WHEN 4/2 DOES NOT EQUAL 2: APPROACHES TO EXTENDING A CATEGORICAL EXPOSURE RANK TO A QUANTITATIVE EXPOSURE RANGE

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Key words: Exposure assessment, categorical exposure, occupational epidemiology, quantitiatve exposure reconstruction

Abbreviations:

ACGIH	American Conference of Governmental Industrial Hygieniests
ANSI	American National Standards Institute
NIOSH	National Institute for Occupational Safety and Health
OSHA	Occupational Safety and Health Administration
PEL	Permissible Exposure Limit
ppm	parts per million
OSHA	Occupational Safety and Health Administration
STEL	Short term exposure limit
TCE	Trichloroethylene
TLV®	registered trademark, Theshold Limit Value
TWA	Time weighted average

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ABSTRACT

Occupational epidemiology studies frequently rely on ranked exposures indicating which jobs are associated with the lowest exposures, the highest exposures, and those at several cut points between lowest and highest. When expressed as categories, these are often designated with a unit value, such as 0 (no exposure), 1 (some exposure), 2 (less than average), 3 (about average), 4 (higher than average) and 5 (highest). In this scale, a rank of 2 cannot be considered two times the exposure of rank 1; similarly, rank 4 is not two times rank 2.

Two approaches are presented based on historical exposure guidelines and utilizing scaling from the log-normal distribution to associate ranks with quantitative ranges of exposure. The following is one approach: 0 is actually unexposed; a rank of 1 has a range that includes the limit of detection for an analytical method used at the time; a rank of 4 has a range that includes the published exposure guideline (e.g., from the industry, a TLV from ACGIH or PEL from OSHA) in effect at a point in time; a rank of 5 would be limited to values that allowed continued work. Using these three benchmarks, ranges can be set for the remaining ranks, using the general guideline that the upper and lower bounds should differ by a factor of 3 or 4 to be meaningfully different. Using this approach for a compound with an exposure guideline of 50 ppm and a limit of detection of 2 ppm, the following ranges might be associated with each rank: 0=none; 1=>0-5; 2= >5-15; 3= >15-45; 4= >45-135; 5, >135. Alternatively, in a situation where exposures are generally known to be low, ranges might be set such that the highest rank is associated the published guideline; in this instance, and depending upon the limit of detection and guideline values, three or four ranks might be sufficient.

The use of air sampling data to adjust the ranges developed from ranks using these two approaches is illustrated with data from an ongoing exposure reconstruction to chemical exposures at a gaseous diffusion plant.

INTRODUCTION

In retrospective occupational epidemiology studies, a range of exposure metrics may be considered, from ever/never employed in an exposure environment to quantitative reconstruction of exposures over a working lifetime. Often, information is available to construct a metric more informative than ever/never; however, rarely do researchers have access to the substantial numbers of quantitative measures of exposure required to reconstruct exposures. In these instances, a combination of resources may be used to construct a semiquantitative estimate of exposure (Stewart et al. 1991). These resources include historical records of the work environment (drawings, procedures, and processes), interviews with long-term workers and managers and any available industrial hygiene data. The semiquantitative estimates, or rankings, usually categorize job titles into groups with similar perceived levels of exposure or similar potential for contact with the agent(s) under study. Ranks range from a group of jobs associated with no exposure through a number of categories with increasing exposure.

Typically, ranks are designated with a unit value, such as 0 (no exposure), 1 (low exposure), 2 (below average), 3 (average), 4 (higher than average) and 5 (highest). Quantitative benchmarks related to published exposure guidelines (e.g., an industry value or a Threshold Limit Value from ACGIH) or a governmentally enforced standard (e.g., a Permissible Exposure Limit or a PEL from OSHA) are not linked to these ranks, as they reflect perceived relative levels of exposure. “Average” for rank 3 is a relative term given the range of exposures at the industry or facility, not average in terms of published values. Similarly, if the ranks were low, medium and high, those providing input to the rank-order would consider the upper most extreme exposure condition at the facility to be “high”, regardless of the relation of exposure in this area to published bench-mark values. In addition, this ordinal ranking does not reflect the underlying log-normal distribution of environmental data that is often encountered (Esmen et al. 1977). For example, in this ordinal scale, a quantitative exposure associated with rank 2 cannot be considered two times the exposure that would be associated with rank 1; similarly, rank 4 is not two times rank 2. Thus, ordinal ranks are generally not associated with bench-mark values and are not distributed as measurement data would be.

