I. INTRODUCTION

The composites industry in the United States includes three manufacturing areas: Polymers, metals, and ceramics.

A. Composites are classified according to their matrix phase. There are polymer matrix composites (PMC's), ceramic matrix composites (CMC's), and metal matrix composites (MMC's). Materials within these categories are often called "advanced" if they combine the properties of high strength and high stiffness, low weight, corrosion resistance, and in some cases special electrical properties. This combination of properties makes advanced composites very attractive for aircraft and aerospace structural parts.

B. This chapter deals with a segment of the polymer composite industry known as advanced polymer matrix composites, or advanced composites. Since the reinforced plastics, or polymer matrix composite industry is much larger than the subject of this chapter, the term "advanced composites" is used here to define this special segment of the industry. Information on this industry has been developed for use by OSHA field personnel to help them understand this new and growing technology.
C. Advanced composites have been identified as an important growth sector in U.S. manufacturing. This identification has led to more use of these materials in existing facilities as well as an increase in the number of advanced composites manufacturing locations. Field staff may expect to encounter composites more frequently in the course of their assignments. At the same time, much of the technology is new and not presented formally in secondary or undergraduate education.

D. Information is presented here on the technology as practiced in current operations. The technology of advanced composites manufacture is continually evolving, and field personnel will learn here what to expect in these processing facilities in the way of materials handled, manufacturing methods, machinery, potential worker exposures, and other relevant health and safety information.

E. The information presented necessarily makes reference to industrial hygiene and safe work practices, but this manual is not intended to provide comprehensive guidelines for assessing compliance with regulations. Much of the terminology used in this manual is peculiar to the composites industry, and for this reason a glossary of terms has been provided in Appendix III:1-1.

II. OVERVIEW OF THE INDUSTRY

Polymer-matrix composites manufacturing is a multibillion dollar industry in the U.S. and one of the few in which the U.S. is conceded to be slightly more advanced than competitors abroad. Composite products range from skateboards to components of the space shuttle. The industry can be generally divided into two basic segments, industrial composites and advanced composites. Several of the composites manufacturing processes are common to both segments. The two basic segments are described below.

A. INDUSTRIAL COMPOSITES The industrial composites industry has been in place for over 40 years in the U.S. This large industry utilizes various resin systems including polyester, epoxy, and other specialty resins. These materials, along with a catalyst or curing agent and some type of fiber reinforcement (typically glass fibers) are used in the production of a wide spectrum of industrial components and consumer goods: boats, piping, auto bodies, and a variety of other parts and components.

B. ADVANCED COMPOSITES

1. This sector of the composites industry is characterized by the use of expensive, high-performance resin systems and high-strength, high-stiffness fiber reinforcement. The aerospace industry, including military and commercial aircraft of all types, is the major customer for advanced composites. These materials have also been adopted for use by the sporting goods suppliers who sell high-performance equipment to the golf, tennis, fishing, and archery markets.
2. While aerospace is the predominant market for advanced composites today, the industrial and automotive markets will increasingly see the use of advanced composites toward the year 2000. At present, both manual and automated processes are employed in making advanced-composite parts. As automated processes become more predominant, the costs of advanced composites are expected to decline to the point at which these materials will be used widely in electronic, machinery, and surface transportation equipment.

3. Suppliers of advanced composite materials tend to be larger companies capable of doing the research and development necessary to provide the high-performance resin systems used in this segment of the industry. End-users also tend to be large, and many are in the aircraft and aerospace businesses.

4. Advanced composite systems are divided into two basic types, thermosets and thermoplastics. Thermosets are by far the predominant type in use today. Thermosets are subdivided into several resin systems including epoxies, phenolics, polyurethanes, and polyimides. Of these, epoxy systems currently dominate the advanced composite industry. Both thermoset and thermoplastic systems will be discussed in more detail in Section IV of this chapter.

III. THE MANUFACTURING PROCESS

A. ELEMENTS The feature common to all composite processes is the combining of a resin, a curing agent, some type of reinforcing fiber, and in some cases a solvent. Typically, heat and pressure are used to shape and "cure" the mixture into a finished part. In composites, the resin acts to hold the fibers together and protect them, and to transfer the load to the fibers in the fabricated composite part. The curing agent, also known as hardener, acts as a catalyst and helps in curing the resin to a hard plastic. The reinforcing fiber imparts strength and other required properties to the composite. Solvents may serve three purposes:

- as part of the resin mixture;
- as part of the process; and
- as a cleaning agent for removing residue from the process equipment.

B. MAJOR PROCESSES Diagrams of the major processes used in the advanced composites industry are provided in Section A of this chapter. The processes vary widely in type of equipment and potential worker exposure. Several of the processes are automated; however, some are manual and require worker contact with the part during manufacture. The basic process types are described below.
0. Formulation is the process where the resin, curing agent, and any other component required are mixed together. This process may involve adding the components manually into a small mixing vessel or, in the case of larger processes, the components may be pumped into a mixing vessel. The potential hazards involve skin, eye, and respiratory contact with the ingredients or final formulation.

1. Prepregging is the process where the resin and curing agent mixture are impregnated into the reinforcing fiber. These impregnated reinforcements (also known as prepregs) take three main forms: woven fabrics, roving, and unidirectional tape. Fabrics and tapes are provided as continuous rolls in widths up to 72 inches and lengths up to several hundred feet. The fabric or tape thickness constitutes one ply in the construction of a multiply layup. Impregnated roving is wound onto cores or bobbins and is used for filament winding. Once the resin mixture has been impregnated onto the fibers, the prepreg must be stored in a refrigerator or freezer until ready for use in the manufacturing process. This cold storage prevents the chemical reaction from occurring prematurely. Prepreg materials are used widely in the advanced composite industry, particularly in aircraft and aerospace. Potential exposure is generally from handling of the fiber or resin.

2. Open Molding processes are those where the part being manufactured is exposed to the atmosphere. The worker typically handles the part manually, and there is a higher potential for exposure. The resin mixture may be a liquid being formed onto a reinforcing material or it may be in the form of a prepreg material being formed for final cure.

3. Closed Molding processes are those in which all or part of the manufacture takes place in a closed vessel or chamber. The liquid resin mixture or prepreg material may be handled or formed manually into the container for the curing step. In the case of liquid resin mixtures, these may be pumped into the container, usually a mold of some type, for the curing step. These processes usually have less worker exposure potential, particularly if the entire process is closed.

4. Sequential or batch processes involve manufacture of a single part at a time, in sequence. This type of process is usually required where the part being made is small and complex in shape, when the curing phase is critical, when finishing work must be minimized, or where a small number of parts is involved.

5. Continuous processes are typically automated to some degree and are used to produce larger numbers of identical parts relatively quickly. These processes are typified by pumping of the resin mixture into the mold, followed by closed curing.
IV. POLYMER MATRIX COMPOSITE (PMC) RESIN SYSTEMS

The advanced composite processes are discussed in more detail in Section V of this chapter. Seven manufacturing processes are covered, along with two preliminary processes and two finishing processes. The number and variety of processes should give some indication of the wide spectrum of workplaces likely to be encountered by field personnel. Potential worker exposure obviously will also vary widely, depending on the size and type of process being used. Since the advanced composite industry is relatively new and still developing, other processes may be developing or changing to meet new performance requirements. Advanced composites exhibit desirable physical and chemical properties that include light weight coupled with high stiffness and strength along the direction of the reinforcing fiber, dimensional stability, temperature and chemical resistance, flex performance, and relatively easy processing. Advanced composites are replacing metal components in many uses, particularly in the aerospace industry.

A. RESINS

The resin systems used to manufacture advanced composites are of two basic types: thermosetting and thermoplastic. Thermosetting resins predominate today, while thermoplastics have only a minor role in advanced composites manufacture.

B. THERMOSETS

0. Thermoset resins require addition of a curing agent or hardener and impregnation onto a reinforcing material, followed by a curing step to produce a cured or finished part. Once cured, the part cannot be changed or reformed, except for finishing. Some of the more common thermosets include:

- epoxies
- polyurethanes
- phenolic and amino resins
- bismaleimides (BMI, polyimides)
- polyamides

1. Of these, epoxies are the most commonly used in today's PMC industry. Epoxy resins have been in use in U.S. industry for over 40 years. The basic epoxy compounds most commonly used in industry are the reaction product of epichlorohydrin and bisphenol-A. Epoxy compounds are also referred to as glycidyl compounds. There are several types of epoxy compounds including glycidyl ethers (or diglycidyl ethers), glycidyl esters, and glycidyl amines. Several of these compounds are reactive diluents and are sometimes added to the basic resin to modify performance characteristics. The epoxy molecule can also be expanded or cross-linked with other molecules to form a wide variety of resin products, each with
distinct performance characteristics. These resins range from low-viscosity liquids to high-molecular weight solids. Typically they are high-viscosity liquids.

2. Since epoxies are relatively high molecular-weight compounds, the potential for respiratory exposure is fairly low. The potential for respiratory exposure is increased when the resin mixture is applied by spraying or when curing temperatures are high enough to volatilize the resin mixture. The potential for dermal exposure is typically much greater than respiratory exposure when working with epoxies. Several advanced composite processes involve some worker contact with the resin mixture. These and the other processes are discussed in more detail in Section V of this chapter.

3. The second of the essential ingredients of an advanced composite system is the curing agent or hardener. These compounds are very important because they control the reaction rate and determine the performance characteristics of the finished part. Since these compounds act as catalysts for the reaction, they must contain active sites on their molecules.

4. Some of the most commonly used curing agents in the advanced composite industry are the aromatic amines. Two of the most common are 4,4’-methylene-dianiline (MDA) and 4,4’-sulfonyldianiline (DDS). Like the epoxies, these compounds have a very low vapor pressure and usually do not present an airborne hazard unless in a mixture that is sprayed or cured at high temperatures. However, potential for dermal exposure is frequently high. The aromatic amines may permeate many of the commonly used protective gloves and thus may be particularly difficult to protect against.

5. Several other types of curing agents are also used in the advanced composite industry. These include aliphatic and cycloaliphatic amines, polyaminoamides, amides, and anhydrides. Again, the choice of curing agent depends on the cure and performance characteristics desired for the finished part.

6. Polyurethanes are another group of resins used in advanced composite processes. These compounds are formed by reacting the polyol component with an isocyanate compound, typically toluene diisocyanate (TDI); methylene diisocyanate (MDI) and hexamethylene diisocyanate (HDI) are also widely used. While the polyols are relatively innocuous, the isocyanates can represent a significant respiratory hazard as well as a dermal hazard.

7. Phenolic and amino resins are another group of PMC resins. With respect to the phenol-formaldehyde resins, the well-known hazards of both phenol and formaldehyde must be protected against. In addition to traces of free
formaldehyde, they may also contain free phenol, and contact with these resins in the uncured state is to be avoided. The urea- and melamine-formaldehyde resins present similar hazards. Free formaldehyde, which is present in trace amounts and may be liberated when their resins are processed, can irritate the mucous membranes.

8. The bismaleimides and polyamides are relative newcomers to the advanced composite industry and have not been studied to the extent of the other resins.

C. THERMOPLASTICS Thermoplastics currently represent a relatively small part of the PMC industry. They are typically supplied as nonreactive solids (no chemical reaction occurs during processing) and require only heat and pressure to form the finished part. Unlike the thermosets, the thermoplastics can usually be reheated and reformed into another shape, if desired.

D. FIBER REINFORCEMENTS

0. Fiber reinforcement materials are added to the resin system to provide strength to the finished part. The selection of reinforcement material is based on the properties desired in the finished product. These materials do not react with the resin but are an integral part of the advanced composite system.

1. Potential worker exposure is typically higher in facilities that manufacture the fibers or use them to produce prepreg material. Most of the fibers in use are considered to be in the nonrespirable range. However, they do have the potential to cause eye, skin, and upper respiratory tract irritation as a result of the mechanical properties of the fibers.

2. The three basic types of fiber reinforcement materials in use in the advanced composite industry are:

   - carbon/graphite
   - aramid
   - glass fibers

Fibers used in advanced composite manufacture come in various forms, including:

   - yarns
   - rovings
   - chopped strands
   - woven fabric
   - mats
Each of these has its own special application. When prepreg materials are used in parts manufacture, woven fabric or mats are required. In processes such as filament wet winding or pultrusion, yarns and rovings are used.

3. The most commonly used reinforcement materials are carbon/graphite fibers. (The terms graphite and carbon are often used interchangeably.) This is due to the fact that many of the desired performance characteristics require the use of carbon/graphite fibers. Currently, these fibers are produced from three types of materials known as precursor fibers:

- polyacrylonitrile (PAN)
- rayon
- petroleum pitch

The carbon/graphite fibers are produced by the controlled burning off of the oxygen, nitrogen, and other noncarbon parts of the precursor fiber, leaving only carbon in the fiber. Following this burning off (or oxidizing) step, the fibers are run through a furnace to produce either carbon or graphite fibers. Carbon fibers are produced at furnace temperatures of 1,000-2,000° C, while graphite fibers require temperatures of 2,000-3,000° C. At these temperatures the carbon atoms in the fibers are rearranged to impart the required characteristics to the finished fiber. The PAN-based fiber is the more commonly used precursor in the advanced composite industry today.

4. Aramid fibers are another human-made product. These fibers are produced by manufacturing the basic polymer, then spinning it into either a paper-like configuration or into fiber. Aramid fibers have several useful characteristics:

- high strength and modulus;
- temperature stability;
- flex performance;
- dimensional stability:
- chemical resistance; and
- textile processibility.

5. Textile (continuous filament) glass fibers are the type used in composite reinforcement. These fibers differ from the wool type in that they are die-drawn rather than spun.

6. A number of solvents are used in the advanced composites industry. These may be introduced into the workplace in three basic ways:
- as part of the resin or curing agent;
- during the manufacturing process; or
- as part of the cleanup process.

Most of the solvents used may be introduced in any or all of the three ways above. For this reason it would be difficult, if not impossible, to separate the solvents into the categories of use. The solvents discussed in this section are grouped by chemical class:

- ketones
- alcohols
- chlorinated hydrocarbons
- others

Several solvents may be used in any one composite process. One or more may be introduced as part of the resin or curing agent, while another may be a part of the manufacturing process. Still another may be used for cleanup. Thus the hazard information for all products used in the process must be considered when evaluating potential exposures. The supplier's Material Safety Data Sheet (MSDS) should be consulted for more specific hazard information.

Composite residues are often difficult to clean from operation equipment and molds. Various solvents have been used for cleaning, with varying degrees of success. Solvents in the workplace may be found in several areas:

- in small containers near process equipment;
- in larger containers (drums or vats) for soaking and cleaning; and
- in process equipment containers (tanks, reactors, molds, etc.).

V. DESCRIPTION OF PROCESSES

A brief description of each process is given, followed by a basic diagram. Details on health hazard information and workplace controls are provided in Sections VI and VII of this chapter.

A. RESIN FORMULATION Resin formulation consists of mixing epoxy or other resins with other ingredients to achieve desired performance parameters. These ingredients may be curing agents, accelerators, reactive diluents, pigments, etc.
B. PREPREGGING Prepregging involves the application of formulated resin products, in solution or molten form, to a reinforcement such as carbon, fiberglass or aramid fiber or cloth. The reinforcement is saturated by dipping through the liquid resin (solution form, see Figure III:1-1) or by being impregnated through heat and pressure (hot melt form, see Figure III:1-2).

C. WET FILAMENT WINDING In the filament wet winding process, continuous fiber reinforcement materials are drawn through a container of resin mixture (Figure III:1-3) and formed onto a rotating mandrel to achieve the desired shape. After winding, the part is cured in an oven.
D. HAND LAY-UP OF PREPREG A prepreg product is laid down and formed to the desired shape (Figure III:1-4). Several layers may be required. After forming, the lay-up assembly is moved to an autoclave for cure under heat, vacuum and pressure.

FIGURE III:1-4. HAND LAY-UP OF PREPREG.

E. AUTOMATED TAPE LAY-UP In this process, the prepreg tape material is fed through an automated tape application machine (robot). The tape is applied across the surface of a mold in multiple layers by the preprogrammed robot (Figure III:1-5).

FIGURE III:1-5. AUTOMATED LAY-UP.
F. RESIN TRANSFER MOLDING Resin transfer molding is used when parts with two smooth surfaces are required or when a low-pressure molding process is advantageous. Fiber reinforcement fabric or mat is laid by hand into a mold and resin mixture is poured or injected into the mold cavity. The part is then cured under heat and pressure (Figure III:1-6).

FIGURE III:1-6. RESIN TRANSFER MOLDING.

G. PULTRUSION In the pultrusion process, continuous roving strands are pulled from a creel through a strand-tensioning device into a resin bath. The coated strands are then passed through a heated die where curing occurs. The continuous cured part, usually a rod or similar shape, is then cut to the desired length (Figure III:1-7).

FIGURE III:1-7. PULTRUSION.
H. INJECTION MOLDING

One of the older plastics processes, injection molding is also the most closed process. It is not normally used in PMC processes due to fiber damage in the plasticating barrel. Thermoplastic granules are fed via a hopper into a screw-like plasticating barrel where melting occurs (Figure III:1-8). The melted plastic is injected into a heated mold where the part is formed. This process is often fully automated.

FIGURE III:1-8. INJECTION MOLDING.

I. VACUUM BAGGING & AUTOCLAVE CURING

Most parts made by hand lay-up or automated tape lay-up must be cured by a combination of heat, pressure, vacuum, and inert atmosphere. To achieve proper cure, the part is placed into a plastic bag inside an autoclave (Figure III:1-9). A vacuum is applied to the bag to remove air and volatile products. Heat and pressure are applied for curing. Usually an inert atmosphere is provided inside the autoclave through the introduction of nitrogen or carbon dioxide. Exotherms may occur if the curing step is not done properly.

FIGURE III:1-9. VACUUM BAGGING AND AUTOCLAVE.
J. MACHINING FINISHING Many of the parts made in PMC processes require some machining and/or finishing work. This may involve drilling, sanding, grinding, or other manual touch-up work. These processes vary widely, depending on the size of the finished part and the amount of finishing work required.

K. FIELD REPAIR Repair of damaged PMC parts is frequently required. The process may consist of several steps including cutting out of the damaged material, depainting of the surface to be repaired, patching and sanding of the damaged area, and repainting of the repaired area.

VI. HEALTH HAZARDS

Potential health hazards associated with the use of advanced composites (Table III:1-1) can be controlled through the implementation of an effective industrial hygiene program. Use of safe work practices, engineering controls, and proper personal protective equipment depends upon an appreciation of health hazard information for a safe work environment.

A. RESINS The resins used in advanced composite processes have high molecular weights (MW > 10,000) with low vapor pressures. High molecular weight is generally associated with decreased volatility. In an epoxy system, the resin components have very low vapor pressures and they are not present as a volatilized airborne hazard.

0. As discussed earlier, epoxy resins are currently the most commonly used resins in the advanced composite industry. The basic epoxy molecule is a reaction product of epichlorohydrin (ECH) and bisphenol-A (BPA). Some epoxies contain trace amounts of residual ECH typically in the range of <1 to 10 ppm (by weight). Industrial hygiene air monitoring for ECH has been done in a number of workplaces, involving a variety of epoxy resin end-uses. Most of the monitoring has shown no detectable levels of ECH in the air. Uncured epoxy resins can present a significant dermal exposure
hazard. In many workplaces, manual processing results in potential skin exposure. This can result in skin irritation, rashes and, subsequently, dermatitis if contact is prolonged. Sensitization to the resins can also develop and may require a change of work assignment.

1. Polyurethane resins are reaction products of polyols and isocyanates. The significant hazard associated with these resin systems is the presence of isocyanates. Exposure to highly toxic isocyanates can have adverse health effects. Exposure to the vapor may cause irritation of the eyes, respiratory tract and skin. Irritation may be severe enough to produce bronchitis and pulmonary edema. Polyurethane resins contacting the eyes may cause severe irritation, and if polyurethane resins are allowed to remain in contact with the skin, they may produce redness, swelling, and blistering of the skin. Respiratory sensitization (an allergic, asthmatic-type reaction) may occur. Among the isocyanates, there is also evidence of cross-sensitization, in which a worker is sensitized to one isocyanate but reacts to others as well.

2. The phenol-formaldehyde resins must be handled with adequate ventilation. Traces of free formaldehyde and phenol may be present. Contact with these resins should be avoided because of the toxicity of these components and the skin-absorption potential of phenol. These components may also be given off during the curing process.

3. The acute toxicity of urea-formaldehyde resins is very similar to the phenol-formaldehyde resins. Free formaldehyde, which is present in trace amounts and may be liberated when the resins are processed, can have an irritating effect on mucous membranes. Skin sensitization to formaldehyde has been observed.

4. The health effects of bismaleimide resin systems have not been extensively studied. Manufacturers of these materials indicate that prolonged or repeated contact may cause skin irritation or sensitization. Dust or vapor from heated products may cause irritation of the eyes, nose, and throat.

5. Polyether and polyester polyols present no particular health hazard in industrial processing.

6. Thermoplastic resins in general are not considered harmful to workers' health. These resins appear harmless when ingested, and no skin irritation has been reported. No toxic effects are known to be associated with the inhalation of thermoplastic-resin dust. Treating it as nuisance or inert dust seems appropriate, although the presence of unreacted monomers may be of concern. These materials present a thermal hazard when handling. Molding operations may give off vapors which are irritating to the eyes.
and cause cold-like symptoms. Some thermoplastics are styrene-based, and presence of this monomer may be of concern.

<table>
<thead>
<tr>
<th>Composite component</th>
<th>Organ system target (possible target)</th>
<th>Known (possible) health effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resins</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Epoxy resins</td>
<td>Skin, lungs, eyes</td>
<td>Contact and allergic dermatitis, conjunctivitis</td>
</tr>
<tr>
<td>Polyurethane resins</td>
<td>Lungs, skin, eyes</td>
<td>Respiratory sensitization, contact dermatitis, conjunctivitis</td>
</tr>
<tr>
<td>Phenol formaldehyde</td>
<td>Skin, lungs, eyes</td>
<td>As above (potential carcinogen)</td>
</tr>
<tr>
<td>Bismaleimides (BMI)</td>
<td>Skin, lungs, eyes</td>
<td>As above (potential carcinogen)</td>
</tr>
<tr>
<td>Polyamides</td>
<td>Skin, lungs, eyes</td>
<td>As above (potential carcinogen)</td>
</tr>
<tr>
<td>Reinforcing materialss</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aramid fibers</td>
<td>Skin (lungs)</td>
<td>Skin and respiratory irritation, contact dermatitis (chronic interstitial lung disease)</td>
</tr>
<tr>
<td>Carbon/graphite fibers</td>
<td></td>
<td>As noted for aramid fibers</td>
</tr>
<tr>
<td>Glass fibers (continuous filament)</td>
<td>Skin (lungs)</td>
<td>As noted above</td>
</tr>
<tr>
<td>Hardeners and curing agentss</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Diaminodiphenylsulfone</td>
<td>--</td>
<td>No known effects with workplace exposure</td>
</tr>
<tr>
<td>Methylenedianiline</td>
<td>Liver, skin</td>
<td>Hepatotoxicity, suspect human carcinogen</td>
</tr>
<tr>
<td>Other aromatic aminess</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Meta-phenylenediamine (MPDA)</td>
<td>Liver, skin (kidney, bladder)</td>
<td>Hepatitis, contact dermatitis (kidney and bladder cancer)</td>
</tr>
<tr>
<td>Aliphatic andcycloaliphatic amines</td>
<td>Eyes, skin</td>
<td>Severe irritation, contact dermatitis</td>
</tr>
<tr>
<td>Polyaminoamide</td>
<td>Eyes, skin</td>
<td>Irritation (sensitization)</td>
</tr>
<tr>
<td>---------------</td>
<td>------------</td>
<td>---------------------------</td>
</tr>
<tr>
<td>Anhydride</td>
<td>Eyes, lungs, skin</td>
<td>Severe eye and skin irritation, respiratory sensitization, contact dermatitis</td>
</tr>
</tbody>
</table>

B. CURING AGENTS

1. Curing agents, or hardeners, used with the epoxy resins are mostly amines, amides, or anhydrides. Two of the most widely used are the aromatic amines, MDA (4,4′-methylenedianiline) and DDS (4,4′-diaminodiphenyl-sulfone).

2. Analysis and review of epidemiologic data and human and animal toxicity data indicates that occupational exposure to MDA may result in reversible liver toxicity (hepatotoxicity). The retina of the eye might be damaged not only by direct contact but also from MDA absorbed through ingestion. MDA is an animal carcinogen and a suspect human carcinogen by any exposure route: ingestion, inhalation, or dermal.

3. Frequently, curing agents containing mixtures of these amines can cause skin staining in processes requiring dermal contact, even when protective gloves are used. Brown and orange stains on walls and ceilings have also been reported. The skin staining has been attributed to MDA; dermal absorption is approximately 2% per hour. Soap and water, rather than any organic solvent, should be used for skin clean-up to avoid any solvent increase of transdermal absorption.

4. The OSHA permissible exposure limits (PEL’S) for MDA are 10 ppb (parts per billion) expressed as an 8-hour time-weighted average, and a short-term exposure limit (STEL) of 100 ppb averaged over any 15-minute period for either general industry or construction uses of MDA. The FR 57(154): 35630 (August 10, 1992) issue published the Final Rule for 29 CFR Parts 1910 and 1926: Occupational Exposure to 4,4′Methylenedianiline (MDA).

5. Another of the amines, DDS, has a significant amount of toxicological data as its pharmaceutical grade, Dapsone™, has been used for years to treat leprosy and certain types of chronic
dermal inflammation. However, at low airborne concentrations, there are no known effects from workplace exposure.

6. Other aromatic amines used in the advanced composites industry include m-phenylene diamine and the various isomers of toluenediamine. These aromatic amines are considered to be only slightly irritating to the skin.

7. Aliphatic and cycloaliphatic amines are strong bases and are considered to be severe eye and skin irritants. Inhalation of these amines can cause irritation of the nose and throat, and lung irritation with respiratory distress. Some of these amines are also skin and respiratory-tract sensitizers. Vapors of the volatile amines may cause conjunctivitis and visual disturbances.

8. Polyaminoamide hardeners have a less irritating effect on the skin and mucous membranes than the aliphatic and cycloaliphatic amine hardeners, but may cause sensitization.

9. Amide hardeners generally have only a slight irritant effect. Should the handling of these hardeners generate dust, measures should be taken to prevent inhalation.

10. The dusts of high-melting solids like most anhydride curing agents are severe eye and skin irritants. Some hydrophthalic anhydrides have high vapor pressures at the usual processing and curing temperatures and the vapors evolved during use of these curing agents can have an irritating effect on the skin, eyes, and respiratory tract. Exposure to the high-melting solids like trimellitic anhydride and tetraphthalic anhydride can cause respiratory sensitization.

C. REINFORCEMENT FIBERS Most of the reinforcing materials used in the industry have the potential to cause eye, skin, and upper respiratory tract irritation as a result of the mechanical-irritant properties of the fibers. The potential synergism has not been clearly defined. The chemical irritation caused by resins can compound the mechanical irritation caused by the fibers.

1. Carbon/graphite fibers dominate the advanced composites industry and may be made from any of three precursors, as discussed in Section C. However, the PAN-based carbon fibers are the predominant form in use today. It is important to ascertain which type of carbon-fiber precursor is used in order to evaluate the hazards.

Pitch-based carbon fibers may be associated with an increased risk
of skin cancer, although the evidence is weak. PAN-based carbon fibers did not cause tumors when the same test was conducted. Standard mutagenicity tests conducted on PAN-based carbon fibers were negative.

The principal hazards of carbon-fiber handling are mechanical irritation and abrasion similar to that of glass fibers. Skin rashes are common and reportedly more severe than from glass fibers. Carbon fibers commonly in use are also greater than six micrometers in diameter, making them unlikely to be respirable. An ongoing survey of workers in a carbon-fiber production plant shows no pulmonary function abnormalities and no evidence of dust-related disease.

Carbon fibers may be coated with a material to improve handling, known generically as sizing. The sizing materials are typically epoxy resins. They may be biologically active and cause irritation or sensitization.

2. Aramid fibers are made from a polymer, poly(p-phenylenediamine terephthalate). Animal and human skin tests of Kevlar™ aramid fibers show no potential for skin sensitization and low potential for irritation. While Kevlar™ fibers are too large to be inhaled (12-15 mm), they may be fractured into respirable fibrils in some composite manufacturing processes. Industrial process monitoring shows that airborne respirable fibril levels are low in typical operations. Measured exposure levels from composite machining are typically below 0.2 fibrils per milliliter of air (0.2 f/ml), as an 8-hour, time-weighted average (TWA), while continuous filament handling generates less than 0.1 f/ml. The physical structure of aramid fibers makes it extremely difficult to generate airborne concentrations.

3. Glass fibers, used as reinforcement in PMC processes, are a continuous-filament form and not the glass-wool (random) type. Practically all glass fibers for composite reinforcement are greater than six microns in diameter. Airborne fiber of this diameter does not reach the alveoli and is nonrespirable. Glass fibers break only into shorter fragments of the same diameter. Their diameter cannot be reduced by machining, milling, or other mechanical processes.

Mechanical irritation of skin, eyes, nose, and throat are common hazards associated with glass-fiber exposure. Continuous-filament glass fiber is not considered fibrogenic. Lung clearance mechanisms are effective for glass fibers.

In June 1987, the International Agency for Research on Cancer
(IARC) categorized continuous-filament glass fibers as not classifiable with respect to human carcinogenicity. The evidence from human and animal studies was evaluated by IARC as insufficient to classify continuous-filament glass fibers a possible, probable, or confirmed cancer-causing material.

Like carbon fibers, glass fibers may also be coated with a sizing material to improve handling. Sizing materials may be epoxy resins, polyvinyl acetate-chrome chloride, polyvinyl acetate-silane, polyester-silane, or epoxy-silane compounds. These materials may be biologically active and cause irritation or sensitization.

D. DUSTS

1. Dusts may be generated in several ways in advanced composite processes. The most common dust-generating processes are machining and finishing of cured parts and in repair of damaged parts. Much of the dust generated in these processes can be very fine and should be considered respirable. Studies of some graphite-epoxy finishing operations found respirable fractions ranging from 25% to 100%.

2. More dust is usually generated in finishing and repair processes since large surface areas are involved. Grinding, routing and sanding are frequently used methods in both processes. The repair process may require the use of abrasive blasting as well as sanding to remove existing paint or coatings. Typically, a synthetic blasting agent, e.g., plastic media blast, is used. Ingredients of the paint or coating being removed, such as lead or chromates, may also be of concern. The repair process may also require cutting or sawing to remove the damaged part area, and both may generate significant amounts of airborne dust.

3. In general, studies on composite dusts indicate that:
   - The dusts are particulate in nature and usually contain few fibers;
   - The dusts are thermally stable up to 250 °C and exhibit a high degree of cure; and
   - Toxicology studies indicate the dusts should probably be controlled at levels below the PEL for inert dust, but not approaching the PEL for crystalline quartz.

E. SOLVENTS

1. Many of the solvents used in advanced composite processes are volatile and flammable. Most are skin and eye irritants, and some
may be readily absorbed through the skin. Precautions must be taken when using organic solvents because they can facilitate the entry of toxic materials into the skin and organ systems. They may also enhance skin sensitization caused by the resin systems. Some (such as methyl alcohol) are poisonous, and all are capable of extracting fat from skin. Harmful effects from industrial exposures come principally from skin contact and inhalation.

2. Selection of the proper glove for protection is important. Permeation data are available for many industrial chemicals, especially solvents. However, in the case of resins and curing agents, not much data are available. This also is true for mixtures of solvents, as little or no testing has been done. Often the glove selection process is one of trial and error. If a skin rash or dermatitis is observed there are several possible causes:

- the wrong gloves may have been selected;
- improper work practices are being followed;
- the employee is deficient in personal hygiene practices; or
- adequate washing facilities are absent.

3. Several of the solvent classes most commonly found in the PMC workplace are listed below, along with general hazard information.

4. Several ketones are frequently found in PMC manufacture. These include:

- acetone (DMK)
- methyl ethyl ketone (MEK)
- methyl isobutyl ketone (MIBK)

These solvents may cause eye, nose, and throat irritation, and prolonged contact with the liquid may result in defatting of the skin and resultant dermatitis. In high concentrations, narcosis is produced with symptoms of headache, nausea, light-headedness, vomiting, dizziness, incoordination, and unconsciousness. Ketones are volatile and flammable. Acetone is a popular solvent used for cleanup and may be found around the workplace in containers for this purpose.

5. Some of the lower-boiling alcohols are sometimes used in composites manufacture. These include:

- methanol (methyl alcohol)
ethanol (ethyl alcohol)
isopropanol (isopropyl alcohol)

These alcohols do not usually present serious hazards in the industrial setting. Toxicity is usually related to irritation of the conjunctivae and the mucous membranes of the upper airway. Contact with the liquid may cause defatting of the skin and dermatitis. These alcohols are volatile and flammable.

6. Three chlorinated hydrocarbon compounds in particular are found in the composites workplace:

- methylene chloride (dichloromethane)
- 1,1,1-trichloroethane (methyl chloroform)
- trichloroethylene

Health effects typical of the group include irritation of the eyes and upper respiratory tract, dizziness, confusion, drowsiness, nausea, vomiting, and occasionally abdominal pain. Visual disturbances may also occur. Due to the solvents' defatting properties, repeated or prolonged skin contact with these liquids may cause dermatitis. Ability to depress the central nervous system is a characteristic property of all members of this group.

These solvents are not particularly flammable. Many manufacturers have replaced the ketones with the above hydrocarbon solvents to reduce the risk of flammability.

7. Other solvents that may occasionally be used are:

- toluene
- xylene
- tetrahydrofuran (THF)
- dimethylsulfoxide (DMSO)
- dimethylformamide (DMF)
- gamma-butyrolactone (BLO)
- n-methyl pyrrolidone (NMP)
- n-butyl acetate
- glycol ethers

Technical literature including MSDS’s from the solvent supplier should be consulted about these or any chemicals used with advanced composites.
VII. WORKPLACE CONTROLS

Good workplace controls are essential in controlling exposure to process materials. Many of the materials, particularly the resins, curing agents, and fibers, present a potential dermal-exposure hazard. Many of the solvents and some of the curing agents present a potential inhalation hazard. Some materials present both a dermal and inhalation hazard. Ingestion may be a potential exposure hazard, but usually involves poor personal hygiene or contamination of eating facilities. The various types of workplace controls described below may typically be found in the advanced composite workplace.

B. ENGINEERING CONTROLS Isolation (e.g., isolated storage, separate process areas, enclosures, closed systems) and local exhaust ventilation are the primary engineering controls found in advanced composites processes. These controls can be found in:

- Resin mixing areas;
- Heated curing areas including autoclaves;
- Finishing and repair areas; and
- Controlling off-gases from exotherms

C. WORK PRACTICE CONTROLS Work practices, as distinguished from engineering controls, involve the way a task is performed. Some fundamental and easily implemented work practices that can be used to minimize exposures when working with advanced composites are:

- good employee training and education;
- following the proper procedures for production, process and control equipment;
- proper use, maintenance, and cleaning of personal protective equipment;
- good personal hygiene program;
- housekeeping;
- periodic inspection and maintenance of production, process and control equipment; and
- good supervision.

D. PERSONAL PROTECTIVE EQUIPMENT

1. Gloves, protective clothing, and eye protection may frequently be required, especially when working with resins, curing agents, and solvents. Selection of the proper protective materials should be
based on permeation data, if available. This type of data are often available for the solvents used, but very little data are available for the resins and curing agents.

2. In many advanced composites processes several chemicals or mixtures are involved. There are essentially no permeation data available for chemical mixtures. This means that, in many cases, glove and clothing selection must be a trial and error process.

3. Generally, the resins are of a larger molecular size and so are less likely to permeate protective materials than the curing agents and solvents. The aromatic amine curing agents are particularly difficult to protect against. In some advanced composites processes, close hand work and contact is required, and a glove must provide good tactility. Often this type of glove provides the least protection against the resin and curing agent.

4. Eye protection can be provided by standard safety glasses with side shields, goggles, or a face shield, as needed.

5. Respiratory protection is not required in many advanced composites processes, due to the low vapor pressure of the materials involved. However, respirators may be required where:
   - Airborne solvent levels are high;
   - Dust levels are high (resin mixing, finishing, repair);
   - Large surface areas and significant hand work are involved; and
   - Exotherms are experienced.

E. ADMINISTRATIVE CONTROLS Employee exposures also can be controlled by scheduling operations with the highest exposures at a time when the fewest employees are present.

VIII. BIBLIOGRAPHY


APPENDIX III:1-1. GLOSSARY.
[Adapted from Advanced Composites Magazine, 1992 Bluebook, Edgell Plastics Publications]

A-stage An early stage of polymerization of thermosetting resins in which the material is still soluble in certain liquids and is fusible. Also called resole. See also B-stage, C-stage.

Ablative A material that absorbs heat through a decomposition process called pyrolysis at or near the exposed surface.

Addition A polymerization reaction in which no by-products are formed.

Additives Ingredients mixed into resin to improve properties.

Adhesive failure A rupture of adhesive bond that appears to be a separation at the adhesive-adherend interface.

Amorphous Polymers that have no order to their molecules, thus no crystalline component.

Anisotropic The tendency of a material to exhibit different properties in response to stresses applied along axes in different directions.

Aramid Aromatic polyamide fibers characterized by excellent high-temperature, flame-resistance, and electrical properties. Aramid fibers are used to achieve high-strength, high-modulus reinforcement in plastic composites.

Areal weight The weight of fiber per unit area (width times length) of tape or fabric.

Aspect ratio The ratio of length to diameter of a fiber.

Autoclave A closed vessel that permits application of pressure and heat used for curing composites.

Autoclave molding A molding technique in which an entire assembly (layup) is placed into an autoclave at 50 to 100 psi, in order to consolidate layers of the part by removing entrapped air and volatiles. Usually includes application of heat to trigger curing of the resin.

Axial winding A type of filament winding in which the filaments are parallel to the axis.
B-stage  Intermediate stage in the polymerization reaction of thermosets, following which material will soften with heat and is plastic and fusible. Also called resistal. The resin of an uncured prepreg or premix is usually in B-stage. See [A-stage][1], [C-stage][2].

Bag molding  A technique in which the composite material is placed in a rigid mold and covered with a flexible bag, with pressure applied by vacuum, autoclave, press, or by inflating the bag.

Balanced laminate  All lamina except those at 0/90 are placed in plus-minus pairs (not necessarily adjacent) symmetrically about the layup centerline.

Bearing strength  The maximum bearing stress that will not cause a composite to fail when applied through a cylindrical fastener surface.

Bearing stress  Applied load divided by bearing area (hole diameter times thickness).

Bias fabric  A fabric in which warp and fill fibers are at an angle to the length.

Biaxial winding  A type of filament winding in which the helical band is laid in sequence, side by side, with no crossover of the fibers.

Bidirectional laminate  A reinforced plastic laminate in which the fibers are oriented in more than one direction in the plane of the laminate.

Bismaleimide  A type of polyimide that cures by an addition reaction, avoiding formation of volatiles, and has temperature capabilities between those of epoxy and polyimide.

Bleeder cloth  A layer of woven or nonwoven material, not a part of the composite, that allows excess gas and resin to escape during cure.

Bleedout  The excess liquid resin appearing at the surface, primarily during filament winding.

Bond strength  The amount of adhesion between bonded surfaces. As measured by load/bond area, the stress required to separate a layer of material from that to which it is bonded.

Boron fiber  A fiber usually of a tungsten-filament core with elemental boron vapor deposited on it to impart strength and stiffness.

Braiding  Weaving fibers into a tubular shape.

Breather  A loosely woven material that does not come in contact with the resin but serves as a continuous vacuum path over a part in production.
Broadgoods  Fibers woven into fabrics that may or may not be impregnated with resin, usually furnished in rolls.

Buckling (composite)  A failure usually characterized by fiber deflection rather than breaking because of compressive action.

Butt joint  A joint in which parts are joined with no overlap.

C-stage  The final step in the cure of a thermoset resin; results in essentially irreversible hardening and insolubility.

Carbon/carbon  A composite of carbon fiber in a carbon matrix.

Carbon fiber  An important reinforcing fiber known for its light weight, high strength, and high stiffness that is produced by pyrolysis of an organic precursor fiber in an inert atmosphere at temperatures above 1,800° F. The material may also be graphitized by heat treating above 3,000° F.

Catalyst  A substance used in small quantities to promote or control the curing of a compound without being consumed in the reaction.

Caul sheet  Plate or sheet the same size and shape used in contact with a composite layup to transmit normal pressure and temperature during cure.

Ceramic-matrix composites  Materials consisting of a ceramic or carbon fiber surrounded by a ceramic matrix, usually SiC (silicon carbide).

Chemical vapor deposition (CVD)  A process in which desired reinforcement material is deposited from vapor phase onto a continuous core; boron on tungsten, for example.

Circuit  One complete traverse of the fiber feed mechanism of a filament-winding machine.

Circumferential winding  A type of filament winding in which the filaments are perpendicular to the axis.

Co-cured  Cured and simultaneously bonded to another prepared surface.

Coefficient of thermal expansion  A material's fractional change in length for a given unit change of temperature.

Commingled yarn  A hybrid yarn made with two types of materials intermingled in a single yarn; for example, thermoplastic filaments intermingled with carbon filaments to form a single yarn.
Composite  A material created from a fiber (or reinforcement) and an appropriate matrix material in order to maximize specific performance properties. The constituents do not dissolve or merge completely but retain their identities as they act in concert.

Compression molding  A technique for molding thermoset plastics in which a part is shaped by placing the fiber and resin into an open mold cavity, closing the mold, and applying heat and pressure until the material has cured or achieved its final form.

Compressive strength  A material's ability to resist a force that tends to crush or buckle; maximum compressive load a specimen sustains divided by the specimen's original cross-sectional area.

Condensation  A polymerization reaction in which simple by-products (for example, water) are formed.

Consolidation  A processing step that compresses fiber and matrix to reduce voids and achieve a desired density.

Contact molding  A technique in which reinforcement and resin are placed in a mold, with cure taking place at room temperature with a catalyst/promoter system, or in a heated oven. No additional pressure is used.

Continuous filament  An individual, small-diameter reinforcement that is flexible and indefinite in length.

Continuous-filament yarn  Yarn that is formed by twisting two or more continuous filaments into a single continuous strand.

Continuous roving  Parallel filaments coated with sizing, gathered together into single or multiple strands, and wound into a cylindrical package. It may be used to provide continuous reinforcement in woven roving, filament winding, pultrusion, prepregs, or high-strength molding compounds, or it may be used chopped.

Core  The central component of a sandwich construction to which the sandwich faces or skins are attached; also, part of a complex mold that forms undercut parts.

Co-woven fabric  A reinforcement fabric woven with two different types of fibers in individual yarns; for example, thermoplastic fibers woven side by side with carbon fibers.

