5. SUMMARY OF DATA REPORTED

5.1 Exposure data

Welding is a broad term for the process of joining metals through coalescence. Approximately 11 million people worldwide are estimated to have the occupational title of welder, and approximately 110 million workers (3% of the worldwide economically active population) may incur welding-related exposures in the workplace. Many types of welding are used in occupational settings, including oxyfuel (gas) and arc welding. Arc welding includes manual metal arc (MMA), gas metal arc (GMA), flux-cored arc (FCA), and gas tungsten arc (GTA) welding. Electric resistance (ER) welding is also used. Most welding is carried out on stainless steel (SS) and mild steel (MS).

Welding results in concurrent exposures including welding fumes, gases, ionizing and non-ionizing radiation, and co-exposures such as asbestos and solvents.

Welding fumes are produced when metals are heated above their melting point, vaporize, and condense into fumes of predominantly fine solid particles with an aerodynamic diameter of less than 1 µm. These fumes are a complex mixture of particles from the wire or electrode, base metal, or any coatings on the base metal. They consist mainly of metallic oxides, silicates, and fluorides.

Measured exposures to fumes from welding on SS or MS range from less than 1 mg/m^3 to over 50 mg/m^3. The welding process, type of metal welded, use of local ventilation, degree of enclosure, and use of personal protection are the major determinants of exposure. Concentrations of welding fumes in western Europe declined during 1983–2003 by 4% per annum. FCA welding generates the highest concentration of welding fumes, followed by GMA and MMA. GTA welding consistently generates lower concentrations of welding fumes, but produces the highest number of ultrafine particles (aerodynamic diameter, < 0.1 µm).

Fumes generated from SS welding could contain up to ten times more chromium and nickel than those generated from MS welding. For SS, the highest total chromium concentrations could exceed 1 mg/m^3 from MMA welding, but concentrations are lower from GMA and GTA welding. Chromium VI concentrations are about a factor of ten lower than total chromium. Nickel concentrations generated by GMA and GTA welding are similar to total chromium, but are lower when performing MMA welding.

Exposure to various gases also occurs during welding. Measured nitrogen oxide (NO_x) concentrations are generally relatively low, but reported maximum concentrations approach or exceed occupational exposure limits. Carbon monoxide exposure as high as 1.5 ppm has been reported for GMA and MMA welding.

Welders can also be exposed to various forms of radiation such as ultraviolet (UV), extremely low-frequency electromagnetic fields (ELF-EMF), and alpha radiation from thorium-232. The level of UV radiation associated with arc welding is in general much higher than for other artificial processes generating UV radiation, and typically orders of magnitude higher than that from natural sunlight. Welders and bystanders can also be exposed to UV radiation indirectly from other welding operations. Welders can experience exposures to ELF-EMF at higher levels than electric power transmission line workers. Thorium oxide has been used in GTA welding electrodes, but the estimated yearly effective doses resulting from this exposure are mostly below the current general population limit.

Welders (shipbuilding welders in particular) might also experience exposure to asbestos, as it has been used as an insulating material in ships and covered rod electrodes, in the cylinders holding acetylene gas, and in heat-protective equipment used by welders. The use of chlorinated solvents for cleaning metal in tandem with welding may result in exposures to hydrogen chloride, and possibly result in phosgene exposure.

The exposure assessments in epidemiological studies considered by the Working Group which relied on a welding-specific questionnaire or a 'welding exposure matrix' were most informative, followed by studies applying general job-exposure matrices and those based on self-reported welding-related exposures. Studies that looked at job titles alone were considered less informative.

