SUMMARY REPORT

ENGINEERING CONTROL OF OCCUPATIONAL SAFETY & HEALTH HAZARDS:

RECOMMENDATIONS FOR IMPROVING ENGINEERING PRACTICE, EDUCATION & RESEARCH

U.S. DEPARTMENT OF HEALTH AND HUMAN SERVICES
Public Health Service
Centers for Disease Control
National Institute for Occupational Safety and Health

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Summary Report
of the
Engineering Control Technology Workshop Technical Panel

U.S. DEPARTMENT OF HEALTH AND HUMAN SERVICES
Public Health Service
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National Institute for Occupational Safety and Health
Division of Training and Manpower Development

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The opinions and conclusions expressed herein are not necessarily those of the National Institute for Occupational Safety and Health.

This summary report is being disseminated to NIOSH staff, other government agencies, the occupational safety and health community, academia, industry, labor, professional societies, and public interest groups. The report is intended to disseminate new information that has been developed by a panel of external technical experts and provides new insight into the prevention of occupational hazards and recommends specific actions by the engineering profession.

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PREFACE

In 1979, the National Institute for Occupational Safety and Health (NIOSH) conducted the NIOSH/University Occupational Health Engineering Control Technology Workshop. This workshop addressed the need for increased effort in the following areas of the engineering field:

1. Design of hazard control systems,
2. Research and development of new and improved control technology, and
3. Educational programs for student and practicing engineers.

In 1981, Texas A&M University hosted the Second Engineering Control Technology Workshop. This session included discussions of strategies to improve the education of the engineer and state-of-the-art of engineering control systems. A major recommendation was made to develop a report with recommendations for a comprehensive strategy to incorporate an awareness of occupational safety and health into engineering practice, education, and research.

In 1983, the University of North Carolina hosted the Third Engineering Control Technology Workshop. This session was held to discuss legal responsibilities, accreditation of academic programs, registration of engineers, and to review issues and strategies as developed in the draft panel report prepared as a result of the second workshop.

This report provides a summary of the comprehensive report prepared by a panel of technical experts. We wish to express our gratitude to the following persons for their contributions: Dr. Melvin First, Harvard University who served as report editor; Dr. Morton Corn, Dr. Charles Billings, and Dr. Peter Lees of Johns Hopkins University; Dr. Robert Harris, University of North Carolina; Dr. Jack Peterson, Peterson Associates; and Dr. Thomas Leamon, Northern Illinois University. Special thanks are due to the following NIOSH personnel who have actively supported the development of this program: Mr. Walter Haag, Dr. Murray Cohen, and Dr. Alan Stevens. Thanks are also due to Ms. Anne Hamilton who served as a technical editor in the preparation of this document.

Further information on the subjects of this summary report and the full report can be obtained at the following address:

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ABSTRACT

This document summarizes a comprehensive report prepared by a technical panel. It is based on a series of workshops conducted to improve engineering practice, education, and research in the field of occupational safety and health. Included are (1) a brief historical review of occupational safety and health engineering, (2) an outline of occupational hazard control information needed by practicing engineers and related professionals, (3) a summary of educational needs in this field, (4) a discussion of needed research on engineering control, and (5) a consolidated list of high-priority recommendations for action.

Historically, the fields of occupational safety and occupational health have been separated, mainly because of the initial emphasis on safety during the Industrial Revolution. Recently, emphasis and attention have been placed on a comprehensive view of occupational safety and health that embraces industrial hygiene, occupational medicine, ergonomics, and safety.

Special information needs of engineers and related professionals must be met if we are to solve the serious national health problems resulting from occupational hazards. First, certain professional groups must be targeted to receive the information needed to effectively participate in the task of providing safe and healthful workplaces. Next, basic information must be made available to these professional groups, including types and areas of hazards, engineering control methods, legal and ethical responsibilities and liabilities, cost effectiveness and benefits of engineering controls, and techniques to monitor the effectiveness of hazard controls.

A specialized body of information is available to educate engineers in the field of occupational safety and health. Three types of current educational needs have been identified: (1) incorporating occupational safety and health into engineering education, (2) providing specialized training in occupational safety and health engineering as a professional field, and (3) providing training in engineering techniques and practices for practitioners of occupational safety and health who are not engineers. Educational programs should cover a full spectrum, including academic degree programs, continuing education courses, and specialized information services for individuals or groups. The engineering

community needs to be aware of occupational safety and health issues and requirements under the law so engineers can fulfill their legal obligations as well as protect the worker and the public by developing and implementing effective hazard control technology.

Research is needed on engineering controls for chemical, physical, and biological hazards. Chemical hazards are those encountered principally through inhalation of workplace air, but they may also be absorbed through the skin or ingested. Physical hazards involve traumatic injuries and exposure to physical agents such as radiation and vibration. Biological hazards include exposure to viruses, bacteria, fungi and their products which may be released accidentally to the work environment.

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Section 1

INTRODUCTION

The goal of occupational safety and health engineering is to prevent occupational disease and injury by management of the work environment. The operating principle is to systematically provide worker protection against safety and health hazards by using techniques that do not place the burden of protection on the worker. Such methods include engineering controls and monitoring systems, which may be supplemented when necessary by appropriate work practices and protective equipment. The skill and experience of the engineering community are required to help solve the serious national problems resulting from exposures to safety and health hazards in the workplace.

To make engineers more aware of their role in developing and implementing engineering controls of occupational hazards, the National Institute for Occupational Safety and Health (NIOSH) sponsored a series of workshops on ways to improve engineering practice, education, and research in the field of occupational safety and health. This summary report is a condensation of the comprehensive report prepared for the 1983 workshop. Included are a brief historical review of occupational safety and health engineering, an outline of occupational hazard control information needed by practicing engineers and related professionals, a summary of education needs in this field, and a discussion of needed research on engineering controls. The final section contains recommendations for action to resolve the high priority needs that have been identified.

Background

Traditional occupational safety and health engineering categories have included *safety engineering* (prevention of traumatic injury in the work place), *occupational health engineering* (prevention of occupational diseases resulting from exposure to hazardous agents), and *ergonomics* (human factors such as fatigue and proneness to error).

