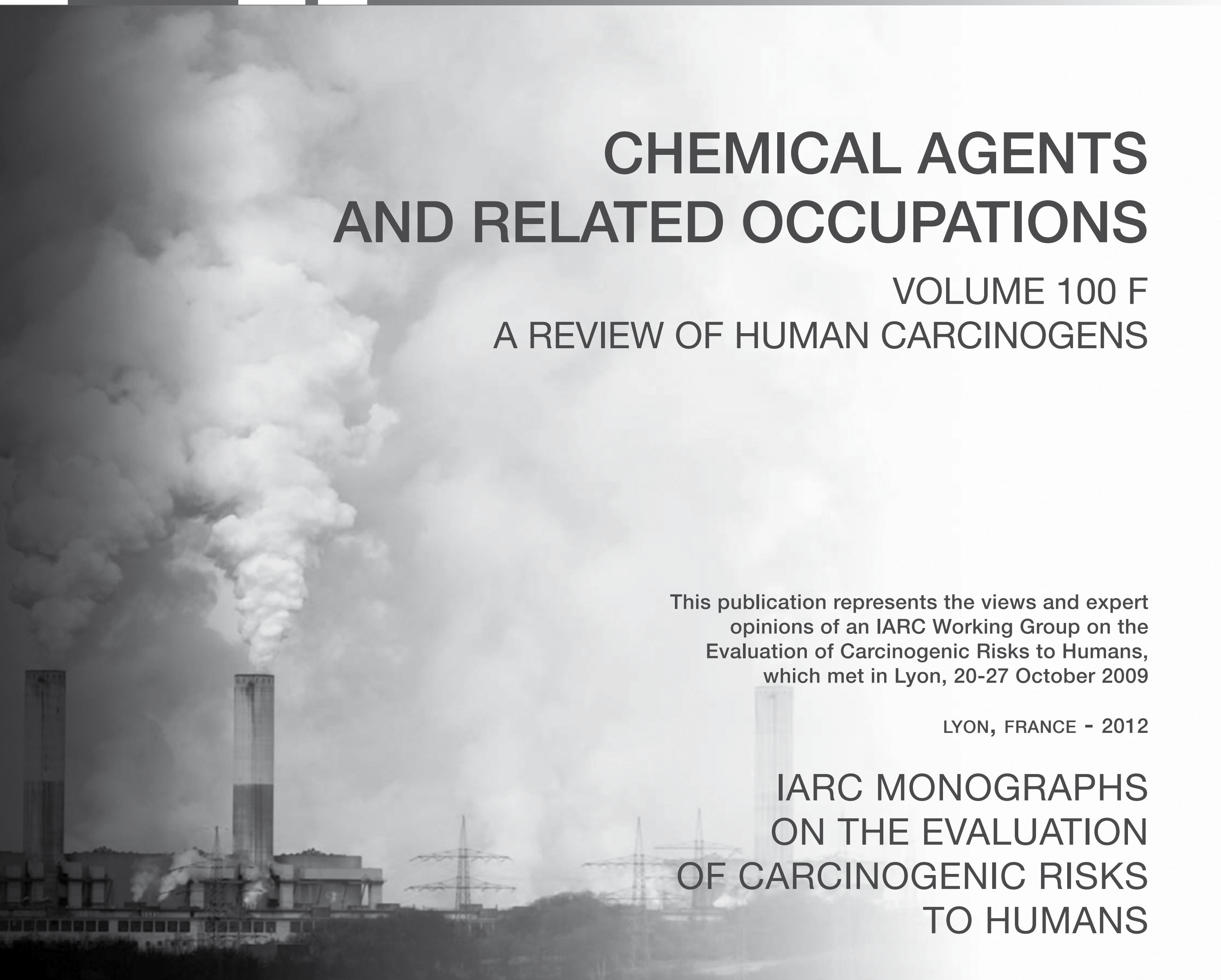
IARC MONOGRAPHS



CHEMICAL AGENTS AND RELATED OCCUPATIONS

VOLUME 100 F

A REVIEW OF HUMAN CARCINOGENS

This publication represents the views and expert opinions of an IARC Working Group on the Evaluation of Carcinogenic Risks to Humans, which met in Lyon, 20-27 October 2009

LYON, FRANCE - 2012

IARC MONOGRAPHS ON THE EVALUATION OF CARCINOGENIC RISKS TO HUMANS

International Agency for Research on Cancer

World Health Organization

MISTS FROM STRONG INORGANIC ACIDS

Occupational exposures to mists and vapours from sulfuric acid and other strong inorganic acids were considered by an IARC Working Group in 1991 (IARC, 1992). Since that time new data have become available, which have been incorporated in this *Monograph*, and taken into consideration in the present evaluation. A separate *Monograph* on 'Isopropyl Alcohol Manufacture by the Strong-acid Process' – updating earlier evaluations on this agent (IARC, 1977, 1987) – appears elsewhere in this volume.

