LUNG CANCER AND ARC WELDING OF STEELS

Commission VIII "Health, Safety and Environment" of the IIW

ABSTRACT

Commission VIII (Health, Safety and Environment) of the International Institute of Welding (IIW) published a critical appraisal of the results of research on the excess risk of lung cancer in arc welders in 1992. Commission VIII agreed to an updated statement on the possible causes of this excess risk and made recommendations for preventive actions to assist in reducing the risk in 2003. This was provided to IIW Member Societies as a Commission VIII Document in 2004 and a published Consensus Statement in 2005. In the 2005 Consensus Statement the Commission remarked that the apparent link between lung cancer and welding as an occupation suggested that the work environment was likely to play a part in causation. The prime suspects identified from the evidence were fume from welding processes, tobacco smoke and asbestos dust – acting alone or together. It was thought by some, that social factors other than occupation, but reflecting income may also play a part. The topic has been kept under review. The elevated risk of lung cancer among welders has persisted in the published medical literature. This 2010 report summarizes, makes comments on and draws conclusions from evidence from the published scientific literature on the topic. Commission VIII ratifies its 2003 Statement, concludes from the review that the prime suspects remain the same and that the cause of the elevated risk has yet to be resolved. Everyone in the industries concerned is exhorted to take effective action to protect welders and those who work with them. Special emphasis is placed on the need to control exposure to welding fumes, at least to national standards, to prevent all exposure to asbestos dust and to encourage and assist welders to avoid exposing themselves and others to tobacco smoke.

IIW-Thesaurus keywords: Arc welding; Cr6 in fume; Health and safety; Ni in fume; Occupational diseases; Occupational health; Smoking; Steels.

1 Introduction

Arc welding of steel is at the centre of the industrialised and industrialising world. For some decades studies of men classified as "welders" have been observed to have had a 30-40 % excess risk of developing lung cancer compared to the general population [1-6]. In this case excess risk can be defined as the difference between the proportion of welders with lung cancer and the proportion of the general population with the same disease. As an example: if the risk of lung cancer in the general population was 100 cases per 100 000 population per year, then one could expect there to be 130 to 140 per year in 100 000 welders (after controlling for age and sex with respect to the general population).

In the most recent meta-analysis published by a team of investigators in 2006, the excess risk was calculated at 22-32 % with no difference observed between the types of steel being welded – on the occasions when these were reported by researchers in their original scientific papers [7]. This evaluation is in full agreement with a former meta-analysis from 1997 [8]. A similarly elevated risk found in Denmark was reported in 2007 after a long follow-up study of a large cohort [9]. While an exposure-response relationship indicated carcinogenic effects related to stainless steel welding, it was uncertain whether the mild steel process carried such a correlation.

Even after allowing for the difficulties in making accurate estimates of the risk of cancer from epidemiological and other studies conducted in different countries and where estimates of exposure are usually somewhat crude [10], this apparently increased risk should not be ignored. Welding is a common task in many occupations – with only a relatively small proportion of those using the processes calling themselves welders [11]. With several million workers around the world using arc welding to some extent or other, and many more exposed at work to fumes arising from the processes as a principal part of their daily tasks, the observed slight excess risk of this usually fatal disease would amount to a significant number of deaths globally.

Commission VIII (Health, Safety and Environment) of the International Institute of Welding has sought to recommend actions which will be most effective in eliminating this apparent occupational risk. Given the number of studies that have been completed, it would be reasonable to expect there to be well-evidenced, consistent descriptions of the presence and level of risk and the factors to

Doc. IIW-2223, recommended for publication by Commission VIII "Health, Safety and Environment."

which this had been attributed, so that the Commission's advice could be focused on the particular hazard or hazards responsible. Regrettably, this is not the case as there have been wide variations in the information gathered and the conclusions that have been drawn, and so identification of the hazardous agents has yet to be achieved with absolute certainty.

In 1992 the Commission agreed that there was information about possible causes for much to be done on a general or empirical basis and published a Consensus Statement on the hazards they thought to be related to this excess risk and precautionary actions that could be taken. This statement has been published in Welding in the World [12] and was critically reviewed in 2003 [13] (see Box 1) and the summary conclusions of the review were published in Welding in the World in 2005 [14]. A detailed analysis of the evidence was made available on a website at www.icdachromium.com [15].

2 Review of the 2003 Statement

To provide a framework for the review, Commission VIII identified six prime suspects for possible causes of lung cancer in the work and social environment of welders. These were

1. "welding fume",
2. asbestos dust,
3. tobacco smoke,
4. ionising radiation (widely used in non-destructive testing of welded fabrications),
5. a social class-linked health package and,
6. for completeness, "something quite different", i.e. a previously unidentified carcinogenic agent.

Information used to draft the 2003 Statement and that garnered from the relatively few additions to the scientific literature since that time is now presented under these headings to allow conclusions to be drawn and summarized in a new Statement.

