

HEALTH AND SAFETY IN FABRICATION AND REPAIR OF WELDED COMPONENTS: ASPECTS, IMPACTS AND COMPLIANCE WITH REGULATIONS



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ABSTRACT

The evaluation of the aspects of health and safety of welding fabrication and repair activities is rather complex, because of the great number of disciplines involved. An attempt at classification of these aspects will be proposed, dividing them into physical aspects – including radiation, heat, noise, electrical dangers, electromagnetic fields and work environment conditions, and chemical aspects, as concerning gases and particulate matters produced during welding (generally referred to as “welding fumes”) and other hazardous chemical substances used during all phases of the fabrication process. This leads the recognized authorities to develop specific regulations which differ generally from one country to another, based on different criteria and which are also sometimes difficult to comply with (e.g. the new exposure limits for welding fumes). An approach to this problem will be given, based on the work of IIW Commission VIII “Health, Safety and Environment”. Emphasis will be placed on the “hot topics” of the moment, including the effects of the manganese found in welding fumes on the central nervous system, the health effects of welding gases, the apparent high risk of lung cancer in welders and the improvement of the welding workplace to reduce the ergonomic impact on musculoskeletal disorders affecting many welders. Moreover, reference will be made to the ISO Technical Reports on the composition of welding fumes currently under discussion, the use of GTAW Thoriated Electrodes and the safety aspects of welding.

IIW-Thesaurus keywords: *Electromagnetic fields; Fume; Fusion welding; Health and safety; Human factors; Maintenance; Management; Mg in fume; Occupational diseases; Occupational health; Reference lists; Repair; Rules; Standards; Toxic materials; TLV; Welders health.*

1 INTRODUCTION

Welding is a complex technology, involving several processes and materials. The evaluation of the health and safety aspects of welding can therefore be extremely complex, because of the large number of disciplines involved.

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Several statistics concerning welding work-related injuries are available, but their reliability can be considered questionable, owing to the difficulties in identifying the welding career (i.e. the loose use of the term “welder”), of the heterogeneity of available data and of the great number of confounding factors which mainly affect long-term studies.

In the following paragraphs, a concise description is provided of those so-called “hot topics” to which the IIW Commission VIII “Health, Safety and Environment” has devoted most of its attention and time over the past years.

2 PHYSICAL ASPECTS OF WELDING

Taking into consideration all the different conditions which can occur during welding fabrication activities

in the various welding fabrication sectors, it is difficult to provide an exhaustive picture of the situation.

The causes of some acute physical injuries such as electrocution, workplace accidents, hearing loss and skin/eye damage due to UV radiation are well-known, as well as the appropriate control and protective measures. Unfortunately, some other physical consequences, such as repetitive strain injury, may provoke more insidious long-term effects which mostly affect the end of the welder's career. Great attention has also been given to the matter of exposure to ElectroMagnetic Fields (EMF) which occurs during the use of welding processes.

2.1 Ergonomic impact of welding

Ergonomy has been defined in 2000 by the International Ergonomics Association (IEA) as "the scientific discipline concerned with the understanding of interactions among humans and other elements of a system, and the profession that applies theory, principles, data and methods to design in order to optimize human well-being and overall system performance".

In the case of welding fabrication, both cognitive and physical strain can be considered as affecting the welder's job.

The first can indubitably be confirmed by experience, the absence of appropriate models and studies can lead to difficulty in identifying adequate corrective measures.

In the case of physical strain, the following basic variables can be considered [1]:

- intensity of the job;
- weight of the handling mass;
- postural strain, taking into consideration the position of the body (e.g. sitting, standing, kneeling, etc.).

Several quantitative approaches have been proposed, based on the handling mass and on several multiplicative factors, taking into consideration the above-mentioned basic variables and related factors.

As an example, the following approach was proposed by the U.S. National Institute for Occupational Safety and Health (NIOSH), based on the evaluation of a Recommended Weight Limit (RWL) through the "Revised NIOSH equation" [2].

$$RWL = LC \times HM \times VM \times DM \times AM \times FM \times CM \quad (1)$$

where **LC** is the Load Constant (estimated at 23 kg) and the other factors taken into account are the type and frequency of the job, as well as the handling of the object (see Figure 1 [3]).

The resultant Recommended Weight is defined for a specific task as the weight of a load that nearly all healthy workers could lift over a substantial period of time (e.g. up to 8 hours), without an increased risk of developing lifting-related musculoskeletal injuries.

