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Prevention Strategies in Industrial Hygiene: A Critical Literature Review

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Little is known of the extent of use of industrial hygiene prevention and control strategies in actual workplaces. The recent occupational safety and health literature was identified as a potential source for identifying which strategies are being utilized and evaluated as a means of controlling or preventing chemical hazards. Using preestablished selection criteria, the peer-reviewed industrial hygiene literature 1994–1999 was searched for articles describing prevention and control strategies for chemical hazards in actual workplaces. Ninety-two articles were found and categorized by the type of strategy discussed, whether strategies were implemented and evaluated, and by several other categories. Almost three-quarters discussed engineering control strategies, mostly local exhaust ventilation. Administrative strategies, including housekeeping, personal hygiene, and medical surveillance, appeared in about half the articles. Personal protective equipment was considered in one-third of the articles, and primary prevention strategies, such as material substitution, were considered in one-quarter. Intervention effectiveness was not consistently evaluated in these articles. In response to these findings, recommendations are made to improve the evaluation and promotion of effective prevention and control strategies.

Keywords: controls, industrial hygiene, literature review, prevention

In 1980 the *Annals of Occupational Hygiene* published an article by C.M. Hammond on dust control concepts that included a survey of the industrial hygiene literature.[1] He lamented the lowly status conferred on prevention and control in the field of industrial hygiene and, to prove his point, produced a table showing that less than 8% of the articles in one journal discussed "environmental control," whereas 40% were devoted to environmental monitoring. He wrote: "One would hope in 10–20 years' time to be able to look back and find the monitoring and environmental control rankings reversed. . . .This would place monitoring nearer its correct position as a back up to good environmental control."

Taking Hammond's hope as a challenge, and as part of a study of the role of prevention in industrial hygiene practice, the authors searched the recent industrial hygiene literature for articles describing prevention and control strategies in actual workplaces. Each article was assessed to determine (1) which strategies (substitution, ventilation, personal protective equipment, etc.) were discussed and/or employed to address actual workplace hazards; and (2) the extent to which prevention and control strategies were evaluated for their effectiveness. Other information about the hazard prevention and control strategies, described later in this article, also was categorized.

Little is known about the extent of use of prevention and control strategies in actual workplaces. Only two reports of hazard prevention and control practices were identified. The first, the National Occupational Exposure Survey conducted between 1981 and 1983, found that 21% of the companies surveyed had undertaken equipment or process modifications to reduce worker exposures in the previous 5 years. Fifteen percent of companies surveyed had undertaken chemical substitution.[2] The second report described an occupational health clinic's industrial hygienists' recommendations in 206 consultations in response to sentinel health events in a variety of businesses.[3] The investigators found

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that industrial hygienists recommended engineering controls in 49% of the cases, administrative strategies in 20%, personal protective equipment in 16%, material substitution in 8%, and training in 7%. The consulted companies did not implement all of the recommendations. They were most likely to implement administrative strategies (64% of recommendations were implemented), followed by personal protective equipment (51.5%), engineering controls and training (each 50%), and material substitution (25%).

Previous comprehensive literature reviews have focused on safety or ergonomic interventions.[4] The literature review in this report is unique in that it addresses the control and/or prevention of health hazards from chemical exposures. Additionally, the literature review described here contributes to the limited body of research on "intervention effectiveness" in occupational safety and health by surveying hazard prevention and control strategies and their evaluation as described in the industrial hygiene literature.

Intervention effectiveness research has been targeted as a priority research area by the National Occupational Research Agenda (NORA).[5] NORA urges the evaluation of the effectiveness of hazard prevention and control strategies "to assure better use of limited resources in workplace applications of control and prevention strategies." Goldenhar et al.'s recent article details recommended methods and theoretical guidelines for intervention effectiveness research in occupational safety and health.[6] Other authors, notably Goldenhar et al.,[7] Robson et al.,[8] Shannon et al.,[9] and Zwerling et al.,[10] also have contributed methodology and critical perspectives on intervention research.

