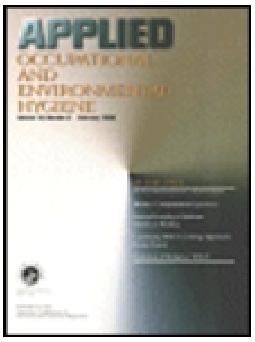

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Applied Occupational and Environmental Hygiene

ISSN: 1047-322X (Print) 1521-0898 (Online) Journal homepage: http://www.tandfonline.com/loi/uaoh20

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To cite this article: Patricia A. Stewart , Helen Triolo , John Zey , Deborah White , Robert F. Herrick , Richard Hornung , Mustafa Dosemeci & Linda M. Pottern (1995) Exposure Assessment for a Study of Workers Exposed to Acrylonitrile. II. A Computerized Exposure Assessment Program, Applied Occupational and Environmental Hygiene, 10:8, 698-705, DOI: 10.1080/1047322X.1995.10387669

To link to this article: https://doi.org/10.1080/1047322X.1995.10387669

Published online: 25 Feb 2011.

Exposure Assessment for a Study of Workers Exposed to Acrylonitrile. II. A Computerized Exposure Assessment Program

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The validity of exposure assessment in retrospective epidemiologic studies has often been questioned, in part because systematic methods have not been developed to estimate historical exposure levels when insufficient monitoring results are available. In addition, documentation as to how the exposure estimates are derived is often lacking. A previously published report described a data management system, called Job Exposure Profiles, that organized and maintained job-related information available on each job in a mortality study of workers exposed to acrylonitrile. This database, and a second one containing almost 19,000 acrylonitrile monitoring results with accompanying documentation (job, department, date, type of sample, etc.), were linked to a computerized, interactive exposure assessment program (EAP) to allow the user to develop historical exposure estimates. The EAP is the subject of this report. In this program, monitoring results were sorted into various subfiles based on their quantity and quality. In cases where monitoring results meeting specified criteria were available, the EAP directly calculated job/department means of the monitoring results for each time period over which there were no significant changes that affected exposure levels in the workplace environment. Where monitoring results were available but did not meet the criteria, the EAP allowed the user to select from various estimation methods. Some of these methods used the remaining monitoring results, while others modified estimates previously developed for other jobs or time periods. From these data and other information provided by the user, the computer program calculated the estimates for the job of interest. This software program is unique in that it provided a structured mechanism for the development of historical exposure estimates and simultaneously allowed the user access to a variety of estimation methods based on the available data. It allowed easy access to, and use of, thousands of monitoring results. Finally, it documented all decisions made by the user. This type of program can be used in other retrospective epidemiologic studies where limited monitoring data are available. STEWART, P.A.; TRIOLO, H.; ZEY, J.; WHITE, D.; HERRICK, R.F.; HORNUNG, R.; DOSEMECI, M.; POTTERN, L.M.: EXPOSURE ASSESSMENT FOR A STUDY OF WORKERS EXPOSED TO ACRYLONITRILE. II. A COMPUTERIZED EXPOSURE ASSESSMENT PROGRAM. APPL. OCCUP. ENVIRON. HYG. 10(8):698–706; 1995.

Accurate exposure assessments for occupational epidemiologic studies are heavily dependent on the availability of industrial hygiene measurements. When measurements are sufficient, statistical models may be used to predict exposure levels for jobs or years for which measurements are nonexistent.[1,2] In most studies, however, monitoring results are not sufficient for such approaches because measurements are not available for all environmental conditions that occurred in the plant. In these cases, investigators may choose to develop exposure estimates using less rigorous estimation procedures. These procedures often include a number of decisions and assumptions that are collectively described as "professional judgment."

When using professional judgment, investigators usually have indicated that monitoring results and information collected on site visits and interviews with long-term workers were used as the basis of the estimates. This approach, however, has suffered from several limitations. It is not usually clear if the same criteria were used to evaluate all jobs. Moreover, detailed quantitative descriptions of how the exposure estimates were derived, which would allow others to duplicate the process, have not generally been provided.

