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BEHAVIORAL TECHNOLOGY FOR REDUCING OCCUPATIONAL EXPOSURES TO STYRENE

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We conducted a test of the usefulness of behavioral methods to control occupational health problems by reducing workers' exposures to toxic chemicals. Four plastics workers were trained in nine behaviors selected for potential to reduce their exposures to styrene, a common chemical with multiple toxic effects. Behavioral measures indicated that the workers quickly came to emit most of the behaviors. Measures of air samples indicated that large decreases in exposures to styrene accompanied the changes in behaviors for the three workers who had been selected because they most needed relief from their exposures and because they had opportunities to control their exposures by the ways they behaved.

DESCRIPTORS: occupational health, styrene exposures, industrial workers, worker training and maintenance, exposures to toxic chemicals

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Epidemiological research indicates that lung disease and cancer are the most important occupational health problems in the United States (National Institute for Occupational Safety and Health [NIOSH], 1983b) and has identified multiple factors as likely contributors to these diseases. Exposures to toxic substances are, by definition, assumed to be particularly dangerous (Bingham, Niemeier, & Reid, 1976).

Engineering controls, physical or chemical means for keeping the substances and people apart, are the common methods of minimizing workers' exposures. In contrast, occupational safety and health professionals often reject control methods that directly involve human behavior because they assume such methods to be less reliable (see Day & Misaqi, 1976, for example). Consistent with these relative emphases, there is a well-developed technology of engineering control methods for many industries (see NIOSH, 1978, for example), but recommendations for behavior control technology are often no more than common sense or suppositions about ways in which behaviors may relate to exposures (see NIOSH, 1983a, for example).

Behavioral safety research can usually use, over relatively short periods of time, data on accidents and injuries as outcome measures to validate behavior control technology and changes in behaviors. For example, Van Houten, Rolider, Nau, Freidman, Becker, Chalodovsky, and Scherer (1985) determined that feedback signs and warning ticket programs lowered the speed of automobiles, and they found that large reductions in the rates of accidents and injuries accompanied the reductions in speed. However, many occupational health problems, including most lung diseases and cancers, develop only after many years of exposure and involve irreversible diseases. Therefore, research cannot practically or humanely use the incidence of the diseases as an outcome measure.

Identification of toxic agents for diseases that appear after long delays typically depends on laboratory and epidemiological research. Subsequent field research aimed at control of the diseases uses measures of exposures to these toxic agents as out-

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Dangel is now at the Graduate School of Social Work, University of Texas at Arlington, and Smith is at the Department of Industrial Engineering, University of Wisconsin at Madison. Albert Stewart, an industrial hygienist, helped to identify the selected work behaviors and to establish the air sampling procedures. Ken Hans patiently taught us the details of the manufacturing processes. Rick Hornung analyzed certain data, and Robert Mason and Don Bushell reviewed the manuscript.

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comes. Therefore, behavioral research on these problems must use the novel combination of technology for controlling and measuring behavior with technology for measuring chemical exposures.

We investigated the use of behavioral methods to reduce exposures to styrene, a common industrial chemical that has multiple toxic properties. Styrene, $C_6H_5CH{=}CH_2$, can enter the body by inhalation, ingestion, and absorption through the skin. Because exposures greater than 100 parts per million (ppm) irritate the eyes and nose (NIOSH, 1983a); because long-term exposures can produce neurological damage (Harkonen, Lindstrom, Seppalainen, Asp, & Hernberg, 1978); because styrene is a mutagen (Loprieno et al., 1978; Milvy & Garro, 1976; Stoltz & Withey, 1977; Vainio, Paakkonen, Ronnholm, Raunio, & Pelkonen, 1976); and because it is a possible carcinogen (Frentzel-Beyme, Thiess, & Wieland, 1978; Jersey et al., 1978; National Cancer Institute [NCI], 1979; Nicholson, Selikoff, & Seidman, 1978; Ponomarkov & Tomatis, 1978), the federal standard, or assumed safe exposure, for styrene is an 8-hr, time-weighted average (TWA) of 100 ppm (Occupational Safety and Health Administration [OSHA], 1976). NIOSH (1983a) has published a recommendation to OSHA that the standard be changed to 50 ppm, TWA.

