Fundamental Aspects in Selection and Use of Respiratory Protective Devices during Welding and Cutting Processes

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Abstract

Inhalation of welding fumes constitutes short term as well as long term health risks and respiratory protective devices (RPDs) of various types are routinely used as a preventive measure during welding and cutting operations.
It is a prerequisite for successful respiratory protection by use of RPDs during welding and cutting that two major factors are considered.
The first major factor is proper selection of a suitable RPD. Respiratory protective devices have various constructional features, working principles and designs depending upon their type. Hence a survey of the classification of the various types of RPDs and of their major advantages and limitations is given with a special view to the welder's situation.
The second factor playing a major role is related to the human factor i.e. the wearer of the RPD. In the practical work situation of the welder a suitable RPD may have been chosen, however, the expected level of respiratory protection may for several reasons never be reached due to certain user characteristics, inexpedient use or incorrect maintenance and storage of the RPDs.

INTRODUCTION

Welding and cutting operations inevitably are accompaigned by the formation of various air contaminants generally known as welding fumes. During manual welding and cutting operations the welding fume reaches the breathing zone of the welder unless preventive measures are taken such as local exhaust ventilation/suction or use of respiratory protective devices (RPDs) by the welder. It is a well established fact that the air contaminants formed during welding and cutting operations constitute short term as well as long term health risks *e.g.* carcinogenic risks are associated with welding and cutting in stainless steel due to a content of nickel and/or chromium (VI) in this parent metal.
Ideally any problems with regard to inhalation risks should be overcome by use of efficient local exhaust ventilation/suction, preferably of the high volume-low pressure type (Fig. 1). However, in a number of practical work situations efficient ventilation/suction either will be very cumbersome or even impossible to establish.

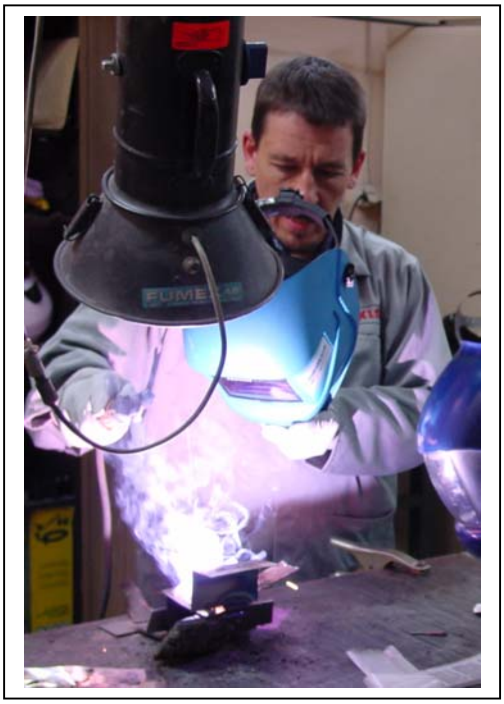

Fig. 1. Efficient high volume-low pressure suction during MMA-welding.

In such situations the welder will have to rely upon an efficient respiratory protective device in order to protect himself against the inhalation risks of the welding fume. However, successful use of RPDs depends on proper selection of a suitable RPD as well as on proper use of the selected RPD. This simple fact has proven valid in numerous industrial work situations where people are exposed to airborne contaminants and is also valid for the welder. Good industrial hygiene practice implies that a RPD which can protect against the inhalation risks be chosen and that the user is carefully trained in the proper use of the RPD. Only then a successful respiratory protection can be obtained.
An ideal way of establishing an efficient respiratory protection program is by using the socalled four-step method:

1. Identify the types of air contaminants (and/or other inhalation hazards) for which you need breathing protection.
2. Establish the health hazards of the air contaminantsor other inhalation hazards.
3. Select the RPD which can protect against the inhalation hazards.
4. Train the user in correct donning, use, inspection, maintenance and storage of the RPD.

IDENTIFYING AIR CONTAMINANTS AND RISK OF OXYGEN DEFICIENCY

General
Depending upon their physico-chemical and chemical properties air contaminants can be in the solid, liquid or gaseous state. Solid or liquid substances occuring as air contaminants normally will be in the particulate state. However, in some cases solid and liquid substances can evaporate more or less and also exist as vapours in the air; vapours by definition being the

volatile phase of a solid or liquid substance. Gases are substances the normal state of which is as a gas *i.e.* they have boiling points below room temperature.
Another type of inhalation hazard is oxygen deficiency of the air. The atmospheric air normally contains appr. 21 % by volume of oxygen. However, under certain circumstances the concentration of oxygen may decrease to a lower critical level. Normally less that 17 % will be considered to be critical but it depends upon the work load of the person. The higher the work load the higher the critical level of oxygen is.
A general summary can be seen in Fig. 2.

