Applied Occupational and Environmental Hygiene
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/uaoh20

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To cite this article: Pam Susi, Mark Goldberg, Pat Barnes & Erich Stafford (2000): The Use of a Task-Based Exposure Assessment Model (T-BEAM) for Assessment of Metal Fume Exposures During Welding and Thermal Cutting, Applied Occupational and Environmental Hygiene, 15:1, 26-38

To link to this article: http://dx.doi.org/10.1080/104732200301827

Applied Occupational and Environmental Hygiene
Volume 15(1): 26–38, 2000

1047-322X/00 $12.00 + .00

The Use of a Task-Based Exposure Assessment Model (T-BEAM) for Assessment of Metal Fume Exposures During Welding and Thermal Cutting

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Elevated disease rates have been documented among construction workers for cancer, pneumonoconiosis, asbestosis, and silicosis. However, methodologies for exposure assessment in construction are not well described in the U.S. literature. Working through a cooperative agreement with the National Institute for Occupational Safety and Health (NIOSH), the Center to Protect Workers' Rights—a research arm of the Building and Construction Trades Department, AFL-CIO—has developed and used a "Task-Based Exposure Assessment Model (T-BEAM)" for construction. The characteristic elements of T-BEAM are: (1) an emphasis on the identification, implementation, and evaluation of engineering and work practice controls; and (2) use of experienced, specially trained construction workers (construction safety and health specialists) in the exposure assessment process.

A task-based approach was used because tasks, or specialized skills, form the single greatest thread of continuity in the dynamic environment of construction. Workers in the construction industry come from several crafts and are typically employed by a large number of contractors throughout their career. Project types (e.g., residential or industrial rehabilitation) are also highly variable and present unique health risks. Finally, because construction involves building, renovating, or dismantling physical surroundings, the work site is constantly changing.

Between 1995 and 1996, T-BEAM was applied to the collection of approximately 200 personal exposure measurements associated with "hot work tasks"—welding and thermal cutting. Data were collected with the assistance of specially trained, journeyman ironworkers, pipe fitters, and boilermakers on nine construction sites located throughout the United States. Portable local exhaust ventilation was provided to participating contractors with the intent of measuring its impact on exposure.

Results indicate that data collected in a standardized, systematic fashion from multiple work sites can be used to characterize exposures among sampled trades. Comparison of results to American Conference of Governmental Industrial Hygienists (ACGIH®) threshold limit values (TLVs®) demonstrate a significant health hazard among sampled trades posed by welding and thermal cutting fume, manganese, nickel, and chromium VI. Direct estimates of the probability of exceeding the ACGIH TLV for respirable particulate suggests that boilermakers (100%) and ironworkers (71%) are at greatest risk. Other task variables evaluated with respect to exposure include task, whether work was performed indoors or outdoors, intermittency of work, and use of ventilation. Use of local or mechanical ventilation reduced mean exposures to fumes significantly.

Keywords Exposure Assessment, Wielding, Construction, Metal Fumes, Exposure Databases

Since 1993, the Center to Protect Workers' Rights (CPWR) has been engaged in the development and refinement of a Task-Based Exposure Assessment Model (T-BEAM) for construction. T-BEAM uses tasks (or specialized skills) as the central organizing principle for data collection, because trade-specific skills form the thread of continuity in the career of a construction worker. The rationale for T-BEAM and the importance of characterizing tasks in construction as part of the exposure assessment process have been described.(1–3) Attempting to characterize exposures by occupation alone is of limited value for the mobile construction workforce and can result in grouping together workers whose exposures may differ significantly. Using tasks as the primary building block of an exposure assessment framework is particularly useful where trade-specific skills, or specialized tasks, form a thread of continuity in the transient career of a construction worker. Therefore, characterizing the lifetime exposure profile of the *journeyman* requires knowledge first and foremost of the principle tasks of the trade.

The defining characteristics of T-BEAM are:

1. Involvement of specially trained journeymen, referred to as construction safety and health specialists (CSHSs), in the exposure assessment process; and
2. An emphasis on the identification, implementation, and evaluation of engineering and work practice controls.

Major work areas of this project have been the development of: (1) field survey instruments for collection of both quantitative and qualitative data; (2) databases for storage, use, and analysis of collected data; (3) an exposure assessment methodology that allows for the mutual collaboration of professional occupational hygienists (OHs) and specially trained, journeymen CSHSs in use of the T-BEAM method; and (4) training curricula for T-BEAM survey teams with emphasis on basic principles of air monitoring for metal fumes and use of survey kits developed by CPWR.

OBJECTIVES OF T-BEAM

The primary objective of T-BEAM is to collect data which will yield information necessary for occupational disease prevention among construction workers, both in the short and long term. In the short term, engineering and/or work practice controls are introduced into the workplace and exposure measurements are collected concurrently for both controlled and uncontrolled operations. Such information is of immediate value to contractors who can purchase effective control equipment and thereby build hazard control into job bid packages. Provided such equipment is used effectively, exposures associated with adverse health effects can be avoided and/or minimized as rapidly as data can be collected, analyzed, and communicated back to the industry. Direct reading instruments combined with real-time video monitoring have been employed as part of T-BEAM for visually demonstrating the impact controls have on reducing task-related exposure levels.

Long-term disease prevention involves accurate characterization of exposure levels associated with chemical, physical, and biological agents that may lead to adverse health effects. T-BEAM seeks to collect sufficient, representative exposure data (including qualitative information about the variables that impact on exposure) for more accurate estimates of the type and intensity of exposure hazards associated with occupational disease. The scientific literature and our knowledge of the magnitude and duration of chemical exposures among construction workers is relatively scant. With the exception of certain regulated agents (e.g., asbestos), we know little about exposure levels associated with most health hazards in construction.(4)

T-BEAM seeks to increase our understanding of exposures among construction workers by utilizing a largely untapped reservoir of information—experienced tradespeople. Beyond being a tool for data collection and analysis, T-BEAM represents an important and promising new approach to exposure assessment. If both reliable and sufficient data are to be collected to characterize exposures in construction, occupational hygienists must rely more upon the knowledge and skills of experienced workers in the construction trades. There is no better understanding than the journeyman's of the complexities of construction and the variability of conditions on a daily and sometimes hourly basis. Recruitment of such individuals as members of the exposure assessment and hazard control team will greatly fortify the collection of data. Additionally, the need for exposure data in construction far exceeds the supply of professional occupational hygienists available to collect it.

This article provides an overview and initial results of application of T-BEAM to "hot work tasks"—primarily welding and thermal cutting. Between 1995 and 1996, CPWR applied T-BEAM in a standardized, systematic fashion to a single set of construction tasks with the intent of building a sufficient database to estimate exposure distributions among sampled trades and to measure the impact of key determinants of exposure. Data were collected at nine construction sites around the country for three welding trades (pipe fitters, ironworkers, and boilermakers). Detailed reports were also prepared by survey teams. Multiple databases were constructed to catalog both quantitative and qualitative information related to sampled tasks, trades, and metal fume exposure levels.