5.2 Human carcinogenicity data

5.2.1 Ocular melanoma

Fewer than ten partially overlapping case–control studies and two independent census-based cohort studies reported on ocular melanoma related to welding. For the case–control studies, the exposure was generally characterized as having worked as a welder often based on a full occupational history collected by questionnaire; for the cohort studies, exposure was based on self-reported job as a welder at the time of census. Most of the case–control studies showed positive associations, generally in the range of twofold and up to tenfold. Two of the three studies that evaluated risk by duration of employment as a welder showed positive trends, whereas the third study showed an overall increased risk but no trend. One of two cohort studies showed relative risk (RR) estimates close to unity for ocular melanoma, whereas the other showed a modest increased risk in welders based on 5 cases but no increased risk in occasional welders. None of the studies characterized exposure to UV from welding, but two studies provided some evidence of associations with proxies for UV exposure, i.e. increased ocular melanoma risk associated with eye burns. One of these studies also reported a positive exposure–response relationship for cumulative occupational exposure to artificial UV radiation, including welding. For most studies the risk estimates were related to an unspecified group of welders, and only three of the studies specified the relative risk estimates for arc welding. This specification by type of welding was not considered highly informative as welders often perform multiple types of welding over their work history, and any welder can be exposed to UV radiation from arc welding being conducted nearby. The Working Group also considered that UV radiation from the sun as well as artificial UV radiation from UV-emitting tanning devices are both risk factors for ocular melanoma in humans (*IARC Monographs*, Volume 100D). Several studies collected information on sun exposure and/or sun bed use, but adjustment for these indicated that the observed associations for welding could not be explained by these sources of UV exposure.

5.2.2 Cancer of the lung

Most of the more than 20 available case–control studies reported elevated risks of cancer of the lung for workers employed as welders reporting welding as their job task, or classified as or reporting to be exposed to welding fumes. The same was true for the majority of the more than 20 cohort studies that assessed the association between welding and cancer of the lung in several industries, and for 6 population-based cohort studies. Furthermore, these studies consistently observed positive associations for both arc and gas welding. In view of the constancy of these associations across different study designs, occupational settings, countries, and time periods, as well as the high quality of several positive studies, chance, information bias, or selection bias are unlikely to explain the results.

Studies used several metrics to assess a possible exposure–effect relationship between exposure to welding fumes and risk of cancer of the lung. Cohort studies mostly reported the duration of employment as a welder. Other studies, mostly case–control in design, calculated more complex cumulative exposure indices that included estimates of intensity, probability, and/or frequency of exposure to welding fumes. Several case–control and cohort studies observed an increasing risk of cancer of the lung with longer employment as a welder. Two large, high-quality case–control studies and four cohort studies using indices of exposure to welding fumes observed associations; two of the higher-quality studies observed associations compatible with a dose–effect relationship. Exposure effects were not consistent across studies but there is difficulty in quantifying exposure to welding fumes retrospectively, particularly for those relying on self-reporting by respondents. Despite these limitations, the observed patterns of risk estimates by cumulative exposure and by duration add support to the association between exposure to welding fumes and increased risk of cancer of the lung.

Tobacco smoking was considered an important potential confounder. However, smoking is unlikely to explain all of the observed excess risk of lung cancer among welders. Positive associations were found in the majority of cohort and case–control studies that adjusted for smoking in multivariable analyses, and with internal analyses of some cohort studies that rendered confounding by lifestyle factors such as smoking unlikely. Furthermore, positive associations were found in analyses restricted to non-smokers or infrequent smokers.

Occupational exposure to asbestos is another potential confounder entailed by many welding jobs. However, asbestos co-exposure is unlikely to explain the excess of lung cancer among welders. Excess lung cancer was observed among welders in cohorts with low or minimal asbestos exposure. Furthermore, almost all studies that adjusted for asbestos exposure, including some with a detailed and high-quality assessment of asbestos exposure, still found substantially elevated risks of lung cancer after adjustment. For example, in one study the relative risk was reduced from 2.25 to 1.93 after adjustment for occupational exposure to asbestos. Similarly, internal analyses which found positive associations within groups of welders may have indirectly adjusted for exposure to asbestos.

Increased risks of cancer of the lung were observed regardless of the material or the welding method in both case–control and cohort studies. The reviewed studies provide no evidence that these increased risks are limited to welding SS base metals or to specific welding processes. Several studies with detailed assessment of welding tasks tended to report higher odds ratios (ORs) for gas welding compared with arc welding. However, although two of these studies distinguished between welders exclusively exposed to gas welding fumes and those exclusively exposed to arc welding fumes, the majority of welders rarely use only one type of welding exclusively; the observed results might therefore reflect other underlying differences such as temporal trends, characteristics of the workplace, or related work practices such as gas cutting.

Gas and arc welding inherently produce fumes. Although welding fumes were not measured directly in the reviewed studies, exposure to fumes was assessed indirectly through indicator variables such as welding process, welding materials, branch of industry, job title, expert assessment or self-report. Since the association with lung cancer was observed for both gas and arc welding and could not be explained by other exposures that occur with these two predominant welding procedures, the Working Group concluded that increased risk of lung cancer among welders can be attributed to exposure to welding fumes.

