Lung Cancer and Electric Arc Welding

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HEALTH AND SAFETY

DRAFT FOR COMMISSION APPROVAL

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Introduction

Electric arc welding of steel is at the centre of the industrialised and industrialising world. With an estimated three million workers around the world using it in some form or another and many more exposed at work to fumes arising from the processes, even a slight excess risk of a serious, commonly fatal disease such as lung cancer associated with it would result in it causing a significant number of deaths globally.

It would appear that these work-related deaths may be occurring as for some decades welders have had a 30-40% excess risk of developing lung cancer compared to the general population.[1-6] This does not mean that this percentage of welders will develop lung cancer but rather that if, for example, the incidence is 100 cases a year in 100,000 in the general male population then it could be expected to be in the region of 135 per year in 100,000 welders.

Research to find a specific causal relationship is especially difficult because lung cancer is the commonest malignancy in the Western world; what needle in this haystack sets welders apart to increase their risk? In 1992 the International Institute of Welding's Commission VIII (Health and Safety) published a statement on the hazards they thought to be related to this excess risk.[7] Since then members of the Commission have kept the situation under active review and have now reached a consensus on an updated and slightly revised statement to be circulated to Member societies so that they may disseminate the information in their own country and also assess how they might contribute to improving research to provide the further knowledge required. This article includes the statement at Annex A and is intended to place it in context by describing the review process and indicating some of the more important sources of information and the course of the debate – and to encourage the industry into action.

The Commission is agreed that, although there is a need for more and better investigation and information, prevention should not wait for all the questions to be answered. Enough is known now to allow useful lifesaving action to be taken by applying traditional occupational hygiene principles skilfully and with vigour.

The welding industry and industries supplying or depending on welding should preserve and enhance their future vitality by working together in well-targeted ways to apply knowledge and skills in health and safety, technology, communication, training and education to protect welders and help them protect themselves. Perfecting risk management can then follow as research delivers the extra information on causation.

Identifying the prime suspects

Although not essential for a start to be made on more effective risk control to protect welders, the agent or agents responsible for this excess risk of lung cancer in welders must be identified before prevention can be optimised. Having searched for and scanned the evidence in the scientific literature for possible agents in the work and social environment of welders Commission VIII identified five broad classes of prime suspects meriting detailed scrutiny.

- "Welding fume" and particularly its constituent compounds containing iron, chromium and/or nickel.
- Asbestos dust.
- Tobacco smoking.
- Socio-economic influences.
- A previously unrecognised agent.

Welding fume

"Welding fume" is a commonly used generic term to describe the dynamic and often biologically active mixture of particulate matter and gases emitted from a welding process used to join metal components. Regulatory authorities, however, use the term "fume" more specifically to describe only the particulate components, and that is the interpretation used by the Commission.

In 1992 the International Agency for Research in Cancer (IARC) published its review of chromium and nickel in welding in which it had cast its net widely over welding fume in general.[8] It concluded that there was inadequate evidence of welding fume carcinogenicity in animals. Drawing heavily on the then recently completed European Cohort Study and reflecting the findings of other epidemiological studies that the excess mortality from lung cancer was present in shipyard welders, mild steel welders and stainless steel welders, but did not appear to be related to duration of employment or cumulative exposure to total fumes, total chromium, hexavalent chromium or nickel, IARC said there was only limited evidence of carcinogenity in humans.

This combination of evidence led to IARC classifying welding fumes as being "possibly carcinogenic to humans" (Group 2B),[8] raising all other forms of welding , including that of mild steel, to the level of concern which had previously been applied only to welding stainless steel.[9]

Three groups of metallic compounds have attracted special attention; iron, chromium and nickel.