Analysis of the collected data has allowed us to answer the following questions:

1. Can exposures be characterized among construction workers absent a fixed work site?
2. Which task variables have significant effects on exposure?
3. What impact does mechanical and local exhaust ventilation have on reducing metal fume exposures among the welding trades?
4. What is the probability of exceeding occupational exposure limits for metal fumes among the sampled trades?

BACKGROUND

Excess mortality and morbidity among construction workers have been described in the literature. In 19 states, Robinson et al. found excess mortality rates among construction workers under age 65 from cancer, asbestos-related diseases, mental disorders, alcohol-related diseases, digestive diseases, falls, poisonings and traumatic fatalities that are usually occupational in origin, and homicides. Trade-specific elevated mortality rates were observed for bone cancer and melanoma (brick masons), stomach cancer (roofers and brick masons), kidney and bone cancer (concrete/terrazzo finishers), nasal cancer (plumbers), pulmonary tuberculosis (laborers), scrotal cancer and aplastic anemia (electricians), acute myeloid leukemia (boilermakers), rectal cancer and multiple sclerosis (electrical power installers), and lung cancer (structural metal workers).(5)

Exposure to welding fumes has been associated with a number of diseases depending on the base metal being welded, the type of electrode used, and which coatings may be on the material being welded.(6–8) The metals of greatest importance to the trades described by this article are mild steels, including structural and carbon steel, and stainless steel. In addition, lead, cadmium, and zinc are common metal pigments contained in steel coatings.

Metals which present chronic health hazards include manganese, found in mild steels, and nickel and chromium, found in stainless steel. Manganese has been associated with Parkinson's disease.(9–12) A recent workers' compensation case recognized the association between this condition and manganese fume exposure generated during welding.(13)

The International Agency for Research on Cancer (IARC) has determined that chromium (VI) is carcinogenic to humans and that metallic nickel and welding fumes are possibly carcinogenic to humans.(14) Nickel and chromium (VI) are also associated with respiratory sensitization.(14)

Sullivan et al. reviewed the literature on respiratory disease among construction workers and found that several chemical agents common to construction have been associated with respiratory disease, including cadmium, bioaerosols, welding fumes, manmade mineral fibers, asbestos, and silica. Despite documentation of the association between chemical agents common to construction and adverse respiratory effects, Occupational Safety and Health Administration (OSHA) compliance data indicate little regulatory monitoring had been conducted by OSHA for chemical agents other than asbestos.(4)

There are between 5 million and 8 million workers employed in the United States construction industry.(15,16) Unionized workers in the U.S. are organized into 15 national/international unions representing at least as many crafts. The organization of construction work has important and unique implications for those engaged in characterizing long-term exposure hazards. Several attributes of the construction workforce and the environment in which it works must be considered in devising an appropriate exposure assessment strategy for this industry. Construction workers move from job to job and from employer to employer, so conditions encountered on one job may be very different from those encountered on another.(1,17) Because construction workers are responsible for erection, rehabilitation, and demolition of essentially all structures and buildings, projects vary widely. A pipe, for example, fitter may be engaged in welding stainless steel process piping during construction of a new semiconductor facility one month, and involved in installation of carbon steel process piping for control of smokestack emissions in an operational copper smelter the next month. Even though primary tasks performed may be similar from job to job, the variables that may affect exposure are perpetually changing.

Exposure assessment is particularly challenging in this context if the results from one job or site are to be used to estimate exposures at another job or site. The method used must capture all the variables which may significantly impact on exposure in some systematic way so that the conditions that determine exposure can be reconstructed after the job is complete and the "site" has become a "building or structure." This requires collection of data among various trades employed at multiple job sites. These data should include both quantitative measurements of exposure and qualitative information on the tasks and practices operative when measurements were made. By collecting both quantitative *and* qualitative data it should be possible to both characterize exposures and determine the importance of variables which contribute to exposure. Examples of qualitative data include work process factors and environmental conditions, including use of ventilation, which might impact exposure. Such information is useful for evaluating control technologies and incorporating those that are effective into scheduled work.

DESCRIPTION OF SURVEYS

Between 1995 and 1996, 10 field surveys were completed on nine different job sites. The survey sites, dates, and sampled trades appear in Table I. T-BEAM Survey Kits were provided to participants for collection of information in a uniform fashion. Prior to each annual survey campaign, a three- to four-day training session was convened for survey teams made up of CSHSs, and OHs. Participants were provided with survey materials and trained in survey methodology use of air monitoring pumps and calibration equipment and general principles of industrial hygiene.

Each survey was initiated by a meeting with union and contractor representatives, site foreman and stewards for the workers being sampled, and the T-BEAM survey team for the purpose of: (1) presenting survey objectives and methods; (2) introducing survey teams to key site personnel; (3) discussing reporting procedures; (4) defining the scope, duration, and logistics for the jobs being surveyed; and (5) planning mobilization of ventilation equipment.

During the opening meeting, the first survey form was completed with input from all those present. This initial survey form defined the project, job, trades, and tasks to be included in the scope of each survey. Standard definitions for these variables and other terms relevant to T-BEAM and provided in survey kits appear in Figure 1.

Selection of workers to be sampled was based upon two criteria: (1) they would be engaged in hot work tasks for at least 60 minutes (cumulative time) during the day selected for sampling, and (2) the work they were performing was considered representative of "typical" work. The importance of not biasing the collected data by selecting workers who might represent "worst case" or "best case" exposure scenarios was emphasized during training and at opening meetings. Survey teams were instructed to sample for at least seven hours of an eight-hour workday, removing pumps only during lunch breaks. National Institute for Occupational Safety and Health (NIOSH)-validated sampling methods were used to determine exposures to both total particulate and selected constituent metals.(18–20)

