Chapter 4

INDUSTRIAL HYGIENE IN THE U. S. ARMY

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INTRODUCTION

From its inception, the U.S. Army has led in developing and using new technologies. This leadership has certainly been true concerning the recognition, evaluation, and control of potential health hazards at army worksites. Keeping up with the diverse mix of potential hazards associated with army operations in the field and in garrison has allowed army industrial hygienists to maintain a nationally recognized role in both the identification of hazards and the implementation of controls. Soldiers in fighting units are commonly exposed to hazardous materials; industrial hygienists recognize and help to control these potentially hazardous occupational exposures. Controlling even such common chemical hazards as degreasing solvents or carbon monoxide helps to ensure that soldiers' health is in a state that maximizes their ability to project combat power. Similarly, identifying and controlling noise hazards helps to protect a sentry's hearing acuity. The ability to recognize subtle enemy approach signals such as breaking twigs or jingling rifle cartridges helps keep entire units safe. At the army's industrial base installations, industrial hygienists help to prevent the loss of experienced civilian personnel who have been exposed to potentially hazardous materials during the production and repair of ammunition and other equipment.

Both the American Industrial Hygiene Association (AIHA)[1] and the American Conference of Governmental Industrial Hygienists (ACGIH)[2] have defined *industrial hygiene* as

> that science and art devoted to the recognition, evaluation, and control of those environmental factors or stresses, arising in or from the workplace, which may cause sickness, impaired health and well-being, or significant discomfort and inefficiency among workers or among the citizens of the community.[1(p5)]

AIHA and ACGIH also define an *industrial hygienist* as

> a person having a college or university degree or degrees, in engineering, chemistry, physics, medicine, or related physical and biological sciences who, by virtue of special studies and training, has acquired competence in industrial hygiene. Such special studies and training must have been sufficient in all of the above cognate sciences to provide the abilities: (1) to recognize the environmental factors and to understand their effect on man and his well-being; (2) to evaluate, on the basis of experience and with the aid of quantitative measurement techniques, the magnitude of these stresses in terms of ability to impair man's health and well-being; and (3) to prescribe methods to eliminate, control, or reduce such stresses when necessary to alleviate their effects.[1(p5)]

To meet the scope of the definition, a fully competent industrial hygienist requires an interdisciplinary education covering not only the basic sciences, toxicology, ergonomics, and physiology but also real-world experience with people and the occupational hazards they encounter daily. Army industrial hygienists are generalists; when they couple their scientific knowledge with the art of industrial hygiene, they perform true preventive medicine in the army: eliminating hazards before they cause harm. In this chapter, the term *industrial hygienist* denotes a qualified professional; the broader term *industrial hygiene personnel* includes members of the profession and supporting technical personnel (technicians). The U.S. Army's military industrial hygienists are either Environmental Science Officers (68N) or Sanitary Engineers (68P); army civilian industrial hygienists are classified by the Office of Personnel Management (OPM) as general schedule (GS) 690 or general manager (GM) 690; industrial hygiene technicians are classified in the general OPM series as GS 640, Health Aide and Technician.

HISTORY

The U.S. Army became seriously involved in industrial hygiene during World War I, when workers in military gas-mask manufacturing plants needed protection not only from chemical agent gases but also from typical industrial—chemical and physical—hazards: varying (and various) gas concentrations, solvents, dust, and noise.[3] Both government- and contractor-operated factories received industrial hygiene evaluations from the army during World War I, but those efforts continued only until the war's end.

During the rapid expansion of war materiel production in the late 1930s, the army's chief of ordnance requested medical care for civilian workers. The surgeon general of the army responded by providing the medical care for hundreds of thousands of ordnance workers. However, full identification, evaluation, and control of worksite health hazards was not emphasized until the United States became involved in World War II.[4]

Soldiers who operated the weapons systems and who were exposed to potential hazards of the ordnance itself also received support from the Army Medical Department (AMEDD). An interdisciplinary team of physicians, engineers, and scientists at the Armored Force Medical Research Laboratory, formed in early 1942 at Fort Knox, Kentucky, did pioneering work on heat stress, exposure to toxic gas from weapons firing, the relationship of fitness and fatigue to performance, ergonomics, and human factors engineering. Working in cooperation with other health professionals, industrial hygienists studied equipment systems, predicted potential hazards, and formulated protective responses, as the following examples from that era demonstrate:

- Because dehydration had decreased their ability to function, a tank crew in the Pacific theater failed to engage the enemy, even under the pressure of war.[5] Industrial hygienists did not respond to the actual medical event—in this example, treating soldiers suffering from dehydration. The role of industrial hygienists included attempting to predict and preempt the hazard. For dehydration from heat, increased water intake based on predicted need, not on thirst, is one of several techniques used to protect soldiers and prevent performance degradation. Others include increased air flow with cooler or drier air to cool by convection and evaporation, and enforcing work-rest cycles to reduce metabolic heat loads.
- General officers were convinced to support tank gun ventilation by having them act as gunner and loader in a test-firing of 75-mm shells in an M-4 tank. After four of the planned 10 rounds had been fired, the ammonia levels reached 400 ppm. The generals, weeping copiously and ready to quit the test, realized firsthand the importance of exhaust ventilation:

> The M-4 tank of 1942 had no ventilation provided to specifically meet the needs of the crew. Engine-cooling air was drawn into the turret and through a heat-exchanger to the engine compartment. But in a stationary tank with the engine not operating, the men received no exchange air. Since the 75-mm gun released considerable carbon monoxide and ammonia as the gun breech opened after firing, there was a clear toxic gas hazard that needed to be corrected. This had not been done, I think, because it was usual to practice gun-fire with the turret hatch open.... [S]ystematic measurements of carbon monoxide and ammonia concentrations under various conditions of firing gave convincing proof of the hazard. This led to development of a compact fan to provide the necessary exhaust ventilation. The report recommending installation of such fans [had previously been disapproved] on the grounds that the tank already had too many gadgets![5(p24)]

During the laboratory's 3 years of operation, researchers at the Armored Force Medical Research Laboratory produced 130 detailed reports of this nature and recommended many improvements to reduce potential adverse health effects and therefore improve the soldiers' fighting capabilities. This laboratory heralded AMEDD's current interest in the interdisciplinary medical consideration of the human component first during the design and development of army systems.[6]

In October 1942, the Department of the Army (DA) established the U.S. Army Industrial Hygiene Laboratory at The Johns Hopkins University to conduct occupational health hazard surveys and investigations in army industrial plants, arsenals, and depots.[4,7] Workers at these facilities had potentially hazardous exposures to militarily unique and common maintenance operations at their worksites. This new laboratory concentrated on four technical and scientific areas: field survey, chemical sampling analysis, engineering design, and medicine and toxicology.

Throughout World War II, personnel at the U.S. Army Industrial Hygiene Laboratory developed and applied industrial hygiene technology to the new and greatly expanded army operations. While the Industrial Hygiene Field Surveys Section did its work at the production and repair plants, the Chemistry Section developed new and improved methods to sample and analyze worksite hazards, the Engineering Design and Development Section conceived innovative controls for industrial hazards, and the Medical Section became more involved in toxicological evaluation of fungicides, insecticides, repellents, flame retardants, and other items with military and industrial applications. The Industrial Hygiene Field Surveys Section and the Engineering Design and Development Section of this laboratory are the specific forerunners of today's U.S. Army Industrial Hygiene Program.

The Industrial Hygiene Field Surveys Section used early, portable, direct-reading instruments to determine carbon monoxide and benzene exposure levels. When potentially hazardous exposures at production facilities involved particulate matter such as toxic dusts or vapors from chlorinated solvents, these early industrial hygienists collected air and bulk samples to be analyzed by the Chemistry Section. They developed the principle that recommendations to control

hazardous exposures had to be as practical, fully described, and inexpensive as possible, and could interrupt neither operations nor individual productivity.[8] Simple, low-cost control tactics to reduce the number of people exposed evolved from this principle: physically moving all personnel unrelated to the operation to other, less hazardous locations; isolating essential operational personnel from the hazards (by enclosing the operations); and using less hazardous techniques such as wet grinding or sanding to keep airborne toxic dust levels low.

Because most situations required some additional exhaust ventilation, the Engineering Design and Development Section prepared original designs, reviewed the Field Surveys Section's ventilation proposals, and conducted performance tests of existing ventilation systems. Much of the work involved controlling carbon monoxide from internal combustion engines, firing-range lead fumes and dust, metal fumes from welding operations, toxic pigments from spray finishing, pneumoconioses-producing dusts from abrasive blasting, acid mists from plating, and solvents from degreasing.[8] Interestingly, over 60% of the exposures studied were in these categories.

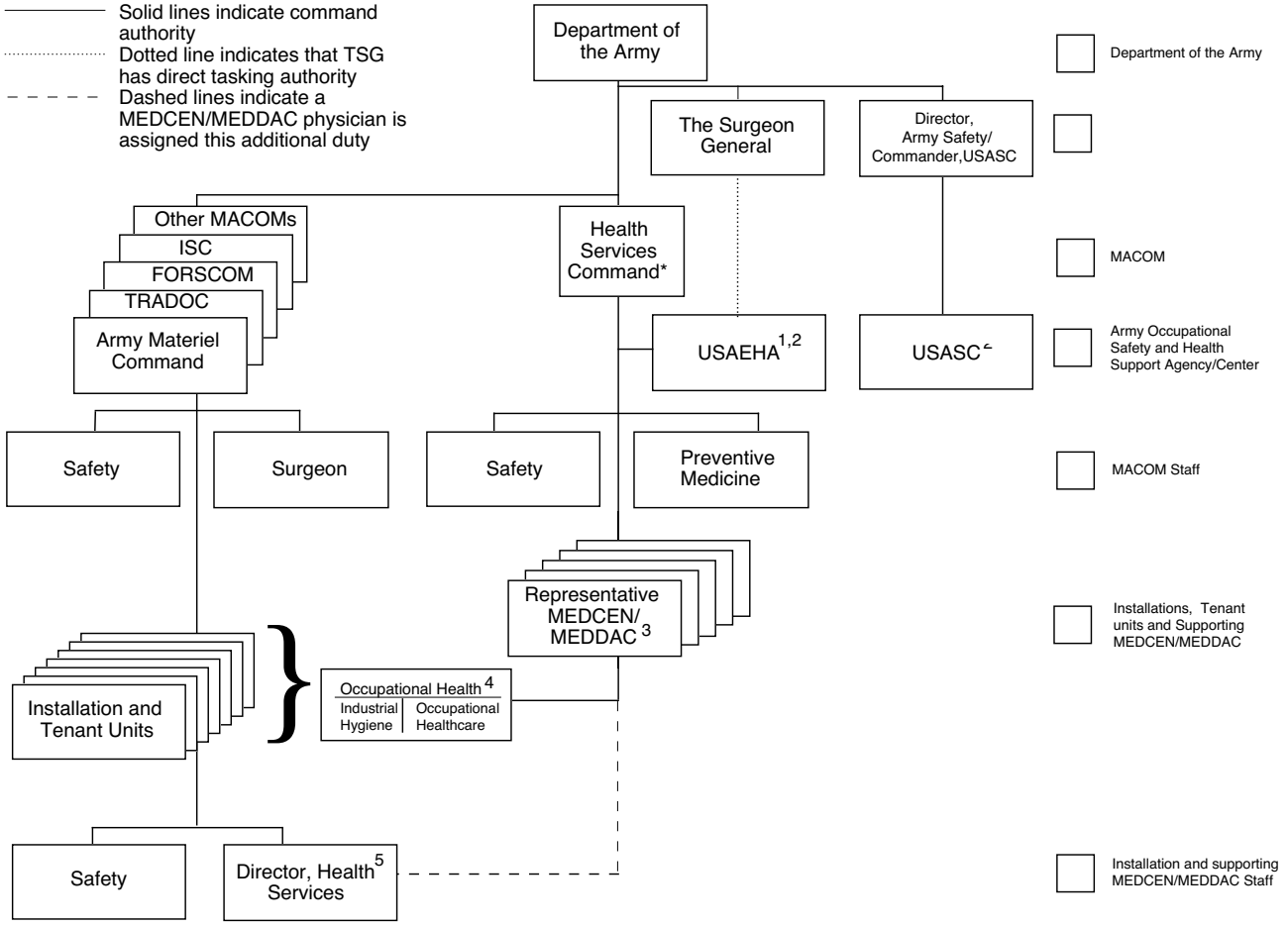
Ammunition loading plants—where open handling of very toxic explosives was commonplace—were the most hazardous facilities that the laboratory personnel evaluated. Workers routinely handled compounds such as trinitrotoluene; amatol; pentolite; tetryl; RDX (***r***esearch ***d***epartment ***ex***plosive, also called *cyclonite*: hexahydro-1,3,5-trinitro-1,3,5-triazine); lead oxide; mercury fulminate; and nitroglycerine. In high-explosives and chemical manufacturing plants, workers were also exposed to acids, nitrocellulose, diphenylamine, and ethyl alcohol; and at arsenals and ammunition depots, to solvents, paints, and chemicals related to the repair, maintenance, and renovation of ordnance materiel. Although these early army industrial hygienists were certainly concerned about the very hazardous explosives compounds, relatively few actual exposures to toxic explosives occurred. Much of the credit for this rests with the representatives from the Office of The Surgeon General assigned to the Safety and Security Division, Office of the Chief of Ordnance, who ensured that the public health aspects of worker protection were U.S. Army policy.[8]

When compared to World War I, fatalities caused by occupational diseases were extraordinarily low during World War II. The fact that industrial hygiene personnel identified hazards and recommended control requirements undoubtedly played a significant role in reducing the rates. In 968,000 man-years of operations in explosives manufacture, there were only 28 occupational disease fatalities: 22 from trinitrotoluene, 3 from oxides of nitrogen, 2 from carbon tetrachlor-ide and 1 from ethyl ether. This was a rate of .03 fatalities per 1,000 man-years, or five deaths per billion pounds of explosives produced. In addition, there were 2.4 lost-time general illness and dermatitis cases per 1,000 man-years of operations. Dermatitis accounted for two-thirds of lost-time cases, and the more serious systemic illnesses had a rate of 0.8 cases per 1,000 man-years of production. However, these rates were "only a small fraction"[8(p167)] of the World War I experience. The 44 members of the Army Industrial Hygiene Laboratory helped achieve such low rates of occupational illness during World War II that they firmly established the utility of industrial hygiene and occupational medicine in the army.

