Applied Occupational and Environmental Hygiene

Quantitative Exposure Assessment Strategies and Data in the Aluminum Company of America

Joseph Damiano

Aluminum Company of America, 425 6th Avenue, Pittsburgh, Pennsylvania, 15219-9989, USA


To cite this article: Joseph Damiano (1995): Quantitative Exposure Assessment Strategies and Data in the Aluminum Company of America, Applied Occupational and Environmental Hygiene, 10:4, 289-298

To link to this article: http://dx.doi.org/10.1080/1047322X.1995.10389038

Full terms and conditions of use: http://oeh.tandfonline.com/page/terms-and-conditions

This article may be used for research, teaching, and private study purposes. Any substantial or systematic reproduction, redistribution, reselling, loan, sub-licensing, systematic supply, or distribution in any form to anyone is expressly forbidden.

The publisher does not give any warranty express or implied or make any representation that the contents will be complete or accurate or up to date. The accuracy of any instructions, formulae, and drug doses should be independently verified with primary sources. The publisher shall not be liable for any loss, actions, claims, proceedings, demand, or costs or damages whatsoever or howsoever caused arising directly or indirectly in connection with or arising out of the use of this material.
Quantitative Exposure Assessment Strategies and Data in the Aluminum Company of America

Joseph Damiano

Aluminum Company of America,
425 6th Avenue, Pittsburgh, Pennsylvania 15219-9989

The occupational exposure assessment is a critical element in the industrial hygiene process directed at worker health protection. In the Aluminum Company of America (Alcoa), exposure assessments are directed at fulfilling several health protection needs through two objectives: (1) the identification of health hazards through the differentiation of acceptable and unacceptable exposures; and (2) the development and maintenance of a database, thereby providing the basis for the education and training of workers on health risks and control of health hazards, the demonstration of compliance with occupational exposure limits, and the resolution of future questions arising from various concerned parties, including workers, labor unions, medical staff, legal staff, and governmental authorities. The Alcoa exposure assessment strategy emphasizes the quantitative assessment of significant exposures to air contaminants and noise. The Alcoa strategy specifies minimum sample sizes for baseline and periodic assessments, as well as criteria for data interpretation. All exposure data elements have been standardized; they include reference to the homogeneous exposure group (HEG), sampling strategy, and circumstances of exposure (e.g., date, shift length, use of personal protective equipment, etc.). The HEG provides an informational link between the exposure values and individual workers. The HEGs are described by the process, job, task, and environmental agent. Furthermore, for each HEG, information is maintained describing the calendar time period of the assessment, as well as the frequency of the exposure during the time interval. These data, once captured and archived, become the basis for worker exposure histories. Damiano, J.: Quantitative Exposure Assessment Strategies and Data in the Aluminum Company of America. Appl. Occup. Environ. Hyg. 10(4):289-298; 1995.

Activity in the Aluminum Company of America

In the Aluminum Company of America (Alcoa), exposure assessment strategies and data support the process for worker health protection illustrated in Figure 1. The central elements of this process are consistent with the traditional definition of industrial hygiene; the process embraces the concepts of anticipation, identification, evaluation, and control. The end product is enhanced health protection.

The health protection process is driven by management support through the allocation of resources. Management is accountable for the prevention of occupational illnesses and disease. The other necessary driving force is the industrial hygiene professional who provides the technical supervision and expertise.

Functionally, the first element of the process is risk identification. This includes the procedures and practices directed at anticipating and identifying potential health hazards. Risk identification involves the early review of new processes, operations, and products.

The exposure assessment element of the process is directed
at identifying workplace health hazards and providing necessary exposure data for other elements of the process.

Health hazard control includes the hierarchical strategies and programs directed at assuring worker health protection. Health hazard control is achieved through engineering measures, work practice controls, personal protective equipment, and training. These efforts are deployed through various administrative programs including hazardous materials control, hearing conservation, radiation safety, respiratory protection, and worker/community education, training, and communications.

Although not a part of industrial hygiene practice, medical surveillance and epidemiologic evaluations are elements of Alcoa’s health protection process. Exposure assessments are used to identify employees whose exposures warrant medical surveillance. For example, workers who are exposed to noise above 82 decibels as an 8-hour average qualify for audiometric testing. Medical surveillance findings may in turn be used to direct and focus health hazard control efforts. For example, hearing changes revealed through audiometry are used to modify and strengthen hearing protection usage.