2.1 Welding fume

"Welding fume" is a generic term which encompasses the dynamic and often biologically active mixture of particulate matter emitted from a welding process used to join metal components. Fume is considered to be an aerosol, most of which is in the respirable range and can therefore reach the deepest parts of the lung.

The International Agency for Research on Cancer (IARC) conducted and published a review in which it made many broad generalizations about the link between cancer and occupational exposure to welding fume [16]. Much of the material it studied had been obtained during the European Cohort Study [6]. IARC classified welding fume in Group 2B "Possibly carcinogenic to humans" having concluded that there was inadequate evidence of welding fume carcinogenicity in animals and only limited evidence of carcinogenicity in humans. The latter conclusion reflected findings of excess mortality from lung cancer in shipyard, mild steel and stainless steel welders but the absence of an apparent linkage to duration of employment or cumulative exposure to total fumes, total chromium, hexavalent chromium or nickel compounds. This IARC classification suggested that the arc welding of many structural materials, including that of mild steel, was at the same level of concern as welding stainless steel [16, 17, 18].

In vitro and in vivo studies may indicate possible causal exposure-response relationships in humans. A soluble welding fume produced by SMAW/MMA of stainless steel has been shown to generate reactive oxygen species. Consequent DNA and cellular damage responses have been shown to be involved in various toxicological

2003 Statement on the excess risk of lung cancer in electric arc welders

"Arc welders as a broad occupational group are at higher risk of developing lung cancer than people in the general population. This excess risk of lung cancer is present in arc welders both of mild and stainless steel.

After much study and debate over recent years, Commission VIII (Health and Safety) of the International Institute of Welding (IIW), an amalgam of medical, scientific and welding engineering experts from many countries, has agreed to reconfirm its earlier statements that the cause of the excess risk might be found in the welding fume and environment, asbestos exposure and/or tobacco smoking. Additionally, it now considers that the balance of published scientific evidence supports the conclusion that, unless welding fumes contain an as-yet-unappreciated carcinogen, this risk is due, in the main, to occupational exposure to asbestos. Tobacco smoking also makes a significant contribution to the overall incidence of the disease.

To eliminate this excess risk of lung cancer, welders and their managers must ensure that:

– there is no further exposure of welders to asbestos,
– exposure to welding fumes is minimised, at least to national guidelines, and
– welders are encouraged and assisted not to smoke tobacco.

To improve the quality of research and hasten complete understanding of this excess risk, research should be coordinated globally. The world-wide welding community should cooperate in this research and contribute to funding it."

Box 1 – Lung cancer statement of Commission VIII in 2003 [12]

and carcinogenic processes in other situations [19]. This remains under review.

Studies of mice exposed to welding fumes have shown that that exposure causes persistent bronchiolar and peribronchiolar epithelial changes (i.e. a particular change in the cells and tissues in the bronchi and the lung) which suggest a need for further studies [20].

When Commission VIII examined the published reports of more recent epidemiological studies [7, 9, 21-23], the excess was still spread across the range of welders and materials. Some reviewers and researchers found an increased risk of lung cancer in "stainless steel welders" [8, 24], while others considered found an increased risk in mild steel welders [references]. A recent meta-analysis [7] found that there was no significant difference between mild and stainless steel welders.

Attention was focused on studies published since 2003. Retrospectively estimated welding fume exposure was positively associated with lung cancer in a nested case-control study in a major US Naval shipyard [25]. Welders were not identified specifically as being at particular risk in a large cohort study in the Netherlands reported in 2008 [22]. Another recently published study focused on a census-based population in Finland [23]. It was shown that the relative risks for lung cancer increased as the estimated cumulative exposure to iron fume and welding fume increased. The relative risks in the highest exposure category was 1.35 (95 % Confidence Interval (CI) 1.05-1.73) for iron fume and 1.15 (95 %CI 0.90-1.46) for welding fumes.

Over the years, iron and, when present, chromium and nickel compounds in welding fume have attracted special suspicion as causes of the excess risk of lung cancer in welders because of suspected or proven causal relationships through other occupational exposures. The Commission believes that when considering the evidence for extrapolating such occupational relationships to welding fume one must remain alert to the possibility that the particle structure and chemical and physical complexity of constituent compounds in welding fume may make their physiological and pathological behaviour differ in important respects such as absorption from that of "pure compounds" and those from other industrial sources.

2.1.1 Iron compounds

Iron compounds (in the form of complex oxides) are found in abundance in emissions from all steel welding processes. Inhaled particles containing this material may be retained in the lungs to cause siderosis and absorbed to be used in metabolism, stored or excreted. Inhalation of iron has been proposed as a carcinogen [26-28]. Iron overload has been described in steel welders and high exposure doses have been associated with carcinogenesis [23, 27]. The risk may increase when individuals are exposed simultaneously to iron and chromium compounds [27].

However, to confound these observations, welders with siderosis, whom one might assume are iron-loaded through heavy prolonged exposure to iron-rich welding fume, appear not to be at greater risk of developing lung cancer than other welders [29]. Moreover, a recently published study of a large cohort of workers in a French carbon steel factory did not detect any relationship between exposure to iron oxides and overall lung cancer mortality, although a moderately increased relative risk was observed among those with the highest exposure level [30].