The U.S. Army Environmental Hygiene Agency (USAEHA), which operates 31 diverse occupational and environmental health mission programs, evolved from this small World War II laboratory. As installation-level industrial hygiene operations became routine and shifted to the medical units—such as Medical Department Activities (MEDDACs) and Medical Centers (MEDCENs)—that provide installation medical support, the USAEHA concentrated more and more on highly specialized hazards such as chemical agent demilitarization, ammunition production, and healthcare-facility operations. The USAEHA also developed a consultant role in defining and responding to industrial hygiene issues having armywide impact, such as determining the medical requirements for respiratory protective equipment in militarily unique environments, and developing many technical and draft policy documents for new or changing hazards (eg, composite materials like Kevlar, asbestos use and disposal, lead hazards, and cumulative trauma disorders).

THE INDUSTRIAL HYGIENE PROGRAM

The U.S. Army Occupational Safety and Health Program is divided at the DA level into *occupational safety* and *occupational health*. The U.S. Army Occupational Safety Program, (defined in Army Regulation [AR] 385-10, *The Army Safety Program*[9]) is structured along Major Army Command (MACOM) lines and is executed by MACOM safety and operating personnel at the MACOM and installation levels. The U.S. Army Occupational Health Program is a medical program (defined in AR 40-5, *Preventive Medicine*[10]) that is struc-



1. U.S. Army Environmental Hygiene Agency HSC Subcommand; The Surgeon General has direct tasking authority
2. USAEHA and U.S. Army Safety Center provide army-level technical support worldwide
3. MEDCEN/MEDDAC support all installations and units in their geographical area
4. MEDCEN/MEDDAC occupational health support all units in the MEDDAC/MEDCEN area
5. Installation Director of Health Services support provided by MEDDAC/MEDCEN

* Although medical commands outside the continental United States (OCONUS) are in other organizational patterns, they have similar medical report responsibilities for their overseas areas

Fig. 4-1. Organizational relationships between the U.S. Army's Occupational Health Program and various installations. **Red:** The Department of the Army (DA) staffs develop army policy related to occupational safety and health. **Blue:** The Major Army Commands (MACOMs)are operating commands that follow DA policies, during their operations, that help ensure that their personnel follow safe and healthful work practices. Health Services Command (HSC) also has additional responsibility to provide medical support for the other MACOMs and their installations. That medical support includes providing industrial hygiene and occupational healthcare services. **Orange:** The U.S. Army Environmental Health Agency and U.S. Army Safety Center (USASC) act to develop depth and focus for the DA's occupational safety and health policies. They draft new policies for DA staff coordination; help the MACOM implement the approved policies through consultation and technical guidance; and perform oversight, investigation, survey, and study missions. **Green:** The various MACOM staffs work their respective safety and health issues for the MACOM. In addition, the HSC preventive medicine staffs also oversee the occupational health support provided to the other MACOMs by HSC's medical centers (MEDCENs)and medical activities (MEDDACs)**. Yellow:** Installation and tenant unit commanders and supervisors are responsible for the occupational safety and health of their personnel. **Tan:** The installation unit safety staff and the MEDCEN–MEDDAC occupational health personnel assist commanders and supervisors to meet that responsibility. The installation Director, Health Services, is an installation staff position filled as an additional duty by a MEDCEN or MEDDAC physician. This medical officer provides advice to the installation commander regarding all medical issues affecting the post.

tured along medical command lines and executed primarily by MEDDAC and MEDCEN personnel, who support all MACOMs and their installations (Figure 4-1). The list of the primary documents that form the legal and regulatory basis of the army's Industrial Hygiene Program is shown in Table 4-1.

Within the Occupational Safety and Health Program, the assigned responsibilities for occupational safety, industrial hygiene, and occupational healthcare are not easy to separate; each area of responsibility has proponents and supporting participants, and there are interrelationships at several points (Figure 4-2). The occupational health portion of the program is divided into two main functional areas: *industrial hygiene* and *occupational healthcare* (which includes both medicine and nursing). Although the control of worksite health hazards is the primary mission of industrial hygiene, it also supports occupational healthcare personnel by

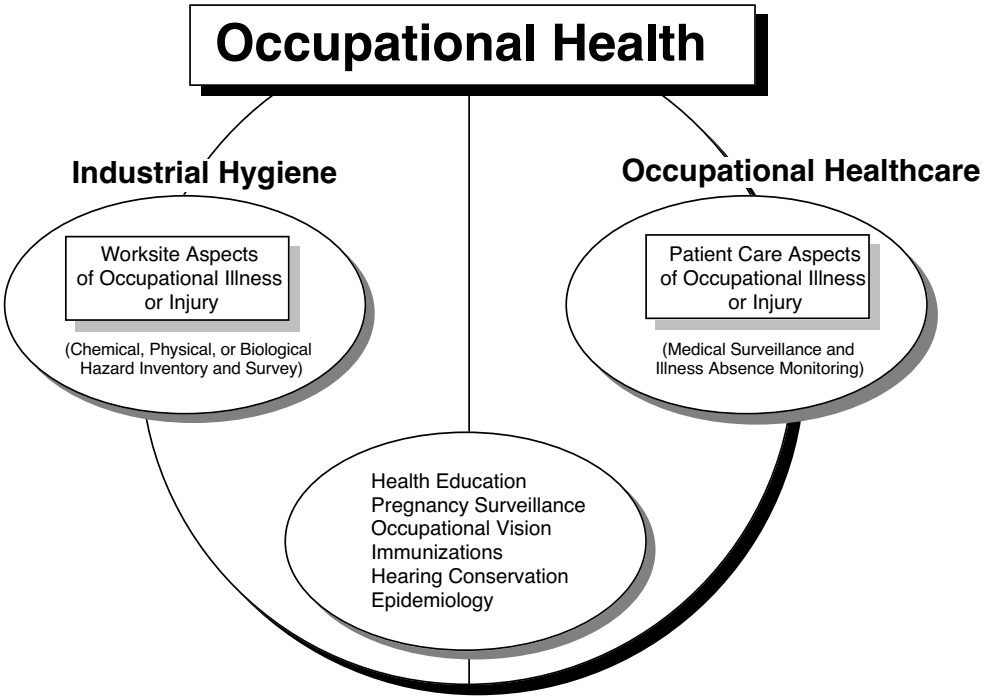
- quantitatively defining the level of worksite exposures to hazardous materials, allowing clinic personnel to (*a*) make informed patient-care decisions regarding medical surveillance and (*b*) target the hazards most likely to cause health effects on workers;
- recommending controls for existing hazards, which, when implemented, can eliminate or greatly reduce medical surveillance requirements; and
- operating the Health Hazard Information Module (HHIM) of the Occupational Health Management Information System (OHMIS), a comprehensive

TABLE 4-1

REGULATORY BASIS FOR AN INDUSTRIAL HYGIENE PROGRAM

Regulation	Description
The Occupational Safety and Health Act of 1970, Pub L No. 91-596	OSHAct, the basic law that requires safe and healthful working conditions for working men and women
Occupational Safety and Health (OSH) Program for Federal Employees, Exec Order No. 12196, 26 February 1980	Order that applies OSHAct standards to all agencies of the executive branch except military personnel and militarily unique situations and equipment
Basic Program Elements for Federal Employee OSH Programs and Related Matters, 29 CFR, Part 1960, rev. 1 July 1987	Regulation to provide OSH Programs for federal employees promulgated by the secretary of labor as required by Exec Order No. 12196
Safety and Occupational Health Policy for the DoD, DoDI 1000.3, 29 March 1979	DoD Instruction that requires adherence to OSHA regulations
DoD Hazard Communication Program, DoDI 6050.5, 29 March 1990	DoD Instruction that prescribes policy and practices for a comprehensive DoD Hazard Communication Program
DoD Occupational Safety and Health Program, DoDI 6055.1, 26 October 1984, rev. 11 April 1989 and 15 August 1989	DoD Instruction that provides policy, procedures, and responsibilities for administration of a comprehensive DoD OSH Program
Industrial Hygiene and Occupational Health Program, DoDI 6055.5, 10 January 1989	DoD Instruction that establishes uniform procedures for recognizing and evaluating health risks associated with chemical, physical, or biological stresses at DoD worksites
Army Safety Program, AR 385-10,* 23 June 1988	Army Regulation that implements safety requirements of federal and defense regulations
Preventive Medicine, AR 40-5,* 19 June 1985	Army Regulation that implements occupational health requirements of federal and defense regulations
Army Industrial Hygiene Program, TB MED 503,* 1 February 1985	Bulletin that explains the organization and responsibilities of the industrial hygiene portion of the Army Occupational Health Program

*Key documents for army installations



	OS&H		
		OH	
Responsibilities	**OS**	**IH**	**OHc**
Safety and health program coordination	P	P	P
Occupational safety functions of AR 385-10	P	R	R
29 CFR 1960 requirements (SAOSHI)	P	P	P
Personal protective equipment	P	P	P
Ergonomics	S	P	S
Epidemiology	R	P	P
Inventory of chemical, biological, and physical hazards	R	P	R
IH surveys	S	P	S

	OS&H		
		OH	
Responsibilities	**OS**	**IH**	**OHc**
Medical surveillance	R	S	P
Health education	R	P	P
Hearing conservation	R	P	P
Occupational vision	R	P	P
Medical treatment	R	S	P
Pregnancy surveillance	R	P	P
Immunizations	R	P	P
Illness absence monitoring	S	S	P
Hazard communication	P	S	S

OS&H: Occupational Safety and Health; OH: Occupational Health; OS: Occupational Safety; IH: Industrial Hygiene; OHc: Occupational Healthcare (includes medicine and nursing)
P: Has primary responsibilities; S: Provides support; R: Referral

Fig. 4-2. Occupational health's two major components—industrial hygiene and occupational healthcare—provide medical support to an installation and its tenant units through the worksite and patient-care aspects of the Occupational Health Program. The Standard Army Occupational Safety and Health Inspection (SAOSHI [CFR 1960]) specifies that both command and supervisory personnel (the Occupational Health Program–installation interface) be involved with issuing and assuring the correct use of personal protective equipment (PPE); communicating the hazards of a worksite to the operators (hazard communication); participating in the annual worksite inspections; and performing other related activities in coordination with supporting occupational safety, industrial hygiene, and healthcare personnel. Usually, commanders designate their own safety officers to work with the supporting medical unit to coordinate accomplishment and oversight of a comprehensive program with the participation of supervisors and supporting medical units. The various safety and occupational health program participants are responsible for performing their own primary missions, supporting other participants, and, at a minimum, ensuring that information regarding hazards is referred for action.

health database that provides exposure and other worksite data to occupational healthcare personnel in an easily accessible and usable form.

Furthermore, the missions of occupational safety and occupational health, especially the industrial hygiene portion, appear, on the surface, to be similar. Confusion frequently exists as to where their mission responsibilities and primacy lie. The primary differences between their missions are that

- occupational safety personnel are mainly concerned with the prevention and control of traumatic injury to personnel, and with accidents that result in loss of materiel; whereas
- industrial hygienists are mainly concerned with factors at the worksite that cause chronic or acute illness, disease, or injury to personnel.

In most instances, the distinction is clear. For example, an overhead crane that drops a load of lumber and injures several people, or a shorted electrical circuit that causes a building fire and electrical burns to personnel are both occupational safety issues. Occupational safety personnel would focus on the cause and prevention of these accidents. But a welder's increased body burden of lead from exposure to fumes from metal coated with lead-containing paint, or a painter's allergic sensitization and respiratory distress after exposure to epoxy resins and isocyanate compounds in chemical agent resistant coatings (CARCs) are industrial hygiene issues.

The two missions intersect where there are dual medical and safety responsibilities. Some situations have both traumatic injury and systemic components. For example, if acid bubbles out of a lead acid battery on high charge and burns a worker's unprotected hands, that is an occupational safety issue; however, the worker's inhaling the acid mist that forms, and the consequent respiratory illness, are industrial hygiene and occupational healthcare issues.

Personal protective equipment (PPE) also involves dual medical and safety responsibilities (see Figure 4-2). For example, the issue and use of respiratory protective equipment has traditionally been the domain of supervisors and occupational safety personnel. However, selecting the proper respirator requires a detailed industrial hygiene exposure evaluation, and the potential user must be medically evaluated before being required to wear a respirator.