METHODS

The occupational safety and health literature 1994–1999 was searched for articles describing control or prevention strategies for chemical hazards in actual workplaces. The search was conducted in the NIOSHTIC, MEDLINE, and Applied Science and Technology Abstracts databases, as well as the tables of contents for the major journals publishing English-language, peer-reviewed industrial hygiene articles. The search terms included: *control, prevention, engineering, ventilation, substitution,* and *respirator* in an "or" Boolean search. Articles covering agricultural and mining workplaces; physical, safety, ergonomic, or biological hazards; and general or laboratory studies of control strategies not related to specific workplaces were excluded. Articles that were not peer-reviewed, such as those appearing in case study reports in journal columns, also were excluded. A final sample of 92 articles was obtained by this screening process.

Each article was abstracted in a form that included fields for bibliographic information; industrial process, including two-digit SIC code; hazard addressed; study purpose; and the categories described later in this article. As shown in Table I, the articles were assessed in five categories: hierarchy of controls, existing controls, new strategies, costs and environment, and types of strategies. The first items related to the hierarchy of controls: were strategies compared and was the hierarchy explicitly considered? (See Figure 1.) The review then distinguished between articles that evaluated existing controls versus those in which a new intervention was discussed. For both existing controls and new strategies, the reviewer determined whether the discussed strategies had been evaluated for their effectiveness. The next part of the review evaluated which type of control or prevention method was discussed in the article and whether it had been implemented or simply suggested as a possible strategy by the authors. If costs and/or environmental concerns were considered in the articles, this also was noted on the form. Descriptive statistics were compiled based on these categories.

Following a preliminary evaluation of the findings by the first author (CR), a test was conducted to attempt to validate the evaluation process and data collection instrument. A second reviewer (ME) utilized the evaluation instrument to review 10 randomly selected articles. The results of the second reviewer were compared with those of the first and poor correlation was found via a direct comparison of responses and by Cohen's kappa test.[11] The evaluation instrument was redesigned to help clarify the categories, and more specific definitions were provided. A second review of the articles with the redesigned evaluation instrument was conducted, and a second validation test was conducted. A 75% agreement (direct comparison) was achieved with the second instrument. The results presented below are from the second review.

RESULTS

The results of this study are presented in Table I. The 92 articles appeared in 12 different journals; however, 62% were published in either *Applied Occupational and Environmental Hygiene* or *American Industrial Hygiene Association Journal.* Although all articles included in this review discussed hazard prevention and/or control issues, 42% of the articles had these issues as their primary focus. Exposure assessment was the primary focus of 25% of the articles. Exposure assessment articles generally limited their discussion of hazard control and prevention to a list of recommendations and did not examine implementation or evaluation of these strategies. Those articles addressing both hazard control/prevention and exposure assessment comprised 29% of the total.

The articles reviewed discussed a wide variety of chemical hazards. Multiple chemicals, lead, and carbon monoxide were the more frequently cited hazards. Manufacturing facilities were the subjects of 40 articles; the service sector was discussed in 26 articles, and construction and multiple sectors each contributed 10 of the sites in the sample. Fifty-eight percent of the articles described individual cases; the remainder discussed multiple workplaces.

Only two articles explicitly discussed the hierarchy of controls, and four compared different strategies for the control or prevention of a particular hazard. In 76% of the articles the authors discussed control or prevention strategies that already existed in the workplaces under study. The effectiveness of existing controls was evaluated in 53% of the articles. In 60% of the cases in which strategies were evaluated, the existing controls were deemed effective or judged effective with limitations by the study authors. Steps were taken to improve existing control strategies in 14% of the articles. In 13% of the articles the authors reported that follow-up studies of effectiveness were conducted at some point after the improvement of the controls or the initial evaluation.

