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ATOMIC ENERGY OF CANADA LIMITED

L'ÉNERGIE ATOMIQUE DU CANADA LIMITÉE

FACEPIECE LEAKAGE AND FITTING OF RESPIRATORS

by

J.M. WHITE

Presented at the First Canadian Conference on Protective Equipment, Toronto, Ontario, 1978 January 23-25

Chalk River Nuclear Laboratories

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Fuite des respirateurs et leur adaptation

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Résumé

On passe en revue la façon dont les contaminants en suspension dans l'air peuvent pénétrer dans les respirateurs et les facteurs qui entrent en jeu dans leur adaptation au visage. On montre que l'adaptation du masque sur le visage est le facteur le plus critique en ce qui concerne la protection de la personne qui le porte.

On décrit des techniques d'essais quantitatifs et qualitatifs d'adaptation et on commente leur application aux programmes de protection par respirateurs.

La mesure quantitative de la fuite d'un respirateur que l'on porte peut servir à indiquer numériquement la protection que l'on obtient. Ces nombres, que l'on appelle souvent des facteurs de protection, sont parfois employés comme base de sélection des respirateurs, pratique que l'on passe en revue.

Ce rapport a été présenté au premier Congrès canadien sur les dispositifs de protection, tenu à Toronto du 23 au 25 janvier 1978. Ce Congrès était parrainé par la Construction Safety Association of Ontario, le Conseil de sécurité du Canada et l'Association canadienne de normalisation.

L'Energie Atomique du Canada, Limitée
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ABSTRACT

The ways in which airborne contaminants can penetrate respirators and the factors which affect the fit of respirators are discussed. The fit of the respirator to the face is shown to be the most critical factor affecting the protection achieved by the user.

Qualitative and quantitative fit testing techniques are described and their application to industrial respirator programs is examined.

Quantitative measurement of the leakage of a respirator while worn can be used to numerically indicate the protection achieved. These numbers, often referred to as protection factors, are sometimes used as the basis for selecting suitable respirators and this practice is reviewed.

This paper was presented at the First Canadian Conference on Protective Equipment in Toronto on 1978 January 23-25. The Conference was sponsored by the Construction Safety Association of Ontario, the Canad· Safety Council and the Canadian Standards Association.

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1. INTRODUCTION

The use of some kind of device to remove dust, fumes and noxious gases from air breathed by workers is not new. The Romans and Greeks in 50 A.D. referred to the use of animal bladders by miners to protect against inhalation of red oxides of lead. Industrial history has many references to respiratory hazards and the action taken to alleviate them.[1]

The industrial revolution in the early 1800's gave rise to more advanced protective devices and at that time the different natures of gases, vapours and dusts were recognized. The most rapid period of improvement in design and function of respirators occurred during World War I when toxic war gases were first used as a military weapon. Since then respirators have been developed to provide adequate protection for almost every kind of work situation.

2. THE PENETRATION OF RESPIRATORS BY CONTAMINANTS

Various routes exist by which dusts, mists, fumes and toxic gases may penetrate a respirator. The common routes are through the filters, the exhalation valves, the eye pieces and other components, and through failure of the facepiece to make a perfect seal with the face. For a particular model of respirator the penetration of contaminants through its component parts is fixed by the design of the respirator, and, given proper maintenance, does not vary much over the normal life of the respirator. However, the seal made between the facepiece and the face may be less reliable and is dependent upon a number of factors and these are listed.

2.1 Factors Affecting the Fit of Respirators

2.1.1 Design of the Respirator

Some respirators are designed and constructed better than others and therefore it is easier to achieve a good face-to-facepiece seal. If the rubber or plastic facepiece is too hard or too soft it obviously is going to be more difficult to achieve a good seal. If the harness or straps which are used to hold the facepiece to the face are not properly arranged or are not of adequate strength it is unlikely that the respirator can be properly fitted to the face of some users. Most respirators currently available were designed to fit male Caucasian workers. There are very few commercially available respirators that will properly fit women or people with small faces. Many Orientals cannot be fitted because their facial contours are not typical of those of most Caucasian workers.