METHODS

The work presented illustrates an approach to associating ordinal ranks with ranges of exposure concentrations that reflect a skewed distribution.

Two examples are shown, each based on historical exposure guidelines and utilizing scaling from the log- normal distribution to associate ranks with quantitative ranges of exposure (Lynch and Ayer, 1966; Rosario et al. 2006). First example: rank 0 is unexposed; a rank of 1 has a range that includes the limit of detection for an analytical method used at the time; a rank of 4 has a range that includes the published occupational exposure guideline in effect at a point in time; a rank of 5 would be associated with a range higher than the guideline but would necessarily be limited to values that allowed continuous work. Using these three benchmarks or no exposure, limit of detection and published guideline, ranges can be set for the remaining ranks according to the general guideline that the upper and lower bounds should differ by a factor of 3 or 4 to be meaningfully different (Lynch and Ayer, 1966). Using this approach for a compound with an exposure guideline of 50 ppm and a limit of detection of 2 ppm, the following ranges might be associated with each rank: 0=none; 1= >0-5; 2=>5-15; 3=>15-45; 4= >45-135;

5=>135. Second example: in a situation where exposures are generally known to be low, ranges might be set such that the highest rank is associated the published guideline; in this instance, and depending upon the limit of detection and guideline values, three or four ranks might be sufficient.

These two approaches were considered in scaling ranks of exposure to trichloroethylene constructed for a cohort mortality study of workers employed 1952-2000. First, sampling methods and the analytical limits of detection were catalogued over time. Sampling through the mid 1960s was conducted during tasks where there was a potential for exposure using evacuated flasks and analyzed using wet chemistry; the limit of detection was approximately 1 ppm (Stack et al. 1961; American Industrial Hygiene Association. 1978). Activated carbon was used subsequently for short-term and most recently for full-shift samples, with the limit of detection dropping from 1 ppm to 0.3 ppm as methods improved (American Industrial Hygiene Association 1978; National Institute for Occupational Safety and Health 1994). Next the U.S. published exposure guidelines and standards for trichloroethylene were summarized and are shown in Table 1 (Cook 1945; American National Standard Institute 1967; Trichloroethylene 2007; National Institute for Occupational Safety and Health 1973; ACGIH 2001; NIOSH. 2007). The earliest compilation of exposure guidelines is found in Cook (1945); while he cites the use of 200 ppm for a full-shift exposure by several State Health Departments, he recommends use of 100 ppm due to animal data.

RESULTS

Using these benchmarks, ranks were associated with ranges of exposure. No range had a midpoint less than 1 ppm, the limit of detection in the early years. This association was completed first using a highest rank associated with an average exposure of 100 ppm, and then with 50 ppm. The resulting values are shown in Table 2. In example A, five ranks are shown, with endpoints of each range differing by a factor of 3 and average values spanning the limit of detection to about 100 ppm. Also shown are ranks and ranges for 15-minute exposures, collected as "worst case" or short-term excursion exposures. In example B, the range of average exposures is reduced, and it can be noted that rank 1 is associated with an average exposure of about 0.3 ppm, the later limit of detection. A tripling of endpoints for each range is illustrated. The range of values for the highest rank is given as a value greater than the upper bound of the adjacent rank. An average value for the highest rank is estimated, based on the approach used. For example A, the average shown for rank 5 using the TWA metric is 90 which corresponds to three times 30 shown as the average of rank 4; the average shown for the 15-minute exposure is 200 or approximately three times the next lower rank value of 67. A similar relation is shown for the highest rank in example B.

This work was undertaken in order to expand ranks developed for the cohort mortality study. Using published documents and input from long-term workers and managers, 2,151 job titles of subjects were first collapsed to 44 job groups(Hahn 2005;

Moser 2005), and a rank was determined for each. Ranks ranged from 0 (no exposure) to 5 (highest). Long-term workers in both production and management reviewed the relative rankings, and concurred in placement. As a final step in determining ranges for the trichloroethylene (TCE) ranks, measurement data were reviewed; representative results are shown in Table 3. No measurements were identified for any job in rank 3. Only one job, operator, was assigned TCE rank 5. Supporting information for several samples included note that the work organization was highly variable, with use of TCE being sporadic.