On balance, there is insufficient evidence to suggest that iron compounds (in the form of complex oxides) in welding fume are a potent carcinogen and an explanation for the excess risk of lung cancer in welders, but research is continuing on this topic.

2.1.2 Chromium compounds

Fume from welding stainless steel and other chromium-containing alloys contains hexavalent chromium (Cr^{VI}) and trivalent chromium (Cr^{III}) compounds. Total and hexavalent chromium concentration varies between processes. For example, total chromium concentrations from SMAW/MMA and FCAW have been reported to be approximately 4 to 6 % of the welding fumes with 60 % or more being soluble hexavalent chromium [31, 32].

Hexavalent chromium is known to be carcinogenic to the respiratory system by the inhalation route in workers in a range of industrial processes including chromium plating [33, 34], the production of chromium compounds including chromates [35-38] and ferrochromium alloys [37]. Dose-response relationships have been established for hexavalent chromium exposure and cancer and the possibility of a threshold effect has been suggested [39]. Metallic and trivalent chromium have not been shown to be carcinogenic.

When hexavalent chromium is present in the fume from welding it is absorbed, at least in part, and excreted in urine [40-47]. While it has been contended that only sparingly soluble hexavalent chromium compounds are carcinogenic, there is evidence that this may also be the case for highly soluble compounds [39]. A soluble SMAW/MMA stainless steel welding fume has been shown to generate reactive oxygen species and consequent DNA and cellular damage responses which have been shown to be involved in various toxicological and carcinogenic processes in other situations [32]. This topic remains under review.

2.1.3 Nickel compounds

There is wide variation in the concentration of nickel and/or its compounds in different steels (e.g. some stainless steels) and nickel-based alloy electrode types. Its compounds usually form a small component of the fume emitted when such steels are welded. Biological monitoring of workers welding with some nickel containing steel consumables have shown that nickel compounds are absorbed [48].

IARC has classified nickel compounds as carcinogenic to humans (Group 1) and metallic nickel as possibly carcinogenic to humans (Group 2B) [16]. A long-persisting excess risk for lung cancer has been established for nickel refinery process workers [49-51] but no excess risk has been observed in nickel platers [52, 53], (who are exposed to soluble compounds), nor in workers employed manufacturing nickel alloys [54]. An authoritative review concluded that both soluble and insoluble nickel compounds probably contributed to these excess risks of exposure to nickel compounds [55], but uncertainty remains. The combined effect of nickel and tobacco smoking appears to demonstrate a mild to moderate multiplicative risk pattern [50, 54].

2.1.4 Ultrafine particles (UFP)

Welding fumes contain a high proportion of UFP (particles with one dimension less 100 nm). Exposures vary from type of welding, from the state of aggregation and agglomeration of particles and the distance of the welder's face from the weld pool. As a population, welders are more exposed to UFP than other occupational groups. In recent years there is increasing evidence that UFP, including those from welding fumes, may contribute to inflammatory processes. These may increase the risk of lung cancer. At present it is too early to draw any conclusions [56]. Commission VIII is keeping this under review.

2.2 Asbestos dust

Occupational exposure to respirable asbestos dust has been found to be associated with a significantly increased risk of lung cancer in addition to the essentially asbestos-specific malignancy of mesothelioma (a malignant tumour of the inside of the chest wall), even after correction for smoking habit and diet [55]. Smoking and asbestos together accounted for the largest number of deaths and cancer registrations in Great Britain in 2004 [57]. The risk of lung cancer increases with the cumulative dose of inhaled asbestos, begins soon after the start of exposure and reaches its maximum effect 10-20 years later. In contrast, mesothelioma has a long latent period – sometimes exceeding 30 years from first exposure.

Many welders have been exposed to asbestos dust during their working life in their current or pre-retirement workplace or brought a heritage of exposure with them to that workplace on relocation, perhaps from shipyards, boiler shops, locomotive and rail carriage or other such manufacturing and repair facilities in industrialised parts of the world. Evidence of previous exposure is supported by the presence of asbestos-related pleural and parenchymal changes in many welders with a history of such work [58] and the scattered reports of mesotheliomas in welders which have been found in several epidemiological studies [20, 57, 59, 60].

Occupational exposure to asbestos has been cited frequently as a suspected cause of the excess of lung cancer in welders. This risk varies, at least in part, with the type of asbestos, extent and duration of exposure and with smoking habit.

Although the use of asbestos has been regulated and restricted progressively in many countries since its lethal effect on health was recognized, it should not be thought that this is the situation world-wide. As reflected by the global tonnage of asbestos that is mined and processed each year it is still widely used in some countries [61].

Whereas some older studies of shipyard welders who may have been heavily exposed to asbestos show significantly increased lung cancer risks, more recent studies did not find shipyard welders at higher lung cancer risk than other welders [6, 20]; this may reflect a decrease in exposure to asbestos over time.