Creep  The dimensional change in a material under physical load over time beyond instantaneous elastic deformation.

Crimp  A fiber's waviness, which determines the capacity of the fiber to cohere.

Critical length  The minimum length of a fiber necessary for matrix shear loading to develop fiber ultimate strength by a matrix.
Cross laminated  Material laminated so that some of the layers are oriented at various angles to the other layers with respect to the laminate grain. A cross-ply laminate usually has plies oriented only at 0°/90°.

Crystallinity  The quality of having a molecular structure with atoms arranged in an orderly, three-dimensional pattern.

Cure  To change the physical properties of a material irreversibly by chemical reaction via heat and catalysts, alone or in combination, with or without pressure.

Cure temperature  The temperature at which a material attains final cure.

Curing agent  A catalytic or reactive agent that brings about polymerization when it is added to a resin.

Damage tolerance  A measure of the ability of structures to retain load-carrying capability after exposure to sudden loads (for example, ballistic impact).

Damping  Diminishing the intensity of vibrations.

Debond  An unplanned nonadhered or unbonded region in an assembly.

Delamination  The separation of a laminated plastic material along the plane of its layers.

Denier  A numbering system for yarn and filament in which yarn number is equal to weight in grams of 9000 meters of yarn.

Design allowable  A limiting value for a material property that can be used to design a structural or mechanical system to a specified level of success with 95% statistical confidence. B-basis allowable: material property exceeds the design allowable 90 times out 100. A-basis allowable: material property exceeds the design allowable 99 times out of 100.

Doubler  Localized area of extra layers of reinforcement, usually to provide stiffness or strength for fastening or other abrupt load transfers.

Draft angle  A mandrel's taper or angle for ease of part removal.

Drape  The ability of prepreg to conform to the shape of a contoured surface.

Dry winding  A type of filament winding in which preimpregnated roving is used.

E-glass  "Electrical glass"; the borosilicate glass most often used for the glass fibers in conventional reinforced plastics.
Fabric, nonwoven  A material formed from fibers or yarns without interlacing.

Fabric, woven  A material constructed of interlaced yarns, fibers, or filaments.

Fatigue  The failure of a material's mechanical properties as a result of repeated stress.

Fatigue strength  Maximum cyclical stress withstood for a given number of cycles before a material fails.

Fiber orientation  The fiber alignment in a nonwoven or a mat laminate in which most of the fibers are in the same direction, thereby affording higher strength in that direction.

Fiber placement  A continuous process for fabricating composite shapes with complex contours and/or cutouts by means of a device that lays preimpregnated fibers (in tow form) onto a nonuniform mandrel or tool. It differs from filament winding (below) in several ways: there is no limit on fiber angles; compaction takes place online via heat, pressure, or both; and fibers can be added and dropped as necessary. The process produces more complex shapes and permits a faster putdown rate than filament winding.

Filament winding  A process for fabricating composites in which continuous reinforcing fibers, either preimpregnated with resin or drawn through a resin bath, are wound around a rotating, removable mandrel.

Filaments  Individual fibers of indefinite length used in tows, yarns, or roving.

Film adhesive  An adhesive in the form of a thin, dry, resin film with or without a carrier, commonly used for adhesion between layers of laminates.

Finish  Material applied to fibers, after sizing is removed, to improve matrix-to-fiber coupling.

Fracture  A rupture of the surface of a laminate because of external or internal forces, with or without complete separation.

Fracture toughness  A measure of the damage tolerance of a material containing initial flaws or cracks.

Glass transition  The reversible change in an amorphous polymer between a viscous or rubbery condition and a hard, relatively brittle one.

Glass-transition temperature (\( T_g \))  The approximate temperature at which increased molecular mobility results in significant changes in properties of a cured resin. The measured value of \( T_g \) can vary depending upon the test method.

Hand layup  A fabrication method in which reinforcement layers, preimpregnated or coated afterwards, are placed in a mold by hand, then cured to the formed shape.
Hardener  A substance used to promote or control curing action by taking part in it; as opposed to catalyst.

Heat-distortion temperature  Temperature at which a test bar deflects a certain amount under specified temperature and a stated load.

Honeycomb  Resin-impregnated material manufactured in, usually, hexagonal cells that serves as a core material in sandwich constructions. Honeycomb may also be metallic or polymer materials in a rigid, open-cell structure.

Hoop stress  Circumferential stress in a cylindrically shaped part as a result of internal or external pressure.

Hybrid composite  A composite with two or more reinforcing fibers.

Impact strength  A material's ability to withstand shock loading as measured by the work done in fracturing a specimen.

Impregnate  To saturate the voids and interstices of a reinforcement with a resin.

Impregnated fabric  See Prepreg.

Interface  The surface between two different materials: in fibers, the area at which the glass and sizing meet; in a laminate, the area at which the reinforcement and the laminating resin meet.

Interlaminar  Existing or occurring between two or more adjacent laminae.

Interlaminar shear  The shearing force tending to produce displacement between two laminae along the plane of their interface; usually the weakest element of a composite.

Isotropic. Having uniform properties in all directions independent of the direction of load application.

Laminate ply  One layer of a laminated product.

Lap joint  A joint made by bonding overlapped portions of two adherends.

Layup  The placement of layers of reinforcement in a mold.

Liquid-crystal polymers  A newer type of thermoplastic, melt processible, with high orientation in molding, improved tensile strength, and high-temperature capability.

Mandrel. The form around which resin-impregnated fiber or tape is wound to form structural shapes or tubes.
Mat  A fibrous reinforcing material comprised of chopped filaments (for chopped-strand mat) or swirled filaments (for continuous-strand mat) with a binder to maintain form; available in blankets of various widths, weights, and lengths.

Matrix  A material in which the fiber of a composite is imbedded; it can be plastic, metal, ceramic, or glass.

Metal-matrix composites  Materials in which continuous carbon, silicon carbide, or ceramic fibers are embedded in a metallic matrix material.

Modulus  A measure of the ratio of load (stress) applied to the resultant deformation of a material, such as elasticity or shear.

Multifilament  A yarn consisting of many continuous filaments.

Nondestructive inspection (NDI)  A process or procedure for determining material or part characteristics without permanently altering the test subject. Nondestructive testing (NDT) is broadly considered synonymous with NDI.

Nonwoven roving  A reinforcement composed of continuous rovings loosely gathered together.

Oriented materials  Composites whose constituents are aligned in a particular way.

Out-life  The period of time a prepreg material remains in a handleable form and with properties intact outside of the specified storage environment; for example, out of the freezer in the case of thermoset prepregs.

PAN  See Polyacrylonitrile.

Peel ply  Layer of material applied to a prepreg layup surface that is removed from the cured laminate prior to bonding operations and leaves a clean resin-rich surface ready for bonding.

Peel strength  Strength of an adhesive bond obtained by stress applied "in a peeling mode." Pitch  A residual petroleum product used in the manufacture of certain carbon fibers.

Planar winding  A type of filament winding in which the filament path lies on a plane that intersects the winding surface.

Ply  The number of single yarns twisted together to form a plied yarn; one of the layers that make up a stack or laminate.

Polar winding  A type of filament winding in which the filament path passes tangent to
the polar opening at one end of the chamber and tangent to the opposite side of the polar opening at the other end of the chamber.

Polyacrylonitrile (PAN)  A product used as a base material in the manufacture of certain carbon fibers.

Polymer  A very large molecule formed by combining a large number of smaller molecules, called monomers, in a regular pattern.

Polymerization  A chemical reaction in which the molecules of monomers are linked together to form polymers.

Postcure  An additional elevated-temperature exposure that is performed often without tooling or pressure to improve elevated-temperature mechanical properties, for example.

Pot life  The length of time a catalyzed thermosetting resin system retains a viscosity low enough for it to be suitable for processing.

Precure  The full or partial setting of a resin or adhesive before the clamping operation is complete or before pressure is applied.

Precursor  For carbon fibers, the rayon, PAN, or pitch fibers from which carbon fibers are made.

Preform  A fibrous reinforcement preshaped to approximate contour and thickness desired in the finished part.

Prepreg  Resin-impregnated cloth, mat, or filaments in flat form that can be stored for later use. The resin is often partially cured to a tack-free state called "B-staging." Catalysts, inhibitors, flame retardants, and other additives may be included to obtain specific end-use properties and improve processing, storage, and handling characteristics.

Pressure-bag molding  A molding technique in which a flexible bag is placed over the contact layup in the mold, sealed, and clamped in place, and pressure applied by compressed air, which forces the bag against the part while the part cures.

Pultrusion  A continuous process for manufacturing composites in rods, tubes, and structural shapes having a constant cross-section. After the reinforcement is passed through the resin-impregnation bath, it is drawn through a shaping die to form the desired cross-section; curing takes place before the laminate can depart from that cross-section.

Quasi-isotropic  Approximating isotropy by orientation of plies in several directions.

Ramping  A gradual, programmed increase or decrease in temperature or pressure to control the cure or cooling of composite parts.
Reinforcement  A material added to the matrix to provide the required properties; ranges from short fibers through complex textile forms.

Release agents  Materials that are used to prevent cured matrix material from bonding to tooling.

Release film  An impermeable film layer that does not bond to the composite during cure.

Resin  A material, generally a polymer, that has an indefinite and often high molecular weight and a softening or melting range and exhibits a tendency to flow when it is subjected to stress. Resins are used as the matrices to bind together the reinforcement material in composites.

Resin rich  Localized area filled with resin but lacking reinforcement fiber.

Resin starved  Localized area lacking sufficient resin for wetout of the fibers.

Resin-transfer molding (RTM)  A molding process in which catalyzed resin is transferred into an enclosed mold into which the fiber reinforcement has been placed; cure normally is accomplished without external heat. RTM combines relatively low tooling and equipment costs with the ability to mold large structural parts.

Roving  A collection of bundles of continuous filaments either as untwisted strands or as twisted yarns.

S-glass  Structural glass; a magnesia/alumina/silicate glass reinforcement designed to provide very high tensile strength.

Sandwich construction  A composite composed of a lightweight core material (usually honeycomb or foamed plastic) to which two relatively thin, dense, high-strength, functional, or decorative skins (also called faces) are adhered.

Scarf joint  A bonded joint in which similar segments of adherends are cut away, with cut areas overlapped and bonded.

Selvage  The narrow edge of woven fabric that runs parallel to the warp. It is made with stronger yarns in a tighter construction than the body of the fabric to prevent raveling.

Shelf life  The length of time a material can be stored and continue to meet specification requirements and remain suitable for its intended use.

Silicon carbide fiber  A reinforcing fiber with high strength and modulus; density is equal to that of aluminum. It is used in organic metal-matrix composites.

Sizing  A compound that binds together and stiffens warp yarn to provide resistance to
abrasion during weaving; normally removed and replaced with finish before matrix application.

Skin A layer of relatively dense material used in a sandwich construction on the surface of the core.

Specific gravity The density (mass per unit volume) of a material divided by that of water at a standard temperature.

Starved joint A joint that does not have the proper amount of adhesive because of insufficient spread or excessive pressure.

Stiffness The relationship of load to deformation for a particular material.

Storage life The amount of time a material can be stored and remain suitable for use.

Strain The elastic deformation of a material as a result of stress.

Stress The internal force that resists change in size or shape, expressed in force per unit area.

Structural adhesive An adhesive used for transferring loads between adherends.

Structural bond A bond joining load-bearing components of an assembly.

Tack The stickiness of a prepreg.

Tape A unidirectional woven prepreg, in widths up to 12 inches for carbon fiber, for example.

Tape laying A fabrication process in which prepreg tape is laid side by side or overlapped to form a structure.

Tensile strength The maximum tensile stress sustained by a plastic specimen before it fails in a tension test.

Thermal conductivity The ability of a material to conduct heat.

Thermoplastic A plastic material that is capable of being repeatedly softened by application of heat and repeatedly hardened by cooling.

Thermoset A plastic material that is capable of being cured by heat or catalyst into an infusible and insoluble material. Once cured, a thermoset cannot be returned to the uncured state.

Tooling resins Plastic resins, chiefly epoxy and silicone, that are used as tooling aids.
Toughness  Tendency of a material to absorb work.

Tow  An untwisted bundle of continuous filaments, usually designated by a number followed by "K," indicating multiplication by 1,000; for example, 12K tow has 12,000 filaments.

Unbond  Area of a bonded surface in which bonding of adherends has failed to occur, or where two prepreg layers of a composite fail to adhere to each other; also denotes areas where bonding is deliberately prevented to simulate a defective bond.

Unidirectional  Refers to fibers that are oriented in the same direction, such as unidirectional fabric, tape, or laminate, often called UD.

Vacuum bag molding  A molding technique in which the part is cured inside a layer of film, from which entrapped air is removed by vacuum.

Viscosity  The tendency of a material to resist flow.

Voids  Pockets of entrapped gas that have been cured into a laminate.

Volatile  Materials in a sizing or a resin formulation that can be vaporized at room or slightly elevated temperature.

Warp  The yarns running lengthwise and parallel to the selvage in a woven fabric.

Water jet  A high-pressure stream of water used for cutting organic composites.

Weave  The pattern by which a fabric is formed from interlacing yarns. In plain weave, the warp and fill fibers alternate to make both fabric faces identical; in satin weave, the pattern produces a satin appearance, with the warp tow over several fill tows and under the next one (for example, eight-harness satin would have warp tow over seven fill tows and under the eighth).

Weft  The yarns running perpendicular to the warp in a woven fabric; also called "woof."

Wet layup  The application of resin to dry reinforcement in the mold.

Wet winding  A type of filament winding in which the fiber strand is impregnated with resin immediately before it contacts the mandrel.

Wetout  The saturation of all voids between strands and filaments of porous materials with resin.

Wetting agent  A surface-active agent that promotes wetting by decreasing the cohesion within a liquid.
Winding pattern  The regularly recurring pattern of the filament path in a filament winding after a certain number of mandrel revolutions.

Woven roving  A heavy, coarse fabric produced by the weaving of continuous roving bundles.

Wrinkle  An imperfection in the surface of a laminate that looks like a crease or fold in one of the outer layers; it occurs in vacuum bag molding due to improper placement of the bag.

X axis  The axis in the plane of the laminate used as 0 degree reference; the Y axis is the axis in the plane of the laminate perpendicular to the X axis; the Z axis is the reference axis normal to the laminate plane in composite laminates.

Yarn  Continuously twisted fibers or strands suitable for use in weaving into fabrics.

Young's modulus  The ratio of normal stress to the corresponding strain for tensile or compressive stresses less than the proportional limit of the material.
I. INTRODUCTION.

A. CAUSAL FACTORS. Modern office buildings are generally considered safe and healthful working environments. However, energy conservation measures instituted during the early 1970's have minimized the infiltration of outside air and contributed to the buildup of indoor air contaminants. Investigations of indoor air quality (IAQ) often fail to identify any harmful levels of specific toxic substances. Often employee complaints result from items such as cigarette smoke, odors, low-level contaminants, poor air circulation, thermal gradients, humidity, job pressures, lighting, work-station design, or noise. Appendix III:2-1 presents a brief discussion of these items.

B. INCIDENCE.

1. The range of investigations of indoor air quality problems encompasses complaints from one or two employees to episodes where entire facilities are shut down and evacuated until the events are investigated and problems corrected.

2. Complaints are often of a subjective, nonspecific nature and are associated with periods of occupancy. These symptoms often disappear when the employee leaves the workplace. They include headache, dizziness, nausea, tiredness, lack of concentration, and eye, nose, and throat irritation.

3. In approximately 500 indoor air quality investigations in the last decade, the National Institute for Occupational Safety and Health (NIOSH) found that the primary sources of indoor air quality problems are:
II. RECOMMENDED VENTILATION RATES.

1. The American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) established recommended ventilation rates for indoor environments in 1973.²

2. ASHRAE amended this standard in 1975 to specify the minimum value of 5 cubic feet per minute (CFM) of outdoor air per person be used in building design. This standard has been incorporated into the building codes of many cities and states.³

3. The 62-1989 standard recommends a minimum of 15 CFM of outdoor air per person for offices (reception areas) and 20 CFM per person for general office space with a moderate amount of smoking. Sixty cubic feet per minute per person is recommended for smoking lounges with local mechanical exhaust ventilation and no air recirculation.⁴

II. ACUTE HEALTH EFFECTS OF MAJOR INDOOR AIR CONTAMINANTS.

A. TYPES OF BUILDING PROBLEMS. Employee complaints can be due to two types of building problems: sick or tight building syndrome and building related illnesses.

1. Sick building syndrome is a condition associated with complaints of discomfort including headache; nausea; dizziness; dermatitis; eye, nose, throat, and respiratory irritation; coughing; difficulty concentrating; sensitivity to odors; muscle pain; and fatigue. The specific causes of the symptoms are often not known but sometimes are attributed to the effects of a combination of substances or individual susceptibility to low concentrations of contaminants. The symptoms are associated with periods of occupancy and often disappear after the worker leaves the worksite.
2. Building-related illnesses are those for which there is a clinically defined illness of known etiology and include infections such as legionellosis and allergic reactions such as hypersensitivity diseases and are often documented by physical signs and laboratory findings. A more thorough description of these illnesses can be found in the American Conference of Governmental Industrial Hygienists (ACGIH) guidelines on evaluating bioaerosols.2

B. MAJOR INDOOR AIR CONTAMINANTS.

General. Although asbestos and radon have been listed below, acute health effects are not associated with these contaminants. These have been included due to recent concerns about their health effects. The investigator should be aware that there may be other health effects in addition to those listed.

1. Acetic Acid.
   Sources: X-ray development equipment, silicone caulking compounds.

   Acute health effects: Eye, respiratory and mucous membrane irritation.

2. Carbon Dioxide.
   Sources: Unvented gas and kerosene appliances, improperly vented devices, processes or operations which produce combustion products, human respiration.

   Acute health effects: Difficulty concentrating, drowsiness, increased respiration rate.

3. Carbon Monoxide.

   Acute health effects: Dizziness, headache, nausea, cyanosis, cardiovascular effects, and death.

4. Formaldehyde.
   Sources: Off-gassing from urea formaldehyde foam insulation, plywood, particle board, and paneling; carpeting and fabric; glues and adhesives; and combustion products including tobacco smoke.

   Acute health effects: Hypersensitive or allergic reactions; skin rashes; eye, respiratory and mucous membrane irritation; odor annoyance.
Sources: Combustion products from gas furnaces and appliances; tobacco smoke, welding, and gas- and diesel-engine exhausts.

Acute health effects: Eye, respiratory and mucous membrane irritation.

6. Ozone.  
Sources: Copy machines, electrostatic air cleaners, electrical arcing, smog.

Acute health effects: Eye, respiratory tract, mucous membrane irritation; aggravation of chronic respiratory diseases.

7. Radon.  
Sources: Ground beneath buildings, building materials, and groundwater.

Acute health effects: No acute health effects are known but chronic exposure may lead to increased risk of lung cancer from alpha radiation.

8. Volatile Organic Compounds (VOC's). Volatile organic compounds include trichloroethylene, benzene, toluene, methyl ethyl ketone, alcohols, methacrylates, acrolein, polycyclic aromatic hydrocarbons, and pesticides.

Sources: Paints, cleaning compounds, moth-balls, glues, photocopiers, "spirit" duplicators, signature machines, silicone caulking materials, insecticides, herbicides, combustion products, asphalt, gasoline vapors, tobacco smoke, dried out floor drains, cosmetics and other personal products.

Acute health effects: Nausea; dizziness; eye, respiratory tract, and mucous membrane irritation; headache; fatigue.


Sources: Microfilm equipment, window cleaners, acid drain cleaners, combustion products, tobacco smoke, blue-print equipment.

Acute health effects: Eye, respiratory tract, mucous membrane irritation; aggravation of chronic respiratory diseases.

10. Asbestos.  
Sources: Insulation and other building materials such as floor tiles, dry wall compounds, reinforced plaster.

Acute health effects: Asbestos is normally not a source of acute
health effects. However, during renovation or maintenance operations, asbestos may be dislodged and become airborne. Evaluation of employee exposure to asbestos will normally be covered under the OSHA Asbestos standard.

11. Synthetic Fibers.
Sources: Fibrous glass and mineral wool.

Acute health effects: Irritation to the eyes, skin and lungs; dermatitis.

12. Tobacco Smoke.
Sources: Cigars, cigarettes, pipe tobacco.

Acute health effects: Tobacco smoke can irritate the respiratory system and, in allergic or asthmatic persons, often results in eye and nasal irritation, coughing, wheezing, sneezing, headache, and related sinus problems. People who wear contact lenses often complain of burning, itching, and tearing eyes when exposed to cigarette smoke. Tobacco smoke is a major contributor to indoor air quality problems. Tobacco smoke contains several hundred toxic substances including carbon monoxide, nitrogen dioxide, hydrogen sulfide, formaldehyde, ammonia, benzene, benzo(a)pyrene, tars, and nicotine. Most indoor air particulates are due to tobacco smoke and are in the respirable range.

13. Microorganisms and Other Biological Contaminants (Microbials).
Includes viruses, fungi, mold, bacteria, nematodes, amoeba, pollen, dander, and mites.

Sources: Air handling system condensate, cooling towers, water damaged materials, high humidity indoor areas, damp organic material and porous wet surfaces, humidifiers, hot water systems, outdoor excavations, plants, animal excreta, animals and insects, food and food products.

Acute health effects: Allergic reactions such as hypersensitivity diseases (hypersensitivity pneumonitis, humidifier fever, allergic rhinitis, etc.) and infections such as legionellosis are seen. Symptoms include chills, fever, muscle ache, chest tightness, headache, cough, sore throat, diarrhea, and nausea.

III. INVESTIGATION GUIDELINES.

A. EMPLOYER AND EMPLOYEE INTERVIEWS.
1. Employer Interview.
   a. What is the magnitude and distribution of employee complaints or illnesses? Are any employees obtaining medical care?
b. What are the design and operational parameters of the heating, ventilating, and air-conditioning (HVAC) system, such as source and amount of fresh air per occupant delivered to the breathing zone; adjustable or local HVAC controls; type of humidifier and how controlled; recent ventilation changes; and areas serviced by various units?

c. Does the frequency and type of maintenance performed on the HVAC systems, such as cleaning and oiling, meet the HVAC manufacturer's recommendations: filter change; prevention of bacterial buildup by use of biocides; repair and cleanup of water leaks; operating fresh air intake damper; and system balance checks?

d. Is smoking allowed in the office, in adjacent areas or in areas serviced by the same ventilation system? Are there designated smoking areas that have separate, nonrecirculating exhaust systems?

e. What type of copying machines, signature machines, spirit duplicators, blueprint machines and other office machines are used in the vicinity of complaints or in areas serviced by the same ventilation system?

f. Has there been any recent renovation or maintenance that can be a source of contaminants, such as painting, carpet installation, air conditioning repairs, use of acid drain cleaners, carpet cleaning, disinfecting of HVAC system, pesticide application?

g. Has there been any recent renovation or maintenance that can alter air flow patterns such as installation of partitions or relocation of air intakes or exhausts?

2. Employee Interviews.

a. What are the complaints and associated symptoms experienced; when do they occur (season, time, days, frequency); where do they occur; how long do symptoms last; do they clear up after leaving work (how soon); have the symptoms been triggered by any specific event or in any specific area; what is the source of symptoms; was any medical diagnosis or care rendered?

b. What are the workers' characteristics, such as smoker, allergies, pre-existing illnesses and disabilities; are they taking any medication; what are the occupational contributors?
B. WALKAROUND INSPECTION. NIOSH has determined that inadequate ventilation is the main problem in 52% of their IAQ investigations. Therefore, ventilation surveys should be initially conducted. During the walkthrough inspection, the investigator could determine the building characteristics, discuss with knowledgeable personnel the proper operation of the HVAC systems, verify information obtained from the employer and employee interviews, perform ventilation-system testing, and, if appropriate, collect screening samples to identify potential causes of the problem.

Evaluation and testing of the HVAC system should follow the procedure established in the Ventilation Investigation chapter of the OTM. Investigators may need to discuss the operation of the ventilation system with building engineers and perform ventilation testing to determine proper fresh air intake. A simple traverse of the fresh-air intake duct may provide adequate information to determine the fresh-air flow. Measurements should be made under maximum and minimum air-flow conditions to determine the range of fresh-air intake.

The walkthrough inspection should cover all the affected areas. Factors to be evaluated include inside and outside contamination sources; the HVAC system, e.g., location of air source, contamination, and proper operation; and occupational contributors, such as those listed in Appendix III:2-1.

1. Potential Problem Areas. The following is a compilation of specific concerns in past investigations but may not apply in every situation.

   a. Are there sources of indoor contaminants that could lead to employee complaints (e.g., copy machines, signature machines, blueprint copiers, paints, cleaning compounds and disinfectants, tobacco smoke, adhesives and glues, off-gassing of construction material and building fabric, contaminants generated by construction or renovation, positive- or negative-pressure work areas, improperly vented gas appliances, air fresheners, pesticides)?

   b. Are there sources of outdoor contaminants that lead to employee complaints (e.g., vehicle exhaust, roofing materials, cooling towers, dust, or other contaminants from construction activity, industrial plant, or building exhaust; gasoline vapors, pollen, biological contaminants, atmospheric pollutants)?

   c. Are heating, ventilating, and air-conditioning systems being operated and maintained properly with respect to location of air
intakes and exhausts, pressure differentials between rooms that may account for influx of contaminants, design for supplied outdoor air, flow and distribution of air, position of dampers, local exhaust ventilation, air-cleaning equipment, HVAC operating times, regular operation checks, equipment cleaning and disinfecting, presence of water leaks or standing water, water-damaged building materials, and bacteriological contamination?

2. Sample Collection.

a. During the walkaround inspection, professional judgment must be exercised to determine if samples should be collected to evaluate potential sources and potential contaminants including gases, vapors, and particulates.

b. Initial sampling will normally consist of collecting environmental data using grab or screening samples with direct reading equipment such as detector tubes, particulate monitors, air velocity measuring instruments, and psychrometers. Screening samples for airborne contaminants should be collected for formaldehyde, carbon dioxide, carbon monoxide, and VOC's which are common potential sources of contamination.

c. Samples may be collected to monitor the possible buildup of contaminants during the workday. Detector tube samples can be collected for carbon dioxide early in the day and again toward the end of the day; direct reading instruments can monitor continuously using a strip chart recorder to obtain a hard copy of contaminant variations during the day.

d. To evaluate thoroughly, collect samples at fresh-air intakes, near return-air ducts, adjacent to both indoor and outdoor potential sources of contaminants, and in employee work areas both for complaint and noncomplaint areas. Sampling methods and equipment are covered in Section IV.

C. ENVIRONMENTAL EVALUATION. Based on initial sampling, further investigations may be performed using standard OSHA sampling procedures listed in the OSHA Analytical Method Manual.

1. Microbiological Evaluation.

a. NIOSH found that 5% of its investigations of indoor air quality involved some type of microbiological contamination.

b. The ACGIH Bioaerosols Committee's guidelines for assessing
the role of bioaerosols\textsuperscript{2} contains information on sampling, analysis, and recommendations for remedial actions. Air sampling should be initiated only after medical or clinical reports indicate the existence of workplace-related illnesses, such as hypersensitivity and allergic disorders, that are likely due to bioaerosols. The Office of Occupational Medicine should be consulted before initiating any sampling.

c. At present, specialized bioaerosol sampling equipment is available through the OSHA Health Response Team. Use of this equipment requires advance arrangements for preparing culture media for sampling, specialized handling techniques for the samples, and arrangements for analysis by laboratories familiar with the handling and processing of biological samples. The OSHA Health Response Team may be consulted for further information.

IV. SAMPLING INSTRUMENTATION AND METHODS.

A. LOW CONTAMINANT LEVELS.
1. Choose sampling procedures that can determine concentrations of toxic materials that are much lower than are normally found in industrial investigations. Few procedures have been validated for these lower level contaminants. Contact the Salt Lake Technical Center (SLTC) with any sampling questions.
2. Present OSHA sampling and analytical procedures were developed to meet precision and accuracy requirements for airborne contaminants in the range of OSHA Permissible Exposure Limits (PEL's) and American Conference of Governmental Industrial Hygienists (ACGIH) Threshold Limit Values (TLV's). These procedures are used for sampling 8-hour Time-Weighted Averages (TWA's) and Short-Term Exposure Limits (STEL's) of 15 or 30 minutes.
3. In many IAQ investigations, extensive air monitoring may not be warranted because inadequate introduction and/or distributions of fresh air may be the main problem.

B. GENERAL SCREENING. Use screening techniques to determine the potential sources that may require more sensitive and accurate evaluation or may require action as described in Section E, depending upon professional judgment.
1. Collect screening samples using detector tubes or direct reading instruments. For increased sensitivity, higher flow rates or longer sampling times may be used. Low range detector tubes are available from manufacturers. Appendix III:2-2 contains a table of screening methods, concentration range, validated testing methods, and contaminant types.
2. Based on screening results, validated sampling procedures may be required to further quantify employee exposures. Much of the information on validated sampling and analytical methods is contained in the OSHA Chemical Information Manual or in the OSHA Analytical Methods Manual.

3. Much of the specialized equipment is available through the OSHA Health Response Team (HRT), Cincinnati Technical Center (CTC), or Regional Offices.

C. OPTIONAL SCREENING FOR COMMON INDOOR AIR CONTAMINANTS, BASED UPON PROFESSIONAL JUDGMENT.

1. Acetic Acid. Use detector tubes (0-10 ppm) to evaluate complaints of eye, nose, and throat irritation. Low levels of acetic acid have been found from off-gassing of silicone caulking compounds and in hospitals where x-ray developing equipment is improperly ventilated.

2. Asbestos. Screening is not a routine procedure. Any requested screening should be done in accordance with the proper OSHA Standards.

3. Carbon Dioxide. Use low level detector tubes (0-2000 ppm) or portable infrared spectrometers to screen for indoor carbon dioxide levels. Carbon dioxide measurement is a useful screening technique which is often helpful in determining whether adequate quantities of outside fresh air have been introduced and distributed into the building.

NIOSH recommendations:

- 250-350 ppm normal outdoor ambient concentrations
- 600 ppm minimal air quality complaints
- 600-1,000 ppm less clearly interpreted
- 1,000 ppm indicates inadequate ventilation; complaints such as headaches, fatigue, and eye and throat irritation will be more widespread; 1,000 ppm should be used as an upper limit for indoor levels

These levels are only guidelines. If carbon dioxide levels exceed 1,000 ppm it does not necessarily indicate that the building is hazardous and should be evacuated. Rather this level should be used
as a guideline that helps maximize comfort for all occupants.  


5. Formaldehyde. Use low-level (0.04-1 ppm) detector tubes to evaluate complaints of eye, nose, and throat irritation which may be due to off-gassing from insulation, building materials, carpets, drapes, or glues and adhesives.

6. Nitrogen Oxides and Ozone. Detector tubes. Also collect outdoor samples since ambient levels of ozone may reach levels that are 1-3 times the PEL of 0.1 ppm during air-temperature inversions. If a more accurate or continuous ozone evaluation is required, a chemiluminescent monitor that is specific for ozone and can measure in the range of 0.01 to 10 ppm is available from the HRT.

7. Radon. A rapid, easy-to-use screening method for measuring radon gas concentrations is available from the SLTC. It is used for deciding if additional measurements are required or remedial actions should be undertaken. Additional longer-term quantitative procedures are available from the HRT if required. The HRT or Regional Offices may be contacted if sampling is to be initiated and for interpretation of the results.

EPA Recommendations\(^8\) for the results of screening samples:

- \(<4 \) picocuries per liter of air (pCi/L) follow-up measurements probably not required
- \(>4 \) pCi/L follow-up measurements should be performed

8. Airborne Particulates. Use a particle counting instrument capable of measuring concentrations as low as 2,000 particles/cubic centimeter (cc) of air for comparing particulates in various areas. The investigator may be able to determine where additional ventilation or air filtration is necessary to eliminate or minimize employee complaints.

For example, if employee complaints are more prevalent in an area where the particulate concentration is 40,000 particles/cc, and other areas are below 15,000 particles/cc, the investigator may recommend that a high efficiency filter be installed or, if the area has a separate ventilation system, that the ventilation rate be increased.
9. Airborne Microorganisms. The ACGIH\textsuperscript{5} recommends a pre-assessment of the extent of microbial contamination prior to initiation of air sampling. Airborne microbials sampling equipment is available from the HRT if sampling is necessary.

Before biological sampling, several precautions must be taken including making arrangements for preparing culture media for sampling, specialized shipping procedures, and making arrangements for analysis by a laboratory familiar with the handling and processing of biological samples. Contact the Directorate of Technical Support for information about laboratories experienced in the analysis of microbial samples and with knowledge of the health effects.

Legionella pneumophila is often present in hot water tanks, washing systems, and pools of stagnant water, but health effects are not observed until the contaminants become aerosolized within the building confinements.

The identification of predominant taxa, or at least fungi, is recommended in addition to determining the number of colony-forming units/m\textsuperscript{3} of air (cfu/m\textsuperscript{3}). During growing seasons, outdoor fungus-spore levels can range from 1,000 to 100,000 cfu/m\textsuperscript{3} of air.

Contamination indicators:\textsuperscript{9}
- 1,000 viable colony-forming units in a cubic meter of air
- 1,000,000 fungi per gram of dust or material
- 100,000 bacteria or fungi per milliliter of stagnant water or slime

Levels in excess of the above do not necessarily imply that the conditions are unsafe or hazardous. The type and concentrations of the airborne microorganisms will determine the hazard to employees.

D.

D. MISCELLANEOUS AIRBORNE CONTAMINANTS.
1. Use a portable infrared spectrometer to evaluate a wide variety of potential air contaminants including acetic acid, ammonia, carbon dioxide, carbon monoxide, nitric oxide, nitrogen dioxide, sulfur dioxide, and a number of volatile organic compounds. It can be connected to a strip chart recorder to obtain a hard copy showing variations of concentration during the day.
2. Take care in interpreting the results since the instrument is not always specific for one compound. Note: Equipment not generally
available in the field, such as the particulate analyzer, infrared spectrometer, and airborne biological sampler is available through the HRT along with a written description of the equipment, operating manuals, and methods of analysis.

V. RECOMMENDATIONS FOR THE EMPLOYER.

The following are general recommendations which, where relevant, should be standard procedure. If followed, they will help prevent or alleviate many indoor air-quality problems.

A. ENGINEERING RECOMMENDATIONS.

1. Ventilation.
   a. Includes the use of natural, dilution, local exhaust, or increased ventilation efficiency. The most effective engineering control for prevention of indoor air quality problems is assuring an adequate supply of fresh outdoor air through natural or mechanical ventilation.
   b. SHRAE in its 62-1989 standard recommends 20 cubic feet per minute (CFM) of outdoor air per occupant for offices. For smoking lounges, up to 60 CFM of outdoor air per occupant should be provided.
   c. When possible, use local exhaust ventilation and enclosure to capture and remove contaminants generated by specific processes. Room air in which contaminants are generated should be discharged directly outdoors rather than recirculated.

2. Efficiency.
   a. Ventilation efficiency can be improved by:
      - Ensuring that outdoor air-supply dampers and room air-vents are open;
      - Removing or modifying partitions or obstructions that block fresh-air flow;
      - Rebalancing the system to prevent inflow or outflow of contaminated air due to pressure differentials between rooms;
      - Preventing poor distribution of make-up air by proper placement of air inlets and exhausts; and
      - Using room fans to improve mixing and dilution of pollutants.
b. Outside air intakes should not be located in close proximity to potential sources of contamination (automobile garages, cooling towers, building exhausts, roadways).

3. **Air Treatment.** Air treatment is the removal of air contaminants and/or the control of room temperature and humidity. Recommendations for air treatment include:
   - The use of filtration, electronic cleaners, chemical treatment with activated charcoal or other sorbents;
   - Humidity control in the range of 20%-60%; and
   - Temperature control in the range of 68-76 F.

4. **Source Controls.** Source controls include substitution, removal, encapsulation, local exhaust ventilation, and use of physical barriers.

B. **ADMINISTRATIVE AND WORK PRACTICE RECOMMENDATIONS.** Recommendations include programs that change the behavioral patterns of occupants.

1. **Preventive Maintenance (PM).** Preventive maintenance plans for humidifiers, water spray, and other HVAC system components should include:
   - Checking damper positions and functioning belts, baffles, ductwork, and system balance;
   - Measuring airflow and performing necessary adjustment if necessary to meet ASHRAE recommendations;
   - Replacing filters on air handling units at regular intervals;
   - Cleaning air distribution ducts and dampers; and
   - Replacing damaged insulation.

2. **Microbial Contamination.**
   
a. Eliminate or control all known and potential sources of microbial contaminants by prompt cleanup and repair of all areas where water collection and leakage has occurred including floors, roofs, HVAC cooling coils, drain pans, humidifiers containing reservoirs of stagnant water, air washers, fan coil units, and filters.

b. Remove and discard porous organic materials that are contaminated (e.g., damp insulation in ventilation system, moldy ceiling tiles, and mildewed carpets).

c. Clean and disinfect nonporous surfaces where microbial growth has occurred with detergents, chlorine-generating
slimicides, or other biocides and insuring that these cleaners have been removed before air handling units are turned on.

d. Maintain indoor air relative humidity below 60% (50% where cold surfaces are in contact with room air).

e. Adjust intake of outdoor air to avoid contamination from nearby soil, vegetable debris, cooling towers, or sanitary stacks unless air is adequately conditioned.

f. Adjust combustion sources such as furnaces or water heaters to assure proper burning and exhaust to an area where re-entrainment will not occur.

g. Minimize exposure by limiting occupancy of contaminated airspace, limiting use of offending sources to specific areas or times, or evacuating contaminated areas until they can be ventilated adequately.

h. Isolate, if feasible, areas of renovation, painting, carpet laying, pesticide application, etc., from occupied areas that are not under construction. If possible, perform this work during evenings and weekends. If ventilation is turned off during weekends or other periods, ensure that system is on so that contaminant concentrations are sufficiently diluted prior to occupancy.

i. Supply adequate ventilation during and after completion of work to assist in diluting the contaminant levels.

j. Personnel affected with hypersensitivity should be thoroughly evaluated and the problem identified and corrected before returning them to the workplace. If, after the remedial action, the illness persists in the workplace, the affected personnel should be considered for permanent reassignment to another area.

k. Eliminate or reduce contamination of the air supply with cigarette smoke by banning smoking or restricting smoking to designated areas which have their air discharged directly to the outdoor rather than recirculated.

VI. REFERENCES.
5. National Institute for Occupational Safety and Health (NIOSH), Feb., 1989. Personal Correspondence to Long Loo, Occupational Safety and Health Administration. (Back to text)


11. ACGIH Committee on Bioaerosols, American Conference of Governmental Industrial Hygienists. 1986. Rationale for Monitoring Viable Microorganisms in the Office Environment. Applied Industrial Hygiene 1:R19-R23. (Back to text)


VII. BIBLIOGRAPHY.


APPENDIX III:2-1. INVESTIGATING OFFICE-RELATED COMPLAINTS.

Investigations of office related complaints using industrial hygiene techniques often fail to identify the source of these problems. The combined effects of multiple, low-level air contaminants have not been investigated thoroughly and may be a cause of the problem.

In a recent NIOSH document, Stress Management in Work Settings, occupational stress is discussed in terms of assessment methods, stress management, and programs and training necessary to reduce occupational stress. The synergistic effect of multiple stressors appears to indicate that building-related problems may be more than an air quality problem. The combined effect of these multiple stressors may interact with employees and could result in acute adverse emotional or physical reactions. In the short term, these reactions may lead to decreased productivity, absenteeism, and high turnover rates and if prolonged may lead to a variety of illnesses including hypertension, coronary heart disease, ulcers, alcoholism and mental illness.

These office-related health problems can be evaluated by a consultant through employee
interviews, analysis of job demands, and training employees. The following potential problems may need to be addressed:

- Physical hazards including noise from nearby sources such as air conditioning systems and printers, inadequate lighting, stress from the operation of video display terminals (VDT's), vibration sources, extremes of heat, cold and humidity, drafts, and poor air circulation.
- Ergonomic problems such as carpal tunnel syndrome or inflammatory disorders of the tendons and joints of keyboard operators due to tasks requiring repetitive motions. Proper design of fixed work stations where employees are required to perform repetitive tasks includes proper lighting to prevent glare, maintaining temperature and humidity in a comfortable range with minimum temperature variations, maximum flexibility in work station design including adjustable chair, keyboard, and screen height, and a work-rest regimen that allows breaks to reduce psychological distress.
- Reduction of job stress by: (a) adequate flow of information from management to employees; (b) explanation of any changes introduced into the workplace including new chemicals, ventilation, production modification, and work schedules; (c) maximizing employee participation in planning and implementing changes; (d) stress reduction techniques including exercise, biofeedback, and assertiveness training; and (e) training workers to understand chemicals they may be working with and their health effects, dose/response relationships, and results of environmental evaluation.

APPENDIX III:2-2. SAMPLING AND ANALYTICAL METHODS.

<table>
<thead>
<tr>
<th>Contaminant</th>
<th>Concentration range</th>
<th>Screening method</th>
<th>Validated method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bioaerosols</td>
<td>0-1,000 cfu/m³</td>
<td>Viable biological sampler</td>
<td></td>
</tr>
<tr>
<td>Carbon dioxide</td>
<td>0-2,000 ppm</td>
<td>DT, IR</td>
<td>Sampling bag, GC/TCD OSHA ID172</td>
</tr>
<tr>
<td>Carbon monoxide</td>
<td>2-50 ppm</td>
<td>DT, meter</td>
<td>Sampling bag, meter</td>
</tr>
<tr>
<td>Formaldehyde</td>
<td>0.04-1 ppm</td>
<td>DT</td>
<td>Coated XAD-2,</td>
</tr>
<tr>
<td>Substance</td>
<td>Limit</td>
<td>Method</td>
<td>Notes</td>
</tr>
<tr>
<td>-----------------</td>
<td>----------------</td>
<td>-----------------</td>
<td>----------------------------------------------------------------------</td>
</tr>
<tr>
<td>Nitric oxide</td>
<td>0-25 ppm</td>
<td>DT</td>
<td>TEA tube with oxidizer, DPP OSHA ID190</td>
</tr>
<tr>
<td>Nitrogen dioxide</td>
<td>0-5 ppm</td>
<td>DT</td>
<td>TEA-Molecular Sieve Tube, IC OSHA ID182</td>
</tr>
<tr>
<td>Particulates</td>
<td>0-40,000 particles/cc</td>
<td>Light scattering meter</td>
<td></td>
</tr>
<tr>
<td>Pesticides</td>
<td>(See OSHA Chemical Information Manual)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ozone</td>
<td>0-0.1 ppm</td>
<td>DT, Chemiluminescent meter</td>
<td></td>
</tr>
<tr>
<td>Radon</td>
<td>4-200 pCi/L</td>
<td>Radon Cartridge, Electect</td>
<td></td>
</tr>
<tr>
<td>VOC's</td>
<td>(See OSHA Chemical Information Manual)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Key:**
- DPP: Differential pulse polarographic
- DT: Detector tubes
- GC: Gas chromatograph
- IC: Ion chromatograph
- IR: Infrared spectrometer
- Meter: Calibrated, direct reading meter available through laboratory, HRT, or area office
- NPD: Nitrogen phosphorus detector
- TCD: Thermal conductivity detector
- TEA: Triethanolamine
NOTE: Referenced OSHA procedures can be found in the OSHA Analytical Methods Manual or the OSHA Chemical Information Manual. See individual manufacturer's literature for information on interferences to the screening or sampling method.
I. INTRODUCTION.

