

New Evidence on the Health Hazards and Control of Metalworking Fluids Since Completion of the OSHA Advisory Committee Report

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Background Metalworking fluids (MWF) are used in the manufacture of engines, transmissions, chassis parts and other products. In 2003, OSHA denied a union petition to promulgate a standard for MWF. The 3rd Circuit Court of Appeals rejected a union lawsuit to compel OSHA to regulate MWF. OSHA relied exclusively on the 1999 Metal Working Fluids Standards Advisory Committee report, therefore, only evidence available before 1999 was quoted supporting the denial. This review was conducted to identify studies published since 1998.

Methods Electronic reference sources were queried for the terms for metalworking fluids, machining fluids, cutting fluids, cutting oils, coolants, machining, and machinist. All items returned were reviewed for relevance to MWF regulation.

Results The review noted 227 reports in the peer reviewed literature directly relevant to regulation of MWF exposures. Of these, 26 addressed cancer; 58 respiratory effects; 32 skin effects or absorption; 45 microbial contaminants; and 76 exposure measurements and controls. Three major studies identified excess cancer including lung, liver, pancreatic, laryngeal, and leukemia associated with MWF exposures. Reports strengthened associations of asthma and hypersensitivity pneumonitis with recent exposure to MWF.

Conclusions Material new evidence demonstrates significant risks to material impairment of health at prevailing exposure levels and feasibility of lower exposure limits. Am. J. Ind. Med. 53:792–801, 2010. © 2010 Wiley-Liss, Inc.

KEY WORDS: metalworking fluids; MWF; OSHA; cancer; respiratory; skin; microbial contamination; exposure measurement; standards; PEL

BACKGROUND

Metalworking fluids (MWF) are used to lubricate, cool tools and the workpiece, and flush away chips during the machining, cutting, grinding and drilling of metal during the manufacture of engines, transmissions, chassis parts in the auto industry, and numerous other products. NIOSH

estimated that a million American workers are exposed to metalworking fluids and lubricants, although the number exposed to MWF in the manufacturing sector is smaller.

In November 1993, the UAW petitioned OSHA for a standard for MWF [Bieber, 1993]. The petition suggested an emergency standard interim with a provisional exposure limit of 0.5 mg/M³ of MWF, pending formal analysis of significant risk and feasibility consistent with the OSHA law. The UAW also asked NIOSH to publish a criteria document and recommend an exposure limit for MWF. In December 1995 OSHA identified MWF as a priority for standard setting, and on August 29, 1996 OSHA formed a Metalworking Fluid Standards Advisory Committee (MWF SAC). OSHA also placed MWF on its agenda for rulemaking. NIOSH issued a criteria document for

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occupational exposure to metalworking fluids in January 1998 [NIOSH, 1998].

NIOSH recommended an exposure limit of 0.5 mg/M³ (or 0.4 mg/M³ thoracic fraction), medical surveillance and other protections. NIOSH concluded that “substantial evidence existed for increased risk of cancer at several sites (larynx, rectum, pancreas, skin, scrotum, and bladder) among workers exposed to MWF before the mid-1970s.” Evidence for and association with cancer at stomach, esophagus, lung, prostate, brain, colon, and hematopoietic system sites was termed “equivocal.” No citations in the NIOSH review for cancer were referenced beyond 1997.

The OSHA Metalworking Fluid Standards Advisory recommended, in July 1999, by a vote of 11–4, that OSHA set an MWF standard including a PEL. The four dissenters, all representatives of employers and including an MWF supplier, recommended OSHA should do “something,” but not set a standard [Sheehan, 1999]. OSHA included MWF on the agency’s regulatory agenda as a long term action.

The Presidency changed parties in January 2001. OSHA removed metalworking fluids from the regulatory agenda in October 2001 and published the result in December 2001. UAW and the United Steelworkers sued to compel OSHA to move forward on October 21, 2003. OSHA formally denied the UAW 1993 petition in December 2003. [Henshaw, 2003] Then, on March 23, 2004, the Third Circuit Court of Appeals denied a UAW petition to compel OSHA to move forward [US Court of Appeals for the Third Circuit, 2004]. No further regulatory action has taken place in the United States or internationally.