2.3 Tobacco smoke

There is no doubt that tobacco smoking increases the risk of lung cancer both in those who smoke and in others who are exposed to environmental tobacco smoke. In 1980 Beaumont and Weiss speculated that cigarette smoking may be a contributory factor to the excess of lung cancer in welders, as they had found that welders tended to smoke more cigarettes than did other occupational groups [2]. Several other investigators have since made the same observation over the years.

If there was consistent, good quality evidence that more welders smoked or welders smoked more heavily than control groups then tobacco smoking alone could offer an explanation of the excess risk for lung cancer. Many studies do indicate that this is the case but others do not. It is concluded from some individual studies, such as a case-control study in Argentina which identified an excess of lung cancer in welders [62], and the authoritative meta-analysis covering the period 1954-2004 published in 2006, that smoking does not appear to be a marked confounder in the relationship between lung cancer and welding [7]. Other studies still find an excess risk for welders after controlling for smoking [63, 64].

Commission VIII has agreed that while tobacco smoke is a cause of lung cancer in welders, as it is generally, there is insufficient consistency within the evidence to indicate that it is the only cause of the excess risk.

2.3.1 Combined effect of tobacco smoking and exposure to asbestos dust

The combined effect of tobacco smoking and exposure to asbestos dust together is greater than that of the exposures acting separately, but the mathematical relationship between smoking, asbestos and lung cancer remains undefined [65]. It must be remembered that there is wide individual variation depending on exposures but it may be concluded that the literature indicates that [63, 64, 65, 66].

– occupational exposure to asbestos alone increases the risk of lung cancer in non-smokers by a factor of about five;
– tobacco smoking without asbestos exposure increases the risk of lung cancer compared to non-smokers by 10 to 20 times;
– tobacco smoking and occupational asbestos exposure can together result in a 50-90 fold excess risk.

2.4 Ionising radiation

Ionising radiation, a proven carcinogen, is emitted by thoriated tungsten electrodes. Exposure can be associated with thorium in the welding fumes and grinding dust during preparation of the electrodes. Exposure due to fumes emitted during gas tungsten arc welding with a thoriated electrode will vary with welding conditions. Commission VIII has agreed that the exposure during DC welding is generally negligible or low; exceptionally, considerable inhalational exposure has been reported to have occurred during AC welding when LEV (Local Extractive Ventilation) is not used [67].

Grinding the electrodes is responsible for almost all electrode consumption and usually produces a notably higher concentration of particles and level of potential ionising radiation exposure than welding; consequently some exposure may arise from the grinding dust when the electrodes are prepared without any specific protective device.

Ionising radiation is also quite widely used in non-destructive testing of welds. However it is uncommon for welders to perform radiographic inspection of welds or be exposed to ionising radiation from non-destructive testing.

A nested case-control study [68] evaluated the relationship between lung cancer risk and external ionising radiation exposure while adjusting for retrospectively estimated potential confounders including smoking habit, and exposure to welding fumes and asbestos. Lung cancer risk was positively associated with exposure to asbestos and welding fume [25], as already mentioned, and to occupational dose of ionising radiation but the association with ionising radiation reduced after the inclusion of work-related medical x-ray doses in the analysis [68].

Although welders might be exposed to ionising radiation during the course of their work, Commission VIII believes that the potential attributable risk from ionising radiation is very low.

2.5 Class-linked ill-health package

There is a difference in lung cancer risk between social classes, as determined by income, in addition to the effects of smoking [69]. This may be due to deprivation impacting on lung health throughout life.

Commission VIII believes that there is no evidence for a significant influence of social class on the incidence of lung cancer among welders.

2.6 Something completely different?

There may be, of course, an as-yet-unappreciated carcinogen in emissions from welding processes or some other aspect of the welders' environment. Commission VIII is keeping this under review.

3 Conclusions

It may be concluded that overall, the findings of studies published since 2003 reinforce the conclusions that Commission VIII drew and promulgated in its earlier statements – without providing any significant clarification of causation. In consequence, the 2005 Consensus Statement remains valid. The problem of increased incidence of lung cancer being persistently associated with employment as a welder remains.

From the evidence presented in the scientific literature and summarized here, Commission VIII has drawn the following overall conclusions:

– Welders performing arc welding of steels have an overall excess risk of 20-40 % for lung cancer compared to the normal population.
– The increased risk appears to be associated with mild steel welding as well as stainless steel welding.
– Work environment is likely to play a part in causation of that increased risk.
– Welding fume from some welding processes contains compounds which have proven to be carcinogens in other work processes.
– The evidence for welding fume being carcinogenic is not strong.
– Many welders have been exposed to asbestos dust which may be a contributor to the increased risk of lung cancer in welders.
– Tobacco smoke is a major cause of lung cancer.
– Exposure to both asbestos dust and tobacco smoke carries a much higher risk than exposure to only one of these factors.