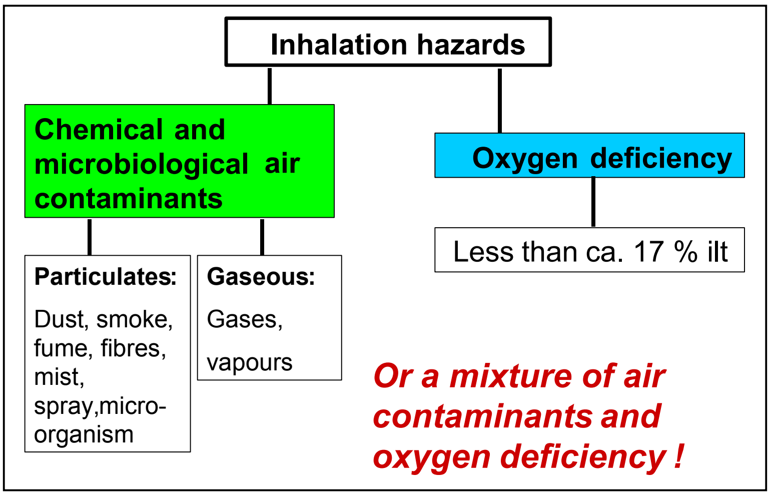

Fig. 2. Survey of general inhalation hazards in a work environment.

In some work environments a combined hazard of air contaminants and oxygen deficiency can occur.

Physical State of Air Contaminants
It is imperative to know whether any air contaminant present in the work environment of the welder exists in the particulate state, in the gaseous state or in both states. The air contaminants identified during welding and cutting are summarised in Fig. 3.
The particle shapes and sizes of a typical welding fume can be seen in Fig. 4 and is characterised by two distinctly different particle sizes. The origin of the bigger particles is from the electrode coverings whereas the smaller particles result from condensation of vapours of the parent metal.
Among the gases formed as can be seen in Fig. 3 special reference is given to the organic vapours of isocyanates. The origin of these is from automotive work shops [1] where body repairment is done on primed metal parts; the primer being polyurethane lackers which are isocyanate based. In connection with welding and cutting in such primed metal plates a number of thermal decomposition products, commonly known as secondary isocyanates, are formed. Much attention has been drawn to these substances during recent years as isocyanates are known to have short term as well as long term toxic effects.
The other gases and vapours referred to in Fig. 3 are commonly known to occur to a greater or smaller extent in the welding fume depending mainly upon the type of welding process [2].
Besides the air contaminants attention should be drawn to the potential hazard of an oxygen deficiency in cases of working in more or less confined spaces.

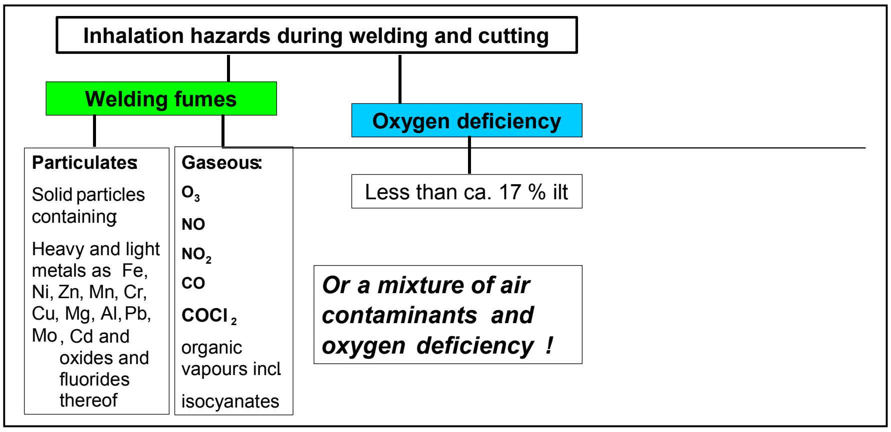

Fig. 3. Classification of inhalation hazards which may occur in the welders working situation