Industrial ventilation generally involves the use of supply and exhaust ventilation to control emissions, exposures, and chemical hazards in the workplace. Traditionally, nonindustrial ventilation systems commonly known as heating, ventilating, and air-conditioning (HVAC) systems were built to control temperature, humidity, and odors.

1. Ventilation may be deficient in:
   - confined spaces;
   - facilities failing to provide adequate maintenance of ventilation equipment;
   - facilities operated to maximize energy conservation;
   - windowless areas; and
   - areas with high occupant densities.

   Any ventilation deficiency must be verified by measurement.

2. There are five basic types of ventilation systems:
   1. dilution and removal by general exhaust;
   2. local exhaust (see Figure III:3-1);
3. makeup air (or replacement);  
4. HVAC (primarily for comfort); and  
5. recirculation systems.

FIGURE III:3-1. COMPONENTS OF A LOCAL EXHAUST SYSTEM.

3. Ventilation systems generally involve a combination of these types of systems. For example, a large local exhaust system may also serve as a dilution system, and the HVAC system may serve as a makeup air system (see Appendix III:3-1 for a primer and Appendix III:3-2 for an explanation of these terms).

II. HEALTH EFFECTS.

A. INDOOR AIR CONTAMINANTS include but are not limited to particulates, pollen, microbial agents, and organic toxins. These can be transported by the ventilation system or originate in the following parts of the ventilation system:

- wet filters;
- wet insulation;
- wet undercoil pans;
- cooling towers; and
- evaporative humidifiers.

People exposed to these agents may develop signs and symptoms related to "humidifier fever," "humidifier lung," or "air conditioner lung." In some cases, indoor air quality contaminants cause clinically identifiable conditions such as occupational asthma, reversible airway disease, and hypersensitivity pneumonitis.

B. VOLATILE ORGANIC AND REACTIVE CHEMICALS (for example, formaldehyde) often contribute to indoor air contamination. The facility's
ventilation system may transport reactive chemicals from a source area to other parts of the building. Tobacco smoke contains a number of organic and reactive chemicals and is often carried this way. In some instances the contaminant source may be the outside air. Outside air for ventilation or makeup air for exhaust systems may bring contaminants into the workplace (e.g., vehicle exhaust, fugitive emissions from a neighboring smelter).

See Section III, Chapter 2, Indoor Air Quality, for a discussion of common indoor-air contaminants and their biological effects.

III. STANDARDS AND CODES.

. CONSENSUS STANDARDS. Appendix III:3-3 is a compilation of OSHA and industry consensus standards. Foremost are those recommended by the Air Movement and Control Association (AMCA), the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), the American National Standards Institute (ANSI), the Sheet Metal and Air Conditioning Contractors National Association (SMACNA), the National Fire Protection Association (NFPA), and the American Conference of Governmental Industrial Hygienists (ACGIH). AMCA is a trade association that has developed standards and testing procedures for fans. ASHRAE is a society of heating and air conditioning engineers that has produced, through consensus, a number of standards related to indoor air quality, filter performance and testing, and HVAC systems. ANSI has produced several important standards on ventilation, including ventilation for paintspray booths, grinding exhaust hoods, and open-surface tank exhausts. Four ANSI standards were adopted by OSHA in 1971 and are codified in 29 CFR 1910.94; these standards continue to be important as guides to design. ANSI has recently published a new standard for laboratory ventilation (ANSI Z9.5). SMACNA is an association representing sheet metal contractors and suppliers. It sets standards for ducts and duct installation. NFPA has produced a number of recommendations (which become requirements when adopted by local fire agencies), e.g., NFPA 45 lists a number of ventilation requirements for laboratory fume hood use. The ACGIH has published widely used guidelines for industrial ventilation.

A. OSHA REGULATIONS. Ventilation criteria or standards are included in OSHA regulatory codes for job- or task-specific worker protection (see Appendix III:3-3). In addition, many OSHA health standards include ventilation requirements. The four standards in 29 CFR 1910.94 deal with local exhaust systems, and OSHA's construction standards (29 CFR 1926) contain ventilation standards for welding. OSHA's compliance policy regarding violation of ventilation standards is set forth in the Field Inspection Reference Manual.

IV. INVESTIGATION GUIDELINES.
INVESTIGATION PHASES. Workplace investigations of ventilation systems may be initiated by worker complaints of possible overexposures to air contaminants, possible risk of fire or explosion from flammable gas or vapor levels at or near the lower explosive limit (LEL), or indoor air quality complaints. The second phase of the investigation involves an examination of the ventilation system's physical and operating characteristics.

A. FAULTY VENTILATION CONDITIONS AND CAUSES. Common faulty ventilation conditions and their probable causes are listed in Table III:3-1. Specific points to consider during any investigation of a ventilation system include emission source, air behavior, and employee involvement. Points that should be included in a review of operational efficacy are shown in Table III:3-2. Appendix III:3-4 contains information on points to be checked in a troublesome exhaust system.

<table>
<thead>
<tr>
<th>Condition</th>
<th>Possible cause(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Worker complaints, improper use of system, nonuse of system, alteration of system by employees.</td>
<td>The hood interferes with work The hood provides poor control of contaminants.</td>
</tr>
<tr>
<td>Excessive employee exposures although flow volumes and capture velocities are at design levels.</td>
<td>Employee work practices need improvement. The ventilation system interferes with work or worker productivity and leads workers to bypass the system. Employee training is not adequate. Design of system is poor.</td>
</tr>
<tr>
<td>Constant plugging of duct.</td>
<td>Plugged ducts occur when transport velocity is inadequate or when vapor condenses in the duct, wets particles, and causes a build-up of materials. These problems are caused by poor design, open access doors close to the fan, fan problems, or other problems.</td>
</tr>
<tr>
<td>Reduced capture velocities or excessive fugitive emissions.</td>
<td>The cause of these conditions is usually reduced flow rate, unless the process itself has changed. Reduced flow rate occurs in the following situations: plugged or dented ducts slipping fan belts open access doors</td>
</tr>
</tbody>
</table>
holes in ducts, elbows
- closed blast gate to branch, or opened blast gates to other branches, or corroded and stuck blast gates
- fan turning in reverse direction (This can occur when lead wires are reversed and cause the motor and fan to turn backwards. Centrifugal fans turning backwards may deliver up to only 50% of rated capacity.)
- worn out fan blades
- additional branches or hoods added to system since initial installation, or clogged air cleaner.

### TABLE III:3-2. PROBLEM CHARACTERIZATION

<table>
<thead>
<tr>
<th>Emission source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Where are all emission sources or potential emission sources located?</td>
</tr>
<tr>
<td>Which emission sources actually contribute to exposure?</td>
</tr>
<tr>
<td>What is the relative contribution of each source to exposure?</td>
</tr>
<tr>
<td>Characterization of each contributor:</td>
</tr>
<tr>
<td>- chemical composition</td>
</tr>
<tr>
<td>- temperature</td>
</tr>
<tr>
<td>- rate of emission</td>
</tr>
<tr>
<td>- direction of emission</td>
</tr>
<tr>
<td>- initial emission velocity</td>
</tr>
<tr>
<td>- pattern of emission (continuous or intermittent)</td>
</tr>
<tr>
<td>- time intervals of emission</td>
</tr>
<tr>
<td>- mass of emitted material</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Air behavior</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air temperature</td>
</tr>
<tr>
<td>Air movement (direction, velocity)</td>
</tr>
<tr>
<td>Mixing potential</td>
</tr>
<tr>
<td>Supply and return flow conditions, to include pressure differences between space and surrounding areas</td>
</tr>
<tr>
<td>Sources of tempered and untempered make-up air</td>
</tr>
<tr>
<td>Air changes per hour</td>
</tr>
</tbody>
</table>
Influence of existing HVAC systems  
Effects of wind speed and direction  
Effects of weather and season

Employee

- Worker interaction with emission source  
- Worker exposure levels  
- Worker location  
- Worker education, training, cooperation

C. BASIC TESTING EQUIPMENT might include:

- smoke tubes
- velometers, anemometers:
  - swinging vane anemometer
  - thermal or hot-wire anemometer
- pressure-sensing devices:
  - U-tube or electronic manometers
  - Pitot tube
  - thermal (thermal and swinging vane instruments measure static pressure indirectly)
  - aneroid ("bellows") gauges
- noise-monitoring equipment
- measuring tapes
- other: rags, flashlight, mirror, tachometer
- combustible gas meter or oxygen meter
- tubes for CO, CO₂, formaldehyde, etc.

D. DOCUMENTATION. The characteristics of the ventilation system that must be documented during an investigation include equipment operability, physical measurements of the system, and use practices.

E. EQUIPMENT OPERABILITY. Before taking velocity or pressure measurements, note and record the operating status of the equipment. For example, are filters loaded or clean? Are variable-flow devices like dampers, variable-frequency drives, or inlet vanes in use? Are make-up units operating? Are system blueprints available?
F. MEASUREMENTS.

1. Duct diameters are measured to calculate duct areas. Inside duct diameter is the most important measurement, but an outside measurement is often sufficient for a sheet metal duct. To measure the duct, the tape should be thrown around the duct to obtain the duct circumference, and the number should be divided by (3.142) to obtain the diameter of the duct.

2. Hood and duct dimensions can be estimated from plans, drawings, and specifications. Measurements can be made with measuring tape. If a duct is constructed of 2½ or 4-foot sections, the sections can be counted (elbows and tees should be included in the length).

3. Hood-face velocities outside the hood or at the hood face can be estimated with velometers, smoke tubes, and swinging-vane anemometers, all of which are portable, reliable, and require no batteries.

   a. The minimum velocity that can be read by an anemometer is 50 feet per minute (fpm). The meter should always be read in the upright position, and only the tubing supplied with the equipment should be used.

   b. Anemometers often cannot be used if the duct contains dust or mist because air must actually pass through the instrument for it to work. The instrument requires periodic cleaning and calibration at least once per year. Hot-wire anemometers should not be used in airstreams containing aerosols.

   c. Hood-face velocity measurement involves the following steps:

   - mark off imaginary areas;
   - measure velocity at center of each area; and
   - average all measured velocities.

   d. Smoke is useful for measuring face velocity (see Figure III:3-2) because it is visible. Nothing convinces management and employees more quickly that the ventilation is not functioning properly than to show smoke drifting away from the hood, escaping the hood, or traveling into the worker's breathing zone. Smoke can be used to provide a rough estimate of face velocity:

   **FIGURE III:3-2. USE OF SMOKE TO DEMONSTRATE AIR FLOW.**

   \[
   \text{Velocity (fpm)} = \frac{\text{Distance (ft)}}{\text{Time (sec)}}
   \]

   **EXAMPLE**

   \[
   \text{Velocity (fpm)} = \frac{2 \text{ ft}}{2 \text{ sec}} \times \frac{60 \text{ sec}}{1 \text{ min}} = 60 \text{ fpm}
   \]
Velocity = Distance/Time, or

\[ V = \frac{D}{T} \]

Squeeze off a quick burst of smoke. Time the smoke plume's travel over a two-foot distance. Calculate the velocity in feet per minute. For example, if it takes two seconds for the smoke to travel two feet, the velocity is 60 fpm.

4. Hood static pressures (SPH) should be measured about 4-6 duct diameters downstream in a straight section of the hood take-off duct. The measurement can be made with a pitot tube or by a static pressure tap into the duct sheet metal (see Figure III:3-3).

![Figure III:3-3. USE OF STATIC PRESSURE TAP INTO DUCT TO MEASURE HOOD STATIC PRESSURE.](image)

- Pressure gauges come in a number of varieties, the simplest being the U-tube manometer.
- Inclined manometers offer greater accuracy and greater sensitivity at low pressures than U-tube manometers. However, manometers rarely can be used for velocities less than 800 fpm (i.e. velocity pressures less than 0.05" w.g.). Aneroid-type manometers use a calibrated bellows to measure pressures. They are easy to read and portable but require regular calibration and maintenance.

5. Duct velocity measurements may be made directly (with velometers and anemometers) or indirectly (with manometers and pitot tubes) using duct velocity pressure.

- Air flow in industrial ventilation ducts is almost always turbulent, with a small, nonmoving boundary layer at the surface of the duct.
- Because velocity varies with distance from the edge of the duct, a single
measurement may not be sufficient. However, if the measurement is taken in a straight length of round duct, 4-6 diameters downstream and 2-3 diameters upstream from obstructions or directional changes, then the average velocity can be estimated at 90% of the centerline velocity. (The average velocity pressure is about 81% of centerline velocity pressure.)

c. A more accurate method is the traverse method, which involves taking six or ten measurements on each of two or three passes across the duct, 90° or 60° opposed. Measurements are made in the center of concentric circles of equal area.

d. Density corrections (e.g., temperature) for instrument use should be made in accordance with the manufacturer's instrument instruction manual and calculation/correction formulas.

6. Air cleaner and fan condition measurements can be made with a pitot tube and manometer.

G. GOOD PRACTICES.

a. The approximate relationship of capture velocity \(V_c\) to duct velocity \(V_d\) for a simple plain or narrow flanged hood is illustrated in Figure III:3-4. For example, if an emission source is one duct diameter in front of the hood and the duct velocity \(V_d = 3,000\) feet per minute (fpm), then the expected capture velocity \(V_c\) is 300 fpm. At two duct diameters from the hood opening, capture velocity decreases by a factor of 10, to 30 fpm.

FIGURE III:3-4. RELATIONSHIP OF CAPTURE VELOCITY \(V_c\) TO DUCT VELOCITY \(V_d\).

b. Figure III:3-5 shows a rule of thumb that can be used with simple capture hoods. If the duct diameter \(D\) is 6 inches, then the maximum distance of the
emission source from the hood should not exceed 9 in. Similarly, the minimum capture velocity should not be less than 50 fpm.

FIGURE III:3-5. RULE OF THUMB FOR SIMPLE CAPTURE HOODS: MAXIMUM CAPTURE DISTANCE SHOULD NOT BE MORE THAN 1.5 TIMES THE DUCT DIAMETER.

![Diagram of simple capture hood with maximum capture distance formula](image)

\[ V_C \geq 50 \text{ fpm} \]

\[ 1.5D \]

1. System effect loss, which occurs at the fan, can be avoided if the necessary ductwork is in place.

a. Use of the six-and-three rule ensures better design by providing for a minimum loss at six diameters of straight duct at the fan inlet and a minimum loss at three diameters of straight duct at the fan outlet (Figure II:3-7).

FIGURE III:3-7. AN ILLUSTRATION OF THE SIX-AND-THREE RULE.

![Diagram of effective flange width with formula](image)

\[ W = X - \frac{1}{2}D \]
b. System effect loss is significant if any elbows are connected to the fan at inlet or outlet. For each 2½ diameters of straight duct between the fan inlet and any elbow, CFM loss will be 20%.

2. Stack height should be 10 ft higher than any roof line or air intake located within 50 ft of the stack (Figure III:3-8). For example, a stack placed 30 ft away from an air intake should be at least 10 ft higher than the center of the intake.

FIGURE III:3-8. MINIMUM STACK HEIGHT IN RELATION TO IMMEDIATE ROOF LINE OR CENTER OF ANY AIR INTAKE ON THE SAME ROOF.

3. Ventilation system drawings and specifications usually follow standard forms and symbols, e.g., as described in the Uniform Construction Index (UCI).

   a. Plan sections include electrical, plumbing, structural, or mechanical drawings (UCI, Section 15). The drawings come in several views: plan (top), elevation (side and front), isometric, or section.

   b. Elevations (side and front views) give the most detail. An isometric drawing is one that illustrates the system in three dimensions. A sectional drawing provides duct or component detail by showing a cross-section of the component.

   c. Drawings are usually drawn to scale. (Check dimensions and lengths with a ruler or a scale to be sure that this is the case. For example, 1/8 inch on the sheet
may represent one foot on the ground.) Good practices to follow when reviewing plans and specifications are listed in Table III:3-3.

**TABLE III:3-3. GOOD PRACTICES FOR REVIEWING PLANS AND SPECIFICATIONS**

- Investigate the background and objectives of the project.
- Understand the scope of the project. What is to be included and why?
- Do the specifications spell out exactly what is wanted? What is expected?
- Do plans and specifications adhere to appropriate codes, standards, requirements, policies, and do they recommend good practice as established by the industry?
- Will the designer be able to design, or the contractor to build, the system from the plans and specifications?
- Will the project meet OSHA requirements if it is built as proposed?

V. PREVENTION AND CONTROL.

A well-designed system and a continuing preventive maintenance program are key elements in the prevention and control of ventilation system problems.

A. ELEMENTS OF A GOOD MAINTENANCE PROGRAM.

B.

1. Establish a safe place to file drawings, specifications, fan curves, operating instructions, and other papers generated during design, construction, and testing.

2. Establish a program of periodic inspection.

   a. The types and frequencies of inspections depend on the operation of the system and other factors.
- Daily: Visual inspection of hoods, ductwork, access and clean-out doors, blast gate positions, hood static pressure, pressure drop across air cleaner, and verbal contact with users. ("How is the system performing today?")
- Weekly: Air cleaner capacity, fan housing, pulley belts.
- Monthly: Air cleaner components.

b. A quick way to check for settled material in a duct is to take a broomstick and tap the underside of all horizontal ducts. If the tapping produces a "clean" sheet metal sound, the duct is clear. If the tapping produces heavy, thudding sounds and no sheet metal vibration, liquids or settled dust may be in the duct.

3. Establish a preventive maintenance program. Certain elements of any ventilation system should be checked on a regular schedule and replaced if found to be defective.

4. Provide worker training. Workers need to be trained in the purpose and functions of the ventilation system. For example, they need to know how to work safely and how best to utilize the ventilation system. Exhaust hoods do little good if the welder does not know that the hood must be positioned close to the work.

5. Keep written records. Maintain written documentation not only of original installations but also of all modifications as well as problems and their resolution.

C. DEALING WITH MICRO-ORGANISMS. If you suspect microbial agents, check for stagnant water in the ventilation system. The presence of mold or slime is a possible sign of trouble. Table III:3-4 lists preventive measures for controlling microbial problems in ventilation systems.

| TABLE II:3-4. PREVENTIVE MEASURES FOR REDUCING MICROBIAL PROBLEMS IN BUILDINGS |
|------------------|------------------|
| ▪ Prevent buildup of moisture in occupied spaces (relative humidity of 60% or less). |
| ▪ Prevent moisture collection in HVAC components. |
| ▪ Remove stagnant water and slime from mechanical equipment. |
| ▪ Use steam for humidifying. |
| ▪ Avoid use of water sprays in HVAC systems. |
| ▪ Use filters with a 50-70% collection efficiency rating. |

OSHA Technical Manual Section III
• Find and discard microbe-damaged furnishings and equipment.
• Provide regular preventive maintenance.

D. VOLATILE ORGANIC OR REACTIVE CHEMICALS. If an organic or reactive chemical (e.g., formaldehyde) is believed to be the primary agent in an IAQ problem, potential controls to consider include additional dilution ventilation, removal or isolation of the offending material, and the transfer of sensitized employees.

E. TOBACCO SMOKE IN AIR. OSHA has published a proposed rule for IAQ (including tobacco smoke in the workplace), and this rulemaking is likely to be completed in the near future. Smoking policies should include provisions for dedicated smoking areas. Dedicated smoking areas should be configured so that migration of smoke into nonsmoking areas will not occur. Such areas should:

• have floor-to-ceiling walls of tight construction;
• be under negative pressure relative to adjacent areas; AND
• be exhausted outside the building and not recirculated.

For more information on investigation of complaints, CSHO’s should consult the NIOSH Guidance for Indoor Air Quality Investigation and the EPA guide Building Air Quality (1991).

VI.
VII. BIBLIOGRAPHY.


American National Standards Institute (ANSI) Standards:
   Z9.1 - Open Surface Tanks Operation
Z9.2 - Fundamentals Covering the Design and Operation of Local Exhaust Systems
Z9.3 - Design, Construction, and Ventilation of Spray Finishing Operations
Z9.4 - Ventilation and Safe Practice of Abrasive Blasting Operations


APPENDIX III:3-1. VENTILATION PRIMER

SELECTION Before an appropriate ventilation system can be selected, the employer should study emission sources, worker behavior, and air movement in the area. In some cases the employer may wish to seek the services of an experienced professional ventilation engineer to assist in the data gathering. Table III:3-5 shows factors to consider when selecting a ventilation system. Combinations of controls are often employed for HVAC purposes.

TABLE III:3-5. SELECTION CRITERIA FOR GENERAL AND LOCAL EXHAUST SYSTEMS

General exhaust ventilation (dilution ventilation) is appropriate when:

- Emission sources contain materials of relatively low hazard. (The degree of hazard is related to toxicity, dose rate, and individual susceptibility);
- Emission sources are primarily vapors or gases, or small, respirable-size aerosols (those not likely to settle);
- Emissions occur uniformly;
- Emissions are widely dispersed;
- Moderate climatic conditions prevail;
- Heat is to be removed from the space by flushing it with outside air;
Concentrations of vapors are to be reduced in an enclosure; and
Portable or mobile emission sources are to be controlled.

Local exhaust ventilating is appropriate when:

- Emission sources contain materials of relatively high hazard;
- Emitted materials are primarily larger-diameter particulates (likely to settle);
- Emissions vary over time;
- Emission sources consist of point sources;
- Employees work in the immediate vicinity of the emission source;
- The plant is located in a severe climate; and
- Minimizing air turnover is necessary.

GENERAL EXHAUST (DILUTION) VENTILATION SYSTEMS General exhaust ventilation, also called dilution ventilation, is different from local exhaust ventilation because instead of capturing emissions at their source and removing them from the air, general exhaust ventilation allows the contaminant to be emitted into the workplace air and then dilutes the concentration of the contaminant to an acceptable level (e.g., to the PEL or below). Dilution systems are often used to control evaporated liquids.

To determine the correct volume flow rate for dilution ($Q_d$), it is necessary to estimate the evaporation rate of the contaminant ($q_d$) according to the following equation:

$$q_d = \frac{(387) \text{ (lbs)}}{(MW)(\text{min})(d)}$$

where:
- $q_d$ = evaporation rate in acfm
- 387 = volume in cubic feet formed by the evaporation of one lb-mole of a substance, e.g., a solvent
- MW = molecular weight of emitted material
- lbs = lbs of material evaporated
- min = time of evaporation
- d = density correction factor

The appropriate dilution volume flow rate for toxics is:

$$Q_d = \frac{(q_d)(K_m)(10^6)}{C_a}$$
where: \( Q_d \) = volume flow rate of air, in acfm

\( q_{ld} \) = evaporation rate, in acfm

\( K_m \) = mixing factor to account for poor or random mixing
(Note: \( K_m = 2 \) to 5; \( K_m = 2 \) is optimum)

\( C_a \) = acceptable airborne concentration of the material (typically half of the PEL).

The number of air changes per hour is the number of times one volume of air is replaced in the space per hour. In practice, replacement depends on mixing efficiency. When using dilution ventilation:

- position exhausts as close to emission sources as possible;
- use auxiliary fans for mixing;
- make sure employees are upwind of the dilution zone; and
- add make-up air where it will be most effective.

LOCAL EXHAUST VENTILATION SYSTEMS A typical local exhaust ventilation system is composed of five parts: fans, hoods, ducts, air cleaners, and stacks. Local exhaust ventilation is designed to capture an emitted contaminant at or near its source, before the contaminant has a chance to disperse into the workplace air.

FAN SELECTION To choose the proper fan for a ventilation system, this information must be known:

- air volume to be moved;
- fan static pressure;
- type and concentration of contaminants in the air (because this affects the fan type and materials of construction); and
- the importance of noise as a limiting factor.

Once this information is available, the type of fan best suited for the system can be chosen. Many different fans are available, although they all fall into one of two classes: axial flow fans and centrifugal fans. For a detailed explanation of fans, see the ACGIH Industrial Ventilation Manual.

HOODS The hood captures, contains, or receives contaminants generated at an emission source. The hood converts duct static pressure to velocity pressure and hood entry losses (e.g., slot and duct entry losses).

Hood entry loss \( (H_e) \) is calculated according to the following equation:
\[ H_e = (K)(VP) = |SP_h| = VP \]

where:
- \( K \) = loss factor
- \( VP \) = velocity pressure in duct
- \( |SP_h| \) = absolute static pressure about 5 duct diameters down the duct from the hood.

A hood's ability to convert static pressure to velocity pressure is given by the coefficient of entry \((C_e)\), as follows:

\[ C_e = \frac{Q_{\text{ideal}}}{\sqrt{VP}} = \sqrt{\frac{1}{Q_{\text{actual}}} \frac{SP_h}{1 + K}} \]

where:
- \( K \) = loss factor
- \( VP \) = velocity pressure in duct
- \( SP_h \) = static pressure

To minimize air-flow requirements, the operation should be enclosed as much as possible, either with a ventilated enclosure, side baffles, or curtains. This helps both to contain the material and to minimize the effect of room air.

When using a capture or receiving hood, the hood should be located as close to the contaminant source as possible. Reducing the amount of contaminants generated or released from the process reduces ventilation requirements.

The hood should be designed to achieve good air distribution into the hood openings so that all the air drawn into the hood helps to control contaminants. Avoid designs that require that the velocities through some openings be very high in order to develop the minimum acceptable velocity through other openings or parts of the hood.

The purpose of most ventilation systems is to prevent worker inhalation of contaminants. For this reason, the hood should be located so that contaminants are not drawn through the worker's breathing zone. This is especially important where workers lean over an operation such as an open-surface tank or welding bench.
Hoods must meet the design criteria in the ACGIH Industrial Ventilation Manual or applicable OSHA standards. Most hood design recommendations account for cross-drafts that interfere with hood operation. Strong cross-drafts can easily reduce a hood's effectiveness by 75%. Standard hood designs may not be adequate to contain highly toxic materials.

The hood should be designed to cause minimum interference with the performance of work. Positioning access doors inside an enclosure that must be opened and closed often means that in practice the doors will be left open, and locating capture hoods too close to the process for the worker's convenience often means that the hood will be disassembled and removed. Hoods should never increase the likelihood of mechanical injury by interfering with a worker's freedom to move around machinery.

Two common misconceptions about hoods that are a part of local exhaust systems are:

- Hoods draw air from a significant distance away from the hood opening, and therefore they can control contaminants released some distance away. It is easy to confuse a fan's ability to blow a jet of air with its ability to draw air into a hood. Hoods must be close to the source of contamination to be effective.

- Heavier-than-air vapors tend to settle to the workroom floor and therefore can be collected by a hood located there. A small amount of contaminant in the air (1,000 ppm means 1,000 parts of contaminant plus 999,000 parts of air) has a resulting density close to that of air, and random air currents will disperse the material throughout the room.

DUCTS Air flows turbulently through ducts at between 2,000-6,000 feet per minute (fpm). Ducts can be made of galvanized metal, fiberglass, plastic, and concrete. Friction losses vary according to ductwork type, length of duct, velocity of air, duct area, density of air, and duct diameter.

AIR CLEANERS The design of the air cleaner depends on the degree of cleaning required. Regular maintenance of air cleaners increases their efficiency and minimizes worker exposure. Different types of air cleaners are made to remove particulates (e.g., precipitators, cyclones, etc.) and gases and vapors (e.g., scrubbers).

STACKS Stacks disperse exhaust air into the ambient environment. The amount of reentrainment depends on exhaust volume, wind speed and direction, temperature, location of intakes and exhausts, etc. When installing stacks:

- Provide ample stack height (a minimum of 10 ft above adjacent rooflines or air intakes);
- Place stack downwind of air intakes;
- Provide a stack velocity of a minimum of 1.4 times the wind velocity;
- Place the stack as far from the intake as possible (50 ft is recommended);
- Place the stack at least 10 ft high on most roofs to avoid recirculation; and
- Avoid rain caps if the air intake is within 50 ft of the stack.

MAKE-UP AIR SYSTEMS Exhaust ventilation systems require the replacement of exhausted air. Replacement air is often called make-up air. Replacement air can be supplied naturally by atmospheric pressure through open doors, windows, wall louvers, and adjacent spaces.
(acceptable), as well as through cracks in walls and windows, beneath doors, and through roof vents (unacceptable). Make-up air can also be provided through dedicated replacement air systems. Generally, exhaust systems are interlocked with a dedicated make-up air system.

Other reasons for designing and providing dedicated make-up air systems are that they:

- Avoid high-velocity drafts through cracks in walls, under doors, and through windows;
- Avoid differential pressures on doors, exits, and windows; and
- Provide an opportunity to temper the replacement air.

If make-up air is not provided, a slight negative pressure will be created in the room and air flow through the exhaust system will be reduced.

HVAC (heating, ventilating, and air-conditioning) is a common term that can also include cooling, humidifying or dehumidifying, or otherwise conditioning air for comfort and health. HVAC also is used for odor control and the maintenance of acceptable concentrations of carbon dioxide.

Air-conditioning has come to include any process that modifies the air for a work or living space: heating or cooling, humidity control, and air cleaning. Historically, air-conditioning has been used in industry to improve or protect machinery, products, and processes. The conditioning of air for humans has become normal and expected. Although the initial costs of air conditioning are high, annual costs may account only for about 1% to 5% of total annual operating expenses. Improved human productivity, lower absenteeism, better health, and reduced housekeeping and maintenance almost always make air-conditioning cost effective.

Mechanical air-handling systems can range from simple to complex. All distribute air in a manner designed to meet ventilation, temperature, humidity, and air-quality requirements established by the user. Individual units may be installed in the space they serve, or central units can serve multiple areas.

HVAC engineers refer to the areas served by an air handling system as zones. The smaller the zone, the greater the likelihood that good control will be achieved; however, equipment and maintenance costs are directly related to the number of zones. Some systems are designed to provide individual control of rooms in a multiple-zone system.

Both the provision and distribution of make-up air are important to the proper functioning of the system. The correct amount of air should be supplied to the space. Supply registers should be positioned to avoid disruption of emission and exposure controls and to aid dilution efforts.

Considerations in designing an air-handling system include volume flow rate, temperature, humidity, and air quality. Equipment selected must be properly sized and may include:

- outdoor air plenums or ducts
- filters
- supply fans and supply air systems
- heating and cooling coils
- humidity control equipment
- supply ducts
- distribution ducts, boxes, plenums, and registers
- dampers
- return air plenums
- exhaust air provisions
- return fans
- controls and instrumentation

**RECIRCULATION** Although not generally recommended, recirculation is an alternative to air exchanging. Where used, recirculation should incorporate air cleaners, a by-pass or auxiliary exhaust system, regular maintenance and inspection, and devices to monitor system performance. Key points to consider in the use of recirculation are shown in Table III:3-6.

<table>
<thead>
<tr>
<th>TABLE III:3-6. RECIRCULATION CRITERIA</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Protection of employees must be the primary design consideration.</td>
</tr>
<tr>
<td>• The system should remove as much of the contaminant as can economically be separated from exhaust air.</td>
</tr>
<tr>
<td>• The system should not be designed simply to achieve PEL levels of exposure.</td>
</tr>
<tr>
<td>• The system should never allow recirculation to significantly increase existing exposures.</td>
</tr>
<tr>
<td>• Recirculation should not be used if a carcinogen is present.</td>
</tr>
<tr>
<td>• The system should have fail-safe features, e.g., warning devices on critical parts, back-up systems.</td>
</tr>
<tr>
<td>• Cleaning and filtering devices that ensure continuous and reliable collection of the contaminant should be used.</td>
</tr>
<tr>
<td>• The system should provide a by-pass or auxiliary exhaust system for use during system failure.</td>
</tr>
<tr>
<td>• The system should include feedback devices that monitor system performance, e.g., static pressure taps, particulate counters, amperage monitors.</td>
</tr>
<tr>
<td>• The system should be designed not to recirculate air during equipment malfunction.</td>
</tr>
<tr>
<td>• The employer should train employees in the use and operation of the system.</td>
</tr>
</tbody>
</table>

**APPENDIX III:3-2. GLOSSARY**

acfm  Actual cubic feet per minute of gas flowing at existing temperature and pressure. (See also scfm.)

ACH, AC/H (air changes per hour)  The number of times air is replaced in an hour.
AIR DENSITY  The weight of air in lbs per cubic foot. Dry standard air at T=68° F (20° C) and BP = 29.92 in Hg (760 mm Hg) has a density of 0.075 lb/cu ft.

ANIOMETER  A device that measures the velocity of air. Common types include the swinging vane and the hot-wire anemometer.

AREA (A)  The cross-sectional area through which air moves. Area may refer to the cross-sectional area of a duct, a window, a door, or any space through which air moves.

ATMOSPHERIC PRESSURE  The pressure exerted in all directions by the atmosphere. At sea level, mean atmospheric pressure is 29.92 in Hg, 14.7 psi, 407 in w.g., or 760 mm Hg.

BRAKE HORSEPOWER (bhp)  The actual horsepower required to move air through a ventilation system against a fixed total pressure plus the losses in the fan. bhp=ahp × 1/eff, where eff is fan mechanical efficiency.

BRANCH  In a junction of two ducts, the branch is the duct with the lowest volume flow rate. The branch usually enters the main at an angle of less than 90.

CANOPY HOOD (Receiving Hood)  A one- or two-sided overhead hood that receives rising hot air or gas.

CAPTURE VELOCITY  The velocity of air induced by a hood to capture emitted contaminants external to the hood.

COEFFICIENT OF ENTRY (C_e)  A measure of the efficiency of a hood's ability to convert static pressure to velocity pressure; the ratio of actual flow to ideal flow.

DENSITY CORRECTION FACTOR  A factor applied to correct or convert dry air density of any temperature to velocity pressure; the ratio of actual flow to ideal flow.

DILUTION VENTILATION (General Exhaust Ventilation)  A form of exposure control that involves providing enough air in the workplace to dilute the concentration of airborne contaminants to acceptable levels.

ENTRY LOSS  See Hood Entry Loss or Branch Entry Loss.

EVASE (pronounced eh-va-say)  A cone-shaped exhaust stack that recaptures static pressure from velocity pressure.

FAN  A mechanical device that moves air and creates static pressure.

FAN LAWS  Relationships that describe theoretical, mutual performance changes in pressure, flow rate, rpm of the fan, horsepower, density of air, fan size, and sound power.

FAN CURVE  A curve relating pressure and volume flow rate of a given fan at a fixed fan
speed (rpm).

FRICION LOSS  The static pressure loss in a system caused by friction between moving air and the duct wall, expressed as in w.g./100 ft, or fractions of VP per 100 ft of duct (mm w.g./m; Kpa/m).

GAUGE PRESSURE  The difference between two absolute pressures, one of which is usually atmospheric pressure.

GENERAL EXHAUST  See Dilution Ventilation.

HEAD  Pressure, e.g. "The head is 1 in w.g."

HOOD  A device that encloses, captures, or receives emitted contaminants.

HOOD ENTRY LOSS ($H_e$)  The static pressure lost (in inches of water) when air enters a duct through a hood. The majority of the loss usually is associated with a vena contracta formed in the duct.

HOOD STATIC PRESSURE ($SP_h$)  The sum of the duct velocity pressure and the hood entry loss; hood static pressure is the static pressure required to accelerate air at rest outside the hood into the duct at velocity.

HVAC (HEATING, VENTILATION, AND AIR CONDITIONING) SYSTEMS  Ventilating systems designed primarily to control temperature, humidity, odors, and air quality.

INDOOR AIR QUALITY (IAQ), SICK-BUILDING SYNDROME, TIGHT-BUILDING SYNDROME  The study, examination, and control of air quality related to temperature, humidity, and airborne contaminants.

in. w.g. (inches of water)  A unit of pressure. One inch of water is equal to 0.0735 in. of mercury, or 0.036 psi. Atmospheric pressure at standard conditions is 407 in. w.g.

INDUSTRIAL VENTILATION (IV)  The equipment or operation associated with the supply or exhaust of air by natural or mechanical means to control occupational hazards in the industrial setting.

LAMINAR FLOW (also Streamline Flow)  Air flow in which air molecules travel parallel to all other molecules; laminar flow is characterized by the absence of turbulence.

LOCAL EXHAUST VENTILATION  An industrial ventilation system that captures and removes emitted contaminants before dilution into the ambient air of the workplace.

LOSS  Usually refers to the conversion of static pressure to heat in components of the ventilation system, e.g., "the hood entry loss."
MAKE-UP AIR  See Replacement and Compensating Air.

MANOMETER  A device that measures pressure difference; usually a U-shaped glass tube containing water or mercury.

MINIMUM TRANSPORT VELOCITY (MTV). The minimum velocity that will transport particles in a duct with little settling; MTV varies with air density, particulate loading, and other factors.

OUTDOOR AIR (OA)  Outdoor air is the "fresh" air mixed with return air (RA) to dilute contaminants in the supply air.

PITOT TUBE  A device used to measure total and static pressures in an airstream.

PLENUM  A low-velocity chamber used to distribute static pressure throughout its interior.

PRESSURE DROP  The loss of static pressure across a point; for example, "the pressure drop across an orifice is 2.0 in. w.g."

REPLACEMENT AIR (also, Compensating Air, Make-Up Air)  Air supplied to a space to replace exhausted air.

RETURN AIR  Air that is returned from the primary space to the fan for recirculation.

scfm  Standard cubic feet per minute. A measure of air flow at standard conditions, i.e., dry air at 29.92 in. Hg (760 mm Hg) (gauge), 68° F (20° C).

SLOT VELOCITY  The average velocity of air through a slot. Slot velocity is calculated by dividing the total volume flow rate by the slot area (usually, \( V_s = 2,000 \) fpm).

STACK  A device on the end of a ventilation system that disperses exhaust contaminants for dilution by the atmosphere.

STANDARD AIR, STANDARD CONDITIONS  Dry air at 68° F (20° C), 29.92 in Hg (760 mm Hg).

STATIC PRESSURE (SP)  The pressure developed in a duct by a fan; the force in inches of water measured perpendicular to flow at the wall of the duct; the difference in pressure between atmospheric pressure and the absolute pressure inside a duct, cleaner, or other equipment; SP exerts influence in all directions.

SUCTION PRESSURE  (See Static Pressure.) An archaic term that refers to static pressure on the upstream side of the fan.

TOTAL PRESSURE (TP)  The pressure exerted in a duct, i.e., the sum of the static pressure and the velocity pressure; also called Impact Pressure, Dynamic Pressure.
TRANSPORT VELOCITY  See Minimum Transport Velocity.

TURBULENT FLOW  Air flow characterized by transverse velocity components as well as velocity in the primary direction of flow in a duct; mixing velocities.

VELOCITY (V)  The time rate of movement of air; usually expressed as feet per minute.

VELOCITY PRESSURE (VP)  The pressure attributed to the velocity of air.

VOLUME FLOW RATE (Q)  Quantity of air flow in cfm, scfm, or acfm.

APPENDIX III:3-3. OSHA AND CONSENSUS STANDARDS

I. OSHA STANDARDS.

A. HEALTH-RELATED VENTILATION STANDARDS. This list includes some, but not necessarily all, OSHA standards that address the control of employee exposure to recognized contaminants.)

General industry

29 CFR 1910.94(a)  Abrasive blasting
29 CFR 1910.94(b)  Grinding, polishing and buffing operations
29 CFR 1910.94(d)  Open surface tanks
29 CFR 1910.252(c)(2)(i)(a) and (b); (c)(2)(ii)  Ventilation for general welding and cutting--General
29 CFR 1910.252(c)(3)  Local exhaust hoods and booths
29 CFR 1910.252(c)(5)(ii)  Fluorine compounds--Maximum allowable concentration
29 CFR 1910.252(c)(12)  Cutting of stainless steels
29 CFR 1910.1003 to .1016  Carcinogens
29 CFR 1910.1025(e)(5)  Lead

Construction

29 CFR 1926.57(a)  Ventilation--General
29 CFR 1926.62(e)(3)  Lead
29 CFR 1926.63(f)(4)  Cadmium
29 CFR 1926.154(a)(1)  Temporary heating devices--Ventilation
29 CFR 1926.353(e)(1) Ventilation and protection in welding, cutting and heating--General welding, cutting, and heating

Maritime

29 CFR 1915.32(a)(2) Toxic cleaning solvents
29 CFR 1915.51(f)(1) Ventilation and protection in welding, cutting and heating--General welding, cutting, and heating
29 CFR 1918.93(a)(1)(iii) Ventilation and atmospheric conditions

B. HEALTH-RELATED VENTILATION STANDARDS OTHER THAN AIRFLOW. This list includes some, but not necessarily all, OSHA standards that do not contain airflow requirements but are located in the health-related ventilation standards.

General Industry

29 CFR 1910.94(a)(5) Abrasive blasting--Personal protective equipment
29 CFR 1910.94(a)(6) Abrasive blasting--Air supply and air compressors
29 CFR 1910.94(a)(7) Abrasive blasting--Operational procedures and general safety
29 CFR 1910.94(d)(9) Open surface tanks--Personal protection
29 CFR 1910.94(d)(10) Open surface tanks--Special precautions for cyanide
29 CFR 1910.94(d)(11) Open surface tanks--Inspection, installation and maintenance
29 CFR 1910.94(d)(12) Open surface tanks--Vapor degreasing tanks

C. FIRE AND EXPLOSION-RELATED VENTILATION STANDARDS. This list includes some, but not necessarily all, OSHA standards that are intended to prevent fire and explosions.

General industry

29 CFR 1910.94(c) Ventilation--Spray finishing operations
29 CFR 1910.103(b)(3)(iii)(b) Hydrogen--Gaseous hydrogen systems--Special rooms
29 CFR 1910.103(c)(3)(iii)(b)  Hydrogen--Liquid hydrogen systems--Special rooms
29 CFR 1910.106(e)(3)(v)  Flammable and combustible liquids--Industrial plants--Unit physical operations--Ventilation
29 CFR 1910.107(d)(1) and (2)  Spray finishing using flammable and combustible materials--Ventilation--Conformance--General
29 CFR 1910.108(b)(1) and (2)  Dip tanks containing flammable combustible liquids--Ventilation--Ventilation combined with drying
29 CFR 1910.307  Hazardous (classified) locations

D. EXCEPTIONS TO 25% OF THE LEL FOR FIRE AND EXPLOSION-RELATED STANDARDS. This list includes but is not limited to OSHA standards that allow concentrations of flammable materials no greater than 10% of the LEL.