Industry-wide action campaigns should be mounted to:

– Minimize the quantity and toxicity of exposure to emissions from welding processes: at a minimum, welders should work to their national standards and guidelines.
– Audit the efficacy of these and other control measures by monitoring the exposure of workers and their health during employment and continuing health monitoring after leaving employment.
– Prevent exposure to asbestos dust.
– Educate welders about the risks of smoking, encourage welders not to smoke tobacco, assist those who want to stop to do so and provide rest areas for non-smoking welders that are free of environmental tobacco smoke.
– Sponsor, coordinate and support further high quality research.

Research design and conduct must be improved. Given the number of studies which have been completed, it would be reasonable to expect there to be more consistent evidence-based conclusions about lung cancer in welders upon which preventive action could be based. Whilst appreciating that there have been some improvements in recent years, Commission VIII believes there to be important lessons for future researchers to learn. The flaws in the design or conduct of past studies which must be avoided in future if research is to provide the soundly-based information the industry requires include:

– Size of study group. Some studies had a relatively small number of subjects and lung cancer deaths and could not hope to reach a conclusion as the power of the study to reach any conclusions was too small.
– Precision. In some studies the term "welder" is used loosely for instance by including caulker burners, a mixture of mild and stainless steel welders and workers using different welding processes with the result that the study and/or referent groups were not homogenous in their potential exposure. More precisely selected subjects and controls might allow formal pooling of exposure data and health effects from studies in different centres.
– Ultrafine particles. Further laboratory research should be focused on the whether there are differential health effects from inhaling welding fume particles in the ultrafine range.
– Unknown occupational exposures. It is rare for the nature and/or dose of the fume and any other significant exposure to have been analysed and reported and so conclusions on causal relationships are based on expectation rather than fact.
– Smoking habit and environmental tobacco smoke exposure is commonly not reported.
– There is evidence of a "healthy worker effect" for welders with a possibly significant number having changed employment before their disease is apparent so that it may be registered against a different occupation.

Summary

The excess risk of lung cancer associated with arc welding of steels

Arc welders as a broad occupational group are at higher risk of developing lung cancer than people in the general population. This excess risk of lung cancer is present in arc welders both of mild and stainless steels. The excess risk is small.

After much study and debate over recent years, Commission VIII (Health, Safety and Environment) of the International Institute of Welding (IIW), an amalgam of medical, scientific and welding engineering experts from many countries, has agreed to reconfirm its earlier statements that the cause of the excess risk might be found in the welding fume and environment, asbestos exposure and/or tobacco smoking.

It should be recognized that the incidence of lung cancer among welders represents exposure to welding fumes and related factors potentially over a considerable period of time.

To eliminate this excess risk of lung cancer, welders and their managers must ensure that:

– Exposure to welding fumes is minimized, at least to national guidelines;
– There is no additional exposure of welders to asbestos;
– Welders are encouraged to stop smoking tobacco and reduce exposure to environmental tobacco smoke in those welders who do not smoke.

To improve the quality of research and hasten complete understanding of this excess risk, research should be coordinated globally. Multidisciplinary research should be aimed at investigating the effects of exposures representative of the range of welding conditions prevalent in today's work environment. The worldwide steel and consumable manufacturers and welding community should cooperate in and support this research.

References

[1] Milham S.: Cancer mortality patterns associated with exposure to metals, Annals of the New York Academy of Science, 1976, vol. 271, no. 3, pp. 243-249.

[2] Beaumont J.J. and Weiss N.S.: Mortality of welders, shipfitters and other metal trade workers in boilermakers Local No. 04, AFL-CIO, American Journal of Epidemiology, 1980, vol. 112, no. 6, pp. 775-786.

[3] Beaumont J.J. and Weiss N.S.: Lung cancer among welders, Journal of Occupational Medicine, 1981, vol. 23, no. 12, pp. 839-844.

[4] National Institute of Occupational Safety and Health (NIOSH): Criteria for a recommended Standard, Welding, Brazing and Thermal Cutting, NIOSH Publication No. 88-110, Government Printing Office, Washington DC, 1988.

[5] Hull C.J., Doyle E., Peters J.M., Garabrant D.H., Bernstein L. and Preston-Martin S.: Case-control study of lung cancer in Los Angeles county welders, American Journal of Industrial Medicine, 1989, vol. 16, no. 1, pp. 103-112.

[6] Simonato L., Fletcher A.C., Andersen E., Anderson K., Becker N., Chang-Claude J., Ferro G., Gerin M., Gray C.N., Kalliomaki P.-L., Kurppa K., Langard S., Merlo F., Moulin J.J., Newhouse M.L., Peto J., Pukkala E., Sjogren B., Wild P., Winkelman R. and Saracci R.: A historical prospective study of European stainless steel, mild steel and shipyard welders, British Journal of Industrial Medicine, 1991, vol. 48, no. 3, pp. 145-154.

[7] Ambroise D., Wild P. and Moulin J.J.: Update of a meta-analysis on lung cancer and welding, Scandinavian Journal of Work, Environment and Health, 2006, vol. 32, no. 1, pp. 22-31.