In a study investigating the mortality of workers exposed to acrylonitrile (AN), procedures were developed to overcome these limitations. A previous report described the computerized program, the Job Exposure Profiles (JEPs), developed to organize information known about the jobs in the study into a system of easy retrieval.[3] The present report describes the second computer program developed for this study, the Exposure Assessment Program (EAP), used to derive historical exposure estimates. It is presented as an example of how other investigators can develop a system for deriving accurate estimates and for documenting their exposure decisions. A detailed evaluation of the assessment methods and their bias is presented elsewhere.[4]

Background

A cohort of approximately 26,000 workers in eight AN-producing and -using facilities, where operations started between 1952 and 1965, has been assembled to evaluate mortality risks of exposure to AN. Estimates of exposure to AN were needed for all jobs between 1952 and 1983, the close of the study. Employer personnel records were abstracted for work histories, and from these work histories job titles and departments were standardized into approximately 3500 plant/department/job combinations. Site visits were made to each workplace to conduct interviews with long-term workers and to collect historical records on operations and on industrial hygiene monitoring data.

One of the features of the EAP was that it allowed the user to select from a variety of estimation methods, based on the availability of the air monitoring data. Because the EAP was the framework for using these methods, a brief description of the available monitoring data and of the estimation methods is provided to facilitate understanding of how the program worked.

Air Monitoring Data

Almost 19,000 air monitoring results had been collected by the companies over the years of the study. The documentation of these data varied in format. Some of the data were computerized, while others were in hard copy. The type of information available on the measurements also varied; for example, some identified the sampling conditions and use of personal protective equipment, while others did not. To allow easy and accurate calculation of means and easy review of the data, the monitoring results and all accompanying documentation on hard copy were computerized. Data from all eight plants were then put into a single format. Job and department titles recorded in the air monitoring records were standardized within a plant; however, these titles did not necessarily correspond to the job titles in the JEPs, even though the latter came from the employers' personnel records. To allow easy retrieval of the monitoring data in the assessment program, the study investigators reviewed the lists of jobs and department titles in the monitoring records and in the personnel records and linked the corresponding titles. For other variables (the sampling conditions, personal protective equipment, etc.) standard codes were developed across the plant data.

The availability of monitoring data determined how the exposure estimates were developed.[4] Full-shift personal air sample results were available after 1977 on many of what would typically be considered exposed jobs (e.g., AN use or production, maintenance, shipping and receiving) in all of the eight plants. For many other jobs, however, no monitoring had been performed. In addition, no full-shift personal monitoring data were available for any job before 1977. In one plant, however, short-term area or personal monitoring had been conducted back to 1963. Finally, approximately 400 air monitoring samples were collected by the study investigators in 1986 after the close of the study for comparing the monitoring results across plants.

Estimation Methods

Development of Baseline Estimates

The first component of the assessment process was the development of at least one baseline value for each job in the study. Baseline estimates could be derived from several estimation methods based on the availability of the data. Where possible, unique job/department/plant/time period combinations, hereafter called "cells," were completed using the methods that required at least six monitoring results to consider the estimates as having reasonable confidence.[4] These methods [calculating means of the measurements, using a ratio of exposures of comparable jobs, using the concept of homogeneous exposure groups (HEGs), and using exposures from multiple areas using a time-weighted average (TWA) equation] are described below. More details on these methods can be found elsewhere.[4] For many jobs, however, no baseline estimate could be derived using these methods. Baseline estimates were therefore developed from other methods (assigning a department-wide estimate, using an air dispersion equation, or using professional judgment) considered to be less accurate because they were generally not based on the more rigorous criteria. Because there was lower confidence in the estimates derived from these methods, only one cell (generally the most recent) was developed per job using these methods. After all of the cells for a job were completed using the methods of greater confidence, or one cell was completed using one of the methods of less confidence, these baseline cells were modified to derive historical exposures by applying what was called the deterministic method.