United States industries produce approximately 7,500,000,000 pounds of styrene each year. NIOSH estimates that at least 30,000 workers in 1,000 plants are exposed to styrene full-time in the manufacture of products such as automobile tires, boats, imitation marble, plastic furniture, surgical instruments, and costume jewelry. Another 300,000 workers periodically contact styrene-containing compounds such as floor waxes, paints, and auto body fillers. The highest exposures are estimated to occur in the fiberglass-reinforced plastics manufacturing industry (NIOSH, 1983b), the focus of this research.

METHOD

Setting and Orientation

The management of LABCONCO, Kansas City, Missouri, a manufacturer of laboratory equipment, elected to allow company employees to participate in the research. Eighteen hourly employees worked in the department that made fiberglass-reinforced plastic parts. The research staff met with the production workers to discuss what was known about the effects of styrene, to describe the general purposes of the research, and to ask for their cooperation.

Manufacturing Processes

Manufacturing involved a series of steps performed by different individuals. First, a worker called a gelcoater sprayed a mixture of pigmented polyester resin and styrene monomer onto a mold with a spray gun that introduced a catalyst into the mix. After the gelcoat layer had polymerized, a worker called a chopper sprayed reinforcing laminations of a resin-styrene mixture onto the gelcoat layer with a gun that again introduced a catalyst and also mixed chopped fibrous glass into the spray. A worker called a rollout next rolled the mixture with metal rollers that removed any gas bubbles in the resin and ensured that the components of the laminations were thoroughly intermixed (*Modern Plastics Encyclopedia,* 1974).

Other workers included mold pullers, who pulled the laminated parts from the molds; trimmers, who sawed and sanded the parts; and finishers, who drilled, assembled and cleaned the various parts. A repairer patched and recycled the molds that were made of particularly hard fiberglass-reinforced styrene plastic.

A part might become the white shell of a laboratory fume hood or bacteriological glove box or the blue front of a cabinet, depending on the color of the pigmented resin and the shape of the mold.

Determination of High Exposure Areas and Jobs

The research staff used momentary air samples, commonly called grab tube samples, to determine styrene concentrations while the workers performed the different jobs in the various parts of the department. The staff collected and analyzed air samples with a Bendix, Model 400, Gastec pump and Zink Styrene detector tubes. This method samples only 100 ml volumes of air over 30-s periods of time with an accuracy of ±25% to 35%. The method was sensitive and accurate enough to determine areas and operations with relatively high exposures because styrene levels in the plant varied by as much as a factor of about 150.

The highest exposure areas and operations, with momentary concentrations of 110 to 280 ppm, were the spray booths at the times the gelcoat mixture and the resin-chopped fibrous-glass mixture were being sprayed onto the molds. The spraying processes were the source of much of the styrene in the air inside the plant. The rollout and curing areas also yielded relatively high momentary concentrations of styrene, ranging from 70 to 170 ppm. Workers in other jobs such as mold repairing and parts finishing had momentary styrene exposures ranging from 2 to 20 ppm. Their exposures primarily resulted from the styrene that drifted about the plant after being introduced by the spraying and curing operations.

Subjects

The research staff asked the gelcoater, the chopper, and the rollout to participate as subjects because they worked in the high exposure jobs and most needed relief from the levels of styrene they were encountering. They also asked the repairer to participate to see if the selected work behaviors would reduce the exposures of a person who was primarily contacting styrene as a result of the ambient concentrations in the plant. All four workers agreed to participate in the research and signed statements of informed consent.

The gelcoater quit his job for better employment after 3 days of data collection. A second worker bid on the job on the basis of seniority. After 5 days of data collection, this second person declared that he liked his previous job better and returned to it. A third person worked as the gelcoater for the remainder of the experiment. These three workers will be referred to as Gelcoater A, B, and C, respectively.

Identification of Potentially Important Behaviors

The research staff observed the work of the four selected people to identify behaviors that might increase or reduce exposures to styrene. In some cases, we simply conjectured about how alternative behaviors might affect exposures to known sources of styrene. In other cases, we collected grab tube samples as a worker performed a job in different ways. These procedures identified nine potentially important behaviors: (a) the gelcoater and chopper activating the spray booth exhaust fans and the rollout and repairer activating floor fans, which forced air across their work areas (creating airflows through the work areas to dilute and remove styrene gas and vapors); (b) all four workers placing the molds on which they were working in the airflows created by the fans (preventing the styrene gas and vapor created by the work from remaining in the area of the workers); (c) the gelcoater and chopper spraying in the direction of the airflow and all workers staying on the upwind sides of molds (causing the styrene to blow away from, rather than toward, the workers); (d) all four workers wearing organic vapor respirators when they worked with sources of styrene; (e) all workers covering their hands with gloves that were impervious to liquids and their arms with long-sleeved shirts or blouses; (f) all four workers turning their work so that they could remain on the upwind side of it; and (g) the two sprayers closing the spray booth doors when they were working with styrene (increasing the airflows produced by the exhaust fans); (h) the two sprayers directing their guns so that at least 50% of the cone of spray fell on the molds or parts being sprayed (decreasing the amount of styrene vaporized into the air and reducing the amount of styrene that would evaporate from overspray); (i) the two sprayers directing their guns so that the center of the cone of spray came no closer than 90° to the direction of another worker in a spray booth (reducing the amount of styrene in the air around other workers).