Iron compounds

Iron compounds is found in abundance in all steel welding fumes and are inhaled and retained to cause siderosis. If, as has been suggested,[10] any of its compounds were to prove to be a potent lung carcinogen then an explanation might have been found for much of the excess risk among welders. Iron makers and workers have been said to have an elevated risk of respiratory tract malignancy[11] but a recent high quality study in a French iron refinery has shown no relationship between exposure to iron oxides and lung cancer mortality even long-serving iron-exposed workers.[12]

Iron over-loading has been described in steel welders and has been associated with carcinogenesis,[13] the risk increasing when individuals are exposed simultaneously to iron and chromium.[14] To confound these observations, welders with siderosis, who 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.[15]

Overall, the lack of definite evidence to the contrary suggests that iron and its compounds in welding fume do not provide a potent carcinogen.

Chromium

Fume from welding stainless steel is rich in hexavalent chromium (Cr VI) and trivalent chromium (Cr III) compounds. The total chromium concentration is higher in Gas Metal Arc Welding (GMAW), the USA term encompassing Metal Inert Gas, Metal Active Gas and CO_2 welding than in Shielded Metal Arc Welding (SMAW) or, in UK parlance, MMA or Stick welding, but the opposite is true for hexavalent chromium concentrations. Total chromium concentration in fumes from SMAW has been most commonly reported in the range 3.8% to 5.86%, with 60% or more being soluble hexavalent chromium.[16]

Chromium compounds are among the few established causes of work- or environment-related cancers that have been known for more than 100 years.[17] Hexavalent chromium is known to be carcinogenic to the respiratory system by the inhalation route in workers in a range of industrial processes; [8] chromium plating[18,19] and in production of chromates[20,21], chromate pigments[22] and ferrochromium. **[23]** Dose response relationships have been established for hexavalent chromium exposure and cancer and the possibility of a threshold effect has been suggested.[21]

There is coincident exposure in most circumstances to trivalent chromium compounds. These demonstrate genotoxicity but are not carcinogenic in animals.[8,24] IARC found there to be inadequate evidence regarding their carcinogenicity in humans.[8] Metallic chromium is not known to be carcinogenic in humans.[8]

Despite assertions that the chemical and physical complexity of such compounds in welding fume may make their physiological behaviour differ from that of "pure" compounds, thus protecting against absorption to a greater or lesser degree, biological monitoring leaves no doubt that when, for example, compounds containing the hexavalent chromium are present in the fume it is absorbed and excreted. [8, 25-33]

While it has been contended that only sparingly soluble hexavalent chromium compounds are carcinogenic, there has been evidence that this may also be the case for highly soluble compounds.[24] This remains under review.

Nickel

IARC has classified nickel compounds as carcinogenic to humans (IARC Group 1). Metallic nickel was classified as possibly carcinogenic to humans (Group 2B).[8] The exact mechanisms of nickel-induced carcinogenesis are not known[34] nor is it not known with certainty which forms of nickel pose the risk.[35]

Human exposure to highly nickel-polluted environments as found in nickel refining[36] is related to an excess risk of lung cancer which is increased dependent on duration of work and cumulative exposure. It appears to be strongest for water-soluble nickel.[35,37] As if to challenge that conclusion, no studies, including a recent one,[38] have pointed to an elevated cancer risk among nickel platers, who are exposed to soluble nickel.[39] Recent epidemiology did not suggest the presence of an occupational cancer hazard in the mortality experience of a cohort of workers employed manufacturing nickel alloys.[40]

The combined effect of exposure to nickel and smoking seems to be a weak to moderate confounder[34] demonstrating a multiplicative risk pattern.[36]

There is wide variation in concentration of nickel in different stainless steel electrode types, ranging in one study from 8 to 27%.[33] Its compounds are usually a very small component of welding fume, usually lower than those containing chromium. In general levels of nickels are critical only when high nickel alloys (>50%) are being welded.[9]