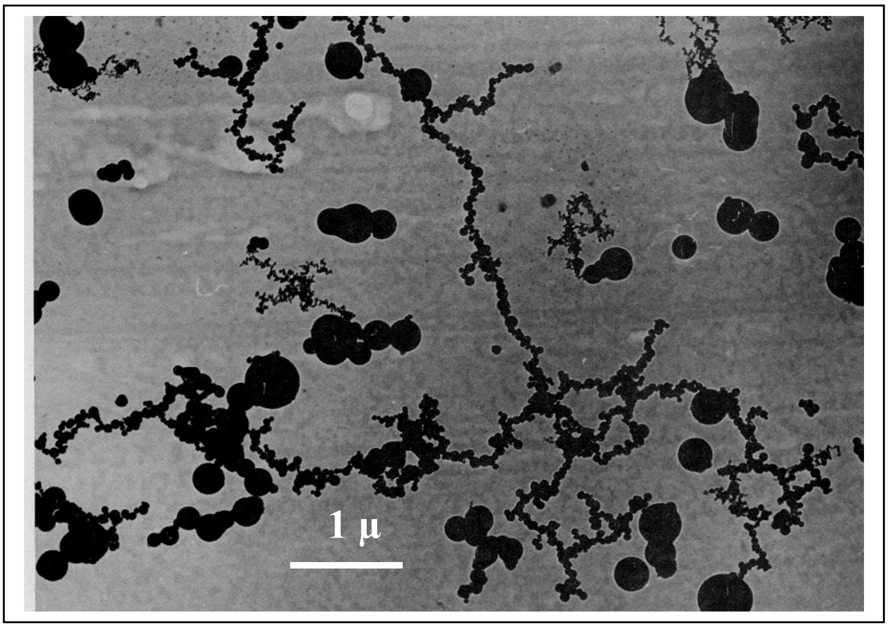

Fig. 4. Welding fume particles from MMA welding

IDENTIFYING TOXIC EFFECTS OF AIR CONTAMINANTS AND OF OXYGEN DEFICIENCY

Airborne contaminants may when inhaled have more or less deleterious or toxic effects of various types causing for example irritation, pulmonary edema, allergy, diseases of the nervous system, cancer *etc*.
The toxic effects of the welding fume are related to the particles as well as the gases formed.
Identification of and information on the specific health hazards of each component in the welding fume may encourage the user to wear the RPD according to the instruction given.

Ideally each type of air contaminant present should also be identified and quantified in order to establish whether it is present in concentrations in excess of current established exposure limits (TLVs). More or less restrictive national regulations exist in various countries and shall be considered in the evaluation of whether or not there is a need for protection against inhalation of a certain component of the welding fume.

SELECTION OF RESPIRATORY PROTECTIVE DEVICES

Major Types of Respiratory Protective Devices
Respiratory protective devices are designed based on either of two principles: Filtering devices use the surrounding air and clean it by the principle of filtration. These devices can be used if a suitable filter is available (a filter which can remove the air contaminants present in the surrounding air). However, filtering devices will never protect against any oxygen deficiency and furthermore gas- and vapour filters have upper performance limits for the concentration levels of the air contaminants.
The level of protection which can be achieved by a RPD not only depends upon the performance of the filter(s) but also on the type of facepiece (headtop).

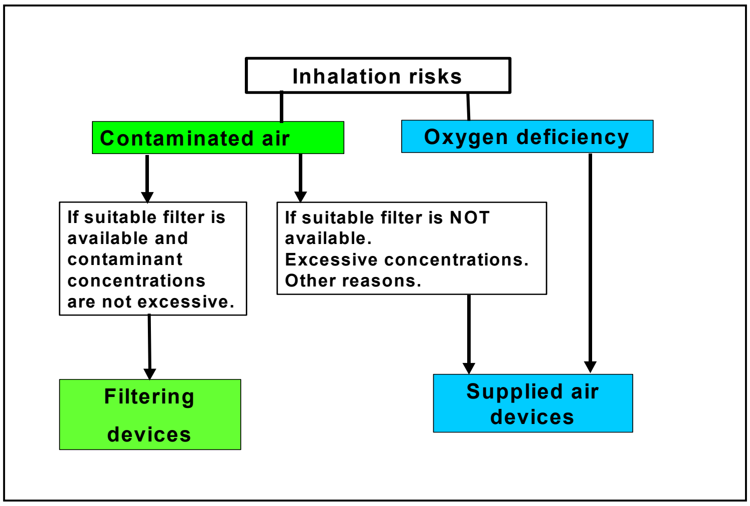

Fig. 5. The choice is between the two major categories of respiratory protective devices; filtering devices and air supplied devices

Air supplied devices feed clean breathable air (normally compressed air) from some distant source to the user of the device and in this way isolate the user from the surrounding air regardless of the type and state of any air contaminant or any oxygen deficiency.