A distinction has always existed between occupational safety (injury) and occupational health (disease) hazards, though both problems had their roots in the Industrial Revolution. Part of the reason for this distinction was the tragic safety record of this period, during which untrained workers (including many women and children) struggled with crude machines to perform tasks that were impossible to accomplish safely. The etiology of occupational diseases was largely unknown at this time. Industrial safety laws began to appear in western Europe early in the 19th century, and a safety inspectorate was developed. Although the negative health effects of mechanization and large-scale production of minerals, metals, and chemicals began to be recognized during the latter years of the Industrial Revolution, the medical approach remained curative rather than preventive. Not until 1910–1912 did the prevention of occupational disease begin to gain firm status in the medical community. Recently, emphasis and attention have been devoted to a comprehensive view of occupational safety and health that encompasses industrial hygiene, occupational medicine, ergonomics, and safety.

Ergonomics (formerly called "human factors") was not a well-developed science until World War II. This field developed as a result of an acute need to reduce the fatigue and proneness to error of airplane pilots, tank operators, and artillery directors by careful redesign of work stations to fit human function. Psychologists played a prominent role in this field and introduced another professional element into occupational safety and health.

A chronology of important events in the history of occupational safety and health engineering appears in Table 1.

Table 1. Chronology of Important Events in the History of Occupational Safety and Health Engineering

Date	*Event*
1810	Early mechanizations in England expanded the workplace to the limits of human endurance (steam engines ventilated mines to greater depths, and speedier machines generated more dust and fumes than could be produced by humans or animals alone).
1810	Inspectorate of Mines set up in France.
1833	Factory inspectorate established in Great Britain.
1842	First U.S. Child Labor Law enacted in Massachusetts.
1854	Great Britain enacted a new mine safety act requiring ventilation in all mines.

Table 1. (Continued) Chronology of Important Events in the History of Occupational Safety and Health Engineering

Date	*Event*
1864 and 1867	The British Factory Acts called for the extraction of injurious dusts by means of fans or other mechanical means.
1866	The British Sanitary Act specifically mentioned ventilation.
1883	The British Factory and Workshop Acts represented the first attempts to regulate a dangerous manufacturing industry and provided for ventilation of stoves and stacks.
1889	Great Britain provided for guards against excessive heat and humidity in cotton cloth factories.
1910	U.S. Bureau of Mines was established.
1910	First National Conference on Occupational Diseases in the United States was held in Chicago.
1911	The National Safety Council was organized in Chicago under the name of The National Council for Industrial Safety.
1912	Alice Hamilton correctly identified inhalation of dust and fumes as the cause of industrial lead poisoning.
1914–15	U.S. Bureau of Mines was first to study silicosis in mines.
1914	Office of Industrial Hygiene and Sanitation (later the Division of Occupational Health) was established in the Division of Scientific Research of the U.S. Public Health Service.
1918	Studies of silicosis began in granite industry and later in the cement, sandstone, marble, pottery, and abrasive industries.
1918	Harvard University joined with the Massachusetts Institute of Technology to provide a program of industrial hygiene instruction and certification that became the world's first degree program in industrial hygiene.
1930's	Professionally staffed occupational health units were formed in the industrialized States.
1930's	Social legislation of the depression era stimulated, enhanced, and sustained the development of all aspects of occupational health and safety.

Table 1. (Continued) Chronology of Important Events in the History of Occupational Safety and Health Engineering

Date	*Event*
1935	The Social Security Act made Federal funds available for establishing and improving State and local industrial hygiene bureaus.
1939–45	Human factors technology (ergonomics) became highly developed as part of the war effort.
1941	A ban on Federal inspection of mines was lifted.
After 1945	Many officers trained in industrial hygiene during the war made permanent careers of occupational safety and health.
After 1945	Occupational Safety and health problems resolved on an ad hoc basis during the war were studied more carefully.
After 1945	Federal interest in traditional industrial hygiene waned in favor of solving the health problems associated with the emerging nuclear industry.
1955	Investigation of the granite industry found that dust concentrations had been reduced to 5 million particles per cubic feet of air and only one doubtful case of silicosis had developed since 1937.
1960's	Federal funds for environmental health training and research were largely directed to air pollution control activities, and industrial hygiene suffered a decade of neglect.
1964	Investigation of granite industry found no verified cases of silicosis among workers hired after 1937.
1966	Congress passed the Metal and Non-metallic Mine Safety Act.
1969	Congress passed the Federal Coal Mine Health and Safety Act.
1970	Congress passed the Occupational Safety and Health (OSH) Act based on the principle that the employer is responsible for in-plant health and safety. This law marked a new era of Federal responsibility for all aspects of occupational safety and health.
1970	The new OSH Act created the Occupational Safety and Health Administration in the U.S. Department of Labor and charged the new agency with the nation-

Table 1. (Continued) Chronology of Important Events in the History of Occupational Safety and Health Engineering

Date	*Event*
	wide enforcement of occupational safety and health laws.
1970	The OSH Act placed responsibility for research, criteria development, manpower development, and training on NIOSH.
1971—80	OSHA promulgated 24 permanent health standards, each of which indicated that engineering controls are required for compliance, except where infeasible.
1974	OSHA acknowledged the technology-forcing aspects of the Occupational Safety and Health Act when promulgating the vinyl chloride standard.
1975	OSHA began to place emphasis on potentially hazardous chemical and physical agents.
1976	NIOSH initiated a control technology program to improve worker protection from an engineering standpoint.
1978	The U.S. Court of Appeals in the coke oven decision ruled that OSHA could promulgate specific engineering and work practice controls but that it could not require the industry to perform research on new engineering controls.
1979	A workshop was held by NIOSH to address engineering control technology. Specific topics included ways to stimulate research and education in the field and methods for educating all engineers in the basics of occupational safety and health.
1980	A symposium was held by NIOSH on occupational safety research and education. Objectives were to (1) establish better communications between safety educators and researchers, (2) exchange ideas about research and curricula, and (3) articulate preliminary guidelines for instructional and research programs.
1981	A second workshop was held by NIOSH to (1) identify research and development needs for engineering controls, (2) explore ways to integrate occupational safety and health engineering with general engineering practice, (3) find ways to incorporate industrial hygiene and safety engineering into the general

Table 1. (Continued) Chronology of Important Events in the History of Occupational Safety and Health Engineering

Date	*Event*
	engineering education process, and (4) identify financial resources to accomplish these objectives.
1981	The Supreme Court in the cotton dust decision ruled that OSHA could impose engineering controls on an industry that could result in the failure of individual firms but not the entire industry.
1983	A third workshop was held by NIOSH to develop specific recommendations and plans for future actions concerning occupational safety and health engineering research, education, and practice.

Current Ranking of Occupational Safety and Health Problems

The following occupational disease and injury categories were ranked in order of their national importance by NIOSH in March 1982.

