CHAPTER 1

Recommendation for a Metalworking Fluids Standard

The National Institute for Occupational Safety and Health (NIOSH) recommends that exposure to metalworking fluid (MWF) aerosols be controlled in the workplace by complying with the recommendations presented in this chapter. These recommendations are designed to protect the safety and health of workers for up to a 10-hr work shift during a 40-hr workweek over a working lifetime. Compliance with all sections of the recommended standard should prevent or greatly reduce the risk of adverse health effects in exposed workers.

1.1 Recommended Exposure Limits

1.1.1 Exposure

NIOSH recommends that occupational exposures to MWF aerosols be limited to 0.4 mg/m^3 of air (thoracic particulate mass*) as a time-weighted average (TWA) concentration for up to 10 hr/day during a 40-hr workweek, measured according to NIOSH Method 0500 [NIOSH 1984]. The 0.4-mg/m^3 concentration corresponds to approximately 0.5 mg/m^3 for total particulate mass.†

This recommended exposure limit (REL) is intended to prevent the respiratory disorders associated with MWF exposure in the workplace. However, concentrations of MWF aerosols should be kept below the REL where possible because some workers have developed work-related asthma, hypersensitivity pneumonitis (HP), or other adverse respiratory effects when exposed to MWFs at lower concentrations. Limiting exposure to MWF aerosols is also prudent because certain MWF exposures have been associated with various cancers. In addition, limiting dermal (skin) exposures is critical to preventing allergic and irritant skin disorders related to MWF exposure. In most metalworking operations, it is technologically feasible to limit MWF aerosol exposures to 0.4 mg/m^3 or less.

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*Thoracic particulate mass is the portion of MWF aerosol that penetrates beyond the larynx.

†Total particulate mass has no precise mathematical definition. For the purposes of this criteria document, total particulate mass is that portion of the aerosol spectrum that would be sampled by a 37-mm, closed-face filter cassette that is worn by a worker and connected to a portable sampling pump operated at 2.0 L/min.

1.1.2 Safety and Health Program

In addition to the REL of 0.4 mg/m^3 (thoracic particulate mass), NIOSH recommends that a comprehensive safety and health program be developed and implemented as part of the employer's management system. Such a program must have strong management commitment and worker involvement. The major elements for a comprehensive, effective safety and health program are (1) safety and health training, (2) worksite analysis, (3) hazard prevention and control, and (4) medical monitoring of exposed workers.

1.2 Definitions

1.2.1 MWF Aerosol

MWF aerosol refers to the mist and all contaminants in the mist generated during grinding and machining operations involving products from metal and metal substitutes. MWF aerosols result from the combination of many factors, including MWF type, application pressure, nozzle (size, type, and position), temperature, tool type and speed, use of chip drags, lack of splash-guarding, ventilation, or air cleaners, and other factors [ANSI 1997].

MWF aerosol may contain a mixture of substances, including any of the chemical components of MWFs or additives to MWFs, chemical contaminants of MWFs that are in service (such as tramp oils or leached metals), metal particles, biological contaminants (such as bacterial and fungal cells or cell components and their related biological byproducts such as endotoxins, exotoxins, and mycotoxins), and other material aerosolized when MWF is used in grinding and machining processes.

1.2.2 The Metalworking Environment

The *metalworking environment* refers to any environment in which workers are exposed to the following: metals, metal alloys being machined, chemical residues from preceding operations, MWF additives, MWF contamination from housekeeping and cleaning processes, biological contaminants (bacterial toxins and metabolic products), or physical contaminants (e.g, chips and fines) from MWFs.

1.2.3 MWF Classes

MWFs are grouped into four major classes:

Straight oil (neat oil) MWFs are severely solvent-refined petroleum oils (lubricant-base oils) or other animal, marine, vegetable, or synthetic oils used singly or in combination and with or without additives. Straight oils are not designed to be diluted with water.

2. *Soluble oil (emulsifiable oil) MWFs* are combinations of 30% to 85% severely refined lubricant-base oils and emulsifiers that may include other performance additives. Soluble oils are diluted with water at ratios of 1 part concentrate to 5–40 parts water.

3. *Semisynthetic MWFs* contain a lower amount of severely refined lubricant-base oil in the concentrate (5% to 30%), a higher proportion of emulsifiers, and 30% to 50% water. The transparent concentrate is diluted with 10 to 40 parts water.

4. *Synthetic MWFs* contain no petroleum oils and may be water soluble or water dispersible. The synthetic concentrate is diluted with 10 to 40 parts water.

1.3 Sampling and Analysis

Until thoracic samplers are more widely available and adopted, an acceptable substitute for the thoracic particulate mass is the total particulate mass sample. To translate the thoracic particulate measurement into an equivalent total particulate measurement, divide the total concentration by a correction factor of 1.25[‡] (or other factor experimentally measured for that operation). Thus the REL of 0.4 mg/m^3 for thoracic particulate mass is equivalent to 0.5 mg/m^3 for total particulate mass.

The recommendation for the thoracic particulate REL and sampler is based on the importance of adverse respiratory health effects and the ability of size-selective sampling to measure the particulates that reach the pulmonary airways [ACGIH 1996; ISO 1995]. NIOSH recommends that samples collected by either thoracic or total particulate samplers be analyzed gravimetrically by NIOSH Method 0500. The methods for sampling thoracic particulates are discussed in Chapter 7, Sampling and Analytical Methods.

1.4 Exposure Monitoring

An effective workplace monitoring program should include routine environmental monitoring of dermal and inhalation exposures. Such monitoring provides a means of assessing the effectiveness of engineering controls, work practices, and personal protective equipment.