Classification of Filtering RPDs
Filtering devices can be classified in 3 different categories: Full face- and half masks with replaceable filters, filtering half masks where the filter(s) is an integral part of the mask and power assisted filtering devices. Synonyms for the latter devices are PAPR (Powered Air Purifying Respirators) and turbo filtering devices. PAPR devices include a fan or blower which draws the contaminated air through one or more filters. The purified air then is fed to a

face piece (head top) of some sort which may be a mask, hood, visor, helmet or shield. Only when combined with a mask these systems can be tight-fitting. The other types of head tops are more or less loose-fitting and the protection given relies upon a slight positive pressure inside the head top due to a relatively high continous flow of filtered air, normally in the range of 150 - 160 l per min.
The head tops of the PAPR devices may be of a special design suited for welders offering in addition to the respiratory protection also protection against the various types of radiation, visible, UV and IR, as well as mechanical protection of head and face for which the welder also needs protection.

The full face- and half masks with replaceable filters as well as the filtering half masks are socalled negative pressure devices. The user creates during inhalation a negative pressure inside the mask which in turn draws the surrounding contaminated air through the filters for purification. The replaceable filters may be for protection against particles only, for protection against certain gases and vapours or combinations of particles and gases/vapours.
Filtering half masks are available for protection against particles only or for protection against particles as well as certain gases and vapours.
Full face and half masks, filtering half masks as well as PAPR devices for use in the European Community shall be certified according to the Directive on Personal Protective Devices and shall be CE-marked.This alsoapplies for the air supplied devices. The basis for the certification normally is testing according to a European standard. Specific standards exist for the various types of masks (head tops), filters etc.[3-10]
It is important to stress that in case of the PAPR devices which consist of several parts as head top, breathing hose, turbo unit (fan) and filter(s) the certification is valid for the socalled "complete system" *i.e.* all parts are tested together and as a whole and the certification is based on the results obtained when testing of all parts working together. Any use of hoses, filters or any other components not belonging to the original device as a whole will render the certification invalid and the device illegal to sell or use.