Epidemiologic studies are directed at identifying new health risks or measuring the impact of known health risks that are not readily assessed through medical surveillance of individual workers. Such studies focus on the incidence of health changes or mortality in a work group. Although epidemiology is not yet a regular part of the health protection process in Alcoa, exposure assessment practices and data are designed to support, if needed, epidemiologic studies. The results of morbidity or mortality studies are also used to focus health hazard controls. For example, a health risk revealed through epidemiology may provide the impetus for reducing an occupational exposure limit.

Workplace health protection is a process and, like the links in a chain, the process is no stronger than its weakest element. In the early 1980s, internal audits in Alcoa revealed that exposure assessment was a weak link. In response to this finding, Alcoa developed an internal standard for occupational exposure assessments. Alcoa’s exposure assessment standard was established in 1985; it has been updated on several occasions. The standard initially emphasized quantitative exposure assessments, and at present qualitative exposure assessment practices are being introduced.

Objectives and Scope
In Alcoa, occupational exposure assessments are directed at achieving the following objectives:

- The identification of health hazards, through the differentiation of acceptable and unacceptable exposures and the communication of exposure assessment findings to all affected workers, contractors, management, and staff.
- The development and maintenance of a database, thereby providing the basis for the demonstration of compliance with occupational exposure limits (OELs); education and training of workers on health risks and control of health hazards; medical surveillance of workers; prioritization and evaluation of health hazard controls; and resolution of future questions arising from various concerned parties including management and technical staff (e.g., medical, legal), workers, labor unions, researchers (e.g., epidemiologic studies), and regulatory authorities.

The scope is all chemical, physical, and biological agents. Physical agents include noise, radiation, heat, and ergonomic factors.

There are three major steps to a workplace exposure assessment; they are: (1) information gathering, (2) a qualitative exposure assessment, and (3) if necessary, a quantitative exposure assessment. Figure 2 illustrates the Alcoa exposure assessment process.

Information Gathering
Information is gathered to characterize the workplace, workforce, and environmental agents. The qualitative assessment utilizes:

- The location’s materials inventory and material safety data sheets, providing information on the quantities of materials in use, and their chemical and physical properties.
- A review of the health effects associated with chemical, physical, and biological agents, including the routes of ex-
exposure, the adequacy of the toxicological data, and the reported rationale for OELs.
- Observation of the workplace, providing information on the industrial processes, jobs, tasks, and the frequency/duration of the associated exposures.
- A review of the engineering controls in place (e.g., noise abatement features, exhaust ventilation, etc.) and their reliability in maintaining adequate control of worker exposures.
- A review of prescribed work practice controls, worker training, and their reliability in maintaining adequate control of exposures (e.g., enforcement of required work practices).
- Observations, comments, and data from workers, safety staff, medical staff, and others regarding the conditions of exposure and health effects.
- Available exposure data, including positional measurements of exposure and exposure assessment data from other workplaces with similar operations.

In practice, this information is the raw material for performing qualitative exposure assessments.

**Exposure Groups**

Unfortunately, there are resource and technological constraints that prevent the assessment of each and every worker’s daily exposure to all environmental agents. Although daily measurement of each worker’s exposure to ionizing radiation may be possible, this is certainly not the case for most hazardous materials and harmful physical agents. In most organizations adequate resources are not available to measure the exposure of each worker and, if such resources were available, it is probably not feasible to monitor exposures every day. Given the day-to-day variability in exposure levels present in most industrial operations, there is often as much need to monitor every day as there is to monitor every worker.\(^{(18)}\)

To address the exposure of all workers every day, it is necessary to group employees with similar exposures.\(^{(20)}\) These exposure groups have been termed homogeneous exposure groups (HEGs).\(^{(3)}\) In the Alcoa exposure assessment standard, an HEG is a group of workers who have similar job functions and who are expected to have similar exposure profiles.

In Alcoa, HEGs are established by observation and are described by the process, job, task, and environmental agent. Individual employees in an HEG are linked to the HEG through the job classification (Figure 3). This linkage to a demographics database provides the ability to construct exposure histories. The classification of employees into HEGs would be more accurate if demographic data were linked to the task element of the HEG; however, that would greatly increase the magnitude of the record keeping effort.