The goal of the environmental sampling strategy is to ensure a more healthful work environment where worker exposure (measured by full-shift samples) does not exceed the REL. Since adverse respiratory health effects can occur at the REL, lower exposures are desirable where feasible. In work where airborne MWF exposures may occur, the initial environmental sampling survey should collect representative personal samples for the entire work shift. Surveys should be repeated at least annually and whenever any

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[‡] Conversion factor from the data of Woskie et al. [1994].

major process change takes place. Surveys should also qualitatively evaluate the workers' potential skin exposures. All routine personal samples should be collected in the breathing zones of the workers. For workers exposed to concentrations above the REL, more frequent monitoring should be undertaken until at least two samples indicate that the worker's exposure no longer exceeds the REL. All workers should be notified of monitoring results and of any control actions taken to reduce their exposures. An environmental sampling strategy should consider variations in work and production schedules and the inherent variability in most environmental sampling [NIOSH 1995].

When the goal of sampling is to determine whether worker exposures are below the REL, random sampling (without a systematic bias excluding high or low exposures for workers or sampling periods) is usually not included in the sampling strategy. Instead, sampling efforts are focused on workers with the highest exposures (i.e., or the maximum-risk workers discussed by Leidel and Busch [1994]). Such targeted strategies are most efficient for identifying exposures above the REL if maximum-risk workers and time periods are accurately identified. However, all workers or worker groups should be periodically sampled to ensure that the targeted sampling includes all workers exposed to MWF aerosols at concentrations above the REL.

Area sampling may be a useful supplement to personal monitoring when determining the source of MWF aerosol exposures and assessing the effectiveness of engineering controls.

1.5 Informing Workers About the Hazards

1.5.1 Safety and Health Training

Employers should establish a safety and health training program for all workers with MWF exposures. Both employees and contract workers should be informed about hazardous chemicals in their work areas and the availability of information from material safety data sheets (MSDSs) or other sources. Workers should also be instructed about the adverse health effects associated with MWF exposures.

Workers should be trained to detect hazardous situations (e.g., the appearance of bacterial overgrowth and degradation of MWFs). Instruction should include information about how workers can protect themselves (e.g., the use of appropriate work practices, emergency procedures, and personal protective equipment).

1.5.2 Hazard Prevention and Control

Workers should be informed that exposures to MWFs during metalworking operations can occur through inhalation of MWF aerosols and through contamination of the skin by settled mists, splashes, dipping of hands and arms into MWFs, or handling of parts coated with MWF. Workers should also know that most exposures can be controlled by a combination of proper MWF use and application, MWF maintenance, isolation of the operation(s), ventilation, and other operational procedures. Workers should be aware that dermal exposures may be reduced by the use of machine guarding and protective equipment such as gloves, face guards, aprons, or other protective work clothes.

1.6 Engineering Controls and Work Practices

Engineering controls and work practices should be used to reduce MWF inhalation and skin exposures in the workplace. A comprehensive control strategy includes guidelines for selecting and using fluids, properly maintaining the fluid, applying the fluids in a manner that avoids unnecessary skin contact and mist generation, containing any generated mist, and exhausting or removing the contained mist.

1.6.1 MWF Selection

The MWFs selected should be as nonirritating and nonsensitizing as possible while remaining consistent with their operational requirements. Petroleum-containing MWFs should be evaluated for potential carcinogenicity using American Society for Testing and Materials (ASTM) Standard D1687–95, *Determining Carcinogenic Potential of Virgin Base Oils in Metalworking Fluids* [ASTM 1997b]. If soluble oils or synthetic fluids are used, ASTM Standard E1497–94 (*Safe Use of Water-Miscible Metalworking Fluids* [ASTM 1997a]) should be consulted for safe-use guidelines, including product selection, storage, dispensing, and maintenance. To minimize the potential for nitrosamine formation, nitrite-containing materials should not be added to MWFs containing ethanolamines.

1.6.2 Fluid Use and Delivery

Many factors influence the generation of MWF mists, which can be minimized through the proper design and operation of the MWF delivery system. American National Standards Institute (ANSI) Technical Report B11 TR 2–1997 (*Mist Control Considerations for the Design, Installation and Use of Machine Tools Using Metalworking Fluids* [ANSI 1997]) provides directives for minimizing mist and vapor generation. These include minimizing fluid delivery pressure, matching the fluid to the application, using MWF formulations with low oil concentrations, avoiding contamination with tramp oils, minimizing the MWF flow rate, covering fluid reservoirs and return systems where possible, and maintaining control of the MWF chemistry.

1.6.3 Fluid Maintenance

A key element in controlling worker exposure to MWFs is the development of a written MWF management plan [ORC 1997]. Components of this plan should include maintenance of the fluid chemistry as well as the fluid filtration and delivery systems.

The machine(s) should be kept clean and free of debris. Parts washing before machining can be an important part of maintaining cleaner MWFs [Joseph 1991].

MWFs should be maintained within the pH and concentration ranges recommended by the formulator or supplier. In addition, they should be maintained at the lowest practical temperature to slow the growth of microorganisms, reduce water losses and change in viscosity, and (in the case of straight oils) reduce the risk of fire.

Drums, tanks, and other containers of MWF concentrates and additives should be stored according to the manufacturers' recommendations. Personal protective clothing and equipment should be used when removing concentrates from the original container, mixing and diluting MWF concentrate, preparing additives (including biocides), and adding MWF emulsions, biocides, or other hazardous ingredients to the coolant reservoir.

Biocides maintain the functionality and efficacy of MWFs by preventing microbial overgrowth. Biocides with a wide spectrum of biocidal activity should be used to suppress the growth of the widely diverse contaminant population. Only the concentration of biocide needed to meet fluid specifications should be used, since overdosing could lead to skin or respiratory irritation in workers, and under-dosing could lead to an inadequate level of microbial control.

MWFs should be routinely monitored and a record should be kept of fluid level in the sump or coolant tank. MWF concentration should be measured by a refractometer or by titration. The fluid pH and the degree of tramp oil contamination should be inspected visually. More frequent testing should be undertaken during hot weather or during periods of increased work output—both of which may result in increased fluid losses [HSE 1994; ORC 1997].