Data Collection

Data were collected on 17 days for each of the four workers, with certain exceptions: the chopper was absent from work on Day 7 and the rollout on Days 2, 7, 15, and 16; the repairer worked in the presence of styrene-containing resin and was, therefore, eligible for data collection only on Days

4, 8, 9, 12, and 15. Data were collected only on Tuesdays, Wednesdays, and Thursdays during successive weeks because work activities were more regular on those days.

On each of the 17 days, four kinds of data were collected: (a) observations of behaviors identified as potentially important to controlling exposures, (b) measures of the workers' exposures to styrene, (c) measures of production accomplished, and (d) observations of the amount of time spent working.

Observation procedures. Five observers practiced using definitions of the behaviors and observing the workers while recording whether or not the indicated behaviors occurred during successive 15-s intervals. Practice continued until any two observers who were simultaneously but independently recording the behaviors of any worker obtained records that agreed on at least 95% of the intervals for every behavior.

A trained observer watched each worker throughout each day on which data were recorded. However, observers collected data only when the workers were in the presence of curing resin or were in the spray booths while the guns were being operated. These procedures resulted in 48 to 243 min of data collection each day the gelcoater, chopper, and rollout were at work. However, there were several days, as noted above, on which the repairer worked but was never in the presence of sources of styrene.

An observer remained within 6 m of a worker, in a position to see the worker, but outside the areas of high styrene concentrations, whenever the worker was in the defined work area. The observer scored whether or not each of the selected behaviors occurred at any time during each 15-s period the worker was in the presence of a source of styrene.

During 18% of all observations, at randomly selected and unannounced times, a second observer, using the same observation procedures and definitions, independently recorded a worker's behaviors simultaneously with the primary observer. The interobserver agreements on intervals of occurrence of specific behaviors were 94% for the chopper, 98% for the rollout, and 97% for the gelcoater, with the percentages based on intervals aggregated over all behaviors and days. The percentages of agreement for individual behaviors were greater than 90 every day for all of the behaviors of every worker. The percentages of agreement exceeded chance agreement for every dual observation for all behaviors with the exceptions of those during which the behaviors were recorded as occurring in 100% of the observation intervals (Hopkins & Hermann, 1977).

Exposure to styrene. Measures of the workers' exposures to styrene were made by collecting air samples from the workers' breathing zones. The workers wore battery-energized Bendix BDX Super Sampler air pumps from waist belts. The pumps were calibrated to draw air through flexible hoses and activated charcoal filters located at the ends of the hoses at a rate of 50 cc per min. The filters were clipped to the workers' collars so that the apertures to the filters were 10 cm from their mouths when their faces were oriented straight ahead.

The observers turned on the pumps whenever the workers began to work in the presence of sources of styrene and turned them off when the workers stopped, thus, providing air samples at the same times observations of behaviors were made. A commercial laboratory accredited by the American Industrial Hygiene Association used NIOSH P&CAM method #127 (NIOSH, 1977), with ethylbenzene as an internal standard, to analyze the contents of the charcoal tubes. Duplicate samples were sent to the laboratory to test the reliability of this measure. The differences between duplicate samples were always less than 10%.

Production. The observers used calibrated sticks to measure the amount of gelcoat and resin used each day from the barrels in which they were supplied. Duplicate, independent measures of these quantities yielded reliabilities above 97%. A daily estimate of production accomplished by each worker was determined by dividing the number of pounds of gelcoat and resin used in the work areas by the number of minutes worked.

Working. The observers collected data on two additional behavioral measures, the number of minutes each worker engaged in assigned jobs and the percentage of observation intervals in which a worker engaged at any time in work behavior.