New strategies—those not in place in a workplace prior to the

Strategy	Example
Elimination/Source Reduction	Substitution
Engineering Controls	Ventilation
Administrative Controls	Training
Work Practices	Housekeeping
Personal Protective Equipment	Respirators

FIGURE 1. Industrial hygiene hierarchy of controls

TABLE I. Characteristics of Chemical Hazard Prevention and Control Articles in the Industrial Hygiene Literature 1994–1999

Article/Study Purpose	n	%	Definition
Control/Prevention	39	42	Self-described as control study; air monitoring only to verify controls
Exposure assessment	23	25	Control discussion is minimal.
Both	27	29	Bias to ''both'' if conducted air monitoring or not a new intervention
Hierarchy of controls			
Strategies compared?	4	4	Ex. ventilation versus substitution
Hierarchy of controls considered?	2	2	Explicit consideration of hierarchy of controls with the control strategy for the described hazard
Existing controls			
Discussed existing controls?	70	76	In place at time of the investigation. Could be more than one.
Improved existing controls?	13	14	Modifications or additions
Evaluated effectiveness of existing controls?	49	53	Any postmodification effort to gauge effectiveness
Existing deemed effective?	16	17	By study authors
Existing deemed effective with limitations?	13	14	By study authors
Existing followed up?	12	13	At some point beyond the initial installation or modification of the control
New strategies			
Proposed new strategies?	54	59	For uncontrolled or inadequately controlled operations
Implemented new strategies?	24	26	
Unclear if implemented?	14	15	Not clear if new strategy was only recommended or was actually implemented
Evaluated effectiveness of new strategies?	26	28	Any postmodification effort to gauge effectiveness
New strategies deemed effective?	14	15	By study authors
New strategies deemed effective with limitations?	8	9	By study authors
New strategies followed up?	3	3	At some point beyond the initial installation of the control
Costs and environment			
Costs discussed?	13	14	Qualitative: ex. ''inexpensive''
Costs quantified?	8	9	May be inexact
Environmental impact discussed?	15	16	Of the control strategy or the process in relation to control strategy
Strategies			
Primary prevention considered?	24	26	A strategy that would result in source reduction, not just exposure reduction. Includes material or equipment substitution, equipment or process modification, preventive or remedial operations, and maintenance.
Substitution considered?	19	21	Discussed or recommended as a potential control strategy
Any primary prevention implemented?	10	11	Clearly put in place to address an identified hazard
Considered engineering control?	66	72	An engineered strategy that reduced exposure potential but not the source of the hazard. Ex. ventilation, wet methods, improved storage of materials
Considered local exhaust ventilation?	56	61	
Implemented any engineering control?	33	36	
Considered other strategies?	49	53	Ex.: smoking restrictions
Considered housekeeping or personal hygiene?	22	24	
Considered medical surveillance?	14	15	
Implemented any other strategy?	32	35	Including other, housekeeping, hygiene, or medical surveillance
Considered personal protective equipment?	30	33	
Implemented personal protective equipment?	18	20	

authors' intervention—were proposed in 59% of the sample. In 26% of the articles it was clear that proposed strategies were implemented. New strategies' effectiveness was evaluated in 28% of the articles and deemed effective in 15%. In 9% of the articles new control strategies were deemed effective with limitations, and three articles described follow-up studies.

Articles were reviewed for their discussion of specific hazard control and prevention strategies. Twenty-six percent mentioned the consideration of primary prevention strategies, such as process changes or material substitutions. Material substitution was the most frequently considered of these. Engineering controls were discussed in 72% of the sample (n=66); 85% of these discussed local exhaust ventilation strategies. Administrative strategies appeared in 53% of the articles. These strategies included housekeeping and/or personal hygiene strategies and medical surveillance. Personal protective equipment was considered in 33% of the articles.