In the case of manual and semi-automatic welding processes, the frequency of the movement, the asymmetry of the job, the coupling multiplier (taking into account the difficulties in performing every activity with the required safety gloves), as well as the length of the

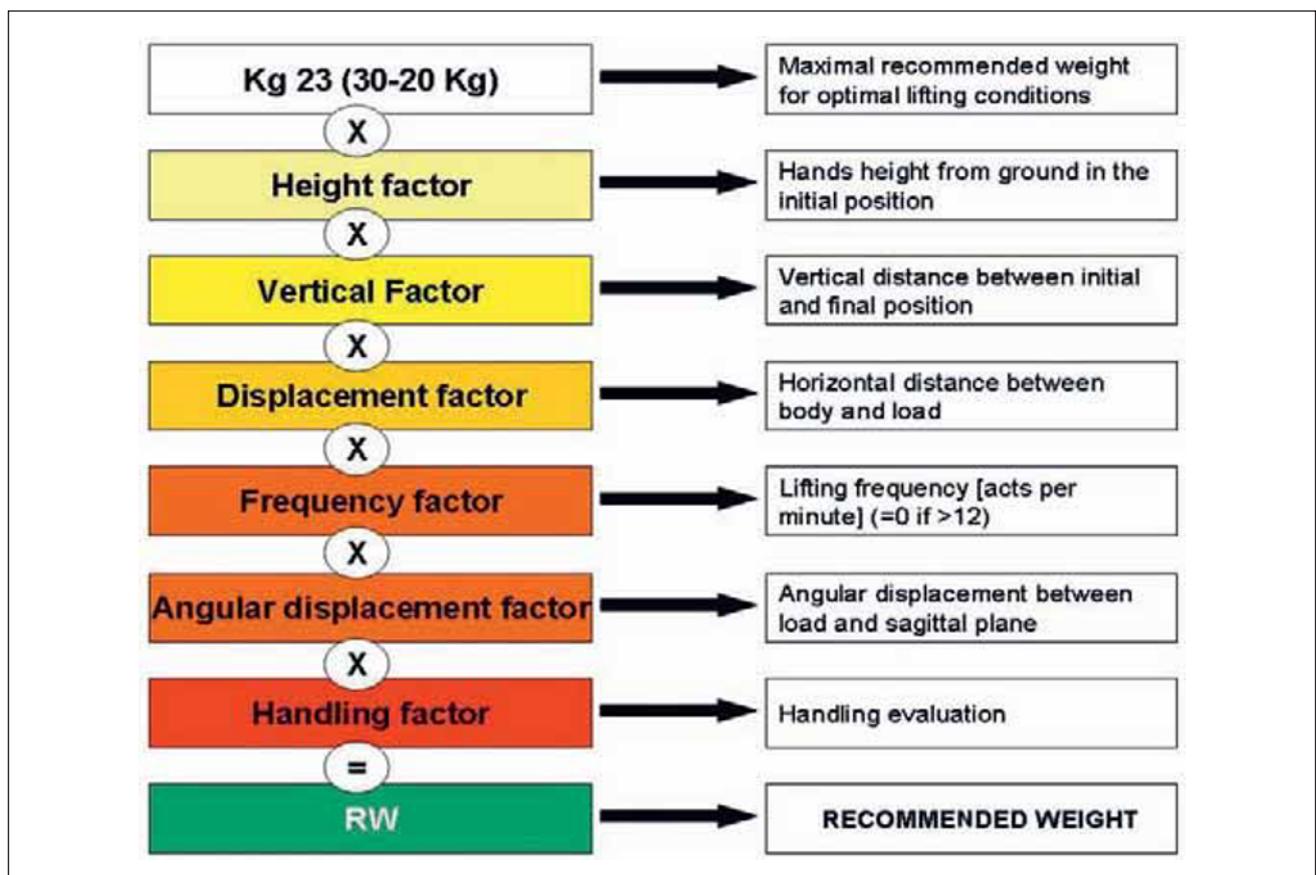


Figure 1 – Revised NIOSH equation

working shifts may produce a RWL which can easily exceed the weight of the welding torch.

As for protective measures, the workplace design can be optimized, fulfilling available guidelines. In the case of the welding workshop, the welding workplace design proposed by R. Kadefors [3] is still a valid reference, whilst the use of ergonomically-improved tools and the use of appropriate shifts seem the only effective tools for those on-site and repair activities in which the welder has to adapt his posture to the specific welding job.