Biological monitoring during nickel plating,[39] nickel refining,[41] and welding with nickel containing filler metal[42] have shown elevated levels of nickel in urine proving that there is absorption of nickel compounds. There is, however, either no correlation or low correlation between nickel levels in air and urine even during high nickel alloy welding so it is of no use for exposure monitoring. Elevated levels persist in urine for weeks. There are slow and fast excretion phases. Only a weak correlation between the nickel levels of plasma and urine has been detected.[43]

Welding fume epidemiology

Almost all the particulate in the fume from an electric arc welding process derives from the action of the electric arc on filler metal and its flux, the coatings and contaminants on the work piece rather than from that metal itself, and from oxidation of spatter ejected from the arc. Thus, if compounds containing chromium and/or nickels are the agents responsible for the excess of lung cancer then that excess should be found among those welders who used filler metals which were rich in them, for example welders of stainless steels - and not in those welders who used materials which contained little or none of the putative materials, principally welders of mild steel. Moreover, one might reasonably expect evidence of a dose-response relationship.

Given the number of studies which have been completed, one might reasonably expect there to be well-evidenced, consistent descriptions of the situation in regard to lung cancer. The requirement seems so straightforward;

to compare the lung cancer experience of welders of chromium-containing stainless steel against that of chromium-free mild steel, yet there has been wide variation in the findings and conclusions drawn in the many epidemiological studies.

The major IARC study[8] concluded that the excess of lung cancer affected not only stainless steel welders but also shipyard and mild steel welders and differences of levels of risk between the stainless steel welders and the others could not be quantified with precision. Moreover, the risk did not seem to be related to duration of employment or cumulative exposure to total fumes, total Cr, Cr VI or nickel.[6,8] A separate study showed similar absence of dose effect relationship in terms of maximum exposure level.[44]

This pattern has continued in epidemiological surveys published since that time with any excess found spread across the range of welders; among the "stainless steel welders" in some studies, among “mild steel welders” in others while in some both groups were affected similarly.

Some workers have been more definite in their albeit contradictory conclusions, some asserting that the risk is significantly greater in stainless steel welders,[45-48] others favouring the excess risk being predominant in mild steel welders. [49-51] A third group of studies confirmed the excess risk of lung cancer but found no significant difference between mild steel and stainless steel welders. [52-56]

Langard, one of the first to appreciate and call attention to the lung cancer risk welders might face, [45] having apparently considered initially that stainless steel welding was the cause of the excess, revised his opinion in the face of new evidence to acknowledge that the case against stainless steel was now weak and to remark on the part that smoking and asbestos might play.[57] Becker developed similar views as his study matured and initial indications were reversed. [55] In his large scale meta-analysis the eminent French epidemiologist Moulin substantiated his long held view that epidemiological studies which were focussed on the risk of lung cancer in stainless steel welders had not produced clear evidence to suggest that they were at higher risk than mild steel welders and that the cause of the excess cancer found among both mild steel and stainless steel remained an unsolved issue.[58]

Faced with this impasse, Commission VIII held a brainstorming session with two leading epidemiologists, each representing one side of the argument for and against “welding fume causes cancer” division, and a group of healthcare professionals, welding engineers and managers, metallurgists and other technologists. Five factors which may have contributed to the lack of consistency became apparent.

First, some studies had a relatively small number of subjects and lung cancer deaths and could not hope to reach a representative conclusion.

Second, in some studies the term “welder” had been used rather loosely, perhaps “to make up the numbers”, with the result that the study and/or control group was not homogenous in its potential exposure. For example some grouped together might be a mix of electric arc welders, oxyfuel welders and even burners[59] with resulting major differences in their exposures. Some classed as stainless steel welders may have done a significant amount of mild steel work, as had all the stainless steel welders in one of the few studies where this might have been explored.[59] Conversely, the “mild steel welders” may have an undeclared history of welding stainless steel. The result is a mixed, imprecise exposure history which prevents clear cut comparisons or, if that history is not taken or appreciated, causes confusion as welders who merit inclusion in the exposed group find themselves used as controls, and vice versa.