This review was conducted to identify studies published since the start of 1999 which might support reopening the record and restarting the standards process.

OSHA’s Reasons for Denial of the Petition and the Court’s Response

Assistant Secretary Henshaw’s 2003 letter of denial of the UAW petition stated “The health effects evidence available at this time is not compelling. The evidence linking current formulations of MWFs to cancer is *equivocal at best*. MWFs aerosols are associated primarily with respiratory conditions of widely varying levels of severity, and the risks MWFs pose for such conditions are unclear” [emphasis added].

The Third Circuit Court of Appeals opined that OSHA’s decision not to go forward with rulemaking would be examined to see if it were “arbitrary and capricious.” Adopting OSHA’s statement of the scientific evidence, the Court noted “...the evidence linking cancer to MWF exposure is equivocal. Even assuming that MWF exposure causes dermatitis, asthma, HP, and other respiratory diseases (which the scientific evidence supports), these diseases, as OSHA recognizes, are rarely fatal. This is not to say that the

health effects of exposure to MWFs are insignificant, but only that OSHA justifiably prioritized the regulation of more severely toxic substances.”

Evidence not in the Record in 1999

Despite OSHA’s claim of a review of recent literature, no references to literature beyond the OSHA MWF SAC report were cited in the letter of denial. The 3rd Circuit relied on OSHA’s statement of reasons in supporting the denial of the union lawsuit. Therefore, evidence since, or evidence not considered, in the MWF SAC report of July 1999 would support reopening the record and restarting the process. The most authoritative review and recommendation to date, and considered by the MWF SAC, was the NIOSH Criteria Document of January 1998. Thus, the authoritative scientific record for OSHA’s decision can be considered to have closed no later than the late 1997, when the NIOSH criteria document was completed and sent for peer review. The MWF SAC was a stakeholder group, not a scientific review group, although it included health scientists. The MWF SAC group relied heavily on the NIOSH Criteria Document, but members were aware of publications in 1998. Therefore, January 1999 was selected as the start date for this review.

The following discussion will consider published studies since the MWF SAC report, grouped by topic: cancer, respiratory effects, skin effects, and MWF composition and control. The latter includes microbiology, chemical composition, exposure measurement, and engineering controls. The discussion of cancer findings will include more detail, since both OSHA and the Court placed great weight on this matter.

METHODS

Electronic reference sources were queried for the terms metalworking fluids, machining fluids, cutting fluids, cutting oils, machining and machinist. Sources were Medline, ISI web of knowledge, JSTOR, Lexis–Nexis and Google Scholar. The NIOSH Criteria Document on metalworking fluids and the OSHA Metalworking Fluid Standards Advisory Committee report were both reviewed. Selected available full text documents were retrieved. Abstracts available electronically were retrieved. Where titles alone could be retrieved, these were taken as evidence of notice of the subject matter but not conclusions. Citations and abstracts were stored in a Pro-Cite data base. Citations were categorized by subject (described below) and each subject chronology synchronized by year with other reports. Upwards of 500 assorted items were identified, catalogued and are summarized here. Non-scholarly articles in the trade press were included in the total but not included in the sum of items deemed material to decisions regarding rulemaking; patents (which are frequent in Google Scholar) were excluded. Proceedings of several national conferences on

MWF were reviewed but presentations in abstract were not counted in this review. These were the MWF conferences sponsored by the Motor Vehicle Manufacturers Association (among other sponsors) in 1995 and 1998, the ACGIH Symposium on oil mist in 2003, and the 3rd Symposium sponsored by the Independent Lubricant Manufacturers Association and the Auto Industry Action Group in 2007.

RESULTS

The search identified over 500 items, dating from 1935. Some of these were event reports or records of regulatory action. Only three foreign language citations were found, of which one appeared after 1999. From these, 227 published reports in the peer reviewed literature since the start of 1999 were noted. Thus, close to half the scientific literature was published after the evidence supporting the denial was compiled. Of this series, 80 were authored by investigators outside the United States. Several key respiratory effects publications came from the UK.

Cancer and MWF

From January 1999 forward, there were 26 publications primarily relevant to an association between MWF exposure and cancer. Some were publications about potentially carcinogenic ingredients; additional publications in the chemical composition category included such ingredients. Key publications will be discussed here.