2.2 Exposure to electromagnetic fields and welding

The question of the possible adverse health effects of electromagnetic fields (EMF) has been a matter of public discussion for some time, but remains unanswered. So far, the following short-term biological effects have been demonstrated:

- in the case of exposure to low frequency EMF, minor effects to nervous system functions, appearance of visual phosphenes and a minor reduction in heart rate;
- exposure to high frequency electromagnetic fields can result in an increase of body temperature, and, in exceptional cases, the overwhelming of the thermoregulatory capacity of the body and the resulting production of harmful levels of tissue heating.

It has, however, to be underlined, the difference between biological and adverse health effects; an adverse health effect causes detectable impairment of the health of the exposed individual, or of his or her offspring; a biological effect, on the other hand, may or may not result in an adverse health effect.

As for long-term effects, in the absence of experimental evidence from cellular or animal studies, and given the methodological uncertainties in the epidemiological literature, there is no chronic disease for which an aetiological relation to EMF can be regarded as established.

Consequently, the ICNIRP (International Commission on Non-Ionising Radiation Protection) has developed reference levels of exposure, the compliance with which ensures maximum protection against this potential source of harm. These levels have been included in the European Directive 2004/40/CE “Minimum health and safety requirements regarding the exposure of workers to the risks arising from physical agents (electromagnetic fields)”.

Arc and resistance welding equipment and relevant power sources produce both low frequency and high frequency electromagnetic fields, the intensity and frequency of which depends on the kind of technology used (Figure 2, [4]). Nevertheless, measurement of the personnel exposure to EMF is in general very complex, especially in workshops where several welding tasks are performed. However, there is no specific evidence of a relation between the welder and diseases which can be attributed to exposure to electromagnetic fields,

with the possible exception of effects on pacemakers or other similar devices.

The IIV Commission VIII has published the following recommendations on this matter. “It is in any case prudent to consider the following steps to minimise occupational exposure as far as is reasonably practicable.

- Maximize the distance of the worker’s body from the electric power source and the welding equipment.
- In electric arc welding, route the electrode and work cables together.
- Do not allow the electrode lead or any electric cable around the body.
- Do not allow the workers body to be between the electrode cable and any other electric cable. Keep all cables together on one side or the other.
- Inform the H&S responsible in case of use of pacemakers”.

3 CHEMICAL ASPECTS OF WELDING

The transfer of chemical agents available in the welding workplace through the skin is not normally considered to be a problem in the case of welders unless the skin is damaged, but account must be taken of ingestion risks, especially in the case of certain substances which may be included in some welding and soldering fluxes (e.g. barium). Consequently, the utmost attention in relation to possible chemical agents has been devoted to the problems of welding fumes, which are composed of gases deriving from the welding process and possible other substances in (or in solution with) the welding materials, and by particulate matters of metals and relevant compounds deriving from the involved consumables and base metals.

Table 1 reports a list of components which have the greatest significance in relation to occupational hygiene, and therefore require the most stringent control measures to ensure that a welder is not exposed to an excessive level of the substance(s) concerned. These are referred to as Key Components (the table is derived from one of the first Technical Reports produced by the IIV Commission VIII to be published by ISO [5]). The table refers to possible components and makes

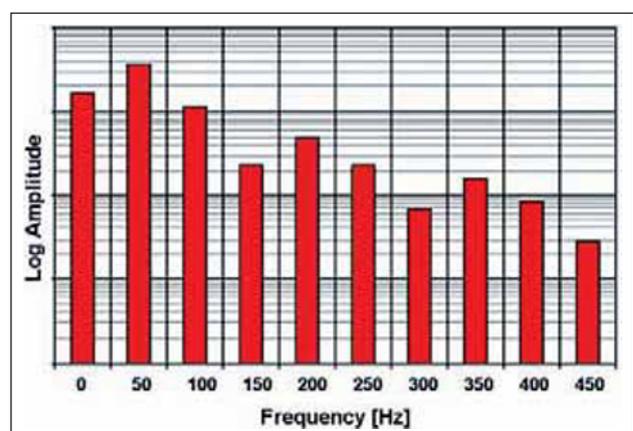


Figure 2 – Amplitude-frequency distribution in TIG welding with an electronic power source [4]