A smaller subset of articles discussed the actual implementation of control and prevention strategies. Primary prevention strategies were described as actually implemented in 11% of the articles. Primary prevention strategies evaluated in the articles included material substitution, equipment changes, process redesign, and operation and maintenance improvements (examples in Figure 2). The implementation of engineering controls and other (adminis-

Strategy	Examples
Substitution	Vegetable oil-based press wash,[17] low-emission building materials[18]
Equipment Modification	High volume/low pressure paint spray guns,[19] electric forklifts[20]
Process Modification	Added cleaning step to prevent byproduct formation[21]
Operations and Maintenance	Sealing leaks in chemical feed lines[22]

FIGURE 2. Primary prevention strategies

trative) strategies was equally prevalent; each appeared in just over a third of the articles. Personal protective equipment was described as implemented in 20% of the articles.

Finally, 16% of the articles considered environmental impact, and 14% discussed the costs of industrial hygiene control strategies.

DISCUSSION AND CONCLUSIONS

This review of the literature can offer insight into several areas of industrial hygiene hazard control and prevention, including (1) the prevalence of hazard control and prevention issues in the field's literature, (2) which strategies are undertaken and whether industrial hygiene practice as described in the literature conforms to "best practice" with regard to prevention, (3) whether evaluation of effectiveness is common, and (4) the role of environmental and cost concerns.

Unfortunately, 20 years on, Hammond's hope for a greater proportion of articles reviewing control and prevention strategies has not come to pass. The overwhelming majority of articles published in the industrial hygiene literature during the period under review concerned some aspect of exposure assessment. Only about 15 published articles per year met the review criteria of addressing chemical hazards in actual workplaces. However, the current review did not include non-peer reviewed articles, nor journal columns such as *Applied Occupational and Environmental Hygiene's* "Case Studies" column, which may have been instituted specifically to address this gap. Additionally, general control articles may be providing critical guidance applicable to a variety of work environments.

This survey found that engineering controls, particularly local exhaust ventilation, dominate industrial hygiene hazard prevention and control practice literature. Industrial hygiene training and texts typically recommend that industrial hygienists follow the "hierarchy of controls" and/or the public health primary prevention model in designing workplace hazard control approaches. The hierarchy of controls suggests an order for the implementation of control methods (see Figure 1). In the primary prevention model inherited from the field of public health, the emphasis is placed not on the particular method, but on the general dictate to prevent hazards at their sources.[12] The hierarchy of controls may have substitution or elimination of the hazard at the top of the list, although it may also feature "engineering controls" as the preferred first approach. Engineering controls, as a category, may encompass (although not prioritize) primary prevention strategies such as substitution. Thus, a finding that local exhaust ventilation strategies are preferred practices suggests that industrial hygiene practice, as described in the literature, is partially in line with recommendations for preferential strategies promoted by the field.

Despite their theoretical primacy, primary prevention strategies—those focusing on reduction of hazards at the source—are not commonly considered in practice; they ranked third in frequency of citation in the literature. And although industrial hygienists sometimes do consider these strategies, they are not often implemented. Only 11% of the articles described the actual implementation of primary prevention strategies.

Primary prevention strategies may deserve new attention because approaches that intervene in the industrial process itself to prevent or reduce hazards can offer benefits over other approaches, including traditional engineering controls such as local exhaust ventilation.[13] These benefits can include total elimination of exposure to the targeted chemical, less reliance on worker compliance or equipment maintenance for success, elimination of the potential for accidental or nonroutine overexposures, prevention of dermal exposures, and process and environmental improvements not related to worker health. Occupational health policy bodies such as the American Industrial Hygiene Association have promoted primary prevention strategies, as did the attendees at the National Institute for Occupational Safety and Health (NIOSH) sponsored conference "Control of Workplace Hazards for the 21st Century—Setting the Research Agenda," held in March 1998.[14,15] However, despite recommendations for the greater use of these techniques, numerous barriers to their implementation persist. These include uncertainty about the performance and safety of substitutes; a lack of familiarity with the process of investigating primary prevention strategies; preferences for ventilation control because it is a part of industrial hygiene professional training; and a lack of power to effect changes in production, such as product reformulation, that go beyond the traditional realm of industrial hygiene.