TABLE I
T-BEAM survey site characteristics, trades, and analytes

Project name and location survey dates	Number of workers sampled by trade	Job description	Analyte and number of samples
Rehabilitation/Maintenance of Oil Refinery New Jersey March 13–24, 1995	5—Boilermakers	Tank bottom replacement involving shielded metal arc (SMA) welding and air carbon arc cutting of carbon steel	Total particulate = 20 Manganese = 18
Pipe Fabrication Shop West Virginia March 20–30, 1995	4—Pipe fitters	Welding of carbon steel (primarily) pipe	Total particulate = 24 Manganese = 24
Bridge Rehabilitation New York March 30–April 25, 1995	5—Ironworkers	Repair and reinforcement of steel bridge involving welding and torch cutting of lead painted steel members	Total particulate = 14
Pipe Fabrication Shop Washington May 31–June 12, 1995	5—Pipe fitters	Welding, cutting, grinding, and burning of carbon steel, stainless steel piping, and galvanized unistrut pipe supports	Total particulate = 26 Nickel = 5 Chromium = 5 Zinc = 4
Replacement of Underground Process Piping, Oil Refinery Indiana July 20–28, 1995	9—Pipe fitters	Replacement of 100-year-old underground process pipes involving SMA welding and pneumatic cutting of carbon steel. Fabrication of hose reels involving SMA welding using stainless steel rods	Total particulate = 19 Manganese = 19 Nickel = 4 Chromium = 4
Semiconductor Plant New Construction Oregon July 31–August 14, 1996	12—Pipe fitters	Site fabrication and installation of heating, ventilation and air conditioning, process piping (carbon and stainless steels), and mechanical equipment in new semiconductor facility. Torch-cutting, cold-cutting, welding piping, and piping stools in multiple locations (outdoor fab tent, temporary clean rooms, and enclosed, newly constructed semiconductor facility).	Total particulate = 23 Manganese = 20 Cadmium = 2 Nickel = 1 Chromium = 1 Lead = 1
Bridge Rehabilitation New York August 2–October 3, 1996	13—Ironworkers	Replacement of steel bridge components involving welding and torch-cutting of stringers, grid deck, and outer walkways.	Total particulate = 27 Manganese = 13 Nickel = 8 Chromium = 5
Semiconductor Plant New Construction California September 9–27, 1996	4—Pipe fitters	Pre-fab of heating, ventilation, and air conditioning chiller systems for new semiconductor facility. Primarily carbon steel pipe welding.	Total particulate = 23 Manganese = 23
Industrial Rehabilitation Pulp and Paper Mill Washington October 29–31, 1996	3—Pipe fitters	Demolition of old and installation of new stainless steel cleaning tanks as part of pulp and paper shutdown project. Involved torch-cutting and welding of mild steel pipe and pipe supports; plasma arc and torch-cutting old and new stainless steel; SMA, gas metal arc, and gas tungsten arc welding new stainless and mild steel.	Total particulate = 9 Manganese = 9 Nickel = 9 Chromium = 9 Chromium VI = 9
Industrial Rehabilitation Aerospace Facility Washington November 4–7, 1996	3—Pipe fitters	Rehab of above-ground mechanical station involving torch-cutting, grinding, and SMA welding of old and new carbon steel pipe. Some torch-cutting of old painted pipe	Total particulate = 10 Manganese = 10 Lead = 2

Occupational hygienists remained on-site for the first three days of data collection to ensure CSHSs were carrying out exposure monitoring, calculating air volumes, and filling out laboratory submittal forms correctly. Survey teams were directed to select up to three constituent metals for analysis by the laboratory, in addition to total particulate. It was suggested that manganese be one of the additional metals where mild or carbon steel was being welded or cut. Analysis for chromium and nickel was suggested for stainless steel. In the case of painted steel, survey teams were directed to analyze for the appropriate metals given the type of coating involved. CSHSs remained on-site for the remainder of the time (generally a total of 10 workdays) with OHs available by phone if support was needed. At the conclusion of each survey, CSHSs shipped the samples to an American Industrial Hygiene Association (AIHA)-accredited laboratory under contract with CPWR. Completed survey forms were mailed to CPWR for entry of collected data into a relational database.

DESCRIPTION OF DATABASE AND DATA ANALYSIS

A total of six database files (three files for each survey year) contain the data collected during field surveys. The database for hot work tasks contains over 2500 records organized into 120 different fields. Included in this database are task variables grouped into the following categories:

1. six process-related variables (e.g., type of hot work and intermittency of work)
2. four material or electrode variables (e.g., base metal, electrode type, coatings)
3. three environmental variables (e.g., indoors/outdoors, type of ventilation)

Project - An extensive construction undertaking that is the responsibility of a project manager or general or prime contractor. Typically, a large number of contractors and crafts will be involved. For example, the Rock and Roll Museum Project in Cleveland, Ohio, was a large new construction project involving a large number of subcontractors and crafts.

Job - A smaller construction undertaking which only involves one or a small number of contractors and crafts; an undertaking which is part of a larger project. For example, in 1994 CPWR surveyed a boiler rehabilitation job which was part of a power plant "turn-around" project.

Process - A series of steps or group of tasks performed for a singular objective. For example, the boiler rehabilitation job described previously involved the following major processes: (1) scrapping out or removing old boiler tubes, (2) prepping and milling old tubes to be joined to new tubes; and (3) joining new tubes to old tubes.

Task - A specific piece of work that is common to the construction trades. For example, the process of scraping out old boiler tubes, described previously, involved the tasks of torch-cutting, rigging, and material handling. In construction, there are a number of tasks which are specialized skills. For example the task (or skill) of welding is central to a number of trades including ironworkers, pipe fitters, sheet metal workers, and boilermakers.

Task Elements - The sequential steps required to perform a task. For example, building a set of sawhorses would require the following steps: (1) select and gather lumber stock; (2) measure and lay out cuts; (3) make cuts to measured dimensions; and (4) nail together cut pieces.

Task Variables - The tools, materials, environmental conditions, work practices, and other factors that may impact on either the type or magnitude of exposure hazard during the performance of a task. For example, the base metal being welded will impact on the type of exposure hazard associated with welding. Welding or thermal cutting of galvanized metal can produce metal fume fever among welders.

Exposure - The term used to describe contact with environmental agents that have the potential to cause harm. Examples of common airborne exposure hazards in construction are metal fumes, solvent vapors, and silica. The level or concentration at which an exposure occurs in combination with the duration of exposure must be assessed to determine the degree of potential hazard.

FIGURE 1
Task-based exposure assessment model (T-BEAM) definitions.

4. three work practice variables (e.g., position of worker relative to fume source)

A subset of these variables was selected for regression analysis. Criteria for selection of variables was based on having sufficient data for any given variable that could be easily categorized and was likely to impact exposure significantly.

The database has been used primarily for two purposes: (1) preparation of reports for communicating results to workers, labor representatives, and participating contractors, and (2) for statistical analysis of exposure measurements and covariates.

Data analysis occurred on two tiers. Descriptive statistical analysis of exposure distributions were calculated by CPWR's Data Unit. In addition, a mixed-model linear regression analysis was used for investigating the distributions of exposures, probabilities of exceeding ACGIH® TLV®s, and the effects of task-related covariates. This article summarizes the data and provides some insight into the major effects of trade, task, and controls. Results of the mixed-model analysis which pools together all sampled trades will be reported separately.(24)

RESULTS

In 1995, 103 full-shift exposures measurements were collected for total particulate among 28 workers. Additional analysis for manganese was requested for 61 of these samples collected among 18 workers. In 1996, 92 full-shift exposure measurements were collected for total particulate among 35 workers. Additional analysis for manganese was requested for 75 of these samples collected among 27 workers. A small set of full-shift samples was also analyzed for nickel (9 samples in 1995/18 samples in 1996), chromium (9 samples in 1995/15 samples in 1996), and chromium VI (9 samples in 1996). A very small number of samples were below either the limit of detection (LOD) or quantitation (LOQ). In these cases, the LOD or LOQ was entered as the sample result and a notation was made in the database that the result was based on the LOD or LOQ. Sample means, standard deviation, and ranges for each analyte are shown in Table II.