[8] Moulin J.J.: A meta-analysis of epidemiologic studies of lung cancer in welders, Scandinavian Journal of Work, Environment and Health, 1997, vol. 23, no. 2, pp. 104-113.

[9] Sørensen A.R., Thulstrup A., Hansen J., Ramlau-Hansen C.H., Meersohn A., Skytthe A. and Bonde J.P.: Risk of lung cancer according to mild steel and stainless steel welding, Scandinavian Journal of Work, Environment and Health, 2007, vol. 33, no. 5, pp. 379-386.

[10] Cherrie J., Van Tongeren M. and Semple S.: Exposure to occupational carcinogens in Great Britain, The Annals of Occupational Hygiene, 2007, vol. 51, no. 8, pp. 653-664.

[11] Lillienberg L., Zock J.-P., Kromhout H., Plana E., Jarvis D., Toren K. and Kogevinas M.: A population-based study of welding exposures at work and respiratory symptoms, The Annals of Occupational Hygiene, 2008, vol. 52, no. 2, pp. 107-115.

[12] Zschiesche W.: On the subject of cancer risk in arc welders, Doc. IIW-1160, Welding in the World, 1993, vol. 31, no. 2, pp. 124-125.

[13] IIW Resolution CVIII R01 03 Statement on cancer risk in welding issued to Member Societies on 22 June 2004.

[14] McMillan G.: Concerns for the health and safety of welders in 2005, Doc. IIW-1719, Welding in the World, 2006, vol. 50, no. 3/4, pp. 38-44.

[15] McMillan G.H.G.: Lung cancer and electric arc welding, The Chromium File, Document n.12, March 2005, International Chromium Development Association, www.icdachromium.com.

[16] International Agency for Research on Cancer, Chromium, nickel and welding, IARC Monograph on the Evaluation of Carcinogenic Risks to Humans, 1990, Report No. 49.

[17] Naherne G.J.: Literature review update on nickel containing welding fumes (1988 to mid-1994), Welding Institute of Canada Report RC512 prepared for the Nickel Development Institute.

[18] IARC: Overall evaluation of carcinogenicity: an updating of IARC Monograph 1-42, Lyon, 1987.

[19] Antonini J.M., Leonard S.S., Roberts J.R., Solano-Lopez C., Young S.H., Shi X. and Taylor M.D.: Effect of stainless steel manual metal arc welding on free radical production, DNA damage, and apoptosis induction, Molecular and Cellular Biochemistry, 2005, vol. 279, no. 1-2, pp. 17-23.

[20] Solano-Lopez C., Zeidler-Erdely P.C., Hubbs A.F., Reynolds S.H., Roberts J.R., Taylor M.D., Young S.H., Castranova V. and Antonini J.M.: Welding fume exposure and associated inflammatory and hyperplastic changes in the lungs of tumor susceptible a/j mice, Toxicologic Pathology, 2006, vol. 34, no. 4, pp. 364-372.

[21] Seel E.A., Zaebst D.D., Hein M.J., Liu J., Nowlin S.J. and Chen P.: Inter-rater agreement for a retrospective exposure assessment of asbestos, chromium, nickel and welding fumes in a study of lung cancer and ionizing radiation, The Annals of Occupational Hygiene, 2007, vol. 51, no. 7, pp. 601-610.

[22] Preller L., Balder H.F., Tielemans E., Van den Brandt P.A. and Goldbohm R.A.: Occupational lung cancer risk among men in the Netherlands, Occupational and Environmental Medicine, 2008, vol. 65, no. 4, pp. 249-254.

[23] Siew S.S., Kauppinen T., Kyyrönen P., Heikkilä P. and Pukkala E.: Exposure to iron and welding fumes and the risk of lung cancer, Scandinavian Journal of Work, Environment and Health, 2008, vol. 34, no. 6, pp. 444-450.

[24] Milatou-Smith R., Gustavsson A. and Sjogren B.: Mortality among welders exposed to high and to low levels of hexavalent chromium and followed for more than 20 years, International Journal of Occupational and Environmental Health, 1997, vol. 3, no. 2, pp. 128-133

[25] Lauritsen J.M. and Hansen K.S.: Lung cancer mortality in stainless steel and mild steel welders: a nested case reference study, American Journal of Industrial Medicine, 1996, vol. 30, no. 4, pp. 383-391.

[26] Weiberg E.D.: The development of awareness of the carcinogenic hazard of inhaled iron, Oncology Research, 1999, vol. 11, no. 3, pp. 109-113.

[27] Humphrey C.D., Levy L.S. and Faux S.P.: Potential carcinogenicity of foundry workers: a comparative in vivo-in vitro study, Food and Chemical Toxicology, 1996, vol. 34, no. 11-12, pp. 1103-1111.

[28] Toyokuni S.: Iron and carcinogenesis; from Fenton reaction to target genes, Redox Report, 2002, vol. 7, no. 4, pp. 189-197.

[29] Myers C.R., Myers J.M.: Iron stimulates the rate of reduction of hexavalent chromium by human chromosomes, Carcinogenesis, 1998, vol. 19, no. 6, pp. 1029-1038.