Maritime

29 CFR 1915.12(a)(2)  Precautions before entering--Flammable atmospheres and residues
29 CFR 1915.13(a)(2)  Cleaning and other cold work (flammable vapors)
29 CFR 1915.35(b)(1), (2), (3)  Painting--Paints and tanks coatings dissolved in highly volatile, toxic and/or flammable solvents
29 CFR 1915.36(a)(2)  Flammable liquids ventilation

Construction
E. SPECIAL CONDITIONS STANDARDS. This list includes some but not necessarily all OSHA standards that involve confined space operations and/or high-hazard contaminants specifically designated in the standard.

General industry

29 CFR 1910.252(c)(2)(i)(c)  Welding, cutting and brazing--Health protection and ventilating--Ventilation for general welding and cutting--General
29 CFR 1910.252(c)(4)  Welding, cutting and brazing--Health protection and ventilating--Ventilation in confined spaces
29 CFR 1910.252(c)(5)(i)  Welding, cutting and brazing--Fluorine compounds
29 CFR 1910.252(c)(8)  Welding, cutting and brazing--Beryllium
29 CFR 1910.252(c)(9)  Welding, cutting and brazing--Cadmium
29 CFR 1910.252(c)(10)  Welding, cutting and brazing--Mercury

Construction

29 CFR 1926.154(a)(2)  Temporary heating devices--Ventilation
29 CFR 1926.353(b)(1)  Ventilation and protection in welding, cutting and heating--Welding, cutting and heating in confined spaces
29 CFR 1926.353(c)(1) and (2)  Ventilation and protection in welding, cutting and heating--Welding, cutting or heating of metals of toxic significance
29 CFR 1926.800(k)  Tunnels and shafts--Air quality and ventilation

Maritime

29 CFR 1915.12(b)(2)  Precautions before entering--Toxic atmospheres and residues
29 CFR 1915.12(c)(2)  Precautions before entering--Oxygen deficient atmospheres
29 CFR 1915.12(d)  Precautions before entering--Exceptions
29 CFR 1915.34(a)(4)  Mechanical paint removers--Power tools--(paint
29 CFR 1915.51(c)(3) Ventilation and protection in welding, cutting and heating--Welding, cutting and heating confined spaces
dust)

29 CFR 1915.51(d)(1) and (2) Ventilation and protection in welding, cutting and heating--cutting or heating of metals of toxic significance.

II. CONSENSUS STANDARDS.

<table>
<thead>
<tr>
<th>Standard</th>
<th>Source</th>
<th>Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air filters</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ASHRAE 52-76</td>
<td>ASHRAE</td>
<td>Methods of Testing Air-Cleaning Devices Used in General Ventilation for Removing Particulate Matter</td>
</tr>
</tbody>
</table>

| Exhaust systems | | |
| NFPA 91-1983 | AIHA | Fundamentals Governing the Design and Operation of Local Exhaust Systems |
| ANSI Z9.4-1979 | ANSI | Ventilation and Safe Practices of Abrasives Blasting Operations |
| ANSI Z9.5-1992 | AIHA | Laboratory Ventilation |

| Fans | | |
| ANSI/UL 507-1976 | UL | Laboratory Methods of Testing Fans for Rating Purposes |
| ASHRAE 51-75 | ASHRAE | Laboratory Methods of Testing Fans for Rating Purposes |
| AMCA 210-74 | AMCA | Laboratory Methods of Testing Fans for Rating Purposes |
| AMCA 99-2404-78 | AMCA | Drive Arrangement for Centrifugal Fans |
AMCA 99-2406-83 AMCA Designation for Rotation and Discharge of Centrifugal Fans
AMCA 99-2407-66 AMCA Motor Positions for Belt or Chain Drive Centrifugal Fans
AMCA 99-2410-82 AMCA Drive Arrangement for Tubular Centrifugal Fans

Industrial duct
SMACNA SMACNA Round Industrial Duct Construction
SMACNA SMACNA Rectangular Industrial Duct Construction

Venting
NFPA 68 NFPA Guide for Explosion Venting
NFPA 204M NFPA Guide for Smoke and Heat Venting

Ventilation
NFPA 96 NFPA Vapor Removal from Cooking Equipment (1984)
NFPA-88A, 88B NFPA Parking Structures (1979); Repair Garages (1979)
ASHRAE 62-1989 ASHRAE Ventilation for Acceptable Indoor Air Quality
ACGIH ACGIH Industrial Ventilation

III. SOURCES OF CONSENSUS STANDARDS.

Copies of the consensus standards are published and available directly from the organization issuing the standard. A minimal fee is often required.

Source Organization
ACGIH American Conference of Governmental Industrial Hygienists
6500 Glenway Ave., Bldg. D-5
Cincinnati, OH 45211

AIHA American Industrial Hygiene Association
2700 Prosperity Ave., Suite 250
Fairfax, VA 22031-4319

AMCA Air Movement and Control Association
30 W. University Dr.
Arlington Heights, IL 60004
Most of the following checks can be made by visual observation and do not require extensive measurements.

If air flow is low in hoods, check:

- Fan rotation (reversed polarity will cause fan to run backwards; a backward-running centrifugal fan delivers only 30-50% of rated flow);
- Fan RPM;
- Slipping belt;
- Clogged or corroded fan wheel and casing;
- Clogged ductwork (high hood static pressure and low air flow may indicate restricted ducts; open clean-out doors and inspect inside ducts);
- Closed dampers in ductwork;
- Clogged collector or air cleaning devices;
- Weather cap too close to discharge stack (a 3/4 duct-diameter gap should exist between cap and stack; weather caps are not recommended);
- Poorly designed ductwork (short radius elbows); (branch entries enter main duct at sharp angles); (ductwork diameter too small for the air-flow needed; and
- Lack of make-up air (high negative pressures affect propeller fan system output; lack of supplied make-up air causes high airflow velocities at doors and windows).

If air flow is satisfactory in a hood but contaminant control is poor, check:
- Crossdrafts (from process air movements); (worker-cooling fans and air-supply systems); (open doors and windows);
- Capture velocity (work operation too far from hood opening);
- Hood enclosure: (door, baffles, or sides may be open or removed); and
- Hood type: (canopy hoods are inappropriate for toxic materials).
I. INTRODUCTION.

Operations involving high air temperatures, radiant heat sources, high humidity, direct physical contact with hot objects, or strenuous physical activities have a high potential for inducing heat stress in employees engaged in such operations. Such places include: iron and steel foundries, nonferrous foundries, brick-firing and ceramic plants, glass products facilities, rubber products factories, electrical utilities (particularly boiler rooms), bakeries, confectioneries, commercial kitchens, laundries, food canneries, chemical plants, mining sites, smelters, and steam tunnels.

Outdoor operations conducted in hot weather, such as construction, refining, asbestos removal, and hazardous waste site activities, especially those that require workers to wear semipermeable or impermeable protective clothing, are also likely to cause heat stress among exposed workers.

A. CAUSAL FACTORS.
1. Age, weight, degree of physical fitness, degree of acclimatization, metabolism, use of alcohol or drugs, and a variety of medical conditions such as hypertension all affect a person's sensitivity to heat. However, even the type of clothing worn must be considered. Prior heat injury predisposes an individual to additional injury.

2. It is difficult to predict just who will be affected and when, because individual susceptibility varies. In addition, environmental factors include more than the ambient air temperature. Radiant heat, air movement, conduction, and relative humidity all affect an individual's response to heat.

B. DEFINITIONS.

1. The American Conference of Governmental Industrial Hygienists (1992) states that workers should not be permitted to work when their deep body temperature exceeds 38°C (100.4°F).

2. Heat is a measure of energy in terms of quantity.

3. A calorie is the amount of heat required to raise 1 gram of water 1°C (based on a standard temperature of 16.5 to 17.5°C).

4. Conduction is the transfer of heat between materials that contact each other. Heat passes from the warmer material to the cooler material. For example, a worker's skin can transfer heat to a contacting surface if that surface is cooler, and vice versa.

5. Convection is the transfer of heat in a moving fluid. Air flowing past the body can cool the body if the air temperature is cool. On the other hand, air that exceeds 35°C (95°F) can increase the heat load on the body.

6. Evaporative cooling takes place when sweat evaporates from the skin. High humidity reduces the rate of evaporation and thus reduces the effectiveness of the body's primary cooling mechanism.

7. Radiation is the transfer of heat energy through space. A worker whose body temperature is greater than the temperature of the surrounding surfaces radiates heat to these surfaces. Hot surfaces and infrared light sources radiate heat that can increase the body's heat load.

8. Globe temperature is the temperature inside a blackened, hollow, thin copper globe.

9. Metabolic heat is a by-product of the body's activity.
10. Natural wet bulb (NWB) temperature is measured by exposing a wet sensor, such as a wet cotton wick fitted over the bulb of a thermometer, to the effects of evaporation and convection. The term natural refers to the movement of air around the sensor.

11. Dry bulb (DB) temperature is measured by a thermal sensor, such as an ordinary mercury-in-glass thermometer, that is shielded from direct radiant energy sources.

II. HEAT DISORDERS AND HEALTH EFFECTS.

A. HEAT STROKE occurs when the body's system of temperature regulation fails and body temperature rises to critical levels. This condition is caused by a combination of highly variable factors, and its occurrence is difficult to predict. Heat stroke is a medical emergency. The primary signs and symptoms of heat stroke are confusion; irrational behavior; loss of consciousness; convulsions; a lack of sweating (usually); hot, dry skin; and an abnormally high body temperature, e.g., a rectal temperature of 41°C (105.8°F). If body temperature is too high, it causes death. The elevated metabolic temperatures caused by a combination of work load and environmental heat load, both of which contribute to heat stroke, are also highly variable and difficult to predict.

If a worker shows signs of possible heat stroke, professional medical treatment should be obtained immediately. The worker should be placed in a shady area and the outer clothing should be removed. The worker's skin should be wetted and air movement around the worker should be increased to improve evaporative cooling until professional methods of cooling are initiated and the seriousness of the condition can be assessed. Fluids should be replaced as soon as possible. The medical outcome of an episode of heat stroke depends on the victim's physical fitness and the timing and effectiveness of first aid treatment.

Regardless of the worker's protests, no employee suspected of being ill from heat stroke should be sent home or left unattended unless a physician has specifically approved such an order.

B. HEAT EXHAUSTION. The signs and symptoms of heat exhaustion are headache, nausea, vertigo, weakness, thirst, and giddiness. Fortunately, this condition responds readily to prompt treatment. Heat exhaustion should not be dismissed lightly, however, for several reasons. One is that the fainting associated with heat exhaustion can be dangerous because the victim may be operating machinery or controlling an operation that should not be left unattended; moreover, the victim may be injured when he or she faints. Also, the signs and symptoms seen in heat exhaustion are similar to those of heat stroke, a medical emergency.

Workers suffering from heat exhaustion should be removed from the hot
environment and given fluid replacement. They should also be encouraged to get adequate rest.

C. HEAT CRAMPS are usually caused by performing hard physical labor in a hot environment. These cramps have been attributed to an electrolyte imbalance caused by sweating. It is important to understand that cramps can be caused by both too much and too little salt. Cramps appear to be caused by the lack of water replenishment. Because sweat is a hypotonic solution (±0.3% NaCl), excess salt can build up in the body if the water lost through sweating is not replaced. Thirst cannot be relied on as a guide to the need for water; instead, water must be taken every 15 to 20 minutes in hot environments.

Under extreme conditions, such as working for 6 to 8 hours in heavy protective gear, a loss of sodium may occur. Recent studies have shown that drinking commercially available carbohydrate-electrolyte replacement liquids is effective in minimizing physiological disturbances during recovery.

D. HEAT COLLAPSE ("Fainting"). In heat collapse, the brain does not receive enough oxygen because blood pools in the extremities. As a result, the exposed individual may lose consciousness. This reaction is similar to that of heat exhaustion and does not affect the body's heat balance. However, the onset of heat collapse is rapid and unpredictable. To prevent heat collapse, the worker should gradually become acclimatized to the hot environment.

E. HEAT RASHES are the most common problem in hot work environments. Prickly heat is manifested as red papules and usually appears in areas where the clothing is restrictive. As sweating increases, these papules give rise to a prickling sensation. Prickly heat occurs in skin that is persistently wetted by unevaporated sweat, and heat rash papules may become infected if they are not treated. In most cases, heat rashes will disappear when the affected individual returns to a cool environment.

F. HEAT FATIGUE. A factor that predisposes an individual to heat fatigue is lack of acclimatization. The use of a program of acclimatization and training for work in hot environments is advisable. The signs and symptoms of heat fatigue include impaired performance of skilled sensorimotor, mental, or vigilance jobs. There is no treatment for heat fatigue except to remove the heat stress before a more serious heat-related condition develops.

III. INVESTIGATION GUIDELINES.

These guidelines for evaluating employee heat stress approximate those found in the 1992-1993 ACGIH publication, Threshold Limit Values for Chemical Substances and Physical Agents and Biological Exposure Indices.

A. EMPLOYER AND EMPLOYEE INTERVIEWS.
1. The inspector will review the OSHA 200 Log and, if possible, the OSHA 101 forms for indications of prior heat stress problems.

2. Following are some questions for employer interviews: What type of action, if any, has the employer taken to prevent heat stress problems? What are the potential sources of heat? What employee complaints have been made?

3. Following are some questions for employee interviews: What heat stress problems have been experienced? What type of action has the employee taken to minimize heat stress? What is the employer's involvement, i.e., does employee training include information on heat stress? (Appendix III:4-1 lists factors to be evaluated when reviewing a heat stress situation, and Appendix III:4-2 contains a follow-up checklist.)

B. WALKAROUND INSPECTION. During the walkaround inspection, the investigator will: determine building and operation characteristics; determine whether engineering controls are functioning properly; verify information obtained from the employer and employee interviews; and perform temperature measurements and make other determinations to identify potential sources of heat stress. Investigators may wish to discuss any operations that have the potential to cause heat stress with engineers and other knowledgeable personnel. The walkaround inspection should cover all affected areas. Heat sources, such as furnaces, ovens, and boilers, and relative heat load per employee should be noted.

C. WORK-LOAD ASSESSMENT.

1. Under conditions of high temperature and heavy workload, the CSHO should determine the work-load category of each job (Table III:4-1 and Figure III:4-1). Work-load category is determined by averaging metabolic rates for the tasks and then ranking them:

   1. Light work: up to 200 kcal/hour
   2. Medium work: 200-350 kcal/hour
   3. Heavy work: 350-500 kcal/hour

2. Cool Rest Area: Where heat conditions in the rest area are different from those in the work area, the metabolic rate (M) should be calculated using a time-weighted average, as follows:

   Equation III: 4-1. Average Metabolic Rate

   \[
   \text{Average}_M = \frac{(M_1)(t_1) + (M_2)(t_2) + \ldots + (M_n)(t_n)}{(t_1) + (t_2) + \ldots + (t_n)}
   \]

   where: \( M \) = metabolic rate
t = time in minutes

4. In some cases, a videotape is helpful in evaluating work practices and metabolic load.

IV. V. FIGURE III:4-1. ACTIVITY EXAMPLES

VI.

- Light hand work: writing, hand knitting
- Heavy hand work: typewriting
- Heavy work with one arm: hammering in nails (shoemaker, upholsterer)
- Light work with two arms: filing metal, planing wood, raking the garden
- Moderate work with the body: cleaning a floor, beating a carpet
- Heavy work with the body: railroad track laying, digging, barking trees

Sample Calculation: Assembly line work using a heavy hand tool

Walking along 2.0 kcal/min
Intermediate value between heavy work with two arms and light work with the body 3.0 kcal/min
Add for basal metabolism 1.0 kcal/min
Total: 6.0 kcal/min


VIII. TABLE III:4-1. ASSESSMENT OF WORK

IX.

<table>
<thead>
<tr>
<th>Body position and movement</th>
<th>kcal/min*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sitting</td>
<td>0.3</td>
</tr>
<tr>
<td>Standing</td>
<td>0.6</td>
</tr>
<tr>
<td>Walking</td>
<td>2.0-3.0</td>
</tr>
<tr>
<td>Walking uphill</td>
<td>add 0.8 for every meter (yard) rise</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Type of work</th>
<th>Average kcal/min</th>
<th>Range kcal/min</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hand work</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Light</td>
<td>0.4</td>
<td>0.2-1.2</td>
</tr>
<tr>
<td></td>
<td>Light</td>
<td>Heavy</td>
</tr>
<tr>
<td>-----------</td>
<td>-------</td>
<td>-------</td>
</tr>
<tr>
<td>Work: One arm</td>
<td>1.0</td>
<td>0.7-2.5</td>
</tr>
<tr>
<td></td>
<td>1.7</td>
<td></td>
</tr>
<tr>
<td>Work: Both arms</td>
<td>1.5</td>
<td>1.0-3.5</td>
</tr>
<tr>
<td>Heavy</td>
<td>2.5</td>
<td></td>
</tr>
<tr>
<td>Work: Whole body</td>
<td>3.5</td>
<td>2.5-15.0</td>
</tr>
<tr>
<td>Light</td>
<td>5.0</td>
<td></td>
</tr>
<tr>
<td>Moderate</td>
<td>7.0</td>
<td></td>
</tr>
<tr>
<td>Heavy</td>
<td>9.0</td>
<td></td>
</tr>
</tbody>
</table>

* For a "standard" worker of 70 kg body weight (154 lbs) and 1.8m² body surface (19.4 ft²).

X.


XI. **SAMPLING METHODS.**

A. **ENVIRONMENTAL MEASUREMENTS.** Environmental heat measurements should be made at, or as close as possible to, the specific work area where the worker is exposed. When a worker is not continuously exposed in a single hot area but moves between two or more areas having different levels of environmental heat, or when the environmental heat varies substantially at a single hot area, environmental heat exposures should be measured for each area and for each level of environmental heat to which employees are exposed.

B. **WET BULB GLOBE TEMPERATURE INDEX.**

1. Wet Bulb Globe Temperature (WBGT) should be calculated using the appropriate formula in Appendix III:4-2. The WBGT for continuous all-day or several hour exposures should be averaged over a 60-minute period. Intermittent exposures should be averaged over a 120-minute period. These averages should be calculated using the following formula:
Equation III:4-2. Average Web Bulb Globe Temperature (WBGT)

$$\text{Average}_{WBGT} = \frac{(WBGT_1)(t_1) + (WBGT_2)(t_2) + \ldots + (WBGT_n)(t_n)}{(t_1) + (t_2) + \ldots (t_n)}$$

For indoor and outdoor conditions with no solar load, WBGT is calculated as:

$$WBGT = 0.7\text{NWB} + 0.3\text{GT}$$

For outdoors with a solar load, WBGT is calculated as

$$WBGT = 0.7\text{NWB} + 0.2\text{GT} + 0.1\text{DB}$$

where:

- $WBGT$ = Wet Bulb Globe Temperature Index
- $\text{NWB}$ = Nature Wet-Bulb Temperature
- $\text{DB}$ = Dry-Bulb Temperature
- $\text{GT}$ = Globe Temperature

2. The exposure limits in Table III:4-2 are valid for employees wearing light clothing. They must be adjusted for the insulation from clothing that impedes sweat evaporation and other body cooling mechanisms. Use Table III:4-3 to correct Table III:4-2 for various kinds of clothing.

3. Use of Table III:4-2 requires knowledge of the WBGT and approximate workload. Workload can be estimated using the data in Table III:4-1, and sample calculations are presented in Figure III:4-1.
C. MEASUREMENT. Portable heat stress meters or monitors are used to measure heat conditions. These instruments can calculate both the indoor and outdoor WBGT index according to established ACGIH Threshold Limit Value equations. With this information and information on the type of work being performed, heat stress meters can determine how long a person can safely work or remain in a particular hot environment. See Appendix III:4-2 for an alternate method of calculation.

TABLE III:4-2. PERMISSIBLE HEAT EXPOSURE THRESHOLD LIMIT VALUE

<table>
<thead>
<tr>
<th>Work/rest regimen</th>
<th>Light</th>
<th>Moderate</th>
<th>Heavy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Continuous work</td>
<td>30.0°C (86°F)</td>
<td>26.7°C (80°F)</td>
<td>25.0°C (77°F)</td>
</tr>
<tr>
<td>75% Work, 25% rest, each hour</td>
<td>30.6°C (87°F)</td>
<td>28.0°C (82°F)</td>
<td>25.9°C (78°F)</td>
</tr>
<tr>
<td>50% Work, 50% rest, each hour</td>
<td>31.4°C (89°F)</td>
<td>29.4°C (85°F)</td>
<td>27.9°C (82°F)</td>
</tr>
<tr>
<td>25% Work, 75% rest, each hour</td>
<td>32.2°C (90°F)</td>
<td>31.1°C (88°F)</td>
<td>30.0°C (86°F)</td>
</tr>
</tbody>
</table>

*Values are in °C and °F, WBGT.

These TLV's are based on the assumption that nearly all acclimatized, fully clothed workers with adequate water and salt intake should be able to function effectively under the given working conditions without exceeding a deep body temperature of 38°C (100.4°F). They are also based on the assumption that the WBGT of the resting place is the same or very close to that of the workplace. Where the WBGT of the work area is different from that of the rest area, a time-weighted average should be used (consult the ACGIH 1992-1993 Threshold Limit Values for Chemical Substances and Physical Agents and Biological Exposure Indices (1992)).

These TLV's apply to physically fit and acclimatized individuals wearing light summer clothing. If heavier clothing that impedes sweat or has a higher insulation value is required, the permissible heat exposure TLV's in Table III:4-2 must be reduced by the corrections shown in Table III:4-3.

E. OTHER THERMAL STRESS INDICES.

1. The Effective Temperature index (ET) combines the temperature, the humidity of the air, and air velocity. This index has been used extensively in the field of comfort ventilation and air-conditioning. ET remains a useful measurement technique in mines and other places where humidity is high and radiant heat is low.

2. The Heat-Stress Index (HSI) was developed by Belding and Hatch in 1965. Although the HSI considers all environmental factors and work rate, it is not completely satisfactory for determining an individual worker's heat stress and is also difficult to use.

<table>
<thead>
<tr>
<th>Clothing type</th>
<th>Clo* value</th>
<th>WBGT correction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Summer lightweight working clothing</td>
<td>0.6</td>
<td>0</td>
</tr>
<tr>
<td>Cotton coveralls</td>
<td>1.0</td>
<td>-2</td>
</tr>
<tr>
<td>Winter work clothing</td>
<td>1.4</td>
<td>-4</td>
</tr>
<tr>
<td>Water barrier, permeable</td>
<td>1.2</td>
<td>-6</td>
</tr>
</tbody>
</table>

*Clo: Insulation value of clothing. One clo = 5.55 kcal/m²/hr of heat exchange by radiation and convection for each degree °C difference in temperature between the skin and the adjusted dry bulb temperature.

Note: Deleted from the previous version are trade names and "fully encapsulating suit, gloves, boots and hood" including its clo value of 1.2 and WBGT correction of -10.


II. CONTROL.

Ventilation, air cooling, fans, shielding, and insulation are the five major types of engineering controls used to reduce heat stress in hot work environments. Heat reduction can also be achieved by using power assists and tools that reduce the physical demands placed on a worker.
However, for this approach to be successful, the metabolic effort required for the worker to use or operate these devices must be less than the effort required without them. Another method is to reduce the effort necessary to operate power assists. The worker should be allowed to take frequent rest breaks in a cooler environment.

. ACCLIMATIZATION.

5. The human body can adapt to heat exposure to some extent. This physiological adaptation is called acclimatization. After a period of acclimatization, the same activity will produce fewer cardiovascular demands. The worker will sweat more efficiently (causing better evaporative cooling), and thus will more easily be able to maintain normal body temperatures.

6. A properly designed and applied acclimatization program decreases the risk of heat-related illnesses. Such a program basically involves exposing employees to work in a hot environment for progressively longer periods. NIOSH (1986) says that, for workers who have had previous experience in jobs where heat levels are high enough to produce heat stress, the regimen should be 50% exposure on day one, 60% on day two, 80% on day three, and 100% on day four. For new workers who will be similarly exposed, the regimen should be 20% on day one, with a 20% increase in exposure each additional day.

A. FLUID REPLACEMENT. Cool (50°F-60°F) water or any cool liquid (except alcoholic beverages) should be made available to workers to encourage them to drink small amounts frequently, e.g., one cup every 20 minutes. Ample supplies of liquids should be placed close to the work area. Although some commercial replacement drinks contain salt, this is not necessary for acclimatized individuals because most people add enough salt to their summer diets.

B. ENGINEERING CONTROLS.

5. General ventilation is used to dilute hot air with cooler air (generally cooler air that is brought in from the outside). This technique clearly works better in cooler climates than in hot ones. A permanently installed ventilation system usually handles large areas or entire buildings. Portable or local exhaust systems may be more effective or practical in smaller areas.

6. Air treatment/air cooling differs from ventilation because it reduces the temperature of the air by removing heat (and sometimes humidity) from the air.
7. Air conditioning is a method of air cooling, but it is expensive to install and operate. An alternative to air conditioning is the use of chillers to circulate cool water through heat exchangers over which air from the ventilation system is then passed; chillers are more efficient in cooler climates or in dry climates where evaporative cooling can be used.

8. Local air cooling can be effective in reducing air temperature in specific areas. Two methods have been used successfully in industrial settings. One type, cool rooms, can be used to enclose a specific workplace or to offer a recovery area near hot jobs. The second type is a portable blower with built-in air chiller. The main advantage of a blower, aside from portability, is minimal set-up time.

9. Another way to reduce heat stress is to increase the air flow or convection using fans, etc. in the work area (as long as the air temperature is less than the worker's skin temperature). Changes in air speed can help workers stay cooler by increasing both the convective heat exchange (the exchange between the skin surface and the surrounding air) and the rate of evaporation. Because this method does not actually cool the air, any increases in air speed must impact the worker directly to be effective.

   If the dry bulb temperature is higher than 35°C (95°F), the hot air passing over the skin can actually make the worker hotter. When the temperature is more than 35°C and the air is dry, evaporative cooling may be improved by air movement, although this improvement will be offset by the convective heat. When the temperature exceeds 35°C and the relative humidity is 100%, air movement will make the worker hotter. Increases in air speed have no effect on the body temperature of workers wearing vapor-barrier clothing.

10. Heat conduction methods include insulating the hot surface that generates the heat and changing the surface itself.

11. Simple engineering controls, such as shields, can be used to reduce radiant heat, i.e. heat coming from hot surfaces within the worker's line of sight. Surfaces that exceed 35°C (95°F) are sources of infrared radiation that can add to the worker's heat load. Flat black surfaces absorb heat more than smooth, polished ones. Having cooler surfaces surrounding the worker assists in cooling because the worker's body radiates heat toward them.

   With some sources of radiation, such as heating pipes, it is possible to use both insulation and surface modifications to achieve a substantial reduction in radiant heat. Instead of reducing radiation from the source, shielding can be used to interrupt the path between the source and the worker. Polished surfaces make the best barriers, although special glass or metal mesh surfaces can be used if visibility is a problem.
Shields should be located so that they do not interfere with air flow, unless they are also being used to reduce convective heating. The reflective surface of the shield should be kept clean to maintain its effectiveness.

C. ADMINISTRATIVE CONTROLS AND WORK PRACTICES.

0. Training is the key to good work practices. Unless all employees understand the reasons for using new, or changing old, work practices, the chances of such a program succeeding are greatly reduced.

1. NIOSH (1986) states that a good heat stress training program should include at least the following components:
   - Knowledge of the hazards of heat stress;
   - Recognition of predisposing factors, danger signs, and symptoms;
   - Awareness of first-aid procedures for, and the potential health effects of, heat stroke;
   - Employee responsibilities in avoiding heat stress;
   - Dangers of using drugs, including therapeutic ones, and alcohol in hot work environments;
   - Use of protective clothing and equipment; and
   - Purpose and coverage of environmental and medical surveillance programs and the advantages of worker participation in such programs.

2. Hot jobs should be scheduled for the cooler part of the day, and routine maintenance and repair work in hot areas should be scheduled for the cooler seasons of the year.

D. WORKER MONITORING PROGRAMS.

0. Every worker who works in extraordinary conditions that increase the risk of heat stress should be personally monitored. These conditions include wearing semipermeable or impermeable clothing when the temperature exceeds 21°C (69.8°F), working at extreme metabolic loads (greater than 500 kcal/hour), etc.

1. Personal monitoring can be done by checking the heart rate, recovery heart rate, oral temperature, or extent of body water loss.

2. To check the heart rate, count the radial pulse for 30 seconds at the beginning of the rest period. If the heart rate exceeds 110 beats per minute, shorten the next work period by one third and maintain the same rest period.

3. The recovery heart rate can be checked by comparing the pulse rate taken at 30 seconds \(P_1\) with the pulse rate taken at 2.5 minutes \(P_3\) after the
rest break starts. The two pulse rates can be interpreted using Table III:4-4.

4. Oral temperature can be checked with a clinical thermometer after work but before the employee drinks water. If the oral temperature taken under the tongue exceeds 37.6°C, shorten the next work cycle by one third.

5. Body water loss can be measured by weighing the worker on a scale at the beginning and end of each work day. The worker's weight loss should not exceed 1.5% of total body weight in a work day. If a weight loss exceeding this amount is observed, fluid intake should increase.

E. OTHER ADMINISTRATIVE CONTROLS. The following administrative controls can be used to reduce heat stress:

- Reduce the physical demands of work, e.g., excessive lifting or digging with heavy objects;
- Provide recovery areas, e.g., air-conditioned enclosures and rooms;
- Use shifts, e.g., early morning, cool part of the day, or night work;
- Use intermittent rest periods with water breaks;
- Use relief workers;
- Use worker pacing; and
- Assign extra workers and limit worker occupancy, or the number of workers present, especially in confined or enclosed spaces.

<table>
<thead>
<tr>
<th>TABLE III:4-4. HEART RATE RECOVERY CRITERIA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heart rate recovery pattern</td>
</tr>
<tr>
<td>Satisfactory recovery</td>
</tr>
<tr>
<td>High recovery (Conditions may require further study)</td>
</tr>
<tr>
<td>No recovery (May indicate too much stress)</td>
</tr>
</tbody>
</table>

II. PERSONAL PROTECTIVE EQUIPMENT.

- REFLECTIVE CLOTHING, which can vary from aprons and jackets to suits that completely enclose the worker from neck to feet, can stop the skin from absorbing radiant heat. However, since most reflective clothing does not allow air exchange through the garment, the reduction of radiant heat must more than offset the corresponding loss in evaporative cooling. For this reason, reflective clothing should be worn as loosely as possible. In situations where radiant heat is high, auxiliary cooling systems can be used under the reflective clothing.
A. AUXILIARY BODY COOLING.

0. Commercially available ice vests, though heavy, may accommodate as many as 72 ice packets, which are usually filled with water. Carbon dioxide (dry ice) can also be used as a coolant. The cooling offered by ice packets lasts only 2 to 4 hours at moderate to heavy heat loads, and frequent replacement is necessary. However, ice vests do not encumber the worker and thus permit maximum mobility. Cooling with ice is also relatively inexpensive.

1. Wetted clothing is another simple and inexpensive personal cooling technique. It is effective when reflective or other impermeable protective clothing is worn. The clothing may be wetted terry cloth coveralls or wetted two-piece, whole-body cotton suits. This approach to auxiliary cooling can be quite effective under conditions of high temperature and low humidity, where evaporation from the wetted garment is not restricted.

2. Water-cooled garments range from a hood, which cools only the head, to vests and "long johns," which offer partial or complete body cooling. Use of this equipment requires a battery-driven circulating pump, liquid-ice coolant, and a container.

Although this system has the advantage of allowing wearer mobility, the weight of the components limits the amount of ice that can be carried and thus reduces the effective use time. The heat transfer rate in liquid cooling systems may limit their use to low-activity jobs; even in such jobs, their service time is only about 20 minutes per pound of cooling ice. To keep outside heat from melting the ice, an outer insulating jacket should be an integral part of these systems.

3. Circulating air is the most highly effective, as well as the most complicated, personal cooling system. By directing compressed air around the body from a supplied air system, both evaporative and convective cooling are improved. The greatest advantage occurs when circulating air is used with impermeable garments or double cotton overalls.

One type, used when respiratory protection is also necessary, forces exhaust air from a supplied-air hood ("bubble hood") around the neck and down inside an impermeable suit. The air then escapes through openings in the suit. Air can also be supplied directly to the suit without using a hood in three ways:

- by a single inlet;
- by a distribution tree; or
- by a perforated vest.
In addition, a vortex tube can be used to reduce the temperature of circulating air. The cooled air from this tube can be introduced either under the clothing or into a bubble hood. The use of a vortex tube separates the air stream into a hot and cold stream; these tubes also can be used to supply heat in cold climates. Circulating air, however, is noisy and requires a constant source of compressed air supplied through an attached air hose.

One problem with this system is the limited mobility of workers whose suits are attached to an air hose. Another is that of getting air to the work area itself. These systems should therefore be used in work areas where workers are not required to move around much or to climb. Another concern with these systems is that they can lead to dehydration. The cool, dry air feels comfortable and the worker may not realize that it is important to drink liquids frequently.

B. RESPIRATOR USAGE. The weight of a self-contained breathing apparatus (SCBA) increases stress on a worker, and this stress contributes to overall heat stress. Chemical protective clothing such as totally encapsulating chemical protection suits will also add to the heat stress problem.

III. BIBLIOGRAPHY.

American Conference of Governmental Industrial Hygienists (ACGIH). 1990. Documentation of the Threshold Limit Values and Biological Exposure Indices. 6th ed. Cincinnati: American Conference of Governmental Industrial Hygienists.


APPENDIX III:4-1. HEAT STRESS: GENERAL WORKPLACE REVIEW.

NOTE: Listed below are sample questions that the Compliance Officer may wish to consider when investigating heat stress in the workplace.

WORKPLACE DESCRIPTION.

A. Type of business
B. Heat-producing equipment or processes used
C. Previous history (if any) of heat-related problems
D. At "hot" spots:
   - Is the heat steady or intermittent?
   - Number of employees exposed?
   - For how many hours per day?
   - Is potable water available?
   - Are supervisors trained to detect/evaluate heat stress symptoms?

ARE EXPOSURES TYPICAL FOR A WORKPLACE IN THIS INDUSTRY?

A. Weather at Time of Review
B. Temperature
C. Humidity
D. Air velocity
E. Is Day Typical of Recent Weather Conditions?  
   (Get information from the Weather Bureau)

F. Heat-Reducing Engineering Controls
G. Ventilation in place?
H. Ventilation operating?
   I. Air conditioning in place?
   J. Air conditioning operating?
   K. Fans in place?
   L. Fans operating?
   M. Shields or insulation between sources and employees?
   N. Are reflective faces of shields clean?

WORK PRACTICES TO DETECT, EVALUATE, AND PREVENT OR REDUCE HEAT STRESS.

A. Training program?
B. Content?
C. Where given?
D. For whom?
E. Liquid replacement program?
F. Acclimatization program?
G. Work/rest schedule?
H. Scheduling of work (during cooler parts of shift, cleaning and maintenance during shut-downs, etc.)
   I. Cool rest areas (including shelter at outdoor work sites)?
   J. Heat monitoring program?
   K. Personal Protective Equipment
   L. Reflective clothing in use?
   M. Ice and/or water-cooled garments in use?
   N. Wetted undergarments (used with reflective or impermeable clothing) in use?
   O. Circulating air systems in use?
   P. First Aid Program
   Q. Trained personnel?
   R. Provision for rapid cool-down?
   S. Procedures for getting medical attention?
   T. Transportation to medical facilities readily available for heat stroke victims?
   U. Medical Screening and Surveillance Program
   V. Content?
   W. Who manages program?
   X. Additional Comments

   (Use additional pages as needed.)

APPENDIX III: 4-2. HEAT STRESS-RELATED ILLNESS OR ACCIDENT FOLLOW-UP.
A. Describe events leading up to the episode.
B. Evaluation/comments by other workers at the scene.
C. Work at time of episode (heavy, medium, light)?
D. How long was affected employee working at site prior to episode?
E. Medical history of affected worker, if known.
F. Appropriate engineering controls in place?
G. Appropriate engineering controls in operation?
H. Appropriate work practices used by affected employee(s)?
I. Appropriate personal protective equipment available?
J. Appropriate personal protective equipment in use?
K. Medical screening for heat stress and continued surveillance for signs of heat stress given other employees?
L. Additional comments regarding specific episode(s): (Use additional pages as needed.)

APPENDIX III: 4-3. MEASUREMENT OF WET BULB GLOBE TEMPERATURE.

Measurement is often required of those environmental factors that most nearly correlate with deep body temperature and other physiological responses to heat. At the present time, the Wet Bulb Globe Temperature Index (WBGT) is the most used technique to measure these environmental factors. WBGT values are calculated by the following equations:

Equation III:4-4. Indoor or Outdoor Wet Bulb Globe Temperature Indexes (WBGI) Indoor or outdoors with no solar load

\[ \text{WBGT} = 0.7\text{NWB} + 0.3\text{GT} \]

Outdoors with solar load

\[ \text{WBGT} = 0.7\text{NWB} + 0.2\text{GT} + 0.1\text{DB} \]

where:

- WBGT = Wet Bulb Globe Temperature Index
- NWB = Natural Wet-Bulb Temperature
- DB = Dry-Bulb (air) Temperature
- GT = Globe Thermometer Temperature

The determination of WBGT requires the use of a black globe thermometer, a natural (static) wet-bulb thermometer, and a dry-bulb thermometer. The measurement of environmental factors shall be performed as follows:

1. The range of the dry and the natural wet-bulb thermometers should be -5°C to +50°C, with an accuracy of ±0.5°C. The dry bulb thermometer must be shielded from the sun and the other radiant surfaces of the environment without restricting the airflow around the bulb. The wick of the natural wet bulb thermometer should be kept wet with distilled water for at least one-half
hour before the temperature reading is made. It is not enough to immerse the other end of the wick into a reservoir of distilled water and wait until the whole wick becomes wet by capillarity. The wick must be wetted by direct application of water from a syringe one-half hour before each reading. The wick must cover the bulb of the thermometer and an equal length of additional wick must cover the stem above the bulb. The wick should always be clean, and new wicks should be washed before using.

2. A globe thermometer, consisting of a 15 cm (6-inch) in diameter hollow copper sphere painted on the outside with a matte black finish, or equivalent, must be used. The bulb or sensor of a thermometer (range -5°C to +100°C with an accuracy of ±0.5°C) must be fixed in the center of the sphere. The globe thermometer should be exposed at least 25 minutes before it is read.

3. A stand should be used to suspend the three thermometers so that they do not restrict free air flow around the bulbs and the wet-bulb and globe thermometer are not shaded.

4. It is permissible to use any other type of temperature sensor that gives a reading similar to that of a mercury thermometer under the same conditions.

5. The thermometers must be placed so that the readings are representative of the employee's work or rest areas, as appropriate.

Once the WBGT has been estimated, employers can estimate workers' metabolic heat load (see Tables III:4-1 and III:4-2) and use the ACGIH method to determine the appropriate work/rest regimen, clothing, and equipment to use to control the heat exposures of workers in their facilities.
I. **INTRODUCTION.**

The term LASER is an acronym for Light Amplification by Stimulated Emission of Radiation. Light can be produced by atomic processes which generate laser light. A laser consists of an optical cavity, a pumping system, and an appropriate lasing medium (Figure III:6-1).

**FIGURE III:6-1 COMPONENTS OF A LASER**
A. The optical cavity contains the media to be excited with mirrors to redirect the produced photons back along the same general path.

B. The pumping system uses photons from another source as a xenon gas flash tube (optical pumping) to transfer energy to the media, electrical discharge within the pure gas or gas mixture media (collision pumping), or relies upon the binding energy released in chemical reactions to raise the media to the metastable or lasing state.

C. The laser medium can be a solid (state), gas, dye (in liquid), or semiconductor. Lasers are commonly designated by the type of lasing material employed.

1. Solid state lasers have lasing material distributed in a solid matrix, e.g., the ruby or neodymium-YAG (yttrium aluminum garnet) lasers. The neodymium-YAG laser emits infrared light at 1.064 micrometers.

2. Gas lasers (helium and helium-neon, HeNe, are the most common gas lasers) have a primary output of a visible red light. CO\textsubscript{2} lasers emit energy in the far-infrared, 10.6 micrometers, and are used for cutting hard materials.

3. Excimer lasers (the name is derived from the terms excited and dimers) use reactive gases such as chlorine and fluorine mixed with inert gases such as argon, krypton, or xenon. When electrically stimulated, a pseudomolecule or dimer is produced and when lased, produces light in the ultraviolet range.

4. Dye lasers use complex organic dyes like rhodamine 6G in liquid solution or suspension as lasing media. They are tunable over a broad range of wavelengths.

5. Semiconductor lasers, sometimes called diode lasers, are not solid-state lasers. These electronic devices are generally very small and use low power. They may be built into larger arrays, e.g., the writing source in some laser printers or compact disk players.
D. The wavelength output from a laser depends upon the medium being excited. Table III:6-1 lists most of the laser types and their wavelength output defined by the medium being excited. Laser use today is not restricted to the laboratory or specialized industries. Table III:6-2 lists some of the major uses of lasers.