The most important of these publications was the 10-year update of the UAW-GM cohort, previously observed from 1940 to 1984 and now extended to 1994 [Eisen et al., 2001]. This added 10 years of latency to everyone in the cohort, and up to 10 years of additional exposure to those active after 1984. Observations for selected causes of death are shown in Table I, combining results taken from both reports. For the first publication, the investigators concluded there was an increase in cancer with increased MWF exposure largely based on exposure-response within the cohort [Eisen et al., 1992]. Only for leukemia (SMR = 1.31, 95% CI = 1.08–1.60) did the excess achieve statistical significance in the cohort as a whole. The update publication observed statistically significant increases in mortality over the whole cohort for 1940–1994 from cancer of all sites (SMR = 1.05, 95% CI = 1.01–1.09), liver (SMR = 1.42, 95% CI = 1.12–1.77), lung (SMR = 1.08, 95% CI = 1.02–1.15) and leukemia (SMR = 1.34, 95% CI = 1.14–1.58). More impressive were the observations during the 10-year update period, reflecting more recent exposures and formulations, and contrasting with the original full cohort report. During the more recent years, mortality was elevated for all causes (SMR = 1.1, 95% CI = 1.07–1.13), all cancer sites combined (SMR = 1.14, 95% CI = 1.08–1.21), stomach (SMR = 1.46, 95% CI = 1.05–1.97), liver (SMR = 1.82, 95% CI = 1.24–2.58), pancreatic (SMR = 1.44, 95% CI = 1.11–1.83), leukemia (SMR = 1.4, 95% CI = 1.04–1.84), and lung (SMR = 1.16, 95% CI = 1.05–1.28). For each of these except leukemia, the SMR substantially

TABLE I. Standardized Mortality Ratios Relative to US Population for Male Autoworkers Exposed to Metalworking Fluids

Cause of Death	1940–1994				1985–1994				1940–1985			
	Obs	Exp	SMR	95% CI	Obs	Exp	SMR	95% CI	Obs	Exp	SMR	95% CI
All causes	13,105	12,975	1.01	0.99–1.03	4,197	3,815	1.1	1.07–1.13	8,908	9,160	0.97	0.95–0.99
All cancers	2,983	2,841	1.05	1.01–1.09	1,134	995	1.14	1.08–1.21	1,849	1,846	1.00	0.96–1.07
Esophageal	83	68	1.22	0.97–1.51	34	25	1.37	0.95–1.92	49	43	1.13	0.86–1.51
Stomach	151	130	1.16	0.98–1.36	42	29	1.46	1.05–1.97	109	101	1.07	0.89–1.30
Colon	252	265	0.95	0.84–1.08	98	92	1.06	0.86–1.30	154	173	0.89	0.75–1.04
Rectal	78	74	1.06	0.84–1.32	17	16	1.07	0.62–1.71	61	58	1.06	0.81–1.35
Liver	78	55	1.42	1.12–1.77	31	17	1.82	1.24–2.58	47	38	1.24	0.92–1.64
Pancreatic	143	144	0.99	0.83–1.16	66	46	1.44	1.11–1.83	77	99	0.78	0.62–0.97
Laryngeal	44	38	1.16	0.85–1.56	11	11	1.02	0.51–1.83	33	27	1.22	0.87–1.71
Lung	1,002	928	1.08	1.02–1.15	401	346	1.16	1.05–1.28	601	582	1.03	0.95–1.12
Skin	35	55	0.64	0.45–0.89	7	22	0.32	0.13–0.66	28	33	0.85	0.59–1.22
Prostatic	261	246	1.06	0.94–1.20	114	108	1.06	0.87–1.27	147	139	1.06	0.90–1.24
Brain	84	74	1.14	0.91–1.41	29	23	1.24	0.83–1.78	55	50	1.09	0.85–1.42
Leukemia	147	110	1.34	1.14–1.58	51	36	1.4	1.04–1.84	96	73	1.31	1.08–1.60
All non-malignant	879	935	0.94	0.87–1.00	388	363	1.07	0.96–1.18	491	572	0.86	0.79–0.94
Respiratory diseases												