1.6.4 Ventilation Systems

The ventilation system should be designed and operated to prevent the accumulation or recirculation of airborne contaminants in the workplace. General principles for the design and operation of ventilation systems are presented in the following publications:

Industrial Ventilation: A Manual of Recommended Practice [ACGIH 1995];
American National Standard: Fundamentals Governing the Design and Operation of Local Exhaust Systems [ANSI 1979]; and
Recommended Industrial Ventilation Guidelines [Hagopian and Bastress 1976].

Exhaust ventilation systems function through suction openings placed near a source of contamination. The suction opening or exhaust hood creates an air motion sufficient to overcome room air currents and any airflow generated by the process. This airflow captures the contaminants and conveys them to a point where they can either be discharged or removed from the airstream. Exhaust hoods are classified by their position relative to the process as *canopy, side draft, down draft* or *enclosure*. ANSI Technical Report B11 TR 2–1997 [ANSI 1997] contains guidelines for exhaust ventilation of machining and grinding operations. Enclosures are the only type of exhaust hood recommended by the ANSI committee. They consist of physical barriers between the process and the worker's environment. Enclosures can be further classified by the extent of enclosure: close capture (enclosure of the point of operation), total enclosure (enclosure of the entire machine), or tunnel enclosure (continuous enclosure over several machines).

If no fresh make-up air is introduced into the plant, air will enter the building through open doors and windows, potentially causing cross contamination of all process areas. Ideally, all air exhausted from the building should be replaced by tempered air from an uncontaminated location. By providing a slight excess of make-up air in relatively clean areas and a slight deficit of make-up air in dirty areas, cross contamination can be reduced. In addition, this air can be channeled directly to operator work areas, providing the cleanest possible work environment. Ideally, this fresh air should be supplied in the form of a low-velocity air shower (<100 ft/min to prevent interference with the exhaust hoods) directly above the worker.

Some commercial air cleaners recirculate exhaust in the workplace. The filters on these units should be inspected for physical integrity and filter loading, and airflow should be measured. Detailed recommendations for air recirculation are contained in *Industrial Ventilation: A Manual of Recommended Practice* [ACGIH 1995]. A better practice might be to connect such machines into a duct system discharging outdoors through a single, larger mist collection unit (see Section 9.4.4, Ventilation Systems).

1.6.5 Protective Clothing and Equipment

Engineering controls are used to reduce worker exposure to MWF aerosols. But in some situations, the added protection of chemical protective clothing (CPC) and equipment (e.g., respirators) should be provided in the event of dermal contact with the MWFs or airborne exposures that exceed the NIOSH REL. Maintenance staff may also need CPC because the nature of the work requires contact with MWFs during certain operations. All workers should be trained in the proper use and care of CPC. After any item of CPC has been in routine use, it should be examined to ensure that its effectiveness has not been compromised. The following recommendations should be used as a guide to the selection of CPC.

When evaluating the performance of CPC materials, three factors should be considered: the chemical resistance of the materials, the physical properties of the materials, and the human factors associated with the materials. Chemical resistance testing of CPC evaluates the interaction between challenge chemicals and the garment material. When feasible, selection of CPC must be based on specific permeation data. Furthermore, the chemical permeation properties of chemical mixtures must be determined by testing—not inferred from the permeation characteristics of the individual constituents of mixtures. Physical properties of CPC are important to barrier performance. Key physical properties for gloves are resistance to flexing, tearing, abrasions, cuts, and punctures. Evaluations of ergonomic factors such as dexterity and grip involve physical properties that are governed by glove thickness. Surface texture is another important property; grip is enhanced by a rough surface. The physical requirements of the task must be balanced against the chemical resistance requirements and the human factors. CPC must protect the worker but must not unduly restrict worker performance.

The physical and chemical properties of CPC may sometimes be derived from tables, charts, and general references used to select the CPC. Chemical resistance data specific to a brand of CPC and physical properties of these materials may be available from the manufacturer. Because few references are available on CPC material for MWFs, selection is based on limited data collected for one cutting oil and one emulsifiable cutting fluid. According to the available data, nitrile affords the most chemical resistance [Forsberg and Mansdorf 1993]. The physical properties of nitrile are rated as excellent for abrasion, tear and puncture resistance, and flexibility. In addition, Silvershield™ and 4H™ material are believed to afford protection similar to that of nitrile. Approximate service life is 4 hr for these materials.

CPC for MWFs should protect the wearer from chemicals as well as punctures, cuts, and abrasions. The use of gloves may increase the risk of injury from possible entanglement in moving tool or workpiece parts. If gloves are required, special attention should be given to guarding the equipment and ensuring that the glove will tear easily if entangled. Workers should also wear safety shoes with slip-resistant soles. Workers should wear faceshields or goggles, protective sleeves, aprons, trousers, and caps as needed to protect the skin from contact with MWFs.

1.7 Respiratory Protection

Respirators should not be used as the primary means of controlling worker exposures. Instead, effective engineering controls (such as machine enclosures or local exhaust ventilation) should be implemented to minimize routine exposures to MWF aerosol. However, workers may use respirators when engineering controls are being implemented and intermittent tasks expose them to concentrations that cannot be kept below the REL by engineering controls alone.

If respiratory protection is needed, the employer should establish a comprehensive respiratory protection program as outlined in the *NIOSH Respirator Decision Logic* [NIOSH 1987b] and the *NIOSH Guide to Industrial Respiratory Protection* [NIOSH

1987a] and as required in the Occupational Safety and Health Administration (OSHA) respiratory protection standard [29 CFR[§] 1910.134]. Respirators should be selected by the person who is in charge of the program and knowledgeable about the workplace and the limitations associated with each type of respirator.

Selection of the appropriate respirator depends on the operation, MWF chemical components, and airborne concentrations of MWFs in the worker's breathing zone (see Chapter 9, Table 9–1). Additional guidance on the selection of respirators can be found in the *NIOSH Respirator Decision Logic* [NIOSH 1987b].