5.2.3 Cancer of the kidney

The Working Group evaluated several cohort studies (each reporting on ≥ 5 exposed cases or deaths) and independent case–control studies (10 studies for each design) that reported on associations between increased risk of cancer of the kidney and exposure to welding fumes. All six cohort studies found positive associations between occupation as a welder and increased risk of kidney cancer. Two large census-based population cohorts conducted in Canada and the Nordic countries reported statistically significant increased risks of 1.2–1.3. Risk estimates were generally higher (ranging from ~1.4 to 3.8), but less precise for the four industrial cohorts (welders in diverse industries in Europe, shipyard welders in Italy, boiler welders in Norway, and metal welders in the USA). The Norwegian study of boiler welders and the Italian shipyard study of welders reported statistically significant estimates of effect. None of the cohort studies adjusted for tobacco smoking or other potential confounders related to lifestyle, but the Canadian population-based cohort study also found a significantly increased risk of cancer of the kidney when the analysis was restricted to "blue-collar" workers, which may reduce the effects of potential confounders. The Working Group also considered that tobacco smoke is a weak kidney carcinogen and that most other non-occupational risk factors for cancer of the kidney would not be expected to be associated with welding, and therefore unlikely to explain the observed associations.

The case–control studies support the findings of the cohort studies. Six of the eight studies reported increased relative risks of cancer of the kidney (ranging from 1.2 to ~5.5). Increased risks were found in studies reporting risk estimates for welding as an occupation and exposure to welding fumes. Three studies evaluated associations for different categories of exposure to welding fumes (e.g. low, high, substantial), but clear exposure–response relationships were not observed. A hospital-based case–control study in Germany reported statistically significant odds ratios for exposure to welding fumes; however, subjects were potentially exposed to high levels of trichloroethylene, a known human kidney carcinogen. Since several case–control studies adjusted for tobacco, smoking was excluded as an explanation for the observed elevated relative risks.

Overall, there were consistent findings of elevated risks in several studies in different geographical areas and occupational settings, and using different study designs. However, not all findings were statistically significant, most studies had only a few exposed cases, and there was little evidence of an exposure–effect relationship; alternative explanations, such as bias and confounding, cannot therefore be reasonably ruled out.

5.2.4 Leukaemia

The Working Group evaluated four case–control studies, a nested case–control study, and three cohort studies (with number of exposed cases > 2) on welding that reported findings for leukaemia or specific subtypes of leukaemia. Almost all case–control and cohort studies reported elevated odds ratios for all types of leukaemia combined and occupation as a welder; however, most risk estimates were small (relative risks increased by 10–30%) and imprecise. The only study reporting a statistically significant risk estimate was the nested case–control study of welders in the Portsmouth Naval Shipyard monitored for radiation exposure; all cases were electric resistance welders and may have been exposed to solvents, including benzene (ORs were adjusted for solvents in general and for radiation). The evidence for myeloid leukaemia is somewhat stronger than for all types of leukaemia combined. All six studies evaluating this type of leukaemia reported elevated odds ratios, two of which were statistically significant, and the Nordic population-based cohort study reported a standardized incidence ratio of 1.23 (95% CI, 0.99–1.52, for male welders). Risk estimates were higher for myeloid leukaemia than combined leukaemia in the three studies that evaluated both. There were concerns about the two studies reporting statistically significant risk estimates: one was the nested case–control study of welders monitored for radiation exposure and the other was a Californian case–control study that reported a very high odds ratio (> 25) for chronic myeloid leukaemia. The only study (with more than 1 exposed case) for lymphoid leukaemia found an odds ratio close to unity. In New Zealand, a study of risk of combined leukaemia (acute myeloid leukaemia and acute lymphoid leukaemia) found a statistically significant association with occupation as a welder or flame cutter.

5.2.5 Non-Hodgkin lymphoma

The Working Group evaluated numerous independent case–control studies (including one pooled case–control study) and four cohort studies on welding that reported findings for non-Hodgkin lymphoma (NHL), including chronic lymphocytic leukaemia and subsets of B-cell lympho-haematopoietic cancers, including multiple myeloma. Classification and coding systems for NHL and its subtypes have changed considerably over the past 20 years, which may introduce heterogeneity between studies because of differences in lymphoma groupings.