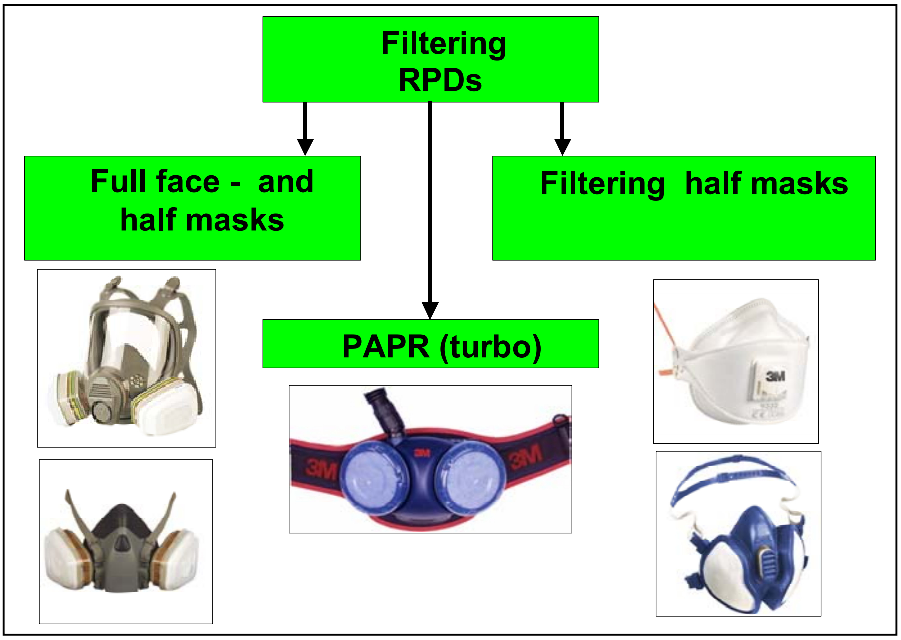

Fig. 6. Classification of filtering devices

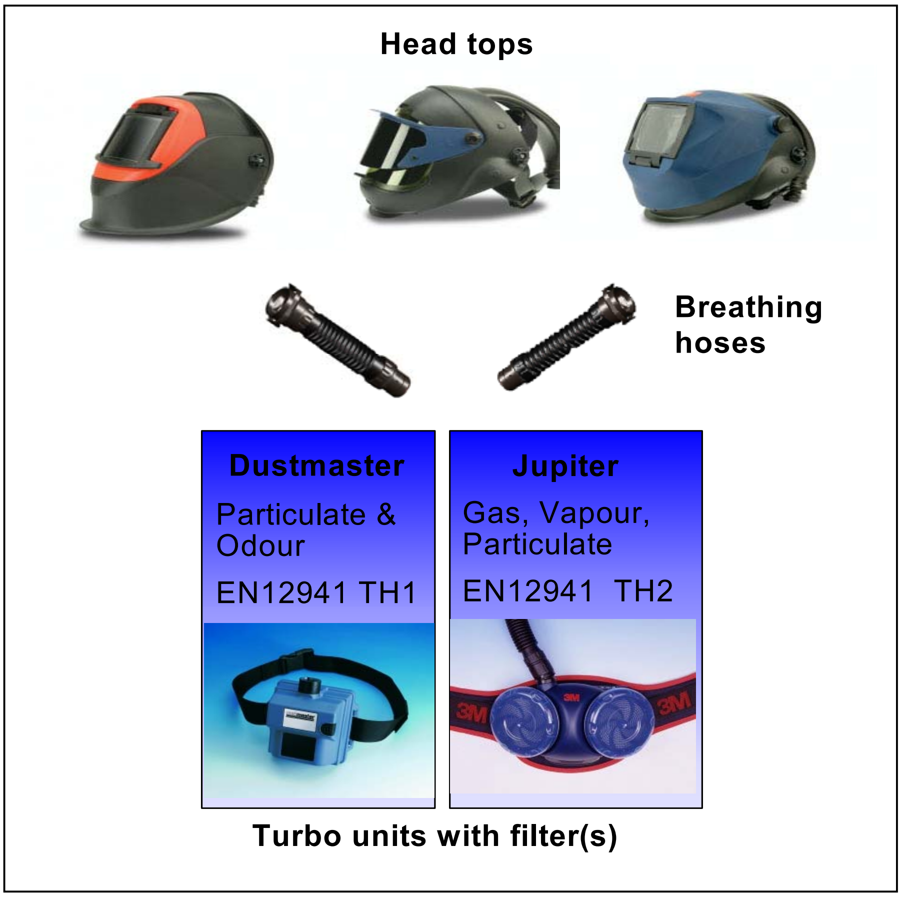

Fig. 7. Example of a turbo device composed of a welder's head top, breathing hose and battery powered turbo unit. In this case all the head tops are certified for use withto turbos shown

Major Filter Types

Particulate filters are classified according to their efficiency for removal of certain standardised aerosols. In the European Standards two test aerosols are used. One being of sodium chloride particles of an aerodynamic mass median diameter of 0.6 µ, the other being of paraffin oil having a mass median diameter of 0.36 µ. The filter classes are P1, P2 and P3 for the replaceable filters [7] and FFP1, FFP2 and FFP3 for the filtering half masks [3]. The P3 filter classification corresponds to the highest filter efficiency.

Gas- and vapour filters are according to the European standards classified according to their capacity (classes 1, 2 or 3) for removal of certain gases and vapours and furthermore in types according to their specificity to remove certain chemical classes of substances [6].
Class 1 gas- and vapour filters are intended for use in concentration not exceeding 1000 ppm and class 2 for concentration not exceeding 5000 ppm. Class 3 filters are not commonly used but are designed for use in max. concentrations of 10000 ppm.
Each type of gas- and vapour filter can be identified by a letter-coding combined with a colour coding. The normal types are (including the coding): Organic vapours (type A, brown), inorganic gases (type B, grey), acid gases (type E, yellow) and ammonia (type K, green).

Other special types of gas- and vapour filters exist and are also standardised. Filters combining two or more of the filter types are also available *e.g.* type ABE.
Filters for PAPR devices are of the same types but differ with respect to classes [8].

