5.3.3.13 Hematopoietic and Lymphopoietic Cancer

One of three cohort studies reporting data on hematopoietic and lymphopoietic cancers found a significantly increased risk (Table 5–17). Tolbert et al. [1992] found that white men ever exposed to soluble oil MWFs had an increased risk for leukemia (SMR=1.33, 95% CI=1.05–1.67), but Poisson regression models found no evidence for an association between leukemia and any class of MWF. Another SMR study found an elevated lymphopoietic cancer risk in a small subgroup (workers employed 1 or more months in the tool and die area of an automotive stamping plant) (MOR=5.38, 95% CI=1.6–18.0, based on three lymphopoietic cancer deaths) [Park et al. 1994]. Among five PMR studies, none found significantly elevated PMRs in the overall analyses. However, Park and Mirer [1996] found that workers who ever worked in grinding with soluble oil MWFs had an increased risk for non-Hodgkin's lymphoma and multiple myeloma (MOR=4.1, 95% CI=1.1–15). Silverstein et al. [1988] found that workers employed as tool grinders for 10 or more years had an increased risk for lymphopoietic cancer (PMR=4.75, P=0.02). Mallin et al. [1986] found an elevated risk for non-Hodgkin's lymphoma among black workers (PMR=6.87, $P<0.05$). In each of these three studies, the authors speculated that solvent exposure [Park and Mirer 1996; Silverstein et al. 1988; Mallin et al. 1986] or biocides [Park and Mirer 1996], rather than MWF fluid exposure, were likely to be responsible for the elevated risks. A population-based case-control study that examined the association between several cancer sites and occupational exposure to several petroleum-derived liquids found evidence suggesting a dose-response relationship between cutting oil exposure and an increased risk for non-Hodgkin's lymphoma (OR among those defined as substantially exposed=1.9, 90% CI=1.0–3.1) [Siemiatycki et al. 1987].

5.3.4 Genetic Effects

Only one epidemiologic study was identified that examined genotoxicity among workers exposed to MWF [Fuchs et al. 1995]. In a German study of 65 male metal workers exposed to synthetic MWFs in seven small-to medium-sized plants, those who worked in areas having a NDELA concentration greater than 500 ng/m^3 had a significantly elevated mean number of DNA strand breaks in mononuclear blood cells compared with workers employed in areas with less than 50 ng/m^3 NDELA (1.69 ± 0.34 workers in areas with greater than 500 ng/m^3 NDELA versus 0.76 ± 0.05 for workers in areas with less than 50 ng/m^3 NDELA, $P<0.01$) [Fuchs et al. 1995]. The average concentration of NDELA present in the cutting fluids at these plants was 20.6 ppm (range 2–135 ppm). In addition, nonsmokers who worked more than 4.5 hr/day had a significantly elevated mean number of DNA strand breaks compared with nonsmokers who worked less than 4.5 hr/day (1.34 ± 0.12 for those working more than 4.5 hr/day versus 0.91 ± 0.12 for those working less than 4.5 hr/day, $P<0.02$). Airborne concentrations of MWFs were not reported. NDELA is a contaminant that may be present in some MWFs and can be formed in MWFs when DEA or TEA reacts with a nitrosating agent (e.g., nitrite). This study provides evidence that nitrosamine exposure may be genotoxic. However, in 1984, EPA prohibited the addition of nitrosating agents to MWF (as previously discussed in Chapter 6).

5.3.5 Information about Exposure Concentrations

Only a few studies described in this chapter provided information about the MWF exposure concentrations during the decades when the MWF-exposed cohorts were employed [Järvholm and Lavenius 1987; Hallock et al. 1994; Silverstein et al. 1988; Park et al. 1988; Park and Mirer 1996]. A summary of the exposure information from these studies is provided below. Additional detail about MWF exposures can be found elsewhere in this document.

In the Järvholm study, the investigators estimated that cutting oil mist concentrations before 1965 were 5 mg/m^3 or greater in the grinding and turning departments. All workers in this study were exposed to these concentrations, since the criteria for inclusion in the study required employment in the turning or grinding department at any time between 1950 and 1966 and a duration of employment of at least 5 years. In the late 1970s, oil mist concentration was reduced to 2 mg/m^3 in the turning departments and to 3 mg/m^3 in the grinding departments.

Estimates of cutting oil exposures were also made for the three plants studied by Eisen et al. [1992] and Hallock et al. [1994]. The estimates were made by fitting industrial hygiene aerosol concentration measurements made between 1958 and 1987 into a linear statistical model. As demonstrated in Table 5–18, MWF exposures from grinding operations were higher than exposures from machining or assembly operations for all three time periods.

Exposure measurements from which these summaries are compiled may not be representative of the plant environment as a whole. Most (57%) of the industrial hygiene reports did not indicate the reason for sampling. The remainder were done at employee or management request, or they were performed by the State health department [Hallock et al. 1994]. It is possible, therefore, that these averages may be higher than the true plant averages because the measurements represent complaint sampling of higher than average exposures [Hallock et al. 1994].

Similar data were reported by Silverstein et al. [1988] and Park et al. [1988]. Silverstein et al. [1988] reported that between 1949 and 1961, industrial hygiene breathing zone samples for total particulate mass in machining areas had a mean level of 15.9 mg/m^3. Breathing zone samples from grinders taken during 1977–79 and in 1980 had mean total particulate masses of 1.7 and 4.3 mg/m^3, respectively. Park et al. [1988] found that breathing zone total particulate mass concentrations near jobs performed with straight MWFs (machining operations) ranged from 0.07 to 2.8 mg/m^3 between 1972 and 1980.

Table 5–18. Estimated mean aerosol concentrations for grinding, machining, and assembly operations, by time period

	1958–69		1970–79		1980–87	
Operation	Number of measurements	Mean concentration (mg/m^3)	Number of measurements	Mean concentration (mg/m^3)	Number of measurements	Mean concentration (mg/m^3)
Grinding	7	17.96	71	3.44	56	2.28
Machining	25	3.35	128	2.13	61	1.66
Assembly	8	0.94	23	0.52	15	0.64

During these same years, concentrations near grinding operations (which were presumed to be using soluble oil MWFs) ranged from 0.6 to 7.2 mg/m^3. Park and Mirer [1996] report that industrial hygiene data from 1954 and later indicate that more than 75% of the MWF mist samples had concentrations below 5.0 mg/m^3, but concentrations ranged up to 15 mg/m^3. Park and Mirer [1996] reported that MWF mist concentrations appeared generally higher before 1975.

This evidence suggests that grinding operations are associated with higher MWF exposures than machining or assembly operations. This evidence also suggests that exposures to MWFs have been dropping since about 1970. Changes made in the 1970s and 1980s that contributed to the declining exposures include installation of air cleaners, enclosures, and local exhaust ventilation, and improvement in recirculated air filtration systems. However, the impact of other relatively recent changes has yet to be determined (e.g., the impact from higher operating temperatures of modern cutting tools on MWF deterioration and other chemical changes, and the impact of higher cutting speeds on aerosol size distributions).

5.3.6 Route of Exposure

Although the route of MWF exposure is generally through dermal contact or through inhalation, the large size of many airborne MWF droplets can lead to gastrointestinal exposure. A significant proportion of airborne MWF particles is in the nonrespirable (extrathoracic) range (i.e., particles with a mass mean diameter >9.8 µm). Eisen et al. [1994] report that in their study approximately, 20% to 33% of the total particulate was in the extrathoracic range. Large particles generally result in gastrointestinal exposures since they are filtered out in the nasopharyngeal region and do not reach the airways. In addition, some of the small particles in the thoracic size fraction are captured by the mucocilliary escalator. The mucocilliary escalator transports the particles to the pharynx, where they are swallowed, thereby permitting gastrointestinal exposure.

5.3.7 Conclusion

Substantial evidence exists for increased risk of cancer at several sites (larynx, rectum, pancreas, skin, scrotum, and bladder) associated with at least some of the MWFs used before the mid-1970s. The inconsistencies between studies with respect to the organ sites that were affected, and the variation in the strength of association between the surrogates of exposure and specific sites are most likely related to the diverse nature of MWF mixtures studied, the absence of detailed exposure information, and the limitations of the epidemiologic tools with which MWF exposures have been studied. The evidence is equivocal for an association between MWF exposure and cancer at several other sites, including the stomach, esophagus, lung, prostate, brain, colon, and hematopoietic system.

As described in an earlier section of the criteria document, there are four classes of MWFs. The types and amounts of chemical constituents can vary across these classes. Furthermore, within each class are many formulations that vary in composition and may contain many different additives and impurities. Some MWF constituents are considered carcinogenic in animals (including N-nitrosamines [IARC 1978a] and PAHs [IARC 1983]). Efforts to reduce these potential carcinogenic exposures have been ongoing. Removal of PAHs from MWFs began in the 1950s, and EPA regulations in the 1980s were directed at reducing nitrosamine exposures. Because different epidemiologic study populations may have been exposed to different classes and formulations of cutting fluids, some lack of consistency in site-specific results between studies should be expected when evaluating the carcinogenicity of these substances. Similarly, when comparing studies with limited information about the intensity of exposure, we would expect variation in the strength of association between exposure and the risk of cancer. NIOSH believes that the consistency among the studies is sufficient to support our conclusions.

Given the small number of epidemiologic studies that have adequate exposure characterization, the specific MWF constituent(s) or contaminant(s) responsible for the various site-specific cancer risks remain to be determined. The study with the most statistical power and detailed exposure information [Tolbert et al. 1992] suggests that specific classes of MWFs are associated with cancer at certain sites. However, within these MWF classes, the specific formulations responsible for the elevated cancer risks remain to be identified. Within the Tolbert et al. [1992] study, straight oil exposure was modestly associated with an increased risk for laryngeal and rectal cancer, and there was limited evidence that synthetic oil MWF exposure was associated with an increased risk for pancreatic cancer. Subsequent case-control studies based on the original cohort have confirmed the association of laryngeal cancer with straight oil MWF [Eisen et al. 1994], and the association of pancreatic cancer with synthetic MWF [Bardin et al. 1997]. The Tolbert et al. study found less evidence that soluble oil exposure is associated with cancer at any specific site. NIOSH believes that it is premature to conclude that all members of the soluble oil class of MWFs were free from carcinogenic risks in the past, since soluble MWFs contain many of the ingredients found in straight oil MWFs—but in different concentrations. Also, many of the epidemiologic studies with positive findings involved exposures to more than one class of MWF.

Non-MWF exposures are unlikely to be responsible for the cancer findings described in this chapter. Smoking and alcohol are associated with some of the cancers observed to be associated with MWF exposure. However, most of the case-control studies controlled for these exposures when appropriate or determined that these exposures were unlikely confounders. Although information about these lifestyle factors are not often collected in occupational cohort mortality or PMR studies, it has been demonstrated that smoking is unlikely to account for RRs >1.3 for lung cancer and other smoking-related diseases [Siemiatycki et al. 1988]. Non-MWF occupational exposures are unlikely to explain the majority of findings, as the common exposure across all of the studies was MWF. Although some non-MWF exposures may have interacted synergistically with MWF exposure to produce some of the observed risks, the existence or extent of such synergism remains to be determined.