THE MEAN OF THE MEASUREMENTS. In this method, arithmetic means were calculated from monitoring results. A single criterion was used to determine when this method could be used: there had to be at least six measurements with sampling duration of at least 6 hours for the given cell. Reasoning for this criterion is given elsewhere.[4]

RATIO METHOD. This method is a ratio method where exposure means of measurements from three jobs were used to estimate the exposure level of a fourth job (i.e.; $A_1 = A_2B_1/B_2$). All four jobs had to be affected by the same sources of exposure and the same controls, and must have spent similar amounts of time being exposed to those sources. Jobs A_1 and B_1 had to have similar tasks and A_2 and B_2 had to have similar tasks. The B jobs were, however, located in a different plant or production unit from the A plant or unit. Jobs A_1, B_1, and B_2 had to have had an estimate previously calculated from the mean of the measurements method described above.

HOMOGENEOUS EXPOSURE GROUP METHOD. An HEG was defined as a group of homogeneously exposed jobs within a plant based on similar sources of exposure, controls, duration of exposure to those sources, and location within the plant. The measurements of all the jobs within the HEG were used to calculate a mean value, which was the estimate for that HEG and for any job in that HEG for which this method was used.

TWA METHOD. In this method a TWA was calculated from several estimates, each representing a different task or location in the plant. Exposure concentrations at locations or for tasks were derived from three different sources:

1. A previously developed estimate for another job or jobs. This job was representative of the exposure level experienced by the job being estimated for a location in the plant. For example, an engineer who spent 1 hour a day in an area may have a similar exposure level when in the area as an engineer who spent 8 hours in the area. The second engineer's exposure estimate could be used as the exposure estimate of the former engineer's when in the area.
2. A mean of area samples or a mean of personal samples not

meeting the requirements of a mean of the measurements estimate (i.e., less than six measurements or less than 6 hours in duration).

3. Professional judgment of the industrial hygienist, which was generally used when assigning a zero value to office environments.

Estimates derived from the preceding four methods were considered to be of high confidence because they relied upon measured exposure data to the extent possible. These methods were applied to all cells wherever possible, and therefore several possible baseline estimates may have been derived for a single job for different time periods. For the jobs for which none of these methods was used because there were insufficient monitoring data available, a baseline estimate was developed for a single time period (usually the most recent) for each job using one of the following methods.

DEPARTMENT-WIDE. This method allowed the industrial hygienist to enter one exposure estimate for all jobs in a department. It was generally used for nonexposed departments, such as administration, where 0.00 parts per million, for example, was entered.

AIR DISPERSION. This method was used to calculate the exposures of outdoor jobs where exposure resulted from being downwind of the AN production units. It was based on an air dispersion model.[5]

PROFESSIONAL JUDGMENT. This method provided the industrial hygienist access to: (1) the means of personal measurements where fewer than six existed, or where the duration was less than 6 hours; (2) the means of area measurements; and (3) the means of measurements after 1983. The industrial hygienist used these data, data from other plants, or anecdotal information to develop an estimate. The confidence in the estimates was lower than those of the preceding methods due to the subjectivity of the method.

Development of Estimates Over Time

After all jobs had at least one baseline estimate, remaining cells were estimated by the deterministic method (see Reference 4 for more details). This method used a deterministic approach that modified the baseline estimates using estimates of the effect that major changes in the workplace (including changes in the process or in engineering controls, changes in production rates,[6] and changes in the frequency of exposure) had on exposure levels.

Other Estimates

The estimates described thus far were estimates of 8-hour TWA air concentrations. These are typically the principal estimates used in epidemiologic analyses. In some instances, however, they may not be the best estimates to evaluate disease risks. For example, in some jobs where respirator use was mandatory an air concentration may not be the best exposure estimate. Exposure estimates were therefore derived that accounted for respiratory protection when respirator use was mandatory for 8 hours a day. For these jobs, a protection factor (PF) was applied to the air concentration previously developed based on the type of respirator: half mask, PF = 10; full facepiece, PF = 50; supplied air, PF = 2000 after being multiplied by 0.65[7] to allow for imperfect protection.