1. Occupational lung disease (including lung cancer pneumoconioses, and occupational asthma);
2. Musculoskeletal injuries (including back injury, carpal tunnel syndrome, arthritis, and vibration white finger disease);
3. Occupational cancers (other than lung cancer);
4. Traumatic deaths, amputations, fractures, and eye losses;
5. Cardiovascular diseases (including myocardial infarction, stroke, and hypertension);
6. Reproductive problems;
7. Neurotoxic illness;
8. Noise-induced hearing loss;
9. Dermatologic problems (including dermatoses, burns, contusions, and lacerations); and
10. Psychological disorders.

The ranking provides a helpful starting point, first to identify the primary causative agents in each category, and then to develop prevention strategies derived from informed engineering practice, education and research. The ten categories provide a frame of reference for the balance of this report.

Section 2

INFORMATION NEEDS OF PRACTICING ENGINEERS AND RELATED PROFESSIONALS

Without the help and commitment of the entire engineering community, the major problems resulting from occupational health and safety hazards cannot be solved. To enlist such help, a number of specific information needs must be met. This means that certain professional groups must be targeted, and that essential basic information must be made available, including types and areas of hazards, legal and ethical responsibilities and liabilities, cost, effectiveness, and benefits of engineering controls, and ways to monitor the effectiveness of hazard controls.

Professional Groups Targeted to Receive Information

Groups that have a special need for information about the engineering control of occupational safety and health hazards include: (1) all practicing engineers, (2) industrial hygiene engineers and professional safety engineers, (3) industrial hygienists and safety practitioners who are not engineers, and (4) professionals in other fields such as attorneys, judges, enforcement officials, and workers.

Practicing Engineers

Though hazard control technology is the special province of industrial hygiene and safety engineers, practitioners of many other engineering disciplines have urgent needs for information in this field. Design engineers are particularly in need, since hazard control should be included in process and equipment design at the earliest possible stage for the optimum results. This information is not, however, normally part of the design engineer's education or background. Much of the basic information used by the industrial hygiene engineer and professional safety engineer should be a part of every engineer's education or, lacking that, be readily available as reference material to the practicing engineer.

Industrial Hygiene Engineers and Professional Safety Engineers

Though the need for technical information transfer is less acute for industrial hygiene engineers and professional safety engineers than it is for other industrial hygienists and safety practitioners, hazard control knowledge is not uniform among them, and the research and discovery process is often duplicated by various groups. Improved communication and information transfer would thus be very useful, even in this highly specialized group.

Industrial Hygienists and Safety Practitioners

Today, most industrial hygienists are not engineers, and the percentage of engineers in this field has been decreasing steadily. In the field of safety, some practitioners have no formal education beyond high school. Although apprenticeship training on the job has provided many of these practitioners with great knowledge about the practical aspects of safety programs, generally they are unable to examine basic causes of safety problems and present options for engineering solutions. Many past failures at solving occupational hazards could have been avoided if the decision-maker had been aware of the complexity of the problem and also knew what to avoid. A notable example early in the 20th century was the disastrous substitution of highly toxic carbon tetrachloride for petroleum naphtha to combat a serious fire hazard in the dry cleaning industry. In this case, a fire hazard was unknowingly traded for a serious vapor inhalation hazard.

Other Professionals

Members of many other professional groups could benefit from increased knowledge of how to control occupational hazards by engineering means. They include attorneys who deal with regulations and enforcement, judges who preside over trials and hearings in the occupational safety and health field, businessmen who make financial decisions about hazard control technology, and the workers, who have the most at stake and are often the least aware of available solutions.

Types of Information Needed

Industrial hygiene and safety engineering educators believe that it is most productive to teach safety and industrial hygiene to engineers rather than teach engineering (a rigorous field of study in itself) to industrial hygienists and safety practitioners who have not been educated as engineers. Engineers need information on the following topics: (1) types and areas of hazards, (2) legal and ethical responsibilities and liabilities of engineers, (3) costs, effectiveness, and benefits of engineering controls, and (4) monitoring the effectiveness of hazard controls.

Basic Information on Types and Areas of Hazards

Types of Hazards

Hazards may be physical, chemical, or biological, and all may be either acute (single-dose, short-term exposure) or chronic (multiple-dose, long-term exposure). The seriousness of the problem can range from a nuisance to a life threat. Nuisance problems deserve much less attention than those that threaten worker health and safety. Thus the practicing engineer needs information about the seriousness of an occupational hazard to set priorities and to determine the needed controls. Information is also needed about hazards that are inadvertently designed into a piece of equipment, a process, or an entire plant. Built-in hazards abound—pinch points on machines or other equipment and inappropriate height of work stations are two common examples. Built-in hazards are the most difficult to avoid and require education and constant reinforcement. Maintenance requirements also need to be examined for inherent hazards that may affect efficiency and subsequently safety. An example would be a difficult and hazardous procedure for checking the lubricant level of a machine. One result might be fewer checks than required and excessive machine breakdowns.

Area of Hazard

All design and process engineers need information about safety and health hazards that exist in the workplace to accomplish their own work correctly. But they also need information about hazards from the workplace that can extend into the community at large and ultimately to the environment. Dangers to the public can include releases of toxic chemicals, traffic hazards resulting from fugitive dust clouds, and dangers from toxic wastes.

Design engineers have very specific legal responsibilities for protecting the public as well as their employers or clients. Engineers who are not industrial hygienists or safety professionals need easy access to information that will permit them to plan, design, and operate industrial equipment, processes, and plants with a minimum of hazard to workers and the community.

Supervisors and workers need particular rather than general information to protect themselves from hazards associated with the materials, equipment, and processes they work with daily. They need to recognize incorrect procedures and malfunctions in their equipment and to know how to effect immediate relief.

Knowledge about the seriousness of exposures, both chronic and acute, is also needed to assist the control effort.

Legal and Ethical Responsibilities and Liabilities of Engineers

All engineers need more information concerning their legal and ethical responsibilities; many are unaware of them. Many engineers lack adequate knowledge of recent legislation in the field of workplace hazard control, and are unaware of how the legal requirements affect the practice of their profession. Severe penalties may be levied on both the engineer and the employer for failure to heed these requirements.

Of all the laws that affect engineers in their practice, the Occupational Safety and Health Act is the one most frequently encountered. Regulations authorized by the Act establish design criteria in terms of a desired result and, in some cases, methods for achieving the result. The regulations also specify equipment that is to be used. Failure to follow these regulations can lead to legal penalties. In addition, regulations often contain deadline dates by which control must be accomplished. Many engineers are unaware of these dates and thus may err in their duties to their employers and to workers.