The measurements shown in Table 3 are generally consistent with the ranks, although there is overlap in these short-term sampling results. The highest results are for jobs in ranks 4 and 5, and the lower results are shown in ranks 1 and 2. Rank 1 was formed to describe jobs with indirect TCE exposure, detectable by odor; the odor threshold of 28 ppm (Amoore et al. 1983), is consistent with a low rank. Duration of the samples is not shown, but none are full-shift time-weighted averages. For early samples, collected using an evacuated flask, the duration is less than one minute; later samples may be 30 minutes or more when pumps were used. In more recent years some longer-term samples were collected, but duration ranged from two to four hours, during the TCE-related tasks. TCE use at the site was restricted to laboratory work only in 1990 (Moser 2005).

The task-based nature of the work at this plant limits our ability to calculate time-weighted average values from these data. Therefore, cumulative exposure in the usual metric of ppm-years cannot be estimated for the cohort. We propose an alternative metric, score-years, calculated by multiplying duration in a rank by the average exposure associated with the rank. This preserves the rank-order, and provides a metric that is more consistent with the log-normal distribution.

CONCLUSION

This method that incorporates a three- or four-fold difference between endpoints of ranges is limited to work environments where the overall range of exposures is large.

In future projects to construct ranks we recommend obtaining specific information on frequency of tasks that result in exposure. This is especially important when the work organization is task-based, work location is associated with potential exposure and the work location varies during a shift.

The application of the procedure requires a balance between limits of detection, and the range of exposure guidelines, in order to define ranges consistent with the log-normal distribution. For example, had we chosen an upper range centered at 25 ppm (one NIOSH value shown in Table 1) with either limit of detection, it would be possible to construct four intervals only (see Table 2). The approach described may be useful in other occupational epidemiology studies where ordinal ranks of exposure have been determined. Because of the employment dates for this cohort, we did not have the need to apply this approach across time periods with different exposure guidelines set by OSHA for compliance; the approach can be extended to incorporate NIOSH guidelines, by constructing time-specific associations between ranks and exposure ranges.

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Table 1. U.S. published occupational exposure guidelines in parts per million (ppm) for trichloroethylene through 2000.

Duration	Guideline (ppm)	Published by*	Year
8-hour TWA	200	Cook[8]	1945
	100	ANSI[9]	1967
	100	OSHA[10]	1971
	50	NIOSH[11]	1973
	100	ACGIH[12]	1976
	25	NIOSH [13]	1992
Ceiling	200	ANSI[9]	1967
	200	OSHA[10]	1971
5 minute excursion in 2 hours	300	ANSI[9]	1967
Short-term exposure limit (STEL)	150	ACGIH[12]	1976
	200	ACGIH[12]	1984

*ANSI-American National Standards Institute
OSHA-Occupational Safety and Health Administration
NIOSH-National Institute for Occupational Safety and Health
ACGIH-American Conference of Governmental Industrial Hygienists

Table 2. Examples associating exposure ranks with ranges of exposure.

A. Example where highest exposure rank is associated with the published exposure guideline of 100 ppm

Exposure metric	Rank	Range (ppm)	Average (ppm)
TWA	0	0	0
	1	>0-2	1
	2	>2-6	3
	3	>6-18	10
	4	>18-54	30
	5	>54-	90
15-minute exposure*	0	0	0
	1,2	>0-40	13
	3	40-120	67
	4, 5	>120-	200

* would not collect sample unless exposure near published level value expected.

B. Example where highest exposure rank is associated with approximately 50% of published guideline of 100 ppm

Exposure metric	Rank	Range (ppm)	Average (ppm)
TWA	0	0	0
	1	>0-1	0.3
	2	>1-3	1.5
	3	>3-9	5
	4	>9-27	15
	5	>27	45

Table 3. Measured trichloroethylene levels at selected jobs and operations, by rank

Job	Rank	Year:	task or job	result (ppm)
Operator	5	1956:	degreaser platform	350
			General area	40
		1980:	operating tank	40
				100
		1990	operating	1-24
Waste Operations	4	1982	dumping drums	50
		1984:	opening waste drum	200
Laboratory	4	1982:	operator	10
				200
				500
Shipping/Receiving	3	no measurements		
Maintenance				
Welding	2	1983:	tank repair	100
				100
				180
				200
		1989:	getting ready to weld	4
				8
			near crack in tank	100
Inspector	1	1983	tank	2