**TABLE III:6-1. WAVELENGTHS OF MOST COMMON LASERS**

<table>
<thead>
<tr>
<th>Laser type</th>
<th>Wavelength (µmeters)</th>
<th>Laser type</th>
<th>Wavelength (µmeters)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Argon fluoride (Excimer-UV)</td>
<td>0.193</td>
<td>Helium neon (yellow)</td>
<td>0.594</td>
</tr>
<tr>
<td>Krypton chloride (Excimer-UV)</td>
<td>0.222</td>
<td>Helium neon (orange)</td>
<td>0.610</td>
</tr>
<tr>
<td>Krypton fluoride (Excimer-UV)</td>
<td>0.248</td>
<td>Gold vapor (red)</td>
<td>0.627</td>
</tr>
<tr>
<td>Xenon chloride (Excimer-UV)</td>
<td>0.308</td>
<td>Helium neon (red)</td>
<td>0.633</td>
</tr>
<tr>
<td>Xenon fluoride (Excimer-UV)</td>
<td>0.351</td>
<td>Krypton (red)</td>
<td>0.647</td>
</tr>
<tr>
<td>Helium cadmium (UV)</td>
<td>0.325</td>
<td>Rholedamine 6G dye (tunable)</td>
<td>0.570-0.650</td>
</tr>
<tr>
<td>Nitrogen (UV)</td>
<td>0.337</td>
<td>Ruby (CrAlO₃) (red)</td>
<td>0.694</td>
</tr>
<tr>
<td>Helium cadmium (violet)</td>
<td>0.441</td>
<td>Gallium arsenide (diode-NIR)</td>
<td>0.840</td>
</tr>
<tr>
<td>Krypton (blue)</td>
<td>0.476</td>
<td>Nd:YAG (NIR)</td>
<td>1.064</td>
</tr>
<tr>
<td>Argon (blue)</td>
<td>0.488</td>
<td>Helium neon (NIR)</td>
<td>1.15</td>
</tr>
<tr>
<td>Copper vapor (green)</td>
<td>0.510</td>
<td>Erbium (NIR)</td>
<td>1.504</td>
</tr>
<tr>
<td>Argon (green)</td>
<td>0.514</td>
<td>Helium neon (NIR)</td>
<td>3.39</td>
</tr>
<tr>
<td>Krypton (green)</td>
<td>0.528</td>
<td>Hydrogen fluoride (NIR)</td>
<td>2.70</td>
</tr>
<tr>
<td>Frequency doubled</td>
<td>0.532</td>
<td>Carbon dioxide (FIR)</td>
<td>9.6</td>
</tr>
<tr>
<td>Nd YAG (green)</td>
<td>0.543</td>
<td>Carbon dioxide (FIR)</td>
<td>10.6</td>
</tr>
<tr>
<td>Helium neon (green)</td>
<td>0.568</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Copper vapor (yellow)</td>
<td>0.570</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Key: UV = ultraviolet (0.200-0.400 µm)
      VIS = visible (0.400-0.700 µm)
      NIR = near infrared (0.700-1.400 µm)

**TABLE III:6-2. MAJOR CATEGORIES OF LASER USE**

<table>
<thead>
<tr>
<th>Alignment</th>
<th>Drilling</th>
<th>Plasma diagnostics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annealing</td>
<td>Entertainment</td>
<td>Spectroscopy</td>
</tr>
<tr>
<td>Balancing</td>
<td>Heat treating</td>
<td>Velocimetry</td>
</tr>
<tr>
<td>Biomedical</td>
<td>Holography</td>
<td>Lidar</td>
</tr>
<tr>
<td>Cellular research</td>
<td>Information handling</td>
<td>Special photography</td>
</tr>
<tr>
<td>Dental</td>
<td>Copying</td>
<td>Scanning microscopy</td>
</tr>
<tr>
<td>Diagnostics</td>
<td>Displays</td>
<td>Military</td>
</tr>
<tr>
<td>Dermatology</td>
<td>Plate making</td>
<td>Distance ranging</td>
</tr>
<tr>
<td>Ophthalmology</td>
<td>Printing</td>
<td>Rifle simulation</td>
</tr>
</tbody>
</table>
### II. NONBEAM LASER HAZARDS.

In some laser operations, particularly in the research laboratory, general safety and health guidelines should be considered.

**A. INDUSTRIAL HYGIENE.** Potential hazards associated with compressed gases, cryogenic materials, toxic and carcinogenic materials and noise should be considered. Adequate ventilation shall be installed to reduce noxious or potentially hazardous fumes and vapors, produced by laser welding, cutting and other target interactions, to levels below the appropriate threshold limit values, e.g., American Conference of Governmental Industrial Hygienists (ACGIH) threshold limit values (TLV's) or Occupational Safety and Health Administration's (OSHA) permissible exposure limits (PEL's).

**B. EXPLOSION HAZARDS.** High-pressure arc lamps and filament lamps or laser welding equipment shall be enclosed in housings which can withstand the maximum pressures resulting from lamp explosion or disintegration. The laser target and elements of the optical train which may shatter during laser operation shall also be enclosed.

**C. NONBEAM OPTICAL RADIATION HAZARDS.** This relates to optical beam hazards other than laser beam hazards. Ultraviolet radiation emitted from laser discharge tubes, pumping lamps and laser welding plasmas shall be suitably shielded to reduce exposure to levels below the ANSI Z 136.1 (extended source), OSHA PEL's, and/or ACGIH TLV's.

**D. COLLATERAL RADIATION.** Radiation, other than laser radiation, associated with the operation of a laser or laser system, e.g., radio frequency (RF) energy associated with some plasma tubes, x-ray emission associated with the high voltage power supplies used with excimer lasers, shall be maintained below the applicable protection guides. The appropriate protection guide for RF and microwave energy is that given in the American National Standard "Safety levels with respect to human exposure to radio frequency electromagnetic fields, 300 kHz to 100 GHz," ANSI C95.1; the appropriate protection guides for exposure to
X-ray emission is found in the Department of Labor Occupational Safety and Health Standards, 29 CFR Part 1910.1096 and the applicable State Codes. Lasers and laser systems which, by design, would be expected to generate appreciable levels of collateral radiation, should be monitored.

E. ELECTRICAL HAZARDS. The intended application of the laser equipment determines the method of electrical installation and connection to the power supply circuit (for example, conduit versus flexible cord). All equipment shall be installed in accordance with the National Electrical Code and the Occupational Safety and Health Act. [Additional specific recommendations can be found in Section 7.4 of ANSI Z 136.1 (1993)].

F. FLAMMABILITY OF LASER BEAM ENCLOSURES. Enclosure of Class IV laser beams and terminations of some focused Class IIIB lasers, can result in potential fire hazards if the enclosure materials are exposed to irradiances exceeding 10 W/cm². Plastic materials are not precluded as an enclosure material, but their use and potential for flammability and toxic fume release following direct exposure should be considered. Flame-resistant materials and commercially available products specifically designed for laser enclosures should also be considered.

III. BIOLOGICAL EFFECTS OF THE LASER BEAM.

A. EYE INJURY. Because of the high degree of beam collimation, a laser serves as an almost ideal point source of intense light. A laser beam of sufficient power can theoretically produce retinal intensities at magnitudes that are greater than conventional light sources, and even larger than those produced when directly viewing the sun. Permanent blindness can be the result.

B. THERMAL INJURY. The most common cause of laser-induced tissue damage is thermal in nature, where the tissue proteins are denatured due to the temperature rise following absorption of laser energy.

1. The thermal damage process (burns) is generally associated with lasers operating at exposure times greater than 10 microseconds and in the wavelength region from the near ultraviolet to the far infrared (0.315 µm-103 µm). Tissue damage may also be caused by thermally induced acoustic waves following exposures to sub-microsecond laser exposures.

2. With regard to repetitively pulsed or scanning lasers, the major mechanism involved in laser-induced biological damage is a thermal process wherein the effects of the pulses are additive. The principal thermal effects of laser exposure depend upon the following factors:
• The absorption and scattering coefficients of the tissues at the laser wavelength. See Table III:6-1 for a summary of more common laser types and wavelengths.

• Irradiance or radiant exposure of the laser beam.

• Duration of the exposure and pulse repetition characteristics, where applicable.

• Extent of the local vascular flow.

• Size of the area irradiated.

C. OTHER.

1. Other damage mechanisms have also been demonstrated for other specific wavelength ranges and/or exposure times. For example, photochemical reactions are the principal cause of threshold level tissue damage following exposures to either actinic ultraviolet radiation (0.200 µm-0.315 µm) for any exposure time or "blue light" visible radiation (0.400 µm-0.550 µm) when exposures are greater than 10 seconds.

2. To the skin, UV-A (0.315 µm-0.400 µm) can cause hyperpigmentation and erythema.

3. Exposure in the UV-B range is most injurious to skin. In addition to thermal injury caused by ultraviolet energy, there is the possibility of radiation carcinogenesis from UV-B (0.280 mm - 0.315 mm) either directly on DNA or from effects on potential carcinogenic intracellular viruses.

4. Exposure in the shorter UV-C (0.200 µm-0.280 µm) and the longer UV-A ranges seems less harmful to human skin. The shorter wavelengths are absorbed in the outer dead layers of the epidermis (stratum corneum) and the longer wavelengths have an initial pigment-darkening effect followed by erythema if there is exposure to excessive levels. These biological effects are summarized in Table III:6-3.

5. The hazards associated with skin exposure are of less importance than eye hazards; however, with the expanding use of higher-power laser systems, particularly ultraviolet lasers, the unprotected skin of personnel may be exposed to extremely hazardous levels of the beam power if used in an unenclosed system design.

NOTE: The primary purpose of an exiting laser beam, e.g. cutting or welding of hard materials, must not be forgotten! Some laser beams designed for material alteration may be effective some distance from their intended impact point.
TABLE III:6-3. SUMMARY OF BASIC BIOLOGICAL EFFECTS OF LIGHT

<table>
<thead>
<tr>
<th>Photobiological spectral domain</th>
<th>Eye effects</th>
<th>Skin effects</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ultraviolet C (0.200-0.280 µm)</td>
<td>Photokeratitis</td>
<td>Erythema (sunburn)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Skin cancer</td>
</tr>
<tr>
<td>Ultraviolet B (0.280-315 µm)</td>
<td>Photokeratitis</td>
<td>Accelerated skin aging</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Increased pigmentation</td>
</tr>
<tr>
<td>Ultraviolet A (0.315-0.400 µm)</td>
<td>Photochemical UV cataract</td>
<td>Pigment darkening</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Skin burn</td>
</tr>
<tr>
<td>Visible (0.400-0.780 µm)</td>
<td>Photochemical and thermal retinal injury</td>
<td>Photosensitive reactions</td>
</tr>
<tr>
<td>Infrared A (0.780-1.400 µm)</td>
<td>Cataract, retinal burns</td>
<td>Skin burn</td>
</tr>
<tr>
<td>Infrared B (1.400-3.00 µm)</td>
<td>Corneal burn</td>
<td>Skin burn</td>
</tr>
<tr>
<td></td>
<td>Aqueous flare</td>
<td></td>
</tr>
<tr>
<td></td>
<td>IR cataract</td>
<td></td>
</tr>
<tr>
<td>Infrared C (3.00-1000 µm)</td>
<td>Corneal burn only</td>
<td>Skin burn</td>
</tr>
</tbody>
</table>

IV. LASER HAZARD CLASSIFICATIONS.

A. INTRODUCTION.

1. The intent of laser hazard classification is to provide warning to users by identifying the hazards associated with the corresponding levels of accessible laser radiation through the use of labels and instruction. It also serves as a basis for defining control measures and medical surveillance.

2. Lasers and laser systems received from manufacturers are required by federal law, 21 CFR Part 1000, to be classified and appropriately labeled by the manufacturer. It should be stressed, however, that the classification may change whenever the laser or laser system is modified to accomplish a given task.

3. It should also be stressed that an agency such as the Food and Drug Administration's Center for Devices and Radiological Health (FDA/CDRH) does not "approve" laser systems for medical use. The manufacturer of the laser system first classifies the laser and then certifies
that it meets all performance requirements of the Federal Laser Product Performance Standard (FLPPS). The forms submitted by the manufacturer to FDA/CDRH are reviewed for technical accuracy, omissions, and errors. If none are found, the manufacturer is notified only that the submission appears to be complete. Therefore, all lasers and laser systems that are manufactured by a company, or purchased by a company and relabeled and placed into commerce, or incorporated into a system and placed into commerce, shall be classified.

B. LASER HAZARD CLASSES.

1. Virtually all of the U.S. domestic as well as all international standards divide lasers into four major hazard categories called the laser hazard classifications. The classes are based upon a scheme of graded risk. They are based upon the ability of a beam to cause biological damage to the eye or skin. In the FLPPS, the classes are established relative to the Accessible Emission Limits (AEL) provided in tables in the standard. In the ANSI Z 136.1 standard, the AEL is defined as the product of the Maximum Permissible Exposure (MPE) level and the area of the limiting aperture. For visible and near infrared lasers, the limiting aperture is based upon the "worst-case" pupil opening and is a 7 mm circular opening.

2. Lasers and laser systems are assigned one of four broad Classes (I to IV) depending on the potential for causing biological damage. The biological basis of the hazard classes are summarized in Table III:6-4.

   a. Class I: cannot emit laser radiation at known hazard levels (typically continuous wave: cw 0.4 µW at visible wavelengths). Users of Class I laser products are generally exempt from radiation hazard controls during operation and maintenance (but not necessarily during service).

      Since lasers are not classified on beam access during service, most Class I industrial lasers will consist of a higher class (high power) laser enclosed in a properly interlocked and labeled protective enclosure. In some cases, the enclosure may be a room (walk-in protective housing) which requires a means to prevent operation when operators are inside the room.

   b. Class I.A.: a special designation that is based upon a 1000-second exposure and applies only to lasers that are "not intended for viewing" such as a supermarket laser scanner. The upper power limit of Class I.A. is 4.0 mW. The emission from a Class I.A. laser is defined such that the emission does not exceed the Class I limit for an emission duration of 1000 seconds.
c. Class II: low-power visible lasers that emit above Class I levels but at a radiant power not above 1 mW. The concept is that the human aversion reaction to bright light will protect a person. Only limited controls are specified.

d. Class IIIA: intermediate power lasers (cw: 1-5 mW). Only hazardous for intrabeam viewing. Some limited controls are usually recommended.

NOTE: There are different logotype labeling requirements for Class IIIA lasers with a beam irradiance that does not exceed 2.5 mW/cm² (Caution logotype) and those where the beam irradiance does exceed 2.5 mW/cm² (Danger logotype).

e. Class IIIB: moderate power lasers (cw: 5-500 mW, pulsed: 10 J/cm² or the diffuse reflection limit, whichever is lower). In general Class IIIB lasers will not be a fire hazard, nor are they generally capable of producing a hazardous diffuse reflection. Specific controls are recommended.

f. Class IV: High power lasers (cw: 500 mW, pulsed: 10 J/cm² or the diffuse reflection limit) are hazardous to view under any condition (directly or diffusely scattered) and are a potential fire hazard and a skin hazard. Significant controls are required of Class IV laser facilities.

TABLE III:6-4. LASER CLASSIFICATIONS--SUMMARY OF HAZARDS

<table>
<thead>
<tr>
<th>Class</th>
<th>UV</th>
<th>VIS</th>
<th>NIR</th>
<th>IR</th>
<th>Direct ocular</th>
<th>Diffuse ocular</th>
<th>Fire</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>IA</td>
<td>--</td>
<td>X*</td>
<td>--</td>
<td>--</td>
<td>Only after 1000 sec</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>II</td>
<td>--</td>
<td>X</td>
<td>--</td>
<td>--</td>
<td>Only after 0.25 sec</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>IIIA</td>
<td>X</td>
<td>X**</td>
<td>X</td>
<td>X</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>IIIB</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>Yes</td>
<td>Only when laser output is near</td>
<td>No</td>
</tr>
</tbody>
</table>
C. HOW TO DETERMINE THE CLASS OF LASERS DURING INSPECTION.

1. The classification of a laser or laser product is, in some instances, a rather detailed process. It can involve determination of the AEL, measurement of the laser emission, measurement/determination of the emission pulse characteristics (if applicable), evaluation of various performance requirements (protective housing, interlocks, etc.) as specified by the FLPPS and/or ANSI standards.

2. It should be stressed that classification is a required specification provided by the laser manufacturer and the label that specifies the class is found in only one location on the laser product. The class of the laser will be specified only on the lower left-hand corner (position three) of the warning logotype label.

The logotype is the rectangular label that has the laser "sunburst" symbol and the warning statement of CAUTION (Class II and some Class IIIA) or DANGER (some Class IIIA, all Class IIIB and Class IV). This label will also have the type of laser designated (HeNe, Argon, CO\textsubscript{2}, etc.) and the power or energy output specified (1 mW CW/Max, 100 mJ pulsed, etc.).

3. Class I lasers have no required labeling indicating the Class I status. Although the FLPPS requires no classification labeling of Class I lasers it does require detailed compliance with numerous other performance requirements (i.e., protective housing, identification and compliance labeling, interlocking, etc.)

D. ANSI Z 136.2 OPTICAL FIBER SERVICE GROUP DESIGNATIONS.

1. Optical Fiber Communication Systems (OFCS) and the associated optical test sets use semiconductor lasers or LED transmitters that emit energy at
wavelengths typically in the range from 0.650 to 1.20 mm into the light-guide fiber-optic cables.

2. All OFCS are designed to operate with the beam totally enclosed within the fiber-optic and associated equipment and, therefore, are always considered as Class I in normal operation.

3. The only risk for exposure would occur during installation and service when light-guide cables are disconnected or during an infrequent accidental cable break.

4. Under the requirements of the ANSI Z 136.2 (1988) Standard "For the Safe Use of Optical Fiber Communication Systems Utilizing Laser Diode and LED Sources," Optical Fiber Communication Systems (OFCS) are assigned into one of four service group (SG) designations: SG1, SG2, SG3a, SG3b, depending on the potential for an accessible beam to cause biological damage.

5. The service group designations relate to the potential for ocular hazards to occur only during accessible beam conditions. This would normally occur only during periods of service to a OFCS. Such designations apply only during periods of service in one of the following four service groups:

   a. Service Group 1: An OFCS that is SG1 has a total output power that is less than the Accessible Emission Limit (AEL) for Class I and there is no risk of exceeding the Maximum Permissible Irradiance (MPI) when viewing the end of a fiber with a microscope, an eye-loupe or with the unaided eye.

   b. Service Group 2: An OFCS is SG2 only if wavelengths between 0.400 and 0.700 mm are emitted and is potentially hazardous if viewed for more than 0.25 second. (Note: At present there are virtually no OFCS's that operate in this wavelength range.)

   c. Service Group 3A: A SG 3A OFCS is not hazardous when viewed with the unaided eye and is hazardous only when viewed with a microscope or an eye-loupe.

   d. Service Group 3B: OFCS that meet none of the above criteria are designated as SG 3B.

   NOTE: OFCS's where the total power is at or above 0.5W do not meet the criteria for optical fiber service group designation. In this case, the OFCS's are treated as a standard laser system.
V. INVESTIGATIONAL GUIDELINES.

A. REQUIREMENTS OF LASER STANDARDS. In the United States, several organizations concern themselves with laser safety. These organizations include the American National Standards Institute (ANSI); the Center for Devices and Radiological Health (CDRH) of the Food and Drug Administration (FDA); the Department of Labor's Occupational Safety and Health Administration (OSHA); and the Council of Radiation Control Program Directors (CRCPD). Several state governments and the CRCPD have developed a model state standard for laser safety.

1. OSHA Regulatory Practice. At the present time, OSHA does not have a comprehensive laser standard, though 29 CFR 1926.54 is applicable to the construction industry. A standard for personal protective equipment (Subpart I) may apply in some cases.

The construction standard 29 CFR 1926.102(b)(2), for eye and face protection, states that "employees whose occupation or assignment requires exposure to laser beams shall be furnished suitable laser safety goggles which will protect for the specific wavelength of the laser and be of optical density (O.D.) adequate for the energy involved."

OSHA citations are issued by invoking the general duty clause or, in some cases, Subpart I. In such cases, the employers are required to revise their reportedly unsafe work place using the recommendations and requirements of such industry consensus standards as the ANSI Z 136.1 Standard. See also Table III:6-8.

2. Specific and Model State Laser Regulations. A few states currently have laser regulations. Requirements are generally concerned with the registration of lasers and the licensing of operators and institutions. Physician-used and other medical lasers are generally exempt from state requirements.

The complexity of state laser regulations may change in the future pending adoption of the "Suggested State Regulation for Lasers" promulgated through the Conference of Radiation Control Program Directors. This model state standard has been adopted in part, for example, by Arizona and Florida. Several other states have enacted some form of regulation. Table III:6-5 summarizes state regulations.

TABLE III:6-5. SUMMARY OF CURRENT STATE LASER REGULATIONS

<table>
<thead>
<tr>
<th>State</th>
<th>Department</th>
<th>Regulation</th>
</tr>
</thead>
</table>
3. FDA Center for Devices and Radiological Health Performance Requirements.

a. The CDRH of the Department of Health and Human Services was chartered by Congress to standardize the manufacture of lasers in interstate commerce after August 2, 1976. CDRH also has the responsibility for enforcing compliance with the medical devices legislation. All manufacturers of surgical lasers must obtain premarket approval of their devices through the CDRH.

b. FDA sanctions the exploratory use of lasers for specific procedures through a process known as an Investigational Device Exemption (IDE). Approval of an IDE permits the limited use of a laser expressly for the purpose of conducting an investigation of the laser's safety and effectiveness. Once an IDE has been prepared and approved by the CDRH, the manufacturer may then actively market the laser for that specific medical or surgical procedure.

c. The FDA/CDRH Federal Laser Product Performance Standard (FLPPS) regulates the manufacturer of commercial laser products, not the user. The standard does not contain specific design specifications, but is a conceptual, performance standard which the
designer of laser products must consider. The intent is to insure laser product safety.

d. FLPSS is applicable to lasers or laser systems sold by a company within or imported into the U.S. In some cases it can also apply when a laser or laser system is transferred within a company for internal use within the U.S. The compliance procedure requires implementation of the procedures and requirements as set forth in the U.S. Federal Laser Product Performance Standard: 21 CFR Part 1000 [parts 1040.10 and 1040.11].

e. Under the requirements of the FLPSS, the manufacturer is first required to classify the laser as either a Class-I, Class-II, Class-I.A., Class-III A, Class-III B, or Class-IV laser product and then to certify (by means of a label on the product) as well as submit a report demonstrating that all requirements (performance features) of the compliance standard are met. Specific performance features include:

- protective housing;
- protective housing warning labels and logotype labels;
- product identification label and certification statement;
- safety interlocks;
- emission indicator;
- remote interlock connector;
- key control;
- beam attenuator;
- specification of control locations;
- viewing optic limitations;
- scanning beam safeguards; and
- manual reset of beam cutoff.

f. FDA/CDRH performance requirements are tabulated in Appendix III:6-1. An outline to assist in evaluating FLPSS laser system performance requirements is included in Appendix III:6-2.

4. The American National Standard Institute (ANSI). An American National Standard implies a consensus of those substantially concerned with its scope and provisions. These standards are intended as a guide for manufacturers, consumers, and the general public. However, there is no inherent requirement for any person or company to adhere to an ANSI standard. Compliance is voluntary unless specifically required by an organization. For example, the U.S. Department of Energy requires adherence to the ANSI Z 136.1 by their staff as well as by all contractor organizations. Appendix III:6-3 summarizes ANSI Standards applicable to laser safety.
B. LASER EXPOSURE LIMITS. At present either the FDA criteria for medical lasers or the following ANSI standards can be useful in evaluating laser safety.

1. FDA Long-Term Exposure Limits. The FDA/CDRH Federal Laser Product Performance Standard (FLPPS) assumes a linearly additive biological effect for exposures to visible light between 10 and $10^4$ seconds (2.8 hours). The standard accepts that a cumulative radiant energy exposure of 3.85 millijoules (mJ) will not cause a biological effect. Hence a 10-second total accumulated exposure corresponds to an average power entering a 7-mm aperture of 385 microwatts ($\mu$W). For an exposure of $10^4$ seconds, the average power would be 0.385 $\mu$W. In the FLPPS, the power level of 0.385 $\mu$W is referred to as the Class I Accessible Emission Limit (AEL) for a visible CW laser.

2. ANSI Z 136.1, Long-Term Exposure Limits.

   a. The ANSI Z 136.1 (1993) standard is a "user" standard and therefore provides maximum permissible exposure (MPE) limits. These were derived by normalizing the power (or pulse energy) data derived from biological research studies relative to a defined limiting aperture. For example, in the visible and near-infrared spectra, the limiting aperture is based upon the diameter of a fully dilated pupil of the human eye, 7 mm. The area of a 7-mm pupil is 0.385 cm$^2$. Hence, the irradiance limit for long-term ocular exposure is computed by dividing the AEL value of 0.385 $\mu$W by the area of the limiting aperture of 0.385 cm$^2$. This yields the worst-case MPE value of 1.0 $\mu$W/cm$^2$ for long-term exposure in the wavelength range of 0.400 to 0.550 mm.

   b. The ANSI Z 136 and FDA/CDRH allowable-exposure limits for CW lasers (Class I limits) are essentially identical for wavelengths between 0.400 and 0.550 $\mu$m. The ANSI limits are, however, more relaxed for wavelengths between 0.550 and 1.40 $\mu$m. ANSI recognizes a decreased biological hazard in the red and infrared regions that is not recognized by the CDRH.

   c. The ANSI Z 136 MPE level for a very long term exposure by a helium-neon laser is, in fact, seventeen times greater than the CDRH standard. In the 1976 revision, ANSI Z 136 introduced the correction factor CB which has a value of 17.5 at the 0.633-$\mu$m HeNe laser wavelength, and, thus, permitted a radiant exposure of 185 mJ/cm$^2$ accumulated exposure for times from $T_1 = 453$ seconds to 104 seconds, and about 18 w/cm$^2$ (7 w in a 7-mm limiting aperture) for continuous operation of exposure durations exceeding 104 seconds.

3. ANSI Z 136.1, Repetitively Pulsed Exposures.
The ANSI Z 136 standard requires a decrease in the maximum permissible exposure (MPE) for scanned or repetitive-pulse radiation as compared to continuous-wave radiation for pulse repetition frequencies (PRF) in the general range of 1000-15000 Hz. Because of pulse additivity, scanned or repetitively pulsed radiation with repetition rates less than 15 KHz have lower retinal damage threshold levels than CW radiation of comparable power.

a. The ANSI Z 136 Standard includes a reduction factor of the threshold for each of the single pulses based on biological data that are not yet well explained by any theory. The FDA/CDRH standard does not recognize this repetitive-pulse correction factor. However, some experts envision the possibility of a repetitively pulsed laser which is Class I by the FDA/CDRH standard could be rated Class II or even Class IIIB by the ANSI Z 136 standard.

b. The ANSI standard requires that multiple-pulse (scanning) lasers operating from 1 to 15,000 Hz have a correction to the single pulse MPE. The correction factor is determined by taking the fourth root of the total number of pulses (N) in a pulse train. Then, the correction factor is calculated such that the MPE radiant exposure or integrated radiance of an individual pulse within the train is reduced by a factor \(N^{-\frac{1}{4}}\).

4. ANSI Z 136.1, Maximum Permissible Exposure Limits.

a. A summary of Maximum Permissible Exposure (MPE) limits for direct ocular exposures for some of the more common lasers is presented in Table III:6-6. For further information on MPE values, refer to the ANSI Z 136.1 "Safe Use of Lasers" Standard.

a. The information in Table III:6-6 provides the MPE value for different lasers operating for different overall exposure times. The times chosen were:

- 0.25 second: The human aversion time for bright-light stimuli (the blink reflex). Thus, this becomes the "first line of defense" for unexpected exposure to some lasers and is the basis of the Class II concept.
- 10 seconds: The time period chosen by the ANSI Z 136.1 committees represents the optimum "worst-case" time period for ocular exposures to infrared (principally near-infrared) laser sources. It was argued that natural eye motions dominate for periods longer than 10 seconds.
- 600 seconds: The time period chosen by the ANSI Z 136.1 committees represents a typical worst-case period for viewing visible diffuse reflections during tasks such as alignment.
- 30,000 seconds: The time period that represents a full 1-day (8-hour) occupational exposure. This results from computing the number of seconds in 8 hours; e.g.: 8 hours × 60 minutes/hour × 60 seconds/minute = 28,800 seconds. Rounded off, it becomes 30,000 seconds.

b. The "safety" exposure limits (MPE's) in Table III:6-6 are expressed in irradiance terms (W/cm²) that would be measured at the cornea. Note that they vary by wavelength and exposure time.

### TABLE III:6-6. SUMMARY: MAXIMUM PERMISSIBLE EXPOSURE LIMITS*

<table>
<thead>
<tr>
<th>Laser type</th>
<th>Wavelength (µm)</th>
<th>0.25 sec</th>
<th>10 sec</th>
<th>600 sec</th>
<th>30,000 sec</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO2 (CW)</td>
<td>10.6</td>
<td>---</td>
<td>100.0 × 10⁻³</td>
<td>---</td>
<td>100.0 × 10⁻³</td>
</tr>
<tr>
<td>Nd: YAG (CW)</td>
<td>1.33</td>
<td>---</td>
<td>5.1 × 10⁻³</td>
<td>---</td>
<td>1.6 × 10⁻³</td>
</tr>
<tr>
<td>Nd: YAG (CW)</td>
<td>1.064</td>
<td>---</td>
<td>5.1 × 10⁻⁴</td>
<td>---</td>
<td>1.6 × 10⁻⁴</td>
</tr>
<tr>
<td>Nd: YAG (Q-switched)</td>
<td>1.064</td>
<td>---</td>
<td>17.0 × 10⁻⁶</td>
<td>---</td>
<td>2.3 × 10⁻⁶</td>
</tr>
<tr>
<td>GaAs (Diode/CW)</td>
<td>0.840</td>
<td>---</td>
<td>1.9 × 10⁻³</td>
<td>---</td>
<td>610.0 × 10⁻⁶</td>
</tr>
<tr>
<td>HeNe (CW)</td>
<td>0.633</td>
<td>2.5 × 10⁻³</td>
<td>---</td>
<td>293.0 × 10⁻⁶</td>
<td>17.6 × 10⁻⁶</td>
</tr>
<tr>
<td>Krypton (CW)</td>
<td>0.647</td>
<td>2.5 × 10⁻³</td>
<td>---</td>
<td>364.0 × 10⁻⁶</td>
<td>28.5 × 10⁻⁶</td>
</tr>
<tr>
<td></td>
<td>0.568</td>
<td>31.0 × 10⁻⁶</td>
<td>---</td>
<td>6.5 × 10⁻⁶</td>
<td>18.6 × 10⁻⁶</td>
</tr>
<tr>
<td></td>
<td>0.530</td>
<td>16.7 × 10⁻⁶</td>
<td>---</td>
<td>2.5 × 10⁻³</td>
<td>1.0 × 10⁻³</td>
</tr>
<tr>
<td>Argon (CW)</td>
<td>0.514</td>
<td>2.5 × 10⁻³</td>
<td>---</td>
<td>16.7 × 10⁻⁶</td>
<td>1.0 × 10⁻⁶</td>
</tr>
<tr>
<td>XeFl (Excimer/CW)</td>
<td>0.351</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>33.3 × 10⁻⁶</td>
</tr>
<tr>
<td>XeCl (Excimer/CW)</td>
<td>0.308</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>1.3 × 10⁻⁶</td>
</tr>
</tbody>
</table>

C. LASER HAZARD COMPUTATIONS.

1. NHZ Definition, Use, and Values.

a. The Nominal Hazard Zone (NHZ) describes the space within which the level of direct, reflected, or scattered radiation during normal operation exceeds the MPE. The NHZ associated with open-beam Class IIB and Class IV laser installations can be useful in assessing area hazards and implementing controls.

b. It is often necessary in some applications where open beams are required (e.g., industrial processing, laser robotics, surgical uses) to define the area where the possibility exists for potentially hazardous exposure. This is done by determining the NHZ. Consequently, persons outside the NHZ boundary would be exposed below the MPE level and are considered to be in a non-hazardous location.

c. The NHZ boundary may be defined, for example, by direct beams (intrabeam) and diffusely scattered laser beams, as well as beams transmitted from fiber optics and/or through lens arrays. The NHZ perimeter is the envelope of MPE exposure levels from any specific laser installation geometry.

d. The purpose of an NHZ evaluation is to define that space where control measures are required. This is an important factor since, as the scope of laser uses has expanded, controlling lasers by total enclosure in a protective housing or interlocked room is limiting and, in many instances, an expensive overreaction to the real hazards. The following factors are required in NHZ computations:

- laser power or energy output;
- beam diameter;
- beam divergence;
- pulse repetition frequency (prf) (if applicable);
- wavelength;
- beam optics and beam path; and
- maximum anticipated exposure duration.

e. Note that the ANSI Z 136 MPE value is required in all NHZ calculations. Examples of NHZ calculations can be found in the appendix of ANSI Z 136.1 (1993). In addition, computer software is also available to assist in the computations for NHZ, optical densities of protective eye wear, and other aspects of laser hazard analysis.
2. NHZ Example Summary. The intrabeam (direct) hazard for a Nd:YAG laser extends from 792 meters to 1410 meters, depending upon whether a 10-second or 8-hour criterion is used, as summarized in Table III:6-7. Similarly, with a lens on the laser, the hazard for a Nd:YAG laser exists over a range from 6.3 meters to 11.3 meters. The diffuse reflection zone for this laser type is, however, markedly smaller, 0.8 meter to 1.4 meters. Nonetheless, the analysis suggests that operating personnel and support staff close to the laser still need eye protection even for diffuse reflections.

Other calculations are also presented in Table III:6-7 for a 500-Watt CO\(_2\) and a 5-Watt argon laser. Note that the NHZ's do not vary for the CO\(_2\) laser (because the MPE values are nearly identical for 10-second and 8-hour criteria). Also note that the diffuse reflection NHZ's are very small except for the 8-hour criterion for the argon laser. In most cases, 0.25 second can be used with visible lasers unless intentional staring is required or intended.

### TABLE III:6-7. NHZ DISTANCE VALUES FOR VARIOUS LASERS

<table>
<thead>
<tr>
<th>Laser type</th>
<th>Exposure criteria</th>
<th>---</th>
<th>Hazard range (meters) ---</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Diffuse</td>
<td>Lens-on-laser</td>
</tr>
<tr>
<td>Nd:YAG</td>
<td>100 Watt 8 hours</td>
<td>1.4</td>
<td>11.3</td>
</tr>
<tr>
<td></td>
<td>1.064 µm 10 seconds</td>
<td>0.8</td>
<td>6.3</td>
</tr>
<tr>
<td>CO(_2)</td>
<td>500 Watt 8 hours</td>
<td>0.4</td>
<td>5.3</td>
</tr>
<tr>
<td></td>
<td>10.6 µm 10 seconds</td>
<td>0.4</td>
<td>5.3</td>
</tr>
<tr>
<td>Argon</td>
<td>5.0 Watt 8 hours</td>
<td>12.6</td>
<td>1.7 × 10(^3)</td>
</tr>
<tr>
<td></td>
<td>0.488 µm 0.25 seconds</td>
<td>0.25</td>
<td>33.3</td>
</tr>
</tbody>
</table>

Laser criteria used for NHZ distance calculations:

<table>
<thead>
<tr>
<th>Laser parameter</th>
<th>Nd-YAG</th>
<th>CO(_2)</th>
<th>Argon</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wavelength (µm)</td>
<td>1.064</td>
<td>10.6</td>
<td>0.488</td>
</tr>
<tr>
<td>Beam power (Watts)</td>
<td>100.0</td>
<td>500.0</td>
<td>5.0</td>
</tr>
<tr>
<td>Beam divergence (mrad)</td>
<td>2.0</td>
<td>2.0</td>
<td>1.0</td>
</tr>
<tr>
<td>Beam size at aperture (mm)</td>
<td>2.0</td>
<td>20.0</td>
<td>2.0</td>
</tr>
<tr>
<td>Beam size at lens (mm)</td>
<td>6.3</td>
<td>30.0</td>
<td>3.0</td>
</tr>
</tbody>
</table>
1. INTRABEAM OPTICAL DENSITY DETERMINATION.

1. Based upon these typical exposure conditions, the optical density required for suitable filtration can be determined. Optical density (OD) is a logarithmic function defined by:

**EQUATION III: 6-1. OPTICAL DENSITY**

\[
OD = \log_{10} \left( \frac{H_0}{MPE} \right)
\]

where:

- \( H_0 \) = Anticipated worst-case exposure (J/cm\(^2\) or W/cm\(^2\))
- \( MPE \) = Maximum permissible exposure level expressed in the same units as \( H_0 \)

2. Based upon the worst case exposure conditions outlined above, one can determine the optical density recommended to provide adequate eye protection for this laser. For example, the minimum optical density at the 0.514 µm argon laser wavelength for a 600-second direct intrabeam exposure to the 5-watt maximum laser output can be determined as follows:

Where:

- \( f \) = 5 Watts
- \( \text{MPE} \) = 16.7 W/cm\(^2\) (using 600-second criterion)
- \( d \) = 7 mm (worst-case pupil size)

Computing the worst-case exposure \( H_0 \):

\[
H_0 = \left[ \frac{\text{Power}}{\text{Area}} \right] = \frac{f}{A} = \frac{4f}{pd^2}
\]
\[ H_0 = \frac{(4)(5.0)}{p(0.7)^2} \]
\[ H_0 = 12.99 \text{ W/cm}^2 \]

Substitution gives:
\[ \text{OD} = \log_{10} \left[ \frac{(12.99)}{(16.7 \times 10^6)} \right] \]
\[ \text{OD} = 5.9 \]

3.

4. The most conservative approach would be to choose an 8-hour (occupational) exposure. In this case, the optical density at 0.514 \( \mu \text{m} \) is increased to \( \text{OD} = 7.1 \) for a 5.0-watt intrabeam exposure because the 8-hour (30,000 §) MPE is reduced to \( 1.0 \times 10^6 \text{ W/cm}^2 \). The OD values for various lasers, computed for various appropriate exposure times, are presented in Table III:6-8. It should be stressed these values are for intrabeam viewing (worst case) only. Viewing Class IV diffuse reflections (such as during alignment tasks) require, in general, less OD. These should be determined for each situation and would be dependent upon the laser parameters and viewing distance.

**TABLE III:6-8. OPTICAL DENSITIES FOR PROTECTIVE EYEWEAR FOR VARIOUS LASER TYPES**

<table>
<thead>
<tr>
<th>Laser type and power</th>
<th>Wavelength (mm)</th>
<th>--- Optical density for exposure durations ---</th>
<th>0.25 §</th>
<th>10 §</th>
<th>600 §</th>
<th>30,000 §</th>
</tr>
</thead>
<tbody>
<tr>
<td>XeCl 50 Watts</td>
<td>0.308(^a)</td>
<td>--</td>
<td>6.2</td>
<td>8.0</td>
<td>9.7</td>
<td></td>
</tr>
<tr>
<td>XeFl 50 Watts</td>
<td>0.351(^a)</td>
<td>--</td>
<td>4.8</td>
<td>6.6</td>
<td>8.3</td>
<td></td>
</tr>
<tr>
<td>Argon 1.0 Watts</td>
<td>0.514</td>
<td>3.0</td>
<td>3.4</td>
<td>5.2</td>
<td>6.4</td>
<td></td>
</tr>
<tr>
<td>Krypton 1.0 Watt</td>
<td>0.530</td>
<td>3.0</td>
<td>3.4</td>
<td>5.2</td>
<td>6.4</td>
<td></td>
</tr>
<tr>
<td>Krypton 1.0 Watt</td>
<td>0.568</td>
<td>3.0</td>
<td>3.4</td>
<td>4.9</td>
<td>6.1</td>
<td></td>
</tr>
<tr>
<td>HeNe 0.005 Watt</td>
<td>0.633</td>
<td>0.7</td>
<td>1.1</td>
<td>1.7</td>
<td>2.9</td>
<td></td>
</tr>
<tr>
<td>Krypton 1 Watt</td>
<td>0.647</td>
<td>3.0</td>
<td>3.4</td>
<td>3.9</td>
<td>5.0</td>
<td></td>
</tr>
<tr>
<td>GaAs 50 mW</td>
<td>0.840(^c)</td>
<td>--</td>
<td>1.8</td>
<td>2.3</td>
<td>3.7</td>
<td></td>
</tr>
<tr>
<td>Nd: YAG 100 Watt</td>
<td>1.064(^a)</td>
<td>--</td>
<td>4.7</td>
<td>5.2</td>
<td>5.2</td>
<td></td>
</tr>
</tbody>
</table>
Nd: YAG (Q-switch)\textsuperscript{b} 1.064\textsuperscript{a} -- 4.5 5.0 5.4
Nd: YAG\textsuperscript{c} 1.33\textsuperscript{a} -- 4.4 4.9 4.9
Nd: YAG operating at a less-common 1.33 µm wavelength.

Note: All OD values determined using MPE criteria of ANSI Z 136.1 (1993).

VI. CONTROL MEASURES AND SAFETY PROGRAMS.

The specific control measures specified in the ANSI Z 136.1 standard are summarized in Table III:6-9. The details of these controls are outlined the following sections.

<table>
<thead>
<tr>
<th>Control measures</th>
<th>I</th>
<th>IA</th>
<th>II</th>
<th>IIIA</th>
<th>IIIB</th>
<th>IV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Protective housing</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Without protective housing</td>
<td>--</td>
<td>LSO shall establish alternate controls --</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Interlocks on protective housing</td>
<td>a</td>
<td>a</td>
<td>a</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Service access panel</td>
<td>b</td>
<td>b</td>
<td>b</td>
<td>b</td>
<td>b</td>
<td>X</td>
</tr>
<tr>
<td>Key switch master</td>
<td>_</td>
<td>_</td>
<td>_</td>
<td>_</td>
<td>_</td>
<td>X</td>
</tr>
<tr>
<td>Viewing portals</td>
<td>_</td>
<td>_</td>
<td>_</td>
<td>_</td>
<td>_</td>
<td>_</td>
</tr>
<tr>
<td>Collecting optics</td>
<td>_</td>
<td>_</td>
<td>_</td>
<td>_</td>
<td>_</td>
<td>_</td>
</tr>
<tr>
<td>Totally open beam path</td>
<td>_</td>
<td>_</td>
<td>_</td>
<td>_</td>
<td>_</td>
<td>X</td>
</tr>
<tr>
<td>Limited open beam path</td>
<td>_</td>
<td>_</td>
<td>_</td>
<td>_</td>
<td>_</td>
<td>X</td>
</tr>
<tr>
<td>Remote interlock connector</td>
<td>_</td>
<td>_</td>
<td>_</td>
<td>_</td>
<td>_</td>
<td>X</td>
</tr>
<tr>
<td>Beam stop or attenuator</td>
<td>_</td>
<td>_</td>
<td>_</td>
<td>_</td>
<td>_</td>
<td>X</td>
</tr>
<tr>
<td>Activation warning system</td>
<td>_</td>
<td>_</td>
<td>_</td>
<td>_</td>
<td>_</td>
<td>X</td>
</tr>
</tbody>
</table>

VII.

A. CONTROL MEASURES: OVERVIEW.

1. There are four basic categories of controls useful in laser environments. These are engineering controls, personal protective equipment, administrative and procedural controls, and special controls. The controls to be reviewed here are based upon the recommendations of the ANSI Z 136.1 standard.

2. Important in all controls is the distinction between the functions of operation, maintenance, and service. First, laser systems are classified on the basis of level of the laser radiation accessible during operation.
Maintenance is defined as those tasks specified in the user instructions for assuring the performance of the product and may include items such as routine cleaning or replenishment of expendables. Service functions are usually performed with far less frequency than maintenance functions (e.g., replacing the laser resonator mirrors or repair of faulty components) and often require access to the laser beam by those performing the service functions. The safety procedures required for such beam access during service functions should be clearly delineated in the laser product’s service manual.

B. LASER SAFETY OFFICER (LSO).

1. The LSO has the authority to monitor and enforce the control of laser hazards and effect the knowledgeable evaluation and control of laser hazards. The LSO administers the overall laser safety program where the duties include, but are not limited to, items such as confirming the classification of lasers, doing the NHZ evaluation, assuring that the proper control measures are in place and approving substitute controls, approving standard operating procedures (SOP's), recommending and/or approving eye wear and other protective equipment, specifying appropriate signs and labels, approving overall facility controls, providing the proper laser safety training as needed, conducting medical surveillance, and designating the laser and incidental personnel categories.