Table 1 – Key components in welding fumes

Material	Process		
	SMAW	GTAW/ GMAW	FCAW (Gas shielded)
Unalloyed and low alloy steel ^a	Mn, Cr or Cr(VI) ^c	Mn, Cr or Cr(VI) ^c	Mn, Cr or Cr(VI)
High alloy steel ^b	Cr(VI) or Ni	Cr, Cr(VI) or Ni	Cr(VI) or Ni
Aluminium	Al, Mn or Zn	Al, Mn or Zn	Co, Cr, Cr(VI) Ni or Mn
Nickel-based	Cr, Cr(VI) or Ni	Cr, Cr(VI) or Ni	Cr, Cr(VI) or Ni
Copper-based	Cu or Ni	Cu or Ni	--

^a Unalloyed and low alloyed steels are here considered to have < 5 % combined alloying elements.
^b High alloyed steels are here considered to have ≥ 5 % combined alloying elements.
^c For the unalloyed and low alloyed steels Cr(VI) amount can be considered negligible compared to Cr(VI) from high alloyed steels (e.g. Cr(VI) in high alloyed steels is 3-6 % and in low alloyed steel 0,05 % in the fume box, see ISO 15011-1).

no reference to the relevant amount in welding fumes (e.g. GMAW and GTAW develop the same component, but with a significant difference in concentration, as in GTAW the amount may be negligible).

Some possible adverse effects of exposure to welding fumes are [6]:

- siderosis, associated with the deposit of iron in the lungs;
- irritation of the respiratory tract, with changes in the lung function and, in some cases, oedema due to welding gases (ozone and nitrogen oxides in particular);
- metal fume fever which presents symptoms similar to influenza and is due to zinc particles released mainly during welding of galvanized steels;
- systemic poisoning due to exposure to fluorides, chromium, lead, barium, etc.;
- mutagenic effects of radiation caused by the possible inhalation of thorium oxides, produced during the grinding of thoriated tungsten electrodes for GTAW.

However, the focus of medical, epidemiological and research studies has been mainly devoted to the long-term effects of behavioural diseases (possibly linked to Mn compounds) and to lung cancer, possibly linked to hexavalent chromium [Cr(VI)] and to nickel oxides.

3.1 Exposure to Mn in welding fumes and Parkinson's disease

A lot of attention has been devoted to this topic, especially after some litigious cases in the U.S.A., where the possible link of Mn in welding fumes to the onset of Parkinson's disease is under discussion.

Manganese and its inorganic compounds have been accepted as occupational neurotoxins, especially in the form of dusts. There is a specific disease, referred to as manganism, which has been observed in several fields of work, including workers in manganese mines. Among the clinical effects recorded is difficulty in coordinating movements, as is the case for Parkinson's disease.

There is still great concern in relation to welding activities insofar as Mn is used as an alloying element in steels, even if the inhalable particles have structures and compositions different from the ones available in

the disintegration processes used for mining and ore milling [6]. It is still under discussion the possibility for these substances to go beyond the blood-brain barrier. Moreover, the effect of Mn seems more linked to the destruction of receptor cells in the nervous system rather than its contribution to the production of dopamine (the acknowledged culprit of Parkinson's disease which affects movement) [7, 8].

IIW Commission VIII extensively studied scientific literature on the matter and produced a document subsequently published as "IIW Statement on Manganese", the conclusions of which can be summarised as follows:

- a) Compounds containing manganese, in complexes with iron and other oxides, are present in fume particles from steel welding and allied processes.
- b) Clinical manganism and Parkinson's disease are two separate diseases, which, with care and thorough investigation, can be differentiated one from the other.
- c) Studies have not supported the conclusion that welders are or have been at any greater risk of developing Parkinson's disease at all, or at an earlier age than others of similar background in other occupations in their community.
- d) Whereas vast numbers of workers worldwide use arc welding to join metal, very few, if any, have developed clinical manganism as a result of exposure to welding fumes. The risk may be slightly greater in allied processes such as thermal cutting and gouging or hardfacing, in which fume emission levels are inherently higher. But again there have been very few cases.
- e) There is no convincing evidence that exposure to manganese-containing fumes during employment as a welder can result in an increased risk of developing neuro-behavioural deficiencies and loss of fine control of movements. There is, however, insufficient evidence to the contrary, to dismiss the possibility with absolute certainty.

In conclusion, it should be recommended that exposure to manganese-containing compounds in fumes and dust be reduced, at least by complying to national occupational exposure limits, as well as the promotion of research in this field.

3.2 Arc welding fumes and lung cancer

The possible presence of fumes in the welding of some chromium compounds and nickel oxides, recognised to be carcinogenic, associated with the epidemiological results which show that arc welders have been exposed to the excess risk of developing lung cancer for decades, focused the interest of the scientific community on welding fumes.