RECOGNIZING HAZARDS

Effective industrial hygiene personnel know and follow all the potentially hazardous operations on an installation. They must begin to learn as much as possible about an installation and its industrial operations, processes, and possible hazards as soon as they arrive, and constantly track any changes. The development of this knowledge base will allow them to make valid comparisons and decisions about changes to any of the operations.

Sources of Information

Industrial hygienists can gain information about an installation from (*a*) the HHIM; (*b*) injury reports and complaint logs from clinics; (*c*) chemical inventories and chemical purchase requests; and, certainly, (*d*) referral from safety personnel, union representatives, supervisors, and individual workers.[11,12] The industrial hygienist maintains the HHIM, a database of in-formation about operations collected from the local installation, the USAEHA, or contractor surveys of worksites. The database can be used to generate virtually any type of report required to define existing conditions. Industrial hygiene personnel develop and maintain an up-to-date HHIM using forms that contain the pertinent information regarding the operation, its personnel, and the potential hazards (Figure 4-3).

Injury and complaint logs from clinics, emergency rooms, and duty officers also provide industrial hygienists with records of potentially hazardous locations for surveys. Chemical inventories and chemical purchase requests, especially for newly introduced chemical compounds, are excellent and frequently overlooked sources of information concerning new or changed industrial processes or worksite operations. Hazard communication training and media reporting have increased the level of awareness of potential hazards from occupational exposures: installation safety personnel, union representatives, supervisors, and individual workers now often refer potential problem situations to industrial hygienists for survey.

Knowledge of the Installation

In addition to these sources of information, the industrial hygienist must become familiar with the particular installation's mission, the operations that support the mission, and the supervisors and production workers who compose the workforce.[11,12] The intimate knowledge required is gained only through

Figure 4-3a

HEALTH HAZARD INFORMATION MODULE; INDUSTRIAL HYGIENE SURVEY

For use of this form, see HHIM User's Guide

SECTION 1. DEMOGRAPHIC DATA

ARLOC	INSTALLATION	BLDG/RM NO.
53456	Ft. Lewis	3516/Bay

LOCATION/CODE	OPERATION/CODE
Vehicle maintenance / GS	Brake Repair / BKR

SURVEY DATE	EVALUATOR (Initials)
910401	TW

MACOM/CODE	SUBMACOM/CODE	SUPERVISOR
FORSCOM / FC	N/A	CW3 Fxxxx

TELEPHONE/DSN NO.	UNIT/ORGANIZATION	RAC	FREQUENCY (hrs/day)
DSN 584-9113	DEH / Motor Pool	3	8

NO. CIV(S)	NO. MIL	NO. CONTRACTOR(S)	NO. LOC(S)	NO. OTHER
3	0	N/A	N/A	N/A

SECTION 2. FACILITY DATA

LAB HOODS	VAPOR DEGREASERS	SPRAY BOOTHS

MAINTENANCE BAYS	OPEN SURFACE TANKS	VENTILATION UNITS
6		1

SECTION 3. SURVEY DATA

CONTROLS PRESENT	EVALUATION	UNIT CODE	CONTROLS REQUIRED	STATUS
LEV	50	FPM	150 FPM	UNCON

PERSONAL PROTECTIVE EQUIPMENT (R = REQUIRED; U = UTILIZED)

GLOVES	R/U	RESPIRATOR	NIOSH TC NO.	MANUFACTURER	R/U
ACID	/	AIRLINE			/
COLD SURFACES	/	AB RASIVE BLASTING HOOD			/
HOT SURFACES	/	DISPOSABLE	None	3M	/ X
NBC AGENTS	/	FULL FACE AIR PURIFYING			/
OIL	X / X	1/2 FACE AIR PURIFYING			/
SOLVENTS	/	POWDERED AIR PURIFYING			/
SURGICAL GLOVES	/	1/4 FACE AIR PURIFYING			/
	/	SELF CONTAINED			/

EYES/FACE	R/U	HEARING	R/U	BODY	R/U	HEAD/FIT	R/U
CHEMICAL SPLASH	/	CANAL CAPS	/	APRONS	/	COLD WEATHER BOOTS/HATS	/
FULLFACE SHIELD	/	EARPLUGS	X / X	COLD WEATHER CLOTHING	/	HARD HATS	/
CHEMICAL/SAFETY	/	HELMETS	/	COVERALLS	/	IMPERMEABLE BOOTS	/
SAFETY/IMPACT	X / X	MUFFS	/ /	FULL BODY SUIT	/	SAFETY/CONDUCTIVE SHOES	X / X
WELDING HELMET	/	MUFF/EARPLUG COMBO	/	HEAT REFLECTIVE VEST/SUIT	/	SAFETY/NON-CONDUCTIVE SHOES	/
		MUFF/EARPLUG W/TIME LIMIT	/	SAFETY BELT/HARNESS	/		

AEHA FORM 271-R (TEST), 1 JAN 92 (HSHB-MI-I)

Fig. 4-3a–c. These five pages are facsimiles of the documents used to conduct a typical industrial hygiene survey using the Health Hazard Information Module (HHIM) database. The hypothetical data in Section 3, Survey Data, show that local exhaust rates are below standard, that noncertified respiratory protective equipment has been used, and that hearing protection is required and used.

Figure 4-3a (continued)

SECTION 4. HAZARD INVENTORY DATA

CAS CODE	HAZARD DESCRIPTION	PAC	EPC
PØ NOISECO	Noise, continuous	2	D
12172-73-5	Asbestos (Amosite)	1	A
12001-29-5	Asbestos (Chrysotile)	1	A

SECTION 5. PERSONNEL DATA

LAST NAME	FIRST NAME	MI	SEX	SSN	CATEGORY
Fxxx	John	A	M	003-04-0567	Civ
Fxxx	Mike	B	M	004-05-0678	Civ
Wxxx	Keith	C	M	005-06-0789	Civ

SECTION 6. COMMENTS

☐ No Comments ☐ See attached Sheet

PRIVACY ACT STATEMENT

Title 5 US Code, Section 301; Executive Order 9397 authorizes the use of your Social Security Number as an identification number. The purpose of this information is to identify and monitor data relating each DA civilian and military employee exposed to a hazardous workplace or operation. The use of this information is to provide histories of exposures for any given worker.

Disclosure of your Social Security Number is not mandatory; however, nondisclosures may result in untimely provision of proper medical monitoring.

2

Fig. 4-3a. This hypothetical survey identified three civilian workers—John F., Mike F., and Keith W. (Section 5, Personnel Data)—who were exposed to asbestos (Amosite and Chrysotile) and continuous noise from brake-repair operations (Section 4, Hazard Inventory Data). This operation has received a high-priority action code (PAC-1) for asbestos sampling and evaluation, and a moderate code (PAC-2) for noise survey. The exposure potential codes (EPCs) show occupational healthcare personnel that the asbestos exposure is controlled (EPC-A) but that surveillance audiometry is required for noise exposure over 85 dBA (EPC-D) even though hearing protection is worn.

Figure 4-3b

INDUSTRIAL HYGIENE AIR SAMPLE DATA — 8 HR TWA

For use of this form see USAEHA TG 141; the proponent is HSHB-LO.

Return Address *(complete address including Zip Code)*: USA MEDDAC ATTN: PM SVC-IH Ft. Lewis WA 99603	Point of Contact *(name/AUTOVON)*: George Sxxx DSN 931-4763 Associated Bulk Samples: [X] Yes [ ] No Bulk Sample No(s):
Samples Collected By: Jay Jxxx	Date Collected: 910401 — Date Shipped: 910402
Project Number:	Sampled Installation: Ft. Lewis — ARLOC: 5 3 4 5 6
Location *(BLDG/AREA)*: 3516 / Bay / GS	Description of Operation *(details on reverse)*: BKR
3 Persons Exposed — 8 Hrs/Day	Method of Collection: CE Filter
Associated Complaints *(be specific) (state NONE if applicable)*: None	3
Analysis Desired: Amosite Asbestos, Chrysotile Asbestos	

Sampling Data

Sample No.	FTLW01	FTLW02						FTLW03
Pump No.	1234	5678						BLANK
Time On	0730	0731						
Time Off	1530	1531						
Total Time (min)	480	480						
Flow Rate (LPM)	2.0	2.0						
Volume (Liters)	960	960						
GA/BZ	BZ	BZ						
Employee Name/ID	004-05-067	005-06-078						
Laboratory No.	AEHA 1	AEHA 2						AEHA 3

Results

Amosite (f/cc)	< 0.005	< 0.1						0
Chrysotile (f/cc)	< 0.010	< 0.2						0

Comments to Lab:

Lab Use Only

Analyst *(initials)*	Reviewed By *(initials)*	Date Received	Date Dispatched
KS	TL	910403	910404

AEHA Form 9-R, 1 Oct 84 (Replaces AEHA Form 9, 1 Oct 80 which is obsolete).

Fig. 4-3b. Because asbestos is a known carcinogen, the industrial hygienist sampled the air immediately; no exposures in excess of the health standards were found, although the local exhaust did not provide the generally recommended level of control.

Figure 4-3b (continued)

Calibration Information				
Pump No.	Calibration (L/min)		Rotometer Setting	Date
	Pre-Use	Post-Use		
1234	2.0	1.9		910401
5678	2.0	2.0		910401

Name of Calibrator: Jay Jxxx

Operation

Source of Contaminant: Old brake lining

Operation Employee(s) Perform: Replace brake shoe lining

Ventilation: [X] Local Exhaust [ ] General Area [ ] None

Personal Protective Equipment *(check if worn)*

- [X] Respiratory Protective Equipment Type: Disposable
- [ ] Protective Clothing Type:
- [ ] Gloves Type:
- [ ] Goggles/Face Shield:
- [X] Ear Protection:
- [X] Other: Safety goggles, safety conductive shoes

Field Notes/Additional Comments

2

Figure 4-3c

BULK SAMPLE DATA

For use of this form see USAEHA TG 141; the proponent is HSHB-LO.

Return Address *(complete address including Zip Code)* *USA MEDDAC* *ATTN: PM SVC-IH* *Ft. Lewis WA 99603*	Point of Contact *(name/AUTOVON)* *George Sxxx* *DSN 931-4763*

Sampled Installation *Ft. Lewis*	Project Number	ARLOC 5 3 4 5 6
Samples Collected By *Jay Jxxx*	Date Collected *910401*	Date Shipped *910402*
Description of Operation *Brake re-lining*		Location *(BLDG/AREA)* *3516/BAY/GS*

Associated Complaints *(be specific)* *None*

Associated Air Samples: [X] Yes [ ] No — If yes, list sample numbers: *FTLW01, FTLW02*

Label Information

Trade Name	NSN	Manufacturer
None		

Address	MSDS Attached
	[ ] Yes [X] No

Analysis Desired: *Amosite and chrysotile Asbestos=C*

Lab Use Only	Sample No.	Constituents	Results	Remarks
	FTLW04	*Amosite*	*50%*	
	FTLW04	*Chrysotile*	*< 5%*	

Comments to Lab:

Lab Use Only

Analyst *(initials)*	Reviewed By *(initials)*	Date Received	Date Dispatched
RS	*KJ*	*910403*	*910404*

Procedures Performed	Comments
TEM	

AEHA Form 8-R, 1 Oct 84 (Replaces AEHA Form 8, 1 Oct 80 which is obsolete)

Fig. 4-3c. Bulk samples were also collected to characterize the types of asbestos present. The data elements tie together administrative, exposure, and control information for a particular date. The ability to query the HHIM database allows industrial hygienists to focus key program resources on hazards based on rational criteria such as exposure levels in excess of the standards, estimates of high exposures, the numbers of personnel affected, possible exposures to carcinogens, and so forth. The identification and subsequent quantification of hazards and exposure levels allow industrial hygiene and occupational healthcare managers to aim their limited resources at priority targets.

daily contact with the workforce at the worksite. Only through frequent observation can industrial hygienists see a true picture of potential hazards. Irregular or infrequent worksite visits are simple snapshots; they lead to false impressions of exposure potentials.

Sources of Occupational Illness

To immediately recognize potentially hazardous situations and substances, industrial hygienists must be familiar with a broad range of industrial operations and processes, and know the typical routes of entry, target organs, and actions of the chemical, physical, and biological agents of occupational illness.

Chemicals

Chemicals typically enter and act on the body through (*a*) direct action on the skin; (*b*) direct action on the respiratory system; (*c*) systemic illness via exposure through skin contact, inhalation, or ingestion; or (*d*) irritant or systemic action from the rare occurrence of physical injection of chemicals into the bloodstream. Experienced industrial hygienists realize that they must also be familiar with the relationship of the chemical's route of entry and mode of action to the operation and process involving the chemical, the engineering controls and PPE available, the short- and long-term exposure times, and the potential that an average worker will have an adverse reaction to the chemical.

Dermatitis is one of the leading indicators that workers are overexposed to chemical hazards. Industrial hygienists who know the typical classifications of dermatitides will be able to recognize the signs of chemical dermatitis and link the medical diagnosis to hazardous operations.[13]

- Primary skin irritants cause direct injury after sufficient contact. Strong organic and inorganic acids and bases are prime examples of this group. Sulfuric acid in automotive batteries or sodium hydroxide in strong inorganic cleaning solutions, for example, can cause serious dermal burns and ulcers.
- Allergic sensitizers do not cause visible effects on first contact. However, for some people, after continued exposure even very small amounts will cause dermatitis at the point of contact or even at other parts of the body. The epoxy resins found in CARCs are skin sensitizers commonly found on army installations.
- Drying agents, mainly organic solvents such as acetone, naphtha, xylene, and toluene, remove fats from skin, leaving it dry and susceptible to cracking and secondary infections.
- Occupational acne and other less frequently seen dermatitides such as photosensitivity, neoplasms, and changes in pigmentation can be associated with overexposure to petroleum, oil or grease, tar, and some chlorinated organic compounds such as the chlorinated phenols.