Training and Maintenance

The observers collected data during several baseline or pretraining days. At the end of baseline, data collection continued, and one member of the research staff, functioning as a trainer, met once with individual workers in their work areas for 10 to 15 min, at the beginning of a day's work shift. The trainer described each of the recommended work behaviors and explained how each behavior might be useful to reduce exposures to styrene. If a worker indicated a lack of understanding of a recommended behavior, the trainer modeled the behavior. The trainer remained with the worker during the first 10 to 15 min of work to praise use of the recommended behaviors and to provide reminders whenever a behavior did not occur in a situation for which he had recommended it.

After the initial training and throughout the remainder of the research, the trainer visited each worker briefly (1–2 min) twice a day while they were working. During these visits, the trainer praised a worker for recommended behaviors he had seen occur and gave suggestions if he had seen the worker fail to behave in a way that he had recommended for a particular situation.

Experimental Design

The training and maintenance procedures began according to a multiple baseline design (Baer, Wolf, & Risley, 1968) with different starting days for different workers. Baseline data were collected for all workers for 8 days. The trainer then trained the chopper and the rollout. Baseline continued for the gelcoater and repairer for the next 3 days, and then they were trained.

RESULTS

Exposure-Related Behaviors

Figure 1 shows the percentage of intervals each of the nine recommended work behaviors was recorded as occurring for the indicated workers across days of the study. Most of the behaviors that were not already occurring regularly during baseline quickly improved following training. These improvements included: all four workers placing the molds to make use of the exhaust ventilation and using the airflow in the work areas; the chopper, rollout, and gelcoater covering their skin with gloves and sleeves; both sprayers closing the spray booth doors and directing the guns so that most of the spray fell on the molds; the rollout and repairer activating the floor fans; and the chopper not spraying toward other workers.

The data on workers turning their work to allow them to remain on the upwind side of sources of styrene suggests that training had no effects on that behavior. In fact, there are but slight increases in the percentage of intervals in which the chopper, rollout, and gelcoater turned molds. The workers needed to turn their work very infrequently to remain upwind of styrene concentrations.

The percentage of intervals in which Gelcoater C wore a respirator increased abruptly following training. However, there were no improvements for the other three workers.

Exposures to Styrene

Figure 2 shows the daily air sample data. During baseline, the mean parts of styrene per million parts of air obtained from the breathing zone of the chopper was 150 with a slight decreasing trend. Following training, the mean was 96 ppm, for a pre- to posttraining decrease of 36%. The baseline mean for the rollout was 121 ppm and the posttraining mean 70 ppm for a 42% decrease. The mean posttraining exposure of Gelcoater C was 91 ppm, a 57% decrease from his baseline mean of 210 ppm and a 51% decrease from the baseline mean of 184 ppm, averaged over all of the gelcoat sprayers. Following training the exposures of the repairer declined slightly from a relatively low baseline mean of 24 ppm.

Production

Immediately following training, temporary decreases, ranging from about 5% to 15%, occurred in the productivity of the chopper and gelcoater,