Because welding fumes are a complex mixture of chemical hazards, these results can be compared to several occupational exposure limits (OELs). NIOSH has found a 40 percent increase in lung cancer and has observed excess respiratory disease including chronic bronchitis, pneumonia, and reduction in pulmonary functions among welders even where exposures were below the OSHA PEL for welding fumes and respirable particulate of 5 mg/m^3. Because of these findings NIOSH believes exposures should be reduced to the lowest feasible level using state-of-the-art engineering controls. In addition, NIOSH recommends that agent-specific exposure limits be applied to constituent metals.(8)

The ACGIH TLV for welding fumes, which is the same as the OSHA general industry PEL, was set at 5 mg/m^3 as an eight-hour time-weighted average (TWA) in 1974.(22) The health effects for which this limit was set are metal fume fever, a transient flu-like condition which occurs from exposure to specific metal fumes, and respiratory tract irritation. A second OEL which could be applied to interpretation of welding fume exposure measurements is the ACGIH TLV for respirable particulate which was lowered to 3 mg/m^3 in 1994.(23) The ACGIH TLV for respirable particulate was set to protect the body's natural pulmonary clearance mechanisms which are compromised by excess dust loading. Such effects are of particular concern with welding fumes which may contain very toxic metals. Ultrafine particles (smaller than 0.1 micrometers in diameter) are believed to pose a greater health risk than respirable particulate. As previously discussed, the lower size range of welding fumes may fall into this ultrafine region of the particle size gradient. The ACGIH currently states that these particles present more of a health risk than larger respirable particles. It also states there is inadequate data available with which to determine an OEL for these particles and that the respirable particulate TLV should therefore not be applied.

Although NIOSH's approach to evaluating and controlling welding fume hazards is the most sound given the toxicity of metal fumes and the lack of adequate OELs with which to gauge measured exposure levels, as a practical matter, some benchmark must be selected for evaluating our results. We therefore elected to use the ACGIH TLV for respirable particulate rather than the outdated and less protective welding fume TLV. However, we recognize the limitations to this approach. Both larger non-respirable particulate and ultrafine particulate may contribute to the total mass of gravimetrically derived sampling results. Use of the respirable particulate TLV to evaluate exposures

TABLE II

Worker exposure sampling results for airborne contaminants

	Sample size		Mean (mg/m^3)		Standard deviation		Range (mg/m^3)	
Analyte	1995	1996	1995	1996	1995	1996	1995	1996
Total particulate	103	92	5.78	4.12	7.04	3.71	< 1.0200–37.2900	0.1000–18.0400
Manganese	61	75	0.20	0.07	0.28	0.08	0.0005–1.3105	0.0010–0.4700
Nickel	9	18	0.06	0.05	0.16	0.12	0.0007–0.4880	0.0002–0.4600
Chromium	9	15	0.10	0.06	0.18	0.12	0.0015–0.5580	0.0002–0.4500
Chromium VI	na*	9	na*	0.01	na*	0.01	na*	0.0021–0.0200

*na = not analyzed.

TABLE III

T-BEAM exposure measurements relative to threshold limit values

Trade	Total number of samples	Number of samples exceeding the ACGIH TLV[A]	Estimated probability of exceeding the ACGIH TLV[B]
		Total particulate	
Boilermakers	20	20	100%
Pipe fitters	134	42	31%
Ironworkers	41	29	71%
		Manganese	
Boilermakers	18	13	72%
Pipe fitters	105	7	7%
Ironworkers	13	2	15%

[A] ACGIH TLV for respirable particulate = 3 mg/m^3; ACGIH TLV for manganese = 0.2 mg/m^3.

[B] Calculation for the probability of exceeding the ACGIH TLV:
(number of samples greater than the ACGIH TLV/the number of samples) * 100
example: total particulate, ironworkers: (29/41) * 100 = 70.73%.

which include non-respirable particulate would overestimate risk while underestimating risk for exposures which include ultrafine particulate.

Probabilities that a random measurement would exceed an ACGIH TLV were estimated for each trade as the ratio of the number of measurements above the ACGIH TLV to the total number of measurements obtained. This empirical approach to estimating the probability makes no assumption that the sample is normally distributed. These results, shown in Table III, indicate the probability of exceeding the ACGIH TLV for respirable particulate is very high among boilermakers (100%) and ironworkers (71%). Probabilities for exceeding the ACGIH TLV for manganese are lower, but still high for boilermakers at 72 percent.

A summary of 1995 and 1996 exposure measurement means relative to current occupational exposure limits appears in Table IV, T-BEAM Exposure Means Relative to Current Occupational Exposure Limits (OELs). The ratio of means to OELs

TABLE IV

1995 and 1996 T-BEAM exposure means relative to current occupational exposure limits (OELs) by analyte

Analyte	Number of samples	Mean (mg/m^3)	Mean/OEL
Total particulate	195	5.00	100% of PEL (respirable—5 mg/m^3) 167% of TLV (respirable—3 mg/m^3)
Manganese	136	0.13	3% of PEL (C) (5mg/m^3) 65% of TLV (0.2 mg/m^3)
Nickel	27	0.05	5% of PEL (1 mg/m^3) 333% of REL (0.015 mg/m^3)
Chromium	24	0.08	8% of PEL (1 mg/m^3) 16% of REL & TLV (0.5 mg/m^3)
Chromium VI	9	0.006	6% of PEL (C) (0.1 mg/m^3) 60% of TLV (0.01 mg/m^3) 600% of REL (0.001 mg/m^3)

Current Occupational Exposure Limit:
Source:
ACGIH: Guide to Occupational Exposure Values (1997)
Abbreviations:
OSHA PEL: Occupation Safety and Health Administration Permissible Exposure Limits
ACGIH TLV: American Conference of Governmental Industrial Hygienists Threshold Limit Value
NIOSH REL: National Institute for Occupational Safety and Health Recommended Exposure Limit
C: Ceiling—the concentration that shall not be exceeded during any part of the working exposure
The numbers in parentheses represent the respective PEL, TLV, or REL.