The exchange of information between the industrial hygienist and occupational healthcare personnel is useful when establishing other clinical diagnoses like occupational lung disease, and when identifying sources of exposure. Therefore, industrial hygienists must be knowledgeable about the direct effects of chemicals on the respiratory system (eg, asthma, pneumoconioses, and some cancers). These effects are caused by vapors, gases, and aerosols (ie, particulates suspended in a gas, usually air; smoke and dust are *solid* aerosols, whereas mist and fog are *liquid* aerosols). The relationship of the health hazard to the physical state of the chemical is discussed in the next section of this chapter.

Industrial hygienists must also be aware that chemical changes caused by human metabolic processes can either toxify or detoxify certain chemicals, and they must be able to make appropriate control recommendations (Table 4-2).

The least likely cause of overexposure to hazardous chemicals is the physical injection of chemicals into the body. Although rare, instances have occurred where high-pressure, compressed air from air guns or spray-paint apparatuses have injected pigments, solvents, and other chemicals through the skin (and potentially into the bloodstream) of the worker.

Physical Agents

The main physical agents of occupational concern for the typical army installation–industrial hygienist include noise, radiation, temperature extremes, and ergonomic stresses. Industrial hygienists measure potential noise-hazardous operations; noise and hearing conservation are covered in Chapter 7, Noise and the Impairment of Hearing. Army industrial hygienists need to identify and list radiation hazards in the HHIM so that occupational medicine and nursing personnel can schedule appropriate medical surveillance. However, health physics and the evaluation and control of nonionizing and ionizing radiation have become specialized fields in the army. Although industrial hygienists have radiation training and provide user support, many installations and medical units have specialty Radiation Protection Officers as-

TABLE 4-2

ENTRY AND ACTION OF TOXIC CHEMICALS (example exposures)

Exposure	Route of Exposure	Potential Health Effect	Recommended Control
Amalgam preparation	Inhalation of Hg vapor	Dementia	Enclosed amalgamation preparation Local exhaust Waste control
Firing-range cleaning	Inhalation/ingestion of Pb dust	Colic Palsy Encephalopathy Anemia	Respirators HEPA vacuum
Laboratory procedures	Ingestion/dermal contact with benzidine dye	Bladder cancer	Substitute reagent
Metal-parts cleaning	Inhalation/dermal contact with organic solvent	Cirrhosis	Local exhaust Protective gloves
Pest-control spraying	Inhalation/dermal contact with carbaryl	Depressed erythrocyte cholinesterase	Respirator Protective clothing

Carbaryl: (1-napthyl N-methyl carbamate)
HEPA: high-efficiency particulate air filters, which remove 99.97% of the aerosol particulates > 0.3 μ

signed to do day-to-day occupational safety and health work related to radiation (see Chapter 15, Nonionizing Radiation, and Chapter 16, Ionizing Radiation).

The adverse effects of heat and cold are concerns of industrial hygiene personnel on army installations. Soldiers' field exposures are the concerns of the supporting preventive medicine unit. The U.S. Army Research Institute of Environmental Medicine (USARIEM) publishes results of their investigations into the effects of and response to these exposures.[14–16] Where temperature extremes do occur, the principles of identification, evaluation, and control are applied using established occupational health standards.

The effects of heat and cold are associated with the *net heat balance* between the working environment and the worker's normal body temperature (98.6°F ±1°F). The body's heat balance *H*, which is usually measured as either BTU / hour or kcal / hour in any environment, can be expressed in the equation

$$H = (\pm R) + (\pm C) + M - E$$

where *R* represents the radiant heat gained or lost, *C* represents the heat gained or lost through convection (transferred between the skin and air), *M* represents the metabolic heat gained from varying work rates, and *E* represents the evaporative heat loss through vaporization of sweat.

Measurement of air temperature, air velocities, radiant loads and humidity, and estimates of work rates and clothing insulation will enable trained industrial hygiene personnel to evaluate potentially hazardous heat or cold conditions. Because these environmental conditions are interrelated, measurement tools were developed that integrate several of these factors for use in heat-stress and wind-chill indices (Figures 4-4 and 4-5). Industrial hygienists can use these measurements to determine hazard levels and, in conjunction with review of the operation, can recommend engineering, work practice, and personal protection controls.[17–20]

Ergonomic stresses are a recently expanding field of interest for army industrial hygienists and other professionals such as physical and occupational therapists, occupational health nurses, occupational medicine physicians, and safety officers. However, industrial hygienists evaluate worksite hazards and have the medical background to appreciate the physiology and anatomy required for ergonomic evaluation. Treating existing back and repetitive-motion illnesses or training personnel in proper lifting techniques is not enough; control of ergonomic hazards at their source

Fig. 4-4. This Reuter Stokes RSS-214 WiBGeT Wet Bulb Globe Thermometer electronically records the wet bulb, dry bulb, and black globe temperatures, then calculates a heat-stress index that is used to determine the protection necessary for the stresses of excessive heat. Heat stress is the subject of US Army Research Institute of Environmental Medicine (USARIEM) Technical Note 91-1, *Sustaining Health and Performance in the Desert*,[15] which can be consulted for further information.

Wind Speed (mph)	Actual Temperature (°F)											
	50	40	30	20	10	0	–10	–20	–30	–40	–50	–60
	Equivalent Chill Temperature (°F											
Calm	50	40	30	20	10	0	–10	–20	–30	–40	–50	–60
5	48	37	27	16	6	–5	–15	–26	–36	–47	–57	–68
10	40	28	16	3	–9	–21	–33	–46	–58	–70	–83	–95
15	36	22	9	–5	–18	–32	–45	–58	–72	–85	–99	–112
20	32	18	4	–10	–25	–39	–53	–67	–82	–96	–110	–124
25	30	15	0	–15	–29	–44	–59	–74	–89	–104	–118	–133
30	28	13	–2	–18	–33	–48	–63	–79	–94	–109	–125	–140
35	27	11	–4	–20	–35	–51	–67	–82	–988	–113	–129	–145
40	26	10	–6	–22	–37	–53	–69	–85	–101	–117	–132	–148
Wind speeds > 40 mph have little additional effect	**Little Danger** (in < 5 h with dry skin; greatest hazard is from false sense of security)				**Increasing Danger** (exposed flesh may freeze within 1 min)				**Great Danger** (exposed flesh may freeze within 30 sec)			

Fig. 4-5. Potential heat loss, skin cooling, and lower internal temperature can be increased by air movement. The wind-chill index integrates windspeed and air temperature to estimate associated risk of cold injury. The wind-chill temperature index is the equivalent still-air (no wind) temperature that would produce the same heat loss on bare skin. A full description of the medical aspects of military operations in the cold is the subject of US Army Research Institute of Environmental Medicine (USARIEM) Technical Note 92-2, *Sustaining Health and Performance in the Cold.* Source of chart: US Army Research Institute of Environmental Medicine Technical Note 92-2. *Sustaining Health and Performance in the Cold: Environmental Medicine Guidance for Cold-Weather Operations.* Natick, Mass: USARIEM; July 1992: 37.

is vital. For example, to eliminate lifting from floor level, industrial hygienists can recommend moving the storage of heavy parts to waist level; to ensure proper wrist position during equipment assembly, they can recommend tools designed to keep the wrist in a neutral position.

Biological Hazards

Biological hazards found on army installations are typically associated with the medical, dental, and veterinary facilities and their supporting agencies such as laboratories. For installations with personnel who spend time outdoors, other typical biological hazards can include such things as poison ivy, insect stings and bites, and arthropod-borne diseases (eg, Lyme disease). Protection is provided though training, avoidance where possible, protective clothing, repellents, and preparation both to identify these outdoor exposures and treat any personnel who report to a clinic. Biological hazards to healthcare workers is the subject of Chapter 5, Health Hazards to Healthcare Workers.

EVALUATING HAZARDS

Worksite exposures change as processes, personnel, and work rates change; as existing controls deteriorate through use; as buildings are modified; and even as seasons change. Therefore, a registry of worksite exposure levels must be maintained to (*a*) prevent hazard assessments based on single samples of potential hazards and (*b*) provide a usable record of increasing or declining exposure trends.

Monitoring Methods

Industrial hygienists use several monitoring methods at worksites to quantify exposure levels.[21–24] The main types of monitoring employ direct reading instruments, indirect measurement (ie, collection of samples for later laboratory analysis), or both. Portable, direct reading instruments are constantly being developed and improved; some in common use include combustion meters, flame ionization detectors, gas chromatographs, photometers, and certain gas-diffusion badges.

Direct Reading Instruments. Instruments that register direct readings allow measurements of worksite exposures to be made in real time. They use analog or digital meters; strip-chart recordings; tape printouts; and color changes in impregnated paper, liquid reagents, or colorimetric glass tubes filled with solid reagents.[22–24]

Direct reading instruments can be used as nonportable monitors to provide a continuous record of chemical concentrations over long periods. They can also be set to sound alarms if worksite concentrations exceed preset exposure level standards. Portable instruments are used to identify sources of potentially hazardous exposures at the worksite, to determine if exposure standards are exceeded, to check engineering controls, and to record exposure.

Chemical detector tubes are narrow glass tubes, sealed at each end, and filled with solid, finely granulated, reagent-impregnated materials (Figure 4-6). The industrial hygienist must first open both ends of the tubes and then pump known volumes of sample air through. Contaminants collect on the media and react to produce a color change. Exposure levels are determined by reading the length of the stain or the degree of color change. However, errors can occur due to chemical interferences, the operator's faulty estimate of the stain reaction, and the quality or age of the reagents.

Another frequently used monitor of exposure levels is the infrared spectrophotometer, which measures the attenuation of specific wavelengths of infrared light as they pass through a gas or vapor sample (Figure 4-7). Infrared spectrophotometers require frequent adjustment, must be calibrated with known concentrations of contaminants, and are subject to interference from chemicals with the same infrared light absorbance spectrum as the target chemical's.

Piezo electrical mass monitors measure aerosol mass by comparing frequency changes in an oscillating crystal exposed to the aerosol with another crystal—one not exposed to the aerosol—used as a blank to cancel out any changes due to temperature, pressure, or humidity (Figure 4-8).[21]

Direct reading instruments have limitations that must be considered before and during their use:

- Although the cost of the least expensive direct reading instrument, a detector tube, is relatively low ($5.00 each), more-accurate and -specific instruments (with electronics and electrochemical cells) can cost more than $5,000 each and can easily exceed $15,000 each.
- Many instruments react to classes or families of chemicals rather than to specific compounds; in some, even completely different chemicals can cause interference (eg, water vapor will interfere with infrared analysis of ethylene oxide on certain instruments).

Fig. 4-6. This GASTEC / Sensidyne pump, model 800 with formaldehyde low range (0.1–5 ppm) detector tubes, is used to rapidly screen areas for formaldehyde gas. Other types of tubes are available to screen for many common chemicals. Each carton contains specific instructions for sample volumes.

Fig. 4-7. This MIRAN 1B2 infrared gas analyzer provides sub-ppm measurement of a wide variety of gases and vapors. This instrument or a variant is frequently used to monitor for ethylene oxide and waste anesthetics in army medical treatment facilities.

Fig. 4-8. This TSI Respirable Aerosol Mass Monitor Model 3500 uses the frequency changes of piezo crystals to determine the mass of 0.01–10 μ particles in air.

- Separate direct reading instruments to measure all the chemicals that might be present at a worksite may be difficult to carry.
- Instruments that use colorimetric techniques, especially the detector tubes, can deviate ±50% from the true values (results within ±25% are acceptable, provided the error range is known and is included in the hazard analysis).
- Direct reading instruments require frequent calibration to meet published accuracy levels because electronic drift, vibration, pressure and temperature fluctuations, reagent batches, and other factors can adversely affect the instruments' accuracy.

The accepted accuracy of various instruments ranges between ±1% and ±25%. Before making recommendations based on a single reading, industrial hygienists must carefully assess an instrument's capability, the worksite's situation, and any new risks that could ensue from significantly changing an industrial process.

Indirect Measurements

Indirect measurement of airborne contaminants requires that industrial hygiene personnel collect the potentially hazardous material of interest and deliver it to the laboratory for analysis. Before a sample can be collected, the industrial hygienist must know (*a*) the physical state (eg, is it an aerosol or a gas or vapor?) of the contaminant and (*b*) the proper *sampling train* (the combination of equipment, connected in series) necessary to collect the specific contaminant in such a way that its volume or weight can be precisely determined in a laboratory.[22–24]

Aerosols contain liquid or solid material suspended in air. They include dusts, fumes, and smokes (solid aerosols) and mists and fogs (liquid aerosols). Aerosols are defined by their (*a*) aerometric diameters and *(b)* method of formation (Table 4-3). Although aerosols of interest to industrial hygienists have diameters ranging from 0.001 to 500 μ, the diameters of aerosols that significantly affect the body enter via the respiratory tract and generally range between 0.1 and no greater than 20 μ. Their size, density, shape, and other aerodynamic properties affect both the quantity of contaminant deposited and the respiratory site wherein the contaminant will accumulate:

- Aerosols with diameters larger than 10 μ tend to deposit in the nose and upper respiratory tract.
- Aerosols with diameters approximately 0.5 to 10.0 μ tend to be carried further and be deposited within the smaller respiratory passages.
- Aerosols with diameters of 0.1 to 0.5 μ are inhaled and exhaled, but tend not to be deposited.
- Extremely small particles (< 0.1 μ) are usually deposited in the smallest air passages after collision with gas molecules in breathing air. However, these particles are so small that their absolute quantity is minuscule, and they usually have no significant effect on human health.