2. The LSO should receive detailed training including laser fundamentals, laser bioeffects, exposure limits, classifications, NHZ computations, control measures (including area controls, eye wear, barriers, etc.), and medical surveillance requirements.

3. In many industrial situations, the LSO functions will be a part-time activity, depending on the number of lasers and general laser activity. The individual is often in the corporate industrial hygiene department or may be a laser engineer with safety responsibility. Some corporations implement an internal laser policy and establish safety practices based upon the ANSI Z 136.1 standard as well as their own corporate safety requirements.

C. CLASS I, CLASS II, CLASS I.A., AND CLASS IIIA LASERS. Accident data on laser usage have shown that Class I, Class II, Class I.A., and Class IIIA lasers are normally not considered hazardous from a radiation standpoint unless illogically used.
Direct exposure on the eye by a beam of laser light should always be avoided with any laser, no matter how low the power.

D.

E. BEAM PATH CONTROLS. There are some uses of Class IIIB and Class IV lasers where the entire beam path may be totally enclosed, other uses where the beam path is confined by design to significantly limit access and yet other uses where the beam path is totally open. In each case, the controls required will vary as follows:

1. Enclosed (Total) Beam Path.
   a. Perhaps the most common form of a Class I laser system is a high-power laser that has been totally enclosed (embedded) inside a protective enclosure equipped with appropriate interlocks and/or labels on all removable panels or access doors. Beam access is prevented, therefore, during operation and maintenance.
   
   b. Such a completely enclosed system, if properly labeled and properly safeguarded with protective housing interlocks (and all other applicable engineering controls), will fulfill all requirements for a Class I laser and may be operated in the enclosed manner with no additional controls for the operator.
   
   c. It should be noted that during periods of service or maintenance, controls appropriate to the class of the embedded laser may be required (perhaps on a temporary basis) when the beam enclosures are removed and beam access is possible. Beam access during maintenance or service procedures will not alter the Class I status of the laser during operation.

2. Limited Open Beam Path.
   a. It is becoming an accepted work practice, particularly with industrial materials-processing lasers, to build an enclosure that completely surrounds the laser-focusing optics and the immediate area of the workstation. Often a computer-controlled positioning table is located within this enclosure. The design often allows a gap of less than one quarter of an inch between the bottom of the enclosure and the top of the material to be laser processed. Such a design enables the part to be laser cut or welded to move while the laser delivery optics remain stationary.
   
   b. Such a system might not meet the stringent "human access" requirements of the FLPPS for a Class I laser, but the real laser hazards are well confined. Such a design provides what can be called a limited open beam path. In this situation, the ANSI Z 136.1 standard recommends...
that the LSO shall conduct a laser hazard analysis and establish the extent of the NHZ.

c. In many system designs, (such as described above), the NHZ will be extremely limited, and procedural controls (rather than elaborate engineering controls) will be sufficient to ensure safe use. In many cases, the laser units may be reclassified by the LSO as Class I under the specifications of the ANSI Z 136 standard.

d. Such an installation will require a detailed standard operating procedure (SOP). Training is also needed for the system operator commensurate with the class of the embedded laser.

e. Protective equipment (eye protection, temporary barriers, clothing and/or gloves, respirators, etc.) would be recommended, for example, only if the hazard analysis indicated a need or if the SOP required periods of beam access such as during setup or infrequent maintenance activities. Temporary protective measures for service can be handled in a manner similar to the service of any embedded Class IV laser.

3. Totally Unenclosed Beam Path. There are several specific application areas where high power (Class IIIB and Class IV) lasers are used in an unenclosed beam condition. This would include, for example, open industrial processing systems (often incorporating robotic delivery), laser research laboratory installations, surgical installations, etc. Such laser uses will require that the LSO conduct a hazard analysis and NHZ assessment. Controls are chosen to reflect the magnitude of hazards associated with the accessible beam.

F. LASER-CONTROLLED AREA. When the entire beam path from a Class IIIB or Class IV laser is not sufficiently enclosed and/or baffled to ensure that radiation exposures will not exceed the MPE, a "laser-controlled area" is required. During periods of service, a controlled area may be established on a temporary basis. The controlled area will encompass the NHZ. Those controls required for both Class IIIB and Class IV installations are as follows:

1. Posting with Appropriate Laser Warning Signs.

a. Class IIIA (beam irradiance 2.5 mW/cm$^2$), Class IIIB and Class IV lasers: Require the ANSI DANGER sign format: white back-ground, red laser symbol with black outline and black lettering (see Appendix III:6–4). Note that under ANSI Z 136.1 criteria, area posting is required only for Class IIIB and Class IV lasers.

b. Class II or Class IIIA areas (if area warning is deemed unnecessary by
the LSO): All signs (and labels) associated with these lasers (when beam irradiance for Class IIIA does not exceed 2.5 mW/cm²) use the ANSI CAUTION format: yellow background, black symbol and letters.

c. During times of service and other times when a temporary laser-controlled area is established, an ANSI NOTICE sign format is required: white background, red laser symbol with blue field and black lettering. This sign is posted only during the time when service is in progress. Examples of area warning signs and logotype designs are given in Appendix III:6-4.

2. Operated by Qualified and Authorized Personnel. Training of the individuals in aspects of laser safety is required for Class IIIB and Class IV laser installations.

3. Transmission from Indoor Controlled Area. The beams shall not, under any circumstances, be transmitted from an indoor laser-controlled area unless for specific purposes (such as testing). In such cases, the operator and the LSO must assure that the beam path is limited to controlled airspace.

G. CLASS IV LASER CONTROLS--GENERAL REQUIREMENTS. Those items recommended for Class IIIB but required for Class IV lasers are as follows:

- Supervision directly by an individual knowledgeable in laser safety.
- Entry of any noninvolved personnel requires approval.
- A beam stop of an appropriate material must be used to terminate all potentially hazardous beams.
- Use diffusely reflecting materials near the beam, where appropriate.
- Appropriate laser protective eye wear must be provided all personnel within the laser controlled area.
- The beam path of the laser must be located and secured above or below eye level for any standing or seated position in the facility.
- All windows, doorways, open portals, etc., of an enclosed facility should be covered or restricted to reduce any escaping laser beams below appropriate ocular MPE level.
- Require storage or disabling of lasers when not in use.

H. ENTRYWAY CONTROL MEASURES (CLASS IV). In addition, there are specific controls required at the entryway to a Class IV laser controlled area. These can be summarized as follows:
• All personnel entering a Class IV area shall be adequately trained and provided proper laser protective eye wear.
• All personnel shall follow all applicable administrative and procedural controls.
• All Class IV area and entryway controls shall allow rapid entrance and exit under all conditions.
• The controlled area shall have a clearly marked "Panic Button" (nonlockable disconnect switch) that allows rapid deactivation of the laser.

Class IV areas also require some form of area and entryway controls. In the past, doorway interlocking was customary for Class IV installations. The ANSI Z 136 Standard now provides four options that allow the LSO to provide an entryway control suited for the installation. The options include:

4. Nondefeatable Entryway Controls. A nondefeatable control, such as a magnetic switch built into the entryway door which cuts the beam off when the door is opened, is one option. In this case, training is required only for those persons who regularly work in the laser area.

5. Defeatable Entryway Controls.

a. Defeatable controls may be used at an entryway, for example, during long-term testing in a laser area. In this case the controls may be temporarily made inactive if it is clearly evident that there is no hazard at the point of entry. Training is required for all personnel who may frequently require entry into the area.

b. Such defeatable controls shall be designed to allow both rapid egress by the laser personnel at all times and admittance to the laser controlled area in an emergency condition. A readily accessible "panic button" or control/disconnect switch shall be available for deactivating the laser under such emergency conditions.

c. Under conditions where the entire beam path is not completely enclosed, access to the laser-controlled area shall be limited only to persons wearing proper laser protective eye wear when the laser is capable of emitting a beam. In this case, all other optical paths (for example, windows) from the facility shall be covered or restricted in such a way as to reduce the transmitted intensity of the laser radiation to levels at or below the MPE for direct irradiation of the eye.

6. Procedural Entryway Controls. A blocking barrier, screen, or curtain that can block or filter the laser beam at the entryway may be used inside the controlled area to prevent the laser light from exiting the area at levels above the applicable MPE level. In this case, a warning light or sound is required outside the entryway that operates when the laser is energized.
and operating. All personnel who work in the facility shall be appropriately trained.

7. Entryway Warning Systems. In order to safely operate a Class IV laser or laser system, a laser warning system shall be installed as described:

- A laser activation warning light assembly shall be installed outside the entrance to each laser room facility containing a Class IV laser or laser system.
- In lieu of a blinking entryway warning, the entryway light assembly may alternatively be interfaced to the laser in such a manner that a light will indicate when the laser is not operational (high voltage off) and by an additional light when the laser is powered up (high voltage applied) but not operating and by an additional (flashing) light when the laser is operating.

A laser warning sign shall be posted both inside and outside the laser-controlled area.

I. TEMPORARY LASER-CONTROLLED AREA. Should overriding interlocks become necessary during periods of special training, service, or maintenance, and access to Class IIIB or Class IV lasers is required, a temporary laser-controlled area shall be devised following specific procedures approved by the LSO. These procedures shall outline all safety requirements necessary during such operation.

Such temporary laser-controlled areas, which by nature will not have the built-in protective features as defined for a laser-controlled area, shall nevertheless provide all of the safety requirements for all personnel, both within and without the temporary laser-controlled area during periods of operation when the interlocks are defeated.

J. ADMINISTRATIVE AND PROCEDURAL CONTROLS.

0. Standard Operating Procedures. One of the more important of the administrative and procedural controls is the written Standard Operating Procedure (SOP). The ANSI Z 136.1 standard requires an SOP for a Class IV laser and recommends SOP's for Class IIIB lasers.

The key to developing an effective SOP is the involvement of those individuals who operate, maintain and service the equipment under guidance of the LSO. Most laser equipment comes with instructions for safe operation by the manufacturers; however, sometimes the instructions are not well suited to a specific application due to special use conditions.
1. Alignment Procedures. Many laser eye accidents occur during alignment. The procedures require extreme caution. A written SOP is recommended for all recurring alignment tasks.

2. Limitations on Spectators. Persons unnecessary to the laser operation should be kept away. For those who do enter a laser area with unenclosed Class IIIB or Class IV beam paths, appropriate eye protection and instruction is required.

3. Protective Equipment. Protective equipment for laser safety generally means eye protection in the form of goggles or spectacles, clothing, and barriers and other devices designed for laser protection.

   a. Laser Protective Eyewear and Clothing.

      ▪ Eye-protection devices designed to protect against radiation from a specific laser system shall be used when engineering controls are inadequate to eliminate the possibility of potentially hazardous eye exposure (i.e., whenever levels of accessible emission exceed the appropriate MPE levels.) This generally applies only to Class IIIB and Class IV lasers. All laser eye wear shall be clearly labeled with OD values and wavelengths for which protection is afforded.

      ▪ Skin protection can best be achieved through engineering controls. If the potential exists for damaging skin exposure, particularly for ultraviolet lasers (0.200-0.400 m), then skin covers and or sun-screen creams are recommended. For the hands, gloves will provide some protection against laser radiation. Tightly woven fabrics and opaque gloves provide the best protection. A laboratory jacket or coat can provide protection for the arms. For Class IV lasers, flame-resistant materials may be best.

      ▪ In general, other controls should serve as primary protection rather than depending on employees to use protective eye wear. Many accidents have occurred when eye wear was available but not worn. This may be because laser protective eye wear is often dark, uncomfortable to wear, and limits vision.

   b. Laser Barriers and Protective Curtains.

      ▪ Area control can be effected in some cases using special barriers specifically designed to withstand either direct or diffusely scattered beams. The barrier will be described with a barrier threshold limit (BTL): the beam will penetrate the barrier only after some specified exposure time, typically 60 seconds. The barrier is located at a distance from the laser source so that the BTL is not exceeded in the worst-case exposure scenario.
Currently available laser barriers exhibit BTL's ranging from 10 to 350 W/cm² for different laser wavelengths and power levels. An analysis conducted in a manner similar to the NHZ evaluations described previously can establish the recommended barrier type and installation distances for a given laser. It is essential that the barrier also not support combustion or be itself consumed by flames during or following a laser exposure.

K. ENGINEERING CONTROLS. Engineering controls are normally designed and built into the laser equipment to provide for safety. In most instances, these will be included on the equipment (provided by the laser manufacturer) as part of the "performance requirements" mandated by the FLPPS. Specifics on some of the more important engineering controls recommended in the ANSI Z 136.1 standard are detailed as follows:

0. Protective Housing. A laser shall have an enclosure around it that limits access to the laser beam or radiation at or below the applicable MPE level. A protective housing is required for all classes of lasers except, of course, at the beam aperture. In some cases, the walls of a properly enclosed room area can be considered as the protective housing for an open beam laser. Such a "walk-in" enclosure can also be a FDA/CDRH Class I provided that controls preclude operation with personnel within the room (viz.: pressure sensitive floor-mat switches, IR sensors, door interlocks, etc.)

1. Master Switch Control. All Class IV lasers and laser systems require a master switch control. The switch can be operated by a key or computer code. When disabled (key or code removed), the laser cannot be operated. Only authorized system operators are to be permitted access to the key or code. Inclusion of the master switch control on Class IIIB lasers and laser systems is also recommended but not required.

2. Optical Viewing System Safety. Interlocks, filters, or attenuators are to be incorporated in conjunction with beam shutters when optical viewing systems such as telescopes, microscopes, viewing ports, or screens are used to view the beam or beam-reflection area. For example, an electrical interlock could prevent laser system operation when a beam shutter is removed from the optical system viewing path. Such optical filter interlocks are required for all except Class I lasers.

3. Beam Stop or Attenuator. Class IV lasers require a permanently attached beam stop or attenuator which can reduce the output emission to a level at or below the appropriate MPE level when the laser system is on "standby." Such a beam stop or attenuator is also recommended for Class IIIA and Class IIIB lasers.
4. Laser Activation Warning System. An audible tone or bell and/or visual warning (such as a flashing light) is recommended as an area control for Class IIIB laser operation. Such a warning system is mandatory for Class IV lasers. Such warning devices are to be activated upon system start-up and are to be uniquely identified with the laser operation. Verbal "countdown" commands are an acceptable audible warning and should be a part of the SOP.

5. Service Access Panels. The ANSI Z 136.1 standard requires that any portion of the protective housing that permits direct access to an embedded Class IIIB or Class IV laser (intended for removal only by service personnel) must have either an interlock or require a tool in the removal process. If an interlock is used and is defeatable, a warning label indicating this fact is required on the housing near the interlock. The design shall not allow replacement of a removed panel with the interlock in the defeated condition.

The FDA/CDRH Federal Laser Product Performance Standard requires warning labels on removable protective housing panels under all conditions.

6. Protective Housing Interlock Requirements.

a. Interlocks, which cause beam termination or reduction of the beam to MPE levels, must be provided on all panels intended to be opened during operation and maintenance of all Class IIIA, Class IIIB, and Class IV lasers. The interlocks are typically electrically connected to a beam shutter. The removal or displacement of the panel closes the shutter and eliminates the possibility of hazardous exposures.

b. Under the requirements of the ANSI Z 136 Standard, for embedded Class IIIB and Class IV lasers only, the interlocks are to be "fail-safe." This usually means that dual, redundant, electrical series-connected interlocks are associated with each removable panel.

c. Adjustments or procedures during service on the laser shall not cause the safety interlocks to become inoperative or the laser radiation outside a Class I laser protective housing to exceed the MPE limits, unless a temporary laser-controlled area is established. The interlocking requirements under the FLPPS are detailed and summarized in Appendix III:6-2.

7. Remote Interlock Connector. All Class IV lasers or laser systems must have a remote interlock connector to allow electrical connections to an emergency master disconnect ("panic button") interlock or to room, door or fixture interlocks. When open circuited, the interlock shall cause the
accessible laser radiation to be maintained below the appropriate MPE level. The remote interlock connector is also recommended for Class IIIB lasers.

L. LASER USE WITHOUT PROTECTIVE HOUSING (ALL CLASSES). In some circumstances, such as during the manufacture of lasers and during research and development, operation of an unenclosed laser or laser system may become necessary. In such cases, the LSO shall determine the hazard and ensure that controls are instituted appropriate to the class of maximum accessible emission to ensure safe operation. Such controls may include but are not limited to:

- access restriction;
- eye protection;
- area controls;
- barriers, shrouds, beam stops, etc.;
- administrative and procedural controls; and
- education and training.

M. OPTICAL FIBER (LIGHT WAVE) COMMUNICATION SYSTEMS (OFCS).

0. Under normal operation such systems are completely enclosed (Class I) with the optical fiber and optical connectors forming the enclosure. During installation or servicing, or when an accidental break in the cable occurs, the system can no longer be considered enclosed. If engineering controls limit the accessible emission to levels below the applicable MPE (irradiance), no controls are necessary. If the accessible emission is above the MPE, the following requirements shall apply:

a. Only authorized trained personnel shall be permitted to perform service on light wave transmission systems if access to laser emission is required.

b. Only authorized trained personnel shall be permitted to use the laser test equipment (Optical Loss Test Set, Optical Time Domain Reflectometer, etc.) during installation and/or service.

c. All unauthorized personnel shall be excluded from the immediate area of access to laser radiation during service and installation when there is a possibility that the system may become energized. The immediate area shall be considered a temporary laser-controlled area.

d. Staring into the end of any broken, severed, or unterminated optical fiber or cable shall be avoided.
e. The end of any broken, severed, or unterminated optical fiber shall not be viewed with unfiltered optical instruments (microscopes, telescopes, etc.) An exception to this is the use of indirect image converters such as an infrared image converter or closed-circuit television system for verification that a fiber is not energized.

f. During a splicing operation (either installation or service), if it is required that the ends of the fiber be examined with an eye-loupe for a satisfactory cut, only an eye-loupe containing an appropriate filter shall be used. If a fusion splicer is used, the appropriate operating safety procedures shall be rigidly adhered to.

VIII. BIBLIOGRAPHY.


Sliney, David H. and Wolbarsh, Myron L., Safety With Lasers and Other Optical


Rockwell, R. James, Jr., "Laser accidents: are they all reported and what can be learned from them?" Journal of Laser Applications, Laser Institute of America, Toledo, Ohio, pp. 53-57, October 1989.


APPENDIX III:6-1. FDA/CDRH REQUIREMENTS FOR LASER PRODUCTS

<table>
<thead>
<tr>
<th>Requirements</th>
<th>I</th>
<th>IA</th>
<th>II</th>
<th>IIIA</th>
<th>IIIB</th>
<th>IV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Performance (all laser products)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Protective housing</td>
<td>R2</td>
<td>R2</td>
<td>R2</td>
<td>R2</td>
<td>R2</td>
<td>R2</td>
</tr>
<tr>
<td>Safety interlock</td>
<td>R3,4</td>
<td>R3,4</td>
<td>R3,4</td>
<td>R3,4</td>
<td>R3,4</td>
<td>R3,4</td>
</tr>
<tr>
<td>Location of controls</td>
<td>_</td>
<td>R</td>
<td>R</td>
<td>_</td>
<td>R</td>
<td>R</td>
</tr>
<tr>
<td>Viewing optics</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>R</td>
</tr>
<tr>
<td>Scanning safeguard</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>R</td>
</tr>
<tr>
<td>Performance (laser systems)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Remote control connector</td>
<td>_</td>
<td>_</td>
<td>_</td>
<td>_</td>
<td>R</td>
<td>R</td>
</tr>
</tbody>
</table>
Key control

<table>
<thead>
<tr>
<th>Emission indicator</th>
<th></th>
<th></th>
<th></th>
<th>R</th>
<th>R</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beam attenuator</td>
<td></td>
<td></td>
<td>R</td>
<td>R</td>
<td></td>
</tr>
<tr>
<td>Reset</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>R</td>
</tr>
</tbody>
</table>

Performance (specific purpose products)

<table>
<thead>
<tr>
<th>Medical</th>
<th>S</th>
<th>S</th>
<th>S</th>
<th>S&lt;sup&gt;8&lt;/sup&gt;</th>
<th>S&lt;sup&gt;8&lt;/sup&gt;</th>
<th>S&lt;sup&gt;8&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surveying, leveling, alignment</td>
<td>S</td>
<td>S</td>
<td>S</td>
<td>S</td>
<td>NP</td>
<td>NP</td>
</tr>
<tr>
<td>Demonstration</td>
<td>S</td>
<td>S</td>
<td>S</td>
<td>S</td>
<td>S&lt;sup&gt;11&lt;/sup&gt;</td>
<td>S&lt;sup&gt;11&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

Labeling (all laser products)

<table>
<thead>
<tr>
<th>Certification and identification</th>
<th>R</th>
<th>R</th>
<th>R</th>
<th>R</th>
<th>R</th>
<th>R</th>
</tr>
</thead>
<tbody>
<tr>
<td>Protective housing</td>
<td>D&lt;sup&gt;5&lt;/sup&gt;</td>
<td>R&lt;sup&gt;5&lt;/sup&gt;</td>
<td>R&lt;sup&gt;5&lt;/sup&gt;</td>
<td>R&lt;sup&gt;5&lt;/sup&gt;</td>
<td>R&lt;sup&gt;5&lt;/sup&gt;</td>
<td>R&lt;sup&gt;5&lt;/sup&gt;</td>
</tr>
<tr>
<td>Aperture</td>
<td></td>
<td></td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>R</td>
</tr>
<tr>
<td>Class warning</td>
<td></td>
<td>R&lt;sup&gt;6&lt;/sup&gt;</td>
<td>R&lt;sup&gt;7&lt;/sup&gt;</td>
<td>R&lt;sup&gt;9&lt;/sup&gt;</td>
<td>R&lt;sub&gt;12&lt;/sub&gt;</td>
<td>R&lt;sub&gt;12&lt;/sub&gt;</td>
</tr>
</tbody>
</table>

Information (all lasers)

<table>
<thead>
<tr>
<th>User information</th>
<th>R</th>
<th>R</th>
<th>R</th>
<th>R</th>
<th>R</th>
<th>R</th>
</tr>
</thead>
<tbody>
<tr>
<td>Product literature</td>
<td></td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>R</td>
</tr>
<tr>
<td>Service information</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>R</td>
</tr>
</tbody>
</table>

Key:
- R = required
- _ = not applicable
- S = same as other products of class
- NP = not permitted
- D = depends on level of interior radiation

Notes:

1. Based on highest level accessible during operation.
2. Required wherever and whenever human access to laser radiation above Class I limits is not needed for product to perform its function.
3. Required for protective housings opened during operation or maintenance, if human access thus gained is not always necessary when housing is opened.
4. Interlock requirements vary according to Class of internal radiation.
5. Wording depends on level and wavelength of laser radiation within protective housing.
6. Warning statement label.
7. CAUTION logotype.
8. Requires means to measure level of radiation intended to irradiate the body.
9. CAUTION if 2.5 mWcm<sup>-2</sup> or less, DANGER if greater than 2.5 mWcm<sup>-2</sup>.
10. Delay required between indication and emission.
11. Variance required for Class IIIB or IV demonstration laser products and light shows.
12. DANGER logotype.

APPENDIX III:6-2. FDA/CDRH FEDERAL PRODUCT PERFORMANCE STANDARD EVALUATION OUTLINE

**LASER EMISSIONS DESCRIPTION:**

Type:

**CLASSIFICATION DESIGNATION:**

<table>
<thead>
<tr>
<th>CLASSIFICATION</th>
<th>CLASS I</th>
<th>CLASS IIA</th>
<th>CLASS IIIA</th>
<th>CLASS IIA</th>
<th>CLASS IIIB</th>
<th>CLASS II</th>
<th>CLASS IV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type:</td>
<td>[ ]</td>
<td>[ ]</td>
<td>[ ]</td>
<td>[ ]</td>
<td>[ ]</td>
<td>[ ]</td>
<td>[ ]</td>
</tr>
</tbody>
</table>

**PERFORMANCE REQUIREMENTS:**

<table>
<thead>
<tr>
<th>REQUIREMENT</th>
<th>PRESENT:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Protective Housing -- All Classes -- 1040.10(f)(1)</td>
<td>[ ] [ ] [ ]</td>
</tr>
<tr>
<td>Safety Interlocks -- All Classes -- 1040.10(f)(2)</td>
<td>[ ] [ ] [ ]</td>
</tr>
<tr>
<td>Note: requirements are dependent on class of internal radiation</td>
<td></td>
</tr>
<tr>
<td>Nondefeatable Interlocks</td>
<td>[ ] [ ] [ ]</td>
</tr>
<tr>
<td>Defeatable Interlocks</td>
<td>[ ] [ ] [ ]</td>
</tr>
<tr>
<td>Remote Interlock Connector -- Classes IIIB &amp; IV -- 1040.10(f)(3)</td>
<td>[ ] [ ] [ ]</td>
</tr>
<tr>
<td>Key Control -- Classes IIIB &amp; IV -- 1040.10(f)(4)</td>
<td>[ ] [ ] [ ]</td>
</tr>
<tr>
<td>Emission Indicator -- Classes II, III &amp; IV -- 1040.10(f)(5)</td>
<td>[ ] [ ] [ ]</td>
</tr>
<tr>
<td>Class II &amp; IIIA: no delay -- 1040.10(f)(5)(i)</td>
<td>[ ] [ ] [ ]</td>
</tr>
<tr>
<td>Class IIIB &amp; IV: with delay -- 1040.10(f)(5)(ii)</td>
<td>[ ] [ ] [ ]</td>
</tr>
<tr>
<td>Indicators on laser and controls, if separated by more than 2 meters. Note: Class IIA is exempt.</td>
<td>[ ] [ ] [ ]</td>
</tr>
<tr>
<td>Beam Attenuator -- Classes II, III &amp; V -- 1040.10(f)(6)</td>
<td>[ ] [ ] [ ]</td>
</tr>
<tr>
<td>Location of Controls -- Classes IIA, II, III &amp; IV -- 1040.10(f)(7)</td>
<td>[ ] [ ] [ ]</td>
</tr>
<tr>
<td>Viewing Optics -- All Classes -- 1040.10(f)(8)</td>
<td>[ ] [ ] [ ]</td>
</tr>
<tr>
<td>Requirement</td>
<td>Class</td>
</tr>
<tr>
<td>----------------------------------------------------------------------------</td>
<td>-------</td>
</tr>
<tr>
<td>Scanning Safeguard -- All Classes -- 1040.10(f)(9)</td>
<td></td>
</tr>
<tr>
<td>Manual Reset Mechanism -- Class IV -- 1040.10(f)(10)</td>
<td></td>
</tr>
<tr>
<td><strong>LABEL REQUIREMENTS:</strong></td>
<td></td>
</tr>
<tr>
<td>Certification Label -- All Classes -- 1010.2</td>
<td></td>
</tr>
<tr>
<td>Identification Label -- All Classes -- 1010.3</td>
<td></td>
</tr>
<tr>
<td>Class Designation and Warning Label -- All Classes except Class I -- 1040.10(g)(1,2,&amp; 3)</td>
<td></td>
</tr>
<tr>
<td>Radiation Output Information (Position 2 on label) -- Classes II, III &amp; IV -- 1040.10(g)(4) Note: Class IIA is exempt.</td>
<td></td>
</tr>
<tr>
<td>Aperture Label -- Classes II, III &amp; IV -- 1040.10(g)(5) Note: Class IIA is exempt.</td>
<td></td>
</tr>
<tr>
<td>Noninterlocked Protective Housing Labels (i.e. service panels) -- All Classes -- 1040.10(g)(6)</td>
<td></td>
</tr>
<tr>
<td>Defeatably Interlocked Protective Housing Labels -- 1040.10(g)(7)</td>
<td></td>
</tr>
<tr>
<td>Warning for Invisible Radiation (wherever applicable - all labels) -- 1040.10(g)(8)</td>
<td></td>
</tr>
<tr>
<td>Positioning of Labels -- 1040.10(g)(9)</td>
<td></td>
</tr>
<tr>
<td>Label Specifications -- 1040.10(g)(10)</td>
<td></td>
</tr>
<tr>
<td><strong>INFORMATION REQUIREMENTS:</strong></td>
<td></td>
</tr>
<tr>
<td>User Information -- 1040.10(h)(1)</td>
<td></td>
</tr>
<tr>
<td>Operator &amp; Maintenance Instructions -- (h)(1)(i)</td>
<td></td>
</tr>
<tr>
<td>Statement of Parameters -- (h)(1)(ii)</td>
<td></td>
</tr>
<tr>
<td>Label Reproductions -- (h)(1)(iii)</td>
<td></td>
</tr>
<tr>
<td>Listing of Controls, Adjustments, and Procedures, including Warnings - (h)(1)(iv)</td>
<td></td>
</tr>
<tr>
<td>Service Information -- 1040.10(h)(2)(ii)</td>
<td></td>
</tr>
</tbody>
</table>

An American National Standard implies a consensus of those substantially concerned with its scope and provisions. These standards are intended as a guide to aid the manufacturer, the consumer and the general public. There is, however, no inherent requirement for anyone or any company to adhere to an ANSI standard. Compliance is voluntary unless specifically required by some alliance. For example, the Federal Department of Energy requires adherence to the ANSI Z 136.1 by their internal staff as well as all contractor organizations. At present, the following ANSI standards can be useful in laser safety matters:


This is the master or "parent" standard in the Z 136 series. Originally published in 1973, this standard has gone through revisions in 1976, 1980, 1986, and 1993. Revisions are currently being considered by the committee for the next publication which should occur in 1991.

The Z 136.1 (1993) standard includes the basis of laser hazard assessment including the Nominal Hazard Zone (NHZ) concept and measurements, establishes Maximum Permissible Exposure (MPE) limits based on bioeffects of the eye and skin, introduces a general classification scheme, specifies the recommended control measures, outlines suggested medical surveillance practice, specifies training requirements and recommends practices for other (nonbeam) concerns.

ANSI Z 136.2 (1988): "FOR THE SAFE USE OF OPTICAL FIBER COMMUNICATION SYSTEMS UTILIZING LASER DIODE AND LED SOURCES"

This ANSI Standard provides guidance for the safe use of optical fiber communications systems (OFCS) utilizing laser diodes and/or LED sources by defining control measures for each of four service group (SG) classifications. This concept eliminates measurements and/or calculations. The standard is limited to OFCS that emit at power levels at or below 0.5 W.

The Z 136.2 standard addresses the same general topics as the base Z 136.1 standard. The significant variation between the two standards lies in the definition of a Maximum Permissible Irradiance (MPI) value based upon a 5 mm limiting aperture in the visible and near-infrared spectral regions. This is in contrast to the larger 7mm limiting aperture used in this spectral region in the ANSI Z 136.1 Standard.

ANSI Z 136.3 (1988): "FOR THE SAFE USE OF LASERS IN HEALTH CARE FACILITIES"

The ANSI Z 136.3 Standard provides guidance for the safe use of lasers for diagnostic and therapeutic uses in health care facilities. The publication includes an extensive appendix that details suggested practice in fourteen medical subspecialty areas. (Although the appendix is not technically a part of the standard.)

Major emphasis is included on the associated hazard topics of airborne contaminants ("plume") and electrical and fire hazards. The information in the base of the standard has been kept less mathematical and refers the reader frequently to the ANSI Z 136.1 Standard if such detail is needed. Summary charts provide information on MPE and NHZ values. Control measures are identical, in most cases, to the master standards, with items special to medical laser systems (foot
pedals, output calibration, QC and safety audits, etc.) given additional coverage.


The fifth edition of the National Electrical Code Handbook is based on the new edition of The National Fire Protection Association's NFPA-70, The National Electrical Code. This document, authored by the NFPA's Electrical Code Committee, is unquestionably the most authoritative and comprehensive document on electrical safety and addresses the topic from both a fire and electrocution point of view. The Handbook includes the complete text of the Code provisions along with explanations. It provides a basis for safety procedures for all electrical hazards associated with lasers.

ANSI Z 87.1 (1989): "PRACTICE FOR OCCUPATIONAL AND EDUCATIONAL EYE AND FACE PROTECTION"

This ANSI standard is included in this listing mainly because a high percentage of industrial facilities require that the eye protection used in their plants meet the ANSI Z 87 requirements. In the past, this basically referred to the "drop ball test" in which a 1-inch diameter ball weighing 2.4 ounces and dropped 50 inches must not fracture the protective lens.

The new Z 87.1 (1989) requires a high-velocity impact test wherein small (1/4 in) diameter steel balls weighing 0.04 ounces are projected at high velocity at the protective filter. In addition, there is a high-mass impact test in which a 1-inch diameter, pointed, heat-treated steel projectile (30-degree cone) that weighs 17.6 ounces is dropped at specified distances. These new requirements place far more stringent performance requirements on safety eye wear.

APPENDIX III:6-4. WARNING SIGNS.

FIGURE III:6-2. CAUTION
Absorb  To transform radiant energy into a different form, with a resultant rise in temperature.

Absorption  Transformation of radiant energy to a different form of energy by the interaction of matter, depending on temperature and wavelength.
Accessible Emission Level  The magnitude of accessible laser (or collateral) radiation of a specific wavelength or emission duration at a particular point as measured by appropriate methods and devices. Also means radiation to which human access is possible in accordance with the definitions of the laser's hazard classification.

Accessible Emission Limit (AEL)  The maximum accessible emission level permitted within a particular class. In ANSI Z 136.1, AEL is determined as the product of accessible emission Maximum Permissible Exposure limit (MPE) and the area of the limiting aperture (7 mm for visible and near-infrared lasers).

Aperture  An opening through which radiation can pass.

Argon  A gas used as a laser medium. It emits blue-green light primarily at 448 and 515 nm.

Attenuation  The decrease in energy (or power) as a beam passes through an absorbing or scattering medium.

**Aversion Response**  Movement of the eyelid or the head to avoid an exposure to a noxious stimulant, bright light. It can occur within 0.25 seconds, and it includes the blink reflex time.

Beam  A collection of rays that may be parallel, convergent, or divergent.

Beam Diameter  The distance between diametrically opposed points in the cross section of a circular beam where the intensity is reduced by a factor of \( e^{-1} \) (0.368) of the peak level (for safety standards). The value is normally chosen at \( e^{-2} \) (0.135) of the peak level for manufacturing specifications.

Beam Divergence  Angle of beam spread measured in radians or milliradians (1 milliradian = 3.4 minutes of arc or approximately 1 mil). For small angles where the cord is approximately equal to the arc, the beam divergence can be closely approximated by the ratio of the cord length (beam diameter) divided by the distance (range) from the laser aperture.

Blink Reflex  See aversion response.

Brightness  The visual sensation of the luminous intensity of a light source. The brightness of a laser beam is most closely associated with the radio-metric concept of radiance.

Carbon Dioxide  Molecule used as a laser medium. Emits far energy at 10,600 nm (10.6 μm).

Closed Installation  Any location where lasers are used which will be closed to unprotected personnel during laser operation.

CO₂ Laser  A widely used laser in which the primary lasing medium is carbon dioxide gas. The output wavelength is 10.6 μm (10600 nm) in the far infrared spectrum. It can be operated in either CW or pulsed.
Coherence  A term describing light as waves which are in phase in both time and space. Monochromaticity and low divergence are two properties of coherent light.

Collimated Light  Light rays that are parallel. Collimated light is emitted by many lasers. Diverging light may be collimated by a lens or other device.

Collimation  Ability of the laser beam to not spread significantly (low divergence) with distance.

Continuous Mode  The duration of laser exposure is controlled by the user (by foot or hand switch).

Continuous Wave (CW)  Constant, steady-state delivery of laser power.

Controlled Area  Any locale where the activity of those within are subject to control and supervision for the purpose of laser radiation hazard protection.

Diffuse Reflection  Takes place when different parts of a beam incident on a surface are reflected over a wide range of angles in accordance with Lambert's Law. The intensity will fall off as the inverse of the square of the distance away from the surface and also obey a Cosine Law of reflection.

Divergence  The increase in the diameter of the laser beam with distance from the exit aperture. The value gives the full angle at the point where the laser radiant exposure or irradiance is $e^{-1}$ or $e^{-2}$ of the maximum value, depending upon which criteria is used.

Embedded Laser  A laser with an assigned class number higher than the inherent capability of the laser system in which it is incorporated, where the system's lower classification is appropriate to the engineering features limiting accessible emission.

Emission  Act of giving off radiant energy by an atom or molecule.

Enclosed Laser Device  Any laser or laser system located within an enclosure which does not permit hazardous optical radiation emission from the enclosure. The laser inside is termed an "embedded laser."

Energy (Q)  The capacity for doing work. Energy is commonly used to express the output from pulsed lasers and it is generally measured in Joules (J). The product of power (watts) and duration (seconds). One watt second = one Joule.

Excimer "Excited Dimer"  A gas mixture used as the active medium in a family of lasers emitting ultraviolet light.

Fail-safe Interlock  An interlock where the failure of a single mechanical or electrical component of the interlock will cause the system to go into, or remain in, a safe mode.
Gas Discharge Laser  A laser containing a gaseous lasing medium in a glass tube in which a constant flow of gas replenishes the molecules depleted by the electricity or chemicals used for excitation.

Gas Laser  A type of laser in which the laser action takes place in a gas medium.

Helium-Neon (HeNe) Laser  A laser in which the active medium is a mixture of helium and neon. Its wavelength is usually in the visible range. Used widely for alignment, recording, printing, and measuring.

Infrared Radiation (IR)  Invisible electromagnetic radiation with wavelengths which lie within the range of 0.70 to 1000 µm. These wavelengths are often broken up into regions: IR-A (0.7-1.4 µm), IR-B (1.4-3.0 µm) and IR-C (3.0-1000 µm).

Intrabeam Viewing  The viewing condition whereby the eye is exposed to all or part of a direct laser beam or a specular reflection.

Irradiance (E)  Radiant flux (radiant power) per unit area incident upon a given surface. Units: Watts per square centimeter. (Sometimes referred to as power density, although not exactly correct).

Laser  An acronym for light amplification by stimulated emission of radiation. A laser is a cavity with mirrors at the ends, filled with material such as crystal, glass, liquid, gas or dye. It produces an intense beam of light with the unique properties of coherency, collimation, and monochromaticity.

Laser Accessories  The hardware and options available for lasers, such as secondary gases, Brewster windows, Q-switches and electronic shutters.

Laser Controlled Area  See Controlled Area.

Laser Device  Either a laser or a laser system.

Laser Medium (Active Medium)  Material used to emit the laser light and for which the laser is named.

Laser Rod  A solid-state, rod-shaped lasing medium in which ion excitation is caused by a source of intense light, such as a flash lamp. Various materials are used for the rod, the earliest of which was synthetic ruby crystal.

Laser Safety Officer (LSO)  One who has authority to monitor and enforce measures to control laser hazards and effect the knowledgeable evaluation and control of laser hazards.

Laser System  An assembly of electrical, mechanical and optical components which includes a laser. Under the Federal Standard, a laser in combination with its power supply (energy source).
Lens  A curved piece of optically transparent material which, depending on its shape, is used to either converge or diverge light.

Light  The range of electromagnetic radiation frequencies detected by the eye, or the wavelength range from about 400 to 760 nm. The term is sometimes used loosely to include radiation beyond visible limits.

Limiting Aperture  The maximum circular area over which radiance and radiant exposure can be averaged when determining safety hazards.

Maintenance  Performance of those adjustments or procedures specified in user information provided by the manufacturer with the laser or laser system, which are to be performed by the user to ensure the intended performance of the product. It does not include operation or service as defined in this glossary.

Maximum Permissible Exposure (MPE)  The level of laser radiation to which a person may be exposed without hazardous effect or adverse biological changes in the eye or skin.

Nd:Glass Laser  A solid-state laser of neodymium:glass offering high power in short pulses. A Nd-doped glass rod used as a laser medium to produce 1064 nm light.

Nd:YAG Laser  Neodymium:Yttrium Aluminum Garnet. A synthetic crystal used as a laser medium to produce 1064 nm light.

Neodymium (Nd)  The rare earth element that is the active element in Nd:YAG laser and Nd:Glass lasers.

Nominal Hazard Zone (NHZ)  The nominal hazard zone describes the space within which the level of the direct, reflected or scattered radiation during normal operation exceeds the applicable MPE. Exposure levels beyond the boundary of the NHZ are below the appropriate MPE level.

Optical Cavity (Resonator)  Space between the laser mirrors where lasing action occurs.

Optical Density  A logarithmic expression for the attenuation produced by an attenuating medium, such as an eye protection filter.

Optical Fiber  A filament of quartz or other optical material capable of transmitting light along its length by multiple internal reflection and emitting it at the end.

Optical Pumping  The excitation of the lasing medium by the application of light rather than electrical discharge.

Optical Radiation  Ultraviolet, visible, and infrared radiation (0.35-1.4 µm) that falls in the region of transmittance of the human eye.

Output Power  The energy per second measured in watts emitted from the laser in the form of
coherent light.

Power  The rate of energy delivery expressed in watts (Joules per second). Thus: 1 Watt = 1 Joule $\times 1$ §

Protective Housing  A protective housing is a device designed to prevent access to radiant power or energy.

Pulse  A discontinuous burst of laser, light or energy, as opposed to a continuous beam. A true pulse achieves higher peak powers than that attainable in a CW output.

Pulse Duration  The "on" time of a pulsed laser, it may be measured in terms of milliseconds, microseconds, or nanoseconds as defined by half-peak-power points on the leading and trailing edges of the pulse.

Pulsed Laser  Laser which delivers energy in the form of a single or train of pulses.

Pump  To excite the lasing medium. See Optical Pumping or Pumping.

Pumped Medium  Energized laser medium.

Pumping  Addition of energy (thermal, electrical, or optical) into the atomic population of the laser medium, necessary to produce a state of population inversion.

Radiant Energy (Q)  Energy in the form of electromagnetic waves usually expressed in units of Joules (watt-seconds).

Radiant Exposure (H)  The total energy per unit area incident upon a given surface. It is used to express exposure to pulsed laser radiation in units of J/cm².

Reflection  The return of radiant energy (incident light) by a surface, with no change in wavelength.

Refraction  The change of direction of propagation of any wave, such as an electromagnetic wave, when it passes from one medium to another in which the wave velocity is different. The bending of incident rays as they pass from one medium to another (e.g., air to glass).

Resonator  The mirrors (or reflectors) making up the laser cavity including the laser rod or tube. The mirrors reflect light back and forth to build up amplification.

Ruby  The first laser type; a crystal of sapphire (aluminum oxide) containing trace amounts of chromium oxide.

Scanning Laser  A laser having a time-varying direction, origin or pattern of propagation with respect to a stationary frame of reference.
Secured Enclosure  An enclosure to which casual access is impeded by an appropriate means (e.g., door secured by lock, magnetically or electrically operated latch, or by screws).

Semiconductor Laser  A type of laser which produces its output from semiconductor materials such as GaAs.

Service  Performance of adjustments, repair or procedures on a non-routine basis, required to return the equipment to its intended state.