1.8 Sanitation and Hygiene

Workers should be encouraged to maintain good personal hygiene and housekeeping practices to reduce their exposures and to prevent MWF contamination of the environment.

Employees should be encouraged to clean MWF-contaminated skin periodically with gentle soaps, clean water, and clean towels. Workers should not need to place their unprotected hands and arms repeatedly into MWFs. Barrier creams may be useful for some workers, but their protective effects are controversial. The use of nonbarrier cream moisturizers may also be protective.

1.9 Medical Monitoring

Medical monitoring (together with any intervention based on results of medical monitoring) represents secondary prevention and should not supplant primary prevention efforts to control inhalation and skin exposures to MWF aerosol. However, as indicated by evidence reviewed in this document, the 0.4-mg/m^3 (thoracic particulate mass) REL for MWF aerosol does not remove all risk for the development of skin or respiratory disease among exposed workers. Medical monitoring is therefore needed for early identification of workers who develop symptoms of MWF-related conditions such as asthma, HP, and dermatitis. If identified early, affected workers can control their exposures and minimize their risks of acute or chronic effects. Another important objective of medical monitoring is to provide standardized data on exposed workers to identify work areas in need of additional primary prevention efforts.

All exposed workers may benefit by inclusion in an occupational medical monitoring program. However, priority should be given to those at highest risk. All workers exposed to MWF aerosol concentrations above a designated level (e.g., half of the REL) should be included. Medical monitoring should be conducted regardless of exposure

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[§] *Code of Rederal Regulations*. See CFR in references.

concentration in work areas where one or more workers have recently developed asthma, HP, or other serious conditions apparently related to MWF exposure. Medical monitoring should be more intense in work areas where exposures are higher or where more workers have more numerous or more severe adverse health effects.

All exposed workers should be provided with appropriate education and training—particularly in the area of self-referral for further medical evaluation if they develop symptoms suggestive of asthma, HP, other respiratory conditions, or dermatitis.

1.9.1 Supervision of the Medical Monitoring Program

The employer should assign responsibility for the medical direction and supervision of the program to a qualified physician or other qualified health care provider (as determined by appropriate State laws and regulations) who is informed and knowledgeable about the following:

- The respiratory protection program
- The identification and management of occupational asthma and other work-related respiratory effects or illnesses
- The identification and management of occupational skin diseases

The employer should provide the necessary information for each worker covered by the medical monitoring program, including the following:

- Current and previous job descriptions
- Hazardous exposures
- Actual exposure measurements
- Personal protective equipment
- Relevant MSDSs
- Applicable occupational safety and health standards

Anyone who administers spirometric tests as part of an occupational medical monitoring program should have completed a NIOSH-approved training course in spirometry or other equivalent training. All spirometry equipment and procedures should comply with American Thoracic Society guidelines that are current at the time of the testing (e.g., ATS [1995]).

1.9.2 Initial or Preplacement Examinations

Newly hired workers and workers transferred from unexposed work areas should receive the initial medical examination before they are assigned to jobs involving exposure to MWF or MWF aerosol. At a minimum, the initial examination should consist of a standardized questionnaire about symptoms, a medical history (of asthma, other serious respiratory conditions, and skin diseases), and an examination of the skin. Baseline spirometric testing may also be useful for comparing results from subsequent tests.

1.9.3 Periodic Examinations

All workers included in the medical monitoring program should receive periodic screening examinations that include a brief standardized questionnaire. The frequency of these examinations for a specific worksite should be dictated by the frequency and severity of health effects in the worker population. They may be semiannual, annual, or biannual. In the absence of a case of disease associated with MWF, an annual examination would be reasonable.

1.9.4 Detailed Medical Examinations for Selected Workers

A worker should undergo additional or more frequent detailed medical evaluations if he or she

- has respiratory symptoms (or physiologic effects) suggestive of asthma or another respiratory condition possibly related to MWF aerosol exposure, or
- has recurrent or chronic dermatitis, or
- is judged by the program director or supervisor to have a medically significant reason for more detailed assessment (see Section 9.8.4, Detailed Medical Examination for Selected Workers).

1.9.5 Physician's Reports to the Worker

Following each examination (initial, periodic, or detailed), the physician should provide a written report to the worker that includes (1) the results of any medical tests performed on the worker, (2) the physician's opinion about any medical conditions that would increase the worker's risk of impairment from exposure to MWF or MWF aerosols (or any other agents in the workplace), (3) the physician's recommended restrictions on the worker's exposure to MWF or MWF aerosols (or any other agents in the workplace) and on the worker's use of respiratory protective devices and/or protective clothing, and (4) the physician's recommendations about further evaluation and treatment of any detected medical conditions.

1.9.6 Physician's Reports to the Employer

Following each examination (initial, periodic, or detailed), the physician should provide a written report to the employer that includes (1) the physician's recommended restrictions on the worker's exposure to MWF or MWF aerosols (or any other agents in the workplace) and on the worker's use of personal respiratory protective devices and/or protective clothing, (2) a statement that the worker has been informed about the results of the medical examination and of any medical conditions that should have further evaluation and treatment, and (3) a signed authorization from the worker permitting the employer to receive the report if it reveals specific findings or diagnoses.

1.9.7 Employer Actions

Medical monitoring and followup medical evaluations should be provided without cost to workers. The employer should assure that the physician's recommended restrictions on exposures and on the use of personal protective equipment are not exceeded. The employer should ensure that the program director or supervisor regularly collaborates with the employer's safety and health personnel (e.g., industrial hygienists) to identify and control work exposures and activities that might place workers at risk.