Although gases and vapors are actually separate physical states, they are grouped together for purposes of this chapter because industrial hygienists use

TABLE 4-3

TYPES OF AEROSOLS

Type	Approximate Range of Diameters (μ)	Formation
Dusts	< 1 – > 500	Formed from solid materials by a mechanical action such as crushing or grinding
Fumes (colloids in air)	0.0001 – 1.0	Formed by vaporizing and condensing solids in air, such as when welding or cutting metal
Smokes	0.01 – 1.0	Produced by incomplete combustion of carbon-containing material
Mists	0.5 – > 100	Produced from liquids by mechanical action such as bubbling, splashing, or atomizing
Fogs	1 – 50	Formed from liquids that have vaporized and recondensed on microscopic particles of dust or fume, usually dense enough to obscure vision

Adapted from McKee SB, Fulwiler RD. Determination of particle size. In: Powel CH, Hosey AD, eds. *The Industrial Environment—Its Evaluation and Control.* Washington, DC: USDHEW, PHS, CDC, NIOSH; 1965: § B-7. PHS Publication 614.

similar sampling techniques to collect them. The common synonymous use of the terms *vapor* and *gas* sometimes causes minor confusion. A substance is considered to be a gas if it maintains that state at room temperature and normal atmospheric pressure; however, a vapor at room temperature is generally very close to changing in physical state from gas to liquid. Industrial hygienists take an interest in these differences because the entry and action of solid or liquid aerosolized chemicals differs from their entry and action as a gas or vapor. The industrial hygienist must consider the context of use. For example, methylene chloride in a paint-stripping preparation can cause dermal irritation if spilled on the skin; however, if inhaled in sufficient concentration, methylene chloride can quickly cause chemical anoxia. Failure of an industrial hygienist to consider these differences can cause a faulty evaluation of hazard potential.

In addition to understanding the physical state of the contaminant, industrial hygienists must also understand the components of a proper sampling train used to measure contaminant levels. Sampling trains for aerosols and gases and vapors are similar, yet have distinct differences in their collecting media (Figure 4-9). For aerosols, sampling trains are generally composed of (*a*) an air inlet device, which can be either a length of stiff or flexible tubing, or a part of the particulate collector; (*b*) a particulate collector; (*c*) a means of controlling flow; (*d*) an airflow metering device; and (*e*) an air pump. The most common particulate collectors use filters and cyclones (Figure 4-10).

Sampling trains for gases and vapors differ from those for aerosols in their collection devices—absorbers and adsorbers (Figure 4-11**)**. Absorption is a chemical process in which the collected gas or vapor reacts with chemicals in the collection device. Commonly used absorption equipment consists of impingers and fritted bubblers. These devices use liquid collection media, each type of which provides different contact times, bubble size, and contact surface. These factors cause the collecting time or surface area or both to vary. In comparison, adsorption is a physical process in which the gas or vapor collected is trapped on the collection media, but with no chemical reaction. Adsorbers are used in packed tubes to collect insoluble or nonreactive gases and vapors. Tubes packed with activated charcoal and silica gel are the most common, but many other adsorbent materials are available for specific collection techniques (Figure 4-12).

Other methods are available for collecting samples

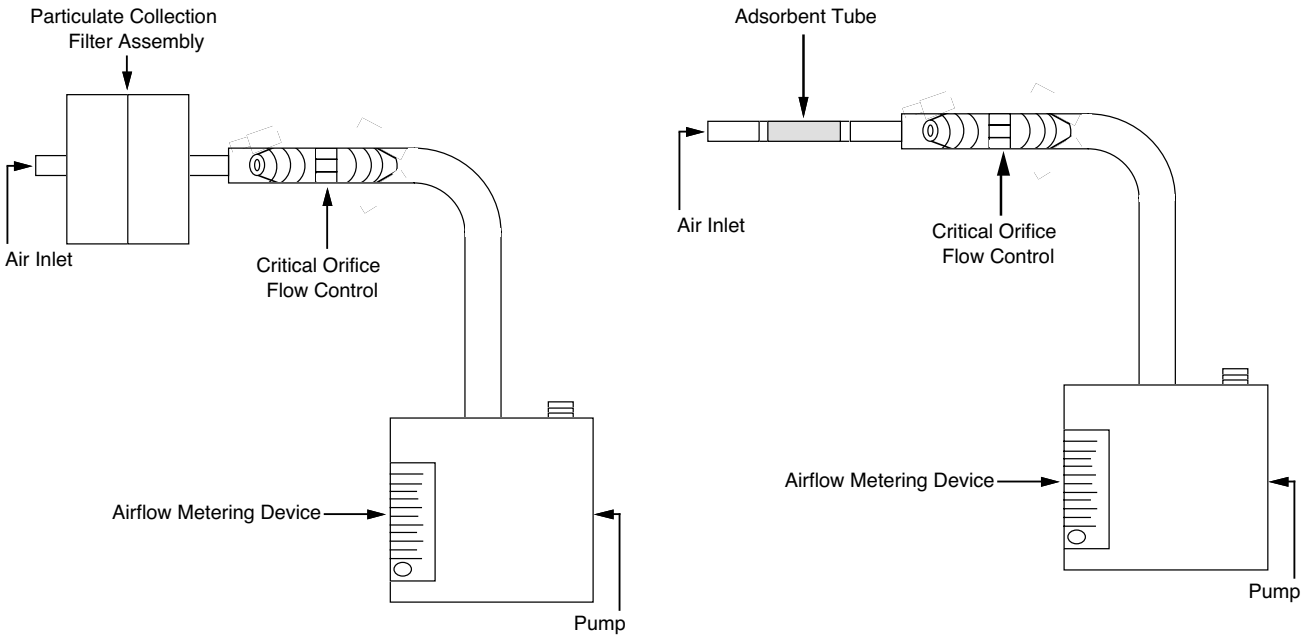


Fig. 4-9 Both these sampling trains for chemical collection use an air-sampling pump without constant flow capability. Flow control can be accomplished with valves or critical air-flow orifices. Control is required to ensure that the exact volume of air collected can be calculated. Without precise flow control, clogged collection devices or variable air pump speed caused by voltage fluctuations could cause a large measurement error. Air pumps are necessary to power the sampling train. Flow from the pump must be calibrated with the entire unit connected as if it were in actual use. This arrangement allows the system to be adjusted to overcome the resistance to air flow found in each separate component of the sampling train. A constant flow pump that uses electronic flow devices can be seen in Figure 4-11.

Fig. 4-10. Particulate filters, left to right: cellulose ester; glass fiber; polyvinyl chloride; a filter taken apart to show the body, support pad, and filter disk; and a filter mounted in a cyclone device that is used to separate out the respirable aerosols. These particulate collection filter assemblies differ according to the laboratory requirements for extracting the hazardous material collected from the filter media.

Fig. 4-11. This DuPont P4LC constant flow pump with its sampling tube attached is a sampling train used to collect many kinds of gas and vapor contaminants. A particulate sampling train would have a filter or filter/cyclone collection device. Constant flow pumps use microprocessors to sense airflow and alter pump speed to maintain a known collection rate.

Fig. 4-12. The midget impinger shown in the left background is used to collect contaminants in a liquid medium; the midget *fritted* impinger shown on the right background breaks up contaminated gases into tiny bubbles, thereby increasing the collection efficiency. The impinger shown in the right foreground is designed to collect samples but not leak into the pump. Collection tubes containing Firebrick, activated charcoal, and silica gel, center foreground, top to bottom, are used to collect various gases and vapors for laboratory analysis.

Fig. 4-13. This 3M Gas Badge, shown in front of its shipping container, is used to monitor for exposure to ethylene oxide; air pumps or other sampling-train components are unnecessary.

Fig. 4-14. Stainless steel, right, or glass, left, evacuation containers have valves to control the collection of grab samples of worksite air into rigid containers of known volume. The flexible collection bags, center, usually have fittings that connect to air pumps, which fill the bag with the air sample.

of contaminants that do not use elaborate mechanical sampling trains. In all methods, samples are collected at a known rate so the air volume collected can be related to the total amount of contaminant found by laboratory analysis. For example, gas-monitoring badges are available for many compounds and use diffusion through a membrane or into an orifice to collect samples at a known rate (Figure 4-13). After the collection period, the badge is sealed to prevent loss by diffusion and is sent to a laboratory for analysis.

Instantaneous or *grab* samples collect actual worksite air; the sample contains whatever contaminant exists at the instant of collection (Figure 4-14). Evacuated containers, displacement collectors, and flexible collection bags are used for collecting grab samples, which are then sent to a laboratory for analysis.

Assessing Measurements

Exposure standards have been developed for many physical and chemical hazards found in the work environment. The Occupational Safety and Health Administration's permissible exposure levels (OSHA's PELs) are regulatory standards that carry the force of law. The ACGIH's Threshold Limit Values (TLVs) are consensus standards that do not carry the force of law. Because both are applied by hygienists in their work, exposure sampling must quantify actual exposures for comparison with these standards to determine when corrective action or medical surveillance is indicated.

Identifying both the limitations inherent in the measurement process and the potential adverse impact of measurement variables are essential for meaningful exposure sampling. Industrial hygienists determine exposure levels by finding the amount of each particular chemical contaminant per unit volume of air; therefore, the mass of the chemical, the volume of the air sample, and the efficiency of the collection all subject this process to potential collection errors.

Reported exposure levels are actually surrounded by a range of possible values; the actual level lies within the range. For example, a laboratory might report that it analyzed an air sample and found 125 ppm benzene. Taking into account the statistical consideration of random and systematic errors found in sample collection, handling, and analysis, the level should have been reported as 125 ppm $\pm$10 ppm, with a confidence level of 95%. If numerous measurements have been taken, the mean and the standard deviations of the mean can be estimated very closely. Estimates are not nearly as good with fewer samples, and only broad confidence limits can be obtained (Exhibit 4-1).

In nonstatistical terms, error in calculating the mass of a chemical is usually a function of (*a*) collection

EXHIBIT 4-1

ERRORS IN MEASUREMENT

All exposure measurements can contain both random and systematic errors; therefore, they are only estimates of actual values. Random errors occur by chance, sometimes higher and sometimes lower than the true value. Systematic errors always skew a value either above or below the actual value. For example, a track coach repeatedly timing a runner with a highly accurate stopwatch will err randomly due to the reaction time required to stop the watch. If the coach uses an inferior watch that runs either fast or slow, however, then the elapsed time measured will always be too slow or fast, and the errors will be systematic. Because both random and systematic errors can occur concomitantly, our goals are to eliminate systematic error and to control for random error.

Systematic Error

The more complex the measurement, the more likely that systematic errors will occur. Typical errors that industrial hygienists see include malfunctioning or incorrectly calibrated equipment, untrained or inexperienced operators, and errors in recording data. For example, there is little chance for error when reading the numeric display on a digital carbon monoxide meter. However, other sources of systemic error could exist with this meter. Is the operator properly calibrating and operating the instrument? Are the correct scales used and are the results recorded in the correct units of measurement? If not, then several sources of systemic error have contaminated this simple, direct measurement of carbon monoxide–exposure levels.

Aggressive quality-control and quality-assurance measures can eliminate these errors. Credentialed operators maintaining, calibrating, and operating measurement equipment, and analytical laboratories participating in quality-control procedures such as external proficiency testing and internal quality control will produce accurate results.

Random Error

Instrument operators introduce random error when they read dials and meters, set flow rates, measure time, prepare solutions, and perform other tasks that require observation and reaction. The random error produced can neither be eliminated nor (for a single measurement) predicted.

Probability theory predicts that in a series of measurements the results will be evenly distributed around the true value. This *central tendency* is a fundamental principle of statistical analysis. It provides a powerful tool to develop measurement strategies that will recognize random error and accurately estimate true values.

Exhibit Figure 1

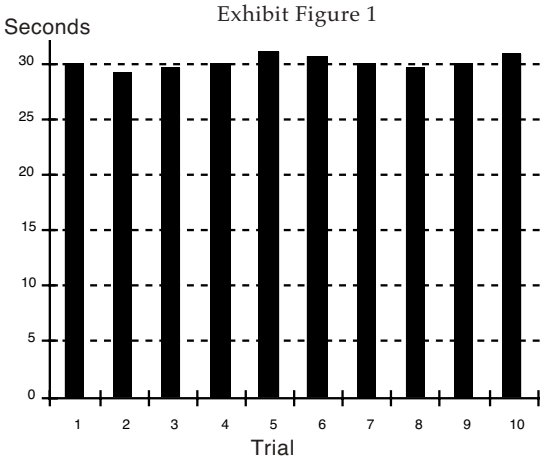
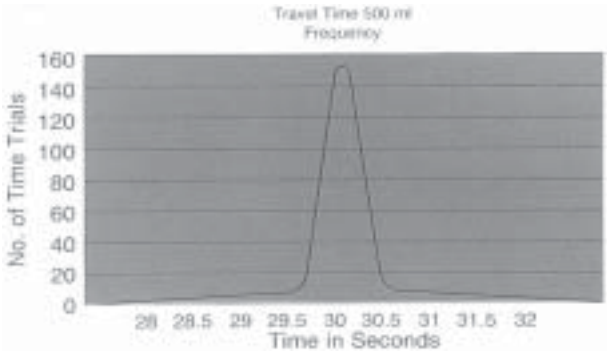


Exhibit Figure 2



For example, 10 timed measurements of air-volume flow (using a soap bubble in a Buret moving from the 0-mL to the 500-mL points) can be represented as a histogram (Exhibit Figure 1). We intuitively understand that the true flow time is close to 30 seconds. This means the air-volume flow is close to 1.0 L/min. And, indeed, the mean of all the measurements is 30 seconds.

