

The Introduction of Quantitative Respirator Fit-Testing at the UKAEA Dounreay Site

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This paper was the recipient of the 2002 ISRP Conference's "Bob Bentley Award" (£1,000).

ABSTRACT

The effectiveness of any tight-fitting respiratory protective equipment (RPE) is dependent on the seal between the facepiece and the individual wearer. The only way to determine the quality of the seal is using either quantitative fit tests (QNFT) or qualitative fit tests (QLFT). Successful completion of a fit test will not ensure a good respirator fit in the workplace as they only show compatibility between the wearer and facepiece during the test.

In October 2000 the United Kingdom Atomic Energy Authority (UKAEA) introduced a program of respirator fit testing at its Dounreay nuclear licensed site using the TSI Portacount system. The program is targeted at personnel who wear a respirator as part of their routine work, and requires as a minimum biennial testing of these personnel. In the past year 430 people have been tested with the N10 respirator, of these 4% have had their respirator requirements modified.

This paper discusses how the test equipment was commissioned, the program of testing, and the results so far obtained.

INTRODUCTION

The purpose of a respirator is to prevent or reduce the inhalation of harmful airborne substances, where this hazard exists. The protection provided by a respirator is dependent on the filtration media and upon an effective face-seal between the wearer and respirator.

Respirators come in various types from a simple dust mask to an air-fed facepiece. Similarly there are many types of filters, including those which protect against only particulate contaminants, and those which protect only against specific chemical contaminants.

This paper discusses the fit testing of negative pressure tight-fitting respirators. These are respirators which do not have any air fed to them, they rely on the wearer drawing air in through the filter by inhaling. The level of protection is dependent on the seal between the respirator and the wearer's face, if the seal is poor then as the wearer inhales, unfiltered air will be drawn in through the areas of leakage and inhaled by the wearer. This results in a reduction in the level of protection afforded to the wearer against the contaminant.

Negative pressure tight-fitting respirators come in three types:

- Full-face respirators enclose the whole face (including the eyes) and form a seal from just below the hairline to the chin.
- Half-mask respirators enclose the nose and chin and form seal around all of the lower face.

- Quarter-mask respirators seal over the nose and mouth, but do not cover all of the lower face.

All types of RPE restrict and put extra strain on the wearer. In the case of negative pressure tight fitting RPE there is additional weight, breathing resistance, restricted visibility, and difficulty with speech. There can also be thermal strain associated with the extra work of wearing RPE, this can make an already uncomfortable work environment more challenging.

As tight fitting RPE relies on a good face-seal, anything which can affect this face-seal must be avoided. This includes any facial hair that breaks the seal, glasses with side-arms, extensive scar tissue around the seal area, etc. Similarly in areas where the wearer will be under thermal strain, the seal will deteriorate as the wearer's skin perspires. As such, respirator wearing times in hot areas should be reduced in order to ensure that the wearer remains protected.

From what has been said previously, it becomes apparent that only those who are medically fit should wear RPE. Even those with a cold can find wearing RPE unbearable. As such Dounreay has introduced medical fitness tests/questions into its respirator fit test program. This issue is discussed further in a later section of the paper.

METHOD

Methods for assessing respirator fit

Respirator fit tests are intended to give an indication of the quality of the seal between the wearer and the respirator, allowing the identification of respirator facepieces that are unsuitable for the wearer. Different methods are available with varying degrees of accuracy. The most basic method is Qualitative Fit Testing (QLFT). This is a pass/fail test that relies on the test subjects' response to a test agent. They use a 1% detectable solution (e.g. banana oil, saccharin, Bitrex) in a test chamber. Should the test subject detect the test agent during any stage of the test then the fit test has failed.

Problems with QLFT include:

- Reliance on the test subject to be truthful as they can mimic or act insensitive to the test agent,
- Errors in making up the test agent,
- Lack of documentation,
- Limited fit factors (this method can only be used for fit factors up to around 100 for definition see following section and equations 1 and 2). (HSE, 2000)

The advantages of QLFT include low cost and low level of maintenance required.

The other methods available can be grouped together under the title Quantitative Fit Testing (QNFT). These methods numerically measure the amount of leakage into the respirator and use this value to assess the adequacy of the respirator fit.

