.2	Inspirable Dust	Rubber Manuf.	P
73	Job Title	7	21	0.428	5.4	Inspirable Dust	Rubber Manuf.	P
74	Job Title	9	25	1.019	54.3	Inspirable Dust	Rubber Manuf.	P
75	Job Title	7	21	0.249	2.7	Inspirable Dust	Rubber Retreading	P
76	Job Title	5	14	1.067	65.5	Inspirable Dust	Rubber Retreading	P
77	Job Title	6	13	0.483	6.6	Inspirable Dust	Rubber Manuf.	P
78	Job Title	12	32	1.939	2000.0	Inspirable Dust	Rubber Manuf.	P
79	Job Title	11	28	0	1.0	Inspirable Dust	Rubber Manuf.	P
80	Job Title	6	16	1.716	834.4	Inspirable Dust	Rubber Manuf.	P
81	Job Title	7	20	0	1.0	Cyclohex. Sol. Fraction	Rubber Manuf.	D
82	Job Title	7	19	0.616	11.2	Cyclohex. Sol. Fraction	Rubber Manuf.	D
83	Job Title	8	21	0.671	13.9	Cyclohex. Sol. Fraction	Rubber Manuf.	D
84	Job Title	5	13	0.136	1.7	Cyclohex. Sol. Fraction	Rubber Manuf.	D
85	Job Title	6	18	0.948	41.1	Cyclohex. Sol. Fraction	Rubber Manuf.	D
86	Job Title	8	22	0.349	3.9	Cyclohex. Sol. Fraction	Rubber Manuf.	D
87	Job Title	6	16	0.024	1.1	Cyclohex. Sol. Fraction	Rubber Manuf.	D
88	Job Title	7	20	0.412	5.0	Cyclohex. Sol. Fraction	Rubber Manuf.	D
89	Job Title	6	13	0.306	3.3	Cyclohex. Sol. Fraction	Rubber Manuf.	D
90	Job Title	5	14	1.442	285.0	Cyclohex. Sol. Fraction	Rubber Manuf.	D
91	Job Title	5	16	0.522	7.7	Cyclohex. Sol. Fraction	Rubber Manuf.	D
92	Job Title	6	14	0.874	30.8	Cyclohex. Sol. Fraction	Rubber Manuf.	D
93	Job Title	9	25	0.653	12.9	Cyclohex. Sol. Fraction	Rubber Manuf.	D
94	Job Title	12	25	0	1.0	Cyclohex. Sol. Fraction	Rubber Manuf.	D
95	Job Title	8	23	1.066	65.3	Cyclohex. Sol. Fraction	Rubber Manuf.	D
96	Job Title	10	27	0.847	27.7	Cyclohex. Sol. Fraction	Rubber Manuf.	D

APPENDIX. Continued

Group	Basis	k	N	$_BS_y$	$_B\hat{R}_{.95}$	Chemical Agent	Industry	Type
97	Job Title	6	14	0.563	9.1	Cyclohex. Sol. Fraction	Rubber Manuf.	D
98	Job Title	9	27	0.606	10.8	Cyclohex. Sol. Fraction	Rubber Retreading	D
99	Job Title	5	14	0.110	1.5	Cyclohex. Sol. Fraction	Rubber Retreading	D
100	Job Title	7	19	0.795	22.6	Cyclohex. Sol. Fraction	Rubber Manuf.	D
101	Job Title	15	40	0.545	8.5	Cyclohex. Sol. Fraction	Rubber Manuf.	D
102	Job Title	15	39	0.643	12.4	Cyclohex. Sol. Fraction	Rubber Manuf.	D
103	Job Title	5	14	0	1.0	Cyclohex. Sol. Fraction	Rubber Manuf.	D
104	Job Class	17	64	0.315	3.4	Inspirable Dust	Rubber Retreading	P
105	Job Class	15	51	0.213	2.3	Inspirable Dust	Rubber Retreading	P
106	Job Class	20	74	0.469	6.3	Cyclohex. Sol. Fraction	Rubber Retreading	D
107	Job Class	15	49	0.58	9.7	Cyclohex. Sol. Fraction	Rubber Retreading	D
108	Job Class	8	16	0.627	11.7	Toluene	Paint Manuf.	G
109	Job Class	9	18	0.805	23.5	Toluene	Paint Manuf.	G
110	Job Class	8	16	0.707	16.0	Xylene	Paint Manuf.	G
111	Job Class	8	18	0.655	13.0	Xylene	Paint Manuf.	G
112	Job Class	8	16	0.595	10.3	Solvent Vapors	Paint Manuf.	G
113	Job Class	9	18	0.565	9.2	Solvent Vapors	Paint Manuf.	G
114	Job Title	12	77	0.411	5.0	Diphenyl	Synthetic Yarn Man.	G
115	Job Title	5	28	0.249	2.7	Diphenyl	Synthetic Yarn Man.	G
116	Job Title	12	77	0.432	5.4	Diphenyl Ether	Synthetic Yarn Man.	G
117	Job Title	5	29	0.193	2.1	Diphenyl Ether	Synthetic Yarn Man.	G
118	Job Title	11	48	0.678	14.3	Inspirable Dust	Pesticide Formulat.	P
119	Job Title	13	57	0.309	3.4	Inspirable Dust	Pesticide Formulat.	P
120	Job Title	5	91	0	1.0	Nitrogen Dioxide	Fertilizer Manuf.	G
121	Job Title	10	28	0	1.0	Styrene	Reinforced Plastics	G
122	Job Title	8	23	0.859	29.0	Styrene	Reinforced Plastics	G
123	Job Title	8	32	0.357	4.1	Styrene	Reinforced Plastics	G
124	Job Title	7	18	0	1.0	Styrene	Reinforced Plastics	G
125	Job Title	8	24	0	1.0	Styrene	Reinforced Plastics	G
126	Job Title	10	30	0.269	2.9	Styrene	Reinforced Plastics	G
127	Job Title	6	18	0.392	4.6	Styrene	Reinforced Plastics	G
128	Job Title	8	24	0.422	5.2	Styrene	Reinforced Plastics	G
129	Job Title	6	29	0.218	2.4	Welding Fume	Locomotive Manuf.	P
130	Job Title	6	29	0.147	1.8	Welding Fume	Locomotive Manuf.	P
131	Job Title	6	29	0.206	2.2	Welding Fume	Locomotive Manuf.	P
132	Job Title	6	29	0.211	2.3	Welding Fume	Locomotive Manuf.	P
133	Job Class	12	37	1.046	60.4	Inspirable Dust	Bread Bakery	P
134	Job Title	10	27	0.427	5.3	Diphenyl Ether	Synthetic Yarn Man.	G
135	Job Title	6	16	0.354	4.0	Diphenyl Ether	Synthetic Yarn Man.	G
136	Job Title	5	14	0.557	8.9	Diphenyl Ether	Synthetic Yarn Man.	G
137	Job Title	9	21	0	1.0	Ethanal	Synthetic Yarn Man.	G
138	Job Title	7	21	0.148	1.8	Solvent Vapors	Printing Plant	G
139	Job Class	19	96	1.145	89.0	Styrene	Reinforced Plastics	G
140	Job Class	9	53	0.895	33.4	Styrene	Reinforced Plastics	G
141	Job Class	20	110	0.643	12.4	Styrene	Reinforced Plastics	G
142	Job Title	53	382	0.53	8.0	Toluene	Petroleum Refining	G
143	Job Title	5	39	0.353	4.0	Toluene	Petroleum Refining	G
144	Job Title	6	176	0.393	4.7	Tetraalkyl Lead	Alkyl Lead Manuf.	G
145	Job Title	6	177	0.153	1.8	Inorganic Lead	Alkyl Lead Manuf.	P
146	Job Title	38	201	0.264	2.8	Benzene	Petroleum Refining	G
147	Job Title	17	89	0.193	2.1	Benzene	Petroleum Refining	G
148	Job Title	18	57	0.152	1.8	Benzene	Petroleum Refining	G
149	Job Title	38	164	0.285	3.1	Benzene	Petroleum Refining	G
150	Job Title	17	741	0.557	8.9	Benzene	Petroleum Refining	G
151	Job Title	16	50	0.222	2.4	Benzene	Petroleum Refining	G