Solid Angle  The ratio of the area on the surface of a sphere to the square of the radius of that sphere. It is expressed in steradians (sr).

Source  The term source means either laser or laser-illuminated reflecting surface, i.e., source of light.

Tunable Laser  A laser system that can be "tuned" to emit laser light over a continuous range of wavelengths or frequencies.

Tunable Dye Laser  A laser whose active medium is a liquid dye, pumped by another laser or flash lamps, to produce various colors of light. The color of light may be tuned by adjusting optical tuning elements and/or changing the dye used.

Ultraviolet (UV) Radiation  Electromagnetic radiation with wavelengths between soft X-rays and visible violet light, often broken down into UV-A (315-400 nm), UV-B (280-315 nm), and UV-C (100-280 nm).

Visible Radiation (light)  Electromagnetic radiation which can be detected by the human eye. It is commonly used to describe wavelengths in the range between 400 nm and 700-780 nm.

Wavelength  The length of the light wave, usually measured from crest to crest, which determines its color. Common units of measurement are the micrometer (micron), the nanometer, and (earlier) the Angstrom unit.

YAG  Yttrium Aluminum Garnet, a widely used solid-state crystal composed of yttrium and aluminum oxides and a small amount of the rare earth neodymium.
I. INTRODUCTION.

This chapter provides information to assist industrial hygienists in the assessment of work sites for potential Legionnaires' disease. It provides information on disease recognition, investigation procedures to identify probable water sources, and control strategies. The primary focus of this document is on the control and prevention of contaminated water sources, not on case identification, an area of expertise primarily exercised by local health departments frequently in conjunction with the Centers for Disease Control and Prevention (CDC) in Atlanta. Appendices include details on conducting an employee awareness program, water sampling protocols and guidelines for acceptable levels of the organism in water, procedures for identifying new cases of the disease, and water treatment and control strategies for facilities where an outbreak has occurred.

II. DISEASE RECOGNITION.

A. CAUSATIVE AGENT.

1. *Legionella pneumophila* was first identified in 1977 by the CDC as the cause of an outbreak of pneumonia that caused 34 deaths at a 1976 American Legion Convention in Philadelphia. *L. pneumophila* had
undoubtedly caused previous pneumonia outbreaks, but the organism's slow growth and special growth requirements prevented earlier discovery.

2. The diseases produced by *Legionella* are called *legionellosis*. More than 34 species of *Legionella* have been identified, and more than 20 linked with human diseases. *L. pneumophila* causes the pneumonia known as Legionnaires' disease and the flu-like Pontiac fever. *L. pneumophila* has also been implicated in wound infections, pericarditis, and endocarditis without the presence of pneumonia. Because the majority of legionellosis is caused by *L. pneumophila*, this chapter will deal exclusively with that organism. Cases where other species of *Legionella* are involved in disease require actions similar to those to control Legionnaires' disease.

3. The *L. pneumophila* bacteria are gram-negative rods that exist in a number of distinguishable serogroups. Each serogroup contains further subtypes that have different surface structures on the cell membrane and can be distinguished by special tests. Evidence indicates that some *Legionella* serogroups are more virulent than others. *L. pneumophila* serogroup 1 is the most frequently identified form of the bacterium isolated from patients with Legionnaires' disease, although other serogroups and subtypes of the bacterium are frequently isolated from water sources. Serogroups 4 and 6 are the next most frequently linked with disease.

B. **SYMPTOMS.**

1. Legionnaires' disease has an incubation period of two to ten days. Severity ranges from a mild cough and low fever to rapidly progressive pneumonia and coma. Early symptoms include malaise, muscle aches, and slight headache. Later symptoms include high fever (up to 105°F), a dry cough, and shortness of breath. Gastrointestinal symptoms including vomiting, diarrhea, nausea, and abdominal pain are common. The disease is treated with erythromycin or a combination of erythromycin and rifampin.

2. Pontiac fever is a non-pneumonia, flu-like disease associated with, and likely caused by, the *Legionella* bacterium. This disease has an "attack rate" of 90% or higher among those exposed, and a short incubation period, 1-3 days. Complete recovery usually occurs in 2-5 days without medical intervention. The factors that cause the same organism to produce two illnesses with major differences in attack rate and severity are not known.

C. **INCIDENCE.** In the U.S., Legionnaire's disease is considered to be fairly common and serious, and the *Legionella* organism is one of the top three causes
of sporadic, community-acquired pneumonia. Because it is difficult to distinguish this disease from other forms of pneumonia, many cases go unreported. Approximately 1,000 cases are reported annually to the CDC, but it is estimated that over 25,000 cases of the illness occur each year and cause more than 4,000 deaths.

D. **RISK FACTORS.** Legionnaires' disease is frequently characterized as an "opportunistic" disease that most frequently attacks individuals who have an underlying illness or weakened immune system. The most susceptible include persons who are elderly, smokers, and immunosuppressed. Individuals with chronic obstructive pulmonary disease (COPD), organ transplant patients, and persons taking corticosteroid therapy are also at elevated risk. The attack rate for the average population is approximately 5% or less. The fatality rate is similar to that of other forms of pneumonia, approximately 15%.

E. **DIAGNOSIS.** CDC guidelines define two types of cases of Legionelloses, probable and confirmed. A *probable* case of Legionnaire's disease is a person who experienced an illness clinically compatible with Legionnaire's and has a single antibody titer of 256 or higher (discussed below), and can be associated with a population of individuals who have experienced confirmed cases of the disease (outbreak). A *confirmed* case of *Legionella* requires a physician's diagnosis of pneumonia based on a chest x-ray and positive laboratory test results. A laboratory test is necessary for confirmation because the symptoms and x-ray evidence of Legionnaires' disease resemble those of other types of pneumonia. Various methods are used to confirm the presence of the disease.

1. **Culture of the Organism.** The definitive laboratory method of confirming the presence of the disease is by culturing viable cells of *Legionella* from sputum, bronchial washing, or autopsy on special media. Further identification of the cultured cells will identify the species and serogroup. Special tests may determine subtype of certain isolates. The sensitivity of this test to detect the disease is reported to be about 70%.

2. **Urine Antigen Test.** The detection of antigen from *L. pneumophila* in the urine is considered a reliable measure of the disease. These antigenic materials may include *L. pneumophila* cells or portions of cells in the urine during and after the disease. The presence of antigen in the urine is a strong indicator of the disease, and a patient may have a positive response for several months following the disease. The sensitivity of this test is limited because the only commercially available urinary antigen test detects only serogroup 1 forms of *L. pneumophila*. The CDC recommends only the radioimmunoassay (RIA) test because the latex antigen (LA) test has a high false-positive rate. Fortunately, 80-90% of the clinically diagnosed cases are caused by serogroup 1. The absence of a positive urinary test is not proof that a patient did not have Legionnaires' disease, but merely indicates the absence of antigen in the urine at the time of the test.
3. **Direct Fluorescent Antibody (DFA) Staining.** Direct fluorescent antibody staining of lung aspirates can detect *L. pneumophila.* However, this test is frequently negative during the initial stages of the disease because few organisms are present in the aspirate or sputum. This test also requires an antigen-specific reagent. There are a multitude of serogroups and subtypes of *L. pneumophila,* and a test will be negative if the exact antigen-specific reagent is not included.

4. **Serology (Antibody Titers).**

   a. An increase in the antibody level in the serum of infected persons occurs several weeks after the onset of the disease. A fourfold increase in the antibody titer coupled with a physician's diagnosis of pneumonia is considered a reliable indicator of disease. This is measured by comparing the antibody level four to eight weeks after onset (convalescent titer) to an initial (acute) titer at the beginning of the disease. Pontiac fever also produces an elevated antibody titer, but the flu-like symptoms of this disease do not match those of Legionnaires' disease.

   b. Frequently only a convalescent titer has been measured from individuals who had symptoms of the disease. For situations in which these cases are associated with an outbreak of Legionnaires' disease, a single titer of 256 to 1 or higher is generally used as a presumptive indication of disease (probable case). Antibody strength is determined by the number of dilutions of serum which elicit a positive antibody response. The reciprocal value of the number of dilutions is the antibody titer. For example, an antibody titer of 256 means a positive antibody test of the patient's serum following serial dilutions of 1:2, then 1:4, then 1:16, etc., until the 1:256 dilution point is reached.

   c. The indirect fluorescent antibody (IFA) test is the accepted diagnostic tool for demonstrating *L. pneumophila* exposure. Another widely used test of antibody response is the enzyme-linked immunosorbent assay method (ELISA). CDC believes that direct comparison of results between IFA and ELISA is not reliable because there are insufficient data to compare the two. The ELISA method has gained wide medical acceptance as a useful means of demonstrating exposure to *Legionella.*

F. **TRANSMISSION.**

1. The likelihood of contracting Legionnaires' disease is related to the level of contamination in the water source, the susceptibility of the person exposed, and the intensity of exposure to the contaminated water. Disease transmission usually occurs via inhalation of an aerosol of water contaminated with the organism. Aspiration of contaminated water into
the lungs may also cause the disease. In the Philadelphia Legionnaires' disease outbreak, the hotel's cooling tower was identified as the likely source of the disease, although domestic water sources were not evaluated.

2. The disease has been associated with domestic hot-water systems in a number of outbreaks. In many instances it has been difficult to identify a likely source for aerosolization of the suspected water source. Although transmission of the disease other than through direct inhalation of aerosols may occur, the mechanisms are not clearly understood. The organism requires water, and the disease cannot occur in the absence of a contaminated water source. There is no evidence that the disease can be transmitted from one person to another.

III. SOURCE IDENTIFICATION.

A. CONDITIONS THAT PROMOTE GROWTH.

1. *L. pneumophila* bacteria are widely distributed in water systems. They tend to grow in biofilms or slime on the surfaces of lakes, rivers and streams, and they are not eradicated by the chlorination used to purify domestic water systems. Low and even nondetectable levels of the organism can colonize a water source and grow to high concentrations under the right conditions.

Conditions that promote growth of the organism include heat, sediment, scale, and supporting (commensal) microflora in water. Common water organisms including algae, amoebae, and other bacteria appear to amplify *Legionella* growth by providing nutrients or harboring the organism. Because of its ability to remain viable in domestic water systems, it is capable of rapid multiplication under the proper conditions.

2. Water conditions that tend to promote the growth of *Legionella* include:

   - stagnation;
   - temperatures between 20° and 50°C (68° - 122°F) (The optimal growth range is 35° - 46°C [95° - 115°F]);
   - pH between 5.0 and 8.5;
   - sediment that tends to promote growth of commensal microflora; and
   - micro-organisms including algae, flavobacteria, and *Pseudomonas*, which supply essential nutrients for growth of *Legionella* or harbor the organism (amoebae, protozoa).

B. COMMON SOURCES OF CONTAMINATED WATER.

1. Water sources that frequently provide optimal conditions for growth of the organisms include:
• cooling towers, evaporative condensers, and fluid coolers that use evaporation to reject heat. These include many industrial processes that use water to remove excess heat;
• domestic hot-water systems with water heaters that operate below 60°C (140°F) and deliver water to taps below 50°C (122°F);
• humidifiers and decorative fountains that create a water spray and use water at temperatures favorable to growth;
• spas and whirlpools;
• dental water lines, which are frequently maintained at temperature above 20°C (68°F) and sometimes as warm as 37°C (98.6°F) for patient comfort; and
• other sources including stagnant water in fire sprinkler systems and warm water for eye washes and safety showers.

2. Water stored below 20°C (68°F) is generally not a source for amplified L. pneumophila levels. However, high levels of bacteria have been measured in the water supplying ice machines. The source of amplification in this case was thought to be heat from the condenser coil of the ice maker to the cold water supply. However, no cases of Legionnaires' disease have been linked to consumption of ice made from contaminated water.

C. MONITORING.

1. Air. An air sample applied to special culture plates by an Andersen-type sampler sometimes demonstrates the presence of the organism in the air. However, negative results are frequent because of the difficulty in maintaining viability of the organism on the culture plates. Air sampling for Legionella is strongly not recommended as a means of measuring potential exposure because of the high likelihood of false negatives.

2. Water. Analysis of water samples from a source suspected of being contaminated with L. pneumophila is a valuable means of identifying potential sources of the disease. A qualified microbiological laboratory experienced in Legionella detection can determine the number of organisms present in colony forming units (CFU) per volume of water and can identify the different serogroups of Legionella pneumophila in the sample. Appendix III:7-2 provides details on the collection, storage, and shipping of water samples.

D. MICROBIOLOGICAL ANALYSIS OF WATER SAMPLES.

1. Cultured Samples. Water samples are cultured on special buffered charcoal yeast extract (BCYE) culture media. Selective isolation processes
to eliminate other microbial overgrowth can determine the number of CFU of *L. pneumophila* per milliliter of water. This process of growth and isolation is time-consuming, and results typically require 7-14 days from the time of submission.

Cultured samples can also be analyzed to identify specific serogroups. Matching the same serogroup and subtype of organism in the patient as found in a water source is considered strong evidence of an associated link.

2. **Direct Fluorescence Antibody (DFA).** The number of organisms in a water sample can also be determined via direct fluorescence antibody (DFA) conjugate tests that stain the organism with a fluorescent dye. This test is unable to distinguish between live and dead bacteria and may also have some cross-reactivity with other bacteria. Sample results can be available in one or two days, and this method can be useful in screening water samples. Use caution, however, in interpreting the results since the potential exists for both false positive and negative results.

3. **DNA Amplification.** A relatively new method for rapid, specific detection of the organism in water employs a polymerase chain reaction (PCR) process to amplify and then detect portions of DNA unique to *L. pneumophila*. This method can produce results in 1 day, and preliminary evidence indicates that its sensitivity and specificity are comparable to those of cell culture, which can take 10-14 days to obtain results. Further testing may lead to acceptance of this technique as the method of choice for monitoring water sources for contamination.

### E. INTERPRETATION OF SAMPLE RESULTS.

1. The probability of infection with *L. pneumophila* is a function both of the intensity of the exposure dose and the level of host susceptibility. Because total eradication of *Legionella* may not be possible, an acceptable control strategy is to minimize the number of organisms present in a water source. Ample evidence indicates that *Legionella* levels are readily controllable. A survey of over 1,000 cooling towers indicates that approximately 60% contained nondetectable levels of *L. pneumophila* when measured by DFA analysis for the number of organisms per milliliter of water (detection limit is 10 bacteria per milliliter of water). In another survey of 663 cooling towers, 57% contained *Legionella* that were not detected when measured by culture (detection limit less than 1 CFU/mL). Other studies of domestic hot-water sources indicate that although the organism is common, especially in large hot-water systems, practical control measures can limit the potential for amplification.
2. A private consulting firm and microbiological laboratory, PathCon Inc. of Norcross, Georgia, has introduced suggested guidelines for control of the organism based on the number of CFU of *L. pneumophila* per milliliter of water (Appendix III:7-3.) These guidelines vary depending on the water source, a recognition by the authors that dose is related both to the potential for exposure and to concentration. For example, recommended exposure limits for contaminated water from a humidifier, which would involve direct exposure to an aerosol are lower than for a cooling tower where the opportunity for exposure is normally less. Work operations such as maintenance on cooling towers may involve direct exposure to cooling tower mist, and precautions to minimize exposure are always necessary. The authors recognize that these guidelines are based on limited data, but they represent the best available information and must suffice until the dose effect of *L. pneumophila* is better understood.

IV. INVESTIGATION PROTOCOL.

A. COMMUNITY HEALTH CONCERNS. It is important to remember that an outbreak of Legionnaires' disease among workers may have its origin in the community and may not be related to the work environment. A Legionnaires' outbreak is both an occupational and a public-health concern, and the investigation may include local public health departments and the Centers for Disease Control (CDC). To minimize employee risk and maximize the effectiveness of effort, close coordination among OSHA, other public agencies, and the employer is imperative.

B. TYPES OF INVESTIGATIONS.

1. The course of action chosen during an investigation of a facility should be based on the degree of certainty that the site is the source of a reported illness. For this reason, two investigation protocols are based on differing levels of suspected risk for exposure to *Legionella*. It is important to remember that these procedures are provided only to assist in the investigation of potential Legionnaires' cases. Individual circumstances may require changes in the investigation. All cases require sound professional judgment in deciding the appropriate course of action.

2. A level-one investigation may be initiated when there is a probable basis for suspecting that workplace water sources are contaminated with *Legionella*, or when there is information that one case of Legionnaires' disease may exist. A level-two investigation should be conducted when more then one possible case of Legionnaires' disease has been reported at a facility.

3. If two or more cases of the disease can be attributed to a work site, assume that a Legionnaires' disease outbreak has occurred. If evidence indicates that the outbreak is still in progress (that is, at least one of the cases has
occurred in the last 30 days), prompt actions should be undertaken to provide maximum protection to employees and eliminate the hazard. Appendix III:7-5 includes examples of actions required to control water sources where an outbreak has occurred.

4. Both investigations follow the same general pattern and include a preliminary opening conference, a walk-through of the facility to conduct a physical assessment of the water systems, a more detailed examination of the systems including a review of maintenance records, assessment of findings, and a closing conference to present control actions based on the findings.

C. LEVEL-ONE INVESTIGATION. Use the following procedure when Legionnaires' disease may be related to the work environment.

1. **Step 1. Obtain an overview of all water systems at the facility.**

   a. A facilities engineer or experienced member of the building maintenance staff should be available to explain system operation and assist in the walkthrough investigation. This person should have a working knowledge of the system's design and current operation.

   b. The overview of the water systems should include plumbing systems, heating-ventilating-air-conditioning (HVAC) systems, and other water reservoirs. A review of the plumbing system should include both hot and cold domestic water systems, water heaters, distribution pipes, water coolers, water treatment equipment, connections to process water systems protected (or unprotected) by backflow preventers, and storage tanks.

   c. The HVAC system review should include cooling towers, evaporative condensers, fluid coolers, humidifiers, direct evaporative air-cooling equipment, indirect evaporative air-cooling equipment, air washers for filtration, etc. Note the location of the fresh-air intakes of the building's air-handling units relative to water sources such as the cooling towers.

   d. Investigate other potential sources of employee exposure including decorative fountains, plant misters, whirlpools, spas, tepid-water eyewashes and safety showers, humidifiers, and water for cooling industrial processes.

   e. Review maintenance records on water systems including water heaters and cooling towers. The records should include temperature checks of domestic water, visual and physical checks of cooling towers, and reports of cooling-tower water-quality assessment and chemical treatment.
f. Identify the locations of portions of the system in which water is allowed to stagnate such as storage tanks or unused plumbing pipe sections ("dead legs"), or infrequently used faucets. Check for cross-connections between domestic and process water systems, and note the condition and type of back-flow prevention devices.

g. Investigate recent major maintenance or changes in the system’s operation. Determine if there were recent or frequent losses of water pressure from the incoming water supply due to line breakage or street repairs. The failure of a back-flow prevention device under loss of pressure can contaminate the system.

2. **Step 2. Conduct a walk-through investigation of the facility.**

   a. Equipment you will need includes a thermometer for measuring water temperatures, a flashlight, and a film or video camera to record observations. Measure and record the temperature of water drawn from each storage-type water heater in the facility. This temperature may be significantly below the water heater's gauge temperature because of heat stratification. Note the presence of rust and scale in this water.

   b. Record the maximum temperature of water at faucets connected to each water heater on the system. Record temperatures at locations near, intermediate, and distant from the heaters. It may be necessary to run the water for several minutes before it reaches a temperature maximum.

   c. Examine the water temperature and the potential for stagnation of cold-water storage tanks used for reserve capacity or to maintain hydrostatic pressure. These should be protected from temperature extremes and covered to prevent contamination. Record the temperature of the domestic cold-water lines at various locations within the facility. Note both the initial temperature and the final equilibrium temperature on the cold-water line, and record the time required to reach equilibrium, because this can be an indicator of the amount of stagnation in the system.

   d. Evaluate cooling towers, evaporative condensers, and fluid coolers for biofilm growth, scale buildup, and turbidity. Record the location of the tower relative to fresh-air intakes, kitchen exhausts, leaves, plant material, or other sources of organic material that might contribute to the growth of the organism.

   e. Record the general condition of the cooling tower. Determine the presence and condition of drift eliminators, which are designed to limit the vapor release from the units, along with the basin temperature of the water in the cooling tower if it is currently being operated. If the cooling tower is operating and is suspected of being contaminated, wear appropriate respiratory protection in the form of a half-face piece respirator equipped
with a HEPA or similar type of filter capable of effectively collecting one-micron particles during the examination of the system.

f. Note the location and evaluate the condition of the sumps for the cooling tower(s), evaporative condenser(s), and fluid cooler(s). These sumps are sometimes located indoors to protect them from freezing. Record the locations of any cross-connections between the cooling tower water system and any domestic water system. These may supply a back-up source of cool water to refrigeration condenser units or serve to supply auxiliary cooling units. The lack of a regular maintenance schedule or water-treatment program for a cooling tower or evaporative condenser system strongly suggests a potential for Legionella contamination.

3. **Step 3. Assess the results of the walkthrough investigation to determine the course of action.** If no potential problems are identified, the operating temperatures measured at water heaters are 60°C (140°F) or above, and the delivery temperature at distant faucets is 50°C (122°F) or higher, no further action will be necessary. However, if the system is poorly maintained and operating temperatures are below recommended minimums, then recommendations for corrective action should be made.

4. **Step 4. Recommend control actions.**

   a. Details of suggested control actions are discussed in Section E. These actions may include disinfection of the domestic water system via heat treatment, chlorination, or other means, and cleaning and disinfecting the cooling tower system according to the Wisconsin Division of Health protocol for "Control of Legionella in Cooling Towers" or a similar process for cleaning heat rejection systems that follows sound practices to minimize potential for Legionella growth.

   b. Additional actions may include eliminating dead legs in the plumbing system, insulating plumbing lines and installing heat tracing to maintain proper temperatures in the system, eliminating rubber gaskets, and removing or frequently cleaning fixtures such as aerators and shower heads.

   c. Corrective actions limited to raising the water heater temperature without evaluating the system for points of stagnation, heat loss and gain, cross-contamination, and other factors that contribute to growth are generally not sufficient.

   d. For a level-one investigation it is not recommended that water samples be collected to confirm the presence of Legionella in the system. The absence of proper operating conditions alone is sufficient for assuming that the water system can pose an unnecessary risk to the employees. Take water samples after the completion of the control actions to confirm that
the corrective measures were successful. The employer may also want to obtain samples before starting corrective actions to assess the extent of the problem.

e. The employer should take necessary corrective actions even if the results of presampling are negative. Water sampling can produce false negatives, a contaminated portion of the system may have been missed, and the absence of *Legionella* organisms at the time of sampling does not insure that the system will remain negative.

f. If, after control actions, the *Legionella* levels in a water source exceed the guidelines in Appendix III:7-3, re-examine the water system to determine if potential contamination points within the system were overlooked and reassess control procedures to determine if they were performed properly. Repeat the procedures as needed until contamination levels meet the guidelines.

D. LEVEL-TWO INVESTIGATION. A level-two investigation is similar to a level-one investigation with several additional steps. Supplemental actions include: (1) medical surveillance of all employees currently on sick leave to identify any new cases, (2) employee awareness training on the disease to minimize employee concerns and aid in early recognition of new cases, (3) assessment of past sick-leave absences for undetected cases of the disease, and (4) collection of water samples during the walkthrough assessment.

1. **Step 1.** Assess water systems as described for a level-one investigation.

2. **Step 2.** Conduct a second walkthrough survey of the facility and collect water samples. Estimate the size of the building and the number of water services during the initial walkthrough and prearrange supply and shipping of the required number of sterile sample containers with the appropriate laboratory. (See Appendix III:7-2 for water sampling procedures.)

3. **Step 3.** Initiate an employee awareness program and monitor current sick leave for new cases. It is important to ensure that employees understand the early symptoms of the disease and seek medical assistance promptly. It is imperative not to alarm the workers. It is equally important to stress the importance of the need to know the health status of all employees on sick leave. (See Appendix III:7-1, Employee Awareness Program.)

4. **Step 4.** Review worker absences to detect other cases. This requires identification of all employees who took three or more consecutive days of sick leave from approximately six weeks before the case of Legionnaires' disease was identified up to the present. Request those employees who may have had pneumonia during this period to undergo additional
voluntary tests for evidence of Legionnaires' disease. (See Appendix III:7-4. Case Identification.)

5. **Step 5. Assess results of worker absence survey and analysis of water systems.** If evidence indicates more than one case of Legionnaires' disease at the workplace, then the site should be treated as having an outbreak. Take immediate control of all water sources to eliminate potential for exposure, and take measures to eliminate the hazard. (See Appendix III:7-5.)

No action is necessary if the results of the investigation are negative, that is, (1) all water and HVAC systems are well maintained and in good operating condition; (2) all water sample results are negative or acceptably low (Appendix III:7-3); and (3) no new cases of the disease have been identified at the work site. Under these circumstances, assume that the site is not the origin of the identified case.

6. **Step 6.** For recommended control actions, see the level-one investigation.

7. **Ongoing Outbreak.**

   a. If the evidence indicates that two or more cases of Legionnaires' disease have occurred at a site, and at least one of the cases was within the last 30 days, assume that an outbreak is in progress and requires a high-priority investigation and prompt action. Conduct a level-two investigation as outlined above, and take the following precautions to protect building occupants.

   b. **Immediately initiate control measures to prevent additional exposures to all water systems that have a reasonable potential for worker exposure including hot and cold domestic water, cooling towers, humidifiers, and any other potential sources of water exposure.** Collect appropriate water samples to determine *Legionella* levels before shutting down the water systems (Appendix III:7-2). These sample results will be invaluable in establishing the cause of the outbreak. A member of the building maintenance or engineering staff who has a working knowledge of the system's design and current operation can explain how the water system operates and the proper procedure for a controlled shutdown.

   *These control actions need not require facility shutdown.* Temporary provisions can allow work to continue: bottled water can be supplied for drinking, shutting off water heaters can eliminate hot-water access, and temporary cooling towers can allow work to continue.

V. **CONTROLS.**
A. **GENERAL DISCUSSION.** This section contains background information on water system operations and proper controls to prevent *Legionella* amplification. This discussion encompasses a variety of water systems, some of which have not been implicated with outbreaks of Legionnaires’ disease. Nevertheless, it is important to remember that any water system can be a source of disease if the water in it is subjected to conditions that promote growth of the organism. Remember, however, that the primary sources of exposure to contaminated water are heat rejection systems (cooling towers, fluid coolers, etc.) and domestic hot-water systems.

B. **COOLING TOWERS, EVAPORATIVE CONDENSERS, AND FLUID COOLERS.** The function of cooling towers, evaporative condensers, and fluid coolers is to reject heat from system fluids through evaporation. Cooling towers remove heat from condenser water via direct-contact evaporation in a wet airstream. This cooled water circulates through the condenser side of a mechanical refrigeration unit to absorb heat. Evaporative condensers operate similarly, except that the refrigerant condenser coils are directly inside the wet air stream and water passing over the coils directly cools the refrigerant. Fluid coolers are employed to reject heat from industrial processes, computer-room air conditioners, etc. Like evaporative condensers, fluid coolers have heat-exchanger coils directly in the wet air stream.

Because all of these systems use a fan to move air through a recirculated water system, a considerable amount of water vapor is introduced into the surroundings despite the presence of drift eliminators designed to limit vapor release. In addition, this water may be in the ideal temperature range for *Legionella* growth, 20° - 50°C, 68° - 122°F.

1. **Inspection and Maintenance.** Visual inspection and periodic maintenance of the system are the best ways to control growth of *Legionella* and related organisms. Good maintenance is necessary both to control *Legionella* growth and for effective operation. The system should be properly monitored and maintained to prevent buildup of scale and sediment and bio-fouling, all of which support *Legionella* growth and reduce operating efficiency.

2. **Biocide.** Unfortunately, measurements of water quality such as total bacterial counts, total dissolved solids, and pH have not proven to be good indicators of *Legionella* levels in cooling towers. Periodic use of biocides is needed to ensure control of *Legionella* growth.

   a. Little information exists on the demonstrated effectiveness of many commercial biocides for preventing *Legionella* growth in actual operations. Recent Australian studies indicate that Fentichlor [2,2’-thiobis(4-chlorophenol)] used weekly for 4 hours at 200 ppm, or bromo-chloro-dimethyl-hydantoin (BCD) in a slow-release cartridge at an initial concentration of 300 ppm are effective in controlling the growth of
Legionella. There are no U.S. suppliers of Fentichlor, although the chemical is licensed by the EPA for water treatment in cooling towers. Towerbrom 60M, a chlorotriazine and sodium bromide salt mixture, has been reported to be effective when alternated with BCD for control of Legionella in U.S. studies of Legionella contamination of cooling towers. The Australian study also indicates that quaternary ammonium compounds, widely used for control of bio-fouling in cooling towers, are not effective in controlling Legionella.

b. Traditional oxidizing agents such as chlorine and bromine have been proven effective in controlling Legionella in cooling towers. Continuous chlorination at low free residual levels can be effective in controlling Legionella growth. It is important, however, that the proper oxidant level be established and maintained because free residual chlorine above 1 ppm may be corrosive to metals in the system and may damage wood used in cooling towers; free residual levels below 1 ppm may not adequately control Legionella growth. Chlorine also combines with organic substances in water to form toxic by-products that are of environmental concern. Frequent monitoring and control of pH is essential for maintaining adequate levels of free residual chlorine. Above a pH of 8.0, chlorine effectiveness is greatly reduced. Proper control of pH will maintain the effectiveness of chlorination and minimize corrosion.

c. Bromine is an effective oxidizing biocide. It is frequently added as a bromide salt and generated by reaction with chlorine. Bromine's effectiveness is less dependent than chlorine on the pH of the water; it is less corrosive; and it also produces less toxic environmental by-products.

d. The effectiveness of any water-treatment regimen depends on the use of clean water. High concentrations of organic matter and dissolved solids in the water will reduce the effectiveness of any biocidal agent. Each sump should be equipped with a "bleed," and make-up water should be supplied to reduce the concentration of dissolved solids.

3. Design.

a. One of the most effective means of controlling the growth of Legionella is to maintain sump water at a low temperature. Sump-water temperatures depend on tower design, heat load, flow rate, and ambient dry-bulb and wet-bulb temperatures. Under ideal conditions, sump-water temperatures in evaporative devices approach the ambient wet-bulb temperature, and that may be low enough to limit Legionella amplification. System design should recognize the value of operating with low sump-water temperatures.

b. High-efficiency drift eliminators are essential for all cooling towers. Older systems can usually be retrofitted with high-efficiency models. A
well-designed and well-fitted drift eliminator can greatly reduce water loss and potential for exposure. Other important design features include easy access or easily disassembled components to allow cleaning of internal components including the packing (fill). Enclosure of the system will prevent unnecessary drift of water vapor, and other design features to minimize the spray generated by these systems are also desirable.

4. **Frequency of Cleaning.** Cooling towers should be cleaned and disinfected at least twice a year. Normally this maintenance will be performed before initial start-up at the beginning of the cooling season and after shut-down in the fall. Systems with heavy bio-fouling or high levels of *Legionella* may require additional cleaning. Any system that has been out of service for an extended period should be cleaned and disinfected. New systems require cleaning and disinfecting because construction material residue can contribute to *Legionella* growth.

5. **Wisconsin Protocol.** Acceptable cleaning procedures include those described in the Wisconsin Protocol. This procedure calls for an initial shock treatment with 50 ppm free residual (total) chlorine, addition of detergent to disperse bio-fouling, maintenance of 10 ppm chlorine for 24 hours, and a repeat of the cycle until there is no visual evidence of biofilms. To prevent exposure during cleaning and maintenance, wear proper personal protective equipment: a Tyvek-type suit with a hood, protective gloves, and a properly fitted respirator with a high-efficiency particulate (HEPA) filter or a filter effective at removing one-micron particles.

6. **Recordkeeping.** A description of the operating system (which includes all components cooled by the system) and details of the make-up water to the system should be available. Written procedures for proper operation and maintenance of the system should indicate the use of scale and corrosion inhibitors, antifoaming agents, and biocides or chlorine use and should be readily available. Log books should list dates of inspections and cleanings, water-quality test results, and maintenance.

**C. DOMESTIC HOT-WATER SYSTEMS.**

1. **Background.** Domestic hot-water systems are frequently linked to Legionnaires’ outbreaks. The term “domestic” applies to all nonprocess water used for lavatories, showers, drinking fountains, etc., in commercial, residential, and industrial settings. Disease transmission from domestic hot water may be by inhalation or aspiration of *Legionella*-contaminated aerosolized water. Water heaters that are maintained below 60°C (140°F) and contain scale and sediment tend to harbor the bacteria and provide essential nutrients for commensal micro-organisms that foster growth of *L.*
*Legionella pneumophila*. Large water heaters like those used in hospitals or industrial settings frequently contain cool zones near the base where cold water enters and scale and sediment accumulate. The temperature and sediment in these zones can provide ideal conditions for amplification of the organism. Dead legs (i.e., sections of piping or plumbing that have been altered or capped such that water cannot flow through) and nonrecirculated plumbing lines that allow hot water to stagnate also provide areas for growth of the organism.

2. **Design.** Water systems designed to recirculate water and minimize dead legs will reduce stagnation. If potential for scalding exists, appropriate, fail-safe scald-protection equipment should be employed. For example, pressure-independent, thermostatic mixing valves at delivery points can reduce delivery temperatures. Point-of-use water heaters can eliminate stagnation of hot water in infrequently used lines. Proper insulation of hot-water lines and heat tracing of specific lines can help maintain distribution and delivery temperatures.

3. **Maintenance.**
   
a. To minimize the growth of *Legionella* in the system, domestic hot water should be stored at a minimum of 60°C (140°F) and delivered at a minimum of 50°C (122°F) to all outlets. The hot-water tank should be drained periodically to remove scale and sediment and cleaned with chlorine solution if possible. The tank must be thoroughly rinsed to remove excess chlorine before reuse.

   b. Eliminate dead legs when possible, or install heat tracing to maintain 50°C (122°F) in the lines. Rubber or silicone gaskets provide nutrients for the bacteria, and removing them will help control growth of the organism. Frequent flushing of these lines should also reduce growth.

   c. Domestic hot-water recirculation pumps should run continuously. They should be excluded from energy conservation measures.

4. **Control.**
   
a. Raising the water-heater temperature can control or eliminate *Legionella* growth. Pasteurize the hot water system by raising the water-heater temperature to a minimum of 70°C (158°F) for 24 hours and then flushing each outlet for 20 minutes. It is important to flush all taps with the hot water because stagnant areas can "re-seed" the system. Exercise caution to avoid serious burns from the high water temperatures used in Pasteurization.

   b. Periodic chlorination of the system at the tank to produce 10 ppm free residual chlorine and flushing of all taps until a distinct odor of chlorine is
evident is another means of control. In-line chlorinators can be installed in the hot water line; however, chlorine is quite corrosive and will shorten the service life of metal plumbing. Control of the pH is extremely important to ensure that there is adequate residual chlorine in the system.

c. Alternative means to control *Legionella* growth include the use of metal ions such as copper or silver (which have a biocidal effect) in solution. Ozonization injects ozone into the water. Ultraviolet (UV) radiation also kills microorganisms. Commercial, in-line UV systems are effective and can be installed on incoming water lines or on recirculating systems, but stagnant zones may diminish the effectiveness of this treatment. Scale buildup on the UV lamp surface can rapidly reduce light intensity and requires frequent maintenance to ensure effective operation.

D. **DOMESTIC COLD-WATER SYSTEMS.**

1. Domestic cold water systems are not a major problem for *Legionella* growth. Maintaining cold-water lines below 20°C will limit the potential for amplification of the bacteria. It is surprising, however, that elevated levels of *Legionella* have been measured in ice machines in hospitals. Cold-water lines near heat sources in the units are believed to have caused the amplification.

2. Dental water lines have recently been recognized as common sources of water contaminated with high concentrations of microorganisms including *Legionella*. However, to date an increased risk of disease among dental staff or patients has not been demonstrated. Dental water line operating conditions are especially appropriate for *Legionella* proliferation because the water is stagnant a majority of the time, the narrow plastic tubing encourages biofilm formation, and the water temperature is usually 20°C (68°F) or higher—some systems maintain water at 37°C (98.6°F). Filtration of water at the point of use with replaceable, in-line, FDA-cleared, 0.22-microns pore sizes filters is recommended for minimizing risk to patients and staff in a dental facility.

3. Water tanks that allow water to remain uncirculated for long periods can also promote growth of bacteria. Such tanks should be eliminated or designed to reduce storage time to a day or less. They should also be covered to prevent contamination and protected from temperature extremes.

4. Cross-contaminations of the domestic cold-water system with other systems should always be suspected. All connections to process water should be protected by a plumbing code-approved device (e.g., back-flow preventer, air gap, etc.). If significant contamination of the domestic cold
water system occurs, the source of contamination must be determined. Inspect the system for "dead legs" and areas where water may stagnate. Elimination of these sections or frequent flushing of taps to drain the stagnant areas may be necessary to limit growth of the organism. Insulate cold-water lines that are close to hot-water lines to reduce the temperature in the line.

5. If the cold-water lines have significant contamination, hyperchlorination can eradicate *Legionella*. Free chlorine levels of 20 to 50 ppm are allowed to remain for one hour at 50 ppm, or two hours at 20 ppm. Faucets are then allowed to run until the odor of chlorine is present, and the water is allowed to remain for approximately two hours.

E. **HVAC SYSTEMS.**

1. HVAC systems are not normally amplification sites for *Legionella*. The organism cannot survive without water, and a properly operated, well-maintained HVAC system is unlikely to be a source of problems. However, the HVAC system can disseminate contaminated water aerosols.

2. Water-aerosol sources are classified as either external or internal.

   a. External sources may emit contaminated aerosolized water that is drawn into a system's fresh-air intake. Mist discharged from cooling towers, evaporative condensers, and fluid coolers can be ingested by the HVAC fresh air intake. When evaluating this path, you should consider:

      - prevailing wind direction and velocity;
      - building effects (e.g., low-pressure zones on leeward sides of buildings and on roof);
      - architectural screen walls; and
      - distance from tower to intake.

   b. Fresh-air intake areaways, typically concrete plenums located at grade level, supply fresh air to air handlers in the basement or lower levels of buildings and can collect organic material (e.g. leaves, dirt, etc.) and water from rain or irrigation.

   c. Do not ignore direct paths such as through an open window. The transmission path through the HVAC system is tortuous, and the bacteria may die from desiccation in the airstream or impact on internal surfaces like filters, duct lining, etc. When evaluating external sources, examine the potential for direct transmission.

   d. Internal sources may provide contaminated aerosolized water that is
then disseminated by the air-distribution system. Contaminated water can leak from pipes into HVAC ducts, where it can be aerosolized and distributed by the system. Potential sources of contaminated water include domestic water systems, fire-sprinklers, refrigeration condensers, etc.

e. HVAC system humidifiers can be hazards. Four types are common:

- Heated-pan humidifiers use a heat source to evaporate water from a pan open to the air stream. Intermittent use of the device coupled with a warm pan of water may support *Legionella* growth. Contaminant-free water is essential.
- Direct steam-type humidifiers inject boiler-generated steam directly into the air stream. These systems normally operate above 70°C (158°F), and *Legionella* cannot survive at that temperature.
- Atomizing humidifiers use mechanical devices or pneumatic air to create a water mist that evaporates into the air stream. A contaminant-free water source is essential.

f. Direct evaporative air coolers may be used as humidifiers. These devices mix water and air in direct contact to create a cool, wet air stream by evaporation. These devices include sumps, which may stagnate when not in use.

g. When draining properly, the water that passes through the condensate pans of cooling coils in an air handler is normally not a source of growth for the organism because of the low temperature of water condensate.

h. Indirect evaporative air cooling in systems designed for dryer climates. One common design circulates cool water from a cooling tower sump through a water coil in the supply air stream. If the coil develops a leak, then pumped cooling tower water will be injected directly into the supply air stream with potentially deleterious effects if the sump water is contaminated with *Legionella*. Indirect evaporative air cooling is also found in air-to-air heat exchangers. One side of the heat exchanger is an evaporative-cooled wet air stream, and the other side supplies air for the conditioned space. If the heat exchanger leaks, the wet air stream can mix with supply air and cause problems if the wet air stream is contaminated with *Legionella*.

i. Many air-handling systems designed for dryer climates employ direct evaporative air cooling. Wet evaporative coolers, slinger air coolers and rotary air coolers common in commercial applications. These devices mix water and air in direct contact to create a cool, wet air stream by evaporation. If these systems are using 100% outside air in a dry climate, the water sump temperature may be low and will not represent a significant risk. However, improperly operated and maintained systems
that use warm, stagnant sump water can present problems.

j. Other equipment may also be potential sources of *Legionella*:

- Residential humidifiers are small, free-standing, portable units that use an internal fan and wet media to disseminate a wet air stream. The sumps of these devices are frequently contaminated with *Legionella*. Daily cleaning is necessary to maintain acceptable water quality, but these units seldom receive appropriate maintenance, and their use in the commercial or industrial workplace is strongly discouraged.
- Computer room air conditioners typically include humidifiers and frequently are not well maintained. They may contain a sump filled with contaminated water.

3. The following are issues to consider when designing HVAC systems to minimize risk from *Legionella* contamination. Most apply to all types of microbial contamination.

a. Minimize use of water reservoirs, sumps, and pans. Chemically untreated, stagnant, warm-water sources provide an ideal environment for *Legionella* growth.

b. Provide a way to drain water sumps when not in use, e.g., an electric solenoid valve on the sump drain. If an HVAC sump is used during the hours when a building is occupied, drain the sump during unoccupied hours.

c. Provide a "bleed" for water sumps so that dissolved solids do not form sediments in the sump.

d. Slope and drain sumps from the bottom so that all the water can drain out and allow the pan to dry.

e. Locate HVAC fresh-air intakes so that they do not draw the mist from a cooling tower, evaporative condenser, or fluid cooler into the system. The American Conference of Governmental Industrial Hygienists publishes "Guidelines For The Assessment Of Bioaerosols In The Indoor Environment," which lists recommended minimum distances between cooling towers and fresh-air intakes.

f. Design indirect evaporative cooling systems with the knowledge that the failure of the heat exchanger will allow wet systems to mix with the air-distribution systems.

g. Use steam or atomizing humidifiers instead of units that use recirculated water. Do not use raw steam from the central heating boiler.
because it contains corrosion inhibitors and anti-scaling chemicals. Atomizing humidifiers must have contaminant-free water.

4. Operate all HVAC equipment as originally designed, and maintain it so that it can perform as designed. Test all HVAC equipment periodically to insure that it is performing as designed. Inactive sumps must be properly drained and bled to prevent accumulation of sediments. Maintenance failures can produce contaminated, stagnant water that can become an ideal environment for *Legionella* growth if heated (e.g., by sunlight).

VI. BIBLIOGRAPHY.


Health and Safety Executive (UK), "The Control of legionellosis including Legionnaires' disease." Health and Safety Series Booklet, HS (G)70, Library and Information Services, Broad Lane, Sheffield S37HQ, Tel: (0742) 752539.