Results for 1940–1994 and 1985–1994 taken from Eisen et al. [2001]. Results for 1940–1985 calculated by difference.

increased between the initial and the extended period, indicating an increase with latency which should be considered an aspect of exposure-response. Non-malignant respiratory disease (NMRD) was elevated during the update period, but the excess did not achieve statistical significance. Based on exposure response modeling, the investigators noted that “associations were found between straight MWF and esophageal, laryngeal and rectal cancer; soluble MWF and cancer of the esophagus, larynx, skin, and brain; synthetic MWF and cancer of the esophagus, liver, and prostate.” The investigators also commented that the SMR values were also elevated for stomach and liver cancer among the persons recently hired, which lends no support to the notion that risks associated with recent exposures are less or null compared to earlier periods. These investigators also published a substantial series of studies observing exposure-response for specific tumor sites within the cohort. These include associations of prostate and brain cancer with increasing cumulative soluble oil exposure [Thurston et al., 2002]. Another investigation explored and determined it was unlikely that differences in smoking and drinking habits were responsible for exposure response relationships for laryngeal cancer [Kriebel et al., 2004; Zeka et al., 2004; Bardin et al., 2005; Thompson et al., 2005; Agalliu et al., 2005a,b; Friesen et al., 2009].

A cohort mortality study of 240,000 Ford Motor Company hourly workers observed that lung cancer was elevated among employees in transmission/gear manufacturing (SMR = 121, 95% CI = 112–130), and engine manufacturing (SMR = 111, 95% CI = 101–123). Stomach cancer was elevated in engine manufacturing (SMR = 147, 95% CI = 110–192) [Delzell et al., 2003]. These are the two main processes using MWF in auto production. Few other exposures of concern for cancer risk are present in such facilities. The Transmission and Chassis processes are equivalent to the facilities in the GM study. The investigators did not attribute the increased lung cancer to increased smoking, since the reduced mortality from NMRD observed in the cohort did not support the smoking hypothesis. Mortality increased with time since hire, a measure of latency and thus exposure-response [Mirer, 2003b].

An update by the National Cancer Institute (NCI) of the General Motors (GM) Cadillac Engine cohort [Kazerouni et al., 2000] observed that among the full cohort, SMRs for liver and biliary tract cancers (SMR = 1.60 95% CI = 1.08–2.28), and testicular cancers (SMR = 2.10, 95% CI = 1.01–3.87) were significantly elevated. Among the subset of workers with heavy oil mist exposure, SMRs were significantly elevated for cancers of the lung (SMR = 1.22, 95% CI = 1.05–1.40), liver and biliary tract biliary tract and liver (SMR = 1.68, 95% CI = 1.02–2.59), testis (SMR = 2.57, 95% CI = 1.11–5.06), and for Hodgkin’s disease (SMR = 2.14, 95% CI = 1.17–3.60). The risk of death due to lung cancer was greatest among workers with

heavy exposure to oil mist employed for 15 or more years. Mortality due to stomach cancer was in excess among workers with heavy exposure to oil mist who were employed for 5 or more years (SMR = 1.42, 95% CI = 0.87 ± 2.19). Workers exposed for 5 or more years experienced a significant excess of lung cancer deaths (SMR = 1.33, 95% CI = 1.04–1.68). Significant excesses of deaths due to asthma (up to SMR = 5.17, 95% CI = 1.89–11.26 in some exposure strata) and emphysema (up to SMR = 1.94, 95% CI = 1.30–2.78 in some exposure strata) were observed.

The emergence of liver cancer in these cohorts finds biological plausibility in the findings that diethanolamine, both an intended ingredient and unwanted impurity in water-based MWF’s, causes liver cancer and liver abnormalities when applied to the skin of mice in chronic studies [NIEHS, 1999, 2001]. Liver abnormalities in mice were observed after sub-chronic skin exposure to a commercial MWF as recommended in process dilutions [Al-Humadi et al., 2000].