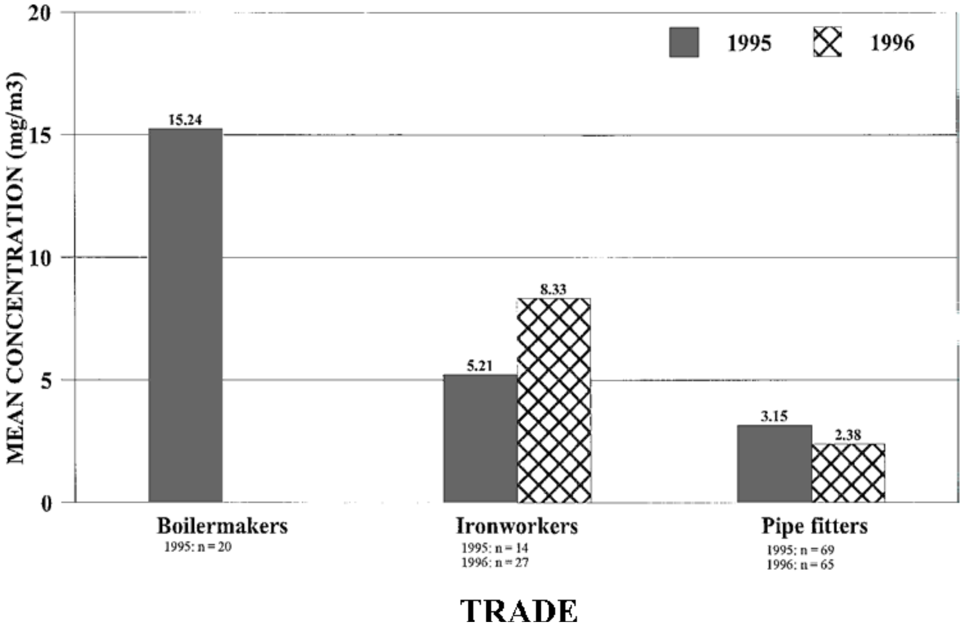

FIGURE 2
Mean total particulate exposure per shift by trade: 1995 and 1996.

which exceed 100 percent include total particulate when compared to the TLV for respirable particulate, nickel when compared to the REL, and chromium VI when compared to both the REL and the TLV.

Mean exposures to total particulate associated with the following variables: trade, task, whether work was performed indoors or outdoors, the intermittency of work, and use of ventilation appears in Figures 2, 3, 4, 5, and 6, respectively. By trade, mean exposure to total particulate was highest among boilermakers, followed by ironworkers and then pipe fitters. With respect to task, (Figure 3) thermal cutting appeared to generate higher total particulate exposure than welding; however, only six personal exposure measurements were associated with thermal cutting versus 148 associated with welding.

On average, exposures associated with outdoor work (Figure 4) were lower than exposures associated with indoor work, and

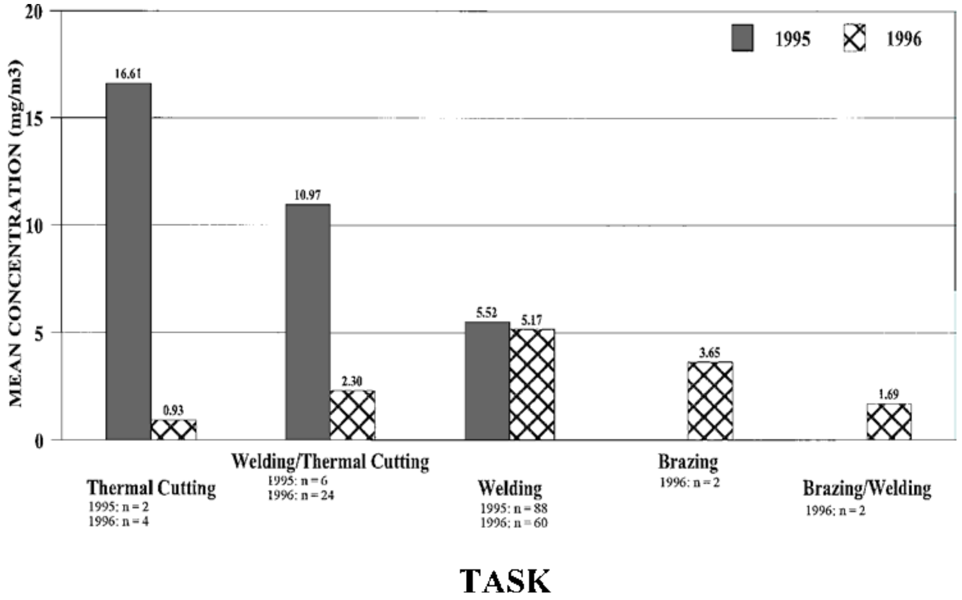

FIGURE 3
Mean total particulate exposure per shift by task: 1995 and 1996.

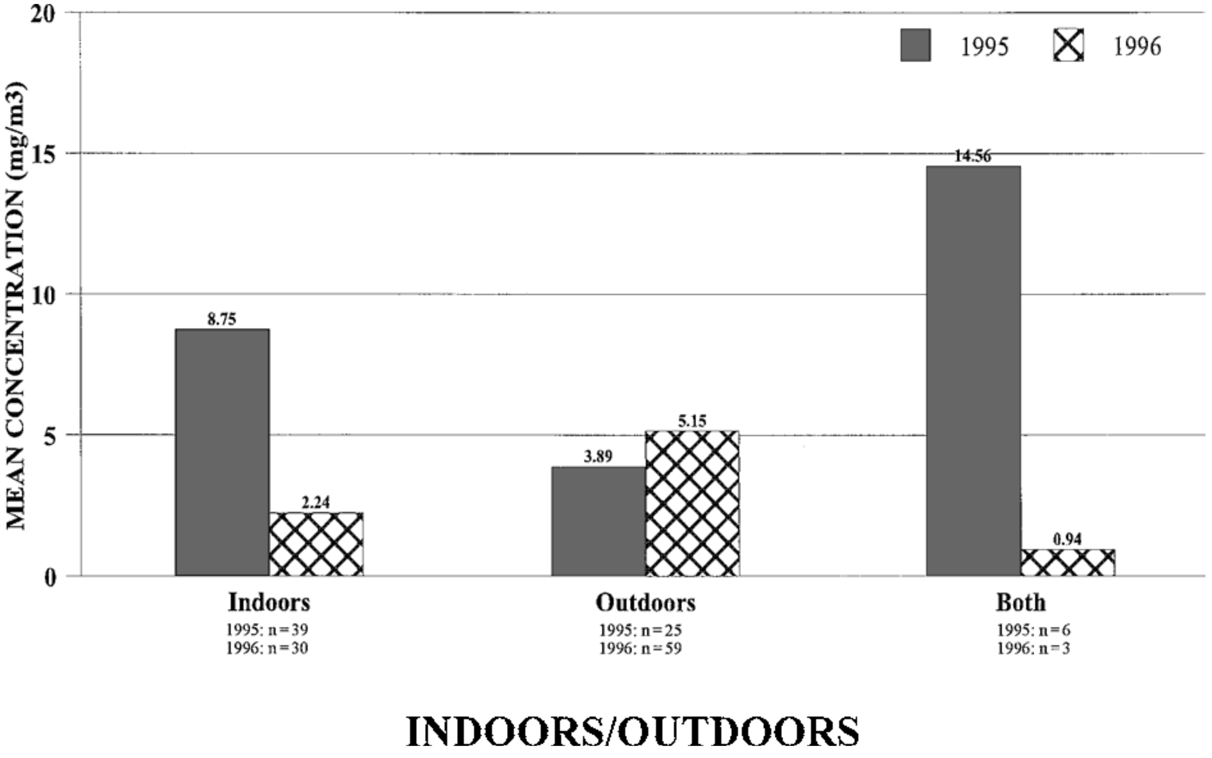

FIGURE 4
Mean total particulate exposure per shift by indoors/outdoors: 1995 and 1996.