The studies that provide the bulk of the evidence suggesting an association between MWF exposure and cancer involved workers employed as early as the 1930s and as late as the mid-1980s. Because there is a latency period of 10 to 20 years between initial exposure to a carcinogen and the initial appearance of a solid-organ cancer caused by that carcinogen, the excess cancer mortality observed in these cohort studies most likely reflects the cancer risk associated with exposure conditions in the mid-1970s and earlier. Over the last several decades, substantial changes have been made in the metalworking industry, including changes in MWF composition, reduction of impurities, and reduction of exposure concentrations. These changes have likely reduced the cancer risks. However, since the epidemiologic data do not usually identify the MWF composition and impurities associated with the cancer risks observed in earlier cohorts, there is insufficient data to conclude that these changes will have eliminated all carcinogenic risks. The risk of cancer from MWF exposures in the mid-1970s and later remains to be determined because a definitive study has not yet been conducted on workers entering MWF-exposed jobs during this period. Thus the NIOSH REL is supported by the substantial evidence associating at least some of the MWFs in commercial use before the mid-1970s with cancer at several sites, and by the potential for current MWFs to pose a similar carcinogenic hazard.

5.4 Dermatologic Conditions

Skin diseases and disorders were reported as the leading occupational illness in the United States during the years 1973–87 [DOL 1988, 1989] and continue to be very common occupational illnesses. The Bureau of Labor Statistics of the U.S. Department of Labor published an occupational skin disease incidence rate of 7.7 per 10,000 full-time workers for 1991 [DOL 1993]. In 1991, the list of industries with the highest incidence rates for skin diseases or disorders included fabricated, screw-machine products (33.3 per 10,000 workers) and general industrial machinery (22.0 per 10,000 workers) [DOL 1993]. Both of these industries involve potential exposure to MWFs.

5.4.1 Cutaneous Disorders

Several cutaneous disorders have been associated with the use of MWFs, including irritant contact dermatitis, allergic contact dermatitis, folliculitis, oil acne, oil keratosis, squamous cell carcinoma, pigmentary changes (melanoderma and leukoderma), oil granuloma, and mechanical injuries from metal shavings [Alomar 1994]. Other cutaneous disorders include nail disorders, paronychia, and photosensitivity reactions. As a generalization, straight oil (insoluble) MWFs are reported to produce folliculitis, oil acne, keratoses, and carcinomas; the water-based oil emulsions (soluble oil and semisynthetic) and synthetic MWFs primarily cause irritant contact dermatitis and occasionally allergic contact dermatitis [Fisher 1986]. Skin carcinomas associated with straight oil MWFs may be of historical interest; refinement techniques such as severely solvent-refined and severely hydrotreated mineral oils have limited the PAH content, which is thought to be the principal skin carcinogen in straight oil MWFs [Järvholm et al. 1990; McKee et al. 1990].

Straight oil (insoluble) MWFs cause follicular and acne-like eruptions on the face, forearms, thighs, legs, and other parts of the body contacting oil-soaked clothing [Finnie 1960; Key et al. 1966]. Oil folliculitis is initially marked by perifollicular erythema, which can further develop into erythematous papules and pustules or furuncles. Tsuji et al. [1992] reported multiple keratoses and a squamous cell carcinoma on the forearms and backs of the hands of a worker exposed for 15 years to straight oil MWFs.

Contact dermatitis of the hands and forearms in workers exposed to soluble oil, semisynthetic, and synthetic MWFs is a common and widespread problem. de Boer et al. [1988, 1989a,b] reported on the prevalence of irritant contact dermatitis and allergic contact dermatitis in a cross-sectional epidemiologic study of 286 workers exposed to MWFs in 10 metalworking factories in the Netherlands. Sixty-one workers (21%) complained of skin problems, mostly of an itchy eruption on the hands and forearms. Dermatitis that cleared or improved during time away from work and recurred after returning to work was reported by 39 workers (14%). On dermatological examination, 39 workers had a dermatitis of irritant or allergic origin for a prevalence rate of 14%

[de Boer et al. 1988, 1989a]. By comparison, the prevalence of dermatitis in a general population study was 4.6% [Coenraads et al. 1983]. Another study of machinists heavily exposed to MWFs showed a 30% prevalence rate of dermatitis [Rycroft 1982]. Sprince et al. [1996] reported that in a study of 4,200 automotive transmission parts workers, machine operators had more combined dermatitis (definite plus possible) compared with assemblers (27.2% versus 13.7%). In a NIOSH HHE investigating exposures to MWFs in an aluminum plant, 11 (14%) of 78 workers reported developing work-related skin irritation during the previous year [NIOSH 1994a]. In another NIOSH HHE conducted in the grinding operations of a metal rod and pin manufacturing facility, 31 (63%) of 49 exposed workers reported itching and burning skin of the hands compared with 20% in an unexposed comparison group [NIOSH 1984]. On skin examination, 18 (37%) of the 49 had moderately severe dermatitis at the time of examination compared with 9% in the unexposed group. Other NIOSH investigations revealed that the prevalence of reported MWF dermatitis in a variety of workplaces ranged from 36% to 67% [NIOSH 1985; 1986a,b; 1989].

Many factors play a role in the development of contact dermatitis, the most important of which is the degree of skin contact with the MWF [Rycroft 1990, Sprince et al. 1996]. Other factors include individual susceptibility, use of personal protective equipment, general factory environment, climate, machine types and control methods, and MWF classes and additives used [Rycroft 1990].

5.4.2 Irritants

Because of the complex composition and variety of potential contaminants of MWFs, the exact etiology of MWF dermatitis is difficult to determine. Several authors have noted that the majority of workers exposed to MWFs (50% to 80%) have irritant contact dermatitis, and the rest have allergic contact dermatitis [Alomar 1994]. The alkaline emulsifiers and solvents contained in soluble and semisynthetic oils are directly irritating to the skin and may change the structure and function of the skin by denaturing keratin, defatting and dehydrating the skin, and causing dryness, fissures, and eczematization [Zugerman 1986]. Irritant contact dermatitis can also be caused by microtrauma from MWF contaminants such as metal shavings and from strong detergents used for handwashing after contact with MWFs. Workers with fair, smooth skin and workers with a history of atopic diseases may be at a higher risk for developing irritant contact dermatitis [Alomar 1994].

5.4.3 Allergens

Primary irritants can also be sensitizers and produce allergic contact dermatitis. Irritant contact dermatitis can lead to a breakdown in the barrier properties of intact skin and allow for penetration of potential sensitizers through damaged skin [Alomar 1994]. Many substances can play a role in allergic contact dermatitis caused by MWF. These include metal contaminants such as chromium, cobalt, or nickel and components or additives such as mercaptobenzothiazole (MBT), triazines (Grotan BK®), N-methylolchloracetamide (Parmetol K50®), Fordice 78®, P-chloro-m-xylenol (PCMX), O-phenylphenol (Dowicide 1®), alkanolamine borate, 5-chloro-2-methyl-4-isothiazolin-3-one and 2-methyl-4-isothiazolin-3-one (Kathon®), paraphenylenediamine, benzisothiazolone (Proxel®), polymethacrylate, ethylenediamine, TEA, colophony, dipentene, Bioban P® CS–1246, P–1487, glycidyl ester of hexahydrophthalic acid, and fragrances [Alomar et al. 1985, 1994; de Boer et al. 1989b; Camarasa et al. 1993; Dahlquist et al. 1984; Damstra et al. 1992].

Skin patch testing has confirmed the allergenic properties of these substances. Thirty-three compounds are included in an oil and cooling fluid skin patch test series (distributed by Chemotechnique Diagnostics AB, Sweden) for the diagnosis of allergic contact dermatitis. This series contains deodorizing agents, bactericides/fungicides/algicides, preservatives, surface active agents, antioxidants, anticorrosive agents, pressure stabilizers, and emulsifiers/emollients. All of these classes of chemicals can be found in MWF and all have been documented to cause allergic contact dermatitis. In addition, workers with allergic contact dermatitis may not have an allergic response to constituents of MWFs, but they may instead respond to the reaction products of the constituents of the MWFs [Shrank 1985]. Even when skin patch testing confirms a skin allergy and a possible etiology for allergic contact dermatitis, it is still impossible to determine what role the allergy played in the dermatitis and what role was played by the irritancy of the MWF preceding, accompanying, or following the sensitization [Rycroft 1990].

The most frequent positives on skin patch testing are obtained from exposure to biocides, corrosion inhibitors, coupling agents, and emulsifiers [Alomar 1994]. In a British study of 174 patients with suspected MWF dermatitis, 43% showed relevant allergic reactions. The most common causes of allergic contact dermatitis in this study were the biocides, especially the formaldehyde releasers [Grattan et al. 1989]. In the de Boer study of 286 metalworkers exposed to MWFs, patch tests were performed on 40 workers. Contact sensitization was established in eight workers. Four of these workers were determined to have allergic contact dermatitis caused by ingredients of MWFs. Of these, three workers were allergic to biocides, and a fourth was allergic to a corrosion inhibitor [de Boer et al. 1989a,b].

5.4.4 Prognosis and Preventive Measures

The prognosis for MWF dermatitis may be poor, as shown in a study of 100 machine operators with documented MWF dermatitis. In a 2-year followup, 78% of those who continued working with soluble oils had not healed; 70% of those who stopped working with the oil had not healed after discontinuing contact with the MWFs [Pryce 1989a]. As shown in this study, primary prevention of MWF dermatitis is key. This could be accomplished through worker protection and engineering controls.

Limiting the dermal exposure of workers to MWFs is the crux of preventive measures. With this goal in mind, preventive measures include [Mansdorf and Lubs 1994; Tucker 1988]:

- Substitution of MWFs, additives, or constituents as appropriate (several studies have indicated an increased skin irritancy potential of semisynthetic MWFs compared with soluble oil MWFs) [Sprince at al. 1996; Wigger-Alberti et al. 1997]
- Process modification, isolation, and ventilation to limit the dispersal of MWFs
- Work practice and administrative controls to assure the proper maintenance of MWFs and workplace cleanliness
- The proper use of personal protective equipment such as protective gloves, aprons, and clothing
- Education and training of the workers regarding dermal effects of MWFs and the importance of personal hygiene in the workplace. MWF-saturated clothing should be changed as soon as possible; skin surfaces that have come in contact with MWFs should be washed as soon as possible with nonirritating and nonabrasive soaps [Zugerman 1986].

CHAPTER 6

Current Occupational Recommendations and Standards

In 1976, NIOSH published *Current Intelligence Bulletin 15: Nitrosamines in Cutting Fluids,* which identified the presence of potentially carcinogenic PAHs and nitrosamines in MWFs and recommended industrial hygiene practices to minimize dermal and respiratory exposures [NIOSH 1976]. OSHA has classified NDMA as a *cancer-suspect agent* [29 CFR 1910.1016]; it is regulated as an occupational carcinogen. Worker exposure to NDMA is controlled through the required use of engineering controls and personal protective equipment, including respirators [20 CFR 1910.1003 and 1910.1016]. NIOSH has identified NDMA as a potential occupational carcinogen and recommends that occupational exposure to NDMA be limited to the lowest feasible concentration [NIOSH 1973].

Particularly in the past, petroleum-based mineral oils used in straight oil, soluble oil, and semisynthetic MWFs were derived through limited refining by vacuum distillation or acid treatment, or they were severely or mildly treated by solvent refinement or hydrotreatment [IARC 1987a]. As noted in Section 4.1.2, the OSHA hazard communication standard [29 CFR 1910. 1200] requires that employers report on the MSDS that a substance is a carcinogen or potential carcinogen when (1) IARC has found sufficient or limited evidence of its carcinogenicity, (2) OSHA has regulated the substance as a carcinogen, or (3) the NTP lists the substance on its annual list of carcinogens.

According to the IARC process parameters of mild hydrotreatment, an oil processed at a hydrogen pressure of 800 psi or less at temperatures up to 800°F is subject to the OSHA hazard communication standard [29 CFR 1910.1200].