[30] Bourgkard E., Wild P., Courcot B., Diss M., Ettingler J., Goutet P., Hemon D., Marquis N., Mur J.M., Rigal C., Rohn-Janssens M.P. and Moulin J.J.: Lung cancer mortality and iron oxide exposures in a French steel-producing factory, Occupational and Environmental Medicine, 2009, vol. 66, no. 3, pp. 175-181.

[31] Yoon C.S., Paik N.W., Kim J.H.: Fume generation and content of total chromium and hexavalent chromium in flux-cored arc welding, The Annals of Occupational Hygiene, 2003, vol. 47, no. 8, pp. 671-80.

[32] Antonini J.M., Stone S., Roberts J.R., Chen B., Schwegler-Berry D., Afshari A.A. and Frazer D.G.: Effect of short-term stainless steel welding fume inhalation exposure on lung inflammation, injury, and defense responses in rats, Toxicology and Applied Pharmacology, 2007, vol. 223, no. 3, pp. 234-245.

[33] Soraham T. and Harrington J.M.: Lung cancer in Yorkshire chrome platers, 1972-97, Occupational and Environmental Medicine, 2000, vol. 57, no. 6, pp. 385-389.

[34] Sorahan T., Burges D.C.L., Hamilton L. and Harrington J.M.: Lung cancer mortality in nickel/chromium platers, 1946-95, Occupational and Environmental Medicine, 1998, vol. 55, no. 4, pp. 236-242.

[35] Gibb H.J., Lees P.S.J., Pinsky P.F. and Rooney B.C.: Lung cancer among workers in chromium chemical production, American Journal of Industrial Medicine, 2000, vol. 38, no. 2, pp. 115-126.

[36] Park R.M., Bena J.F., Stayner L.T., Smith R.J., Gibb H.J. and Lees P.S.J.: Hexavalent chromium and lung cancer in the chromate industry: a quantitative risk assessment, Risk Analysis, 2004, vol. 24, no. 5, pp. 1099-1108.

[37] Lippold R.S., Mundt K.A., Austin R.P., Liebig E., Panko J., Crump C., Crump K. and Proctor D.: Lung cancer mortality among chromate production workers, Occupational and Environmental Medicine, 2003, vol. 60, no. 6, pp. 451-457.

[38] Hayes R.B., Sheffet A. and Spirtas R.: Cancer mortality among a cohort of chromium pigment workers, American Journal of Industrial Medicine, 1989, vol. 16, no. 2, pp. 127-133.

[39] Gibb H. and Chen C.: Evaluation of issues relating to the carcinogen risk assessment of chromium, The Science of Total Environment, 1989, vol. 86, no. 1-2, pp. 181-186.

[40] Tola S., Kilpio J., Virtamo M. and Haapa K.: Urinary chromium as an indicator of the exposure of welders to chromium, Scandinavian Journal of Work, Environment and Health, 1977, vol. 3, no. 4, pp. 192-202.

[41] Mutti A., Cavatoro A., Pedroni C., Borghi A., Giaroli C. and Franchini I.: The role of chromium accumulation in the relationship between airborne and urinary chromium in welders, International Archives of Occupational and Environmental Health, 1979, vol. 43, no. 2, pp. 123-133.

[42] Sjogren B., Hedstrom L. and Ulfvarson U.: Urine chromium as an estimator of air exposure to stainless steel welding fumes, International Archives of Occupational and Environmental Health, 1983, vol. 51, no. 4, pp. 347-354.

[43] Welinder H., Littorin M., Gullberg B. and Skerfving S.: Elimination of chromium in urine after stainless steel welding, Scandinavian Journal of Work, Environment and Health, 1983, vol. 9, no. 5, pp. 397-403.

[44] Bonde J.P. and Christensen J.M.: Chromium in biological samples from low level exposed stainless steel and mild steel workers, Archives of Environmental Health, 1991, vol. 46, no. 4, pp. 225-229.

[45] Stridsklev I.C., Hemmingsen B., Schaller K.H., Raithel K.J. and Kangard S.: Biological monitoring of chromium and nickel among stainless steel welders using the MMA method, International Archives of Occupational and Environmental Health,1993, vol. 65, no. 4, pp. 209-219.

[46] Stridsklev I.C., Schaller K.H. and Langard S.: Monitoring of chromium and nickel in biological fluids of stainless steel welders using the flux-cored-wire (FCW) welding method, International Archives of Occupational and Environmental Health, 2004, vol. 77, no. 8, pp. 587-591.

[47] Edme J.L., Shirali P., Mereau M., Sobaszek A., Boulenguez C., Diebold F. and Haguenor J.M.: Assessment of biological chromium among stainless steel and mild steel welders in relation to welding process, International Archives of Occupational and Environmental Health,1997, vol. 70, no. 4, pp. 237-242.

[48] Akesson B. and Skerfving S.: Exposure in welding of high nickel alloy, International Archives of Occupational and Environmental Health, 1985, vol. 56, no. 2, pp. 111-117.