Elevated risks for all NHL were found for those with the occupation welder in most of the 13 case–control studies, and were statistically significant in 4 studies. Importantly, one study found a significant association with daily exposure to welding after controlling for occupational co-exposures (benzene, pesticides, ELF-EMF), and medical and lifestyle factors (medical history, education, smoking); risks were higher among daily welders versus often welders (i.e. those who weld at least once per week, but less than once per day). Although a pooled analysis of 10 case–control studies did not find an association with all NHL, it did find an association with the NHL subtype of diffuse large B-cell lymphoma (DLBCL). A USA-based case–control study also found a significant association with DLBCL, and a Canadian case–control study found a significant association with diffuse small cleaved-cell lymphoma. Findings were inconsistent across five small studies on multiple myeloma. The cohort studies were limited in their ability to evaluate risk due to the paucity of studies reporting an estimate, the small numbers of exposed cases in the industrial studies, and the cruder exposure assessments in the population-based cohorts (compared with the case–control studies). A non-significant excess risk of NHL was found in the IARC multicentre cohort; the highest risk was observed among those who had held the occupation of welder for 30 years. Risk estimates for NHL or its subtypes were close to or below unity in two population-based cohort studies and a cohort study of Norwegian boiler welders.

Overall, the case–control studies suggest a small excess risk of NHL among welders, but the evidence is not consistent across study design and was not observed in some of the larger studies. It is reasonable that the inconsistency across studies could be explained by the fact that risk factors for NHL could differ by subtype; however, the current database is inadequate for evaluating the association between welding and specific NHL subtypes.

5.2.6 Cancer of the bladder

More than 18 case–control studies and more than 10 cohort studies reported on the association between cancer of the bladder and exposure to welding fumes. The case–control studies were considered more informative than the cohort studies because they typically had a larger number of exposed cases, had stronger methods for exposure assessment, and adjusted for smoking while the cohort studies did not. The possibility of confounding by smoking in the cohort studies could not be excluded by the Working Group as a possible explanation for the moderately higher relative risk estimates reported by the cohort studies compared with the case–control studies. The Working Group noted that, despite a large number of case–control studies of adequate size, including several that were of relatively high quality, most reported relative risk estimates that were close to unity. Three case–control studies reported estimates by duration of welding or exposure to welding fumes, but the trend was inconsistent across studies. Several cohort studies reported elevated relative risk estimates for welding, although they were generally based on a small number of welder cases. One large multicentre cohort study of over 11 000 welders in Europe reported an elevated standardized mortality ratio for bladder cancer, while the risk estimate was lower, but still greater than unity, for incidence of bladder cancer.

5.2.7 Cancer of the brain

Four case–control studies and more than five cohort studies reported on the association between cancer of the brain and exposure to welding fumes. Three of the case–control studies reported odds ratios of less than or close to unity, all based on small numbers of exposed cases. A fourth case–control study reported an odds ratio of 1.26 (95% CI, 0.98–1.45) and weak evidence for a higher risk being associated with longer duration of welding. Several cohort studies reported elevated relative risk estimates, although generally based on small numbers of welder cases, and some of these were deemed to be of low quality and therefore uninformative. There were two large census-based cohort studies that showed inconsistent results: a study from Canada reported an increased risk of cancer of the brain in welders in an internal analysis (RR, 1.16; 95% CI, 0.83–1.63), while a study based on the Nordic cancer registries showed no association.

None of the studies adjusted for occupational exposure to ionizing radiation, so potential confounding could not be excluded.

Two case–control studies reported on welding in relation to incidence of meningioma. A study from China reported elevated odds ratios for both men and women exposed to “welding rod”, although each was based on small numbers of exposed cases. A much larger international case–control study on meningioma that assessed exposure to welding fumes through a job-exposure matrix reported an odds ratio of 1.79 (95% CI, 0.78–4.1; 12 exposed cases) for women and 1.15 (95% CI, 0.86–1.54; 82 exposed cases) for men. Trends according to categories of cumulative exposure and duration (years) of exposure to welding fumes were not observed.