The determination of exposure groups is the most delicate element of the exposure assessment process. Training has been

---

**FIGURE 2.** Exposure assessment process.
job classifications are largely established for payroll purposes by job classification assignments in an effort to group workers who labor and exposures in the workplace. Accordingly, the industrial hygiene professional may need to modify a plant’s personnel-based job classification assignments in an effort to group workers who are expected to have similar exposure profiles. This is difficult in workplaces involving flexible work teams, batch operations, and research. Nevertheless, the establishment of HEGs is a necessary element of the exposure assessment strategy.

The homogeneous exposure group is a tool that supports both qualitative and quantitative exposure assessments. In practice, the designation of the task element of the HEG is generally unnecessary for qualitative exposure assessments, while the task element of the HEG is generally necessary for quantitative exposure assessments.

Qualitative Exposure Assessment

The qualitative assessment is an estimate of exposure relative to an occupational exposure limit. This process is illustrated in Figure 4. The qualitative exposure assessment assumes the absence of personal protective equipment (e.g., respirators, ear plugs, etc.). The qualitative assessment will classify exposures into one of the following categories:

- Unacceptable – Controls must be immediately implemented and a quantitative exposure assessment is required. In the context of the qualitative assessment, an exposure is deemed unacceptable if (1) the exposure level is expected to give rise to adverse health effects, (2) the exposure is expected to exceed the OEL, or (3) a health hazard is expected to present. The identification of exposures maintained at low levels by existing engineering and work practice controls is critical information for managing exposure control programs.

Among the insignificant exposures, there is value in differentiating those exposures that are maintained at low levels through engineering controls and work practice controls from those exposures that are low and no health hazard controls are present. The identification of exposures maintained at low levels by existing engineering and work practice controls is critical information for managing exposure control programs.

The triggers for performing quantitative exposure assessments were established through a consensus of industrial hygienists in Alcoa. The intent was to have some requirement for exposure sampling at levels below OELs in order to create a database that demonstrates compliance with OELs. Criteria as low as 10 percent of the OEL and as high as 50 percent of the OEL were considered.

In those instances where an OEL is not available, the industrial hygienist is faced with the following choices:

- Establish an OEL
- Acquire more information on the health effects of the environmental agent, and then (1) establish an OEL or (2) determine that the exposure is acceptable or unacceptable based upon professional judgment.
- Determine that the exposure is acceptable or unacceptable in view of the information available on the health effects of the environmental agent and the conditions of exposure.

The time and resources needed to acquire more health effects data and/or establish an OEL may not be worthwhile. Nevertheless, the exposure assessment cannot proceed to the quantitative stage since a quantitative exposure assessment is predicated upon the presence of an OEL.

In summary, there are three end points to the qualitative exposure assessment; they are: (1) implementation of controls, (2) a quantitative exposure assessment, and (3) no action.
Tasks
In the Alcoa exposure assessment standard, a task is a work element or series of work elements whose associated exposure is assessed in accordance with the integration period of the OEL (e.g., 8 hours, 15 minutes, etc.). Prior to conducting quantitative exposure assessments, consideration is given to refining homogeneous exposure groups through the identification of significant tasks. In the Alcoa strategy:

- A specific task within an HEG must be designated if the exposure is significant and occurs on a less than daily basis. An example task is "flue wall repair," which is performed routinely in some furnaces, but perhaps no more than 1 day per week. In this example the process is maintenance, the job is brickmason, the task is flue wall repair, and the environmental agent could be refractory ceramic fibers. There is value in estimating and recording the frequency of the task (e.g., days per year) for both the hygienist who will need to interpret sampling data and others in the future who may need to assess the risk associated with past exposures.

- A specific task must also be identified when assessing compliance with a peak exposure limit, such as an American Conference of Governmental Industrial Hygienists (ACGIH) ceiling limit or short-term exposure limit. Such assessments will generally focus on specific tasks where significant short-term peak exposures are anticipated. An example is a 15-minute assessment of exposure to toluene 2,4 diisocyanate associated with polyurethane paint mixing. Similar to the task frequency, there is value in recording the number of peak excursions occurring per day where the task is identified for the purpose of assessing compliance with a peak exposure limit.

In a few work environments it may be difficult to anticipate when the peak exposures (and the tasks associated with the peak exposures) will occur. In this scenario, random short-term samples or continuous monitoring with data logging may be effective measurement strategies. For record keeping purposes the peak exposure values could be linked to the task title "random peak samples."