Zhao et al. [2005] reported on a cohort of aerospace workers which included machinists. Based on semi-quantitative assessment of exposures, and internal comparisons to non-exposed in the cohort, exposure to mineral oils increased mortality and incidence of lung cancer (1.56; 1.02–2.39 and 1.99; 1.03–3.85), and incidence of melanoma (3.32; 1.20–9.24). Mineral oil exposures also contributed to incidence and mortality of esophageal and stomach cancers and of non-Hodgkin’s lymphoma and leukemia when adjusting for other chemical exposures.

Mirer, reporting to a symposium on oil mist organized by the American Conference of Governmental Hygienists, reviewed the literature available in 2003, concluded there was “sufficient evidence” that metalworking fluid exposure should be classified as “known to be carcinogenic to humans” [Mirer, 2003a]. Savitz, reporting at the same symposium, based his assessment heavily on the Harvard-GM cohort. Although citing the 2001 update, most of his discussion focused on analyses of the cohort experience only through 1992. Savitz expressed no clear opinion on the strength of the evidence or classification, but stated: “The most notable associations, based on precision, magnitude, and evidence for increasing risk with increasing exposure, are those between straight metalworking fluids and both rectal and laryngeal cancer, as well as soluble metalworking fluids and laryngeal cancer” [Savitz, 2003].

Respiratory Conditions

For respiratory effects, 58 publications were noted starting with 1999, supplemented by extensive additional publications regarding microbial and microbial product composition discussed below. A few key publications will be discussed here.

One relevant 1999 publication was known and cited by the MWF SAC: The observation of increased airway

responsiveness among workers newly exposed to metal-working fluids, a rare inception cohort study, allows inference that the low levels of exposure, including straight oils found in small workplaces, are effect levels [Kennedy et al., 1999]. A similar study focused on following back asthma, including to small workplaces [Rosenman et al., 1997]. These studies lack sophisticated exposure or exposure-response assessments, but clearly establish an effect level under existing conditions.

Among the studies since 1999, many reported Hypersensitivity Pneumonitis (HP) outbreaks among workers exposed to MWF's. Many of these outbreaks involved dozens of employees. Most of these publications were framed by the hypothesis that mycobacterial contamination of MWF's was necessary for an outbreak [Fox et al., 1999; Shelton et al., 1999; Hodgson et al., 2001; Dangman et al., 2002; NIOSH, 2002; Bracker et al., 2003; Falkinham, 2003; O'Brien, 2003; Trout et al., 2003; Beckett et al., 2005; Gupta and Rosenman, 2006]. These observers noted increases in a spectrum of respiratory conditions including asthma and other airway disease among the same populations where the HP cases arose. Respiratory conditions other than HP predominated.

Two investigators demonstrated in the laboratory a condition equivalent to HP, using mycobacteria-contaminated MWF's [Gordon et al., 2006; Thorne et al., 2006].

However, investigators of a recent, major outbreak of HP presented convincing evidence for the absence of mycobacteria in the MWF's in the afflicted facility [Dawkins et al., 2006; Robertson et al., 2007].

As noted above, excess mortality from respiratory causes was observed in the NCI cohort update as statistically significant, and in the GM cohort was elevated in the second observation period but did not achieve statistical significance.

Skin Effects

Exiting 1998, there was little dissent that MWF's as a class cause dermatitis. However, for these effects, 32 more publications were noted starting in 1999. Publications related to skin penetration as well as skin disorders were included in this class.

Skin penetration of MWF ingredients emerged as a concern for systemic toxicity, noted above, and also for dermatological effects [Shvedova et al., 2001, 2002; Ducos and Gaudin, 2003; Baynes and Riviere, 2004; Baynes et al., 2005; Xu and Que Hee, 2006; Suuronen et al., 2007].

There remains continuing interest in which specific ingredients might be responsible for allergic contact dermatitis. Biocides and ethanolamines are specific concerns [le Coz, 2001; Baynes et al., 2002; Brinkmeier et al., 2002; Geier et al., 2002, 2003, 2004a,b,c, 2006; Isaksson, 2002;

Zissu, 2002; Jensen and Andersen, 2003; Madan and Beck, 2006; Malloy et al., 2007]. Agents causing allergic contact dermatitis might also be suspected of causing respiratory sensitization after inhalation [Suuronen et al., 2007].