QNFT methods include:

- Generated Aerosol Test Chambers (using corn oil, salt, etc.)
- Condensation Nuclei Counters (for example TSI Portacount Plus)
- Controlled Negative Pressure (CNP) (for example Dynatech Fit Tester 3000)

Generated Aerosol Test Chambers are recognised as an established laboratory method and have been used for CE certification of RPE for many years. They are able to provide a sensitive and accurate method of measuring fit. This method allows for the simulation of actual work and is a recognised method, however it has a high initial outlay, and can only be used in its fixed location.

A more recent development is the Condensation Nuclei Counter, in essence a dust counter that grows particles in order to detect them. In the case of the TSI Portacount Plus submicron particles are grown into super micron alcohol droplets that can then be counted. Simulation of actual work can be undertaken without the high initial outlay required for a test chamber. The equipment is portable so tests can be carried out anywhere where the ambient particle concentration is reasonably high and relatively constant.

Controlled negative pressure units use a flow meter to measure the flow required to hold a set pressure in the respirator. Testing requires a great deal of interaction between the operator and test subject as the person must remain motionless and hold their breath while a measurement is being taken. This method does not allow for the simulation of actual work.

The HSE recommends QNFT using either a generated aerosol test chamber or condensation nuclei counter/ambient particulate counting device (HSE, 2000).

Fit Factors

All QNFT give a numeric fit factor. A fit factor is defined as follows (TSI, 2001).

$$\text{Fit Factor (FF)} = \frac{\text{Concentration outside mask}}{\text{Concentration within mask}} \quad (1)$$

A fit factor of 2,000 means that the air inside the respirator is 2,000 times as clean as the air outside.

The overall fit factor is calculated by:

$$\text{Overall Fit Factor} = \frac{\text{Number of exercises}}{\frac{1}{(FF\ 1)} + \frac{1}{(FF\ 2)} + \frac{1}{(FF\ 3)} + \frac{1}{(FF\ 4)} + \dots} \quad (2)$$

Where FF 1, FF 2, FF 3, etc. denote the fit factors for the separate exercises

Since fit testing uses respirators fitted with a P3 filter which is at least 99.95% efficient (BSEN, 2000), any particles that get into the respirator must come in through leaks. It must be noted that fit factors give a measurement relating only to the test. The numerical value does not indicate the level of protection that can or will be achieved in the workplace. The fit factor value does not carry any real meaning much above the pass/fail cut off. For example a fit factor of 16,000 should be treated the same as a fit factor of 6,000; both show compatibility between the wearer and the RPE, but the increase in value should not be mistaken for achieving an increased level of protection in the workplace. These values can also be strongly dependent on the ambient particulate concentration discussed in the following section.

When planning work, all workplaces must adhere to the assigned protection factors (APF) in HS(G)53 (HSE, 1998). These are based on the results of a strict regime of laboratory tests in which groups of wearers performed specific head and body movements. The HSE believe that these values are indicative of the protection that will be provided in the workplace, and have therefore set the APFs as the maximum protection value that may be assumed for each type of RPE. It must be noted that some individuals will achieve a higher level of protection than these APFs while others will obtain less protection - however, in general, the HSE believe that provided RPE is used correctly the majority of persons should be able to achieve this level of protection.

Particulate Sampling

As mentioned previously QNFT relies on accurate measurements of the particulate concentration from both the ambient atmosphere and from the wearer's breathing zone.

a) Ambient Atmosphere

During commissioning of the TSI Portacount Plus it was identified that to have consistent results it is important to have a controlled ambient concentration. Large variations in the numerical fit factor values were observed depending on the ambient concentration, (e.g., 3,000-50,000). It is feasible, using very high ambient concentrations, to get almost anyone to pass a respirator fit test whether they are particularly compatible with the facepiece or not. For example, a person tested with an ambient particulate concentration of around 5,000 may obtain an overall fit factor of 2,000 but, by increasing the ambient concentration to 50,000 this fit factor may be increased by up to an order of magnitude.

Extensive tests identified an operating range for the test program at Dounreay. The tests are performed with an ambient concentration of around 17,000, (the set range is between 10,000 and 20,000), with a maximum variation of 10% within any test.

b) Mask Atmosphere

Some manufacturers offer probed masks for use with machines like the Portacount. These are generally just the standard respirator with an adapter fitted through the visor area. This type of mask takes a sample from above the nose and mouth area, which is not necessarily an accurate representation of conditions within the inner mask. Even removal of the inner mask will not necessarily provide a sample representative of the air the person is breathing. The location of the sample probe and the probing method can, and usually does, result in different fit factors. The 'ideal' sample probe placement is in the area in front of the nose and mouth in order to sample air similar to that the person is breathing. When using 'ready probed masks' it is important that subjects are tested using a test mask of the same type and size as the wearers; this approach does not allow the testing of subject's own masks.