Because the amount of an airborne vapor received by the body depends on the amount inhaled, a third estimate was derived that took into account respiratory rates based on the levels of physical activity. These levels were defined to correspond to ventilation volumes of 0.68, 1.31, and 1.94 m^3/h, respectively.[8] An adjusted exposure estimate was calculated by multiplying the air concentration by the respiratory rate and by 8 hours.

Finally, AN can be absorbed dermally.[9] Because the absorption rate in humans was not found in the literature, a dermal exposure score was calculated by multiplying the frequency of dermal exposure, arbitrarily selected as 5 for frequent (i.e., more than once a day) and 1 for infrequent (i.e., less than once per day) by the concentration of AN in the liquid.

EAP

To develop the exposure estimates, an interactive, computerized, menu-driven, user-friendly program was developed that used JEP information, the monitoring data, and additional information entered by the industrial hygienist.

Of the 3500 jobs, 2000 were considered to have had exposure to AN. For each of these, a JEP had been completed, identifying a description of the process, the job location, job tasks and duties, changes that occurred in the workplace that may have affected exposure levels, any unusual occurrences, such as spills, and the production rates of the AN operations.[3] Also noted were the frequency of AN exposure; the frequency of peak exposures and of dermal exposure to AN; use of personal protective equipment; reported health effects; the level of physical activity associated with the job; and the presence of other exposures. This information was reviewed by the industrial hygienist prior to developing an estimate for a job. It was also used directly by the EAP as described below.

In the EAP, exposure estimates were developed for each job/department/plant/time period. Time periods, rather than years, were used as the unit of time to minimize the number of estimates needing development. These time periods were defined by the start and stop dates of all the significant changes identified in the JEPs.

Prior to calculating an estimate, the user selected the appropriate time period for which an estimate was to be made, selected the estimation method to be used, and entered the appropriate information as requested by the program. The EAP then calculated the exposure estimate, retained the information entered by the industrial hygienist, and documented the method used to calculate the estimate.

The estimation methods depended heavily on the air measurements and on the estimates previously developed for other jobs or for other time periods on the job of interest. Each particular method, however, used different types of data. For example, using the mean of the measurements as the estimation method required at least six measurements of at least 6 hours in duration. To ensure appropriate use of the data and comprehensive and accurate documentation of the method used, the data required by the different methods were arranged into subfiles. Only the appropriate subfile was accessible to the user when using a method.

```
EXPOSURE ASSESSMENT - Air Monitoring Record Selection

            4840468: B PLANT | TECHNICIAN   (1970-1983)
                   Current period (1): 1981-1983

N= 8   | Mean= 0.24   | S.D.= 0.13   | S.E.= 0.05   | C.V.= 58.84

Del   AN value   N   Gt_lt   Year   Repres   Shortened plant comments
      0.10       1           81
      0.10       1           81
      0.50       1           81
      0.30       1           82
      0.20       1           83
      0.20       1           83
      0.30       1           83
      0.20       1           83

<F1> Calculate Statistics   <F2> View comments   <F5> Delete/Undelete
<F10> Save estimate         <Esc> Quit
```

FIGURE 1. The screen indicating information available for viewing in the mean of the measurements method. "Gt__lt" indicates that the measurement was greater than or less than the AN value. "Repres" (representativeness) indicates the conditions under which the measurements were taken. Other documentation (comments, sample duration, etc.) could be viewed by pressing the right arrow.

The Mean of the Monitoring Results

If the user selected this method, the program presented the individual monitoring results and accompanying documentation (duration, comments, etc.; Figure 1). The number of samples, the mean, the standard deviation, the standard error, and the coefficient of variation were calculated by the program automatically. Although not used in this AN study, if the user had wished to remove particular results from the calculation of the means because they were outliers, the user simply would have highlighted the result from the "Del" (for delete) column and pressed a function key to recalculate the statistics. Either mean could have been saved as the final estimate. After the estimate was developed it was multiplied by the frequency of exposure identified in the JEP. If the frequency was daily (i.e., 5 days a week), a weight of 1.0 (a full week) was used; if the frequency was 2 to 3 days a week, the weight was 0.4; and if the frequency was 1 day a week or less, the weight was 0.1.