1. Exposure Data

1.1 Manufacturing processes

Major industries with exposure to strong inorganic acid mists include those that manufacture phosphate fertilizer, isopropanol (isopropyl alcohol), synthetic ethanol (ethyl alcohol), sulfuric acid, nitric acid, and lead batteries. Exposure also occurs during copper smelting, and pickling and other acid treatment of metals (Suresh, 2009).

Minor uses of sulfuric acid include applications in petroleum refining, mining, metallurgy, and ore processing, in the synthesis of inorganic and organic chemicals, synthetic rubber and plastics, in the processing of pulp and paper, the manufacture of soap and detergents, cellulose fibres and films, inorganic pigments and paints, and in water treatment. The use of sulfuric acid is declining in some industries. For example, there is a trend in the steel industry to use hydrochloric acid instead of sulfuric acid in the metallurgic process of pickling, and hydrofluoric acid has replaced sulfuric acid for some applications in the petroleum industry (IARC, 1992; ATSDR, 1998; NTP, 2005).

1.2 Human exposure

1.2.1 Occupational exposure

Strong inorganic acid mists may be produced as a result of the use of inorganic acids, including sulfuric acid, in various industrial processes, as indicated in the previous section (IARC, 1992). The amount of vapour or mist that is produced varies with the process and the method. In pickling, for instance, mist may escape from tanks filled with acid, when hydrogen gas and steam rise from the surface of the solution (NTP, 2005).

CAREX (CARcinogen EXposure) is an international information system on occupational exposure to known and suspected carcinogens, based on data collected in the European Union from 1990 to 1993. The CAREX database provides selected exposure data and documented estimates of the number of exposed workers by country, carcinogen, and industry (Kauppinen *et al.*, 2000). Table 1.1 shows the results for strong inorganic acid mists containing sulfuric acid in the European Union by industry (CAREX, 1999).

From the National Occupational Exposure Survey (1981–83) it was estimated that

Table 1.1 Estimated numbers of workers exposed to strong inorganic acid mists containing sulfuric acid in the European Union

Industry, occupational activity	
Manufacture of industrial chemicals	78400
Manufacture of fabricated metal products, except machinery and equipment	67800
Construction	63600
Wholesale and retail trade and restaurants and hotels	63300
Medical, dental, other health and veterinary services	58000
Iron and steel basic industries	37100
Manufacture of other chemical products	33800
Manufacture of electrical machinery, apparatus, appliances and supplies	30800
Manufacture of machinery except electrical	29300
Food manufacturing	25300
TOTAL	700000

From CAREX (1999), see also Kauppinen *et al.* (2000)

approximately 776000 workers (including approximately 174000 women) in the United States of America (USA) were potentially exposed to sulfuric acid (NIOSH, 1990). [The Working Group noted that these numbers do not specifically reflect exposures to strong inorganic acid mists.]

Exposure to strong inorganic acid mists containing sulfuric acid may occur by inhalation, ingestion, and dermal contact. Exposure depends on many factors including particle size, proximity to the source, and control measures such as ventilation and containment. Data on particle-size distribution of acid mists are limited, and sampling methods have generally not differentiated between liquid and gaseous forms of the acids (IARC, 1992; NTP, 2005).

Sulfuric acid is used with other strong inorganic acids in many manufacturing processes, during which strong inorganic acid mists may be generated. Data from studies on exposure to inorganic acid mists published since the previous *IARC Monograph* (IARC, 1992) are briefly summarized below.

Sathiakumar *et al.* (1997) reviewed and categorized 25 epidemiological studies on the basis of high (> 1 mg/m^3; 8-hour time-weighted average), moderate (0.1–1 mg/m^3) and low (< 0.1 mg/m^3) exposure to sulfuric acid mists. Workers in the production of sulfuric acid and isopropanol, and in metal pickling were considered to have potentially high exposure, while workers in the production of soap and detergent, nitric acid, and ethanol were assumed to have moderate exposure. The lowest estimated exposures were for workers in copper and zinc refining and in the production of phosphate fertilizers and lead batteries. This grouping generally applies to exposures that occurred before 1970. In the early 1970s, the exposure started to decline due to the use of lower concentrations of the acids and improved industrial control measures.

Aerosol sampling was conducted at 24 locations in eight plants that manufactured phosphoric acid and concentrated fertilizer in Florida (USA) and in two locations as control sites elsewhere in Florida. In general, sulfate, fluoride, ammonium, and phosphate were the major chemical species found in the fertilizer plants. At the sulfuric acid tank, sulfate was the dominant substance, with a maximum PM_{10} sulfate concentration of 181 µg/m^3. The concentrations of sulfate-containing PM_{10}, including ammonium sulfate, calcium sulfate, and sulfuric acid were lower than 200 µg/m^3 at all locations (Hsu *et al.*, 2007a, b, 2008).

In a multidisciplinary cross-sectional study of 22 galvanic plants in Sao Paulo, Brazil from 1993 to 1996, ambient air was collected and personal exposure measurements were conducted on five consecutive working days. The geometric means for the concentration of sulphuric acid in ambient-air samples from five anodising plants varied from 34.7 to 2133.6 µg/m3 (total range, 7.2–2780.0 µg/m3); for personal samples, the geometric means ranged from 12.7 to 396.5 µg/m3 (total range, 5.3–865.6 µg/m3) (Grasel *et al.*, 2003).