Another commercially available product is a TSI adapter. The adapter screws in between the respirator and filter. From the adapter flexible tubing can be fed through the filter valve into the breathing area, and the tubing fixed using a metal clip and suction cup. This product allows for the testing of subject's own masks as the adapter only takes minutes to remove and re-fit. Using this type of adapter does have some disadvantages. It can result in an increase in the amount of tubing and number of bends required to obtain the sample, and the tubing does on occasion collapse (normally if the adapter and tubing have been left in position for a period of time). The only way to identify a collapse or sharp kink in the tubing is through removal of the adapter and visual inspection, however during the time that the tubing is compromised subjects will obtain higher fit factors. This creates the potential for subjects with poor respirator fits to pass the test.

Neither of the above methods, on their own, would meet the requirements given in BSEN 136 (1998) or BSEN 140 (2000). These standards stipulate that masks should be probed through the face blank or visor and then into the inner mask using as short a length of thin tubing as possible. Sample tubing should then end in a multi-holed adapter position close to the centre-line of the mask and nearly touching the wearer's lips.

In general, on the Dounreay site respirators are worn once then returned for laundry, maintenance and return to the central store for re-issue. Only two types of respirator are used by UKAEA staff; with the majority using the Avon N10 respirator. This is available in four sizes, with size one being the largest and size four the smallest. The only work group which does not use the Avon N10 respirator exclusively are

the asbestos workers who wear the Protector Sabre. Due to the small range of RPE on the site, and the once-wear use it was decided that it would be most appropriate to get a range of respirators probed and kept for the fit testing.

In the case of the Avon N10 respirator we were able to probe it through the disused straw port, a feature from the military version. Rigid plastic tubing was fitted in this port, forming a tight seal, then inside the mask formed metal tubing connects to the sample adapter positioned in front of the mouth. The sample adapter used is a small plastic ball with holes spaced equidistantly round its circumference (in accordance with the guidance in BSEN 140 (2000)). By using rigid tubing the problem encountered with the TSI adapter of sharp kinks or collapsed areas giving spurious results was overcome. Figure 1 shows a probed N10 respirator.

The Protector Sabre respirator is tested as a negative pressure mask, though it is generally utilised as a powered respirator. A special adapter was purchased to replace the blower unit which was then attached to a multi-holed ball adapter. Due to the mask features the sample point is slightly above the mouth and off-centre. Figure 2 shows the probed Sabre mask.



Figure 1. A Probed N10 Respirator



Figure 2. A Probed Sabre Respirator

It is important that once a mask has been probed you ensure that there is minimal leakage, otherwise the results obtained will all be very low. This was achieved using a mannequin head to ensure reproducible respirator fitting. Firstly a measurement was taken using an original mask fitted on the mannequin head with the TSI adapter, a fit factor was then calculated. A second measurement was taken using the probed respirator on the mannequin head (using the same ambient air concentration as the first) and a fit factor was calculated. Any problems with leakage due to the probing could be identified as the second fit factor should be much lower than the first.

Exercise Protocols

In order to ensure that a test is representative of normal wearing an exercise protocol for the respirator fit testing had to be designed. BSEN 136 (1998) and BSEN 140 (2000) stipulate test requirements for CE marking of respirators. These are:

1. Walking at 6 km/h for two minutes
2. Turning head from side to side (15 times) for two minutes while continuing to walk
3. Moving head up and down (15 times) for two minutes while continuing to walk
4. Reciting the alphabet or agreed text out loud for two minutes while continuing to walk
5. Walking at 6 km/h for two minutes

TSI suggest the OSHA 29 CFR 1910.134 Protocol (1998) of eight exercises of at least one minute duration (with the exception of exercise six which need only last fifteen seconds and can be excluded from the overall fit factor):

1. Normal breathing while standing
2. Deep breathing while standing
3. Moving head from side to side slowly, pausing momentarily at each side to take a breath, again while standing
4. Moving head up and down slowly while standing
5. Talking while standing
6. Grimace
7. Bending to touch toes
8. Normal breathing while standing

The majority of respirator work at Dounreay tends to be 'light work'. Therefore it was decided that standing would be the most suitable position though use of a treadmill or exercise bike was considered. It was decided to use all of the exercises as recommended by TSI, but using eighty seconds duration for all except the grimace exercise, which lasts thirty seconds. By using eighty seconds for each exercise a sixty second in-mask sample is obtained (the instrument requires the rest of the time to take the ten second ambient reading at the beginning and end of each exercise).