In testimony for the OSHA rulemaking on air contaminants [54 Fed. Reg. 2445 (1989)], NIOSH recommended an exposure limit for mineral oil mists of 5 mg/m^3 as a 10-hr TWA with a short-term exposure limit (STEL) of 10 mg/m^3. NIOSH submitted comments to the record noting that certain types of oils and their additives may present a carcinogenic hazard [NIOSH 1988a]. The current OSHA PEL for mineral oil mists is 5 mg/m^3 as an 8-hr TWA. ACGIH has published a notice of intended change for the threshold limit value (TLV) for severely refined mineral oil mist: 5 mg/m^3 as an 8-hr TWA [ACGIH 1997b]. The *Notice of Intended Changes* section of *1997 TLVs® and BEIs®* [ACGIH 1997a] also includes proposed TLVs (8-hr TWAs) for *Oil mist, mineral, sum total of 15 polynuclear aromatic hydrocarbons (PAHs) listed as carcinogens* *by the U.S. National Toxicology Program (NTP)*. This TWA has the A1—*Confirmed Human Carcinogen* designation.

The current standard for *particulates not otherwise regulated* [29 CFR 1910.1000] may not adequately protect workers exposed to the hazardous components or contaminants of MWFs for which PELs and RELs have not been established. In testimony for the 1989 OSHA rulemaking on air contaminants, NIOSH pointed out that *particulates not otherwise regulated* have health effects beyond those attributed to the physical irritant properties of particulates and that a PEL of 10 mg/m^3 would not prevent the toxicologic effects associated with many of these substances [NIOSH 1988b]. The current OSHA PEL for *particulates not otherwise regulated* is 15 mg/m^3 as an 8-hr TWA for total dust and 5 mg/m^3 as an 8-hr TWA for respirable particulates. The ACGIH TLV for *particulates not otherwise classified* is 10 mg/m^3 (TWA) for inhalable particulates and 3 mg/m^3 (TWA) for respirable particulates. The ACGIH TLV for TEA is 5 mg/m^3 as an 8-hr TWA [ACGIH 1993]. NIOSH, OSHA, and the Mine Safety and Health Administration (MSHA) have not established exposure limits for TEA. Additional exposure limits have been established for individual additives, components, and contaminants of MWFs (see Table 6–1).

On the basis of spirometric data from workers exposed to cotton dust, Rylander et al. [1985] calculated an endotoxin threshold of 33 nanograms (ng)/m^3; Castellan et al. [1987] calculated an endotoxin threshold of 9 ng/m^3. Palchak et al. [1988] suggested an endotoxin action level of 30 ng/m^3 for industrial processes involving large-scale cultures of genetically engineered *E. coli*. Milton et al. [1996] studied endotoxin exposure in a fiber glass manufacturing facility and concluded that endotoxin exposures of 4 to 15 ng/m^3 (mean, 8.9 ng/m^3) and higher were strongly associated with acute effects on peak expiratory flow and FEV$_1$. NIOSH, ACGIH, and OSHA have not established exposure limits for endotoxin. Table 6–1 presents a partial listing of NIOSH RELs, OSHA PELs, and ACGIH TLVs that are relevant to occupational exposure to MWFs.

Table 6-1. Current recommendations and standards

MWF component	NIOSH REL	OSHA PEL	ACGIH TLV
Acetaldehyde	Ca[*]	200 ppm (360 mg/m^3) TWA	25 ppm (45 mg/m^3) ceiling,[†] A3[‡]
Ammonia	25 ppm (18 mg/m^3) TWA, 35 ppm (27 mg/m^3) STEL[§]	50 ppm (35 mg/m^3) STEL	25 ppm (17 mg/m^3) TWA, 35 ppm (24 mg/m^3) STEL
Cadmium	Metal and compounds: Ca	Metal and compounds: 0.005 mg/m^3	Elemental: 0.01 mg/m^3 TWA, (A2)[**] Compounds: 0.002 mg/m^3 TWA, (A2)
Chlorine	0.5 ppm (1.45 mg/m^3) 15-min ceiling	1 ppm (3 mg/m^3) ceiling	0.5 ppm (1.5 mg/m^3) TWA, 1 ppm (2.9 mg/m^3) STEL
Chromium:[††]			
1. Compounds Cr (II and III)	0.5 mg/m^3 TWA	0.5 mg/m^3 TWA	0.5 mg/m^3 TWA as Cr III, A4[‡‡]
2. Metal	0.5 mg/m^3 TWA	1 mg/m^3 TWA	0.05 mg/m^3 TWA as soluble Cr VI, A1[§§]
3. Cr (VI)	0.001 mg/m^3 TWA	0.1 mg/m^3 TWA	0.01 mg/m^3 TWA as insoluble Cr VI, A1
Cobalt metal dust and fume	0.05 mg/m^3 TWA	0.1 mg/m^3 TWA	0.02 mg/m^3 TWA, A3
Diethanolamine (DEA)	3 ppm (15 mg/m^3) TWA	No PEL	0.46 ppm (2 mg/m^3) TWA (skin)
Formaldehyde	Ca; 0.016 ppm TWA, 0.1 ppm 15-min ceiling	0.75 ppm TWA, 2 ppm STEL	0.3 ppm ceiling (0.37 mg/m^3), A2
Hydrogen sulfide	10 ppm (15 mg/m^3) (10-min) ceiling	20 ppm ceiling, 50 ppm (10-min) maximum peak	10 ppm (14 mg/m^3) TWA, 15 ppm (21 mg/m^3) STEL
Monoethanolamine (ethanolamine) (MEA)	3 ppm (8 mg/m^3) TWA, 6 ppm (15 mg/m^3) STEL	3 ppm (6 mg/m^3) TWA	3 ppm (7.5 mg/m^3) TWA, 6 ppm (15 mg/m^3) STEL
Nickel metal and compounds	0.015 mg/m^3 TWA, Ca	1 mg/m^3 TWA	1 mg/m^3 TWA (metal and insoluble compounds); 0.1 mg/m^3 TWA (soluble compounds)

See footnotes at end of table.

(Continued)

Table 6-1 (Continued). Current recommendations and standards

MWF component	NIOSH REL	OSHA PEL	ACGIH TLV
Oil mist (mineral)	0.4 mg/m^3 TWA (thoracic particulate mass) or 0.5 mg/m^3 (total particulate mass) in metalworking operations	5 mg/m^3 TWA	5 mg/m^3 TWA, 10 mg/m^3 STEL TLV-TWA[***]
Oil mist, mineral, sum total of 15 polynuclear aromatic hydrocarbons (PAHs) listed as carcinogens by the U.S. National Toxicology Program (NTP)	No REL	No PEL	0.005 mg/m^3
Sulfur chloride (sulfur monochloride)	1 ppm (6 mg/m^3) ceiling	1 ppm (6 mg/m^3) TWA	1 ppm (5.5 mg/m^3) ceiling
Triethanolamine (TEA)	No REL	No PEL	5 mg/m^3 TWA
Viable microorganisms (total bacteria and fungi, and single genera)	No REL	No PEL	No TLV

[*] The Ca notation indicates that NIOSH lists this component as a potential occupational carcinogen.

[†] Unless otherwise noted, the ceiling value should not be exceeded at any time.

[‡] ACGIH lists A3 as an animal carcinogen.

[§] The STEL is 15 minutes unless otherwise indicated.

[**] ACGIH lists A2 as a suspected human carcinogen.

[††] Chromic acid and chromates (as CrO_3), chromium (II) and chromium (III) compounds (as Cr), and chromium metal (as Cr). The NIOSH REL (10-hr TWA) is 0.001 mg Cr(VI)/m^3 for all hexavalent chromium—Cr(VI)—compounds. NIOSH considers all Cr(VI) compounds (including chromic acid, tert-butyl chromate, zinc chromate, and chromyl chloride) to be potential occupational carcinogens. The NIOSH REL (TWA) is 0.5 mg Cr/m^3 for chromium metal and chromium (II) and chromium (III) compounds. The OSHA PEL is 0.1 mg CrO_3/m^3 (ceiling) for chromic acid and chromates (including tert-butyl chromate with a "skin" designation and zinc chromate); 0.5 mg Cr/m^3 (TWA) for chromium (II) and chromium (III) compounds; and 1 mg Cr/m^3 (TWA) for chromium metal and insoluble salts.

[‡‡] ACGIH lists A4 as not classifiable as a human carcinogen.

[§§] ACGIH lists A1 as a confirmed human carcinogen.

[***] ACGIH Notice of Intended Change is as follows: the TLV (TWA) is 5.0 mg/m^3 for severely refined and 0.2 mg/m^3 for mildly refined; the TLV (TWA) is 5 µg/m^3, A1 (confirmed human carcinogen) for the sum total of 15 PAHs listed as carcinogens by NTP.

CHAPTER 7

Sampling and Analytical Methods

NIOSH recommends thoracic sampling and gravimetric measurement of MWF aerosol using NIOSH Method 0500 [NIOSH 1994c] with a sampling device that collects the thoracic fraction. The limit of quantitation (LOQ) for this method, or the lowest mass that can be measured with acceptable precision, is 0.13 mg/m^3. If a thoracic sampling device is not available, a total dust sampler can be used and the result can be divided by 1.25 to estimate the thoracic fraction. NIOSH Method 0500 can be used to measure the total material collected. However, when there are simultaneous exposures to nontoxic particulate materials, NIOSH Method 5026 [NIOSH 1994c] or a similar method may be useful to estimate the soluble component of the workroom aerosol.

7.1 Background of Current Methods

The sampling and analytical methods used to assess airborne MWF exposures in the most recent respiratory epidemiologic studies by Kennedy et al. [1989], Greaves et al. [1995a,b, 1997], and Robins et al. [1994] were based on a gravimetric measurement of airborne particles, with some differences in selection of particle size distribution. These methods are susceptible to interference from contaminating materials such as environmental or construction dusts and (infrequently) metal particles. The problem can be reduced by extracting the MWF from the non-MWF particles with an appropriate solvent or solvents. Currently, little or no scientific evidence suggests that "extractable" MWF is superior to thoracic or particulate aerosol as a predictor of adverse health effects from MWF aerosols.

NIOSH is evaluating a provisional method developed by the ASTM E34.50 Committee for separation of MWF from co-sampled material. Samples are collected on polytetrafluoroethylene (PTFE) filters and extracted with a ternary solvent blend. The difference in the weight of the filter before and after collection yields the total mass sampled. The difference in the weight of the filter before and after extraction is the weight of the MWF. This method was successfully evaluated by NIOSH for the extraction of four MWFs spiked onto PTFE filters. The technique is undergoing further evaluation in a large-scale field test. Other methods that have been used for MWF aerosols are listed in Table 7–1.

Table 7–1. Comparison of current MWF analytical methods

Method	Type	Flow (L/min)	Maximum volume	Filter	Pad	Sorbent	Extraction solvent: Filter	Extraction solvent: Sorbent
NIOSH Method 0500	G[*]	1.0–2.0	133	37-mm, 5.0-µm PVC	Yes	NA	NA	NA
NIOSH Method 0600	G	1.7–2.2	400	10-mm cyclone, 5-µm PVC	No	NA	NA	NA
NIOSH Method 5026	IR	1.0–3.0	500	37-mm, 0.5–0.8 µm PVC or MCE	No	NA	Trichloroethane, trifluoroethane	NA
Chrysler	G	1.0–2.0	133	37-mm, 5.0-µm PVC	Yes	NA	Toluene	NA
Ford FIH 005	G	2.0–3.0	1440	37-mm type A or GFF	Yes	NA	Trichloroethylene or perchloroethylene	NA
Ford FIH 005 (mod)	G, GC	1.0	480	37-mm type A or GFF	Yes	600-mg charcoal tube	Trichloroethylene or perchloroethylene	Carbon disulfide

[*] Abbreviations: G = gravimetric, GC = gas chromatography, GFF = glass fiber filter, IR = infrared, MCE = mixed cellulose ester, NA = not applicable, PAD = backup pad, PVC = polyvinyl chloride.