2.1.2 Facial Contours and Facial Hair

Anthropometric studies of the faces of North American male and female workers show wide differences in the size and shape of human heads. These studies show that one size and one design of respirator cannot possibly fit everyone. The studies also show that it is more difficult to design and manufacture good fitting oronasal respirators than full facepiece types. A good fit in this case implies a good seal between the face and the facepiece and is not necessarily related to comfort. An additional complication that has not yet been satisfactorily solved is the difficulty encountered when the respirator user has a growth of facial hair which interferes with the face-to-facepiece seal. Studies show that even one day's growth of beard will reduce the effectiveness of the seal by as much as a factor of 10. After just a few days' growth of facial hair the seal is virtually non-existent. Men with beards just cannot achieve a satisfactory fit with any tight fitting respirator. Loose fitting hoods which are supplied with fresh air may satisfy the needs of these users in some circumstances.

2.1.3 Training

A person will not be as comfortable while wearing a respirator as he or she is when not wearing one and the degree of comfort obtained is not related to the face-to-facepiece seal. Often a lightweight respirator preferred by workers because it is comfortable will not provide the protection needed or anticipated. There is also a tendency for some workers to cinch up the head straps of their respirator prior to entering a highly toxic atmosphere because they believe that by making the straps very tight they are achieving a better fit. The opposite is often the result as the facepiece may be distorted in such a way as to break the seal. Obviously the user must know how to wear a respirator properly and know its capabilities and its limitations. The best way to give the user this knowledge is by an adequate training program. It is a sad fact that many commercial, government and educational institutions in this country do not realize the importance of training their employees to use respirators correctly. Some organizations do have comprehensive respirator programs but do not stress the importance of achieving a satisfactory seal between the facepiece and the face.

2.1.4 Knowledge Required for Respirator Selection

The user should employ the correct type of respirator. There are many types of commercially available respirators designed to satisfy different respirator requirements. Too often purchasing agents and safety officers buy respirators for their employees based only upon the lowest cost. Too often they do not match the capability of the respirator to the kind of protection required. It is vital that respirators be selected on the basis of the protection required. To make an intelligent selection one must decide on the amount of leakage through the respirator that can be tolerated. Leakage through components such as the filter and through the face-to-facepiece seal must be considered. The amount of leakage which can be tolerated will depend on the toxicity of the contaminants in the atmosphere of the work place, on the concentration of the contaminants and on the length of time the worker is exposed. Only by having this knowledge and by knowing how well a respirator fits can an intelligent selection be made.

2.1.5 Worker Acceptance

No one wants to wear a respirator unless there is a valid reason to do so. Sometimes it may be difficult to convince a worker that he needs to wear one. Arguments that management should provide suitable engineering controls so that respirators need not be worn may be presented and are valid to a degree. Engineering controls may be practicable but may not completely eliminate the need for respirators. The worker may say that he does not believe he needs to wear one because he worked on that job before and did not need one. He may have a dozen more reasons for not wearing one. Nevertheless, it is up to his management to convince him that when he needs a respirator he must wear it and wear it in a proper manner. One way of convincing a worker of how effective respirators can be is by fitting him with the aid of a device which quantitatively measures the leakage between the face and the facepiece. This information plus some knowledge of the toxicity of the material in the work place have been found to be excellent persuaders.

2.1.6 Maintenance of Respirators

The stories of non-maintenance of respirators are legion. Many organizations, workers and safety officers do not realize the importance of good respirator maintenance programs. A respirator is a piece of mechanical equipment and after use it must be properly maintained. If not, the fit may be affected and leakage may occur. Any organization that requires the routine use of respirators should have a suitable respirator maintenance program.

3. THE FITTING OF RESPIRATORS

The importance of training users on how to fit a respirator to the face cannot be over-emphasized. It is essential that the user know the capability of the respirator he is required to wear and the degree of protection he can reasonably expect from it. He must be able to fit himself with the respirator in a reproducible manner. There are several methods available to him for testing the fit. Some of these methods are qualitative, a few are quantitative and not all can be used with every type of respirator. There is no suitable method for determining the quality of fit achieved with some types of respirators. Respirators in this category are often the single use type or oronasal types that employ inefficient filters and are used mainly against nuisance dusts.