Microbial Research

The review found 45 publications concerned with microbial populations, microbial products such as endotoxin, and microbial control. A time course study observed that microbial populations returned to pre-cleaning levels within hours after an apparently high-quality dump, clean and recharge [Veillette et al., 2004]. These and other investigators observed that culturing for gram negative bacteria accounted for less than 5% of viable microorganisms, and that multiple culturing methods still left 90% of the population occult as "viable non-culturable" [Virji et al., 2000; Lewis et al., 2001; Sloyer et al., 2002; Skerlos and Slac, 2003; Chang et al., 2005; Yadav et al., 2006].

Extensive work identified a mycobacterial population commonly found in MWF's as a new species [Moore et al., 2000; Wilson et al., 2001].

Observers have opined that the emergence of HP in 1995 followed an industrial fashion of more aggressive treatment of MWF's with microbicides aimed at limiting numbers of gram negative bacteria thought to be responsible for irritation and asthma. This found some support in the observation of an apparent increase in mycobacterial contamination with treatment by formaldehyde-releasing triazine biocides [Watt, 2003].

Exposure Measurement and Control

Since 1999, 76 publications were identified describing exposure measurement methods, exposures, and control techniques for MWF's. These included some overlap with endotoxin measurements and contributions of microbial components to exposure.

Limitations of historical exposure assessment methods were clearly depicted by continuing research, including inlet losses of large MWF aerosol particles, time and distance variation of particle size mix, and evaporation losses from gravimetric filter sampling.

For discussions of a PEL, exposure-response studies are anchored in thoracic fraction gravimetric particulate, measured with a cascade impactor in support of the GM mortality and respiratory effect studies [Woskie et al., 2003]. Extraction methods were not employed in that series of studies, which generated the benchmark recommendation of 0.5 mg/M³ (or 0.4 mg/M³ thoracic particulate) for the PEL from NIOSH, the MWF SAC and the UAW. "Total" particulate, or extractable total particulate sampling with a

closed face filter cassette, the most frequently used routine sampling method, excludes the mass of the largest mist particles close to a source, and were observed to return values close to but somewhat greater than thoracic [Yacher et al., 2000; Simpson, 2003; Reh et al., 2005; Verma et al., 2006]. Fine particles, 1 μm and below, were observed to be prominent in exposure at distances from the source [Sioutas, 1999; Dasch et al., 2005; Wang et al., 2005, 2007; Peters et al., 2006; Heitbrink et al., 2007]. The likely dynamic is generation of larger particles by mechanical action at the source, followed by evaporation of the water component of the aerosol to generate smaller particles with increasingly concentrated non-volatile components. Evaporation of the oil component of straight, soluble and semi-synthetic exposures, and thus underestimation of exposure relative to the benchmark health studies, has been demonstrated. Evaporation may reach 50% of the collected material under some conditions [Raynor et al., 2000; Volckens and Leith, 2002a,b].

Mapping of exposure with real time aerosol monitoring equipment was shown to be feasible and useful in planning control strategies [O'Brien, 2003]. Real-time measurements demonstrated the fact of intermittent high exposures in facilities with low average exposures, and the feasibility of measuring those exposures [O'Brien et al., 2001]. Recirculation of MWF mist into workroom air from the most frequently employed process mist collection devices was demonstrated [Boundy et al., 2000; Thornburg, 2000]. Investigators suggested that this regeneration of mist could arise from physical condensation processes as well as filter penetration [Volckens and Leith, 2003].

Feasibility of reducing MWF exposures to 0.5 mg/M^3 or below may be inferred from many studies, including all health effects reports which contain exposure data. Many of these report prevailing exposures less than 0.5 mg/M^3 , frequently at 0.25 mg/M^3 and below [Heitbrink et al., 2000; Thornburg, 2000; Yacher et al., 2000; Piacitelli et al., 2001; Rosenthal and Yeagy, 2001; Dasch et al., 2002; Leith et al., 2003; Stear, 2003; Ross et al., 2004; Raynor et al., 2005]. A recent study directly addressed the feasibility and practicality of retrofitting equipment for controlling exposures generated by existing high production, linear transfer lines [Sheehan and Hands, 2007].