Air Supplied Devices
These types of devices isolate the user from any air contaminant in the surroundings as well as oxygen deficiency. However, they will only give adequate protection if the compressed air fed to the devices is of a breatheable quality *i.e.* the concentrations of specified contaminants are below certain criteria values given in standards [11] or national legislation. Furthermore the amount of compressed air fed to the device shall exceed a certain minimum value in order to establish and maintain a slight overpressure in the head top.
Like the PAPR devices these devices consist of several parts: Head top, breathing hose, belt regulator and a compressed air supply tube from the belt regulator to a filter panel. Also in this case the certification is valid for the socalled "complete system" *i.e.* all parts are tested together up to the outlet of the filter panel and the certification is based on the results obtained when testing of all parts working together. Any use of any component not belonging to the original system will render the certification invalid and the device illegal to sell or use.

Fig.8. Components of a supplied air breathing apparatus. The filter panel is not part of the certified device. Besides the regulator (Flowstream) special regulators for cooling or heating of the air are also shown

Air is supplied at a minimum flow in the range of 150 l/min or more and the air flow is adjustable by means of the regulator in the belt.

Selection of The Respiratory Protective Devices
Having established the inhalation hazards in the welder’s environment the first choice will be between a filtering device or an air supplied device. Any restrictions imposed by national regulations shall be considered in the decision making as well as the welder’s need for free movement during the work and the availability of filters for efficient removal of the actual air contaminants. User characteristics shall also be considered.

It is of the utmost importance to realise that no commercially available filters of today will protect against all the air contaminants present in the welders environment. Whether there is a need for such a filter or not depends upon a work place evaluation of the exposure of the welder and any local regulations from the national work environment authorities. However, if there is a need for respiratory protection against certain components in the welding fume for which no efficient filter exists, the only type of RPD which can be recommended is the air supplied devices. These are normally supplied with compressed air of sufficient purity to make it breatheable and the devices will protect against any contaminant present in the air as well as oxygen deficiency. Air supplied devices shall never be confound with the PAPR (turbo) devices which still rely upon the principle of filtering the contaminated surrounding air.

In many welding and cutting situations the decision is taken only to protect against the particles of the welding fume and neglect the presence of any gases and vapours. The particles can be efficiently removed by particle filters of the types P2 (FFP2) or P3 (FFP3) or equivalent turbo filters as welding fume particles do not differ from other particles with respect to aerodynamic properties.

The gases and vapours of the welding fume, however, are more difficult to remove by filtration. Carbon monoxide cannot be removed and nitrogen oxide only to a certain extent (low concentrations, short duration). Recommendations are given in Fig. 9. However, one should always consult the filter manufacturer in order to obtain exact information about the performance of his gas- and vapour filters.

Contaminant	Gas Filter Type
O_3	A
NO	none
NO_2	E
CO	none
$COCl_2$	B
Organic vapours	A
Isocyanates	A

Fig. 9. Gases and vapours frequently found in various concentrations in the welding fume and recommended filter types for their removal

Protection Factors

The European standards for each of the types of RPDs give socalled Nominal Protection Factors (NPF) for each type of RPD. Nominal protection factors are minimum requirements for the achieveable level of protection when the RPDs are tested upon a panel of human test subjects according to the method given in the standard.

Protection factors are the ratio between the concentration of a certain test substance in the surrounding air and the concentration of the same test substance inside the mask or head top *i.e.* in the breathing zone of the test subject. Protection factors thus simply give values for how much cleaner the air inside the RPD shall be as a minimum compared with the surrounding air.

Nominal protection factors are measured under laboratory conditions and measurements of protection factors under actual work conditions, Work place Protection Factors (WPFs) as a rule are lower than the nominal protection factors. One among several reasons for this finding is the human factor *e.g.* anatomy, behaviour and other characteristics of the user.

Nominal protection factors for the more important types of RPDs are given in Fig. 10.

Type of RPD	NPF
Filtering half mask FFP2	10
Filtering half mask FFP3	50
Half mask with A2P3 filter	10, 50
Half mask with compressed air	50
Welding head top with turbo and A2P filter	50
Welding head top with compressed air	50

Fig. 10. Examples of nominal protection factors

Selection of the proper RPD shall also be with a view to the nominal protection factors of the various types of devices based on the assessment of the level and types of air contaminants.

TRAINING AND INSTRUCTION OF THE USER

The level of protection obtained during practical work when using RPDs depends upon the properties of the RPD as well as upon a number of characteristics of the user as shown in Fig. 11.