7.2 Potential Sampling and Analytical Method Bias and Sources of Error in Measuring MWFs

7.2.1 Sampling According to ACGIH Conventions

The ACGIH [1997b] and the ISO [1995] recommend size-selective sampling to target measurements for specific regions of the respiratory system. ACGIH recommends three types of particle size-selective TLVs: (1) inhalable particulate mass for materials that are hazardous when deposited anywhere in the respiratory tract, (2) thoracic particulate mass TLVs for materials that are hazardous when deposited anywhere within the lung airways and gas-exchange region, and (3) respirable particulate mass TLVs for materials that are hazardous when deposited in the gas-exchange region. Because NIOSH has established the REL primarily to prevent adverse respiratory effects, thoracic sampling is the most appropriate approach when thoracic samplers are widely available and adopted.

7.2.2 Thoracic Samplers

Several options exist for thoracic sampling of MWFs. A personal cascade impactor has been used for measuring the size distribution of aerosols. The information from this impactor can be used to calculate the thoracic fraction of the sampled aerosol [Baron and Willeke 1986]. Alternatively, the stage that cuts at 10 µm can be used to simulate a thoracic preclassifier and the remaining aerosol collected on the downstream filter [Kriebel et al. 1994]. A recently developed sampler uses a cyclone operated at 1.6 L/min that matches the cutpoint of the thoracic curve [Kenny and Gussman 1997; Maynard 1997].

Another sampler that can be used as a thoracic sampler is one designed to match the EPA PM-10 curve. The PM-10 curve is sharper than the thoracic curve; but for typical MWF size distributions ($\sigma_g > 2.0$, median $d_{ae} < 20$ µm), the use of a sharper cut introduces less than 20% bias. For most of this range of size distributions, the bias is less than 10%.

The CIP-10 sampler is also designed to sample the thoracic fraction [Fabriés 1992; Görner et al. 1994]. This device collects the thoracic fraction on an open-pore foam which is weighed. The CIP-10 sampler is expensive because of its air-moving system (which is integral to the sampler) and because of sampler import costs. However, it has the advantage of sampling at 7 L/min, thereby allowing the collection of short-term samples or more accurate full-shift samples. Another thoracic sampler also uses a porous foam as the size-classifying device [Vincent 1989] but is not commercially available. Chen et al. [1996] have developed a better match to the thoracic curve with a foam-based preclassifier by using two different pore-size foam sections in parallel.

An alternative to the use of a thoracic sampler is the use of a total dust sampler with a correction factor applied to convert to the thoracic fraction. This approach is subject to bias when the MWF size distribution changes. Although the reported size distributions for some MWFs have a median size smaller than 10 µm [Woskie et al. 1994], the size distribution of MWFs should be measured to ensure that the median size is small. Kriebel et al. [1994] compared total aerosol samples (using a closed-face cassette) with "thoracic" samples (using an impactor with a 50% cut point at 10 µm) and obtained a median ratio of total to thoracic of 1:4. Based on some measured size distributions [Woskie et al. 1994], the calculated median of the ratio of total to thoracic is about 1.25.

7.2.3 Sampler Inlet Biases

Inlet sampling efficiency can be a major source of bias in collecting aerosol particles. This bias generally increases with increasing particle size and increasing external air velocities. Bartley et al. [1994] have addressed the bias involved in sampling respirable aerosol. They reported that sampling bias is highly affected by the aerodynamic diameter of the aerosol being monitored, with biases ranging from +10% to -30% for both the 10-mm nylon cyclone and the Higgins-Dewell cyclone for aerosols with aerodynamic particle size less than 25 µm. Biases are also present in total dust sampling. Chen and Baron [1996] demonstrated a significant bias that depends on the orientation of the sampler to the wind. The orientation of the sampler inlet relative to the worker's body may play an important role—that is, a sampler inlet pointing horizontally away from the body may be more accurate than an inlet pointing downward. An extensive study of the sampling efficiencies of most conventional inhalable or "total" aerosol samplers (including the closed-face cassette) indicates that these samples are biased (especially for larger-diameter particles) and depend on wind speed [Kenny et al. 1997]. However, the bias is relatively small for all tested "total" and inhalable samplers when the median aerosol diameter is less than 25 µm. In one study, measured MWF personal exposure size distributions suggest that typical size distributions may have median aerodynamic diameters smaller than 10 µm [Woskie et al. 1994]. This finding indicates that sampling thoracic MWF aerosols may involve more bias than sampling respirable aerosol—but considerably less bias than sampling total aerosol. Further research is required for a more precise estimate of aerosol sampling bias.

7.2.4 Other Sampler Biases

A number of factors regarding aerosol sampler accuracy have been investigated during the past 30 years. A review by Baron [in press] indicates that factors such as sampler leakage, sampler conductivity, internal flow patterns, and collection medium stability are important in the development of an accurate sampler. Several of these factors are often overlooked in the development of samplers and can contribute significantly to errors in field measurements. During area sampling at a lead abatement site, the 37-mm closed-face cassette was compared with a new sampler. The newly developed sampler produced a variability of 10% relative standard deviation (RSD), and the closed-face cassette produced 100% RSD at 2 L/min [Hauck et al. 1997]. Since the closed-face cassette violates several factors affecting accuracy and precision, as indicated by Baron, and has poor inlet characteristics [Kenny et al. 1997], it is not surprising that its use results in higher variability. However, because of its common use and availability, the closed-face cassette can be used as a surrogate for thoracic sampling (with the above-mentioned correction factor) until better samplers are available. Together with improved samplers, the closed-face cassette can provide data for comparison with earlier measurements.

Many MWFs have a significant vapor pressure at room temperature. When MWFs are generated as an aerosol, the large increase in surface area allows the equilibrium vapor pressure above the particle surface to be reached more quickly. The droplets evaporate more quickly than as a bulk liquid, especially when the aerosol droplets are collected on a filter. The droplets are then suspended in a high-velocity air stream and can lose volatile components during the sampling period. Two collection techniques have been suggested to reduce the evaporative loss: impaction [Wang and John 1988] and electrostatic precipitation [McAneny et al. 1995]. In both cases, the aerosol is deposited as a bulk liquid on a surface that is somewhat removed from the high-velocity air stream—rather than as a high-surface-area particulate intimately exposed to the air stream in a filter.

Leith et al. [1995] compared filter sampling with electrostatic precipitator sampling in both laboratory [McAneny et al. 1995] and field studies. The electrostatic precipitator collected concentrations that were up to five times greater than those collected by the filter method; this difference indicates significant filter losses. The loss depended on the vapor pressure of the oil, the ambient temperature, the size of the droplets, the type of filter, and the concentration of vapor in the sampled atmosphere. The last factor was indicated by evaporative losses being greatest at low oil mist concentrations when vapor concentration was also expected to be low. The proposed sampling and analytical method using filtration does not take into account evaporation of the MWF. Using this method may increase the variability of results and introduce an uncontrolled bias. Further research may result in recommendation of an improved sampling method that significantly reduces evaporative losses during sampling.

7.2.5 Estimating Total Method Bias

No studies have been performed on the accuracy of thoracic samplers. Further research is required to estimate the method bias.

7.2.6 Estimating Total Method Precision

For a gravimetric technique, the estimated LOQ is 130 µg per filter [Glaser and Shulman 1996; Shulman and Glaser 1997]. This estimate is based solely on the mass at which the gravimetric error becomes 10%. If the analytical finish involves further extraction of the sample, the imprecision is likely to increase. In several analytical scenarios, the sample is extracted, but different extraction efficiencies are obtained. The maximum imprecision associated with sampling and analysis at the LOQ can be estimated if appropriate estimates of all error sources are known. Table 7–2 lists the potential sources of error (RSDs) for various MWF analytical techniques effective at or near the LOQ. Although the magnitudes of these sources of imprecision are generally unknown, assumptions must be made to allow for their estimation. Generally, the pump precision is assumed to be 0.05. Intersampler variability may be quite large, depending on the orientation of the sampler to the airstream, particle size, particulate static charge, and wind velocity [Bartley et al. 1994; Baron et al. 1995; Kenny et al. 1997; Almich and Carson 1974]. For example, Bartley et al. [1994] have demonstrated an intersampler variability of up to 10% for the 10-mm cyclone. In addition, Almich and Carson [1974] reported a 10% intersampler variability due to charge effects in the 10-mm cyclone and filter. Knight and Kirk [1982] discussed other sources of variability. Although the issue of sampling variability remains to be settled, an upper limit of approximately 0.10 appears rea- sonable for this parameter.

For aerosol sampling only, the analytical imprecision at the LOQ is assumed to be due entirely to the gravimetric analysis and is estimated to be 0.10 at the LOQ. Pooling all sources of analytical and sampling variability enables computation of a maximum relative standard deviation for the total procedure [RSD_T]—0.15 for aerosol sampling at the LOQ.

For a solvent extraction technique, it is reasonable to allow for incomplete extraction of the MWF aerosol. Extractables are removed by washing the filter with a solvent. An aliquot of the sample is then evaporated to dryness in a preweighed cup. The mass difference is then determined. This process may introduce imprecision into the analytical method as a result of the extraction step [$RSD_{extract}$] and reweighing steps [$RSD_{reweighing}$]. The extraction is assumed to be precise regardless of the amount extracted (i.e., [$RSD_{extract}$] is not needed to estimate [RSD_T]). Using techniques described elsewhere, Bevington [1969] and Shulman and Glaser [1997] considered the effect on the overall RSD for three situations in which the fraction extracted corresponded to 10%, 50%, and 90% of the total mass sampled. Even for high levels of extraction efficiency (e.g., 90%) the overall precision of analysis is approximately 0.15.

NIOSH sampling and analytical methods require 95% of all samples collected to fall within +/- 25% of the true mean or standard value, accounting for both bias and imprecision within the sampling method [Kennedy ER et al. 1995]. For a method with zero bias, the maximum suggested RSD is 0.128. Information from a round-robin study of MWF sampling and analytical methods [D'Arcy et al. 1995] indicates that some data collected by three particulate sampling and analysis methods at concentrations ranging from 0.55 to 1.77 mg/m^3 may not meet NIOSH sampling and analytical requirements. Although the round-robin study data are still preliminary, the need for improved sampling and analytical methodology is apparent.

Table 7–2. Potential sources of error (RSDs) for various MWF analytical techniques effective at or near the LOQ

Type of sample	RSD for pump	RSD for intersampler	Fraction extracted	RSD for weighing	Estimated RSD for total process*
Aerosol only	0.05	0.10	NA	0.10	0.150
Extractables only	0.05	0.10	0.1	1.00	1.006
			0.5	0.20	0.229
			0.9	0.11	0.158
Extractables relative to total mass			0.1	1.005	1.005
			0.5	0.224	0.224
			0.9	0.149	0.149

*Values for all sample types except total aerosol are minimum values. The true value depends on the unknown correlation between pump error in the extracted and unextracted portions. The same considerations apply to the sampling error. The minimum value assumes that the RSD for the pump is constant for the different fractions and that the absolute standard deviation for weighing the filter and the collection cup are approximately equal.

If no uncorrectable bias is assumed in these methods, the NIOSH precision requirements would be approached for sampling and analysis of thoracic aerosol and high recoveries of total extractables. For all other sampling and analytical method designs, these criteria would not be met.