Ratio Method

To use this method, the industrial hygienist identified the study codes of the three jobs to be used to estimate that of the fourth (the polymer operator in Figure 2). (Study codes were easily identified for jobs of interest by requesting the program to list all jobs in the plant or in the department with their codes. This was done by pressing a function key.) After the user identified the time periods of interest, the program retrieved the estimates of the three identified jobs and automatically calculated the estimate of the fourth job.

HEG

For this method the user identified the study codes of all the appropriate jobs in the HEG, as in the ratio method. The program retrieved all personal measurements of 6 hours or more in duration on those jobs for that time period (Figure 3). If there were at least six measurements available, the program calculated a mean of the measurements as the estimate. Once an estimate was developed using this method, the jobs defined the HEG and were saved in a subfile. Other methods could be used to calculate estimates for jobs within an HEG, but whenever the HEG method was selected as the method for a job previously defined as being within an HEG, no changes in the jobs of that HEG (and thus the mean) were possible. When the HEG method was selected for one of those jobs, the program automatically retrieved the HEG mean.

TWA

Any combination of three different types of exposure concentrations were used in the TWA method: (1) a previously developed estimate for another job; (2) a mean of area samples or a mean of personal samples not meeting the requirements of a mean of the measurements estimate (i.e., less than six measurements or less than 6 hours in duration); or (3) a concentration entered by the industrial hygienist. When using this method, the industrial hygienist selected the concentrations from the sources shown above. If a job estimate was indicated, the user identified the study code of the job and the time period desired. The program then retrieved the job and displayed the estimate (the assistant head operator in Figure 4a). Selecting the second option allowed the industrial hygienist to

```
EXPOSURE ASSESSMENT - Ratio Method Calculation

4840716: B PLANT | POLYMER OPERATOR (1967-1983)
Current period (2): 1978-1980

A1:  1.41       B1:  0.60
----------  =  ----------
A2:  1.97       B2:  0.84

A2:  (78-80) 4840756 B PLANT | SALT HANDLER
B1:  (78-81) 4841716 Z PLANT | POLYMER OPERATOR
B2:  (78-81) 4841756 Z PLANT | SALT HANDLER

    Average daily exposure:  1.41
    Weekly frequency of exposure: 1.0
    JEP-recorded frequency of exposure: 1.0 (continuous)

    Save this information? Y

<Y> Save estimate   <N> Redo estimate or freq   <Esc> Quit
```

FIGURE 2. The screen indicating the ratio method after the estimates for jobs A2, B1, and B2 have been retrieved and the estimate for job A1 has been derived.

```
EXPOSURE ASSESSMENT - Homogeneous Exposure Group Method

4840468: B PLANT | TECHNICIAN (1970-1983)
Current period (1): 1981-1983

Current HEG Definition
```

Jobcode	Department	Job Title	Record Count
4840164	B PLANT	FOREMAN	0
4840401	B PLANT	SUPERVISOR	5
4840468	B PLANT	TECHNICIAN	0
4840669	B PLANT	MAINTENANCE COORDINATOR	0
4840736	B PLANT	PRODUCTION TECHNICIAN	3

```
Keep this HEG? Y

<Y> Continue w/Record Selection   <N> View Dependencies, Redefine HEG
```

FIGURE 3. The screen indicating the HEG method, showing the five jobs identified by the user as being in a HEG. The "Record Count" indicates the number of measurements available by job for this time period. The screen seen after this is shown in Figure 1.