Penalties for violations can include fines and forfeitures as well as criminal prosecution. Engineers can be held liable for the errors and omissions of their subordinates and for hazards that remain unabated despite orders to the contrary. Adequate follow-up is a means of self-protection that should be used by all engineers.

The legal responsibility of the engineer in charge is not specifically stated in the law, but it is implied. Many other laws in addition to the OSH Act impose duties and obligations on engineers. The professional engineer is also required by law to act according to the prevailing practice of the profession or to be prepared to show why not.

Occupational safety and health engineers have dual responsibilities to their employers and to their employer's employees, as do design and process engineers. This duality poses ethical problems that may be difficult to resolve, especially in cases where adequate worker protection results in substantial cost increases to the employer.

A number of means are available to engineers for becoming informed about new legal requirements. The *Federal Register* is published daily and contains revised regulations, proposed changes to regulations, and other public notices. The *Code of Federal Regulations* is updated regularly and is easily obtained. Federal agencies publish extracts of the law, as well. Applicable books and journal articles are available. Theoretically, all engineers can acquaint themselves with the regulations governing their practice, but many engineers believe that educators have the primary responsibility for teaching occupational safety and health law. Although engineering schools present courses on engineering law, few have courses devoted to the OSH Act.

Cost, Effectiveness, and Benefits of Engineering Controls

Because all engineers are expected to achieve the most with the least cost, information is needed on both the cost and effectiveness of engineering controls. After the efficacy of control options is assured, cost must be examined. Factors to consider include those for engineering design, capital costs, cost for enclosure, ventilation, or process change, maintenance costs, benefits of accelerated depreciation permitted by Federal law for some equipment, and tax advantages represented by investment tax credits.

The benefits of engineering control of hazards have not been systematically identified and need to be documented for engineers, practitioners, employers, and workers. A summary of benefits follows:

1. Lives can be saved and good health can be promoted.
2. Reduction in occupational injuries and illnesses can decrease the premium paid for worker's compensation.
3. Group health insurance rates can be reduced as amounts paid out decrease.
4. Excess labor costs incurred by workers absent because of illness or injury can be reduced.
5. Savings can be realized in personnel replacement and training costs.
6. Penalties charged by OSHA can be avoided—especially escalating penalties for repeated violations.
7. Imprisonment for Federal violations can be avoided, and legal costs can be saved.
8. Good will can be secured from employees, stockholders, and the public.

Monitoring the Effectiveness of Hazard Controls

Engineers and other practitioners of occupational safety and health need information about means for monitoring the effectiveness of hazard controls. The law occasionally requires such monitoring, but effectiveness of controls depends on consistent monitoring in three areas: production equipment, process streams, and equipment installed solely for protection of exposed workers.

Monitoring of hazard control can sometimes involve only a simple walk-through inspection, but often it involves the use of complex air sampling and other measurement equipment used by specially trained personnel. Computerized systems can also provide essential monitoring data. Worker exposure to toxic agents can be evaluated by means of biological monitoring using samples of blood, urine, breath, saliva, or tissues. Medical surveillance of exposed workers is the final defense.

An engineer must be aware of available methods and the consequences of possible failures in order to make wise choices of monitoring methods.

Section 3

EDUCATIONAL NEEDS IN THE FIELD OF OCCUPATIONAL SAFETY AND HEALTH ENGINEERING

Though basic engineering techniques may be applied to solve many occupational safety and health problems, not all engineers are qualified to practice in this area. A specialized body of information is needed to educate engineers in this field. Specifically, the educational needs are of three types:

1. *Incorporating occupational safety and health into engineering education.* Training is needed in occupational safety and health for all engineering students and engineers so that they can deal with occupational safety and health problems in their particular fields.
2. *Providing specialized training in occupational safety and health engineering as professional fields.* Specially trained engineers engage in research, education, consultation, and industrial practice in these fields.
3. *Providing training in engineering techniques and practices for practitioners of occupational safety and health who are not engineers.* Training permits these professionals to recognize needs for better engineering controls, to evaluate and correct engineering control systems, and to deal effectively with engineering specialists. Orientation in this field is of great value for those engaged in industrial management, law, and medicine.

Types of Educational Programs

Three types of educational programs are pertinent to occupational safety and health engineering: (1) academic degree programs, (2) continuing education programs, and (3) information services for individuals or groups (books, journals, professional meetings).

Academic degree programs may be at the graduate, baccalaureate, or associate level. Graduate programs are related particularly to occupational safety and health engineering as a professional field and to nonengineering practitioners. Baccalaureate programs in engineering should all include some information on occupational safety and health. Lectures and courses at this level must be made available to provide at least an awareness of occupational safety and health engineering problems and solutions. The inclusion of such instructional material in undergraduate engineering curricula should have a major impact on improving worker protection, since more than 60,000 Bachelor's degrees in engineering are granted annually in the United States. These graduates form a large pool of upwardly mobile personnel who have initial and continuing opportunities to influence safety and health in their organizations.

Associate degree programs are important for training technicians who may participate in occupational safety and health engineering activities. Such programs are expected to have little effect on meeting the three types of educational needs outlined earlier.

Continuing education programs can help meet all three categories of educational needs. They are particularly applicable to occupational safety and health training for all practicing engineers and for practitioners who are not engineers.

Information services help maintain engineering skills, but they do not alone meet the basic needs for occupational safety and health education.

Special Reasons for Promoting Occupational Safety and Health Education

A number of special issues underline the importance of education in occupational safety and health engineering. Regulations authorized by the Occupational Safety and Health Act make the failure to perform certain duties by managers and employers subject to civil, and in some cases criminal, penalties. Thus, a special course outlining requirements under the Act would be advisable for all undergraduate student engineers.

The responsibility of engineers for public safety extends to the operators of the devices and processes they design or manage. Training in public safety concerns is therefore fundamental to engineering education.

Job performance evaluations are enhanced by good safety and health records. Furthermore, employment opportunities are increased by training in occupational safety and health.

Salaries for established industrial hygiene practitioners compare well with those for engineers, but the high potential earnings of baccalaureate engineers create problems in recruiting recent engineering graduates to graduate programs in the safety and health field.

Status of Educational Programs

Information is sparse on educational programs dealing specifically with engineering in occupational safety and health. Programs available to engineers are classified as academic degree programs, continuing education, information and technology transfer activities of professional organizations.