However, more measurements produce a more-accurate estimate, and the more measurements taken, the more nearly correct the estimate will be. Eventually, further measurement is not worth the effort. If several hundred measurements of the time for a soap bubble to travel from the 0-mL to the 500-mL points on a Buret were plotted, a bell-shaped curve representing a normal probability distribution would develop (Exhibit Figure 2).

Truly random errors will be normally distributed around the mean. In a bell-shaped curve, the standard deviation (SD) measures this dispersion. In a normal distribution, approximately 68% of the values fall within the range of the mean, ±1 SD; 95% within ±2 SD; and 99% within ±3 SD. Generally, industrial hygienists will use the 95% confidence limits for their measurements.

Adapted from Johnson, DL, Bell ML. Sources and Control of Error in Industrial Hygiene Measurements. Presented at the First Annual Occupational Health Nurse Symposium; 18–22 June 1990; Xerox Training Center, Leesburg, Va.

efficiency, (*b*) sample stability, or (*c*) handling in the laboratory. A known collection efficiency is required for accurate determination of gas- and vapor-exposure levels. Chemicals in their gas or vapor phases are equally likely to be captured if temperature, pressure, and flowrate are kept constant. The collection of particulates, however, varies with their size, shape, and quantity. Various particulate samplers have different collection efficiencies for smaller and larger aerosolized particulates. Overloading the chemical onto filters or precipitators can cause variable collection efficiencies. In addition to error in chemical mass calculations as a function of collection efficiency, sample stability is also a factor. Losses or gains in chemical mass occur after formal collection has been completed. For example, chemicals having high vapor pressure can boil out of the collection media, and additional target chemicals can enter and contaminate samples that were improperly sealed at the worksite.

Other sampling errors can occur in the laboratory. The target chemical can react with the collection or storage container and be lost to laboratory analysis. Similarly, although laboratories generally have extremely accurate and highly sensitive analytical techniques and equipment, laboratories can lose chemical mass through a failure to fully extract the contaminant from the sampling media.

However, the greatest error in sample collection usually occurs in the field, when the sample volume is incorrectly determined. The instruments used to collect samples at the worksite are not designed to be as accurate as fixed laboratory bench equipment. Equipment used in the sampling train can also be affected by changes in temperature or pressure, physical damage during transportation, power-supply voltage changes, and operator error. Many flowrate and volume calibration devices are available, and sampling personnel must use them both before and after sampling to document the accuracy of the collection procedure (Exhibit 4-2 and Figure 4-15).

EXHIBIT 4-2

AIR-SAMPLING CALIBRATION PROCEDURES

- Use standard devices with care and attention to detail.
- Check all standard materials, instruments, and procedures periodically to determine their stability, operating condition, or both.
- Recalibrate a device whenever it has been changed, repaired, received from a manufacturer, subjected to use, mishandled, or damaged, and at any time when its accuracy is questioned.
- Understand how an instrument should be operated before attempting to calibrate it; use a procedure or setup that will not change the characteristics of the instrument or standard within the operating range required.
- When in doubt about procedures or data, assure their validity before proceeding to the next operation.
- Make all sampling- and calibration-train connections as short and constriction- and resistance-free as possible.
- Exercise extreme care when reading scales, timing, adjusting, and leveling, and during all other similar sample-collection operations.
- Allow sufficient time to stabilize conditions, overcome inertia, and establish equilibrium during calibration and sampling.
- Obtain enough points and different flow rates on a calibration curve to generate confidence in the plot obtained. Plot each point from more than one reading wherever practical.
- Maintain a complete permanent record of all procedures, data, and results. Include trial runs, known faulty data (with appropriate comments) instrument identification, connection sizes, and ambient barometric pressure and temperature.
- When a calibration differs from previous records, determine why the change occurred before accepting the new data or repeating the procedure.
- Properly identify the conditions of calibration, the device calibrated, the material it was calibrated against, the units involved, the range and precision of calibration, the date, and the name of the person who performed the actual procedure for all calibration curves and factors. If possible, indicate the location of the original data, and place appropriate calibration data on the instrument.

Adapted from Lippman, M. Instruments and techniques used in calibrating sampling equipment. In: *The Industrial Environment—Its Evaluation and Control.* Washington, DC: USDHEW, PHS, CDC, NIOSH; 1973: Chap 11.

Fig. 4-15. The Gilian Instrument Corporation's Gilibrator Bubble Generator provides an efficient method of determining airflow rates before, during, and after sample collection.

Worksite Sampling Strategy

For each sampling situation, the industrial hygienist must use a logical sample collection strategy that will characterize the exposure of personnel at the worksite. The National Institute for Occupational Safety and Health (NIOSH) has published a recommended *decision logic* to help determine strategy (Figure 4-16). Whatever technique is used, industrial hygienists must consider five factors: the location, timing, and personnel to be sampled; the sampling period; and the number of samples.[12,25]

Location

Samples may be collected at the worker's breathing zone, at a specific worksite, or in the general area. The definition of a worker's exposure presupposes sample collection at the worker's breathing zone. However, it is sometimes impossible or dangerous to fit a worker

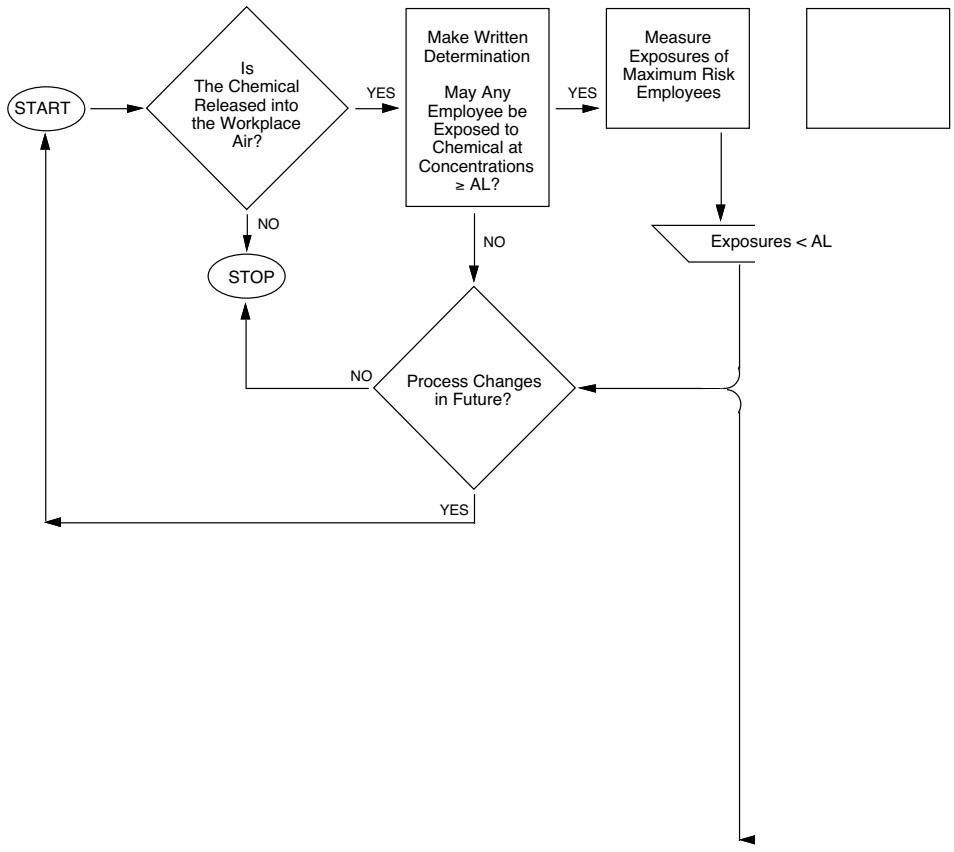


Fig. 4-16. Recommended employee exposure determinations and measurement strategy. This sampling logic uses the current permissible exposure levels (PELs) and the action level (AL, which is one-half the PEL) to set up a sampling strategy to determine exposures and sampling frequency. Source: Reprinted from National Institute for Occupational Safety and Health. *Occupational Exposure Sampling Strategy Manual.* Washington, DC: US GPO; 1977: 11.

with even the small air-sampling pumps or to place a direct reading instrument in the worker's breathing zone. In these instances, the industrial hygienist should collect samples close to the worker at the worksite. While breathing-zone samples are preferable, sampling at the worksite, or even in the general area of operation, can be used to define the effectiveness of engineering control measures, round out exposure data by defining the spread of contaminants, and support breathing-zone sampling results.

Timing

Worksite exposures change throughout the day. Times as short as a shift or as long as an entire season can alter the evolution, distribution, and dilution of hazardous chemicals. When developing the sampling logic, industrial hygienists must consider what time of day, week, month, or year will fully characterize exposure. This, of course, requires that the industrial hygienist be thoroughly familiar with the procedures used at the worksite and the differences in operations that are likely to depend on seasonal or weather conditions. For example, ventilation may be reduced to keep an area warm in winter, or increased to cool it in summer.

Personnel

Sampling the breathing zone of each individual at a worksite provides the most detailed information. However, this option would be impractical if 40 people were doing the same work. To collect samples that are as representative as possible, the industrial hygienist must make on-site determinations to designate the personnel with the highest probability of overexposure. NIOSH's *Occupational Exposure Sampling Strategy Manual* contains a method to determine the number of different samples that will ensure that at least one person from the top 10% exposure group is included in the sample, with 90% confidence (Table 4-4).[25(p35)]

For example, if 31 workers are all sanding paint off damaged trucks in a large maintenance bay, then N = 31. To be 90% confident that at least one of the three workers (10% of 31) with the highest of all exposures is included in a partial sample, at least 16 workers (n = 16) should be selected at random from the 31. Thus, we sample about 50% of the group to be 90% sure that at least one worker in the highest 10% of all exposures is included.

Sampling Period

The industrial hygienist has to analyze several variables to determine the volume and duration of sampling necessary to define the contaminant level at the worksite. Some variables that influence this determination include the appropriate exposure standard, the capability of the collection instruments, the estimated chemical concentration at the worksite, and the laboratory's capability. In most cases, the critical variable is the laboratory capability: their analytical equipment may need more volume of sample than can be collected during a short-term operation. The industrial hygienist and the analyst must come to agreement on the amount of sample required to satisfy both their needs.

NIOSH describes sampling periods as (*a*) full work period / single sample, (*b*) full work period / consecutive samples, (*c*) partial work period / consecutive samples, and (*d*) random grab samples (Figure 4-17).[25] Each of these sampling periods has a different purpose. For example, an 8-hour period single sample will provide only one number: the *average* exposure over

TABLE 4-4

SIZE OF SAMPLE THAT WILL INCLUDE TOP 10% EXPOSURES AND ACHIEVE 90% CONFIDENCE LIMITS

Size of Group (N)*	No. of Required Samples†
8	7
9	8
10	9
11–12	10
13–14	11
15–17	12
18–20	13
21–24	14
25–29	15
30–37	16
38–49	17
50	18

*N: Size of original group judged to have the same exposure potential

†n: Size of partial sample if N > 7 (the entire group must be sampled if N ≤ 7)

Reprinted from Keenan RG. Direct reading instruments for determining concentrations of aerosols, gases, and vapors. In: *The Industrial Environment—Its Evaluation and Control*. Washington, DC: USDHEW, PHS, CDC, NIOSH; 1973: Chap 16.

the entire 8-hour period. If a worker were exposed to 40 ppm for 1 hour, 100 ppm for 6 hour, and 0 ppm for 1 hour, and all exposures were collected on one sample medium, the laboratory would find only that the exposure over the 8-hour period averaged 80 ppm. Therefore, unless a direct reading instrument with a recorder is used as the collection device, industrial hygienists will not be able to determine if short-term overexposures occurred during this 8-hour period. These overexposures could be high enough to cause acute effects, yet not exceed the 8-hour standard when averaged. To escape this difficulty, consecutive, short-duration sampling over the 8-hour period provides both the full exposure and the short-term exposure levels (STELs). A time-weighted average (TWA) can be calculated from the series of sample results to determine the daily average and, because three different collection devices were used, we also see partial-period results:

$$\frac{(40\ \text{ppm} \bullet 1\ \text{h}) + (100\ \text{ppm} \bullet 6\ \text{h}) + (0\ \text{ppm} \bullet 1\ \text{h})}{8\ \text{h}}$$

$$= \frac{640\ \text{ppm/h}}{8\ \text{h}} = 80\ \text{ppm TWA}$$

Partial-period sampling can be used when the operation is uniform throughout the day, or when it is only done intermittently. One-time samples using detector tubes or evacuated containers can be useful as screening devices, but they provide only a single snapshot of possible exposure.