Steenland (1997) described a follow-up study of a cohort of 1156 acid-exposed steelworkers employed in the USA between 1940 and 1965. The workers were followed until the end of October 1994. Historically, sulfuric acid was the most common acid used for pickling, but in the mid-1960s it was gradually replaced by hydrochloric, nitric, hydrofluoric, and hydrocyanic acid, with hydrochloric acid being the most common. For two of the three plants, personal exposure levels for sulfuric acid in air averaged 0.19 mg/m^3 in the period 1975–79 (time-weighted average, based on 15 samples) and the average concentration in the work area was 0.29 mg/m^3 (based on 34 samples). Exposures in the third plant were estimated to have been similar.

Exposure to mineral acid mists was assessed at two battery manufacturers (factories A and B, established in 1914 and 1929, respectively) and two steel works (factories C and D, established in 1948 and 1945, respectively) in the United Kingdom. In both factories exposure to sulfuric acid occurred principally during the formation and charging processes. Other exposures included those to asbestos – crocidolite and chrysotile –, lead, stibine, and pitch. Fixed-site monitoring of sulfuric acid was conducted from 1970 onwards and showed concentrations in air of 0.1–0.7 mg/m^3 in factory A, and 0.4–2.0 mg/m^3 in factory B. In the steel works C and D, sulfuric acid was used to clean steel before plating and galvanizing. Although its use was phased out in favour of hydrochloric acid in both factories, sulphuric acid continued to be used in the hot sheet finishing and plating areas in factory C, and in galvanizing processes in factory D. No occupational hygiene measurements of acid mists were available for either steel factory (Coggon *et al.*, 1996).

2. Cancer in Humans

Occupational exposures to mists from strong inorganic acids (e.g. sulfuric, hydrochloric, nitric and phosphoric acids) were last evaluated by a previous *IARC Monograph* (IARC, 1992), which concluded that there is *sufficient evidence* for the carcinogenicity to humans of occupational exposure to strong-inorganic-acid mists containing sulfuric acid.

2.1 Cohort studies

Industries with exposure to strong inorganic acids have been categorized with respect to potential average exposure levels to sulfuric acid mists: highest — metal pickling, sulfuric acid production, isopropanol production; moderate — soap and detergent production, nitric acid, and ethanol production; and low — copper and zinc refining, phosphate fertilizer production, and lead battery production (Sathiakumar *et al.*, 1997).

2.1.1 Metal pickling

Sulfuric acid and other inorganic acids have been used to pickle steel (i.e. remove scale and oxides from the metal surface) as part of the finishing process in the steel industry. Cohorts in Sweden, the USA and France have been studied (Mazumdar *et al.*, 1975; Ahlborg *et al.*, 1981; Beaumont *et al.*, 1987; Steenland *et al.*, 1988; Steenland & Beaumont, 1989; Steenland, 1997; Moulin *et al.*, 2000; see Table 2.1, available at http://monographs.iarc.fr/ENG/Monographs/vol100F/100F-28-Table2.1.pdf). Studies on cancer of the larynx showed statistically significant excess risks in Sweden (Ahlborg *et al.*, 1981) and the USA (Steenland, 1997), while in a study from France non-significant excesses were found (Moulin *et al.*, 2000). In the US cohort, Steenland & Beaumont (1989) found a significant excess risk for cancer of the lung, considering a latency period of 20 years.

2.1.2 Sulfuric and nitric acid manufacture

Englander *et al.* (1988) reported a non-significant twofold excess of respiratory cancers and increases in bladder-cancer mortality in a Swedish sulfuric acid factory. Excesses of myeloid leukaemia were noted in an Italian sulfuric acid factory (Pesatori *et al.*, 2006), and increased risks for lung and pleural cancer were found in a Norwegian nitric acid plant (SIR = 4.5; 95%CI: 2.6–7.2) (Hilt *et al.*, 1985). An elevated lung-cancer mortality was observed among men working with acid mixtures in an Italian factory, but the increase was not statistically significant (Rapiti *et al.*, 1997). Likewise, at two US tanneries where sulfuric acid was used in the de-liming, bating and pickling subdepartments of the beamhouse, an elevated lung-cancer mortality was found, but the increase was not significant (Stern, 2003; see Table 2.1, on-line).

2.1.3 Manufacture of isopropanol and ethanol

See also the *Monograph* on Isopropyl Alcohol Manufacture by the Strong-acid Process in this volume.