7.3 Sampling and Analytical Issues Involved in Establishing the REL

7.3.1 LOQ

Several issues remain to be resolved regarding the sampling and analytical method accuracy and precision for aerosols, particularly for all classes of MWF aerosols. Appropriate sampling and analytical methods should be used to address operations that involve exposure to both MWF and non-MWF material. The standard should be established at a mass concentration that exceeds the LOQ of sampling and analytical methods. Current gravimetric LOQ data indicate that a gravimetric standard of 0.4 mg/m^3 (thoracic particulate mass) is feasible with respect to sampling and analytical methods. NIOSH Method 0500, modified to sample with a thoracic preclassifier, is an acceptable method.

7.3.2 STELs and Ceiling Limits

The ILMA has stated that a STEL or ceiling limit of 2.0 mg/m^3 may be more protective of worker safety and health than a TWA exposure limit; they indicate that such a limit should at least be coupled with a TWA exposure limit [Howell 1996].

One difficulty in adopting either a STEL or a ceiling limit lies in measurement. In the publication *Occupational Exposure Sampling Strategy Manual* [NIOSH 1977] NIOSH recommends that samples taken to determine ceiling limits be collected during periods of maximum expected concentrations. A minimum of three 15-min samples should be taken during each work shift, and the highest of the three measurements should be used to estimate the worker's upper exposure for that shift. In many cases, the work process appears to be relatively constant during the work shift, and random techniques are required to estimate the upper bounds of exposure. For example, to identify at least one 15-min period from those representing the top 20% of exposures with a 95% confidence level, eleven 15-min (nonoverlapping) samples are needed. The total aerosol sampling and gravimetric analysis techniques proposed in this criteria document should provide adequate sensitivity to monitor exposures reliably at a concentration of 2.0 mg/m^3 during a 15-min sampling period. Thus the sampling and analytical costs of determining exposure to a STEL or ceiling limit could range from 3 to 11 times that of a TWA limit. In addition to the sampling difficulties, only one of the epidemiologic studies used real-time sampling to measure short-term exposure [Sprince et al. 1997].

Real-time measuring instruments can be used as an alternative to conventional sampling and analysis using pumps and filters with subsequent gravimetric analysis. Aerosol photometers are real-time aerosol instruments that are reliable, easy to use, and relatively inexpensive. They sample the workroom air and instantaneously measure the concentration of airborne dusts and mists by measuring the amount of light scattered by these materials. Although the results of these measurements are typically displayed with the units mg/m^3, these numbers should be considered as estimates of the true concentration, since the amount of light scattered depends on the characteristics of the aerosol in addition to its concentration. Aerosol photometers respond roughly to particle volume; thus the instrument readings measure any water contained in the MWF. Gravimetric techniques measure only the residual, nonvolatile particles retained on a filter. The aerosol photometer response also depends on the physical configuration of the light-scattering element, the wavelength of light used, and the size and optical properties of the aerosol particles. Thus these instruments must be calibrated by comparing them with gravimetric techniques for each combination of aerosol size and fluid type. The initial cost of an aerosol photometer is approximately 10 times the cost of a conventional sampling pump; however, some of this initial cost is offset by subsequent (potential) savings in analytical costs.

In addition to the difficulty and cost of measuring a STEL or ceiling concentration, few epidemiologic data exist from which to develop criteria for short-term exposures. Thus no recommendations are made for a STEL or ceiling limit in this document.

CHAPTER 8

Basis for the Recommended Standard

8.1 Introduction

Under the authority of the Occupational Safety and Health Act of 1970 (Public Law 91–596), NIOSH was established to develop and recommend criteria for identifying and controlling workplace hazards that could result in occupational illness or injury. To formulate these recommendations, NIOSH evaluates all relevant scientific information about a given hazard. This information includes health effects data, routes of exposure, preventive measures (e.g., engineering controls, safe work practices, personal protective equipment), and the feasibility of controlling hazards and thereby reducing or eliminating adverse health effects.

NIOSH has primarily used peer-reviewed, published articles to form conclusions about health hazards associated with MWF exposures. In addition, NIOSH has reviewed several recent, unpublished epidemiologic investigations of worker exposures to MWFs. These investigations were sponsored by the Occupational Health Advisory Board (OHAB) of the International Union, United Automobile, Aerospace and Agricultural Implement Workers of America and the General Motors Company (UAW-GM) as part of their joint safety and health activities. The OHAB, which is made up of six to seven university scientists, solicits research proposals from academic institutions. Following peer reviews of proposed research projects, OHAB funds, monitors, and facilitates the progress of selected proposals. Final research reports are prepared by the investigators after nonbinding peer review by OHAB. NIOSH included three such investigations [Kriebel et al. 1994; Greaves et al. 1995a,b; Robins et al. 1994] in addition to a traditionally peer-reviewed study by Kennedy et al. [1989] when determining the need for an REL for MWF aerosol. Greaves et al. [1995b] and the studies by Kriebel et al. [1994] and Robins et al. [1994] have now been published [Greaves et al. 1997; Kriebel et al. 1997; Robins et al. 1997; Sama et al. 1997].

This chapter briefly summarizes the major findings from Chapters 5 and 6, which contain the health basis for the proposed REL and the information about past and current exposures to MWF aerosol.

Major changes have been introduced into the U.S. machine tool industry over the last several decades. The overall consumption of MWFs (specifically synthetic MWFs) increased as tool and cut speeds increased. Advances in automation enabled the machines to be partially enclosed, which facilitated the application and use of local exhaust ventilation. During the 1970s and 1980s, many U.S. plants installed recirculating air cleaners, improved the recirculating air filtration systems, and renovated the factories. The improvements were prompted partly by the ACGIH TLV of 5 mg/m³ for mineral oil mist [ACGIH 1997b] established in the 1960s, and its promulgation by OSHA as a PEL in 1970 [29 CFR 1910.1000].

Hallock et al. [1994] described the effect these improvements had on the automotive industry in reducing exposures to airborne MWFs. Concentrations declined significantly over the 30-year period 1958–87, with an arithmetic mean concentration of 5.42 mg/m³ (total particulate mass) observed before 1970 and 1.82 mg/m³ after 1980. The geometric mean for MWF aerosol concentration at the plants studied by Hallock et al. [1994] was 0.56 mg/m³ after 1980.

Since 1987, MWF exposures in the automotive industry have continued to decline. In the most recent studies of automobile manufacturing, worker exposures to aerosols of straight oil, soluble oil, and synthetic MWFs (mean exposure concentrations in nongrinding operations) were reported to be <1.0 mg/m³ (total particulate mass) [Hallock et al. 1994; Kriebel et al. 1997; Greaves et al. 1995a,b, 1997; Robins et al. 1994]. Kriebel et al. [1997] reported mean exposures (7-hole sampler) of 0.24 mg/m³ to aerosols of straight oil MWFs and 0.22 mg/m³ to soluble oil MWFs. MWF aerosol concentrations generally below 1.0 mg/m³ were also reported by Greaves et al. [1995a,b, 1997], with mean concentrations (thoracic fraction) for several plant surveys of 0.2 to 0.68 mg/m³ (straight oil MWFs), 0.35 to 0.65 mg/m³ (soluble oil MWFs), and 0.41 mg/m³ (synthetic MWFs). Likewise, Robins et al. [1994] reported that MWF aerosol exposures for automotive parts manufacturing workers ranged from 0.1 to 0.6 mg/m³ (thoracic fraction) for soluble oil MWFs.

The occupational exposure data compiled by the NIOSH HHE program (1972 to 1993) also show that exposure to airborne MWFs has generally decreased over time. These data indicate that the arithmetic mean personal exposures were 1.23 mg/m³ (n=21 plants) in the 1970s, 0.57 mg/m³ in the 1980s (n=15 plants), and 1.0 mg/m³ in the 1990s. However, these figures are based on data from only two plants. The overall mean concentration was 0.96 mg/m³ for 38 plant-based HHEs.

This decline in airborne exposures has also been reported in the OSHA IMIS, which compiles the air sampling data from OSHA inspectors (Table 3–3). The OSHA exposure data for mineral oil mist represent a substantial cross-section of industry. These exposure data demonstrate a steady decline in exposure concentrations from before 1980 to the present. The arithmetic mean concentration (gravimetric method analysis) for all samples collected during this period was 0.92 mg/m³ (total particulate mass); for the period January 1991 to April 1995, the arithmetic mean was 0.49 mg/m³.

The increasing percentage of samples with airborne concentrations below 0.5 mg/m³ over time suggests that improvements in engineering controls and work practices have occurred. Before 1980, 37% of the air samples contained MWF concentrations below 0.5 mg/m³ (total particulate mass), whereas 73% of the samples from the most recent period (1991–95) contained concentrations below 0.5 mg/m³ (total particulate mass).

Without a detailed description of the worker exposures (e.g., MWFs or processes or operations using MWFs) for data reported in the IMIS or the NIOSH HHEs, it is not possible to evaluate the technologic feasibility of controlling all MWF aerosol exposures to concentrations below the REL. However, the historical trend in declining exposure concentrations suggests that significant accomplishments have been made in the reduction of exposures. Further investigation and research will be needed to determine more precisely the technologic feasibility of reducing all MWF aerosol exposures to concentrations below the REL.

8.2 Effects of MWF Exposure

8.2.1 Nonmalignant Respiratory Effects

Substantial evidence indicates that workers currently exposed to MWF aerosols have an elevated risk of asthma [Forbes and Markham 1967; Robertson et al. 1988; Savonius et al. 1994]. Published clinical case reports indicate that MWF-induced asthma appears to involve known sensitizers in some cases but that various other agents (possibly acting through irritant or inflammatory mechanisms) may be responsible for a high proportion of cases [Forbes and Markham 1967; Robertson et al. 1988; Savonius et al. 1994]. Table 5–1 presents selected risk estimates for asthma morbidity derived from these studies.

8.2.1.1 Asthma and Synthetic MWFs

Convincing evidence indicates that workers exposed to synthetic MWFs have an increased risk of work-related asthma. Some evidence from cross-sectional studies suggests a tendency for affected workers to transfer away from jobs involving exposure to MWF aerosol. In the Eisen et al. [1997] study (which attempted to control for this job-transfer bias), the adjusted risk estimate for exposure to synthetic MWF aerosol was about three times the risk relative to unexposed populations. Estimated MWF aerosol exposures in the 2 years before diagnosis ranged from 0.36 to 0.91 mg/m³ (inhalable mass), with a mean of 0.6 mg/m³. Risk estimates were elevated in all three studies of asthma and exposure to synthetic MWF aerosol [Greaves et al. 1995b, 1997; Eisen et al. 1997; Rosenman et al. 1995], although the finding in the Greaves [1995b] study was not statistically significant (Table 5–1). Additional evidence indicates that exposure to synthetic MWF aerosol increases airways hyperresponsiveness over time [Kennedy et al. 1995b,c].