a

```
EXPOSURE ASSESSMENT - Time-Weighted Average Calculation

4840637: B PLANT | HEAD OPERATOR (1967-1983)
Current period (3): 1978-1978

Areas   Estimate   % Time   Comments

   1      3.38       5      CONTROL ROOM/229
                            B-PLANT                      , n=  4

   2      1.56      95      4840548 B PLANT | ASST HEAD OPERA
                            Period  3: 78-78

-> 3

   4

   5

Press one of the following function keys:
<F1> Enter Jobcode  <F2> Enter Conc  <F3> Enter Area   <F5> Redo an Area
<F7> Derive Conc    <F10> Calculate Estimate           <Esc> Quit
```

b

EXPOSURE ASSESSMENT - Time-Weighted Average Calculation

4840637: B PLANT | HEAD OPERATOR (1967-1983)
Current period (3): 1978-1978

Department	Area		Yr	n	Mean
ADMINISTRATION	CLERK		78	4	0.03
B PLANT	AS:WET AREA (78) N=126	(usr)	78	1	2.19
B PLANT	KNIFE SHARPENING AREA	(der)	78	1	0.99
B PLANT	PS: DRY AREA 78 N=17	(usr)	78	1	0.18
B PLANT	PS: N=51 AVG OF WET OPS	(usr)	78	1	1.64
B PLANT	PS: WET AREA OPS	(usr)	78	1	1.64
B PLANT	PS:N=145 ALL AREAS 78-78	(usr)	78	1	1.31
B PLANT	PS:POLY AREA 78-80 N=404	(usr)	78	1	1.81
B-PLANT	B1/B2		78	26	2.19
B-PLANT	BALER		78	4	0.16
B-PLANT	CHEMICAL ENGINEER		78	4	0.16
B-PLANT	CLERK		78	4	0.16
B-PLANT	CONTROL ROOM - UNKNOWN		78	1	1.90
B-PLANT	CONTROL ROOM/229		78	4	3.38

Use the arrow keys and <Enter> to select an area

FIGURE 4. The screen indicating the TWA method. (a) Shows how the concentrations of two areas (the control room/229 and the assistant head operator's area) were documented. (b) Shows how the estimate of 3.38 was derived from four area measurements (n = 4) taken in the 229 control room.

select from a subfile of means of personal measurements on jobs for which there were fewer than six measurements and/or which were of less than 6 hours duration for the time period of interest, means of area measurements for the time period of interest, or means of area or personal samples taken after the close of the study (1983). These means were displayed [in Figure 4b, control room/229 (n = 4)] and the user highlighted the appropriate mean to include it in the TWA estimate. If a concentration was entered by the industrial hygienist, the program prompted for the basis of the estimate for documentation as to how the estimate was derived. After entering the appropriate concentrations, the user entered the percent of

EXPOSURE ASSESSMENT - Assign Exposure

4840716: B PLANT | POLYMER OPERATOR (1967-1983)

Period	Method	Exposure (ppm)	Exp Freq	Exp w/PPE	Inhal Exp (mg/day)
81-83	MON	0.89	1.0	0.14	20.07
78-80	RTO	1.41	1.0	0.22	31.88
77-77	MON	3.19	1.0	3.19	72.27
74-76	DET	2.94	1.0	2.94	66.61
67-73		0.00	1.0	0.00	0.00

Dermal Exp Level: 10

<Enter> Calculate Exposure <F2> View Sig Chgs

FIGURE 5. The screen identifies the methods and the estimates ("Exposure") for four time periods, along with the estimates accounting for respiratory use ("Exp w/PPE"), the level of physical activity ("Inhal Exp"), and dermal exposure ("Dermal Exp Level"). The frequency of exposure ("Exp Freq") was also identified (1 = 4 to 5 days/week).

time spent at each of the concentrations (Figure 4a) and the program calculated the estimate.

Department-Wide

In this method the user identified the concentration assigned to this job and the basis for that assignment. All jobs within this department were then assigned the same concentration by the program automatically.