Academic Degree Programs

Some 150 degree-granting institutions in the United States offer academic programs in occupational safety and/or health. These range from 2-year associate degree programs to doctoral programs. Fifteen institutions are identified by NIOSH as Occupational Safety and Health Education Resource Centers that offer academic programs in the following four specialty areas; occupational safety, industrial hygiene, occupational medicine, and occupational health nursing. These centers serve as regional resources in these professional fields and are located at the following universities:

Harvard University
Johns Hopkins University
City University of New York
University of Alabama at Birmingham
University of Arizona
University of California, Berkeley
University of California, Irvine
University of Cincinnati
University of Illinois at Chicago
University of Michigan
University of Minnesota
University of North Carolina at Chapel Hill
University of Texas at Houston
University of Utah
University of Washington

In some cases, the Center is a consortium involving several institutions.

Industrial hygiene and occupational health engineering are generally considered to be specialties in the broader field of environmental engineering. Graduate level education in environmental engineering prepares engineers with a variety of undergraduate majors for practice in environmental protection and hazard control. Undergraduate programs tend to be preprofessional in this field.

An evaluation of Educational Resource Centers in 1980 indicated that industrial hygiene was the most firmly established academic program in the Centers, but that greater emphasis was needed on training in hazard prevention through facility design and modification. More emphasis was also recommended on safety as an academic program at the Centers.

Baccalaureate programs in industrial hygiene are not as numerous or well developed as graduate programs. The number of undergraduate engineering programs that include some instruction in occupational safety and/or health has not been determined. Some occupational safety and health courses may be electives, or such information may be incorporated into other courses.

Continuing Education

Because much Federal legislation in the past decade or so has created demands for persons trained in the engineering control of safety and health hazards, the need is being increasingly filled by short-course training. Industrial hygiene short courses typically emphasize evaluation rather than control of occupational hazards, but this emphasis may change as the program matures. Agencies that present or sponsor such courses include the Occupational Safety and Health Educational Resource Centers, other colleges and universities, Federal agencies, professional associations, and private companies.

One- or two-hour refresher courses on specific topics are often presented as part of professional society meetings, but such sessions are not a means of in-depth training.

Information and Technology Transfer

Though a number of journals deal with research and practice in the field of occupational safety and health, none emphasizes engineering control technology. The reason is that reports on the practice of engineering control are scattered throughout the scientific and engineering literature. NIOSH operates the National Institute for Occupational Safety and Health Technical Information Center (NIOSHTIC). NIOSHTIC has computerized files of pertinent literature that permit key-word, computerized search of much of the U.S. literature and some foreign sources.

Many books are available on the various aspects of occupational safety and health, but new text books at the graduate level are urgently needed on the subject of engineering control of occupational safety and health hazards.

Manuals that are especially useful in continuing education for specific industry groups have been developed by NIOSH. Included is an eight-section series entitled *Industrial Hygiene Engineering and Control* (1978). This series constitutes an introduction to industrial hygiene engineering and control, industrial ventilation, thermal stress, sound, industrial illumination, radiation, and ergonomics. Both student and instructor's manuals are available. More recently, NIOSH published an instructor's guide on engineering control of occupational health hazards in the foundry industry.

Professional Certification and Accreditation

Professional certification and accreditation is supplied by several organizations in the field of occupational safety and health. The American Board of Industrial Hygiene certifies as diplomates of the American Academy of Industrial Hygiene qualified applicants who successfully complete a two-day written professional examination. The Board requires that each diplomate present evidence of continuing professional qualification every six years to maintain certification. Certification may be as a generalist (comprehensive practice) or as a specialist (e.g., industrial hygiene engineering).

The Board of Certified Safety Professionals (BCSP) certifies qualified persons for professional practice in the field of safety. Certification may be as a generalist (comprehensive practice) or as a specialist (e.g., system safety engineering).

The Accreditation Board for Engineering and Technology (ABET) is the recognized agency for accreditation of academic programs in engineering. A program for accreditation of industrial hygiene academic programs is not yet in effect, but the American Academy of Industrial Hygiene is developing one. The American Society of Safety Engineers has developed an accreditation procedure for baccalaureate programs in occupational safety and health.

Relating Resources to Educational Needs

Academic Degree Programs

With regard to academic degree programs, incorporating occupational safety and health into undergraduate engineering education appears to offer the greatest challenge and to have the greatest potential for rewards. The need is to introduce into engineering school curricula, lectures, and courses that promote an awareness of occupational safety and health engineering problems and widely applied control methods. This awareness is particularly needed in courses on facility and process design. Activity in this area appears to be low except for the availability of elective courses in a few schools. The reasons for this situation are:

1. Engineering educators are not generally cognizant or convinced of a need.
2. Changes in engineering education come about slowly.

3. Engineering school curricula are already crowded with course requirements, and requests abound for inclusion of additional material.
4. Engineering faculty are generally unprepared to present material on occupational safety and health.

The following recommendations list specific and independent ways to promote the incorporation of occupational safety and health into engineering education:

1. Develop specific technical instructional materials that can be used as the basis for a required course and can be added to existing engineering courses (particularly those on design of facilities, devices, and processes).
2. Develop one or more specialty courses to serve as technical electives for existing engineering curricula.
3. Develop a sequence of 12 to 15 hours of course work as a basis for a specialty option or minor within existing engineering curricula.
4. Develop specialty short courses, seminars, and workshops as avenues of continuing education for the engineer graduate (particularly faculty and practicing engineers).

Strong incentives for faculties to adopt educational programs such as those listed above would result from advocacy by the ABET for the necessary curriculum change. Another strong incentive would be advocacy for such instruction by employers of graduating engineers.

The need for graduate-level programs in the specialty of occupational safety and health engineering presents a different problem. Few such programs exist, and those that do are ill-defined. NIOSH support (or that of another agency) in the context of centers of excellence would be powerful encouragement for a graduate program that is trying to strengthen itself in this area. Most schools of public health do not award engineering degrees. Those schools that have strong faculty capability for graduate-level engineering education but cannot grant engineering degrees should endeavor to develop cooperative degree programs with neighboring engineering schools.

Engineering in occupational safety and health education for nonengineers is principally a problem at the graduate level. The needs are for appropriate courses, texts, and faculty. The latter may require particularly innovative solutions such as short-term visiting appointments or exchanges, joint appointments in complementary institutions, workshops for new faculty, and review of faculty salary structures.

The Nation's engineering schools now suffer from deteriorating laboratory facilities, faculty shortages, and a declining number of students seeking doctoral degrees in engineering. Work pressures are great on current faculties, salaries are inadequate, and graduate education for engineers is simply not cost effective. Recruiting of faculty in occupational safety and health engineering appears to parallel the national experience in engineering schools.