Several studies have been devoted to this matter, in an attempt to investigate the presence of carcinogenic compounds in welding fumes, to establish the mechanism of formation of the fumes and to establish a relationship between fumes and cancer in welders.

Nevertheless, the chemical uncertainties in the evaluation of compounds available in welding fumes, the understanding of the physical phenomena occurring in the welding arc which is still sadly lacking, as well as the presence of several confounding factors, still lead to some level of uncertainty.

The major study published by the International Association for Research on Cancer (IARC) concluded that the excessive occurrence of lung cancer was to be found not only among stainless steel welders (where carcinogenic Cr and Ni compounds may be available), but also among shipyard and mild steel welders, with a difference in the level of risk not being precisely quantifiable [9, 10]. This is undoubtedly linked to the presence of confounding factors such as the presence of asbestos in the welding environment and to the typical habit of welders to be tobacco smokers [11].

After years of study and debate, Commission VIII is prone to confirm that the reason for the excess risk in welders might be found in the combination of substances present in the welding workplace, including welding fumes, but that the most significant role played is occupational exposure to asbestos and, secondly, to tobacco smoke.

3.3 Welding and cutting on containers

Although the most chemical aspects possibly associated with welding activities may be considered similar, independent of the place where the activity is performed, repair of containers may represent a further potential source of harm due to the possible presence of hazardous substances formerly contained and/or developed during welding.

Hazardous substances, as referred to herein, include but are not limited to, those that are explosive, combustible, toxic or corrosive. They may be present in a container having previously held one of the following:

- volatile liquid that can release potentially hazardous flammable or toxic vapours or any combination thereof;
- an acid or alkaline material that reacts with metals to produce hydrogen;
- a non-volatile liquid or solid that at ordinary temperature will not release potentially hazardous vapours, but

will do so if the container is heated. For example, combustible vapours or hazardous decomposition products may be generated by the heat of welding or cutting;

- a dust cloud or finely-divided airborne particles that may still be present in an explosive concentration.
- a flammable or toxic gas.

In the event of a substance being recognised as hazardous, or that there is lack of knowledge about it, the correct procedure shall consist in the clearing of the immediate area outside and inside the container, followed by isolation from further contamination by hazardous substances and by the cleansing or rendering inert of the substance through an appropriate method. Specifically, inerting is another means of isolation, consisting of filling the container with an inert medium such as water, inert gas or sand, and then emptying it again. Only after these activities are performed, welding and/or cutting can be executed, based on an appropriate welding procedure [12].

In addition, it shall be noted that containers with metal liners and internal and external coatings of plastic, refractory and/or other materials, should be handled carefully, as the coating or liner itself may release vapours or fumes when heated, or liquids may be trapped between the coating or liner and the container wall. Because of the possibility of hazardous products being released and of damage to the coating, hot work on such containers should only be performed under the supervision of persons with knowledge of the container's contents and of the coating or liner.

4 EXPOSURE LIMITS AND COMPLIANCE WITH REGULATIONS

As can be noted from an in-depth investigation of the items reported in the previous paragraphs, the study of the phenomena occurring during welding fabrication and of their effects on humans requires significant knowledge of welding technology and metallurgy, design, industrial hygiene, medicine, ergonomics, epidemiology, chemistry and many other disciplines. In general, some separation of objectives has to be recognized, as the world of medicine tends to focus on research of the effects on humans, regardless of the manufacturing process, while the welding technology world seems much more interested in identifying appropriate schemes and tools for balancing the safeguard of workers with industrial needs, in terms of productivity and market competitiveness.

A specific forum for the exchange of knowledge is therefore a necessary tool for performing such an evaluation; working units are consequently established both at international and national levels. The case of the IIW Commission VIII is an example of this, where members hail from a wide range of work disciplines in industry and academia. But this is the exception rather than the rule.

4.1 Exposure limits

A preliminary representative example of this process is the study of the components of welding fumes and the definition of the relevant exposure levels. Table 2 reports a selection of exposure limits for some countries and some substances [13, 14]. Having analysed the trend in the definition of such levels, a general tendency to considerably decrease the permissible concentration can be recorded (e.g. In 2007, Sweden moved from 0,02 mg/m³ to 0,005 mg/m³ for Cr(VI) compound concentration).