The designation of a task is not always necessary. Exposure data may be linked directly to the job when exposures occur daily and are assessed as an 8-hour average. For example, a surface mining operator may be exposed to coal dust in a number of work areas and tasks. Since exposure to coal dust occurs each day and coal dust is assessed as an 8-hour average, specific task information is not needed to resolve the exposure assessment and create a meaningful exposure history. It should be noted, however, that task-specific exposure data may be needed in a diagnostic assessment to determine how sources and tasks contribute to the overall exposure for the purpose of identifying and prioritizing engineering controls.

As noted earlier, the identification of HEGs by observation in some work environments is very challenging. It is especially difficult in batch manufacturing operations and research/development. Perhaps in these environments, the product or project could be the designated task element of the HEG.

Flexible work teams are increasingly popular. A common design is a group of workers who are responsible for operating a process, and each team member is trained and available to operate each workstation. In establishing HEGs, the industrial hygienist will probably determine that the work team constitutes the process and the job. However, the designation of specific tasks will depend upon how the team deploys its members. It may be useful to designate the specific workstations as tasks in the presence of interday rotation of team members through the workstations. However, if the workers practice random intraday rotation through workstations, there is little or no benefit in designating the task element of the HEG.
FOR A GIVEN HOMOGENOUS EXPOSURE GROUP:

BEGIN: qualitative assessment indicates exposures can exceed 30% OEL (or 50% OEL for noise)

COLLECT FIVE (5) OR MORE RANDOM SAMPLES (n)

ARE TWO (2) OR MORE SAMPLES > OEL AND REMAINING SAMPLES ≥ 50% OEL

ARE ALL SAMPLES < 50% OEL?

MINIMUM BASELINE

COLLECT 8-n ADDITIONAL SAMPLES

FIGURE 5. Criteria for a minimum baseline. This algorithm is used to determine the minimum number of samples for a baseline. It is not used to determine if exposures are acceptable or unacceptable.

Quantitative Exposure Assessments

Quantitative exposure assessments are required if the qualitative assessment indicates unacceptable, significant, or unknown exposures to the environmental agent. Where quantitative exposure assessments are indicated, the industrial hygienist will need to prioritize HEGs. The AIHA(3) has suggested various criteria for prioritization, including:

- number of workers exposed,
- toxicity of the environmental agent,
- frequency and duration of exposure,
- confidence in the exposure rating (qualitative assessment).

Unacceptable exposures are generally a low priority. The measurement of unacceptable exposures may help with the selection of controls or may help gauge the effectiveness of a control. For example, respiratory protection should be selected in view of workplace exposure levels and protection factor criteria. Also, the effectiveness of engineering or work practice controls can be assessed through exposure measurements performed prior to and following implementation of controls.

The quantitative data are generally collected through personal air sampling or personal noise dosimetry. Biological monitoring is sometimes employed where there is a significant potential for exposure via dermal absorption or inadvertent ingestion.

The Alcoa standard contains minimum data requirements for personal air sampling and noise dosimetry. At least five or eight samples are required for the initial determination. Figure 5 is the algorithm used to determine the minimum number of samples. Essentially, if sampling results are high or low relative to the OEL, five samples are adequate; otherwise, at least eight samples are required. Tasks occurring fewer than 12 days per year are exempt from the minimum data requirements. This exemption was established for practicality, and it is directed at requiring minimum exposure data for tasks whose exposure frequency is greater than approximately 5 percent of a 250 day/year work schedule. Although tasks occurring 11 or fewer days per year are exempt from the minimum data requirements, the industrial hygienist must assure that the assessment is resolved (e.g., acceptable or unacceptable) through a qualitative decision or the measurement of exposure.

In Alcoa, exposure assessment data are used to demonstrate compliance with governmental exposure limits. If this was the only objective, the exposure assessment strategy could be simplified by focusing on worst case conditions. However, to appropriately utilize exposure data for epidemiology and other future applications, it is necessary to employ a more ambitious sampling strategy whose purpose is to create a database that more accurately reflects the magnitude and variation in exposure data for all workers.

In collecting personal air and noise samples, a random sampling strategy is employed to the greatest extent feasible. The common practice is to arbitrarily schedule sampling dates and then, on those dates, arbitrarily choose among employees in the HEG. If sample data are to be used inferentially, they should be randomly collected.(3,4,17,18) Although there are practical limitations to collecting true random samples, this strategy is essential to minimize bias in the database. In the Alcoa strategy, personal samples collected through a random sampling strategy are termed baseline samples.