Pass/Fail Criteria

The HSE suggests a fit factor of at least 2000 for tight fitting full-facepiece respirators. This value comes from using a total inward leakage of 0.05% (as specified in BSEN 136 (1998). TSI follows guidance from OSHA which states a minimum overall fit factor of 100 for half-masks and 500 for full-facepiece respirators. The grimace exercise may be excluded from the overall fit factor (OSHA, 1998). At Dounreay the criteria is a minimum fit factor of 2000 for each exercise (except the grimace exercise which is not included as the aim is to break the face-seal). Failure on any one exercise necessitates repeating the respirator fit test.

Re-testing

All asbestos workers undergo a respirator fit test annually. All other operations staff who may wear respirators as part of their routine duties shall be tested at least once every two years as the face shape may change over this period. During the fit test staffs are made aware of the following factors that could necessitate them requiring a respirator fit test before their retest date:

- Weight change by 20 pounds or more,
- Significant scarring occurring around the face seal area,
- Significant dental restructuring including the removal of dentures,
- Reconstructive or cosmetic surgery on the face.

Medical Fitness

OSHA 29 CFR 1910.134 (1998) gives a sample medical questionnaire in its appendix. This was used as a base for the questionnaire used at Dounreay. Every person joining the UKAEA Dounreay site with UKAEA is subject to a pre-work medical. Further to this, there is an additional medical for classified persons every 3 years until that worker is 40, every 2 years while between 40 and 50, and then annually until they retire.

The medical questionnaire used with the respirator fit test is intended to identify any medical conditions that may have arisen during the time since the last classified person medical. It is a simple yes/no sheet

listing a variety of different medical conditions that may affect respirator wear. A nurse within the Occupational Health Department (OHD) reviews each medical questionnaire prior to starting the respirator fit test.

Training of Fit Test Operators

The fit test operators on the Dounreay site are all nurses within the Occupational Health Department. All the nurses have to undergo an initial written and practical assessment after a period of training. The training covers legislation, fitting respirators, and the use and maintenance of the TSI Portacount Plus. Upon successful completion they undertake a short period of performing respirator fit tests while supervised. Following this they are then observed annually to ensure that they are still adhering to the protocols and best practice.

Introduction of the Fit Test Program

The fit test program was introduced on the Dounreay site in October 2000. Generally it has taken the following format:

1. Line Managers have been asked to nominate operations staff who may be required to wear a respirator during routine work.
2. An appointment is made and a medical questionnaire is sent to the candidate.
3. The medical questionnaire is completed and brought by the individual to their respirator fit test appointment in the OHD.
4. The respirator fit test operative reviews the questionnaire. If there are any medical conditions on the form that the fit test operative is unsure of then the subject is referred to the site doctor.
5. The respirator fit test operative enquires what size of respirator the subject would normally wear, then measures the subject with an Avon measuring gauge (for the N10 respirator only).
6. If there is a discrepancy the respirator fit test operative may give the subject a choice between the measured size and their normal size (especially if the measurement is borderline). This allows the subject to be tested initially in the mask that feels more comfortable, and if they fail then they will be tested in the other size.
7. The subject is then asked to don the correct size mask and relax for five minutes. This allows the subject to ensure that the mask is sitting comfortably on the face, preventing adjustment during the test.
8. The fit test is carried out using the following test protocol: normal breathing (80 seconds), deep breathing (80 seconds), head side to side (80 seconds), head up and down (80 seconds), talking (80 seconds), grimace (30 seconds), bending (80 seconds), normal breathing (80 seconds). During this time the fit test operative will check that the ambient is within the set range and relatively constant.
9. Should the subject obtain a fit factor of less than 2000 for any of the test exercises (excluding the grimace exercise) then the test may be stopped and the subject informed. In this instance the test may be re-done with the same size of mask or with a different size.
10. At the end of a successful test the limitations of the measurement and its importance is explained, and then they are reminded of their size and the importance of wearing the correct size of RPE.
11. At the end of an unsuccessful test the candidate will be informed that they may not wear a respirator during routine work until they successfully complete a respirator fit test. However they will be invited back for further respirator tests during which different sizes will be tried. In the case of an emergency they may still wear a respirator. If after further tests, the individual cannot be fitted with a suitable respirator, then they may not wear any of the respirators for routine work until a suitable respirator is identified.
12. A note is sent to their line management of the result, a record is kept in OHD and in two years time they will be called back for another respirator fit test.