8.2.1.2 Asthma and Soluble Oil MWFs

The evidence associating asthma and exposure to soluble oil MWF aerosol is somewhat less consistent than that for synthetic MWFs, but more studies have investigated this relationship. Only Greaves et al. [1995b, 1997] and Rosenman et al. [1997b] presented elevated risk estimates that were statistically significant, but five of the seven epidemiologic studies of soluble oil MWF exposures reported elevated risk estimates for asthma, with point estimates ranging upward from 1.7 [Rosenman et al. 1997b; Greaves et al. 1995b, 1997; Kriebel et al. 1994; Robins et al. 1994; Massin et al. 1996]. Four of these five studies estimated mean current exposures to soluble oil MWF aerosol ranging from 0.22 (inhalable fraction) to 1.49 mg/m^3 (total extractable oil aerosol) [Kriebel et al. 1994; Robins et al. 1994; Greaves et al. 1995b, 1997; Massin et al. 1996]. In the other study (for which mean exposures were not reported), 90% (44/49) of the air samples yielded oil mist measurements of less than 1.0 mg/m^3 [Rosenman et al. 1997b]. In two studies [Ameille et al. 1995; Eisen et al. 1997], the risk estimates were less than 1, even though exposures were not lower than in the more positive studies. However, Ameille et al. [1995] found evidence suggesting that affected workers had transferred from jobs with exposure to soluble oil MWF aerosol, which may have biased findings from that study. Also, the negative finding of Eisen et al. [1997] is difficult to interpret in view of the statistically significant positive association between asthma and cumulative exposure to soluble oil MWF aerosol in the same study group [Greaves et al. 1995b, 1997]. In addition, Massin et al. [1996] and Wild and Ameille [1997] both found a positive association between increased bronchial responsiveness and cumulative exposure to soluble oil MWF aerosol. Overall, the preponderance of evidence from all these studies indicates that airways hyperresponsiveness and asthma are both associated with exposure to soluble oil MWF aerosol.

8.2.1.3 Asthma and Straight Oil MWFs

The epidemiologic evidence for an association between asthma and exposure to straight oil MWF aerosol is less convincing than that for synthetic and soluble oil MWFs. None of the five studies of straight oil MWFs [Rosenman et al. 1997b; Greaves et al. 1995b, 1997; Eisen et al. 1997; Kriebel et al. 1994; Ameille et al. 1995] documented a significantly increased risk (Table 5–6). Rosenman et al. [1997b] found that workers exposed to straight oil MWF aerosol had a 10% prevalence of new asthma since hire or new work-related symptoms consistent with work-related asthma—a lower prevalence than that found among groups of workers exposed to aerosols of the other major types of MWF. Since the Rosenman study did not include a reference group of unexposed workers, and since the participation rate was not reported, it is unclear whether the 10% prevalence is an elevated rate. In two of the other four studies, the point estimate for asthma risk was elevated [Eisen et al. 1997; Kriebel et al. 1994]. Some clinical case reports suggest that asthma is associated with exposure to straight oil MWF aerosol [Forbes and Markham 1967; Robertson et al. 1988] or to compounds commonly found in straight oil MWFs [Savonius et al. 1994]. Overall, the risk of asthma exists but is likely to be lower with straight oil MWF aerosol than with other types of MWF aerosols.

Risk may be elevated even at MWF aerosol concentrations below the NIOSH REL. However, the risk for asthma is likely to be dose-dependent and would therefore be expected to be even greater at concentrations exceeding the NIOSH REL.

8.2.1.4 Respiratory Effects Other Than Asthma

In addition to associating MWF aerosol exposures with asthma, evidence also links other adverse respiratory health effects with such exposures. Except for one early study [Ely 1970], epidemiologic studies of respiratory symptoms are generally consistent and (in the case of the more recent studies) provide compelling evidence that occupational exposure to MWF aerosols causes symptoms consistent with airways irritation, chronic bronchitis, and asthma.

The evidence suggests that each class of MWFs (straight, soluble, semisynthetic, and synthetic) can induce respiratory symptoms at MWF aerosol exposure concentrations at or above the NIOSH REL. To date, no convincing evidence identifies any component or components of MWF aerosol as the predominant cause of these symptoms. Roughly a twofold to sevenfold increase in risk for various respiratory symptoms has been associated with mean aerosol exposures ranging from 0.22 mg/m^3 (inhalable fraction) to 0.55 mg/m^3 (thoracic fraction) among groups of workers exposed to MWFs (Table 5–2). In a large study with mean exposures for the major types of MWFs between 0.41 to 0.55 mg/m^3 (thoracic fraction), Greaves et al. [1995b, 1997] found strong and statistically significant quantitative exposure-response relationships between cumulative concentrations of MWF aerosols and respiratory symptoms.

The onset or worsening of many symptoms over a workshift as well as the substantial symptomatic improvement reported by many affected workers when away from work, provide additional evidence that MWF aerosol represents a hazardous exposure. In some affected individuals, respiratory symptoms may precede the development of overt asthma—much as the symptoms of episodic coughing, wheezing, and phlegm predate the diagnosis of asthma by an average of more than 2 years in the much better studied occupational asthma associated with western red cedar dust [Chan-Yeung et al. 1982].

Similarly, studies of acute airflow reductions measured across shifts also provide evidence that exposure to MWF aerosols is associated with asthma. Four studies evaluated acute cross-shift lung function decrements in workers exposed to MWF aerosols [Kennedy et al. 1989; Kriebel et al. 1994, 1997; Robins et al. 1994, 1997; Sprince et al. 1997]. All but one of these studies found that the incidence of cross-shift lung function decrement is associated with occupational MWF aerosol exposures (Table 5–4). The one negative study involved average MWF exposures of 0.33 mg/m^3

(range 0.04 to 1.44 mg/m^3) measured with a light-scattering device calibrated with Arizona road dust [Sprince et al. 1997]. However, this study revealed a strong association between exposure concentration and acute respiratory symptoms. The studies with straight oil MWF exposures [Kennedy et al. 1989; Kriebel et al. 1994, 1997] offered no evidence that these exposures were less likely to cause the acute drops in lung function than the soluble oil MWF exposures. The evidence indicates that exposure to MWF aerosols causes acute reductions in ventilatory function regardless of the MWF type. Moreover, in all three studies with affected worker populations, these acute airflow reductions occurred in a dose-related manner and were attributable to MWF aerosol concentrations exceeding approximately 0.5 mg/m^3 (thoracic particulate mass). In two of the three studies [Kennedy et al. 1989; Kriebel et al. 1994, 1997], the acute airflow reductions were statistically significant at substantially lower aerosol concentrations.

Previous history of childhood asthma appears to increase the risk of acute lung function decrements associated with MWF aerosols, though such decrements occur in the absence of such history. Some evidence suggests that smoking (both active and possibly passive) or baseline airways obstruction may increase susceptibility to cross-shift lung function decrement induced by occupational MWF aerosol exposures [Robins et al. 1997]. Exposure characteristics of MWFs evaluated in one or more of the epidemiologic studies include bacterial count, fungal count, endotoxin, and various elements (including sulfur) [Robins et al. 1997; Kriebel et al. 1997; Sama et al. 1997]. Some of these characteristics show some promise as indicators of MWF aerosol potency, but the data are insufficient to displace the much better documented gravimetric aerosol concentration as the preferred indicator of MWF aerosol potency.

8.2.1.5 Rationale for Reducing MWF Exposures

Reducing MWF exposures to concentrations below the NIOSH REL whenever feasible is prudent because such reductions are likely to decrease the number of new cases of MWF-related asthma in exposed working populations. The evidence of increased asthma risk in some studies and the sharply increased risk of respiratory symptoms and acute pulmonary function changes with exposures above the NIOSH REL suggest that reducing exposures to concentrations below the NIOSH REL will decrease the incidence of all these conditions. Reducing the number of workers with acute respiratory symptoms or decrements in lung function may reduce the number of workers who seek medical evaluation and treatment [Rosenman et al. 1997b]. Though some workers with symptoms or acute respiratory decrements may not develop clinical asthma, they may still seek medical evaluation and treatment. The prevention of asthma is an important priority. Although clinical asthma may be mild in many affected workers, it can sometimes be debilitating. Occupational asthma frequently persists as a chronic condition even after affected workers are removed from exposure

[Chan-Yeung and Malo 1993a]. NIOSH is concerned that the same may be true for MWF-related asthma.

MWF exposures should be reduced to decrease the risk of MWF-related asthma and to decrease the risk of chronic airways disease. Repeated, modest acute airways effects from chronic exposure to MWF aerosol—though apparently reversible when workers are removed from exposure—may ultimately lead to irreversible impairment and chronic pulmonary disability. Acute effects and chronic lung impairment are linked for a variety of other occupational respiratory hazards [Peters 1974; Wegman et al. 1982; Weill 1984; Tabona et al. 1984; Becklake et al. 1988; Hankinson and Hodous 1983; Christiani et al. 1994; Glindmeyer et al. 1994; Becklake 1995; Schwartz et al. 1996]. No studies relate acute decrements caused by MWF aerosols with chronic airways obstruction among exposed metalworkers. Except for one small, older study [Järvholm 1982] and another study now in progress [Kennedy et al. 1995b], no prospective study has been conducted to determine long-term changes in lung function of workers exposed to MWF aerosols. However, completed studies demonstrate that occupational exposure to MWF aerosols causes acute respiratory effects. And based on substantial evidence cited earlier in this paragraph, it is prudent to assert that long-term exposure may cause chronic lung impairment in workers who experience acute respiratory effects.

Six cross-sectional studies of pulmonary function provide some evidence that MWF aerosol exposure has a chronic pulmonary effect [Krzeniak et al. 1981; Greaves et al. 1995a, 1997; Ameille et al. 1995; Massin et al. 1996; Kriebel et al. 1994; Sprince et al. 1997]. Findings from most of these studies generally indicate that occupational exposure to MWF aerosols is associated with reduced pulmonary function (Table 5–3). Three of the four studies with average exposures at or above the NIOSH REL have significant positive findings [Krzeniak et al. 1981; Greaves et al. 1995a; Ameille et al. 1995]. One of the two studies with average exposures below the NIOSH REL has a positive finding [Kriebel et al. 1994]. Pulmonary function evidence suggests that smoking may interact with MWF aerosol exposure to reduce lung function [Ameille et al. 1995; Robins et al. 1997]. Evidence from the largest study involving the major types of MWFs (and adjusted for smoking) suggests that cumulative exposures to straight oil MWF aerosol at a mean concentration of 0.43 mg/m^3 (thoracic particulate mass) and to synthetic MWF aerosol at a mean concentration of 0.39 mg/m^3 (thoracic particulate mass) are both associated with chronic pulmonary function effects that occur in a dose-related manner [Greaves et al. 1995a]. The results are less consistent for current exposure to soluble oil MWF aerosol. The investigators expressed caution about the lack of clear evidence for the chronic effects of exposure to soluble oil MWFs. They noted that most of the workers exposed to one MWF had also been exposed to other MWF types at some time. Overall, these six studies provide limited support for associating MWF aerosol exposures above the NIOSH REL with chronic reductions in pulmonary function.

In addition to work-related asthma and chronic airway effects, current MWF exposures are associated with HP [Bernstein et al. 1995; Rose et al. 1996; Kreiss and Cox-Ganser 1997]. Eight clusters of HP in the automotive industry among MWF-exposed workers have been reported [Kreiss and Cox-Ganser 1997]. MWFs associated with HP are synthetic, semisynthetic, and soluble oil MWFs, all of which are water-based or are diluted with large amounts of water. Microbial contaminants in MWFs are postulated to be the cause of HP outbreaks among workers exposed to MWF aerosol. The outbreaks seem to be associated with unusual flora such as acid-fast bacteria in MWF. *Mycobacterium chelonae* is a common factor in several of the outbreaks. Cases have been associated with MWF concentrations both above and below the NIOSH REL. Some workers with HP have been able to return to jobs that involve no MWF exposure or to jobs that involve exposure to a different MWF. It is not clear whether reducing MWF exposure concentrations alone will effectively reduce the risk of HP.