[49] Grimsrud T.K., Berge S.R., Haldorsen T. and Andersen A.: Exposure to different forms of nickel and risks of lung cancer, American Journal of Epidemiology, 2002, vol. 156, no. 12, pp. 1123-1132.

[50] Grimsrud T.K., Berge S.R., Martinsen J.I. and Andersen A.: Lung cancer incidence among Norwegian nickel-refinery workers 1953-2000, Journal of Environmental Monitoring, 2003, vol. 5, no. 2, pp. 190-197.

[51] Grimsrud T.K.and Peto J.: Persisting risk of nickel related lung cancer and nasal cancer among Clydach refiners, Occupational and Environmental Medicine, 2006, vol. 63, no. 5, pp. 365-366.

[52] Pang D., Burges D.C.L. and Sorahan T.: Mortality study of nickel platers with special reference to cancers of the stomach and lung, Occupational and Environmental Medicine, 1996, vol. 53, no. 10, pp. 714-717.

[53] Kiilunen M., Aitio A. and Tossavainen A.: Occupational exposure to nickel salts in electrolytic plating, The Annals of Occupational Hygiene, 1997, vol. 41, no. 2, pp. 189-200.

[54] Sorahan T.: Mortality of workers at a plant manufacturing nickel alloys 1958-2000, Occupational Medecine, 2004, vol. 54, no. 1, pp. 28-34.

[55] International Committee on Nickel Carcinogenesis in Man, Report of the International Committee on Nickel Carcinogenesis in Man, Scandinavian Journal of Work, Environment and Health, 1990, vol. 16, no. 1, pp. 1-82.

[56] Brand P., Gube M., Gerards K., Bertram J., Kaminski H., John A.C., Kuhlbusch T., Wiemann M., Eisenbeis C., Winkler R. and Kraus T.: Internal exposure, effect monitoring, and lung function in welders after acute short-term exposure to welding fumes from different welding processes, Journal of Occupational and Environmental Medicine, 2010, vol. 52, no. 9, pp. 887-892.

[57] Health and Safety Executive, RR95 – The burden of occupational cancer in Great Britain, e-publication: http://www.hse.gov.uk/research/rrhtm/rr595.htm.

[58] McMillan G.H.: The risk of asbestos related diseases occurring in welders, Journal of Occupational Medicine, 1983, vol. 25, no. 10, pp. 727-730.

[59] Steenland K.: Ten-year update on mortality among mild-steel welders, Scandinavian Journal of Work, Environment and Health, vol. 2002, pp. 28, no. 3, pp. 163-167.

[60] Becker N.: Cancer mortality among arc welders exposed to fumes containing chromium and nickel, Results of a third follow-up:1989-95, Journal of Occupational and Environmental Medicine, 1999, vol. 41, no. 4, pp. 294-303.

[61] Joshi T.K. and Gupta R.K.: Asbestos in developing countries; magnitude of risk and its practical implications, 2004, International Journal of Occupational Medicine and Environmental Health, vol. 17, no. 1, pp. 179-185.

[62] Pezzotto S.M. and Poletto L.: Occupation and histopathology of lung cancer: A case-control study in Rosario, Argentina, American Journal of Industrial Medicine, 1999, vol. 36, no. 4, pp. 437-443.

[63] Jockel K.-H., Ahrens W., Pohlabeln H., Bolm-Andorff U. and Muller K.M.: Lung cancer risk and welding – Results from a case-control study in Germany, American Journal of Industrial Medicine, 1998, vol. 33, no. 4, pp. 313-320.

[64] Danielsen T.E., Langard S. and Andersen A.: Incidence of cancer among Norwegian boiler welders, Occupational and Environmental Medicine, 1996, vo. 53, no. 4, pp. 231-234.

[65] Berry G. and Liddell F.D.K.: The interaction of asbestos and smoking in lung cancer, A modified measure of effect, The Annals of Occupational Hygiene, 2004, vol. 48, no. 5, pp. 459-462.

[66] Selikoff I.J. and Hamond E.C.: Asbestos and smoking, JAMA, the Journal of the Medical Association, 1979, vol. 242, no. 5, pp. 458-459.

[67] Ludwig T., Schwass D., Seitz G. and Siekmann H.: Intakes of thorium while using thoriated tungsten electrodes for TIG welding, Health Physics, 1999, vol. 77, no. 4, pp. 462-469.

[68] Yiin J.H., Silver S.R., Daniels R.D., Zaebst D.D., Seel E.A. and Kubale T.L.: A nested case-control study of lung cancer risk and ionising radiation exposure at the Portsmouth Naval Shipyard, Radiation Research, 2007, vol. 168, no. 3, pp. 341-348.

[69] Hart C.L., Hole D.J., Gillis C.R., Smith G.D., Watt G.C.M. and Hawthorne V.M.: Social class differences in lung cancer mortality: risk factor explanations using two Scottish cohort studies, International Journal of Epidemiology, 2001, vol. 30, no. 2, pp. 268-274.