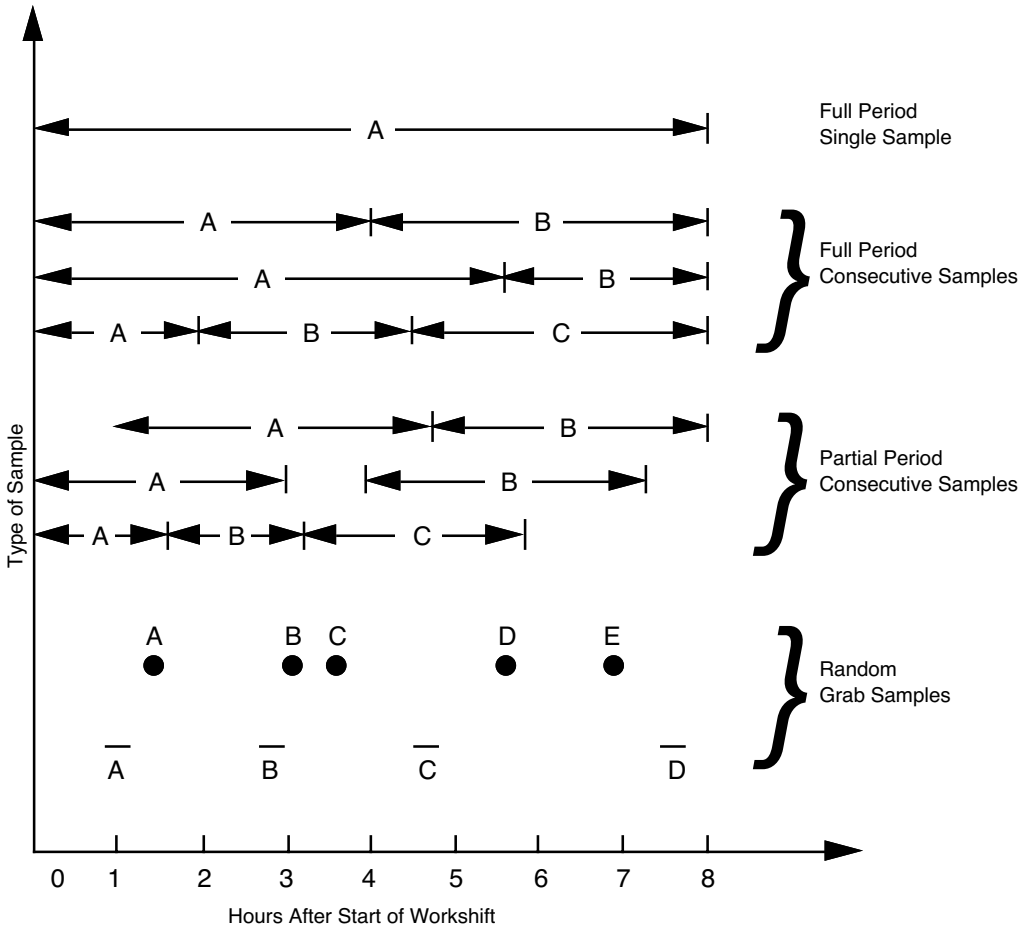


Fig. 4-17. Full period single samples provide only average exposures for the entire day; this technique cannot determine short-duration overexposures that might occur during a shift. Full period consecutive samples can be used to define exposures for different phases of an operation or to determine if exposure varies. As many as 16 and 32 samples (for 30- or 15-min intervals) are sometimes used to characterize exposures during an 8-hour workday. Partial period samples are useful for intermittent operations. Grab samples can be taken during expected peak exposures to determine if more sampling is required. Source: Reprinted from National Institute for Occupational Safety and Health. *Occupational Exposure Sampling Strategy Manual.* Washington, DC: US GPO; 1977: 38.

Number of Samples

The industrial hygienist also determines the number of samples required to accurately determine a worksite exposure. Single samples, even if they encompass a full shift, are not sufficient to characterize exposures. Many factors can alter exposures, such as interference from adjacent operations, the age of the chemicals used, and a change of operators. Only a series of samples taken over time and recorded in the HHIM can provide the record of exposure that is needed to show constant or fluctuating exposure levels. Industrial hygienists must adjust the sampling number over time if sample results prove to be all low, all high, or erratic.

Interpreting the Findings

The factors that industrial hygienists analyze to determine whether particular exposures are hazardous to health include (*a*) the reported exposure concentration (with appropriate consideration of the variance caused by sampling error), (*b*) the worksite (including the duration and type of exposure), (*c*) the nature and toxicity of the chemical, and (*d*) the existing standards. Various systemic sampling errors occur and the reported exposure concentration contains a positive or negative variance around the true exposure. This can have little impact if the reported exposure is far below or far above the health standards. Frequently, however, the reported result falls near the standard, and the statistical variance prevents making an accurate determination of whether the exposure has exceeded the standard. Then, the industrial hygienist must develop and execute a new, more defined sampling strategy, which could include more frequent consecutive samples or lower detection limit on the monitoring instrument.

Because most standards are based on the conventional 40-hour work week, unusual schedules (> 8 h/d or 40 h/wk) require a special assessment of the hazard. Although the standards are generally proportionately reduced to incorporate increased exposure time and decreased recovery time, more complex models use pharmacokinetics to adjust exposure standards.[26,27]

To determine a hazard potential, industrial hygienists must know the rationale behind an exposure standard; they must correlate all exposure variables with the standard, while also considering that the standard was developed using data from animals, accidents, and laboratories. However, conditions at the actual worksite may not bear any relation to the data that were used to set the standard. The length of exposure, the physical state and purity of the chemical, and its toxicity will affect the industrial hygienist's determination.

The standards used by U.S. Army industrial hygienists are designed to conserve the fighting strength by controlling preventable disease and injury through command-oriented, occupational-, environmental-, and personal-protection programs. These standards are detailed in AR 40-5[5] and Technical Bulletin Medical (TB MED) 503[28] and include

- DoD and Department of the Army Occupational Safety and Health (DA OSH) standards for military (field and garrison) and nonmilitary worksites, for which regulatory agencies either have or have not issued OSH standards, and which are included in DoD and DA Pamphlets, circulars, TB MEDs, and messages;
- OSHA standards, including PELs, which are written into the regulations, and emergency temporary standards with minor adaptations as necessary, to conform with DA administrative practices;
- other regulatory worksite standards issued under statutory authority by other federal agencies such as the Department of Transportation and the Environmental Protection Agency;
- special DA OSH standards developed for militarily unique equipment, systems, and operations; and
- alternate worksite standards based on publications relating to worksite exposure criteria.

The army uses alternate standards in lieu of existing OSHA standards or when no OSHA standard exists. The current ACGIH TLVs[26] are used in DA military and civilian worksites if the OSHA PELs are less stringent or if no OSHA standard exists.

Outside the continental United States, DA OSH standards apply to Industrial Hygiene Program activities unless Status of Forces Agreements (SOFAs) require United States military forces overseas to comply with more stringent laws in host countries. In the absence of SOFAs, the most stringent applicable United States regulations apply.

The relationship of the current sample to the historical record of sample results that is kept in the HHIM must also be kept in mind. A significant difference from the historical record could be the result of an unreported change in the work routine or the chemical supply. It could also be nothing more than a human error in sample collection, transport, or analysis. In any case, when the record shows compa-

rable results that suddenly change, industrial hygienists must look closely at both industrial operations and industrial hygiene procedures. Another use of HHIM records is to display either increasing or decreasing trends in exposure levels. Gradually changing exposures could result from inappropriate maintenance of control equipment, progressive operational changes, or deteriorating chemical purity.

CONTROLLING HAZARDS

After industrial hygienists have characterized the hazards of a worksite, they provide recommendations to control or eliminate them.[11,29,30] Control measures are classified as *primary* and *secondary*. Not every type of control is necessary or appropriate in every situation: the willingness of the employees to accept and use the controls, the operating costs, and maintenance problems must all be considered.

Primary Controls

Primary controls—substitution, isolation, and local exhaust ventilation—prevent or eliminate worker exposure.

Substitution

Some hazards can be eliminated by substituting a less hazardous, yet effective chemical for the hazardous one (chemical substitution), or changing the process that produces the hazardous exposure (process substitution).

Although it is one of the best primary control measures, chemical substitution is not without its own risks if it is not fully researched before implementation, and carefully monitored thereafter. For example, an unsuccessful chemical substitution occurred in the dry cleaning industry: carbon tetrachloride was substituted for petroleum naphtha to eliminate a fire hazard. When carbon tetrachloride was later found to be associated with liver damage, chlorinated hydrocarbons such as trichloroethylene and perchloroethylene were substituted. Perchloroethylene is now listed as a suspected carcinogen.

Fluorinated hydrocarbons (Freons) have also been suggested for dry cleaning, and, because they have very low inhalation and fire hazard properties, they appear to be safe. However, these compounds are not without toxicity and also contribute to the deterioration of the earth's ozone layer (see Chapter 13, Solvents, Fluorocarbons, and Paints).

Like chemical substitution, process substitution can effectively control hazards. In many cases, the process itself increases exposure levels by spewing the chemical into the air or by transforming the chemical's physical state to one that more readily gains entry into (or onto) the worker. For example, instead of welding metals together with oxyacetylene or electric arc techniques, welders can join metals by bolting, riveting, or resistance spot welding. These processes generate virtually none of the metal and *flux* (an antioxidation compound) fumes associated with oxyacetylene or electric arc welding. Another example of process substitution can be seen in a painting operation. Instead of spray painting parts, workers could dip them or use electrostatic painting. Dipping reduces exposure to both paint solvents and paint pigments, and electrostatic spray painting controls exposure mainly to the pigments. Another example is the substitution of wet grinding for dry. This substitution reduces dust generation and therefore reduces possible exposures.

Isolation

Isolation is a control technique that imposes a barrier between the worker and the hazard. Barriers are generally distance or a physical structure. In some cases, merely increasing the distance between the worker and the hazard can reduce the hazard potential, especially for hazards such as heat, noise, or radiation, where intensity falls off rapidly with distance. Physical barriers can be as simple as a small operator's booth above the process or a reflective wall between the worker and a radiant heat source. However, complicated isolation systems (eg, enclosing the whole process or monitoring the work via television cameras) may sometimes be necessary. If hazards are completely isolated within process sites, consideration must be given to the hazard that will occur if a worker must enter the isolated machine or operation. In these cases, the exposure can suddenly increase from zero to extremely high levels. Industrial hygienists must prepare for such emergencies in advance.

Although PPE and work schedules serve as physical and temporal barriers to hazardous exposure, neither is considered to be an isolation technique. Both allow for more actual contact with the hazard than the other primary controls and therefore are classified as secondary controls.

Local Exhaust Ventilation

Properly designed, installed, and maintained local exhaust ventilation prevents exposure by capturing the contaminant at its source and removing it before it reaches the worker's breathing zone. However, the phrase "properly designed, installed, and maintained" does not fully convey the complicated nature of ventilation design nor the importance of adequate system maintenance (Table 4-5). A complete understanding of ventilation-system work requires significant training and experience. The ACGIH publishes a manual detailing the engineering of industrial ventilation, which is revised frequently.[31]

Secondary Controls

Secondary controls are used to reduce, but not entirely eliminate, exposure and include (*a*) general ventilation, (*b*) PPE, (*c*) worksite monitors, (*d*) medical surveillance, (*e*) administrative controls, and (*f*) training and education. Occasionally, several types of primary and secondary controls are employed together to control exposure.

General Ventilation

General ventilation dilutes a contaminant with clean air to concentrations below the accepted standards. However, industrial hygienists must consider the possible shortcomings of general ventilation as a method of exposure control. For example, the contaminant must not recirculate into the work area through adjacent air inlets and outlets. Buildings with designed air recirculation, intended to save money on air-temperature adjustment or filtration systems, can cause the same problem. General ventilation permits workers to be exposed to the contaminant; therefore it should not be used as a control for very toxic material, or when the contaminant cannot be diluted because workers are close to the source.[31]

Personal Protective Equipment

PPE must only be used as interim measures, or if engineering control absolutely is not feasible. These devices do not remove, reduce, or eliminate hazards from the worksite; they are merely insubstantial barriers between the worker and the hazard. Effective PPE is available for use as a temporary, emergency, or short-term control.[32]

No PPE is effective unless it is properly used. Any misuse or failure of the protective equipment will cause the worker to be exposed to the contaminant. Unfortunately, most PPE is uncomfortable and workers may misuse the devices. Respirators, hearing protection, face shields, gloves, and other PPE can cause physical and mental strain if they must

TABLE 4-5

LOCAL EXHAUST VENTILATION

Design Flaw	Resultant Problem
90° turns in ducting	Increased airflow resistance
Failure to provide make-up air to replace exhaust air	System resistance and drafts
Underestimating ventilation airflow system resistance	Undersized fans and motors
Use of blast gates	Inadequate control of airflow, system imbalance
Improper sizing of ducting	Inadequate control of airflow
Maintenance Requirement	**Problem Created by Omitting Procedure**
Lubrication of fan and motor bearings	Bearing seize-up, airflow stoppage, and equipment damage
Tightening/replacing fanbelts	Little or no air movement
Cleaning/replacing clogged filters	Increased airflow resistance and decreased contamination control
Cleaning of fan belts	Decreased fan efficiency
Confirmation of proper direction of fan-blade rotation	Little or no air movement

be worn all day. Therefore, industrial hygienists should strive to use primary controls so that PPE is unnecessary.