In addition to acid mists, workers in isopropanol and ethanol production may be exposed to alloy/sulfates and isopropanol oils. Cohort studies in one factory in the United Kingdom and four in the USA where isopropyl alcohol and ethyl alcohol were manufactured by the strong-acid process showed a significant excess of cancers in the upper respiratory tract – nasal sinus, pharynx, larynx – and buccal cavity. Hueper (1966) found significant excesses of nasal sinus and larynx cancers combined (SIR 21.9, 95%CI: 7.9–56.1) based on two cases each. In the same facility, Lynch *et al.* (1979) reported significant excesses for cancer of the larynx. Subsequently, a nested case–control study among workers in the same plant assessed 50 upper respiratory tract cancer cases and controls with regards to exposure to sulfuric acid and other agents. Those with "high" sulfuric acid exposure had an increased risk (OR, 5.2; 95%CI: 1.2–22.1) for pharyngeal, sinus, or laryngeal cancer (Soskolne *et al.*, 1984; see Table 2.1, on-line).

Excess risks for buccal cavity and pharynx cancer were identified in an isopropyl alcohol production unit in the USA, which began operation in 1941 and had employed 433 workers through 1965 (Enterline, 1982).

Weil *et al.* (1952) reported a highly significant risk for nasal sinus cancer, based on four cases, in an isopropyl alcohol production facility in the USA. A case–control study of lympho-haematopoietic malignancies at the same plant showed an elevated risk for non-Hodgkin lymphoma among workers ever exposed to alkyl sulfates, including those in the isopropyl and ethyl alcohol production units, where sulfuric acid was used (Ott *et al.*, 1989). In a subsequent mortality study conducted in this facility, workers in isopropanol and ethanol production had a statistically significantly increased mortality risk for lympho- and reticulosarcoma (Teta *et al.*, 1992; see Table 2.1, on-line). Mortality from upper respiratory and lympho-haematopoietic cancers was also investigated in another isopropanol- and ethanol-manufacturing facility in the USA, but significant cancer excesses were not observed in this case (Teta *et al.*, 1992). In an isopropyl alcohol-manufacturing unit in the United Kingdom, nine cancer deaths had occurred by 1980, including one from nasal sinus cancer; this was statistically significant (Alderson & Rattan, 1980).

2.1.4 Soap manufacture

The only study of soap-manufacturing workers exposed to sulfuric acid vapours in the hydrolysis and saponification areas, found increased risks – not statistically significant – for laryngeal cancer incidence and mortality through 1983 (Forastiere *et al.*, 1987).

2.1.5 Manufacture of phosphate and nitrate fertilizer

Sulfuric acid is used to convert phosphate rock to phosphoric acid and superphosphate; nitric acid is the precursor of nitrate fertilizers. Many fertilizer plants manufacture these two acids on site (Al-Dabbagh *et al.*, 1986; Rafnsson & Gunnarsdóttir, 1990; Hagmar *et al.*, 1991; Fandrem *et al.*, 1993; Checkoway *et al.*, 1996). Several research groups studied phosphate-fertilizer manufacturing in the USA (Stayner *et al.*, 1985; Block *et al.*, 1988; Checkoway *et al.*, 1996). All found elevated lung cancer mortality, with higher rates for those who had been employed longer. Nitrate-fertilizer manufacture has been studied in Iceland, Norway, the Russian Federation, Sweden, and the United Kingdom (Al-Dabbagh *et al.*, 1986; Rafnsson & Gunnarsdóttir, 1990; Hagmar *et al.*, 1991; Fandrem *et al.*, 1993; Zandjani *et al.*, 1994; Bulbulyan *et al.*, 1996). None of these studies found statistically significantly elevated risks among workers potentially exposed to nitric acid mists except the study from Sweden (Zandjani *et al.*, 1994), which showed a standardized incidence ratio (SIR) for stomach cancer of 1.50 ($P < 0.05$) for 27 men hired before 1960, and an SIR for testicular cancer of 3.33 ($P < 0.05$) for 5 men hired during or after 1960. In a factory complex where both phosphate and nitrate fertilizers were manufactured, Bulbulyan *et al.* (1996) reported a statistically significant increase in stomach-cancer mortality for men in the sulfuric acid tower department (11 deaths, SMR 2.04, 95%CI: 1.02–3.66) (see Table 2.1, on-line).

2.1.6 Battery manufacture

Mortality for all cancers combined and for various separate respiratory cancers has been reported from four cohort studies of battery-manufacturing workers (one including cohorts from steel works as well) in the United Kingdom and the USA (Malcolm & Barnett, 1982; Cooper et. al., 1985; Coggon *et al.*, 1996; Sorahan & Esmen, 2004; see Table 2.1, on-line). In two studies, excesses of laryngeal cancer were found (Cooper *et al.*, 1985; Sorahan & Esmen, 2004). Within the United Kingdom cohort, a nested case–control analysis was carried out in two battery-manufacturing plants and two steel works, with respect to exposure to acid mists. The study included 15 cases with upper aerodigestive cancers (ICD-9 140–141, 143–149, 160–161) and 75 controls. The odds of cancer among those with high exposure to acids, or among those with five or more years of high exposure were increased compared with those with no exposure to acids, but this was not statistically significant (Coggon *et al.*, 1996).