RESULTS AND DISCUSSION

The results for the past year are shown in Figure 3. Note that no tests were carried out in September 2001 as the instrument was away for calibration.

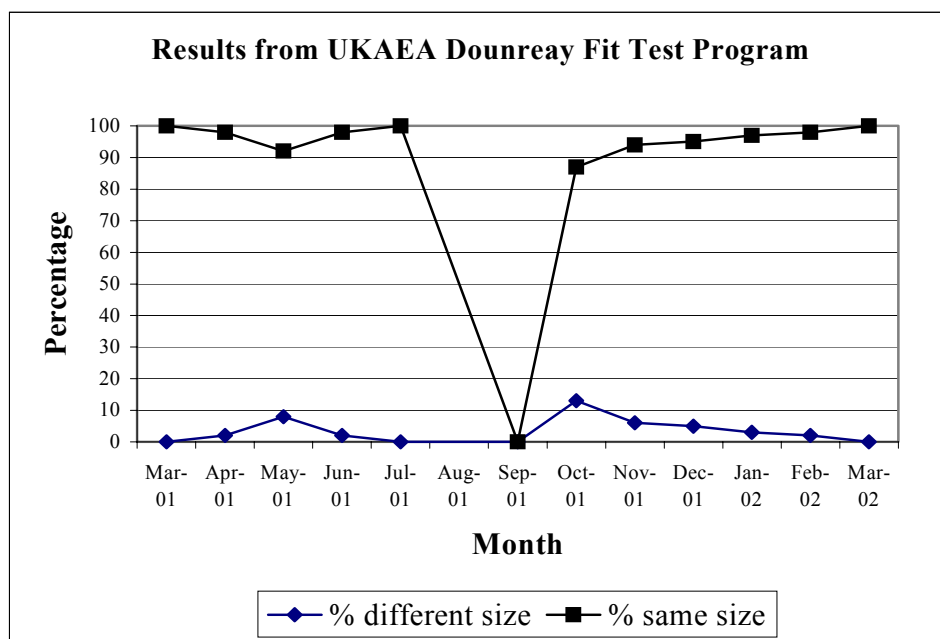


Figure 3. Percent of Subjects Passing Fit-Test with the Same Size of Normal Use Respirators or a Different Size.

From those who conducted the tests between March 2001 and March 2002 96% passed wearing their normal size (this was often the size they were fitted with when they first started work at Dounreay). Four per cent had their requirements modified, in general these people were borderline between two sizes of N10 respirator and were either moved up or down one size.

In the majority of cases where the respirator requirements were modified the candidate was changed from a size two respirator to a size one or a size three respirator. Mainly it has been men who have been changed to a size one respirator, and women to a size three respirator.

Only one individual has, to date, not been compatible with any of the respirator types or sizes on site.

Tests have also been carried out on some of the men on site who have varying degrees of facial hair. All the results from these tests have been in agreement with the findings of earlier studies such as the study done by E.C. Hyatt *et al.* (1973). At Dounreay a small proportion of the candidates (less than 10%) passed a respirator fit test with a beard. Those that passed tended to have beards with longer hair, such that the hair could be folded over, and often this was of slightly finer hair. Both of these attributes allowed the respirator to sit closer to the face than if the wearer had a coarse short beard. Dounreay has adopted the policy that no one who has facial hair that impinges on the face seal may wear a respirator routinely. However, in the event of an emergency they may wear a respirator. They have been made aware that in such an instance they may have a reduced protection factor.

CONCLUSION

A program of respirator fit testing has been in place on the Dounreay site for approximately a year and a half. During this time 467 individuals have been tested with 4% of those requiring their respirator requirements to be modified.

The test protocols outlined in this paper have been operated without any problem, and in general personnel on the site have welcomed the introduction of this program. Regular fit testing (and sizing) should assist in reducing the potential for intakes due to poorly fitting RPE.

ACKNOWLEDGEMENTS

I wish to thank the following persons within UKAEA for their technical assistance in writing this paper. They are Peter J Thompson, Anthony Ridgley, John Cuthbert, and Shondiah Tolworthy.

Disclaimer

Reference to manufacturer's products does not signify the endorsement or recommendation by the UKAEA.

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