8.2.2 Cancer

Before the mid-1970s, substantial evidence indicated that at least some MWFs are associated with increased cancer risk at several organ sites (larynx, rectum, pancreas, skin, scrotum, and bladder) (see Section 5.3.3). The studies were not highly consistent with respect to the specific organ sites affected and the strength of association between the disease and the surrogates for exposure data. The inconsistencies are most likely related to the diverse nature of the MWF mixtures studied, the absence of detailed exposure information, and the limitations of the epidemiologic tools used to study the exposures. Because different epidemiologic study populations may have been exposed to different classes and formulations of MWFs, some lack of consistency in site-specific results should be expected when evaluating the carcinogenicity of these substances. The evidence is equivocal for an association between MWF exposure and cancer at several other sites, including the stomach, esophagus, lung, prostate, brain, colon, and hematopoietic system.

The study with the most statistical power [Tolbert et al. 1992] suggests that certain classes of MWFs are associated with cancer at certain sites. However, within these MWF classes, the formulations responsible for the elevated cancer risks are not identified. Within the Tolbert study, straight oil MWF exposure was associated with an increased risk for laryngeal and rectal cancer, and synthetic MWF exposure was associated with an increased risk for pancreatic cancer. Currently, no consistent evidence indicates that soluble oil MWF exposure is associated with cancer at any site. To conclude that no members of the soluble oil class of MWFs posed cancer risks in the past is premature, since soluble oil MWFs contain many of the ingredients found in straight oil MWFs—but in different concentrations. Also, many of the other epidemiologic studies with positive findings involved exposures to more than one class of MWF.

Non-MWF exposures in the MW environment are not likely to be responsible for the cancer findings described in Chapter 5. Smoking and alcohol are associated with some of the cancers associated with MWF exposure. However, the case-control studies controlled for these exposures when appropriate or determined that they were unlikely confounders. Although information about these lifestyle factors is not often collected in occupational cohort mortality or PMR studies, smoking is unlikely to account for relative risks greater than 1.3 for lung cancer and other smoking-related diseases [Siemiatycki et al. 1988]. However, some non-MWF exposures may have interacted with MWF exposure to produce or enhance the observed responses.

The studies that provide the bulk of the evidence associating MWF exposure and cancer involved workers employed as early as the 1930s and as late as the mid-1980s. Because the average latency period is 10 to 20 years between initial exposure to a carcinogen and the appearance of a solid organ cancer, the excess cancer mortality observed in these cohort studies most likely reflects the cancer risk associated with exposure conditions in the mid-1970s and earlier. Over the last several decades, substantial changes have been made in the metalworking industry, including changes in MWF composition and reduction in MWF impurities and exposure concentrations. Efforts to reduce potentially carcinogenic exposures have been ongoing. Removal of PAHs from MWFs began in the 1950s, and EPA regulations in the 1980s were directed at reducing nitrosamine exposures. These changes are likely to have reduced the cancer risks. However, since few epidemiologic data support the association of MWF composition and impurities with the cancer risks observed in earlier cohorts, the data are insufficient to conclude that these changes have eliminated all cancer risks. Furthermore, many workers who entered jobs involving MWF exposures in the mid-1970s or later are now completing the minimum latency period of 10 to 20 years since first exposure, and a definitive study of a large cohort of such workers has not been conducted. Thus the risk of cancer from MWF exposures in the mid-1970s and later remains to be determined.

The NIOSH recommendation for reducing MWF aerosol exposures is supported by substantial evidence associating some MWFs used before the mid-1970s with cancer at several organ sites, and by the potential for current MWFs to pose a similar carcinogenic hazard. However, the primary basis of the NIOSH recommendation is the risk that MWFs pose for nonmalignant respiratory disease.

8.2.3 Dermatologic Effects

Surveillance data from the Bureau of Labor Statistics [DOL 1993] lists industries with potential MWF exposures as having some of the highest incidence rates of skin diseases. Several skin diseases can result from skin contact with MWFs and their contaminants. Straight oil MWFs are often reported to produce folliculitis, oil acne, and keratoses; the water-based oil emulsions (soluble oil and semisynthetic) and synthetic

MWFs primarily cause irritant contact dermatitis and occasionally allergic contact dermatitis [Fisher 1986]. Skin carcinomas are historically associated with the PAH content of mildly refined base oils. Severe refining methods can reduce the PAH content to less than 1% [Skisak 1995].

Contact dermatitis (either irritant or allergic) is the most commonly reported skin disease associated with MWFs. Prevalence rates in cross-sectional epidemiologic studies range from 14% to 30% [de Boer et al. 1988, 1989a,b; Rycroft 1982]. Dermatitis prevalence rates of 14% to 67% have been observed in a variety of workplaces where workers were exposed to MWFs [NIOSH 1984, 1985, 1986a,b, 1989, 1994a]. The impact and significance of dermatitis may go unrecognized because workers often continue to work in spite of active skin lesions, burning, and itching. However, the high prevalence rates of dermatitis indicate that many workers are susceptible to the irritating or sensitizing nature of MWFs and contaminants.

Many factors play a role in the development of dermatitis and other skin diseases in workers exposed to MWFs:

- The MWF class and additives used
- The amount of skin contact with MWFs (e.g., through splashing or repeated or prolonged immersion)
- Skin abrasion or cuts
- Individual susceptibility to irritants or allergens in MWFs
- Inadequate cleansing of the skin after contact
- The irritant nature of some soaps, detergents, and other cleansing materials used by the workers
- Reuse of MWF-soaked clothing or materials
- Use of personal protective equipment such as faceshields and clean, nonirritating, nonsensitizing gloves and aprons
- The cleanliness of the general work environment
- Climate (high or low humidity and hot, warm, or cold temperatures)
- Machine types and operations, and engineering control methods (e.g., tight-fitting machine enclosures)

Sufficient dermal exposure assessment and absorption studies have not been conducted for MWFs. In a variety of unguarded metalworking operations and situations in which workers wear no personal protective equipment (e.g., gloves, aprons, and face and eye protectors), workers may be frequently splashed or may repeatedly dip their unprotected hands and arms into MWFs. High-speed, high-feed operations may produce aerosols that settle on the skin and mucosal surfaces. In addition, MWFs on the skin may not readily evaporate or be easily washed off. In these cases, the degree of skin contact may be underestimated [Rosenstock and Cullen 1986]. The amount of dermal absorption for many of the MWF components and additives is unknown for intact, abraded, irritated, or otherwise damaged skin.

Because of the poor prognosis for workers with MWF dermatitis [Pryce et al. 1989a], dermatitis prevention is important, and limiting the dermal exposure to MWF is the crux of preventive measures. Other preventive measures may include the following [Mansdorf and Lubs 1994; Tucker 1988; Zugerman 1986]:

- Substituting safe, less irritating, or nonallergenic additives or MWF constituents
- Using process modification, isolation, and ventilation to limit the dispersal of MWFs
- Using work practices and administrative controls to assure proper MWF maintenance and workplace cleanliness
- Properly using personal protective equipment such as protective gloves, aprons, and clothing
- Educating workers about the dermal effects of MWF contact and the importance of workplace personal hygiene
- Changing MWF-saturated clothing quickly
- Washing skin surfaces that have contacted MWFs as soon as possible with nonirritating and nonabrasive soaps

8.2.4 Effects of Microbial Contamination

Water-based and water-contaminated MWFs typically contain both bacteria and fungi. The organisms may be introduced as transients from the air, make-up water, or extraneous materials introduced into the tanks; or they may be disseminated from flocs of biomass that have sloughed from the biofilms growing on the system surfaces. Rossmoore [1981] reported aerobic bacterial counts of 10^5 to 10^7 colony-forming units/ml in MWFs; Salmeen et al. [1987] reported densities that consistently exceeded 10^9 colony-forming units/ml. These counts are similar to those obtained from untreated municipal sewage, but they still greatly underestimate the total extent of microbial contamination because they do not account for anaerobic and other nonculturable bacteria, nor do they include fungi. Microbial growth in MWFs is a long-recognized problem, but the emphasis has generally been on maintenance of MWF processing characteristics [Hill 1983; Salmeen et al. 1987; Mattsby-Baltzer et al. 1989b, 1990] rather than on the possible health risks for exposed workers. Workers may be exposed to microbially contaminated MWFs by extensive skin contact with contaminated MWF [Salmeen et al. 1987] and by inhaling contaminated aerosols [Mattsby-Baltzer et al. 1989b]. Not surprisingly, researchers have suggested that some respiratory health effects seen in exposed workers may be related to contaminating microorganisms or their products (such as endotoxins, exotoxins, and mycotoxins) [Holdom 1976; Hill and Al-Zubaidy 1979].

The toxic effects of endotoxin inhalation are particularly well known; they include fever, obstructive pulmonary effects, and inflammation [Snella 1981; Kabir et al. 1978; Rylander and Vesterlund 1982]. Robins et al. [1995b] reported personal exposures of automotive workers to endotoxin concentrations ranging from 16.4 to 234 endotoxin units/m^3 [Robins et al. 1994]. For comparison, Rylander and Jacobs [1997] have suggested an occupational threshold concentration equivalent to 100 endotoxin units/m^3 to prevent airways inflammation [Rylander and Jacobs 1997]. Although endotoxins may contribute to adverse respiratory effects, the role of endotoxins in MWF-associated respiratory effects (including asthma) has not been determined.

One published report describes an MWF-aerosol-associated outbreak of a self-limiting nonpneumonic form of legionellosis with influenza-like symptoms [Herwaldt et al. 1984].

Exposure to MWF aerosols has been commonly assessed either as an aerosol mass (gravimetric measurement) or as mass obtained by solvent extraction of the sampling filter. Neither method specifically measures the microbial concentrations or toxins. Therefore, any measurement based on these sampling and analytical methods would not quantitatively or qualitatively assess microbiological and toxin exposure concentrations. Health data are currently insufficient to support an REL for bacterial or fungal concentrations in contaminated MWFs, but the potential of these contaminants as health hazards for exposed workers should be investigated. The emphasis should be placed on a total MWF system management program—including careful fluid monitoring, record-keeping, and maintenance; the judicious use of biocides only as a preventive measure and not as a treatment for microbial overgrowth; a system of mist control including close-capture ventilation and machine enclosures; and training for employees and management on the hazards and proper use of MWFs.

8.3 Rationale for the REL

The NIOSH REL for occupational exposures to MWF aerosol is 0.4 mg/m^3 (TWA) for thoracic particulate mass. 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/m³ for thoracic particulate mass is equivalent to a 0.5 mg/m³ for total particulate mass.

The NIOSH REL of 0.4 mg/m³ for thoracic particulate mass (or 0.5 mg/m³ for total particulate mass) is based on four major considerations: (1) the adverse respiratory health effects of MWF aerosol exposure, (2) the selection of an index for measuring MWF aerosol exposure, (3) the applicability of the REL to all types of MWFs, and (4) the technological feasibility of the REL.

8.3.1 Respiratory Health Effects

Substantial evidence indicates that MWF aerosol exposure at concentrations above the REL adversely affects the respiratory systems of many workers. Serious adverse respiratory effects related to MWF aerosol exposure include nonspecific respiratory symptoms, acute impairment of lung function, asthma, and HP. In addition, some evidence suggests that long-term exposure to MWF aerosol can cause chronic lung function impairment even in the absence of overt clinical asthma or HP. By analogy to other occupational respiratory hazards, it is prudent to assume that chronic lung function impairment can result from repeated acute effects on lung function caused by MWF aerosol exposure.

Although some adverse respiratory effects occur at MWF aerosol exposures below the NIOSH REL, evidence indicates that acute impairment of lung function and asthma may be less severe at lower concentrations. However, no exposure-response studies have related HP to MWF aerosol concentration. In addition to reducing MWF aerosol exposures, improvements in the management of fluid systems and microbial contamination of water-containing MWF will most likely be required for most effective control of MWF-associated respiratory health effects, including HP.