The worst case sampling strategy is commonly employed by industrial hygiene professionals. The worst case strategy is directed at identifying the most highly exposed individuals in a workplace in order to assess compliance with governmental exposure limits.(22) Although this is an effective strategy, worst case data do not reflect the magnitude and variation in day-to-day exposures. Worst case samples are an overestimate of average exposures and should not be used inferentially to represent past exposures. For example, if worst case samples were used in an epidemiologic study, it could lead to an inaccurate estimate of risk.(17)

Another major sampling strategy is diagnostic, where samples are collected in an effort to identify sources of exposure and how various activities contribute to exposure. Diagnostic
assessments are frequently performed if the qualitative assessment, or initial quantitative assessment, reveals exposures exceeding the OEL. A common practice in a diagnostic assessment is to collect a series of personal samples in sequence in an effort to analyze the relative contribution of various work elements. Since diagnostic data are collected with some specific exposure scenario in mind, they are not random samples.

Although the worst case and diagnostic strategies are sometimes used in Alcoa, sampling data collected by worst case and diagnostic strategies are not considered baseline samples and are excluded from statistical descriptions of past exposures.

There are other sampling strategies in addition to the conventional random, worst case, and diagnostic strategies. For example, Nicas and Speare have proposed a more efficient strategy employing a task-based statistical model.

In the context of the quantitative exposure assessment, an exposure is considered unacceptable if: (1) exposures predictably exceed the OEL; or (2) if unpredictable, overexposures occur greater than 12 days per year (5% exceedance).

The industrial hygienist is expected to investigate the circumstances of any exposure value (averaged over the appropriate integration period; 8 hours, 15 minutes, etc.) that exceeds the OEL. If the specific work elements, tasks, or days in which the exposure exceeds the OEL can be predicted in view of available information on the workplace and work practices, these exposures are considered unacceptable and must be controlled.

Most overexposures are predictable. If not initially predictable, overexposures may become predictable following a diagnostic exposure assessment. However, variable conditions exist in some processes such that overexposures cannot be predicted. If the specific work elements, tasks, or days which lead to exposures exceeding the OEL cannot be predicted, the industrial hygienist must consider the frequency of exposures in excess of the OEL. If the frequency exceeds 5 percent, exposures on all days and tasks must be controlled. No single method is specified for calculating the percent exceedance. The industrial hygienist may employ log probability plotting, the National Institute for Occupational Safety and Health “probability of noncompliance,” or other methodologies. In any event, the determination of acceptability or unacceptability is a professional judgment; descriptive and inferential statistics are inputs to professional judgment.

It is critical not to overlook the health risks associated with concomitant exposures. The ACGIH mixture value concept is employed wherever workers are simultaneously exposed to two or more hazardous materials affecting the same target organ.

It should be recognized that the long-term average exposure (arithmetic mean) is a better measure of health risk than the frequency of exposures above the OEL for an environmental agent exhibiting chronic toxicity and a long biological half-life. Unfortunately, OSHA and other governmental agencies have not established statistical criteria for assessing day-to-day compliance with OELs. Accordingly, the Alcoa criteria for interpreting sampling data were selected and adopted in an effort to maximize compliance with OELs. Although the Alcoa strategy, utilizing random sampling, may not assure compliance as well as a strategy based upon measuring the worst case, the Alcoa strategy does provide for the creation of a database that reflects the day-to-day magnitude and variability in exposure.

**TABLE 1. Periodic Sampling Frequency (Air Contaminants Only)**

<table>
<thead>
<tr>
<th>Geometric Mean of Baseline Data</th>
<th>Toxicity</th>
<th>Approximate Sampling Frequency in Years</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;50% of the OEL</td>
<td>High</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Low</td>
<td>3</td>
</tr>
<tr>
<td>≥50% of the OEL and ≤100% of the OEL</td>
<td>High</td>
<td>0.5</td>
</tr>
<tr>
<td>&gt;100% of the OEL</td>
<td>High</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Low</td>
<td>3</td>
</tr>
</tbody>
</table>

*Materials are classified as high or low toxicity. High toxicity materials exhibit chronic health effects (e.g., carcinogens, sensitizers, reproductive toxins, etc.) or an acute oral LD₅₀ <50 mg/kg. Low toxicity materials include noise, primary irritants, and nuisance dust.