2.1.7 Other industries

Two nested case–control studies, one in the Norwegian nickel-refining industry (Grimsrud *et al.*, 2005) and one in the chemical industry in the USA (Bond *et al.*, 1986; 1991) were reviewed. In the first study, a job-exposure matrix for sulfuric acid mist was developed, the second study developed a job-exposure matrix for hydrochloric acid; neither found an association between acid mist exposure and lung cancer.

2.2 Case–control studies

Case–control studies of cancer of the upper respiratory tract, larynx, lung, stomach, and other sites have evaluated whether exposure to acid mists affected the cancer risk (see Table 2.2, available at http://monographs.iarc.fr/ENG/Monographs/vol100F/100F-28-Table2.2.pdf).

2.2.1 Cancer of the nasal cavity and sinuses

Incident cases of sinonasal (ICD-9 160) cancer in Piedmont, Italy, were matched with hospital controls from the ear/nose/throat and orthopaedics departments over a four-year period. For those whose histology was basocellular, mucoepidermoid, neuroendocrine, undifferentiated, or unspecified, ever having been exposed to acid mists at work was associated with a higher risk for these cancers (OR, 7.5; 95%CI: 2.0–28) (d'Errico *et al.*, 2009).

2.2.2 Cancer of the larynx

In Uruguay, 112 men diagnosed with laryngeal cancer between 1993 and 1995 were compared with 509 controls with cancer at other sites: there was an OR of 1.2 (95%CI: 0.6–2.5) for those who had been occupationally exposed to acid mists for up to 20 years, while the OR for 21 or more years of exposure was 1.8 (95%CI: 1.1–3.1) (De Stefani *et al.*, 1998). Soskolne *et al.* (1992) assessed the duration and intensity of exposure to sulfuric acid among laryngeal cancer cases in a case–control study in Canada and found a dose–response progression from ≤ 10 years of probable exposure (OR, 1.97; 95%CI: 0.6–6.1) to > 10 years of substantial exposure (OR, 5.6; 95%CI: 2.0–15.5). Zemła *et al.* (1987) asked 328 men with laryngeal cancer and 656 controls without cancer about "constant exposure to vapours of sulfuric, hydrochloric, or nitric acid" and reported a relative risk of 4.27 ($P < 0.001$). In five other studies (Olsen & Sabroe, 1984; Cookfair *et al.*, 1985; Brown *et al.*, 1988; Eisen *et al.*, 1994; Shangina *et al.*, 2006) no increased risks, or elevations that were not statistically significant, were found (see Table 2.2, on-line).

2.2.3 Cancer of the lung

Risks for cancer of the lung in association with exposure to acid mists, sulfuric or hydrochloric acid, or "any inorganic acid or base" have been reported from six case–control studies (see Table 2.2, on-line). No increased risks were found in three nested case–control studies (Bond *et al.*, 1986; Bond *et al.*, 1991; Moulin *et al.*, 2000; Grimsrud *et al.*, 2005) in the USA, France and Norway, or in an ecological study in Lithuania (Petrauskaite *et al.*, 2002).

2.2.4 Cancer at other sites

Three studies compared information on death certificates. The limitations of this type of study include possible misclassification, e.g. when the death certificate lists occupation and industry only for the most recent job rather than for the longest employment. Data on possible confounders are often lacking as well.

In two studies from the USA an increased risk for cancer of the stomach was found associated with exposure to sulfuric acid, which was derived from a job-exposure matrix applied to the occupation and industry indicated on the death certificates (Cocco *et al.*, 1998, 1999; see Table 2.2, on-line). Nearly 42000 certificates for deaths from stomach cancer were compared with certificates for decedents from non-malignant diseases. White men with low, medium, or high exposures to sulfuric acid, showed increasing ORs (p for trend < 0.01) for stomach cancer, compared with those not exposed to sulfuric acid. For black men the increase was more moderate, and for women – among whom only 17 of 16864 were rated as having high exposure to sulfuric acid – the ORs were lowest for the high-intensity group (Cocco *et al.*, 1999). A smaller study of cancer of the gastric cardia (ICD-9 151.0) compared 1056 men who died of this cancer with 5280 men who died of non-malignant disease. Men ever-exposed to sulfuric acid showed an OR of 1.2 (95%CI: 1.0–1.4), and increasing probability and increasing intensity of exposure were both associated with a significant P for trend (< 0.05 for probability, < 0.01 for intensity) (Cocco *et al.*, 1998).

Another US study based on death certificates evaluated breast-cancer risk and exposure to acid mists, comparing 33509 cases and 117 794 controls. Homemakers had been excluded, as well as controls who had died of other cancers. Thus excluding women with a low probability of exposure, those with the highest level of exposure to acid mists had statistically significantly elevated ORs for breast cancer, i.e. 1.16 (for whites) and 1.44 (for blacks), after adjustment for age and imputed socioeconomic status (Cantor *et al*., 1995).

3. Cancer in Experimental Animals

No data were available to the Working Group.

4. Other Relevant Data

See the *Monograph* on 'Isopropyl Alcohol Manufacture by the Strong-acid Process' in this volume.