8.3.2 Index for Measuring MWF Exposures

A major consideration in determining the REL was whether it should be based on the total particulate mass or the thoracic fraction of the total particulate mass. Since most specific MWF components linked with these effects are uncertain, a surrogate measure of exposure such as the thoracic or total particulate mass is necessary. If only the adverse respiratory effects are considered, an REL measured as thoracic particulate mass is preferable to one measured as total or inhalable particulate mass.

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[*] Conversion factor adapted from data of Woskie et al. [1994].

Increasingly, industrial hygienists are adopting more precisely defined criteria for different size fractions of airborne particulates or aerosols [Soderholm 1993]. In simple terms, these new criteria separate airborne particulates into three fractions. Soderholm [1993] has specified the characteristics of the ideal sampler that would accurately collect these fractions. The concentrations measured by an inhalable particulate sampler and the older "total" sampler (such as the 37-mm, closed-face cassette used in the NIOSH Method 0500) are expected to be approximately equal in environments where the geometric median or mass median particle diameter is smaller than about 10 µm.

Observations from three plants suggest that MWF aerosols generally involve particles in the range of 2 to 8 µm when size is expressed either as geometric mean diameters or mass median diameters [Woskie et al. 1994]. Thoracic mass was strongly correlated ($r=0.95$) with inhalable mass [Woskie et al. 1994]. In most MWF environments, the correlation between the older "total" particulate mass and the thoracic fraction will be high. Although the thoracic fraction of the MWF aerosol is likely to be more strongly associated with respiratory effects, the inhalable or older "total" particulate mass may be more strongly associated with the risk of occupational cancer. The nonrespiratory cancers epidemiologically associated with some past MWF exposures may have resulted from ingestion of MWF particulates following deposition in the nose, mouth, or throat. Most of the recent epidemiologic studies of adverse respiratory effects measured the thoracic fraction rather than the older "total" particulate mass. NIOSH recommends an exposure limit for MWF aerosol based on thoracic particulate mass. However, until thoracic samplers are more widely available and adopted, NIOSH recommends the use of total particulate mass sampling for MWF aerosol. The methods for sampling thoracic particulates are discussed in Chapter 7. 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 1997b; ISO 1995]. NIOSH recommends that samples collected by either method be analyzed gravimetrically by NIOSH Method 0500.

NIOSH considered proposing an REL based on a provisional method developed by the ASTM (ASTM E34.50) Committee for separation of MWF from co-sampled material. Samples are collected on polytetrafluoroethylene (PTFE) filters and extracted with a ternary solvent blend. The difference in the weight of the filter before and after collection yields the total mass sampled. The difference in the weight of the filter before and after extraction is the weight of the MWF. The technique is undergoing evaluation in a large-scale field test and is discussed in Chapter 7. NIOSH decided not to propose an REL based on this provisional method because it has not been fully evaluated. Currently, little or no scientific evidence suggests that "extractable" MWF is superior to thoracic or inhalable particulate aerosol as a predictor of adverse health effects from MWF aerosols. However, extractable MWF aerosol measurements may be useful in occupational environments where there are simultaneous exposures to nontoxic particulate materials and MWF aerosols.

8.3.3 Applicability of REL to All MWFs

NIOSH recommends that the MWF aerosol REL apply equally to all classes of MWFs because all have been associated with adverse health effects (although for some effects, limited evidence indicates variation in risk by class). The cancer study with the most statistical power [Tolbert et al. 1992] suggests that specific classes of MWFs are associated with cancer at certain sites. Within the Tolbert study, straight oil MWF exposure was associated with an increased risk for laryngeal and rectal cancer, and synthetic MWF exposure was associated with an increased risk for pancreatic cancer. NIOSH believes it is premature to conclude that all soluble classes of MWFs were free of past carcinogenic risks, since soluble MWFs contain many ingredients found in straight oil MWFs—but in different concentrations. Also, many of the epidemiologic studies with positive findings involved exposures to more than one class of MWF. The substantial evidence of carcinogenicity for some MWFs in commercial use before the mid-1970s and the possibility that some of the currently used MWFs continue to pose a carcinogenic hazard support the recommendation (based on respiratory disease risk) for reduced exposures to all types of MWFs. Removal of PAHs from MWFs began in the 1950s, and EPA regulations in the 1980s were directed at reducing nitrosamine exposures. These changes are likely to have reduced the risk of cancer in MWF-exposed workers, but only future epidemiologic research can determine whether the hazard has been totally eliminated.

Several different skin diseases can result from skin contact with MWFs and their contaminants. Straight oil MWFs are often reported to produce folliculitis, oil acne, and keratoses; the water-based oil emulsions (soluble oil and semisynthetic) and synthetic MWFs primarily cause irritant contact dermatitis and occasionally cause allergic contact dermatitis [Fisher 1986]. Skin carcinomas are historically associated with the PAH content of mildly refined base oils (previously used in straight oil and soluble oil MWFs). Skin diseases associated with MWFs suggest that all types of MWFs can have adverse health effects.

Substantial evidence indicates that adverse respiratory effects are associated with all classes of MWFs (straight oil, soluble oil, synthetic, and semisynthetic) and with related exposures from contaminants and additives (see Sections 5.1 and 8.2.1). Respiratory effects include symptoms consistent with airways irritation, chronic bronchitis, and asthma; acute reductions in pulmonary function; chronic impairment in pulmonary function; increased airways reactivity to methacholine challenge; asthma; and HP. Substantial evidence indicates that respiratory symptoms and acute reductions in pulmonary function occur with all types of MWF exposures (Tables 5–2 and 5–4). Limited epidemiologic evidence shows that all types of MWFs are associated with chronic reductions in pulmonary function (Table 5–3). Evidence also indicates that exposure to aerosols of microbially contaminated water-based (i.e., soluble, semisynthetic and synthetic) MWFs is associated with risk of HP [Bernstein et al. 1995; Rose et al. 1996; Kreiss and Cox-Ganser 1997]. Substantial evidence exists for an increased risk of asthma in workers exposed to synthetic and soluble oil MWFs, and some evidence exists for an elevated risk with straight oil MWF exposures (Table 5–1) [Forbes and Markham 1967; Robertson et al. 1988; Savonius et al. 1994]. In addition to the evidence for asthma with MWF exposure, there is evidence of increased airway reactivity following methacholine challenge [Wild and Ameille 1997; Massin et al. 1996; Kennedy et al. 1995b,c]. As with other occupational exposures that cause respiratory symptoms, acute reductions in pulmonary function, and asthmatic disease, NIOSH believes that it is prudent to assume that MWFs cause chronic pulmonary function impairment even in the absence of overt clinical asthma. Reducing chronic MWF exposures to the NIOSH REL or lower should reduce the likelihood that these exposures will cause substantial reductions in pulmonary function. NIOSH recommends that the REL apply equally to all classes of MWFs. Additional research may make it possible to identify MWF formulations with substantially lower risks.

8.3.4 Technologic Feasibility of Controlling MWF Exposures

Keeping MWF aerosol exposures at or below the REL is technologically feasible for most metalworking operations. This assertion is supported by the following observations: (1) MWF aerosol concentrations have steadily declined over the last several decades, as indicated by the OSHA IMIS data set, NIOSH HHEs, and environmental measurements reported in the scientific literature; (2) the automation has increased for machining operations; and (3) engineering controls have been widely implemented and good work practices have been adopted. The most complete information available about the decrease in MWF aerosol exposures comes from the automotive manufacturing industry. Mean MWF aerosol concentrations were between 0.2 and 0.55 mg/m³ (thoracic fraction) in most recent respiratory studies [Greaves et al. 1995a,b, 1997; Robins et al. 1994; Kriebel et al. 1994]. A recent engineering study found that median aerosol exposure concentrations (total particulate mass) were 0.5 mg/m³ for older machines without retrofit enclosures, 0.44 mg/m³ for older machines with retrofit enclosures, and only 0.21 mg/m³ for enclosed new machines [Hands et al. 1996]. Presumably, machines without enclosures were those with inherently lower emissions. These data indicate that more complete and effective enclosure is possible when the machine is designed with an enclosure. Although the trend in the industry may be toward higher production rates and thus higher MWF aerosol production, these data show that aerosols can be controlled effectively by machine enclosure, ventilation, and air cleaning.

MWF aerosol exposures can be minimized by using the same basic principles of control in both small and large industries. Small metalworking operations may not employ large fixed automation such as transfer machines, but they may use smaller, more flexible machine tools. Older tools found in large and small industries may not be adequately enclosed. The lack of enclosures on older machines could be partially offset by their lower production rates (turning speed, MWF application, machine utilization, etc.), which may reduce the generation of mists.

Between 1990 and 1995, OSHA compliance data collected from a wide variety of industries showed that 73% of the MWF aerosol concentrations were less than 0.5 mg/m³ (Table 3–3). These data indicate that MWF aerosol exposures are now being kept below 0.5 mg/m³ in many workplaces. Data are not limited on the feasibility of reducing exposures that exceed 0.5 mg/m³ (total particulate mass) at specific worksites. Worker exposures at nonautomated metalworking operations may be difficult to control. One study by Yacher et al. [1997] demonstrated a threefold reduction in exposures (from 0.3 to 0.1 mg/m³) after air-cleaning devices were installed on previously enclosed but nonventilated machines. Many nonautomated machines involve worker/machine interactions that place the worker close to (i.e., at arm's length of) the point of MWF aerosol generation and at risk for substantial dermal exposure. If the worker cannot be isolated from the machine, it may prove difficult to use local ventilation or enclosures to reduce the aerosol exposure.

Newer, automated metalworking machines allow work stations to be positioned to minimize aerosol exposures. With these machines, aerosol-generating operations can be effectively enclosed, and the aerosols can be exhausted and processed in air cleaners for recirculation or discharge to the environment.

8.4 Summary

NIOSH recommends that exposures to MWF aerosols be limited to 0.4 mg/m³ for thoracic particulate mass (which corresponds to approximately 0.5 mg/m³ for total particulate mass) as a TWA for up to 10 hr/day during a 40-hr workweek, measured according to NIOSH Method 0500. The NIOSH REL is intended to prevent the diverse respiratory effects associated with MWF exposure. Limiting MWF aerosol exposure is also prudent because of the association of past MWF exposures with various cancers. Measurement of MWF aerosol is generally a practical and reasonable surrogate of exposure data for nonbiological agents in MWFs that cause the adverse health effects. In most MWF operations it is technologically feasible to keep worker exposures at or below 0.4 mg/m³ (thoracic mass).

The NIOSH REL or lower concentrations can be readily achieved for operators of newer machines equipped with engineering controls. The NIOSH REL may not be technologically feasible for older machines that have inadequate engineering controls. In some metalworking operations, it is feasible to reduce exposures to concentratisons substantially below the NIOSH REL. Keeping exposures below the NIOSH REL is desirable because evidence indicates adverse respiratory effects in some workers exposed to MWF aerosol at the NIOSH REL. Further research may allow NIOSH to develop more protective future recommendations regarding recommended levels of microbiological contaminants, other specific components of MWFs, and lower concentrations of MWF particulate exposure.

Keeping MWF aerosol exposures at or below the NIOSH REL will significantly reduce the risk of adverse health effects in exposed workers. To further minimize health risks, a comprehensive safety and health program should be implemented to provide for worker education and training, worksite analysis, fluid management, mist control, and medical monitoring. Reducing MWF exposures to concentrations below the REL is an important step in protecting workers, but the steps outlined in the occupational safety and health program described in Chapter 9 are also highly important. In particular, the prevention of dermal exposures to MWFs is critical in preventing MWF-related skin disorders.