Any RPD will affect the user wearing it in various ways. But the user also affects the RPD and its performance.

Properties of RPD	Filter efficiency, compressed air quality Adjustability and shapeliness of mask (headtop) *shape, size, material* *design of sealing edge* Efficiency of outlet valve State of maintenance *defect parts, cleanliness*
Use of RPD	Donning of RPD *fitting, adjustment and control* Wear time percentage *duration of wearing the RPD in % of working time* Beard or other facial hair Physical activity level, speaking Sweat Wrinkles, scars

Fig. 11. Important factors affecting user protection

RPDs restrict the movements of the user more or less rendering the job to do more difficult which in turn may have an effect on precision in work and subsequently upon the quality of the outcome of the work, namely the product. Besides these ergonomic burdens use of RPDs also places physiological burdens upon the user: Heat, cold, humidity, breathing resistance and higher carbon dioxide concentrations in the inhaled air. The magnitude and effects of these burdens depend upon the work load of the user as well as the work conditions, for example temperature and humidity, and upon the type of RPD chosen.
The impact of the user upon the RPD can be caused by the behaviour of the user as well as by his anatomy or rather face antropometry and physiognomy incl. any beard or other facial hair which could interfere with the sealing of the mask, visor, hood or helmet to the face (Fig.12).

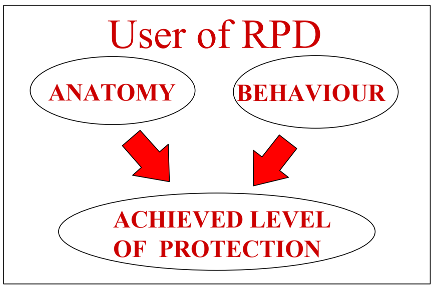

Fig. 12. The user affects the level of protection in the work situation

In order to minimize these effects it is of vital importance that the user be given instruction or even training in how to check, put on, fit, adjust and wear the RPD in the correct way. Furthermore instruction in the correct cleaning, maintenance and storage conditions shall be part of the training.

Antropometric Measures and Physiognomy
Facial dimensions, shapes and contours differ from one human to another. The antropometric variability is responsible for variations in protection factors between wearers. Proper and careful adjustment of a mask may help to reduce these variations between wearers but in other cases there will be a need for masks of different sizes. Manufacturers of today consequently have half masks in three different sizes.
Using a PAPR device or an air supplied device with a suitable head top may also reduce the problem.

Wear Time
It is not uncommon that respirator users during work in a contaminated area for some or another reason removes the mask while still in the contaminated area. Only few respirator users are aware of the dramatic lowering of the average protection factor which is caused by removing the mask for even very short time. Assuming as an example that a user of a RPD works for 100 minutes and keeps his mask on all the time he may obtain a protection factor of *e.g.* 100 over the entire period of work.This means that the average concentration of air contaminants in the breathing zone inside the RPD is a 100-fold lower than in the surrounding air. Removing the mask for only 5 minutes thus wearing the mask for only 95 minutes (95 % wear time) will reduce the average protection factor from 100 to 16.8 as can be seen from fig. 11. Other calculated examples can be seen from the table in fig. 13. It is a striking feature that if reducing the wear time to 80 % the average protection factor obtained will decrease to a level of 4-5 regardless of the type of RPD chosen *i.e.* whether the RPD has a protection factor of 1000 or of 25 for a 100 % wear time.

	Percentage of time when the mask is worn while working in contaminated location (wear time)			
	80 %	90 %	95 %	100 %
Resulting protection factor	4.3	7,4	11,4	25
	4,6	8,5	14,5	50
	4,8	9,2	16,8	100
	4,98	9,9	19,6	1000
	4,99	9,99	19,9	10000

Fig. 13. Calculated values of protection factors for various wear times

Beard and Other Facial Hair
Any object interfering with the sealing between a face piece (mask or head top) will increase the leakage of contaminated surrounding air into the breathing zone of the user of the RPD. Beards, including stubbles, as well as other facial hair which can interfere with this sealing

compromise safety and should not be allowed. Extensive investigations during the last 40-50 years clearly show this. Examples of the effects of growing beard are shown in Fig. 14. [12].