Air Dispersion

To develop estimates using the air dispersion method, the user entered the amount of emissions being released by the AN unit into the atmosphere and the approximate distance of the job (in feet) and the direction of the job's production unit from the AN production unit. The computer automatically calculated an exposure estimate based on an air dispersion model.[3,5] This value was assigned to all jobs in the department.

Professional Judgment

In this method, the user assigned a concentration for the job and documented how that estimate was derived.

Deterministic

After selecting this method, the user could view a brief description of the changes that were responsible for changes in exposure levels as they had been entered in the JEPs. For each change, the size of the source affected and the amount of reduction or increase that the change had on exposure levels, or the "effect," were entered by the user. These values were based on information available on the plant, on other plants in the study, and from the published literature. The program then calculated the value of the estimate by adjusting the baseline estimate of an adjacent cell in time, using the size and effect of the change, a ratio, where appropriate, of the production rates over the two time periods of interest as identified in the JEPs, and any change in the frequency of exposure that occurred (also from the JEPs). This estimate was the baseline estimate for the next adjacent period.

Other Estimates

The information needed for the supplemental estimates (Figure 5), that is, accounting for respiratory protection ["Exp w/PPE" (exposure with personal protective equipment)], level of physical activity ["Inhal Exp" (inhalation exposure)], and dermal exposure ["Dermal Exp Level"], was retrieved by the program from the JEPs. The estimates were calculated automatically by the program at the same time that the air concentration estimates were calculated.

Quality Control

Three reports were generated from the EAP that were used to increase the quality of data. One listed the sizes and effects assigned to all jobs for each significant change. A review of this report made it easy to spot keying errors or inconsistencies across jobs for the same change. A second printout of all the estimates by job and year allowed a reviewer to evaluate trends in exposure levels over time and to spot any unusual deviances among jobs within a department or among years within a job. Finally, a report was generated that described all the decisions made by the industrial hygienist to allow a detailed review of these decisions.

Discussion

This article describes an interactive computerized program developed to directly calculate job/department/plant/time period-specific mean exposures when sufficient monitoring data existed, and to develop estimates of exposures when monitoring results were insufficient to calculate means. Several estimation methods were developed to take full advantage of the large number of monitoring results of varying quality. Having a variety of estimation methods to choose from was useful because very often the monitoring data available to the industrial hygienist varied in quality or quantity. Full advantage was taken of the monitoring data because the industrial hygienist was able to select the best estimation method for the data available, rather than being locked into a single method that could be used when data were rare or nonexistent as well as when data were plentiful.

The program provided a structured framework for developing the exposure estimates using these various methods. For example, within each method only the data appropriate to that method were accessible by the user through the use of subfiles. Estimating exposures indirectly from monitoring data of other jobs or years could result in the industrial hygienist being inconsistent and therefore would be more likely to develop inaccurate estimates. Having the structured framework minimized the inconsistences, which should help to increase reproducibility of the estimates.

The program also documented all decisions made by the industrial hygienist. These included the specific monitoring results used in calculating means; the jobs used in the HEG and in the ratio methods; and the concentrations and time estimates used in the TWA method. The program also documented the sizes and effects, the production rates, and the frequencies assigned in the deterministic method; the level of emissions and the distance in the air dispersion method; and the basis of the estimates if the department-wide or professional judgment method was used. A reviewer can easily follow the map of how all estimates were developed. In addition, the method used for the development of each method was retained, so that the certainty around the estimate[4] could be used by the epidemiologist when estimating the relative risk of disease.

Even when there were insufficient monitoring results to rely exclusively on means, measurements nonetheless were extensively relied upon in the program. How they were used, however, depended on their quantity and quality. Where measurements were sufficient, means were derived as the value of the estimate. Some of the estimation methods used in this study relied upon other previously developed estimates derived from monitoring results (ratio, HEG, deterministic) or from area measurements (TWA). These estimates were considered to be of higher confidence because they were based on monitoring data. To use these estimates when developing another estimate, the user simply identified the job and time period of interest, and the program retrieved the estimates and calculated the new estimate. Where measurements were not sufficient, other estimation methods (department-wide, air dispersion, professional judgment) were used, but such estimates were identified as being of lower confidence. The program also allowed the calculation of several supplemental estimates adjusted for respirator use, respiratory rate, and dermal exposure. These features of the program (access to measurement means, access to already developed estimates, and automatic calculation of supplemental estimates) were almost instantaneous in the program. The ease and speed with which these data and the estimates were obtained eliminated transcription errors, ensured accurate calculations, and reduced fatigue of the user.