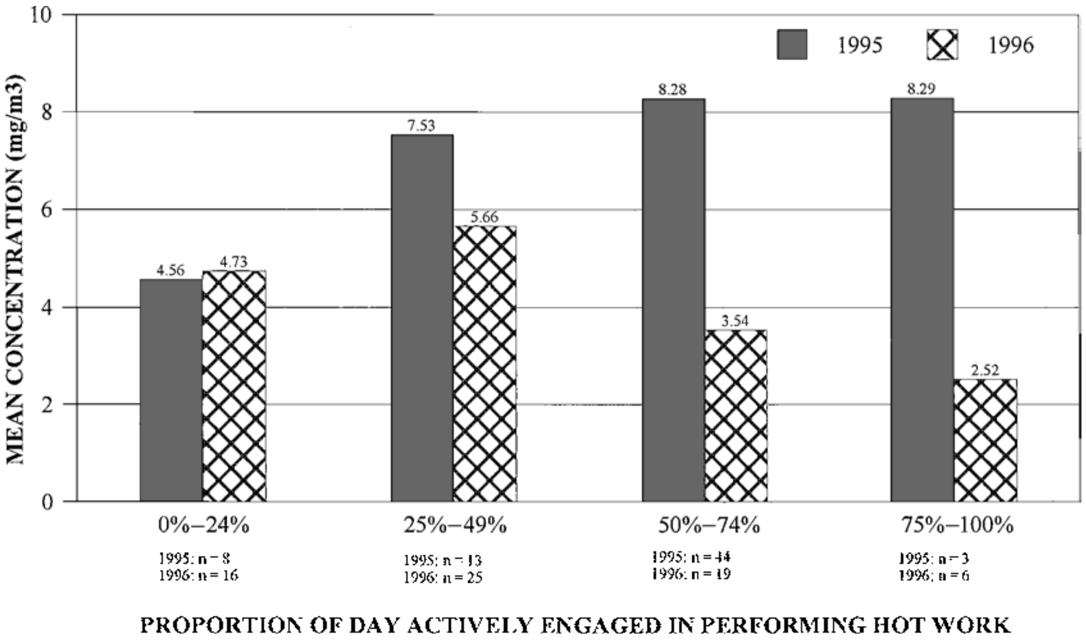

FIGURE 5
Mean total particulate exposure per shift by proportion of day actively engaged in performing hot work: 1995 and 1996.

indoor exposures were significantly lower in 1996 (mean = 2.24 mg/m^3) than in 1995 (mean = 8.75 mg/m^3). This approximate fourfold reduction in sample means many have more to do with use of more effective ventilation equipment in 1996 and the fact that boilermakers were not sampled during this year. However, comparison of exposures associated with work outdoors versus work indoors (Figure 4) illustrates several important concepts relative to exposure assessment in construction. First, our data demonstrate that working outdoors surrounded by natural ventilation (a scenario common to construction) is no guarantee that workers will not be overexposed to hazardous agents. As illustrated in Figure 4, mean exposures were above the OSHA PEL and ACGIH TLV for welding fumes in 1996 and above the TLV for respirable particulate in 1995.

Second, use of local exhaust ventilation (LEV) and mechanical ventilation is much less effective outdoors where ambient air movement is likely to overwhelm the ability of ventilation systems to push or pull contaminant away from the breathing zone of workers. Exposure data from 1996 illustrate this because indoor exposures were approximately half outdoor exposures. We were not successful in introducing LEV onto surveyed job sites until 1996.

Finally, use of ventilation indoors may not be sufficient in enclosed environments where contaminant generation rate exceeds the removal or dilution rate of such equipment. Figure 4 shows that the highest mean exposures were in 1995 when work was done either "indoors" or "both indoors and outdoors." Much of this excess exposure was associated with sampling among boilermakers where multiple welders were working in an enclosed tank much of the day and mechanical ventilation was in use but apparently inadequate for contaminant generation rates.

Regarding the intermittency of the work, Figure 5 suggests that exposures are of concern even when workers spend less than 25 percent of the workday engaged in hot work tasks. Finally, we were able to demonstrate, through a comparison of means, that use of mechanical and/or local exhaust ventilation was effective in reducing exposures to total particulate associated with welding and thermal cutting.

As discussed previously, we were not successful in introducing local exhaust ventilation (LEV) until 1996, which is why we have only presented a comparison of exposures by use of ventilation for this year. The LEV units used were of two types. One was a small portable unit with flexible duct for both capturing and exhausting contaminant. This unit was not equipped with any filtration system, but instead, removed contaminant at the source through a small, circular hood equipped with a magnetic foot that could be quickly and easily positioned on metal stock being welded. The second unit was much larger and equipped with a high efficiency particulate air (HEPA) filter. The body of the unit was supported by a frame with wheels and the hood was attached to an elbow made of rigid steel with a movable elbow joint. All LEV in use during surveys was one of these types of units.