3.1 Qualitative Fit Testing

3.1.1 Negative Pressure Test

This test requires no special equipment and can be used with any respirator that employs a filter or canister whose inlet can be easily covered with the palm of the hand. The user puts on the respirator and closes off the inlet opening of the canister by covering it with the palm of his hand or by replacing the tape seal. He inhales so that the facepiece collapses slightly and holds his breath for 10 seconds. If the facepiece remains slightly collapsed and no inward leakage of air is detected, the face-to-facepiece seal is considered to be satisfactory.

3.1.2 Positive Pressure Test

The respirator is worn and the exhalation valve is closed and the user exhales gently into the facepiece. The fit is considered satisfactory if a slight positive pressure can be built up inside the facepiece without any evidence of outward leakage of air at the face-to-facepiece seal.

3.1.3 Isoamyl Acetate (Banana Oil) Test

Respirators equipped with activated charcoal cartridges may be tested for leaks in an atmosphere containing an organic vapour such as isoamyl acetate. The test may be conducted without a special test chamber because an adequate concentration (100 ppm) can be obtained in any room by evaporating 17 cm^3 of isoamyl acetate for each 30 m^3 of room volume. If the person wearing the respirator can stay in the test atmosphere for a minute or two without detecting the odor of isoamyl acetate, the respirator is properly fitted. If the odor of isoamyl acetate is detected he should retreat to fresh air, readjust the facepiece and then repeat the test.

It may be necessary to conduct fitting tests in the field. The fit may be checked by pouring a few drops of isoamyl acetate onto a piece of cotton and holding it near the facepiece.

3.1.4 Stannic Chloride Smoke Test

An irritant smoke tube (glass tube 12 cm long by 1 cm diameter, filled with stannic chloride-impregnated pumice) is used to produce a very irritating smoke when air is blown through the tube. The smoke is directed at the facepiece seal and leakage is indicated by irritation of the throat and lungs.

freshly produced smoke particles from this tube range from less than 0.1 to 3.0 μm in diameter. The glass tube is scored at each end for easy breaking. A squeeze bulb with a short rubber tube connected to the smoke tube blows air through the tube; visible smoke is immediately formed by contact with moisture in the atmosphere. The irritant is HCl adsorbed on the particulate.

3.1.5 Titanium Tetrachloride Smoke Test

An irritant smoke generated from a tube containing titanium tetrachloride is used. When air is blown through a titanium tetrachloride smoke tube, visible smoke is immediately formed by contact with moisture in the atmosphere, but the smoke is reported to be less irritating than that produced by stannic chloride. When testing a halfmask respirator with a smoke tube, precautions should be taken to protect the eyes.

3.2 Quantitative Methods of Evaluating Leakage

3.2.1 Freon

The respirator is worn under a small plastic hood into which Freon gas is introduced. Samples of air are taken from inside the respirator and are analysed with a commercially available instrument to determine Freon content and thus leakage. Freon gas is of low toxicity and is easily obtained.

3.2.2 Sodium Chloride Aerosol

A submicron sodium chloride aerosol is blown into a small plastic hood which is placed over the head of the wearer whose respirator is to be tested. The amount of sodium chloride in the exhaled breath is measured with a flame photometer.

Routine fitting tests of the respirator can be made in a few minutes. A sodium chloride aerosol has the advantage of being non-toxic. Penetrations as low as 0.1% can be measured.

3.2.3 Helium Leak-Detection Method

An accurate method of measuring the leakage between the face and facepiece of a respirator is by means of a helium atmosphere in a tent-type enclosure. The helium leaking into the face cavity is measured with a spectrometer.

3.2.4 Uranine

A submicron uranine aerosol is used to measure the overall leakage of a respirator equipped with a high-efficiency filter. This aerosol has the advantage of low toxicity and its fluorescence can be measured quantitatively down to 0.001 μg.