Such levels arise from evaluations in different industrial sectors where metals are handled, including mines and ore mills. An initial problem can be identified when applying such an approach to the welding fabrication field, as the evaluation of conformity to such levels in a welding environment can be very expensive, and in some cases, even the measurements can be impossible to be performed. Moreover, compliance with these levels might be quite difficult to accomplish, if very strong protective measures have not been adopted, which may induce other types of diseases (e.g. use of a respiratory mask may induce ergonomic problems such as weariness). In this regard, a study has been carried out in Sweden, to evaluate the impact of the new proposed exposure limits, revealing major difficulty in establishing conformity.

The same kind of problems can be identified in the case of electromagnetic fields. Difficulty can be encountered mainly with regard to the action values, which, if exceeded, require the welding manufacturer to identify and implement protective measures. Once again, the problem lies in evaluation, as the frequency is difficult to identify (not only in a welding workshop, where several welding units are working at the same time, but even for only one electronic power source) and to the fact that limits can easily be exceeded, especially in resistance welding processes.

In conclusion, the following two factors can be considered as characterising the matter of exposure limits:

- limits can greatly differ, depending on the country and, as a matter of fact, any convergence will tend to lower levels (at least in the older industrialised countries).
- as limits decrease, difficulty in measurement increases.

As a result, the welding industry in developed countries seems at times caught between the drive to continu-

ally decrease exposure levels and the need to compete in the marketplace with developing countries, where the same stringent levels are often not regulated or enforced.

4.2 Tools for compliance with regulations

Technically speaking, there is a strong need for practical schemes to help manufacturers reach conformity at lower limits, and to identify measures which will reasonably guarantee conformity without the need for a measurement. The United Kingdom has already moved in this direction, as the Health and Safety Executive (HSE) produces leaflets which report measures for engineering control of the process, requiring easy, technically-achievable steps to assure conformity.

Moreover, a very encouraging condition is that, in almost all cases, a correct approach to the welding process and procedure implies a reduction in exposure (e.g. correct welding parameters in GMAW guarantee the most advantageous ratio between fume emission rate and weld metal deposition rate). Practically speaking, this means that the quality of the product and the safeguard of personnel can move together in the direction of competitiveness.

In conclusion, the most profitable tool for trying to solve this situation might be the application of models and criteria to the design of the welding fabrication processes, and the implementation of health and safety management schemes. Such schemes need to be fully-integrated economically with the fabrication process, leading to better use of human and natural resources in general, while appropriately managing the quality of the products. The two key elements common to any applicable scheme are the need for correct management of the whole welding fabrication process (and ISO 3834 “Quality requirements for fusion welding of metallic materials” might be considered a technical basis for that), as well as an adequate degree of competence of personnel working at all levels, in all the aspects involved, including welders, welding operators, welding coordinators, industrial hygienists and senior management.

In this regard, some positive results are being achieved in Australia and Europe, where management schemes specifically devoted to health and safety in welding are already available for certification on a voluntary basis.

The European Federation for Welding, Joining and Cutting (EWF) has already produced an international network for certification of welding fabrication manufacturers, in which a Health and Safety management scheme (referred to as EWF SMS) can be linked to the ISO 3834 certification. Even the IIW, which is starting its certification activities, is considering the possibility of joining this network with great interest. The absence of recognition by national authorities, however, could lead industry to the misconception that this could be only an expensive and unnecessary exercise.

Table 2 – Exposure limits for welding fume

Country	Year	Limit [mg/m ³]		
		Type	Ni	Cr(VI)
United Kingdom	2005	WEL	0,5	0,05
Netherlands	2006	MAC	-	0,25
Sweden	2007	OEL	0,1	0,005
U.S.A.	2006	PEL	1	0,005

5 THE WAY FORWARD

Identifying an international approach could help in reducing, if not destroying, those barriers which so often spring up to prevent agreement being reached on exactly what should be done. IIW Commission VIII (and national welding institutes) could play a significant role in this process, but only if internationally-recognised throughout the welding and joining industry and the world of medical science. Through the promotion of this activity, the IIW would be providing both developed and emerging economies with the tool for “improving the quality of life through optimum use and innovation of welding and joining technologies”, the mission of the IIW.

The first step to reaching the target of a sustainable welding environment is, therefore, the exchange of knowledge. All efforts undertaken in this direction, both at the international level by the IIW and at the national level (several welding institutes are deeply involved in this process nationally), could be rendered useless if not arising from widespread consensus, if not managed by adequately competent personnel, and if the recommended solutions are not adopted by the exposed welding personnel.

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