Moreover, mild steel welders who had never welded stainless steel or other chromium alloys, but worked in a facility where SS is welded, unexpectedly showed very significantly increased concentration of chromium in urine and blood compared to metal workers and electricians who had never welded at all, despite strict precautions to prevent contamination.[29] Perhaps, as suggested in that report, there may be a very small percentage of chromium in construction steel, less than 1%, but the concentration in welding fumes may be higher due to preferential vaporisation.

So it may be concluded that, all in all, mild steel welders are probably not the best referent group for stainless steel welders because of the risk of cross-contamination from earlier work with stainless steel, working close to stainless steel welding even though welding mild steel and even absorbing chromium compounds from mild steel work. If the exposures of the study groups are mixed then it is not surprising that the evidence and conclusions drawn from them are inconsistent between studies.

Third, there is evidence of an overall “healthy worker” effect for welders which is stronger for stainless steel welders, perhaps because they tend to be better paid, and this may have led to an underestimation of the lung cancer risk for them.

So what for the future? What should be done about welding fume?

The evidence seems to weigh against it being a major cancer hazard – but we have seen that the evidence gathering mechanisms have been flawed. – and, of course, the absence of evidence does not necessarily provide evidence of the absence of a relationship.

The next two risk factors are possibly the most important influences on the excess overall as these may offer an explanation for much if not all of the extra risk. These are inhalation of asbestos dust and/or tobacco smoking. dust.

Asbestos dust

Exposure to respirable asbestos dust is associated with an increased risk of lung cancer.[60] One study from the Netherlands has indicated that after adjustment for smoking and diet, about 11.6% of cases of lung cancer in men is attributable to a lifetime occupational exposure to asbestos.[61]It has been a frequently arraigned suspect as the cause of the excess risk of lung cancer in welders, at least in part, this risk varying with the type of asbestos, extent and duration of exposure, and smoking habit, and being greatest in smokers but still significant in non-smokers [5, 44,55,58-63]

Many welders have been exposed to this dust during their working lives in their present workplace or have brought a heritage of previous exposure with them, perhaps from shipyards where it could be notably high,[64] boiler shops, locomotive and rail carriage works and other such manufacturing and repair facilities in industrialised parts of the world.

That many of these welders were exposed to significant levels of asbestos dust at work is borne out by the scattering of cases of the malignant tumour mesothelioma in welders found in several epidemiological studies[65] and perhaps most notably the cooperative European Cohort study[6] which made such a contribution to the IARC monograph on welding.[8] Asbestos dust is almost uniquely the cause of that disease.

Tobacco smoking

There is no doubt that smoking tobacco increases the risk of lung cancer in users. In 1980 Beaumont and Weiss speculated that cigarette smoking may be a contributing factor to the excess of lung cancer in welders as they tend to smoke more cigarettes than do other occupational groups.[2] Others have expressed that opinion over the last 24 years. [51,58,59,62,65]

If there was more convincing evidence of more welders smoking or welders smoking more heavily than the control groups and their socioeconomic group in general population then tobacco smoke could offer at least a partial explanation for the excess risk of lung cancer in welders. Unfortunately, where evidence about the smoking habits of welders is available it is inconsistent, some surveys showing more smoking than in the general population and others not showing that excess. Overall, there is not convincing evidence that tobacco smoking alone could explain the excess risk of lung cancer.

Combined effects of tobacco smoking and asbestos exposure

The effect of exposure to asbestos and tobacco smoking together is greater than that of the single effects acting separately. There is argument as to the nature of the relationship; multiplicative, additive or more complicated and nebulous.[63, 66-70] On average, and there is wide individual variation depending on exposures:

- occupational asbestos exposure alone increases the risk of lung cancer in non-smokers by a factor of about five;
- tobacco smoking without the asbestos exposure results in about 10 to 20-fold increase in cancer risk;;

- while those who smoke and have been occupationally exposed to asbestos can have a 50 to 90 fold excess risk of lung cancer.