Conclusions

A computerized program has been described that was used to estimate historical occupational exposures for an epidemiologic study in which monitoring data were insufficient to rely solely upon the calculation of means or upon the use of a statistical model. It allowed the use of several estimation methods, depending on the availability of appropriate information, and relied heavily on monitoring results. It also followed structured procedures and extensively documented all decisions. The program is being modified to allow use by others. Contact the first author for more information.

Acknowledgments

The authors gratefully acknowledge the valuable guidance of Dr. Roy Shore, Dr. Robert Harris, Dr. Richard Monson, and Dr. Carol Rice in this project. They thank Mary Masters, Judy Rayner, and Melody Chen at Westat, Inc. for assistance in the development of this program, and David Chesnut at IMS for assistance in assembling the monitoring data. Finally, they thank Yolanda Ballou and Alexander Passee for typing assistance.

Disclaimer

Mention of any product or manufacturer does not constitute endorsement by either the National Cancer Institute or the National Institute for Occupational Safety and Health.

References

1. Dement, J.M.; Harris, R.L.; Symons, M.J.; Shy, C.M.: Exposures and Mortality Among Chrysotile Asbestos Workers. Part I. Exposures Estimates. Am. J. Ind. Med. 4:399–419 (1983).
2. Greife, A.L.; Hornung, R.W.; Stayner, L.G.; Steenland, K.N.: Development of a Model for Use in Estimating Exposure to Ethylene Oxide in a Retrospective Cohort Mortality Study. Scand. J. Work Environ. Health 14(suppl):29–30 (1988).
3. Stewart, P.A.; Lemanski, D.; White, D.; et al.: Exposure Assessment for a Study of Workers Exposed to Acrylonitrile. I. Job Exposure Profiles: A Computerized Data Management System. Appl. Occup. Environ. Hyg. 7:820–825 (1992).
4. Stewart, P.A.; Hornung, R.; Zey, J.; et al.: Exposure Assessment for a Study of Workers Exposed to Acrylonitrile. III. An Evaluation of Exposure Assessment Methods. (in preparation).
5. Schroy, J.M.: Prediction of Workplace Contaminant Levels. In: Proceedings from the NIOSH—Sponsored Symposium on Control Technology in the Plastic and Resins Industry, pp. 190–206. Environmental Control, Rockville, MD (1979).
6. Esmen, N.: Personal communication (1989).
7. Toney, C.R.; Barnhart, W.L.: Performance Evaluation of Respiratory Protective Equipment Used in Paint Spraying Operations. U.S. Department of Health, Education, and Welfare, Cincinnati, OH (1976).
8. Task Group on Lung Dynamics: Deposition and Retention Models for Internal Dosimetry of the Human Respiratory Tract. Health Physics 12:173–201 (1966).
9. U.S. Environmental Protection Agency: Health Assessment Document for Acrylonitrile. EPA 600/8-82-007. U.S. EPA, Washington, DC (1983).

Appendix

The EAP was written in a Clipper (Nantucket Corporation, now Computer Associates) program that ran on an IBM-compatible PC under DOS (version 3.1 or higher). It was fully compiled and linked so that Clipper was not required to run the program. The program required a hard disk (the system before estimate databases had been added required 2 to 3 Mbytes), a floppy disk drive for performing system backups, and at least 1 Mbyte of memory. It is recommended that the program not be operated with other programs resident in memory, since it used a large amount of memory. A color monitor was desirable but not required. The current version of the system was easy to install and maintain, and only minimal support from a midlevel programmer was required.