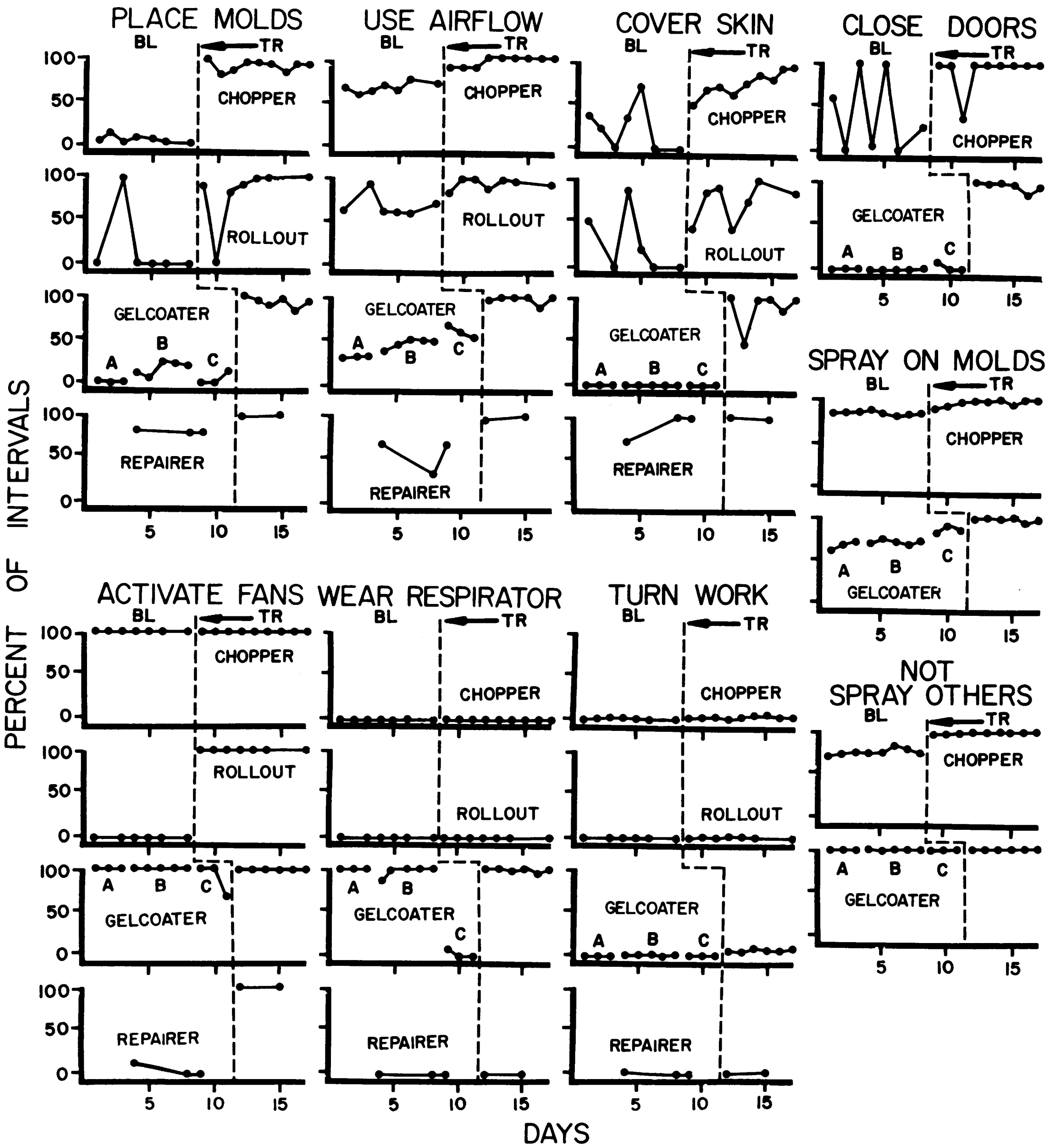

Figure 1. Percentage of intervals during which the observers recorded each of the indicated behaviors for each of the workers. Missing data points indicate that workers were absent or did not work with sources of styrene. BL indicates the baseline period and the vertical dashed line marked TR indicates the point at which training occurred.

as measured by the pounds of resin and gelcoat processed per minute. However, their rates of production subsequently increased so that, by the end of data collection, they were slightly higher than during baseline. The pounds of resin processed by the rollout were yoked to the productivity of the chopper because they worked with exactly the same parts. The repairer's production data did not change from baseline to posttraining.

Working

The data on the percentage of intervals each of the workers engaged in assigned tasks, given that they were in the work areas, and the amount of time they spent in the work areas did not change from baseline to posttraining periods. The only striking differences involved those among the three gelcoaters during the baseline period. Gelcoater B, who had bid on the job but subsequently asked to be reassigned to other work, spent much less time working than did either of the other two gelcoaters. Otherwise, all the workers worked from 90% to 100% of observation intervals during both baseline and posttraining periods.