1.9.8 Followup Medical Evaluations

Workers who are transferred as a result of the physician's opinion should be re-evaluated later to document that the intended benefit (e.g., reduced symptoms and/or reduced physiologic effects) has been achieved. Transferred workers should continue to be monitored periodically until they have been asymptomatic for at least 2 years. If symptoms persist, the responsible physician should carefully consider any continuing (e.g., irritant) exposures that may be exacerbating the worker's condition.

In addition, workers who have negative physiologic test results despite symptoms suggestive of asthma should be carefully followed and should receive another medical evaluation during an episode of acute symptoms.

1.10 Labeling and Posting

Warning labels and signs should be posted on or near hazardous metalworking processes. Depending on the process and MWF exposure concentration, warning signs should state the need to wear protective clothing or an appropriate respirator for exposure to MWF aerosol concentrations exceeding the REL.

If respiratory protection is required, the following statement should be posted:

RESPIRATORY PROTECTION REQUIRED IN THIS AREA

All labels and warning signs should be printed in both English and the predominant language of workers who do not read English. Workers unable to read the labels and signs should be informed verbally about the hazards and instructions printed on the labels and signs.

CHAPTER 2

Production, Formulation, Application, and Deterioration

The term *metalworking fluids (MWFs)* is commonly used in the lubricant production and compounding industries and in the manufacturing industries that perform machining, grinding, forming, or treating operations. This generic term encompasses coolants and lubricants used during the fabrication of products from metals and metal substitutes to prolong the life of machine tools, carry away metal chips, and protect or treat the surfaces of the material being processed. The discussions presented in this document pertain to MWFs formulated and manufactured for grinding and machining operations. Manufacturers and formulators have identified four MWF subgroups: metal-removal fluids, metal-forming fluids, metal-protecting fluids, and metal-treating fluids [Howell 1996]. See Sections 1.2.1 and 1.2.2 for definitions of MWF aerosol and the metalworking environment.

A variety of factors must be examined to evaluate worker exposures to MWFs thoroughly. Inhalation and skin exposures in the metalworking environment include those resulting from aerosolization and splashing of MWFs from fluid application, machining processes, and other operations. Workers may be exposed to the metals being machined, residues from preceding operations, MWF additives, MWF contaminants from housekeeping and cleaning processes, biological contaminants (e.g., bacterial toxins and metabolic products), and physical contaminants (e.g., chips and fines). Excessive exposure may be caused by inadequate machine enclosures, poorly designed ventilation systems, high-pressure or excessive fluid application, contamination of the MWFs with tramp oils, improper selection of the MWFs, and lack of maintenance.

2.1 Production and Use

MWFs were first used in the early 1900s to prolong the tool life of metalworking equipment [Newhouse 1982]. The Independent Lubricant Manufacturers Association (ILMA) reported that 71.5 million gallons of MWFs were produced in the United States in 1992 [ILMA 1993]. These fluids (i.e., cutting oils, machining fluids, lubricants, and coolants) reduce friction between the cutting tool and the work surface, reduce wear and galling, protect surface characteristics, reduce surface adhesion or welding, carry away generated heat, and flush away swarf, chips, fines, and residues [Nachtman and Kalpakjian 1985]. MWFs are designed for use in various machining operations such as turning, grinding, boring, tapping, threading, gear shaping, reaming, milling, broaching, drilling, hobbing, and band and hack sawing [Weindel 1982].

2.2 Formulation

MWFs are grouped into four major classes: straight oil, soluble oil, semisynthetic, and synthetic MWFs (see Section 1.2.3 and Table 2–1).

2.2.1 Straight Oil MWFs

Straight oils (cutting oils) function as lubricants, improve the finish on the metal cut, and prevent rusting [Frazier 1982; CRC 1985]. Depending on the application, petroleum oils used in straight oil MWFs are usually mineral oils from highly refined naphthenic (generally saturated, ring-type structures) or paraffinic oils (straight or branched-chain saturated hydrocarbons) [Bigda and Associates 1980]. The lubricant base oils may also be reprocessed oils from various sources.

Mineral oils may serve as a blending medium or as an additive carrier in straight oils. Mineral oils may be derived from highly refined petroleum stocks or from reprocessed oils of unknown origin. Animal, marine, or vegetable oils may be used singly or in combination with straight oils to increase the wetting action and lubricity [Cookson 1971]. Straight oils containing both fatty oil and sulfur additives provide greater lubricity, whereas those containing sulfochlorinated mineral oils have improved antiweld properties* over a wide temperature range. Sulfochlorinated mineral oils with fatty oils added are good for heavy-duty, slow-speed operations [CRC 1985]. ILMA [1996] reports that current formulations have reduced or eliminated the addition of both sulfur and chlorine compounds.

2.2.2 Soluble Oil MWFs

Soluble MWFs (emulsions and water soluble oils) cool and lubricate to prevent welding of the cutting tool to the work surface, reduce abrasive wear of the tool at high temperatures, and prevent distortion caused by residual heat [Frazier 1982]. The mineral oils (paraffinic or naphthenic base oils) of soluble MWFs are blended from highly refined, high-viscosity oil bases. Soluble MWF concentrates are diluted with water before use [ILMA 1996]. They contain surface-active emulsifying agents to maintain the oil-water mix as an emulsion [Cookson 1971; Menter et al. 1975]. Superfatted emulsions of soluble MWFs are produced by the addition of fatty oils, fatty acids, or esters; extreme-pressure emulsions for very heavy-duty operations are produced with the addition of sulfur, chlorine, or phosphorus derivatives [CRC 1985].

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*That is, properties that prevent the welding of the tool with the workpiece or chips.