DISCUSSION

The denial by OSHA of the UAW petition for a standard for MWF, while issued in 2004, quoted only evidence from the MWF SAC report of 1999. That report relied on evidence in the scientific literature available at the close of 1998. Therefore, evidence since January 1999 was considered to judge whether it supported restarting the standard setting process for MWF.

At the start of 1999, most mortality studies of MWF exposed workers had observed increased cancer at some anatomical site or sites, but no site was increased in every study. Substantial increases and exposure-response were found in some studies, but the study considered strongest (the GM-Harvard study) observed more modest increases over the full cohort, and depended on exposure-response within the cohort for determining an association.

The main stated reason for denial of the UAW petition was that evidence for carcinogenicity of MWF exposure was not compelling enough for OSHA to divert resources from other activities: "Second, OSHA is currently preparing to propose standards for three toxic substances that pose more serious health risks than MWFs do. These substances are hexavalent chromium, crystalline silica and beryllium. The limited agency resources available for toxic substance rulemakings cannot be diverted to MWFs without compromising the progress of these higher priority projects."

Looking forward from the 1999 time frame of OSHA's assessment, 26 publications, including two major cohort mortality studies, reinforced the already available evidence for carcinogenicity. The updated Harvard-GM study, considered the strongest, observed both increases in cancer in the full cohort compared to the general population (overcoming the healthy worker effect), exposure-response for cancers at certain anatomical sites, and increases with latency, another measure of exposure-response. Recent exposures were associated with significant increased risk. This provided no support for the claim that recent exposures pose no hazard, primarily a due to improved treatment of the oil component. At this time scientific evidence of MWF carcinogenicity is both strong and materially stronger than in 1999. This alone warrants re-opening standards-setting for these fluids.

Regarding future studies of cancer among worker populations exposed to metalworking fluids, there remains value to follow various cohorts in time, since later appearing tumors reflect more recent exposures. However, it appears unlikely that the clear results of associations will be materially strengthened or undermined.

Exiting 1998, there was little debate that adverse respiratory effects increased with exposure to water-containing MWF's, including: symptoms complaints, cross-shift lung function drop, occupational asthma, and hypersensitivity pneumonitis. Debatable questions related to standard setting include: Is there a respiratory effect from straight oils alone? What are effect and no-effect levels? Is endotoxin, a product of gram negative bacteria typically found in MWF's, the cause of irritation symptoms, asthma and cross shift lung function drop? And, if so, can aggressive metalworking fluid management reduce exposure to microbial products as an alternative to relying on an airborne exposure limit requiring expensive ventilation and enclosures? Later, as hypersensitivity pneumonitis outbreaks

emerged with greater force, additional questions emerged: Are the atypical mycobacteria or their products in metal-working fluids necessary to cause HP? Do mycobacteria emerge in MWF's as a result of aggressive fluid management? Can a better MWF management strategy control both gram negative and atypical mycobacteria and their products as an alternative to relying on an airborne exposure limit requiring expensive ventilation and enclosures?

Even accepting OSHA's characterization of respiratory effects known in 1999, the concern for effects under prevailing exposure conditions has grown materially. The literature review yields 58 publications relevant to respiratory effects. Asthma was observed to be clearly associated with MWF exposure, as is HP. While asthma can be fatal, and occupationally induced asthma can expand its triggers into non-occupational exposures, HP presents as a more severe and more easily attributable condition. Both can result in permanent restriction of employees from further exposure to MWF. These cases have repeatedly been observed to arise from prevailing exposure conditions. Since HP and occupational asthma can result in permanent disability, these conditions are clearly "material impairments to health or functional capacity" in terms of the OSHA law.

Allergic contact dermatitis may also result in permanent restriction from exposure to MWF, and thereby job loss. Therefore, this is also a "material impairment to health." This was a concern among the 32 publications identified. However, the observation of skin penetration by MWF ingredients, especially diethanolamine, in physiologically significant amounts, adds an important consideration for risk assessment. This observation provides additional biological plausibility to observations of liver cancer and liver disease among workers exposed to MWF.