5.2.8 Cancers of the head and neck

The Working Group considered case–control studies as being more informative than cohort studies when examining the association between welding and cancers of the head and neck. Due to the relatively low incidence of these cancers, either the number of cases was small or no relative risks were reported in many of the cohort studies. The evaluated case–control studies also controlled for smoking and alcohol drinking, the major risk factors for cancers of the oral cavity, pharynx, and larynx. However, the studies were hampered in their ability to evaluate these cancers by specific site because of the small numbers of exposed cases. Although positive associations were observed in some studies, these limitations prevented the Working Group from drawing any conclusions.

For sinonasal cancer, three out of the four case–control studies that reported on welding found positive associations. In one study that reported results by histological type the association was limited to squamous cell carcinoma, and a significant trend with duration was observed. However, no association with exposure to welding fumes was found in the largest case–control study for any histological type of sinonasal cancer. A pooled analysis of 12 case–control studies on sinonasal cancer also found no evidence of an elevated risk of sinonasal squamous cell carcinoma among welders. Only four cohort studies report on sinonasal cancer. No deaths from sinonasal cancer were observed in a large European study of welders, whereas non-significant increases in risk were found in a Danish study of boiler welders and in two census-based cohorts.

5.2.9 Other cancer sites

Associations between exposure to welding fumes and several other cancers, including cancers of the pancreas, colorectum, stomach, oesophagus, prostate, and testis, as well as between parental welding exposure and diverse cancers in offspring, were each examined in a few studies. The Working Group concluded that the data for these cancer sites did not permit any conclusion to be drawn with respect to the carcinogenicity of exposures related to welding.

5.3 Animal carcinogenicity data

No long-term studies on the effects of exposure to welding fumes in experimental animals treated by inhalation were available to the Working Group. One short-term inhalation study and two oropharyngeal aspiration studies examined the carcinogenicity of welding fumes in male A/J mice, and one intratracheal instillation study was conducted in male hamsters. The Working Group judged an intrabronchial implantation study in rats to be inadequate for the evaluation. The short-term inhalation study in male A/J mice exposed to GMA-SS welding fumes gave negative results. One oropharyngeal aspiration study in male A/J mice exposed to GMA-SS, MMA-SS, or GMA-MS welding fumes gave negative results. A second oropharyngeal aspiration study in male A/J mice exposed to MMA-SS welding fumes also gave negative results. The study in male hamsters exposed to low and high concentrations of MMA-SS welding fumes by intratracheal instillation reported two malignant lung tumours (a single tumour in each group); the Working Group deemed the study to be inconclusive, however, because of the comparison with undocumented historical controls. An oropharyngeal aspiration initiation–promotion study and an inhalation initiation–promotion study in male A/J mice examined exposure to GMA-SS welding fumes as a lung tumour promoter after initiation with 3-methylcholanthrene. Both studies showed a significant promoter effect of GMA-SS welding fumes on lung tumorigenicity.

5.4 Mechanistic and other relevant data

Toxicokinetic data from exposed humans concerned metals, and data regarding the deposition and clearance of particulate matter from welding fumes were sparse. All types of welding are associated with siderosis, a pulmonary accumulation of iron. In studies of MS welders, metals (chromium, nickel, and manganese) were measured in blood and urine, demonstrating absorption and excretion. Many studies in SS welders measured chromium in the blood and urine, and several also evaluated nickel and aluminium, demonstrating absorption and excretion. In rats, lung deposition of these same metals (chromium, nickel, and manganese) was demonstrated, followed by tissue distribution (e.g. to brain, lymph nodes, heart, kidney, spleen, and liver), and one study demonstrated urinary excretion. Comparable results were found between a study in non-human primates and a study in mice. Manganese distribution to specific brain regions was shown in multiple studies in rats and in one non-human primate study.

With respect to the key characteristics of human carcinogens, adequate data were available to evaluate if welding fumes: induce chronic inflammation; are immunosuppressive; are genotoxic; induce oxidative stress; alter cell proliferation, cell death, and nutrient supply; and modulate receptor-mediated effects.

There is *strong* evidence that welding fumes induce chronic inflammation and are immunosuppressive. More than 20 panel studies in humans with short-term exposure to various arc welding fumes reported increases in biomarkers of lung and systemic inflammation, some with exposure–response relationships. Other studies reported the similar or more pronounced effects of exposure to SS welding fumes. Several studies demonstrated increases in mediators of chronic inflammation in arc welders exposed to MS welding fumes. No information was available concerning whether the effects are sustained after exposure cessation. Several epidemiological studies of different design showed an increased risk of infection (pneumonia) in welders as a consequence of exposure-related immune suppression, while one molecular epidemiology investigation provided a plausible mechanism involving platelet-activating factor receptor. In a few toxicogenomic and metabolomic studies of arc welders exposed to MS fumes, changes were observed in eicosanoid levels and inflammatory pathways.