Respirators. The classifications of respirators include (*a*) air purifying respirators, (*b*) air supplying respirators, and (*c*) self-contained breathing apparatuses. The air purifying respirators remove contaminants by filtration, absorption, adsorption, or catalytic action. Air supplying respirators provide breathable air from compressors, blowers, or air cylinders. Self-contained breathing apparatuses supply air to the worker from a rebreathing device or an air tank that the worker carries.

The proper selection, use, escape requirements, and care of respirators is a complex subject; the currently accepted respirator selection decision logic must be fully considered before utilizing respirators (Figure 4-18).[33] Such concerns as the level of exposure, oxygen level, warning properties of contaminants, protection levels of each respirator class, carcinogenic properties of the contaminants, immediate danger to life or health,[34] levels of the contaminants, escape requirements, and approval restrictions must be fully considered before respirators are utilized. NIOSH, the accepted approval authority, and AIHA publish detailed materials on these subjects.[33–36] These must be read and understood before selecting respirators as protective devices.

Once qualified personnel have selected the proper respirator, workers and supervisors must receive training regarding its proper use and care. Workers and supervisors must understand the rationale behind the use of respirators instead of engineering controls. The user must be fully involved to understand the need for using such uncomfortable protective equipment. Existing OSHA and U.S. Army regulations also contain details concerning the full requirements for a complete respirator program.[33,37,38]

Eye and Face Protection. Eye and face protection provide a barrier against hazards ranging from liquid chemicals to solid projectiles to intensive light radiation. Individuals who select the protective devices must know the form of the hazard. For example, chemical splashes, mists, and streams require different levels of protection, ranging from chemical-splash goggles to full-face shields. Similarly, various levels and forms of intense visible, infrared, and ultraviolet light also require different protection levels in goggles and welders' face shields: oxyacetylene cutting, for example, does not require the level of eye protection against intense light that is needed for electric arc welding.

Gloves and Other Clothing. Gloves, leggings, boots, aprons, and other protective clothing provide a barrier to chemicals that either affect the skin itself, or gain entry to the body through the skin. Protective clothing is made with myriad materials, each with different permeation characteristics for different chemical groups. These characteristics range from easily penetrated to very protective.[39,40] When selecting protective clothing, industrial hygienists should consider not only an item's protective ability, but also its comfort and fit, and the likelihood that workers will wear it.

Worksite Monitors

Worksite monitors are warning devices that signal when a preset limit of exposure has been reached. These devices have some value, but they allow exposure lower than the monitor's alarm setting to occur. If worksite monitors are not calibrated or maintained, exposures can occur well above standards or settings. Additionally, if monitors are too sensitive or are set at too low a level, workers may either ignore or disable the frequent warning signal.

Medical Surveillance

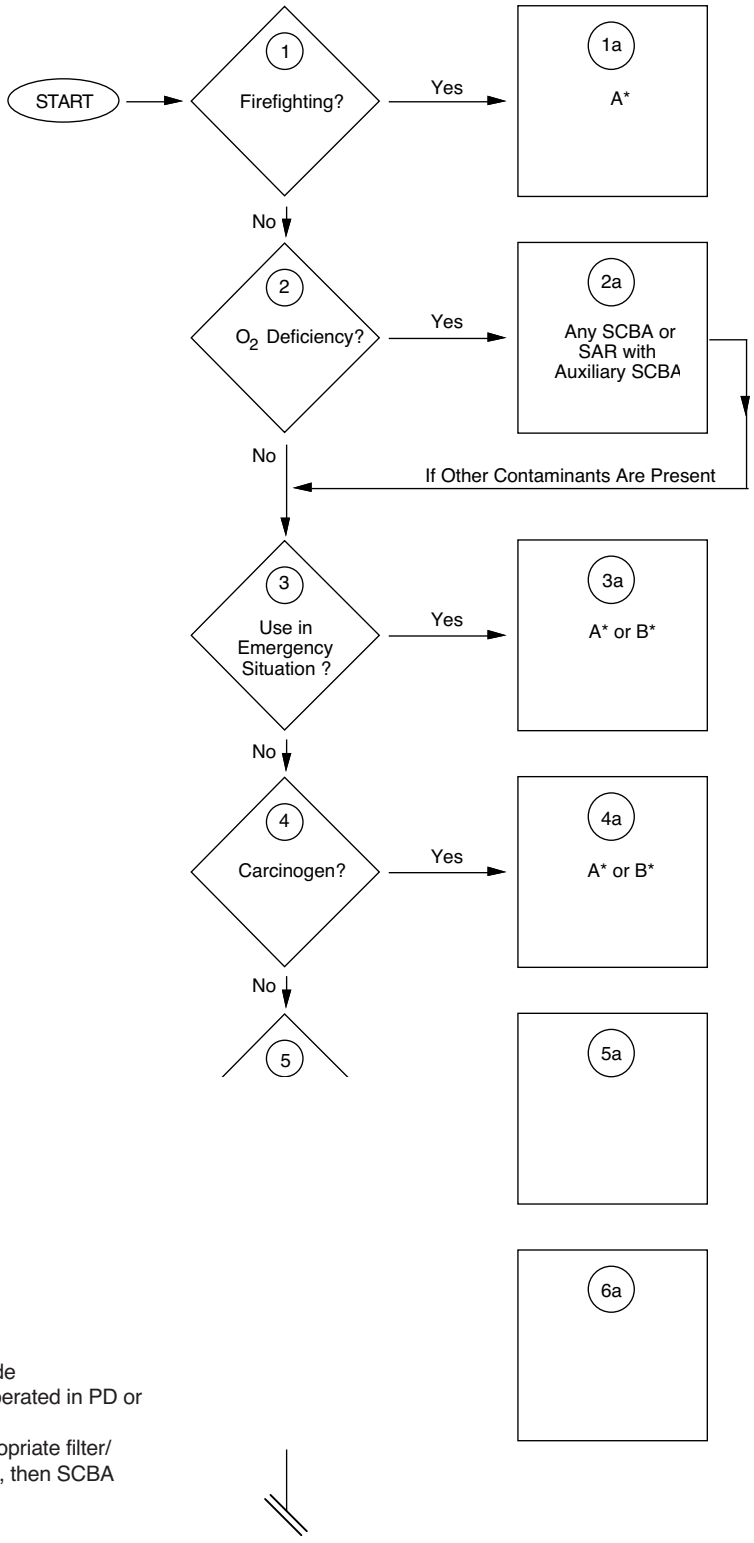
Medical surveillance is an important secondary control because it alerts medical personnel that potential overexposures are occurring. This control can also identify those hypersusceptible individuals who might have adverse effects at exposures below the standards. Although medical surveillance allows early detection, exposure to the hazard has already occurred.

Administrative Controls

Exposure time limits and standing operating procedures (SOPs) are administrative controls. Exposure time limits ensure that, although short-term exposures over the exposure standard may occur, the 8-hour TWA remains below the standard. Operational SOPs direct the correct use of chemicals or personal protection. However, unless these controls are enforced, overexposure can certainly occur.

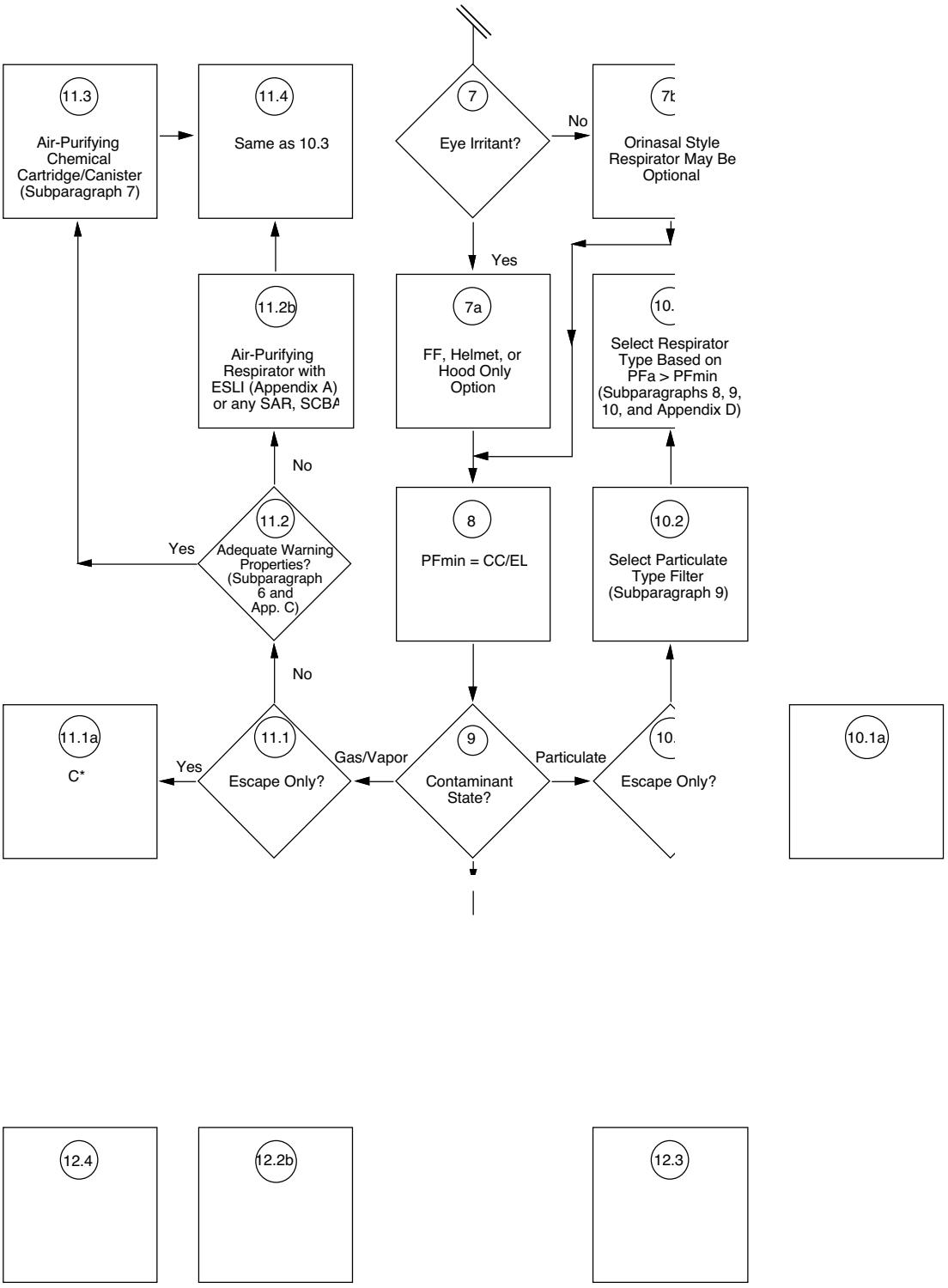
Training and Education

Workers, supervisors, engineers, and managers need to know and understand the hazards, their health effects, and the protective techniques recommended. The communication of worksite hazards to workers is now not only a basic, common-sense requirement, it is also a federal regulation.[34,41]



CC: Contaminant Concentration
EL: Exposure Limit
ESLI: End of Service Life Indicator
FF: Full Facepiece
IDLH: Immediately Dangerous to Life or Health
PD: Pressure Demand
PF: Protection Factor
PFa: Assigned PF
PFmin: Minimum PF
PP: Positive Pressure
SCBA: Self-Containing Breathing Apparatus
SAR: Supplied-Air Respirator
A*: SCBA with FF operated in PD or PP mode
B*: Type C supplied-air respirator (airline) operated in PD or PP mode with auxiliary SCBA
C*: Escape respirator or gas mask with appropriate filter/sorbent (Subparagraph 5); if O_2 deficient, then SCBA

Fig. 4-18. The National Institute of Occupational Safety and Health's (NIOSH's) Respirator Decision Logic provides a basis for selecting appropriate respirators. Users must first determine if a primary control is required, and must fully understand the nuances of each decision point. A decision to use respiratory protection indicates that a respiratory hazard exists;



therefore, proper selection is a serious undertaking. Circled numbers refer to full-text descriptions of the respiratory decision logic in the source document. Reprinted from US Department of Health and Human Services. *NIOSH Respirator Decision Logic*. USDHHS, PHS, CDC, NIOSH; 1987: 19–20. DHHS (NIOSH) Publication 87-108.

SUMMARY

Industrial hygiene in the U.S. Army and the United States developed apace. The need to keep healthy, trained, productive personnel at materiel-production facilities operating at full capacity during our wartime mobilizations provided the initial impetus for the field of occupational health and the subdiscipline of industrial hygiene. The utility of hazard identification and control in the workplace has not faded. The expansion of industrial hygiene operations in the army and in the United States has significantly improved both quality of life and productivity.

Industrial hygiene, occupational healthcare, and occupational safety have separate but interrelated responsibilities. Their shared, broadly based concerns and interests make their close cooperation and coordination essential. Trained and experienced industrial hygienists are necessary to define work practices, understand and use appropriate monitoring equipment, analyze exposure data in relation to the route of entry and action, and determine the best control measures.

The basic goal of industrial hygiene is simple: identify, evaluate, and control worksite hazards. However, putting this into practice requires extensive education and experience. Industrial hygienists must be aware of the many sources of error in industrial hygiene measurements. Eliminating or controlling systematic and random error is a matter of aggressive quality control and quality assurance, and of the appropriate statistical treatment of data. Occupational health professionals should be aware of sources of error, be alert for flawed exposure estimates, and be prepared to ask the hard questions necessary to perform their true preventive medicine mission: eliminating and controlling occupational health hazards before they can do harm.

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