Though the demands on the time of current engineering faculty are great, interest in occupational safety and health engineering must be stimulated and fostered. One approach would be to offer short courses and teaching materials in the field. Financing summer institutes in attractive settings might also be effective.

Attracting more engineers to graduate programs might be accomplished through offers of financial support. NIOSH training grants for graduate programs in occupational safety and health do include funds for student support, but the level is modest for engineering graduates.

Textbooks needed include one for undergraduate engineering courses on occupational safety and health, and one for graduate programs on the subject of occupational safety and health engineering. Text material is also needed on occupational safety and health for inclusion in texts for engineering design courses. Meeting the latter need will require innovation and ingenuity, as well as a close working relationship between engineering educators and specialists in the occupational safety and health engineering field from academia and private practice.

Continuing Education

Though restructuring of undergraduate programs will ultimately have the largest impact on occupational safety and health engineering education, a major short-term improvement can be made with continuing education programs. Immediate needs for occupational safety and health practitioners are largely being met through mid-career retraining of scientists and engineers. Many training courses are being conducted, but they need to have a greater emphasis on hazard control as opposed to hazard recognition and evaluation. The principal target group for engineering short courses should be design and process engineers in industry. The need is also great for short courses specifically designed for engineering faculty with incentives for faculty participation.

Section 4

NEEDED RESEARCH ON ENGINEERING CONTROLS

Needed research on engineering controls can be listed in three categories based on the type of hazard—chemical, physical, or biological. Chemical hazards are encountered principally through inhalation of workplace air, but chemicals can also be absorbed through the skin or ingestion. Physical hazards may cause disease and traumatic injuries through contact with physical agents. Biological hazards include exposure to viruses, bacteria, fungi and their products that are released accidentally to the work environment.

Methods for controlling chemical, physical, and biological hazards in the workplace are listed below. Engineering controls are the first seven items on the list:

1. Elimination of the hazardous agent
2. Substitution of less hazardous agents
3. Isolation of process, material, or worker
4. Enclosure of process
5. Ventilation of process or work environment
6. Change of process
7. Change of product
8. Housekeeping
9. Dust supression
10. Maintenance
11. Sanitation
12. Work practices
13. Education
14. Labeling and warning systems
15. Personal protection devices
16. Environmental monitoring
17. Waste disposal practices
18. Administrative control
19. Medical control
20. Management program

In addition, major engineering contributions are essential for many of the other hazard control methods (for example, the design, development, and manufacture of a respiratory protective device, the maintenance of plant equipment, and the development of safe work practices). A complete hazard control system may consist of engineering controls plus supplementary control measures such as work practices, warning systems, and personal protective equipment.

A typical workplace and occupational health hazard, as shown in Figure 1, consists of a source or potential source of contamination, a transmission medium (such as air), and receptors in the environment (the workers). As shown in Figure 2, control of workplace hazards involves intervention or change associated with three zones of influence: the source characteristic, the transmission path, and the receptor. The current trend is to identify needed hazard controls in the design stages of a workplace and thus to eliminate costly retrofitting after construction. In addition to proper design, successful engineering controls depend on effective maintenance procedures to assure correct operation of equipment. Continuous workplace monitoring is needed to determine the effectiveness of control systems.

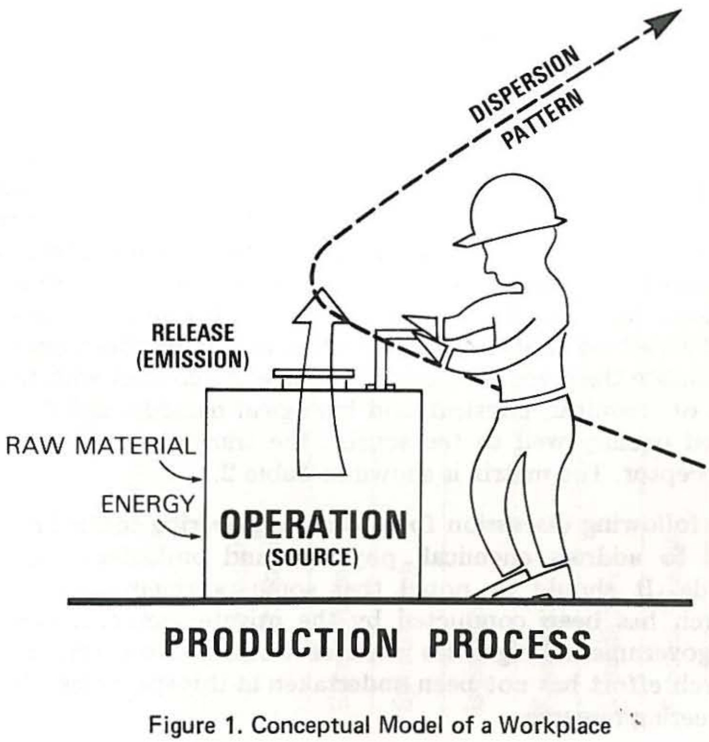

Figure 1. Conceptual Model of a Workplace

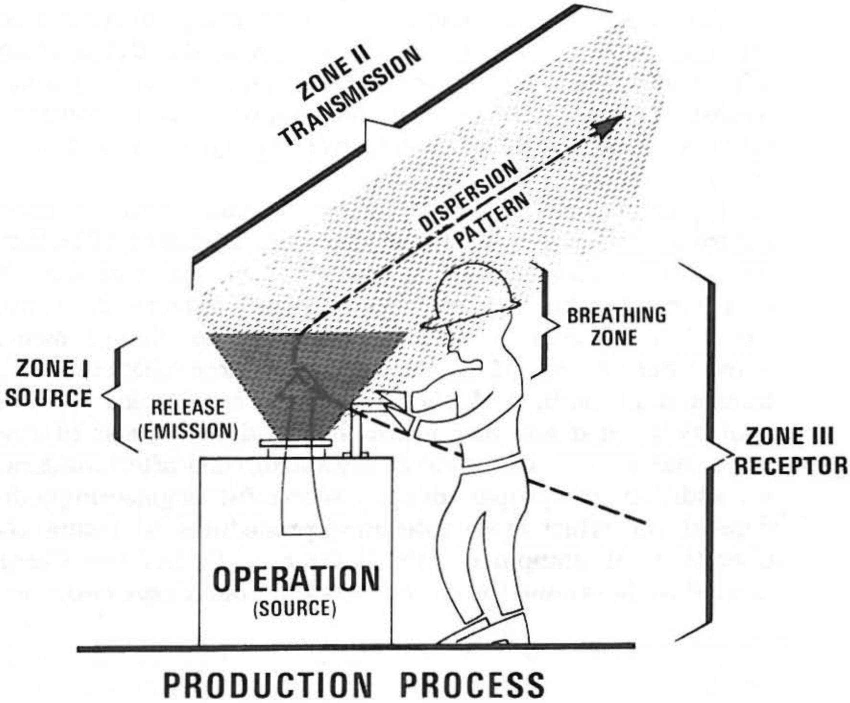

Figure 2. Conceptual Model of the Three Zones of Influence to Control Workplace Hazards