3.2.5 Dioctyl Phthalate (DOP)

Dioctyl phthalate dispersed as small particles by using air operated generators forms an aerosol which is suitable for testing the fit of respirators. The technique involves exposing the respirator wearer to the DOP aerosol and measuring the concentration which has penetrated past the respirator.

4. THE CAPABILITY OF RESPIRATORS IN ACHIEVING A SATISFACTORY FIT

4.1 Oronasal Respirators - Air Purifying Type

The penetration of contaminants through the respirator depends upon many factors. Some of these have been discussed previously. If only good quality oronasal respirators fitted with high efficiency filters are considered, the most likely source of penetration is between the face and the facepiece because the interior is always under negative pressure when the individual is breathing. Some individuals can achieve facepiece leakage as low as 0.01%. However, 5% to 10% penetration is average under normal working conditions when a good respirator program is conducted. Improved fit and reduced leakage can be expected if quantitative fit testing is part of the respirator program. Improved respirator facepiece design, better head harness for attaching the respirator to the head and new materials of construction that will follow facial contours to a better degree may in the future result in less face-to-facepiece leakage.

4.2 Full Facepiece Respirators - Air Purifying Type

A better fit can be obtained with full facepiece respirators than with oronasal respirators provided the respirators are well designed, properly constructed, and well maintained. The penetration should be less than 1%. Most people will achieve lower penetration than this but a few will not be able to do as well. The total number of persons who can achieve a satisfactory fit will be increased by using respirators of different sizes or even by using respirators produced by different manufacturers. The only way one can be certain he has achieved a satisfactory fit, however, is by means of a quantitative fit test.

4.3 Air Supplied Respirators

Any respirator in which a positive pressure can be maintained inside the facepiece while it is worn will provide better protection than one which does not have this feature. Fit is therefore not quite as critical and the user can be more confident that his selection will give him satisfactory protection.

5. CURRENT STATUS OF RESPIRATOR FITTING

The problem of obtaining a satisfactory fit with a respirator does not have a simple solution. The main difficulty arises because people have different sizes and shapes of faces. Therefore a respirator that may be satisfactory for one individual may be unsatisfactory for another. Women have smaller faces than men and racial origin is known to have an effect. Asians usually have smaller faces than Caucasians. Their facial contours are different and these differences do affect the fit. Several studies of facial sizes and contours have been made. One of the most recent was completed by Webb Associates for the Los Alamos Scientific Laboratories. Based upon this work the LASL respirator group have recommended the use of 35-person or 25-person panels for testing the fit of different models of respirators. Various proposals have been made to NIOSH* to use these and other panels as part of their program in granting approvals. NIOSH are moving towards more comprehensive fit testing of some types of respirators.

*National Institute of Occupational Safety and Health

The practice of using fit test data to calculate what are called protection factors is fairly widespread. A protection factor in this case is defined as the concentration outside the respirator divided by the concentration inside while it is worn. Attempts have been made to assign protection factors to classes of respirators, but if an average value is used this penalizes the very good respirator and gives the poor one a "free ride". Many manufacturers are reluctant to use anthropometric panels to obtain fitting data for several reasons, not the least of which are cost and product liability. Manufacturers are not required to indicate the percentage of the adult population that their respirators will fit. In fact they are not required to say anything about respirator fit. Currently, some manufacturers are opposed to the use of fit testing data when specifying suitable respiratory protection. However, the trend seems to be to employ fit testing data in some manner. It would be ideal if a user could make certain facial measurements and match this to a manufacturer's product much in the way one purchases a pair of shoes. The respirator manufacturers are a long way from this ideal but progress is being made. Some manufacturers are actively considering producing various sizes of respirators.

The question in your minds must be - where does all this leave me? At present the only way you can be sure that your workers are being properly fitted with respirators is by means of quantitative fit tests. If the hazard you are concerned about is not considered critical, qualitative fit tests may be satisfactory. Other factors must also be considered, such as, adequate training of users, acceptance by the users, the degree of hazard, the cost and applicable legislation. A good respirator program is expensive to set up and maintain but is far less expensive than the cost of employee injuries and ill health. Like most things in this world you get exactly what you pay for - there are no bargains.

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