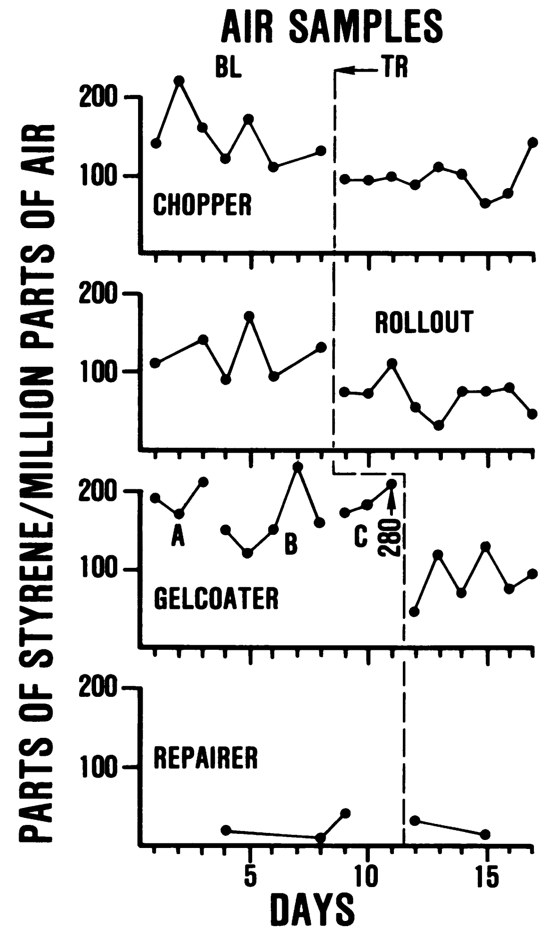

Figure 2. Parts of styrene per million parts of air in the samples taken from the workers' breathing zones.

DISCUSSION

Simple on-the-job training and maintenance procedures that required little time reliably produced most of the behavior changes selected as being potentially useful for the workers. Sizable reductions in measures of exposures to styrene accompanied the behavioral changes for the three workers identified as having the best opportunities to control their exposures.

Reactivity of the data may compromise the apparent effectiveness of the training and maintenance procedures. The presence of the elaborate data collection procedures may have been a necessary condition for the obtained results. This kind of limit is a hazard of most applied behavioral research.

The research necessarily raises many questions about the durability of the changes in behaviors, the relative effectiveness of the different behaviors, and the susceptibility of other industries and other behaviors to this kind of approach. The procedures maintained the changed behaviors for only a few days following training, and no further claims for durability can be made. The research staff generally speculated that the most important behaviors were the ones that created and took advantage of airflows. However, only research comparing the various component behaviors can validate this speculation.

The reader should view the expected negative results for the repairer with caution. The prediction that the procedures would have little effect for him was based on the assumption that only those workers who dealt directly with styrene and styrene-containing substances would have good behavioral opportunities to control their exposures. The usefulness of this assumption is unknown. The results for the repairer showed that he emitted most of the selected behaviors and only infrequently dealt directly with styrene. The sample may have been too limited to be a fair test for reductions in exposures.

The training and maintenance procedures were quite simple; personnel in most plants should be able to replicate them. However, they were surely less than maximally effective. The changes in behaviors and the reductions in exposures might be viewed as all the more impressive in light of the simplicity of the independent variable.

The failure to promote better respirator usage is consistent with the common observation that respirator usage is notoriously disagreeable to some workers because of the discomfort and inconvenience caused. In fact, in the research reported here, one of the workers commented unequivocally, as soon as that practice was mentioned during training, that he would not wear a respirator. Perhaps stronger behavioral procedures such as those used to encourage use of ear protection (Zohar, Cohen, & Azar, 1980; Zohar & Fussfeld, 1981) can be adapted to improve respirator usage if that is an important behavior. In any case, the reader should note that more reliable wearing of respirators would not have further reduced the measure of styrene used in this research because the charcoal filters that collected styrene-containing air would not have been covered by any commonly used respirator.

The research casts doubt on the generality of claims that engineering control methods are to be preferred at the expense of behavioral control methods. The common engineering controls for reinforced plastics manufacturing processes are the use of booths to contain the styrene and exhaust ventilation to remove it from the booths and to dilute the styrene levels in the air in the booths. LABCONCO used both of these engineering methods. However, reliable behavioral controls that took advantage of existing engineering controls clearly improved the protection of the most seriously exposed workers. Only further research can define the range of ways in which engineering and behavioral control can interact.

There may have been temporary declines in productivity for two of the workers, the chopper and the rollout, following training. However, even if the temporary declines in production were a result of the changes in work behaviors, they were not great and the baseline rates recovered after 4 days. The workers spent steady amounts of time in the work areas, and they worked most of the time they were in the work areas before and after introduction of the changes in behaviors. The fact that there were no important changes in productivity and time spent working is promising because ready company acceptance probably demands that there be no serious disruption of the work flow, and good worker acceptance probably demands that recommended behaviors not be too time consuming.

This research extends a considerable literature on behavioral approaches for occupational safety (Sulzer-Azaroff, 1982) to occupational health problems that involve exposures to toxic substances. The behavioral approach to occupational health requires a novel wedding of measurement technologies for behaviors and chemical exposures. It is interesting that the two kinds of measures had comparable reliabilities in this study. However, exposure-measuring technology is more widely described in the occupational health literature and is protected by government standards (NIOSH, 1977).

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