Since 1999 there has been a major expansion of knowledge regarding microbial composition. Concerns for respiratory conditions, especially the emerging and expanding HP problem, associated with microbial species and microbial products, drove a burst of 45 publications from several laboratories following 1999. Since the 1950s, microbial control in MWF's had been directed by concerns for degradation of production characteristics and odors, with a limited concern for respiratory irritation. The primary measure was cultured gram negative bacteria, sometimes accompanied by cultured fungi. More sophisticated analytic methods were sought for detecting atypical microorganisms (especially mycobacteria) and for endotoxin, which might build up in fluids even if populations of gram negative bacteria were controlled.

At the time of the conclusion of the work of the MWF SAC, opponents of a stricter exposure limit argued that the most severe respiratory effects arose from microbial products in the MWF, emphasizing endotoxin derived from gram negative species known to colonize MWF's. They argued that MWF maintenance would reduce or eliminate these health

effects, and that sub-milligram exposure limits were not needed to prevent respiratory effects. HP was attributed to mycobacterial contamination. The 45 papers published since 1999 clearly demonstrate that most of the biological load in MWF's is not measured by current techniques, a necessary element of effective MWF maintenance. Also, after superior dump, clean and recharge procedures, the measurable microbial load swiftly reappears, including mycobacterial contamination. The British Powertrain study of a major HP outbreak demonstrated that mycobacteria were not present, suggesting that HP can be caused by multiple microbial species or by chemical constituents. Finally, a suite of 76 publications on exposure, methods of exposure measurement and exposure control demonstrate that reduction of exposure into the range recommended by NIOSH and significantly below is feasible.

Measurement issues reflect on both feasibility and health effects. Measurement reflects on health effects because gaps in quantitative exposure-response relationships in historical studies would have less force if measurement complexity undermined the ability to see such a relationship if it were there. Measurement of MWF exposure by cascade impactors employed in the Harvard-GM study has not been compared to measurement of MWF particulate by the conventional filter methods. Closed-face filter total particulate measurements (NIOSH 0500) exclude large droplets present close to the point of generation, in some conditions collecting only 1/3 of the aerosol. Short time peaks in exposure were unaccounted for by gravimetric methods, but would plausibly be important for respiratory effects. Recirculating local exhaust ventilation—a prominent control measure—has been shown to spread small particle MWF exposure rather than contain it. Since impaired exposure assessments will bias epidemiological studies to the null, the strength of the evidence from existing studies is heightened.

Observations of exposure levels below 0.5 mg/M^3 in operating facilities clearly demonstrate the feasibility of control to that level and below.

Two research opportunities were identified in this review. Chronic inhalation bioassays of representative MWF types, followed by bioassays of particular ingredients might be helpful to identify specific ingredients of MWF's responsible for carcinogenicity and respiratory conditions observed among employees exposed to these mixtures. These would not be material to setting an OSHA PEL, which could be done for mixtures, but would provide health hazard evidence for materials found in other exposure circumstances, such as formaldehyde release biocides or petroleum sulfonates. Second, the role of in use contamination of MWF in causing respiratory conditions could be illuminated by studying pressroom personnel in stamping plants. Drawing compounds for stamping are frequently formulated of the same ingredients as MWF's in machining, but not recycled and contaminated to the degree that MWF's are.

CONCLUSION

It may be argued that OSHA's decision to ignore the recommendations of the Metalworking Fluid Standard Advisory Committee and to suspend work on an MWF standard was incorrect. Similarly, it can be argued the 3rd Circuit decision upholding OSHA's decision not to act was wrongly decided. Nevertheless, a substantial increase in the knowledge of the health effects of metalworking fluids since those actions has been documented.

Since the close of 1998, 227 reports in the peer reviewed literature relevant to the MWF hazards were identified: 26 related to MWF induced occupational cancer; 56 related to respiratory effects; 32 related to skin effects and skin penetration; 45 regarding microbial populations in MWF; and, 76 regarding measurement and control. These demonstrate material risk to health and functional capacity at prevailing exposure levels, and at levels of 0.5 mg/M³ and below. Further, they demonstrate the technical and economic feasibility of a standard and PEL substantially lower than 0.5 mg/M³. Collectively these data support reopening standards-setting to regulate MWF exposures to levels below 0.5 mg/M³.

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