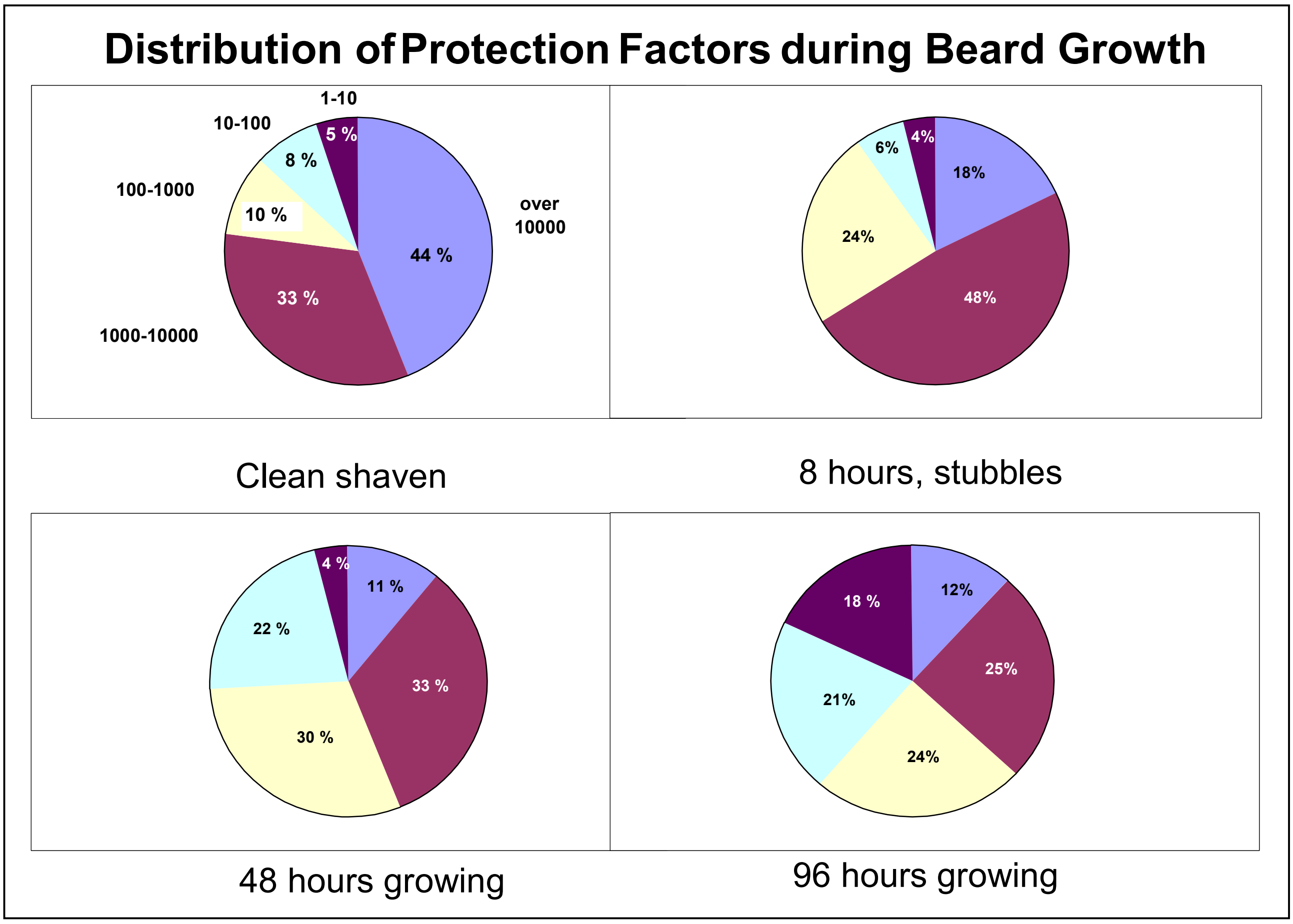

Fig. 14. Percentages of test subjects obtaining protection factors in five ranges as a fnction of beard growth. Results of a systematic investigation of a very well fitting half mask under controlled laboratory conditions.

Other Important Factors

Physical activities as moving (head, body) and talking are generally seen to increase leakages. Sweat may sometimes, at least for the tight fitting facepieces (half masks), reduce leakages to some extent. Wrinkles and scars also increase the leakage into a mask [12].

CONCLUSIONS

There is no reason to believe that welders differ from other workers with respect to problems in connection with use of respiratory protective devices. What has been said here is based on practical experience as well as work place measurements carried out on numerous work places in different trades during the last 35 years.

It is therefore recommended to follow these guidelines to ensure that welders obtain a proper respiratory protection.

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