Health Department Victoria; Melbourne Australia, "Guidelines for the Control of Legionnaires' Disease" in *Environmental Health Standards*, 1989.


Muraca, P., J.E. Stout, and V.L. Yu. "Comparative assessment of chlorine, heat, ozone, and UV


**APPENDIX III:7-1. EMPLOYEE AWARENESS PROGRAM.**

The purpose of an employee awareness program is to inform the employees of the potential outbreak, and to educate them about the disease. This educational program should be part of a level-two investigation or for a Legionnaires' disease outbreak. This program is of critical importance to aid in early recognition of the disease. It is also important to help alleviate employee concerns about the disease. This program should supplement the case identification program to discover previously undetected cases of the illness at the work site.
The employer should implement the following elements of this program immediately upon recognition of more than one probable or confirmed case of disease in the work place:

- An initial employee training session which provides basic information about the disease and actions being taken to investigate the problem;
- An ongoing general information service to provide updates and answer questions that may arise among employees; and
- Medical and psychological counseling services when an outbreak has occurred.

Below is a sample letter and supplemental information on the disease that the employer can use for informing employees of a potential or actual outbreak. **SAMPLE LETTER FROM EMPLOYER TO EMPLOYEES**

---

**DATE:**

**MEMO TO: ALL EMPLOYEES**

**FROM: MANAGEMENT OFFICIAL**

**SUBJECT: Legionnaires' Disease**

On _________________, we were notified that one of the employees of our company had contracted legionellosis, commonly referred to as Legionnaires' disease. The employee is assigned to _________________ on ___________ shift.

We want to share with you some general information concerning the disease. In addition, we want to tell you what we are currently doing here at _________________ to ensure all necessary steps are taken to address health concerns.

Legionellosis, or Legionnaire's disease, is a type of pneumonia caused by *Legionella* bacteria. Legionnaires' disease is not contagious, and you cannot catch it from another person. The bacteria are common and grow in water. People often receive low-level exposure in the environment without getting sick. Legionellosis usually occurs only when someone who is already susceptible receives concentrated exposure to the bacteria. Persons who are heavy smokers, elderly, or whose ability to resist infection is reduced are more likely to contract Legionnaires' disease than healthy nonsmokers. According to the Centers for Disease Control in Atlanta, there are between 10,000 and 50,000 cases of Legionnaire's disease every year in the U.S. We are cooperating fully with local health officials who are investigating this matter. Most cases of legionellosis are isolated and are not
associated with an outbreak. To date, _____ case(s) of the disease has/have occurred among employees in this facility.

To identify any other cases, we will review sick-leave records for the period ____________ to _____________. Employees who took more than three consecutive days of sick leave will be identified, and we will attempt to determine if any in that group experienced pneumonia-like symptoms (fever, shortness of breath, cough). Those who used three or more consecutive days of sick leave during this period can expect to be contacted by a representative of our company for an interview. If you experienced a pneumonia-like illness in the past two months but used fewer then three consecutive days of sick leave, contact ____________ to arrange an interview.

To assure that you are being protected during the interim, we are also instituting a medical surveillance program to identify any new or old cases. Part of this surveillance will be to ask you a few questions about your illness when you call in sick to your supervisor. In addition, we are offering counseling and employee information services. If you would like to take advantage of these services or want more information, contact your manager. For the present, please pay attention to the following important points:

WHAT YOU SHOULD DO NOW:

1. If you are not sick, there is no need for you to see a doctor.

2. If you are now sick with a cough and fever:

   I. See your private doctor or contact ____________ to arrange to see a ____________ physician.

   II. Tell the physician that you work in a building that may be involved in a Legionnaires' disease outbreak.

   III. If you see a physician, notify ____________ so that your illness can be tracked.

If you have any concerns or questions concerning this issue, please ask your manager. Your health and safety are of great concern to us, and we will be grateful for your cooperation in this matter. As further information develops we will keep you informed.
SAMPLE INFORMATION TO BE OBTAINED BY INTERVIEW WITH EMPLOYEES CALLING IN ON SICK LEAVE

Interviewer:__________________________ Date:________________

SUPERVISOR SURVEY FORM

We are screening employee illnesses as a result of our Legionnaire's disease incident. You are not obligated to participate in the survey, but your participation will help you and your fellow workers.

We recommend that you see a physician if you currently have pneumonia-like symptoms such as severe chills, high fever, a cough, and difficult breathing.

Are you currently experiencing these symptoms?

Yes_____ No_____ Prefer not to answer______

- If the answer to the question is "No," do not complete the rest of this form. Thank you for your cooperation.
- If the answer is "Yes," please read the statement below and complete the bottom half of this form (Employee name, etc).
- If you answer is "Prefer not to answer," please complete ONLY the bottom half of this form (Employee name, etc).

STATEMENT: You will be contacted by ______________ to obtain additional information necessary to complete our survey.

Thank you!

Employee's Name ____________________________________________
Work Telephone Number _________________________________
Home Telephone Number ________________________________
Shift: Day ___ Swing ___ Graveyard ___ Rotating ___
Branch __________________________/Organization Code ____________
Employee's Supervisor _______________________________________
Telephone Number _________________________________________
Date _________________________________
LEGIONNAIRES' DISEASE: QUESTIONS AND ANSWERS

BACKGROUND.

Legionnaires' disease is a common name for one of the several illnesses caused by *Legionella* bacteria. Legionnaires' disease is an infection of the lungs that is a form of pneumonia. A person can develop Legionnaires' disease by inhaling water mist contaminated with *Legionella*.

*Legionella* bacteria are widely present at low levels in the environment: in lakes, streams, and ponds. At low levels the chance of getting Legionnaires' disease from a water source is very slight. The problem arises when high concentrations of the organism grow in water sources. Water heaters, cooling towers, and warm, stagnant water can provide ideal conditions for the growth of the organism.

Scientists have learned much about the disease and about the *Legionella* bacteria since it was first discovered in 1976. The following questions and answers will help you learn more of what is currently known about Legionnaires' disease.

Q. What are the symptoms of Legionnaires' disease?

A. Early symptoms of the illness are much like the flu. After a short time (in some cases a day or two), more severe pneumonia-like symptoms may appear. Not all individuals with Legionnaires' disease experience the same symptoms. Some may have only flu-like symptoms, but to others the disease can be fatal.

Early flu-like symptoms:

- slight fever
- headache
- aching joints and muscles
- lack of energy, tired feeling
- loss of appetite

Common pneumonia-like symptoms:

- high fever (102°F to 105°F, or 39°C to 41°C)
- cough (dry at first, later producing phlegm)
- difficulty in breathing or shortness of breath
- chills
- chest pains
Q. How common is Legionnaires' disease?

A. It is estimated that in the United States there are between 10,000 and 50,000 cases each year.

Q. How does a person get Legionnaires' disease?

A. A person must be exposed to water contaminated with *Legionella* bacteria. This exposure may happen by inhaling or drinking water contaminated with the *Legionella* bacteria. For example, inhaling contaminated water mist from a cooling tower, a humidifier, or even a shower or sink can cause the disease.

Q. How soon after being exposed will a person develop symptoms of the disease?

A. If infection occurs, disease symptoms usually appear within 2 to 10 days.

Q. Are some people at a higher risk of developing Legionnaires' disease?

A. Yes, some people have lower resistance to disease and are more likely to develop Legionnaires' disease. Some of the factors that can increase the risk of getting the disease include:

- organ transplants (kidney, heart, etc.);
- age (older persons are more likely to get disease);
- heavy smoking;
- weakened immune system (cancer patients, HIV-infected individuals);
- underlying medical problem (respiratory disease, diabetes, cancer, renal dialysis, etc.);
- certain drug therapies (corticosteroids); and
- heavy consumption of alcoholic beverages.

Q. Is Legionnaires' disease spread from person to person?

A. No. Legionnaires' disease is not contagious and cannot be transmitted from one person to another.

Q. What causes Legionnaires disease?

A. Legionnaires' disease is caused by inhaling water contaminated with rod-shaped bacteria called *Legionella pneumophila*. There are over 30 different species of *Legionella*, many of which can cause disease. *Legionella pneumophila* is the most common species that causes disease.

Q. Does everyone who inhales *Legionella* into the lungs develop Legionnaires' disease?
A. No. Most people have resistance to the disease. It is thought that fewer than 5 out of 100 persons exposed to water contaminated with *Legionella* will develop Legionnaires' disease.

Q. Is Legionnaires’ disease easy to diagnose?

A. No. The pneumonia caused by *Legionella* is not easy to distinguish from other forms of pneumonia. A number of diagnostic tests allow a physician to identify the disease. These tests can be performed on a sample of sputum, blood, or urine.

Q. How is Legionnaires' disease treated?

A. Erythromycin is currently the antibiotic of choice. Early treatment reduces the severity and improves chances for recovery. In many instances this antibiotic may be prescribed without the physician's knowledge that the disease is Legionnaires' because erythromycin is effective in treating a number of types of pneumonia.

Q. How did Legionnaires' disease get its name?

A. Legionnaires' disease got its name from the first outbreak in which the organism was identified as the cause. This outbreak occurred in 1976, in a Philadelphia hotel where the Pennsylvania American Legion was having a convention. Over 200 Legionnaires and visitors at this convention developed pneumonia, and some died. From lung tissue, a newly discovered bacterium was found to be the cause of the pneumonia and was named *Legionella pneumophila*.

Q. Is Legionnaire's disease a new disease?

A. No, Legionnaires' disease is not new, but it has only recently been identified. Unsolved pneumonia outbreaks that occurred before 1976 are now known to have been Legionnaires' disease. Scientists are still studying this disease to learn more about it.

Q. Are *Legionella* bacteria widespread in the environment?

A. Yes, studies have shown that these bacteria can be found in both natural and man-made water sources. Natural water sources including streams, rivers, freshwater ponds and lakes, and mud can contain the organism in low levels.

Q. Could I get the disease from natural water sources?

A. It is unlikely. In the natural environment the very low levels of this organism in water sources probably cannot cause disease.

Q. What water conditions are best for growth of the organism?
A. Warm, stagnant water provides ideal conditions for growth. At temperatures between 68° and 122°F the organism can multiply. Temperatures of 90°-105°F are ideal for growth. Rust (iron), scale, and other micro-organisms can also promote the growth of *Legionella*.

Q. What common types of water are of greatest concern?

A. Water mist from cooling towers or evaporative condensers, evaporative coolers (swamp coolers), humidifiers, misters, showers, faucets, and whirlpool baths can be contaminated with the organism and if inhaled or swallowed can cause the disease.

Q. Can Legionnaires' disease be prevented?

A. Yes. Avoiding water conditions that allow the organism to grow to high levels is the best means of prevention. Specific preventive steps include:

- Regularly maintain and clean cooling towers and evaporative condensers to prevent growth of *Legionella*. This should include twice-yearly cleaning and periodic use of chlorine or other effective biocide.
- Maintain domestic water heaters at 140°F (60°C). The temperature of the water should be 122°F or higher at the faucet.
- Avoid conditions that allow water to stagnate. Large water-storage tanks exposed to sunlight can produce warm conditions favorable to high levels of *Legionella*. Frequent flushing of unused water lines will help alleviate stagnation.

Q. Do you recommend that I operate my home water heater at 140°F?

A. Probably not if you have small children or infirm elderly persons who could be at serious risk of being scalded by the hot water. However, if you have persons living with you who are at high risk of contracting the disease, then operating the water heater at a minimum temperature of 140F is probably a good idea.

Q. What can be done if a water system is already contaminated or is suspected of being contaminated?

A. Special cleaning procedures can eliminate *Legionella* from water sources. In many cases these procedures involve the use of chlorine-producing chemicals or high water temperatures. Professional assistance should be sought before attempting to clean a water system.

Q. Can my home water heater also be a source of *Legionella* contamination?

A. Yes, but evidence indicates that smaller water systems such as those used in homes are not as likely to be infected with *Legionella* as larger systems in work places and public buildings.

Q. Can *Legionella* bacteria cause other diseases?
A. Yes. In addition to Legionnaires' disease, the same bacteria also cause a flu-like disease called Pontiac fever.

Q. How does Pontiac fever differ from Legionnaires' disease?

A. Unlike Legionnaires disease, which can be a serious and deadly form of pneumonia, Pontiac fever produces flu-like symptoms that may include fever, headache, tiredness, loss of appetite, muscle and joint pain, chills, nausea, and a dry cough. Full recovery occurs in 2 to 5 days without antibiotics. No deaths have been reported from Pontiac fever.

Q. Are there other differences between Legionnaires' disease and Pontiac fever?

A. Yes. Unlike Legionnaires' disease, which occurs in only a small percentage of persons who are exposed, Pontiac fever will occur in approximately 90% of those exposed. In addition, the time between exposure to the organism and appearance of the disease (called the incubation period) is generally shorter for Pontiac fever than for Legionnaires' disease. Symptoms of Pontiac fever can appear within one to three days after exposure.

APPENDIX III:7-2. PHYSICAL SURVEY AND WATER SAMPLING ROTOCOL.*

Arrange with the appropriate laboratory for supply and shipment of sterile sampling containers, and for analysis of water samples. During the initial walk-through, estimate the size of the building and the number of water services at the facility to determine the number of samples and the size of the purchase order. When investigating the water services within a building, it will be helpful to obtain or prepare a simple schematic diagram of the water services. Note the following features:

- The location of the incoming supply and/or private source.
- The location of storage tanks, water treatment systems, and pumps.
- The location of water heaters and boilers.
- The type of fittings used in the system (e.g., taps, showers, valves) and the material from which the pipework is made.
- The location of all cooling towers, evaporative condensers, and fluid coolers at the facility. The location and type of all systems served by the cooling tower water including sump tanks, condensers, and indirect evaporative cooling coils in air handling units.
- The location of any evaporative cooling systems or humidifiers.
- The location of ornamental fountains, whirlpools, eye washes, safety showers, or other water sources within or near the facility.

Trace the route of the service from the point of entry of the water supply. Note the condition of pipes, jointing methods used, insulation, sources of heat, and the kind of insulation in water storage tanks. Also note carefully any disconnected fittings, "dead legs," and cross-connections with other services. Once you have identified these features, take water samples from:
• The incoming water supply.
• Each storage tank and water heater.
• A representative number of faucets for each of the hot and cold water systems in the facility.
• All cooling towers, evaporative condensers, humidifiers, spas, showers, etc.
• The water entering or leaving any other type of fitting or piece of equipment under particular suspicion.

It is important not to overlook any potential water sources in the building. Water from ice machines, hand spray bottles, decorative fountains, and for plastic injection molding equipment have been implicated in past outbreaks or have been found to be significantly contaminated. The ability to maintain an open mind is essential in conducting an investigation because of the variety of potential sources of contamination at a facility.

WATER SAMPLING PROCEDURE.

Wear appropriate respiratory protection in the form of a half-face piece respirator equipped with a HEPA filter or a similar type of filter media capable of effectively collecting particles in the one micron size range during the examination of water systems if a significant potential exists for exposure to high concentrations of contaminated aerosols.

Collect samples in polypropylene (nalgene) containers (250 mL-1 L) that have been autoclaved at 121°C for 15 minutes. The microbiological laboratory that will analyze the samples should be able to provide the bottles. A local hospital or state health department should be able to autoclave the bottles. It is important not to flush the system to be sampled before collecting samples. Collect at least a 250 mL sample. Measure the temperature of the sampled water. It is preferable to accomplished this by measuring the water stream flowing from the water source and not by placing the thermometer in the sample container. To avoid cross-contamination of the samples, sanitize the thermometer with isopropyl alcohol before measuring the temperature of each sample. When measuring temperature from faucets, showers, water fountains, etc., record the initial water temperature, and then allow the fixture to discharge until the temperature stabilizes. Record the initial and final temperatures, and the time needed to stabilize.

Domestic Water Heaters.

• Take a sample of water from the bottom drain.
• Collect a sample of water from the outlet pipe if the plumbing provides for access.

Faucets and Showers.

• Collect a "before-flush" (initial flow) sample of water.
• Collect an "after-flush" sample of water when the maximum temperature has been reached.

The initial (before-flush) sample is intended to indicate the level of contamination at the sample point or fitting, and the final sample should reveal the quality of the water being supplied to the fitting. Collect sterile-swab samples from faucets or shower heads by removing the fitting and
vigorously swabbing the interior. Swab samples may be positive for *Legionella* even when water samples from the source are negative. Sterile test tubes containing sterilized swabs are available for convenient sampling and shipping.

**Cooling Towers.**

- Take a sample from the incoming supply to the tower.
- Take samples from any storage tanks or reservoirs in the system (i.e., chilled-water return tanks or header tanks).
- Take a sample from the basin of the cooling tower at a location distant from the incoming make-up water, and from the water returning from the circulation system at the point of entry to the tower.
- Take a sample of any standing water in the condensate trays or from the cooling coils.

**Humidifiers, Swamp Coolers, and Spas.**

- Take a sample from the water reservoirs. Sample the incoming water supply if it is accessible.
- For cooling towers, humidifiers, swamp coolers, and building water services, collect samples of sludge, slimes, or sediments, particularly where accumulations occur.
- Take swabs of shower heads, pipes, and faucets and rehydrate from water taken from the sampling site. Swab areas of scale buildup (i.e., remove shower heads, faucet screens, and aerators). Use prepackaged sterile swabs and small glass or polypropylene bottles (autoclaved) for this purpose.

**SAMPLE TRANSPORTATION.**

Prepare samples for shipment carefully, as follows:

- Wrap vinyl tape clockwise around the neck of each bottle to hold its screw cap firmly in place and seal the interface between the cap and the bottle.
- Wrap absorbent paper around bottles, and place the bottles in a sealable (zip-lock) plastic bag.
- Place the sealed plastic bag in an insulated container (styrofoam chest or box).

Samples should not be refrigerated or shipped at reduced temperature. They should be protected from temperature extremes such as sunlight or other external heat or cold sources. Ship to laboratory using overnight mail. If shipping on a Friday, make arrangements for weekend receipt. The samples should be stored at room temperature (20° ± 5°C) and processed within 2 days.

**APPENDIX III:7-3. WATER SAMPLING GUIDELINES.**

Use the following guidelines to assess the effectiveness of water system maintenance. These guidelines are based on limited data and are subject to change. They are intended to apply only to water systems being used by healthy individuals and are not necessarily protective for persons who are immunocompromised.

The levels requiring action vary for the source of exposure based on the assumption that some routes or exposure result in a greater dose to the lung. For this reason, humidifiers and similar devices such as misters and evaporative condensers which produce an aerosol mist that can be directly inhaled should be controlled to lower levels. Remember that these numbers are only guidelines, and the goal is zero detectable *Legionella* in a water source. Levels of *Legionella* equal to or greater than the values in the table constitute a need for action, as described below.

**Action 1:** Prompt cleaning and/or biocide treatment of the system.

**Action 2:** Immediate cleaning and/or biocide treatment. Take prompt steps to prevent employee exposure.

<table>
<thead>
<tr>
<th>Action</th>
<th>Cooling tower</th>
<th>Domestic water</th>
<th>Humidifier</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>100</td>
<td>10</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>1,000</td>
<td>100</td>
<td>10</td>
</tr>
</tbody>
</table>

**APPENDIX III:7-4. LEGIONNAIRES' DISEASE CASE IDENTIFICATION.**

The purpose of this phase of an investigation will be to identify cases of Legionnaires' disease among the workers. The investigation will include identification of all employees who took three or more consecutive days of sick leave days from six weeks before the Legionnaires' case was identified to the present. Following a screening process, all employees who have been identified as having had pneumonia, or potentially having had pneumonia, during this period will be requested to undergo voluntary medical testing to detect evidence of Legionnaires' disease. A physician's diagnosis of pneumonia or pneumonia-like symptoms that include a fever (101°F) and cough indicate a need for further evaluation. A sample program is described below.

Examine sick leave records to identify all employees who used three or more consecutive days of sick leave from 6 weeks before the earliest known case to the present. These employees will be interviewed. If it appears that an employee experienced a pneumonia-like illness, the attached
surveillance questionnaire will be completed. Employees who feel that they might have had symptoms of Legionnaires' disease but did not use three or more consecutive days of sick leave should also be interviewed.

Employees who have experienced a pneumonia-like illness and have seen a physician should be requested to sign a medical release form to allow the company and/or OSHA to obtain additional information from the physician. The physicians of all employees who have seen a physician and have signed a medical release will be interviewed using the physician interview survey form (attached).

Employees participating in surveys such as the one described above must be informed of their Privacy Act rights as well as their right to protect their own medical information. Physician-patient confidentiality must not be violated. Necessary medical information may be communicated only with the patient's written permission. When seeking employees' permission, clearly inform them that the purpose of obtaining a proper diagnosis and sharing this information with the Agency is to protect them and their fellow workers against the potential threat of legionellosis. All medical records will be handled in accordance with 29CFR 1913.10. It may be necessary for the CSHO to obtain medical releases from the employees interviewed so that amplifying information can be obtained from a company health unit or the employee's physician.

Arrangements similar to that described above should be sought for permanent contract employees controlled by separate contractor organizations in the building, e.g., janitors, cafeteria workers, security personnel.

Based on an interview with the employee's physician, potential cases should be considered for a clinical test to detect additional cases. Most probably this will be a serological test to determine the antibody level of the individual. A single antibody titer of 1/256 or greater based on a physician's diagnosis of pneumonia should be interpreted as a probable case of Legionnaires' disease. In the event that an antibody titer level for Legionella was obtained at the time of illness, or if serum collected from the patient at the early phase of the illness (acute phase) is available, then an antibody titer level should be determined from this sample to determine the convalescent to acute titer ratio. A fourfold increase in this titer will be sufficient to confirm a case of Legionnaires' disease.

Other diagnostic tests may also be appropriate. If the potential case occurred recently, then a urine antigen test may detect *Legionella pneumophila* serogroup-1 antigen. A positive urine antigen test for a diagnosed pneumonia case is also accepted as evidence of a confirmed case. However, this test is available only for *Legionella pneumophila* serogroup-1 infections. Culture currently symptomatic individuals for *Legionella*. A positive culture indicates confirmation.

If this process detects one or more additional cases of disease, then the facility should be considered to have experienced an outbreak. The immediacy of the action will depend on whether the outbreak is ongoing or occurred 30 days or more in the past. Take prompt action to control exposure at the site if there is evidence that the outbreak is still occurring. Whatever the circumstances, initiate control procedures and continue medical surveillance of the workforce to detect any new cases of disease and identify the water source responsible for the outbreak.
HEALTH SURVEILLANCE QUESTIONNAIRE - LEGIONELLOSIS

Records show that you took sick leave for three consecutive days or more. We would like to ask a few questions.

1. Name: (last)____________________, (first)________________
   Age:_____ Sex: _____ Work Location:____________________
   Home Phone:___________ Work Phone:________________________

2. Dates of absence(s):____________________________________

3. Stated reason for absence:_______________________________

Ask about the following symptoms:

4. Fever: Yes ____ No____ If yes, highest temperature ____.

5. Cough: Yes___ No ___

6. Headache: Yes_____ No____

7. Diarrhea: Yes_____ No____

8. Shortness of breath: Yes ____ No __

9. Chest pain: Yes ____ No ____

10. Did you see a physician about these symptoms? Yes ___ No ___
    Was a chest x-ray taken? Yes_____ No____
    Were you diagnosed as having pneumonia? Yes ___ No ___
    Were you tested for legionellosis? Yes_____ No____
    Physician's name:______________________ Phone:_____________
    Physician's Address:____________________________________

11. Were you admitted to a hospital? Yes ____ No ____
If yes, which hospital?_____________________________________

Admission Date: _________________ Date released: __________

12. Interviewer:________________ Date:______________

PHYSICIAN SURVEY QUESTIONNAIRE - LEGIONELLOSIS

We are calling to inform you that _______________________ is a patient of yours and an employee at ____________. He/she has signed a medical release giving us permission to contact you to obtain information about her/his recent illness. This questionnaire will be used to determine if your patient’s recent illness could be classified as a pneumonia that may have been caused by exposure to *Legionella* at the workplace.

1. Name of Physician: ________________________________
   Address:____________________________________________
   Phone:____________________________________________

2. Date of visit(s): (1st)_______ (2nd)________ (3rd)_______

3. What was the patient's complaint?:_____________________
   Cough? yes no unknown
   Short of breath? yes no unknown
   History of fever? yes no unknown

4. Physical Findings: ________________________________
   Abnormal chest or lung findings: _______________________
   Rales? yes no not examined
   Dyspnea? yes no not examined
   Cyanosis? yes no not examined
   Temperature ______
   Other:____________________________________________

5. Chest x-ray done? yes no
Findings: ________________________________________________

6. Sputum culture?  yes  no

Results: ________________________________________________

Laboratory: _______________________________________________

Sputum cultured for *Legionella*?  yes  no

Laboratory: _______________________________________________

7. Diagnostic testing?  yes  no

Type of test: Urine Antigen Test, Direct Fluorescent Antibody

Serology Tests:
Indirect Fluorescent Antibody (IFA) _____
ELISA _____
Laboratory: _______________________________________________

8. Diagnosis or impression: ________________________________

---

**EPIDEMIOLOGICAL QUESTIONNAIRE**

**Background**

Employee's Name: ____________________________ Age: _____ Gender: _____
(last, first)

Home: _______________________________________________________
(city, zip)

Race/Ethnicity: white, black, native American, Hispanic, Asian, Other  (circle one)

Are you currently taking any oral steroid medications?:  Y/N

On what date did you first become ill?:  ___ / ___ / ___
How many days were you ill?: ______

Was anyone else in your family ill?: Y/N

If Yes, who? _________________________________

What symptoms did they have? _________________________________

Since __________, have any of your friends been diagnosed with pneumonia?: Yes/No

If Yes, who? _________________________________

**Work Exposure**

*During the 10 days prior to your illness:*

Job Description: __________________________________________________

Primary work area: ______________________________________________

List all areas in _______ building where you spend any time:

<table>
<thead>
<tr>
<th>Area</th>
<th>Hours per week</th>
</tr>
</thead>
<tbody>
<tr>
<td>_____________________________</td>
<td>_____________________________</td>
</tr>
<tr>
<td>_____________________________</td>
<td>_____________________________</td>
</tr>
<tr>
<td>_____________________________</td>
<td>_____________________________</td>
</tr>
<tr>
<td>_____________________________</td>
<td>_____________________________</td>
</tr>
<tr>
<td>_____________________________</td>
<td>_____________________________</td>
</tr>
</tbody>
</table>

Did you shower at work?: Yes/No

If Yes, where and how may times per week?: __________________

List all places you eat lunch:____________________________________

List all places where you take a break: ____________________________
List all restrooms you use: ________________________________

Do you smoke in the restrooms (or spend "extra" time, i.e., if a lounge is present): Yes/No

If Yes, Where:______________________________

Did you attend any training courses outside of the building?: Yes/No

If Yes, where were they held? ______________________________

Do you have a second job?: Yes/No

If Yes, what job and where:

____________________________________________________________________

Any other places that you have not mentioned where you spend time while on the job?:

________________________________________________________

Community Exposure (During the 10 days prior to your illness)

Did you use any health clubs?: Yes/No

If Yes, which ones?: ______________________________

How many times?________________________________________

Did you use any hot tubs (whirlpool spas)?: Yes/No

If Yes, list which hot tubs and when used:

____________________________________________________________________

Did you attend any churches?: Yes/No

If Yes, where________________________________________

How many times?__________

Have you had any dental work performed?: Yes/No

If Yes, where________________________________________
APPENDIX III:7-5. WATER TREATMENT PROTOCOLS FOR FACILITIES THAT HAVE EXPERIENCED A LEGIONNAIRES' OUTBREAK.

BACKGROUND.

This section describes actions required to abate the threat of further infection in a building in which an outbreak of Legionnaires’ disease has occurred. For purposes of this document, an "outbreak of Legionnaires' disease" may be said to exist when medically confirmed cases of Legionnaires' disease are epidemiologically associated with a building or some portion of a building. This usually means that two or more confirmed cases of Legionnaires' disease have been identified within a six-week period at the site.

Under most circumstances evacuation of the building is not recommended. It will be necessary, following confirmation of an outbreak, to isolate individuals who are at high risk of contracting the disease from all potential sources of infection. Individuals at high risk include the immunosuppressed, such as persons who have had organ transplants, individuals receiving chemotherapy including corticosteroids, and other individuals in poor health. In addition, a medical monitoring program must be instituted to track all workers currently on sick leave.
Following these initial actions, the building must be inspected to identify all potential *Legionella* sources including the HVAC cooling systems (cooling towers, evaporative condensers), domestic water systems, humidifiers, and any sources of water that are maintained above 20°C (68°F) and has a potential for being aerosolized.

Before flushing or disinfecting the water in these suspected sources, take water samples for analysis to determine the predominant serotypes and subtypes of *L. pneumophila* in the water source and to determine the number of colony forming units (CFU) per unit of water. This information will be helpful in identifying the source of the disease if the subtype of *L. pneumophila* has been identified in the afflicted worker population. Because of the 10-day to two-week delay in obtaining sample results, corrective action should begin immediately.

Because sampling for *Legionella* can be inconclusive, sampling results alone should not determine the appropriate course of action in a building where an outbreak has occurred. **ALL POTENTIAL SOURCES OF CONTAMINATION WILL BE ASSUMED TO BE CONTAMINATED AND TREATED ACCORDINGLY IN THE EVENT THAT AN OUTBREAK HAS OCCURRED.** Water sampling and testing must be in accordance with currently accepted, state-of-the-art procedures.

Treatment of potential sources of contamination following sampling is described below. After the treatment collect and analyze water samples for CFU of *L. pneumophila* to determine the effectiveness of the treatment. Upon re-use of a water system following treatment, periodic maintenance and regular water sampling are essential to ensure that the maintenance continues to be effective. Included are proper maintenance procedures for controlling the organism in a facility's water sources.

**COOLING TOWERS AND EVAPORATIVE CONDENSERS.**

An HVAC condenser water system absorbs heat from the AC refrigeration units and rejects it to the atmosphere through evaporation in cooling towers. Evaporative condensers operate similarly to cooling towers except that refrigerant coils are inside the water path, and water passes over the coils to cool the refrigerant gas directly. Because both cooling towers and evaporative condensers use a fan system to move air through a recirculated water system, they introduce a considerable amount of water vapor into the surroundings even with drift eliminators designed to limit vapor release. In addition, this water is typically in the 20°-50°C (68°-122°F) range, ideal for *L. pneumophila* growth.

**Water Sampling Protocol.** Before starting decontamination, collect an adequate number of water samples in sterile containers. These samples should be cultured to determine the degree of contamination and the subtype of *L. pneumophila* before treatment. Collect at least three water samples (200 milliliters to 1 liter volume). Include water from the incoming make-up water supply, water from the basin of the unit most distant from the make-up water source, and recirculated water from the HVAC system at its point of return to the unit.

**Clean-up Procedure.**
1. Clean and disinfect the entire cooling system including attached chillers and/or storage tanks (sumps) following the "Wisconsin Protocol" Emergency Protocol, as follows:

   - "Shock" treat cooling tower water at 50 ppm free residual chlorine.
   - Add dispersant.
   - Maintain 10 ppm chlorine for 24 hours.
   - Drain system.
   - Refill and repeat steps a through d.
   - Inspect system for visual evidence of biofilm. If found, repeat steps a through d.
   - Perform mechanical cleaning (cooling tower design may require modified procedures).
   - Refill system, bring chlorine to 10 ppm, and circulate for one hour.
   - Flush system.
   - Refill with clean water in accordance with an effective water treatment program. The unit is now ready to be returned to service.

2. Identify and eliminate all water leaks into the cooling water system.

3. After completing step 1, sample the cooling water for analysis of CFU of L. pneumophila. The unit may be put into service provided the medical monitoring program has been implemented. If sample culture results indicate detectable levels of L. pneumophila, repeat chlorination and resample the water.

4. Once the nondetectable level for L. pneumophila has been achieved, institute maintenance as outlined in the Wisconsin Protocol to ensure continued safe and proper operation, as follows:

   - Inspect equipment monthly.
   - Drain and clean quarterly.
   - Treat circulating water for control of microorganisms, scale, and corrosion. This should include systematic use of biocides and rust inhibitors, preferably supplied by continuous feed, and monthly microbiologic analysis to ensure control of bacteria.
   - Document operation and maintenance in a log or maintenance records book.

5. Test cooling-system water at the following intervals to verify that there is no significant growth of Legionella, as follows:

   - Test weekly for the first month after return to operation.
   - Test every two weeks for the next two months.
   - Test monthly for the next three months.

6. The standard for Legionella concentration throughout the six months of monitoring is fewer than 10 CFU per milliliter (based on PathCon guidelines). If no water samples exceed this level, monitoring may be suspended. The maintenance program must continue indefinitely.

If any sample contains 10 or more CFU Legionella per milliliter, take immediate steps to reduce levels to acceptable limits. These steps may include increased frequency of application or
concentration of biocides, pH adjustment, additional "shock" treatments, or any other action that reduces *Legionella* levels. Take new water samples and begin the testing schedule again. Make the results of all water monitoring tests available to building occupants.

**DOMESTIC WATER SYSTEMS.**

Domestic water systems are designed to provide heated water for washing, cleaning, consumption, etc. A large building may have multiple independent systems. These systems usually include a boiler or heater, a recirculating piping system, and pipes terminating in taps and fixtures. Operating temperatures vary depending on system design, energy conservation programs, and intended use of the water. It is recommended that water heaters be kept at a minimum of 60°C (140°F) and all water be delivered at each outlet at a minimum of 50°C (122°F).

It is essential to identify all parts of the domestic water systems where water may stagnate (e.g., "dead legs" or laterals that have been capped off, storage tanks that have "dead zones" or are not frequently used). For treatment to be effective, the stagnant zones must be removed from the system. Rubber and plastic gaskets in the plumbing system may also serve as a *Legionella* growth medium. Eliminate or minimize use of these materials and substitute materials not conducive to *Legionella* growth. It is also important to identify and test the integrity of all backflow preventers to assure protection of domestic water from cross-contamination with process water through a building code-approved method.

**WATER SAMPLING PROTOCOL.**

Collect water samples before beginning treatment to determine potential contamination. Draw 200 milliliters to 1 liter of water from the draw-off valve of all water heaters into a sterile container. Check the temperature of the water in these units to determine if it is significantly lower than the set temperature. Sample a representative number of domestic hot-water faucets or outlets. It is important not to flush the faucet before taking a sample because the end section of the water system may be a source of contamination. Collect a 200 milliliter to 1 liter "preflush sample" of the first hot water drawn from the outlet. Allow the water to run and measure the temperature, and then collect a second, "postflush" sample when the water temperature is constant. Submit the water samples to a laboratory qualified to measure CFU of *Legionella* per milliliter of water.

Use the clean-up procedure below to treat all hot-water systems that have either been tested and found to contain detectable levels of *Legionella* or have been assumed to be contaminated.

1. Disinfect the system using any effective chemical, thermal, or other treatment method. For example:

   - Pasteurize the hot water system by heating the water to at least 70°C (158°F) and maintain this temperature for a minimum of 24 hours. While maintaining the temperature at 70°C (158°F), continuously flush each faucet on the system with hot water for 20 minutes.
Use an accepted chemical disinfectant such as chlorine or an acceptable biocide treatment to clean the system. Thoroughly flush the system after treatment to remove all traces of the corrosive and possibly toxic chemicals.

Follow any other technique that has demonstrated effectiveness and safety.

2. Maintain domestic water heaters at 60°C (140°F) and water delivered at the faucet at a minimum of 122°F (50°C). Where these temperatures cannot be maintained, control Legionella growth with a safe and effective alternative method.

3. After treatment, resample the hot water from each storage tank. If Legionella are detected, re-treat and resample the water system. If no measurable levels are found in this system and all other potential sources have also been addressed, go to the next step.

4. Test the domestic hot- or warm-water system for Legionella on the following schedule to assure that recontamination has not occurred:
   - Weekly for the first month after resumption of operation.
   - Every two weeks for the next two months.
   - Monthly for the next three months.

5. Use the Pathcon criteria for Legionella in domestic water systems during the monitoring period. If 10 or more CFU per milliliter of water are present, re-treat the system according to steps 1-3 above. Resume weekly testing (step 4) after retreatment. If levels remain below 1 CFU per milliliter, no further monitoring is necessary. If the levels are between 1 and 9 CFU per milliliter, continue monthly sampling of the water indefinitely and continue efforts to determine the source of contamination. Make test results available to building residents.

**TEPID WATER SYSTEMS.** Warm-water systems or tepid water systems dilute domestic hot water from a water heater with cold water upstream from the outlet source are not recommended. Warm water left in these lines is at ideal temperatures for amplification of _L. pneumophila_. Localized mixing at the source to temper very hot water is more acceptable. Another alternative is "instantaneous" point of delivery heating of water using individual steam heating systems at each outlet.

**DOMESTIC COLD-WATER SYSTEMS.** Domestic cold-water systems are designed to provide water for drinking, washing, cleaning, toilet flushing, etc. These systems have not been a major source of concern for Legionnaires' disease because _L. pneumophila_ will not amplify at low temperatures. Cold-water storage and delivery should be at less than 20°C (68°F) to minimize potential for growth. Cold-water lines near hot-water lines should be insulated. Try to eliminate stagnant places in the system as dead legs or storage tanks that are not routinely used.

Detectable levels of _L. pneumophila_ in the system may indicate contamination of the source water supply and should represent the maximum allowable level in the system. If sampling of the system indicates a level of contamination significantly greater than that of the incoming domestic water supply system, treat the system and identify the source of contamination or amplification. By definition, these systems have no provision for heating water, and therefore disinfection cannot be by heat treatment. Follow the clean-up procedure below if cold-water systems are
shown to contain measurable *Legionella* or are assumed to be contaminated.

**Clean-Up Procedure.**

1. Clean and disinfect all cold water systems including storage tanks, drinking fountains, water lines, and water outlets, as follows:
   
   - Use an accepted chemical disinfectant such as chlorine or other acceptable biocide.
   - Use any other technology that has been shown to be safe and effective.

2. Ensure that cold-water systems are maintained so that conditions do not promote growth of *Legionella*. Maintain temperatures at 20°C (68°F) and keep residual chlorine in the range of 1-2 ppm. In practice this level of chlorination may be objectionable and may also be excessively corrosive to metal pipes and containers.

3. Take samples according to sampling guidelines. If analysis shows no detectable *Legionella* and all other potential sources have been addressed, go to the next step.

4. Flush all cold-water outlets and fountains for four minutes, twelve hours before re-entry.

5. When steps a through d have been successfully completed, return the building to normal operation but test the domestic cold-water system for *Legionella* according to the following schedule:
   
   - Weekly for the first month after resumption of operation.
   - Every two weeks for the next two months.
   - Monthly for the next three months.

6. The same criteria used for hot water systems described above will also be used for the cold-water system during the monitoring period. Ten or more CFU per milliliter of water require retreatment of the system according to steps 1-3 above. Following retreatment, resume weekly testing and repeat the schedule outlined in step 5. If *Legionella* levels remain below 1 CFU per milliliter, additional monitoring is not necessary. If levels are between 1-9 CFU per milliliter, continue monthly sampling of the water source indefinitely and try to identify the source of contamination. Make monitoring results available to building occupants.

**HVAC AIR DISTRIBUTION SYSTEMS.**

Under normal conditions HVAC systems are not likely to be sources of *L. pneumophila* unless water contaminated with the bacteria enters the system. Under normal conditions, condensate pans on coiling coils should not serve as a water source in which amplification of the bacteria can occur because the temperature of the water is below 20°C (68°F). Improperly drained condenser pans may produce tepid conditions that can encourage microbial and fungal growth. Proper maintenance will lessen problems related to other diseases such as humidifier fever and asthmatic responses, and will minimize the possibility of a Legionnaires' outbreak.

Most probably, for a Legionnaires' disease outbreak to be linked directly with the HVAC system,
Legionella-contaminated water must continuously enter the system, be aerosolized, and be delivered to building occupants. Examine the systems to rule out this possibility, as follows:

- Inspect the entire air distribution system (including return and exhaust systems) for visual evidence of water accumulation.
- Eliminate all water leaks and remove any standing water found in the system. Replace or eliminate any water-damaged insulation in the system.
- Operate the HVAC system using 100% outside air for 8 hours before returning the building to normal operation.

Sampling of air in the ducts to prove that the duct system is free of Legionella is not required and would be pointless. No reliable way to detect Legionella in the air is available, and Legionella can live only in water. If the ducts are dry, they cannot serve as a source of Legionella.

Following return of the building to normal operation, keep outside-air supply rates as high as possible for one month. At a minimum, the outdoor air requirements of ASHRAE Ventilation Standard 62-1989 must be met.

**HUMIDIFIERS AND MISTERS.**

Many HVAC systems supply humidified air to building occupants to maintain comfort. Improperly maintained humidifiers can be both amplifiers and disseminators of a variety of bioaerosols; however, generally the cool temperatures in HVAC systems are not conducive to growth of *L. pneumophila*. cold-water humidifiers in HVAC systems must be connected to a domestic water source and provided with a drain line to remove the water. Stand-alone, console-type humidifiers that recirculate water for humidification should not be used because the water in these systems becomes contaminated with micro-organisms rapidly. These stand-alone units have been linked to an outbreak of Legionnaires’ disease in a hospital. Ideally, HVAC humidifiers should use steam injection systems that eliminate potential microbe problems.

Cold-water humidifiers require rigorous maintenance to ensure that the water source does not contribute to potential problems. Since humidifiers discharge into HVAC air distribution systems, inspect for standing water and treat according to the HVAC Air Distribution System protocol above. Where water in humidifiers has been sampled and shown to contain measurable Legionella, or where such water has been assumed to be contaminated with Legionella, use the following protocol:

1. Disinfect water in piping or reservoirs feeding the humidifier with chlorine or other effective biocides.

2. Sample the humidifier water to assure "kill" of Legionella. Samples must have no detectable CFU of Legionella per milliliter of water. If one or more are detected, repeat treatment and sampling.

3. Ensure that an adequate maintenance program is in effect to reduce the growth of Legionella. Water storage temperatures should be above or below the 20° - 50°C (68° - 122°F) range, and the system must be kept clean.
4. Before using the humidifier, flush the piping and/or reservoir thoroughly to remove biocides.

5. When steps 1 through 4 have been successfully completed, return the humidifier to operation and test the unit's water system to detect recontamination with *Legionella* according to the schedule below:

- Weekly for the first month.
- Every two weeks for the next two months.
- Monthly for the next three months.

The criterion for *Legionella* in humidifier water systems during monitoring is fewer than 1 CFU per milliliter. If no samples exceed the criterion, suspend monitoring and continue the maintenance program indefinitely.

If any sample shows one or more CFU of *Legionella* per milliliter, retreat and retest the system according to the schedule above (step 5). Make monitoring results available to building occupants.