Table 2–1. Components of the four MWF classes (undiluted)[*]

		Amount			
Component	**Function**	**Straight oils**	**Soluble oils**	**Semi-synthetics**	**Synthetics**
Water	Acts as coolant solvent, diluent	Dissolved 10–500 ppm/wt[†]	5–40 parts/ 1 part concentrate	10–40 parts/ 1 part concentrate	10–40 parts/ 1 part concentrate
Mineral oil	Carries lubrication	60%–100%	30%–85%	5%–30%	‡
Emulsifier	Emulsifies	‡	5%–20%	5%–10%	5%–10%
Chelating agents	Tie up ions in solution	‡	0%–1%	0%–1%	0%–1%
Coupling agents	Stabilize	‡	1%–3%	1%–3%	1%–3%
Viscosity index improvers	Maintain viscosity	§	‡	‡	‡
Detergent	Prevents deposit formation	§	§	§	§
Plasticizer	Reduces tackiness	‡	§	§	§
Antimist agent	Reduces misting	§	§	‡	‡
Antiweld agent	Prevents welding	0%–20%	0%–20%	0%–10%	0%–10%
Oiliness agent	Increases film strength	§	‡	‡	‡
Surfactant wetting agent	Reduces surface tension	0%–10%	5%–20%	10%–20%	10%–20%
Dispersants	Prevent fine agglomeration and deposit formation	§	‡	‡	‡
Passivator	Prevents staining	§	‡	‡	‡
Anti-foaming agents	Prevent foaming	0–500 ppm	0–500 ppm	0–500 ppm	0–500 ppm

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See footnotes at end of table.

(Continued)

Table 2-1 (Continued). Components of the four MWF classes (undiluted)[*]

Component	Function	Amount			
		Straight oils	Soluble oils	Semi-synthetics	Synthetics
Alkaline reserve	Acts as buffer control	[‡]	2%–5%	2%–5%	2%–5%
Dyes	Identify, leak detection	[‡]	0–500 ppm	0–500 ppm	0–500 ppm
Odorant	Masks odor	[§]	[§]	[§]	[§]
Corrosion inhibitors, anti-rust	Prevent rust film barrier	0%–10%	3%–10%	10%–20%	10%–20%
Biocides, bioresistant components	Control bacterial and fungal contaminants	[‡]	0%–2%	0%–2%	0%–2%
Extreme pressure additives	Act as reaction lubricant films	0%–40%	0%–20%	0%–10%	0%–10%

[*] Adapted from Key et al. [1983], ILMA [1990, 1994a], and Howell [1996].

[†] CRC [1985]. Dissolved water concentrations in mineral oils range from 10 to 100 mol per million carbon atoms, depending on ambient humidity and temperature.

[‡] Not present in this MWF class.

[§] Usually present in this MWF class.

2.2.3 Semisynthetic MWFs

Semisynthetic MWFs contain small amounts of oil (5% to 30% in the concentrate) and may be formulated with fatty acids, sulfur, chlorine, and phosphorus derivatives to provide lubrication for higher speeds and feed rates [CRC 1985].

2.2.4 Synthetic MWFs

Synthetic MWFs contain no petroleum oil. The simplest synthetics are made with organic and inorganic salts dissolved in water. They offer good rust protection and heat removal but usually have poor lubricating ability. Others may be formulated with synthesized hydrocarbons, organic esters, polyglycols, phosphate esters, and other synthetic lubricating fluids [CRC 1985]. Synthetics are stable, can be made bioresistant [Passman 1992], and provide effective cooling capacity at high speeds and feeds. They eliminate smoking, reduce misting, and provide detergent action and oxidative stability [Vahle 1982].

2.2.5 MWF Ingredients and Additives

Refined petroleum oils may be used as base oils in all MWFs except the synthetics. The chemical constituents in these refined oils depend on the original crude and the refining processes. Refined petroleum oils are complex mixtures of hydrocarbons (aromatics, naphthenes, paraffins, and cycloparaffins), metal compounds, and organic compounds containing sulfur, oxygen, and nitrogen. Less variability exists among the finished oils as the refining processes increase in severity. Solvent extraction or severe hydrotreating can reduce the total aromatic hydrocarbon content. Severe treatment with fuming sulfuric acid can almost completely remove aromatics, including polyaromatic hydrocarbons (PAHs) [IARC 1984].

2.3 MWF Application

MWFs can be manually applied to the cutting zone of the tool and the work or delivered as a mist in a high-velocity air stream. A continuous stream of MWF delivered by a low-pressure pump (a minimum pressure may be necessary for adequate operation) can be directed through a nozzle at the cutting edge of the machine tool or through the tool and over the work to carry away the metal chips or swarf. A variety of fluid nozzle designs are available, depending on the application needed [Smits 1994]. A distribution system may be used to control MWF flow volume and flow pressure. The MWF recirculating system and sump can be complex and may contain large amounts of MWFs. The MWFs are routinely collected through gravity flow, velocity flow, or conveyorized trenches. They are then recirculated to the cutting zone of the machine tool through filtration systems, chip-handling conveyors, belt skimmers or decantation tanks (to remove contaminating substances such as tramp oils), and chillers or plate-and-frame heat exchangers. Table 2–2 lists general applications of MWFs, and Table 2–3 lists general types of process and ancillary chemicals.

2.4 Deterioration of In-Service MWFs

Physical, chemical, and microbial effects can cause in-service MWFs to deteriorate. Contaminants such as wear debris, rust, weld spatter, lint, metal chips and abrasives, as well as contaminants entering through broken seals, dirty oil filter pipes, chemical residue on components, or the addition of incorrect additives can accelerate MWF breakdown. Depending on the alloy being machined and the machining process, metal particulate or dissolved metal may contaminate the MWFs. Machining or parts manufacture includes a variety of process operations from parts machining to assembly of the finished product. During many of these operations, process chemicals and ancillary lubricants may contaminate the MWFs. Industrial lubricants and in-process cleaners may leak into or be carried by parts being machined and contaminate the fluids.