Needed research in engineering control technology can be identified through a matrix, which can be used to locate the source of emissions for each workplace and methods of control. The absence of controls for specific sources can also be identified, along with the need for remedial research. Priorities for research can then be set based on estimates of hazard. A matrix has been developed to associate the seven methods of engineering control with familiar types of chemical, physical, and biological hazards, and it may be applied equally well to the source, the transmission medium, or the receptor. The matrix is shown in Table 2.

The following discussion focuses on engineering control research needs to address chemical, physical, and biological workplace hazards. It should be noted that some pertinent and valuable research has been conducted by the private sector, universities, and governmental agencies such as NIOSH. However, a major research effort has not been undertaken in this specialized field of engineering research.

Table 2. Engineering Control Matrix Applied to Hazards

	Control at Source/Transmission/Receptor		
Type of Hazard / Engineering Control	Physical	Chemical	Biological
Elimination			
Substitution			
Isolation			
Enclosure			
Ventilation			
Process Change			
Product Change			

Research Needed On Engineering Control of Chemical Hazards

Approximately 68,000 chemicals have been listed under the Toxic Substances Control Act (TSCA). Though the current major focus is cancer-causing chemicals, all potentially toxic chemicals warrant control.

Control techniques for hazardous chemicals are largely recommended and implemented before they can be effectively evaluated in terms of worker protection. In most cases, no body of knowledge exists that can predict effectiveness. Even when such information does exist, the manufacturer often treats it as proprietary.

Major efforts are now under way to characterize the chemical emissions from all types of equipment to derive standard emission rates. With standard emission rates, a designer could determine the degree of control needed to comply with guidelines or standards. These investigations are in their infancy, however, and are not unlike efforts to characterize outdoor air pollution emissions during the late 1950's and 1960's.

This analytical approach to chemical emission rates could replace the traditional case-by-case empirical methods with standard modeling techniques. Because the method offers great promise to designers, research should aim to determine equipment emission factors and validate near field dispersion models that can calculate chemical concentrations in the workplace. Typical data must be collected for all phases of operation and maintenance before a facility is constructed so that engineering controls can be built into the process.

With regard to retrofit controls, the preferred approach is to capture emissions at the source. Standard control approaches and creative engineering are needed to supplement current published ventilation approaches based on empirical observations. Effective controls for generic processes should be published with many examples that can be applied with little or no alteration by small industries who have no in-house engineering skills.

Research should also be conducted to develop standard test procedures to judge the effectiveness of controls after installation.

The need to conserve energy has kindled much interest in recirculating cleaned workroom air, but the reliability and effectiveness of air cleaning for many complex vapors and aerosols have not yet been established. The costs for such systems and the availability of monitoring equipment also need to be investigated.

Research Needed On Physical Hazards

Physical hazards to health in the workplace include heat and cold, noise and vibration, electromagnetic radiation, ambient pressure, and acceleration or deceleration. Many hazards are also associated with accidental trauma from physical contact with machines, vehicles, flying objects, etc. Engineering controls are widely used for all kinds of physical hazards.

Occupational noise may be used to illustrate the need for research on engineering control of physical hazards. One great need in this field, although not an engineering research task, is the development of recognized noise exposure criteria, since there is a continuing controversy as to what is an acceptable sound level. Another significant need is data resources. Though the principles of noise transmission and control are well understood, a description is needed of the noise sources that exist, the controls that have been tried, and which controls work effectively. Also needed is a complete bibliography to enable development of specific noise profile data.

Phenomena of sound generation and propagation are known at the macrosocpic level, but microscopic processes and molecular effects are not understood. These phenomena require analytical explanation and description to point the way to innovation.

To control noise generation from machinery, research must be conducted to prepare and validate suitable computer-aided design and computer-aided manufacturing (CAD/CAM) computer programs for noise emission and suppression as an integral part of machine design. A computer program is also needed to predict sound pressure levels anywhere within a single room. These design data could then be used to predict the effects of various control measures. Such a computer model would be the industrial counterpart of the general ambient noise prediction model (PREDICT) for environmental noise impact modeling.

Solutions to noise hazards need to be identified, characterized, and catalogued for efficient research planning.

Research Needed On Biological Hazards

Engineering controls for biological hazards were developed mainly during the post-World-War-II era as part of the biological warfare effort. Engineering control methods for bacteria and viruses are of four types: (1) source control, (2) primary containment (using negative air pressure and directional air flow within a biological safety cabinet), (3) secondary containment (using negative air pressure and directional air flow throughout a building), and (4) air filtration. Procedural and biological controls must often be used along with engineering controls. Biological controls used to supplement engineering controls include the use of host cells that have been altered to prevent their survival outside special laboratory environments. The need for such supplemental controls indicates a need for research on better engineering controls.

Research needs for biological hazards include the following items:

- information on the validity of primary and secondary containment measures;
- design of new containment equipment;
- development of tools and instruments that limit containment in laboratories and promote proper use through convenience;
- increased automation in laboratory operations and equipment;
- development of monitoring devices for filter systems; and
- investigation of engineering controls for certain nonlaboratory operations such as wastewater treatment and hazardous waste disposal.

Section 5

CONCLUSIONS AND RECOMMENDATIONS

This background document and the NIOSH workshops have attempted to address the search for new and better ways to apply engineering control technology to the prevention of health and safety hazards in the workplace. Conclusions and recommendations are outlined here. The recommendations have not been ranked.

Conclusions

1. The elimination or control of occupational safety and health hazards is best accomplished at the process, machine, or facility design stage. Retrofit control must be added when a hazard exists, but it is usually more costly and less effective than control in the initial design.
2. To eliminate the man/machine interface, certain job tasks must be eliminated through automation, including robotics.
3. Engineered safeguards need to be better coordinated with work activities so that safety controls will not be overridden to reduce job fatigue or increase productivity.
4. Engineered safeguards must be more efficient and more secure to reduce maintenance and repair requirements.
5. Engineered safeguards must be designed for easy access and error-free operation.
6. Workers must be trained properly and motivated to follow instructions carefully in safety and health matters and to care properly for engineered safeguards.
7. A caring attitude must be fostered among all workers, especially those engaged in hazardous occupations.