5. Evaluation

There is *sufficient evidence* in humans for the carcinogenicity of mists from strong inorganic acids. Mists from strong inorganic acids cause cancer of the larynx.

Also, a positive association has been observed between exposure to mists from strong inorganic acids and cancer of the lung.

No data on the carcinogenicity of mists from strong inorganic acids in experimental animals were available to the Working Group.

While it is plausible that areas of localized low pH from inhalation of inorganic acid mists could damage DNA and increase cancer risks, the evidence supporting DNA-damage induction or any other mechanism as the cause of the observed cancers due to the inorganic acid mists is weak.

Mists from strong inorganic acids are *carcinogenic to humans (Group 1).*

References

Ahlborg GA Jr, Hogstedt C, Sundell L, Aman CG (1981). Laryngeal cancer and pickling house vapors. *Scandinavian Journal of Work, Environment & Health*, 7: 239–240.

Al-Dabbagh S, Forman D, Bryson D *et al*. (1986). Mortality of nitrate fertiliser workers. *Br J Ind Med*, 43: 507–515. PMID:3015194

Alderson MR & Rattan NS (1980). Mortality of workers on an isopropyl alcohol plant and two MEK dewaxing plants. *Br J Ind Med*, 37: 85–89. PMID:7370197

ATSDR (1998). *Toxicological Profile for Sulfur Trioxide and Sulfuric Acid* (TP-117). Atlanta, GA: Agency for Toxic Substances and Disease Registry, pp. 189.

Beaumont JJ, Leveton J, Knox K *et al*. (1987). Lung cancer mortality in workers exposed to sulfuric acid mist and other acid mists. *J Natl Cancer Inst*, 79: 911–921. PMID:3479642

Block G, Matanoski GM, Seltser R, Mitchell T (1988). Cancer morbidity and mortality in phosphate workers. *Cancer Res*, 48: 7298–7303. PMID:3191500

Bond GG, Flores GH, Shellenberger RJ *et al*. (1986). Nested case-control study of lung cancer among chemical workers. *Am J Epidemiol*, 124: 53–66. PMID:3717140

Bond GG, Flores GH, Stafford BA, Olsen GW (1991). Lung cancer and hydrogen chloride exposure: results from a nested case-control study of chemical workers. *J Occup Med*, 33: 958–961. PMID:1744744

Brown LM, Mason TJ, Pickle LW *et al*. (1988). Occupational risk factors for laryngeal cancer on the Texas Gulf Coast. *Cancer Res*, 48: 1960–1964. PMID:3349470

Bulbulyan MA, Jourenkova NJ, Boffetta P *et al*. (1996). Mortality in a cohort of Russian fertilizer workers. *Scand J Work Environ Health*, 22: 27–33. PMID:8685670

Cantor KP, Stewart PA, Brinton LA, Dosemeci M (1995). Occupational exposures and female breast cancer mortality in the United States. *J Occup Environ Med*, 37: 336–348. doi:10.1097/00043764-199503000-00011 PMID:7796202

CAREX (1999). *Carex industry specific estimates – Summary*. Available at http://www.ttl.fi/en/chemical_safety/carex/Documents/5_exposures_by_agent_and_industry.pdf.

Checkoway H, Heyer NJ, Demers PA (1996). An updated mortality follow-up study of Florida phosphate industry workers. *Am J Ind Med*, 30: 452–460. doi:10.1002/(SICI)1097-0274(199610)30:4<452::AID-AJIM11>3.0.CO;2-3 PMID:8892551

Cocco P, Ward MH, Dosemeci M (1998). Occupational risk factors for cancer of the gastric cardia. Analysis of death certificates from 24 US states. *J Occup Environ Med*, 40: 855–861. doi:10.1097/00043764-199810000-00004 PMID:9800169

Cocco P, Ward MH, Dosemeci M (1999). Risk of stomach cancer associated with 12 workplace hazards: analysis of death certificates from 24 states of the United States with the aid of job exposure matrices. *Occup Environ Med*, 56: 781–787. doi:10.1136/oem.56.11.781 PMID:10658565

Coggon D, Pannett B, Wield G (1996). Upper aerodigestive cancer in battery manufacturers and steel workers exposed to mineral acid mists. *Occup Environ Med*, 53: 445–449. doi:10.1136/oem.53.7.445 PMID:8704867

Cookfair D, Wende K, Michalek A, Vena J (1985). A case-control study of laryngeal cancer among workers exposed to sulfuric acid. *American Journal of Epidemiology*, 122: 521

Cooper WC, Wong O, Kheifets L (1985). Mortality among employees of lead battery plants and lead-producing plants, 1947–1980. *Scand J Work Environ Health*, 11: 331–345. PMID:4070998

d'Errico A, Pasian S, Baratti A *et al.* (2009). A case-control study on occupational risk factors for sino-nasal cancer. *Occup Environ Med*, 66: 448–455. doi:10.1136/oem.2008.041277 PMID:19153109

De Stefani E, Boffetta P, Oreggia F *et al.* (1998). Occupation and the risk of laryngeal cancer in Uruguay. *Am J Ind Med*, 33: 537–542. doi:10.1002/(SICI)1097-0274(199806)33:6<537::AID-AJIM3>3.0.CO;2-N PMID:9582944