Unacceptable exposures may be sampled at the 2- or 3-year frequency, regardless of the data’s geometric mean relative to the OEL.

**Reassessments**

Qualitative and, if necessary, quantitative exposure assessments are required whenever there is a change in the workplace, work force, or environmental agents that may significantly affect exposure levels.

To create exposure histories, HEGs are labeled initially with a “begin” date, and later with an “end” date if exposures significantly change or cease. This record keeping system facilitates the assembly of exposure histories.

In the absence of observable and significant changes in exposure levels, the Alcoa standard includes the criteria for periodic surveillance listed as Tables 1 and 2. The periodic surveillance frequency for noise is 3 years regardless of the exposure level. New data obtained through periodic surveillance are pooled with the existing baseline data unless the newly acquired data reveal a significant change in exposure levels.

The periodic surveillance criteria were established through a consensus of industrial hygienists in Alcoa. These criteria were favorably reviewed in the Chemical Manufacturers Association, publication by Harris, “Guideline for Collection of Industrial Hygiene Exposure Assessment Data for Epidemiologic Use.”

Also for purposes of exposure surveillance, continuous monitoring instrumentation and alarms should be considered in the presence of a significant risk for an acute harmful

**TABLE 2. Periodic Sample Size (Air Contaminants and Noise)**

<table>
<thead>
<tr>
<th>Number of Employees in Job Class</th>
<th>Geometric Standard Deviation of Baseline Data</th>
<th>Minimum Number of Samples</th>
</tr>
</thead>
<tbody>
<tr>
<td>≤30</td>
<td>≤2.00</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>&gt;2.00</td>
<td>5</td>
</tr>
<tr>
<td>&gt;30</td>
<td>≤2.00</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>&gt;2.00</td>
<td>9</td>
</tr>
</tbody>
</table>
exposure to a hazardous material exhibiting poor warning properties (e.g., toxic gas or vapor, radioactive material).

**Exposure Database**

Exposure data are managed in two arenas; they are (1) HEG data and (2) sample data.

HEG data and records are created and maintained to facilitate the management and analysis of the exposure database. In Alcoa, HEGs records are keyed to the four elements; they are:

- Process (department)
- Job
- Task
- Environmental agent (material)

Process and job codes are established by the plant industrial hygienist, whereas the task and environmental agent codes are established by Alcoa’s Corporate Health Services staff. This provides for standardization and permits data retrieval and analysis across plants. As noted earlier, demographic records are linked in through the job element of the HEG. Demographic records must have a begin and an end date for each worker-job assignment. The following data are maintained for each HEG:

- Task frequency estimate, in days per year
- Number of peak excursions per day (estimated if assessing compliance with peak exposure limit)
- HEG begin date
- HEG end date.

These data, once captured and archived, become the basis for worker exposure histories.

The necessary data for personal samples are:

- Unique sample number
- Date and begin/end sampling times
- Plant site or location
- The HEG
- The sampled worker and his/her unique identification number
- The work schedule as the shift length. The identification of shift length (e.g., 8, 10, or 12 hours) may not be adequate because work schedules with the same shift length may differ in patterns of work days. The specific work pattern, metabolic clearance of the environmental agent, and other factors should be considered in adjusting OELs in the presence of a nontraditional work schedule.(23)
- Personal protective equipment, if used (e.g., respiratory protection, hearing protection, gloves, etc.).
- The OEL averaging time for the assessment (e.g., instantaneous for a ceiling limit assessment, 15 minutes for a STEL, and 8, 10, or 12 hours for a full-shift, time-weighted average).
- Sampling and analytical data. Information should be captured identifying who collected the sample, the sampling instrumentation, flow rate, and calibration data. The sampling and analytical methods are critical where the measured result may differ in accordance with the methodologies. For example, it would be inappropriate to group dust exposure values collected by the old ACGIH criteria for respirable dust with samples collected by the new International Standards Organisation criteria.(26) Similarly, noise dosimeter samples collected in accordance with a 5-dB doubling rate should not be mixed with samples collected with a 3-dB doubling rate.
- The sampling strategy or reason for sampling: random, worst case, or diagnostic.
- Measured exposure level and unit of measure.
- Observations and comments. This includes information describing where the sample was collected (e.g., building, production line, etc.), the presence of abnormal conditions and work practices, and observations about the potential for exposure via skin contact or inadvertent ingestion. Such information must be recorded since it may affect the interpretation of the sampling data or recommendations for control. Observations and comments are important inputs to professional judgment, and exposure assessments cannot be made in the absence of professional judgment.