Class-linked health package

Repeatedly studies of the health of workers show that manual workers have a greater risk of ill health in general and lung cancer in particular than “white collar" workers. This may well effect welders. It would be consistent with there being no different between stainless steel welders and others.

There is a difference in lung cancer risk between social classes in addition to the effects of smoking.[71] This can be explained by poor lung health, deprivation and poor socioeconomic conditions throughout life. As well as anti-smoking measures, reducing socioeconomic inequalities and targeting individuals with poor lung function for help with smoking cessation could help reduce further lung cancer incidence and mortality in the general population – and if targeted properly, reduce it in welders.

Something quite different?

There may, of course, be an as-yet-unappreciated carcinogen at work in welding fume or some other aspect of the welders' environment.

Conclusions

Commission VIII concluded that:

- Electric arc welders have an excess risk of 30-40% for lung cancer.
- Work environment is likely to play a part in causating of that excess.
- Asbestos dust and tobacco smoke are likely to be major contributors to causation.
- Welding fume from some processes contain compounds of elements such as chromium and nickel proven to be carcinogens in other work activities.
- The evidence for welding fume or any of its constituents acting as a carcinogen is not strong.
- It would, however, be prudent to treat welding fume as a mild carcinogen risk factor until it is proved to be non-carcinogenic.
- There is nothing to suggest the presence of a mystery carcinogen in the fume.
- Industry-wide campaigns should be mounted to control these three risk factors – asbestos, tobacco smoking, and the quantity and toxicity of welding fumes - and to measure the level of success which has been achieved in disease prevention.
- Campaigning should extend beyond work to improve life style as poor life style seems to be reflected in poor health –including lung cancer.
- Further research is needed to identify carcinogens in welding fume or give it a completely clean bill of health.

Support required for research

The further information required to reach firm conclusions and gain confidence that welders, and the industry, are protected appropriately will be gained only through large-scale, well-coordinated research in which exposures are defined more precisely than has been achieved to date and which seeks to prove or disprove a causal relationship between these exposures and the excess risk of lung cancer. This can be achieved only with more active support from industries which supply or use welding by way of finance, access to study populations and to records of past exposures – including those which reveal over-exposure relative to national standards.

Lung Cancer and Welding Action Check List

It may seem from these conclusions and the statement in the Annex that the Commission is saying nothing new. The difference lies in the vigour and quality of activity which it believes must be achieved to make a real difference. This must deliver a culture change sufficient to bring the wellbeing of the welders to the fore from concept to completion – and so allow the industry to thrive and prosper with sufficient recruits under training and skilled operators working not forced into inefficiency or retirement by occupational illness. Key action points are.

- Everyone in the industry should be concerned with reducing the risk of lung cancer. They must use available knowledge to afford appropriate protection at work to welders and those about them.

- There must be no more exposure to inhalable asbestos.

- Welders should be informed of the excess risk of lung cancer, have it explained and be told how to reduce the risk.

- They should be told of the special risks of smoking and advised and assisted to cease smoking.

- Minimise fume emission and exposure at least to below national standards. Plenty of advice is available from health and safety agencies and the literature.[72,73] Again, even in the absence of a sound evidence base, common sense demands that extra efforts are made to minimise and preferably avoid exposure to compounds of nickel and chromium in fume. Do this through better:
  - concepts and designs with safe fabrication in mind;
  - process specification and substitution;
  - process modification to reduce emission;[74-77]
  - engineering controls such as ventilation;
  - education and training.

- Commission and support high quality research and success monitoring projects..

Annex A

Lung cancer and electric arc welding

**A Statement by Commission VIII (Health and Safety)
of the International Institute of Welding**

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

After much study and debate over recent years, Commission VIII, 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 of lung cancer 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 may be 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 standards,
- 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 worldwide welding community should cooperate in this research and contribute to funding it.

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