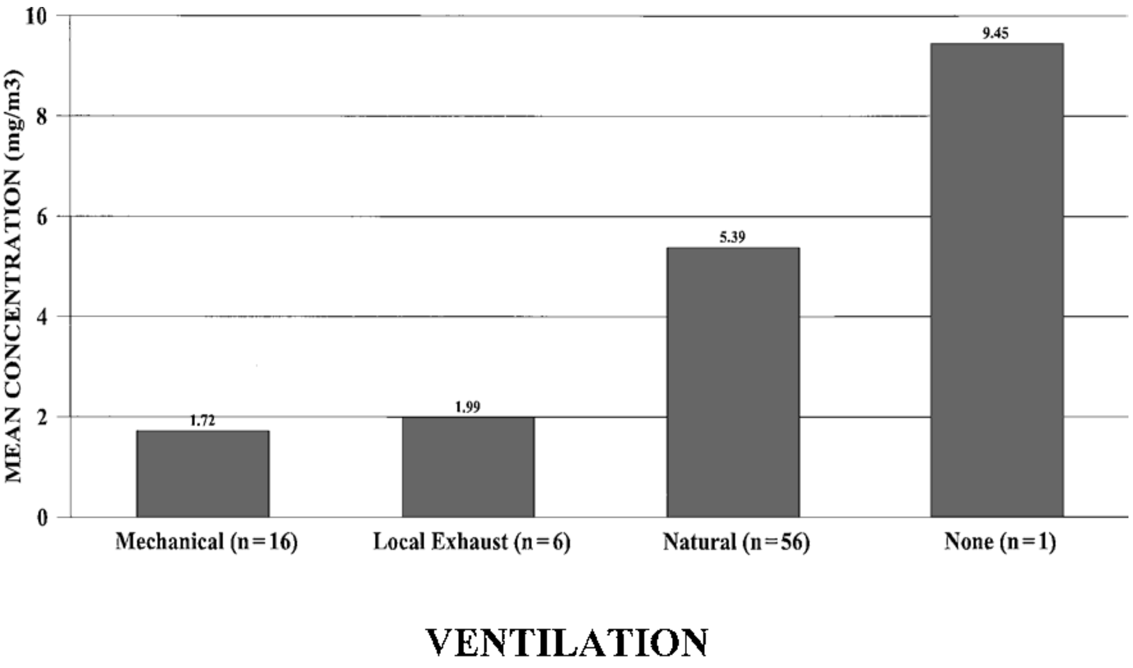

FIGURE 6

Mean total particulate exposure per shift by ventilation: 1996.

Mechanical ventilation in use included fans and blowers. Natural ventilation was defined as outdoor air. When samples were collected indoors but air from outside was able to pass through a window or door opening into the work space, survey teams were instructed to describe ventilation as "natural." If sampled workers were working in an enclosed area without any natural or mechanical ventilation, the category of "none" was used to describe ventilation. The sample mean for 1996 total particulate exposure measurements associated with use of mechanical and local exhaust ventilation was 1.79 mg/m^3 (22 samples) versus 5.46 mg/m^3 (57 samples) for natural or no ventilation. A t-test for the difference in the means of exposure measurements collected with use of local/mechanical ventilation versus natural/no ventilation was highly statistically significant (p-value = 0.0001).

DISCUSSION

Construction workers represent a substantial and unique part of the U.S. workforce. Despite the transient nature of construction work, specialized skills or tasks are typically repeated from job to job within respective trades, particularly in the unionized sector of construction where utilization and organization of skilled labor is well developed. Despite the fact that skills or specialized tasks may remain relatively consistent within certain trades, the conditions that contribute to the nature and magnitude of construction health hazards are perpetually changing, both within the working life of any individual worker and over time as technologies, materials, tools, and market demands shift and evolve. This article describes the first attempt to characterize construction exposure distributions across multiple sites, trades, project types, and regions of the United States.

We have demonstrated two very important general findings that are likely to be independent of the task serving as our initial focus. First, we have demonstrated that exposures among construction trades can be characterized across multiple work sites by collecting data in a systematic, well-organized manner. Secondly, we have provided preliminary results suggesting the importance of task-related variables in affecting exposures among workers in the sampled trades.

The importance of documenting task variables, or "exposure determinants " as part of the exposure assessment process has been well described in the literature.(25) Measuring the impact of exposure variables in a transient workforce is particularly important where the absence of a single employer or fixed work site requires that "exposure scenarios" be constructed either prospectively or retrospectively, depending on use of the data. From the point of view of those in the industry able to influence project/job design, objective data on the performance of engineering and work practice controls is essential for preventing excess exposure to substances that are regulated by OSHA or have been associated with disease.

As evident from the comparison of results to the ACGIH TLVs, there is a significant health hazard to the sampled trades posed by welding and thermal cutting fume, manganese, nickel, and chromium (VI). The most significant task variable for which employers have some control appears to be use of mechanical or local exhaust ventilation. It is important to understand that use of local or mechanical ventilation does not in itself guarantee that regulatory and health concerns will be eliminated. Thus, personal air monitoring for the purpose of verifying the effectiveness of control technologies is essential to a comprehensive exposure assessment and control program. The highest exposures measured during the two years of field surveys involved an enclosed operation with mechanical ventilation.

In the first round of implementing T-BEAM at sites across the country, we were necessarily limited by resources and access to sites. Of course, more extensive assessments at additional sites are necessary to confirm the findings at the sites surveyed. Only one site per trade was surveyed among boilermakers and ironworkers. The vast majority of exposure measurements were associated with pipe fitters engaged in stick welding on mild steel. Among the three trades, pipe fitters had the lowest exposures to total fume and presumably to the constituent metals therein. Because exposure data were weighted toward mild steel, we made a large number of measurements for manganese, but relatively few for other constituent metals such as chromium (both elemental and hexavalent) and nickel, associated with stainless steel, or other metals associated with painted steel.

Despite the limitations of the data, manganese appears to be a metal of concern, particularly for boilermakers whose probability of exceeding the ACGIH TLV was relatively high. More data is needed for ironworkers and boilermakers which were represented at only one site each. More data is also needed for work with stainless steel since only one project involved significant amounts of welding and thermal cutting on stainless steel. Finally, the type of task also appears to affect exposure. For example, total particulate exposure during thermal cutting and thermal cutting/welding combinations were two to three times that associated with welding.

CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE RESEARCH

During 1995 and 1996, a Task-Based Exposure Assessment Model (T-BEAM) was applied to the collection of approximately 400 personal exposure measurements for fumes and metals associated with "hot work tasks," primarily welding and thermal cutting. The use of specially trained journeyman construction workers in tandem with OHs proved to be a very efficient means for collecting large amounts of both qualitative and quantitative exposure data from multiple job sites. Because the participating CSHSs were very familiar with the tasks being investigated, they were particularly conversant in the variables of interest and adept at finding and communicating with the workers sampled.

Not only has the use of specially trained construction workers proven effective in collecting exposure data in various construction sectors, many industry representatives have come to view the training and participation of workers in assessing job site exposures as a critically important sub-objective of our overall effort. With the use of trained workers as a key characteristic of T-BEAM, the project is unique because it has begun to build institutional expertise within the industry (employers, unions, and workers), to assess their own occupational health exposures from job site to job site. In short, T-BEAM has allowed us to collect task-based data to characterize exposure and at the same time build institutional expertise/resources within industry to recognize hazards and implement controls to reduce exposure.

Through analysis of this data we have demonstrated the following:

- Data can be collected in a standardized, systematic fashion to characterize exposures in construction, even in the absence of a fixed work site.
- The probabilities that measured exposures exceeded OELs were extremely high in some cases, particularly for boilermakers and ironworkers.
- Use of mechanical and local exhaust ventilation significantly reduced exposures to welding fumes.