**Reporting Exposure Assessments**

Figure 1 makes no mention of exposure data, but it is exposure data that sustain the health protection process. Exposure data are a means to an end and their value is not realized until the data are utilized in a constructive and systematic manner. In Alcoa, exposure assessment data are utilized to differentiate acceptable from unacceptable exposures. These findings must be communicated in a timely and effective manner to management and all affected workers; this includes all workers in the HEG and, if appropriate, their labor representatives. Depending upon the specific circumstances, the findings may also be reported to medical and engineering staff.

The database structure and quantitative assessment criteria have been integrated into a software system for data retrieval, analysis, and reporting. The minimum baseline criteria described earlier are used to analyze the adequacy of sample data for each HEG. Also, the periodic surveillance criteria are employed to determine routine sampling schedules.

The software database is employed to calculate and report descriptive statistics for each HEG. These descriptive statistics include:

- Number of samples
- Date range of samples (earliest date and most recent date)
- Sample mean
- Geometric mean
- Geometric standard deviation
- Exposure level range (low and high)
- Percent of samples exceeding the OEL.

The descriptive statistics are used to identify and report unacceptable exposures, thus facilitating the management of health hazard control programs and projects. Also, the same descriptive statistics are used to identify employees who may qualify for medical surveillance. It should be noted that despite the emphasis on random sampling, logistical constraints often force campaign sampling. The geometric standard deviations calculated from sampling campaign data may be biased to underestimate the true day-to-day variability in exposure levels.(28)

Finally, the exposure histories in the Alcoa database may be used in the future, perhaps to answer a physician’s questions about a worker’s past exposures, or perhaps to assist an epidemiologist in constructing a retrospective exposure assessment.(17,18,28,29)
Challenges
Various opportunities have been identified for strengthening the exposure assessment strategy. Certainly, written descriptions of the processes, jobs, and tasks are a worthwhile enhancement to the program. This information may be needed in future years to answer questions about past exposures. The AIHA has suggested various methods for documenting descriptions of the workplace and work force.5,6,7,30

A systematic method and software tool are needed for documenting qualitative exposure assessments. The proposals from the AIHA, Tait, and Dow may be good models.5,6,7,30

The greatest challenges come in the area of refining HEGs. Alcoa utilizes personnel databases to identify workers in HEGs. Payroll job classifications frequently do not represent HEGs. It is a tedious and practical challenge to reclassify workers into HEGs.

Another, perhaps more difficult, challenge is to classify workers down to the task level of the HEG. Since demographic records are linked to the HEG at the job level (Figure 3), there are at least some workers whose exposure history will indicate exposure in a task they do not or have not performed.

Even if the aforementioned classification problems were eliminated, workers would still not be accurately classified into HEGs. The reason is that many exposures in the workplace are more reflective of an individual's work practices than the ambient workplace concentrations of an air contaminant or ambient noise levels.30 Rappaport has published a methodology for statistically classifying workers into uniform exposure groups through an analysis of the "within-worker" versus the "between-worker" variability of sampling data. Exposure databases should be statistically analyzed in an effort to refine HEGs.

Finally, some years ago Alcoa developed a coding scheme working in parallel with plant HEG codes to facilitate the grouping of similar HEGs across locations. In this a priori job grouping scheme, each job classification in each location was assigned to a parallel job described by a standard coding of the appropriate product, operation, and technology. Although this scheme could have been an effective tool for interplant exposure assessments, it proved to be unworkable and was abandoned. The system required an impractical amount of technical management and supervision. Although there is no system at present for grouping HEGs across plants, each location's HEG database provides the basis for ad hoc groupings if necessitated by a health issue.

Conclusion
Exposure assessment serves a central role in supporting health hazard controls, medical surveillance, epidemiology, and ultimately employee health protection. The health protection process is sustained by management support, industrial hygienists, and exposure data. To the extent that industrial hygienists can identify commonalities in exposure data and agree upon standardization, qualitative and quantitative exposure data become more than the information sustaining the health protection process; exposure data become the "currency" of the industrial hygiene community.

References