Eisen EA, Tolbert PE, Hallock MF *et al.* (1994). Mortality studies of machining fluid exposure in the automobile industry. III: A case-control study of larynx cancer. *Am J Ind Med*, 26: 185–202. doi:10.1002/ajim.4700260205 PMID:7977395

Englander V, Sjöberg A, Hagmar L *et al.* (1988). Mortality and cancer morbidity in workers exposed to sulphur dioxide in a sulphuric acid plant. *Int Arch Occup Environ Health*, 61: 157–162. doi:10.1007/BF00381012 PMID:3220587

Enterline PE (1982). Importance of sequential exposure in the production of epichlorohydrin and isopropanol. *Ann N Y Acad Sci*, 381: 1 Brain Tumors344–349. doi:10.1111/j.1749-6632.1982.tb50398.x PMID:6953799

Fandrem SI, Kjuus H, Andersen A, Amlie E (1993). Incidence of cancer among workers in a Norwegian nitrate fertiliser plant. *Br J Ind Med*, 50: 647–652. PMID:8393697

Forastiere F, Valesini S, Salimei E *et al.* (1987). Respiratory cancer among soap production workers. *Scand J Work Environ Health*, 13: 258–260. PMID:3616557

Grasel SS, Alves VAF, da Silva CS *et al.* (2003). Clinical and histopathological changes of the nasal mucosa induced by occupational exposure to sulphuric acid mists. *Occup Environ Med*, 60: 395–402. doi:10.1136/oem.60.6.395 PMID:12771390

Grimsrud TK, Berge SR, Haldorsen T, Andersen A (2005). Can lung cancer risk among nickel refinery workers be explained by occupational exposures other than nickel? *Epidemiology*, 16: 146–154. doi:10.1097/01.ede.0000152902.48916.d7 PMID:15703528

Hagmar L, Bellander T, Andersson C *et al.* (1991). Cancer morbidity in nitrate fertilizer workers. *Int Arch Occup Environ Health*, 63: 63–67. doi:10.1007/BF00406200 PMID:1649801

Hilt B, Langård S, Andersen A, Rosenberg J (1985). Asbestos exposure, smoking habits, and cancer incidence among production and maintenance workers in an electrochemical plant. *Am J Ind Med*, 8: 565–577. doi:10.1002/ajim.4700080608 PMID:3000174

Hsu Y-M, Wu C-Y, Lundgren DA *et al.* (2007a). Chemical characteristics of aerosol mists in phosphate fertilizer manufacturing facilities. *J Occup Environ Hyg*, 4: 17–25. doi:10.1080/15459620601067225 PMID:17162477

Hsu Y-M, Wu C-Y, Lundgren DA, Birky BK (2007b). Size-resolved sulfuric acid mist concentrations at phosphate fertilizer manufacturing facilities in Florida. *Ann Occup Hyg*, 51: 81–89. doi:10.1093/annhyg/mel066 PMID:17032693

Hsu Y-M, Wu C-Y, Lundgren DA, Birky BK (2008). Size distribution, chemical composition and acidity of mist aerosols in fertilizer manufacturing facilities in Florida. *Aerosol Sci*, 39: 127–140. doi:10.1016/j.jaerosci.2007.10.008

Hueper WC (1966). *Occupational and Environmental Cancers of the Respiratory System*. Berlin/New York: Springer-Verlag.

IARC (1987). Overall evaluations of carcinogenicity: an updating of IARC Monographs volumes 1 to 42. *IARC Monogr Eval Carcinog Risks Hum Suppl*, 7: 1–440. PMID:3482203

IARC (1977). Some fumigants, the herbicides 2,4-D and 2,4,5-T, chlorinated dibenzodioxins and miscellaneous industrial chemicals. *IARC Monogr Eval Carcinog Risk Chem Man*, 15: 1–354. PMID:330387

IARC (1992). Occupational exposures to mists and vapours from strong inorganic acids and other industrial chemicals. *IARC Monogr Eval Carcinog Risks Hum*, 54: 1–310. PMID:1345371

Kauppinen T, Toikkanen J, Pedersen D *et al.* (2000). Occupational exposure to carcinogens in the European Union. *Occup Environ Med*, 57: 10–18. doi:10.1136/oem.57.1.10 PMID:10711264

Lynch J, Hanis NM, Bird MG *et al.* (1979). An association of upper respiratory cancer with exposure to diethyl sulfate. *J Occup Med*, 21: 333–341. PMID:469594

Malcolm D & Barnett HA (1982). A mortality study of lead workers 1925–76. *Br J Ind Med*, 39: 404–410. PMID:7138801

Mazumdar S, Lerer T, Redmond CK (1975). Long-term mortality study of steelworkers. IX. Mortality patterns among sheet and tin mill workers. *J Occup Med*, 17: 751–755. PMID:1206443