Our experience in the collection and analysis of the data described by this article lead us to recommend that occupational hygienists, labor organizations, contractor associations, and government interests responsible for occupational safety and health research and training consider the following needs and how they might answer those needs:

- Additional exposure data, particularly for those trades, processes, and metals that are poorly represented in the T-BEAM database, are needed to better characterize exposure risk among construction trades.
- Joint labor/management funds in the construction industry should consider use of T-BEAM survey methods, materials, and centralization of collected data and analysis to maximize the value of information derived from personal air monitoring of employees.
- Development of journeymen technicians able to assist occupational hygienists in the assessment and control of occupational health hazards should be a priority within the industry and among government agencies charged with skills development, worker training, and occupational health and safety responsibilities.
- More implementation and evaluation of local exhaust ventilation as well as other engineering controls is needed to reduce exposure to welding fumes in the variety of work settings in which construction workers are employed.
- Exposure assessment efforts for construction hazards should involve systematic collection of descriptive information as well as personal exposure measurements to allow for development of exposure scenarios and to determine which variables might be important determinants of exposure risk.

ACKNOWLEDGMENTS

This work was conducted through a cooperative agreement with NIOSH (grant no. U02/CCU312014). We are indebted to a large number of researchers, labor representatives, and contractors who have assisted in this effort by providing their expertise, cooperation, and time. Because of the large number of individuals involved, it is impossible to acknowledge everyone.

Sub-grantees to CPWR who have been essential in the conceptional development of T-BEAM and carrying out much of the work include the Occupational Health Foundation, Mount Sinai School of Medicine, and West Virginia University. The Building and Construction Trades Department, AFL-CIO and its affiliates, particularly the Plumbers and Pipefitters, the Ironworkers and Boilermakers, have assisted us not only with obtaining access to construction projects but also identifying knowledgeable journeyman who were vital to the collection of the data described by this article.

Several individuals at NIOSH have given generously of their time in our efforts to develop and use T-BEAM. We are particularly grateful to Dennis O'Brien, Ken Mead, and Margie Wallace who assisted us with identifying and evaluating control technologies. Steve Rappaport provided a thorough edit of our original manuscript and has been an essential resource in analysis of collected data. Finally, we acknowledge the significant contribution made by Sherri Wilson, not only in preparation of this manuscript, but, more importantly, in creating and maintaining the rich database of information which serves as the foundation for the work described.

REFERENCES

1. Susi, P.; Schneider, S.: Database Needs for a Task-Based Exposure Assessment Model for Construction. Appl Occup Environ Hyg 10(4):394–399 (1995).
2. Greenspan, C.A.; Moure-Eraso, R.; Wegman, D.H.; et al.: Occupational Hygiene Characterization of a Highway Construction Project: A Pilot Study. Appl Occup Environ Hyg 10(1):50–58 (1995).
3. Goldberg, M.; Levin, S.M.; Doucette, J.T.; et al.: A Task-Based Approach to Assessing Lead Exposure Among Iron Workers Engaged in Bridge Rehabilitation. Am J Ind Med 31:310–318 (1997).
4. Sullivan, P.A.; Bang, K.M.; Hearl, F.J.; et al.: Respiratory Disease Risks in the Construction Industry, vol. 10, no. 2, Occupational Medicine: State of the Art Reviews. Hanley & Belfus, Inc., Philadelphia (1995).
5. Robinson, C.; Stern, F.; Halperin, W.; et al.: Assessment of Mortality in the Construction Industry in the United States, 1984–1986. Am J Ind Med 28:49–70 (1995).
6. Sjögren, B.; Ulfvarson, U.: Respiratory Symptoms and Pulmonary Function Among Welders Working with Aluminum, Stainless Steel and Railroad Tracks. Scand J Work Environ Health 11:27–32 (1985).
7. American Industrial Hygiene Association (AIHA). Welding Health and Safety Resource Manual. AIHA, Akron, Ohio (1984).
8. National Institute for Occupational Safety and Health: Criteria for a Recommended Standard—Welding, Brazing and Thermal Cutting. DHHS (NIOSH) Publication No. 88-1101. NIOSH, Cincinnati, OH (1988).

9. Hobart Material Safety Data Sheet, Troy, Ohio. Revised December 1990.
10. Nelson, K.; Golnick, J.; Korn, T.; et al.: Manganese Encephalopathy: Utility of Early Magnetic Resonance Imaging. Br J Ind Med 50:510–513 (1993).
11. Roels, H.; Lauwerys, R.; et al.: Epidemiological Survey Among Workers Exposed to Manganese: Effects on Lung, Central Nervous System, and Some Biological Indices. Am J Ind Med 11:307–327 (1987).
12. Wang, J.D.; Huang, C.C.: Manganese Induced Parkinsonism: An Outbreak Due to an Unrepaired Ventilation Control System in a Ferromanganese Smelter. Br J Ind Med 46:856–859 (1989).
13. The Center to Protect Workers' Rights: Workers' Compensation Is Awarded to Welder Who Has Parkinson's Disease. Impact on Construction Safety and Health 15(2):3 (1997).
14. International Agency for Research on Cancer: IARC Mographs on the Evaluation of Carcinogenic Risks to Humans, Chromium, Nickel and Welding, volume 49. IARC, Lyon, France (1990).
15. Bureau of Labor Statistics, U.S. Department of Labor: Employment and Earnings. Government Printing Office, Washington, D.C. (1996).
16. Bureau of the Census: Statistical Abstract of the United States: 112th ed. Bureau of the Census, Washington, D.C. (1992).
17. Ringen, K.; Stafford, E.J.: Intervention Research in Occupational Safety and Health: Examples from Construction. Am J Ind Med 29:314–320 (1996).
18. National Institute for Occupational Safety and Health: NIOSH Method 0500: Total Particulates not Otherwise Regulated. In: NIOSH Manual of Analytical Methods. NIOSH, Cincinnati, OH (1994).
19. National Institute for Occupational Safety and Health: NIOSH Method 7300: Chromium Elements by ICP. In: NIOSH Manual of Analytical Methods. NIOSH, Cincinnati, OH (1994).
20. National Institute for Occupational Safety and Health: NIOSH Method 7600 Modified: Chromium, Hexavalent. In: NIOSH Manual of Analytical Methods. NIOSH, Cincinnati, OH (1994).
21. Burgess, W.A.: Recognition of Health Hazards in Industry—A Review of Materials and Processes, 2nd ed., pp. 194–195. John Wiley and Sons, Inc., New York (1995).
22. American Conference of Governmental Industrial Hygienists (ACGIH): Documentation of the Threshold Limit Values and Biological Exposure Indices, 60th ed., pp. 1726–1727. ACGIH Inc., Cincinnati, OH (1991).
23. ACGIH: Documentation of the Threshold Limit Values and Biological Exposure Indices, 60th ed., Supplement: Particulate (Insoluble) pp. 1–5. ACGIH Inc., Cincinnati, OH (1996).
24. Rappaport, S.M.; Weaver, M.; Taylor, D.; et al.: Application of Mixed Models to Assess Exposures Monitored by Construction Workers During Hot Processes. Annals of Occ Hyg 43(7) (1999).
25. Gomez, M.R.; Rawls, G.: Conference on Occupational Exposure Databases: A Report and Look at the Future. Appl Occup Environ Hyg 10(4) (1995).