Table 2–2. General applications of MWFs*

General categories	General application	Formulation technology
Removal fluids	Machining and grinding, honing	Straight or neat oil, soluble or emulsifiable oil, synthetic, semisynthetic
Forming fluids	Stamping, drawing, coining, cold heading, wire/bar/rod drawing, piercing, forging, rolling, other	Straight or neat oil, soluble or emulsifiable oil, synthetic, semisynthetic
Protecting fluids†	Fingerprint displacing, indoor or outdoor storage, other	Straight or neat oil, soluble or emulsifiable oil
Treating fluids	Quenching, other	Straight oil, soluble or emulsifiable oil, synthetic

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†Protecting fluids are often brought in on sheet steel products during stamping operations and offer shorter-term protection compared with the protection provided by coatings or phosphatized surfaces.

Table 2–4 lists industrial lubricants that are used around machine tools and that may leak into and contaminate the MWFs as "tramp oils." Table 2–5 describes the general use of in-process cleaners in surface preparation during routine machining processes. Many intermediate cleaning steps can be included throughout a component manufacturing process, and in-process cleaners may repeatedly contaminate MWFs. In addition, oil may degrade from excessive temperatures.

The oxidation of MWF oils and constituents can lead to the formation of acids, resins, varnishes, sludges, and carbonaceous deposits. Alkanolamine concentration may increase over time. Addition of makeup water may increase metal salts, which tend to destabilize semisynthetic and soluble MWFs [ILMA 1996]. MWFs may increase in viscosity, and oil-insoluble solids may plug orifices, pipes, and filters, restricting flow or causing sticking of machining components. Water can cause corrosion problems and affect the MWF viscosity and oxidation rate. Other additives such as biocides and anticorrosives may be depleted with use, requiring routine product addition or supplemental additions to maintain MWF performance.

Additional contaminants from the working environment such as food scraps, floor sweepings, cigarette butts, etc. can cause changes in MWFs. Bacterial and fungal contamination and growth can cause the chemical breakdown of MWFs; in addition, they may release endotoxin and other substances into the MWFs. Microorganism growth and contamination and release of toxins are discussed in Section 4.2.2.

Table 2–3. MWF operations including process chemicals and ancillary lubricants*

Process	Operation	Process chemicals	Ancillary lubricants
Forming	Casting, forging, rolling, stamping, piercing, coining, drawing, and press forming	Die cast lubes, forging compounds, rolling oils, drawing lubricants	Hydraulic fluids, greases, and bearing lubes
Machining	Deburring, boring, milling, honing, drilling, grooving, turning, tapping, chamfering, broaching, and grinding	All classes of MWFs	Spindle oils, gear lubes, way lubes, hydraulic fluids, greases, chain lubes, and bearing lubes
Heat treating	Quenching, martempering, and carburization	All types of quenching fluids, martempering oil, and carburizer	Hydraulic fluids, greases, and bearing lubes
Finishing	Reaming, honing, lapping, grinding, and straightening	Honing oil, tapping compounds, and MWFs	Spindle oils, gear lubes, way lubes, hydraulic fluids, greases, chain lubes, and bearing lubes
Cleaning and surface preparation	Cleaning, drying, degreasing, phosphatizing, and painting	Cleaning compounds, degreasers, paint, and phosphatizing agents	Greases and bearing lubes
Assembly	Assembling	Degreasers and cleaning compounds	Hydraulic fluids and greases

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Table 2–4. Industrial lubricants: formulation and application*

Industrial lubricants	Formulation	Application
Hydraulic oils	Rust and oxidation inhibited oils and antiwear hydraulic oils, water glycol fluids, phosphate and polyol esters, water/oil emulsions	Machine tool/transfer line hydraulic systems
Spindle oils	Neat oils	Machine oils
Slidway lubricants	Neat oils	Machine tools, transfer lines
Gear lubricants	High- and extreme-pressure gear oils, open gear lubricants	Machine tools, transfer lines, gear boxes, open gears
Greases	Lithium, aluminum complex, polyurea, barium complex, calcium complex, clay	Bearings
Wire rope lubricants	Pigmented/nonpigmented neat oils, greases	Wire rope

*Submitted by ILMA [1996].

Table 2-5. In-process cleaners*

In-process cleaners	Formulation	Application
Alkaline	High-pH inorganic binders, chelators, surfactants, cosolvents; high-pH organic amines, surfactants, and cosolvents	Component cleaning, rust removal, corrosion prevention
Acid	Low-pH inhibited phosphoric, sulfuric, muriatic	Metal preparation and rust removal
Emulsion	Oil/solvent emulsion surfactants	Component cleaning
Solvent	Hydrocarbon terpene	Component cleaning

*Submitted by ILMA [1996].

CHAPTER 3

Potential for Occupational Exposures to MWFs

Workers can be exposed to MWFs through skin contact by (1) exposure to splashes and aerosols during immersion or flooding of the machine tool or work, and (2) handling parts, tools, and equipment covered with MWFs. Workers may also be exposed to MWFs by inhalation of aerosols [Bennett and Bennett 1987]. During machining of parts, workers are exposed by MWF flow through fluid circulation systems, air cleaners in a recirculating local exhaust ventilation system, adjacent operations, and persistence of fugitive emissions in workroom air.

3.1 The National Occupational Exposure Survey

The National Occupational Exposure Survey (NOES) [NIOSH 1983] was conducted by NIOSH during 1981–82 to estimate the number of workers potentially exposed to chemical, physical, and biological agents. The NOES database consists of a stratified probability sample of 4,490 businesses in 98 U.S. geographic locations representative of the nonagricultural, nonmining, and nongovernment businesses covered under the Occupational Safety and Health Act of 1970 (Public Law 91–596).

The NOES lists an estimated 1.2 million workers who are potentially exposed to agents collectively called *metalworking fluids* in 39 industry codes (2-digit Standard Industrial Classification [SIC] Codes). Approximately 59% of all workers potentially exposed to MWFs were employed in three industrial categories (Table 3–1), and 35% of the total were employed in the category *Machinery, except electrical* (SIC 35).

The largest number (67%) of all workers potentially exposed to MWFs belonged to three occupational groups identified in Table 3–2.