APPENDIX. Continued

Group	Basis	k	N	$_{B}S_{y}$	$_{B}\hat{R}_{.95}$	Chemical Agent	Industry	Type
152	Job Title	5	44	0.385	4.5	Benzene	Petroleum Refining	G
153	Job Title	10	54	0.824	25.3	Benzene	Petroleum Refining	G
154	Job Title	8	68	0.299	3.2	Benzene	Petroleum Refining	G
155	Job Title	22	145	0.715	16.5	Benzene	Petroleum Refining	G
156	Job Title	17	118	0.243	2.6	Benzene	Petroleum Refining	G
157	Job Title	18	90	0.134	1.7	Benzene	Petroleum Refining	G
158	Job Title	25	105	0.404	4.9	Benzene	Petroleum Refining	G
159	Job Title	14	87	0.355	4.0	Benzene	Petroleum Refining	G
160	Job Title	13	73	0.249	2.7	Benzene	Petroleum Refining	G
161	Job Title	15	87	0.36	4.1	Benzene	Petroleum Refining	G
162	Job Title	15	167	0.649	12.7	Benzene	Petroleum Refining	G
163	Job Title	14	38	1.278	149.9	Benzene	Petroleum Refining	G
164	Job Title	13	50	0.642	12.4	Benzene	Petroleum Refining	G
165	Job Title	15	36	0	1.0	Sulfur dioxide	Aluminum Reduction	G
166	Job Title	16	38	0	1.0	Total Dust	Aluminum Reduction	P
167	Job Title	14	34	0.089	1.4	Total Fluoride	Aluminum Reduction	G,P
168	Job Title	14	34	0	1.0	Fluoride Dust	Aluminum Reduction	P
169	Job Title	15	36	0.205	2.2	Hydrogen Fluoride	Aluminum Reduction	G
170	Job Class	8	24	0	1.0	Formaldehyde	Resin Manuf.	G
171	Job Class	18	55	0.099	1.5	Formaldehyde	Resin Manuf.	G
172	Job Class	8	24	0.259	2.8	Formaldehyde	Resin Manuf.	G
173	Job Title	6	54	0	1.0	Organic Vapor	Pesticide Manuf.	G
174	Job Title	5	1139	0.435	5.5	Organic Vapor	Pesticide Manuf.	G
175	Job Title	16	5076	0.341	3.8	Organic Vapor	Pesticide Manuf.	G
176	Job Title	62	1162	0.857	28.8	Organic Vapor	Pesticide Manuf.	G
177	Job Title	16	592	0.232	2.5	Inorganic Mercury	Chloralkali Prod.	G
178	Job Title	6	18	0.092	1.4	Benzene	Spray Painting	G
179	Job Title	6	18	0.212	2.3	Benzene	Spray Painting	G
180	Job Title	6	18	0.165	1.9	Toluene	Spray Painting	G
181	Job Title	6	18	0	1.0	Toluene	Spray Painting	G
182	Job Title	6	18	0.06	1.3	Xylene	Spray Painting	G
183	Job Title	6	18	0.27	2.9	Xylene	Spray Painting	G