With the increasing importance of environmental health to the industrial hygiene field, the literature also was reviewed for consideration of environmental issues in decisions about hazard prevention and control strategies. Few articles discussed environmental concerns, such as the fate of contaminants vented from workplaces. Additionally, costs are critical to any industrial hygienists' recommendations, yet they do not figure in the literature of controls and prevention.

Based on this review of the industrial hygiene literature, control strategy effectiveness does not appear to be universally evaluated in industrial hygiene practice. Effectiveness was evaluated in 70% of the cases in which existing control or prevention approaches were discussed and 53% of the cases in which new control or prevention strategies were proposed. The quality of the evaluations that were conducted in these workplaces was not assessed in this study. Only a small number of the articles discussed the results of follow-up evaluations that might determine the effectiveness of an approach over time. Both NIOSH's *National Occupational Research Agenda* and the Center for Disease Control and Prevention's *Healthy People 2010* stress the need for evaluation of occupational health interventions to promote effective strategies. Shannon's article on evaluation of safety interventions also warned of the potential dangers of unevaluated interventions: They may waste resources; they may be ineffective; and they may cause more harm than good.[9]

Limitations

The objective of this review was to better understand industrial hygienists' approach to hazard prevention and control by looking at the published literature, given an absence of the resources necessary for a large-scale workplace survey. However, this literature

review exhibits several limitations that are inherent in this type of investigation. The three greatest limitations are (1) the selection filter of "publication bias," (2) the necessarily subjective evaluation of the article contents, and (3) that the articles were reviewed by a single individual. With regard to the first limitation—publication bias—although the sample did include a significant diversity in hazards and work environments, there is no assurance that this review of the literature captures a representative sample of actual industrial hygiene practice. Indeed, it is likely that this sample underrepresents more routine strategies that might not be deemed novel enough for publication. It would, however, capture new strategies such as primary prevention approaches.

To curtail the effects of the other two limitations—subjective review and single reviewer—a validation study was conducted and the evaluation instrument was redesigned to increase accuracy. Term definitions were developed to aid consistent analysis.

Because of the limitations and the limited scope of the study, it is not possible to draw definitive conclusions regarding the current state of chemical hazard control based on this review. However, the trends of the results may provide useful themes for further investigation and stimulate discussion of control approaches and theory.

Recommendations

Given the findings of this study, the following actions are recommended.

- In line with the recommendations of the NORA Intervention Effectiveness Team, evaluation should become a more central component of industrial hygiene prevention and control practice and research. Goldenhar et al.'s and NIOSH's publications can serve as useful guides to developing and evaluating the effectiveness of health protection interventions.[6,8]
- In addition to evaluating effectiveness, investigators also should increase their attention to costs; environmental impacts; comprehensive effects on the work environment, such as increased job demand; and other potential consequences of hazard prevention and control interventions. Knowledge of these "extra" variables may help ease the implementation and assure the success of effective strategies.[16]
- Industrial hygienists should be guided by the systematic and preventive approach to hazard prevention developed by NIOSH, which recommended the following.

> The central strategy for the ordered evaluation of feasible and effective control options must be based on sound time-tested public health policy. This strategy can be expressed as an ordered effectiveness hierarchy of elements for prevention of overexposure of workers to hazardous agents. The three elements of this effectiveness hierarchy of control solutions, in order of preference are: 1) First, prevent or contain hazardous workplace emissions at their source; 2) Next, remove the emissions from the pathway between the source and the worker; 3) Last, control the exposure of the worker with barriers between the worker and the hazardous work environment.[12]

- NIOSH's *Hazard Controls* case studies series of effective controls should be expanded to include a greater number of hazards and strategies to prevent them. Given the paucity of information on effective primary prevention strategies in the literature, the *Hazard Control* series might make extra effort to promote these.
- Research should be conducted to uncover the barriers and opportunities for the greater utilization of primary prevention techniques alone, or in conjunction with other prevention and control strategies. Industrial hygiene academic and training programs should include instruction in primary prevention techniques.

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