In numerous studies in male rats and mice, short-term and subchronic exposure to welding fumes (SS but not MS) stimulated cellular influx primarily of alveolar macrophages, neutrophils, and lymphocytes when evaluated immediately after exposure, or after subchronic (in rats and mice) or chronic (in mice) observation periods. Cellular infiltration was associated with an accumulation of inflammatory cytokines in the bronchoalveolar lavage fluid (BALF). In the few available studies in vitro, results were mixed.

Fewer experimental animal studies were available for immune suppression. Subchronic exposure to SS or MS welding fumes impaired resolution of pulmonary infection in several studies of male rats or female mice, with evidence of systemic as well as local immunosuppression. In lung gene-expression arrays, SS welding fumes dysregulated pathways signalling a strong immunological response in rats and mice, and perturbed immunosuppression pathways in non-human primates. Two studies in vitro reported impaired function in mouse immune cells.

There is *moderate* evidence that welding fumes are genotoxic. In exposed humans, the results of studies on genotoxicity are heterogeneous. Both positive and negative results were obtained, especially for chromosomal aberrations and sister-chromatid exchange rates in lymphocytes. Studies on micronucleus formation in lymphocytes and exfoliated cells generally had methodological concerns, such as having scored an inadequate number of cells. Studies on DNA damage (two of which compared measurements before and after exposure) generally gave positive results. Evidence was found for an increase in 8-hydroxy-2′-deoxyguanosine (8-OHdG) in blood plasma and in urine, with two studies of controlled crossover exposure and two field studies showing an effect during the welding work shift. Few data from experimental animals were available, with largely positive results for DNA damage in rats and in assays for genotoxicity in bacteria.

There is *moderate* evidence that welding fumes induce oxidative stress. All five identified short-term panel studies of exposure to various types of welding fumes in humans (including TIG/GTA welding on Al; arc welding on MS) reported increases in 8-OHdG in urine and in hydrogen peroxide in exhaled breath or urine. Four of these studies observed exposure–response relationships with particulate matter of diameter less than 2.5 µm ($PM_{2.5}$) or particle number concentrations. In several cross-sectional observational studies, exposure to various types of welding fumes was associated with increases in oxidative stress markers and decrements in antioxidant status (glutathione, superoxide dismutase activity) in the blood and urine. In three studies in male Sprague-Dawley rats, SS welding fumes increased markers of lung oxidative stress. Gene expression arrays in male mice showed that SS and MS welding fumes activated stress-response pathways in the lungs. In numerous studies of primary and immortalized cells in vitro, both SS and MS welding fumes induced production of reactive oxygen species (ROS). In acellular systems, SS and MS fumes generated ROS and oxidized macromolecules. No experimental studies of inhalation exposure, or studies demonstrating experimental challenge, were identified.

There is *moderate* evidence that welding fumes alter cell proliferation or death. Few data were available from exposed humans. In numerous studies in both male rats and mice, short-term and subchronic durations of exposure to primarily SS welding fumes increased BALF albumin levels and/or lactate dehydrogenase activity measured immediately after exposure, or after subchronic (in rats and mice) or chronic (in mice) observation periods. Proliferative pulmonary lesions were induced. In the few available gene-expression array studies, SS welding fumes perturbed pathways related to cell proliferation in non-human primates and rodents, while MS welding fumes induced circadian rhythm signalling and cell survival pathways in mice. Both SS and MS welding fumes induced cytotoxicity and/or altered mitochondrial function in a variety of mammalian cells in vitro.

There is *weak* evidence that welding fumes modulate receptor-mediated effects. Data from exposed humans were inconsistent and several studies had methodological weaknesses. No information was available from experimental systems.

There were no data on cancer susceptibility.

In exposed humans, pulmonary, cardiovascular, ocular, and neurological effects were observed, as well as renal effects when cadmium is present. In experimental systems, pulmonary, cardiovascular, and neurological effects were observed.