Recommendations

General Recommendations

1. The practice of occupational safety and health engineering should be conducted as a collaborative discipline among

the existing industrial hygiene and occupational safety specialties. Engineering students should be made aware of occupational safety and health responsibilities, problems, and control techniques as undergraduates; the comprehensive practice of occupational safety and health engineering should be taught at the graduate level.

2. Textbooks are urgently needed on the subjects of occupational safety and health for undergraduate engineering students, and on the engineering control of occupational safety and health hazards for graduate students. Such textbooks will spawn the development of new courses and heighten student interest.
3. Consideration should be given to establishing guidelines for the design engineer that are similar to the Nuclear Regulatory Commission's ALARA (as low as reasonably achievable) guidelines. The latter place a dollar value on every man-rem avoided. Such guidelines for occupational safety and health engineers would help solve the cost/benefit dilemmas that arise in applying "to the extent feasible" criteria as required by the Occupational Safety and Health Administration.
4. Government agencies in the occupational safety and health field should encourage and participate in the development of consensus standards applicable to engineering control of occupational hazards. Consensus standards that can be used by small companies should be emphasized.

Recommendations for Educational Institutions

1. All undergraduate engineering curricula should include a required course that will include instruction on the responsibilities of engineers for occupational safety and health and an awareness of occupational safety and health engineering problems and solutions.
2. Elective courses in occupational safety and health engineering should be made available in all undergraduate engineering curricula.
3. A sequence of courses should be available in established engineering curricula leading to a specialty option or a minor in occupational safety and health engineering.
4. Undergraduate engineering faculty who teach design courses should be encouraged to take continuing education courses in occupational safety and health engineering.
5. Graduate engineering programs in occupational safety and health should clearly identify their programs and seek ABET accreditation.

6. Graduate engineering programs in occupational safety and health should identify and develop areas of research in occupational safety and health engineering control technology.
7. Schools that do not offer engineering degrees but that have strong engineering credentials and offer graduate programs in occupational safety and health should seek some means for offering programs that lead to an engineering degree. Cooperative arrangements with engineering schools might be one method.
8. Special effort should be concentrated on recruiting engineering students for graduate programs in occupational safety and health engineering.
9. For engineers who are already in practice, academic programs in occupational safety and health should be offered at the graduate level and as part of a continuing education program.
10. Either university-based or independent continuing education programs should be developed and geared to specific or general topics in occupational safety and health engineering.
11. Schools offering graduate programs in occupational safety and health for nonengineering students should strengthen their programs in engineering control techniques.
12. Schools offering graduate programs in occupational safety and health should develop two kinds of continuing education programs in engineering controls—advanced courses for safety and health professionals, and awareness courses for design and process engineers.

Recommendations for the Accreditation Board for Engineering and Technology

1. The concept of public safety included in accreditation criteria should be interpreted or extended to include protection of workers from illness and injury.
2. Accreditation reviews and site visits should be designed to encourage attention by engineering schools to occupational safety and health instructional responsibilities.

Recommendations for NIOSH

1. Educational needs for occupational safety and health engineering should be identified and existing programs that meet these needs should be supported financially and otherwise.
2. Engineering research efforts, including the assessment, development, and demonstration of new and improved control technology, should be fostered.

3. Instructional materials, including case studies, on occupational safety and health engineering should be developed for undergraduate engineering design courses, engineering course electives, and undergraduate engineering minors in occupational safety and health.
4. Substantially increased stipend support should be offered to engineering graduates to attract them to graduate programs in occupational safety and health with a commitment to occupational safety and health engineering research.
5. An advisory panel of technical experts should be established to provide technical guidance on engineering activities. The panel should meet annually to review work efforts and recommend future efforts.

Recommendations for OSHA

1. Intramural and extramural training of agency and state staff in occupational safety and health engineering control technology should be intensified.
2. The adequacy of existing engineering controls should be evaluated during inspections and investigations and reported with an ongoing high priority.

Recommendations for the Private Sector

1. High priority should be given to occupational safety and health engineering when industrial programs of engineering recruitment and financial assistance to engineering education are conducted.
2. The participation of engineer employees in graduate safety and health education should be increased by more generously approving time away from work and underwriting the endeavor.
3. Programs should be developed and underwritten for short-term residence of occupational safety and health university educators in industrial facilities to promote improved faculty understanding of engineering control approaches to potential health and safety problems.
4. The private sector should share successful control technology applications in their facilities with the professional safety and health community by means of publication in the open literature and other communication media.

Recommendations for Labor Organizations

1. Information on hazard recognition, safe working procedures, and engineering methods of health protection should be

made available to workers, local unions, and labor/management committees.

2. Labor contract agreements should contain provisions concerning: (a) how workers are to be informed of the hazards in their environment, (b) results of hazard assessments, and (c) actions to control hazards.

Recommendations for Professional Engineering Societies

1. Engineering organizations should further the education of their members in the use of engineering controls for occupational hazards.
2. Short courses in occupational safety and health engineering should continue to be held at national or regional meetings of engineering-oriented groups. Interprofessional cooperation should be encouraged to increase the availability of such courses.
3. Professional organizations should encourage the publication of data on the benefits of controlling workplace hazards. Benefits of engineering controls should be emphasized since they are best suited to cost analysis.

Recommendations for Research Programs

1. Research on engineering safeguards should consider fully all the human interactions customarily involved in engineered solutions to occupational hazards.
2. Research in applied physics, engineering science, and physical chemistry should be conducted in areas that will lead to fundamental knowledge needed for eliminating, controlling, and monitoring all types of occupational safety and health hazards. This effort should be recognized as multi-disciplinary research that will contribute to occupational hazard prevention in the engineering design process.
3. Fundamental research on source and process emission factors and near field dispersion models should be encouraged and supported. Such research may apply and should be coordinated with engineering research on occupational safety.
4. Increased research and demonstration efforts should be directed at air cleaning and monitoring systems for workplace air recirculation. Results should be used to guide research on cost reduction and improved efficiency of these systems.
5. The design of industrial ventilation systems should be based firmly on fundamental engineering principles.
6. An expert panel should be convened to define urgent engineering research needs in the burgeoning field of biological

safety. Little is known about the engineering control of biological hazards; thus the whole field of biological safety needs serious study to define engineering safety requirements.

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