3.2 Occupational Exposures to Mineral Oil Mists

The Integrated Management Information System (IMIS) developed by OSHA tracks a substantial cross-section of industrial occupational exposures and compiles this information under SIC Codes. An examination of airborne mineral oil mist exposures in industries identified by SIC Codes found little evidence of substantial inter-industry differences in mean exposure concentrations. From 1979 to 1995, the occupational exposure data compiled in IMIS demonstrate a steady decline in airborne exposure

Table 3-1. Industries with the largest number of workers potentially exposed to MWFs*

		Workers exposed full time†		Workers exposed part time	
SIC Code	Description	Number	%	Number	%
35	Machinery, except electrical	151,300	37	286,000	34
34	Fabricated metal products	70,900	18	117,300	14
37	Transportation equipment	58,900	15	66,800	8
All	All industries	403,800	100	832,800	100

*Source: NIOSH [1983].
†Note: Workers exposed to one MWF full time may be exposed to a second MWF part time.

Table 3-2. Occupations with the largest number of workers potentially exposed to MWFs*

Bureau of the Census occupational code	Description	Number of workers exposed full time†	Number of workers exposed part time
637	Machinists	171,200	291,600
779	Machine operators (not specified)	56,100	130,300
777	Miscellaneous	60,800	111,900
All	All occupations	403,800	832,800

*Source: NIOSH [1983].
†Note: Workers exposed to one MWF full time may be exposed to a second MWF part time.

concentrations (Table 3-3). The arithmetic mean concentration for all samples collected during this period was 0.92 mg/m^3 (total particulate mass). The percentage of total aerosol exposures of less than 0.5 mg/m^3 increased from 36.7% before 1980 to 73% after 1990. The arithmetic mean concentration for the period 1989–94 was 0.49 mg/m^3.

3.3 NIOSH Health Hazard Evaluations

Since 1967, NIOSH has conducted more than 70 health hazard evaluations (HHEs) of industries with occupational exposures to MWFs or mineral oil aerosols. Skin disorders (skin irritation, eczema, rashes, oil acne) were the most frequently reported health problems, followed by complaints of eye, nose, and throat irritation (mucous membrane irritation) and respiratory symptoms or disorders (breathing problems, cough, chest tightness, asthma).

Exposure data from 38 HHEs indicate that airborne MWF exposures have generally decreased over time. The arithmetic mean personal exposure concentrations (total particulate mass) were 1.23 mg/m^3 (n=21 plants) in the 1970s, 0.57 mg/m^3 in the 1980s (n=15 plants), and 1.0 mg/m^3 in the 1990s (n=2 plants): the latter increase is based on only two plants. The overall mean concentration for the 38 plant-based HHEs was 0.96 mg/m^3. The exposure data collected at these 38 plants show airborne concentrations similar to those in the OSHA IMIS data set. These two data sets indicate an overall reduction in airborne MWF exposures since 1980.

3.4 Reported Exposures in the Automotive Industry

Kriebel et al. [1994], Greaves et al. [1995a,b; 1997], and Robins et al. [1994] examined the respiratory effects and associated MWF airborne exposures for automobile component manufacturing workers. All three investigators reported an arithmetic mean MWF airborne exposure concentration of <1.0 mg/m^3. Kriebel et al. [1994] reported mean exposure concentrations of 0.24 mg/m^3 (total aerosol mass, 7-hole sampler) for straight oil MWF aerosols and 0.22 mg/m^3 for soluble oil MWFs. Greaves et al. [1995a,b; 1997] reported similar concentrations with mean concentrations (thoracic fraction) for several plant surveys; the mean concentration ranged from 0.2 to 0.68 mg/m^3 for straight oil MWFs and from 0.35 to 0.65 mg/m^3 for soluble oil MWFs; it was 0.41 mg/m^3 for synthetic fluids. Likewise, Robins et al. [1994] reported soluble MWF exposures for automotive parts manufacturing workers of 0.1 to 0.6 mg/m^3 (thoracic fraction). Airborne MWF concentrations significantly declined during the period 1958–87, with an arithmetic mean concentration of 5.42 mg/m^3 (total aerosol mass) observed before 1970 and 1.82 mg/m^3 after 1980 [Hallock et al. 1994]. The three data sources (OSHA IMIS, NIOSH HHEs, and the epidemiologic studies mentioned earlier [Kriebel et al. 1994; Greaves et al. 1995a, 1997; Robins et al. 1994, 1997; Sprince et al. 1997]) suggest that the average airborne aerosol exposures in the 1990s are lower (<1.0 mg/m^3) than the 1.8 mg/m^3 aerosol exposures recorded for the 1980s by Hallock et al. [1994].

Table 3–3. Mineral oil mist air-sampling data collected by OSHA inspectors, February 1979–February 1995[*]

Range of mineral oil mist in samples[†] (mg/m^3)	Samples collected									
	Before 1980		1980–84		1985–90		After 1990		Total	
	Number	% total	Number	% total	Number	% total	Number	% total	Number	% total
0.00[‡]	22	20.18	62	12.25	221	25.40	182	34.60	487	24.21
>0.0–≤0.1	1	0.90	15	2.96	58	6.66	37	7.03	111	5.51
>0.1–≤0.3	5	4.58	72	14.22	166	19.08	114	21.67	357	17.75
>0.3–≤0.5	12	11.00	66	13.04	108	12.41	51	9.69	237	11.78
>0.5–≤1	20	18.34	32	6.32	23	2.64	26	4.94	101	5.02
>1	49	44.95	259	51.18	294	33.79	116	22.05	718	35.70
Total	109	100.00[§]	506	100.00[§]	870	100.00[§]	526	100.00[§]	2,011	100.00[§]

[*] Source: IMIS [1995].
[†] Table includes personal and area samples.
[‡] Nondetectable.
[§] Column does not add to 100 because of rounding.