Moulin JJ, Clavel T, Roy D *et al.* (2000). Risk of lung cancer in workers producing stainless steel and metallic

alloys. *Int Arch Occup Environ Health*, 73: 171–180. doi:10.1007/s004200050024 PMID:10787132
NIOSH (1990). *National Occupational Exposure Survey 1981–83*. US Department of Health and Human Services, Public Health Service, National Institute for Occupational Safety and Health. http://www.cdc.gov/noes/noes4/70870sco.html
NTP (2005). NTP 11th Report on Carcinogens. *Rep Carcinog*, 11: 1–A32. PMID:19826456
Olsen J & Sabroe S (1984). Occupational causes of laryngeal cancer. *J Epidemiol Community Health*, 38: 117–121. doi:10.1136/jech.38.2.117 PMID:6747509
Ott MG, Teta MJ, Greenberg HL (1989). Lymphatic and hematopoietic tissue cancer in a chemical manufacturing environment. *Am J Ind Med*, 16: 631–643. PMID:2556914
Pesatori AC, Consonni D, Rubagotti M *et al.* (2006). Mortality study in a cohort of workers employed in a plant producing sulphuric acid *Med Lav*, 97: 735–748. PMID:17219763
Petrauskaite R, Pershagen G, Gurevicius R (2002). Lung cancer near an industrial site in Lithuania with major emissions of airway irritants. *International Journal of Cancer*, 99: 106–111. doi:10.1002/ijc.10314
Rafnsson V & Gunnarsdóttir H (1990). Mortality study of fertiliser manufacturers in Iceland. *Br J Ind Med*, 47: 721–725. PMID:2173946
Rapiti E, Fantini F, Dell'Orco V *et al.* (1997). Cancer mortality among chemical workers in an Italian plant. *Eur J Epidemiol*, 13: 281–285. doi:10.1023/A:1007355519112 PMID:9258526
Sathiakumar N, Delzell E, Amoateng-Adjepong Y *et al.* (1997). Epidemiologic evidence on the relationship between mists containing sulfuric acid and respiratory tract cancer. *Crit Rev Toxicol*, 27: 233–251. doi:10.3109/10408449709089893 PMID:9189653
Shangina O, Brennan P, Szeszenia-Dabrowska N *et al.* (2006). Occupational exposure and laryngeal and hypopharyngeal cancer risk in central and eastern Europe. *Am J Epidemiol*, 164: 367–375. doi:10.1093/aje/kwj208 PMID:16801374
Sorahan T & Esmen NA (2004). Lung cancer mortality in UK nickel-cadmium battery workers, 1947–2000. *Occup Environ Med*, 61: 108–116. doi:10.1136/oem.2003.009282 PMID:14739376
Soskolne CL, Jhangri GS, Siemiatycki J *et al.* (1992). Occupational exposure to sulfuric acid in southern Ontario, Canada, in association with laryngeal cancer. *Scand J Work Environ Health*, 18: 225–232. PMID:1411364
Soskolne CL, Zeighami EA, Hanis NM *et al.* (1984). Laryngeal cancer and occupational exposure to sulfuric acid. *Am J Epidemiol*, 120: 358–369. PMID:6475913
Stayner LT, Meinhardt T, Lemen R *et al.* (1985). A retrospective cohort mortality study of a phosphate fertilizer production facility. *Arch Environ Health*, 40: 133–138. PMID:2992396
Steenland K (1997). Laryngeal cancer incidence among workers exposed to acid mists (United States). *Cancer Causes & Control*, 8: 34–38. doi:10.1023/A:1018427003878 PMID:9051320
Steenland K & Beaumont J (1989). Further follow-up and adjustment for smoking in a study of lung cancer and acid mists. *Am J Ind Med*, 16: 347–354. doi:10.1002/ajim.4700160403 PMID:2610208
Steenland K, Schnorr T, Beaumont J *et al.* (1988). Incidence of laryngeal cancer and exposure to acid mists. *Br J Ind Med*, 45: 766–776. PMID:3203082
Stern FB (2003). Mortality among chrome leather tannery workers: an update. *Am J Ind Med*, 44: 197–206. doi:10.1002/ajim.10242 PMID:12874853
Suresh B (2009). *Sulfuric acid*. In: *Chemical Economics Handbook Program*. Menlo Park, CA: SRI International.
Teta MJ, Perlman GD, Ott MG (1992). Mortality study of ethanol and isopropanol production workers at two facilities. *Scand J Work Environ Health*, 18: 90–96. PMID:1604278
Weil CS, Smyth HF Jr, Nale TW (1952). Quest for a suspected industrial carcinogen. *Archives of Industrial Hygiene and Occupational Medicine*, 5: 535–547.
Zandjani F, Høgsaet B, Andersen A, Langård S (1994). Incidence of cancer among nitrate fertilizer workers. *Int Arch Occup Environ Health*, 66: 189–193. doi:10.1007/BF00380779 PMID:7814099
Zemła B, Day N, Swiatnicka J, Banasik R (1987). Larynx cancer risk factors. *Neoplasma*, 34: 223–233. PMID:3600887