

The Development and Assessment of a Dual Cavity Respirator

Suzanne H. Pelfrey, George Mathers and Grant S. Richardson

Defence Science and Technology Laboratory (Dstl), Porton Down, Salisbury, Wiltshire
SP4 0JQ United Kingdom
E-mail: shpelfrey@dstl.gov.uk

ABSTRACT

The dual cavity respirator has been developed in the UK in collaboration with the Defence Threat Reduction Agency in the US. Its design isolates the positive/negative pressure transients encountered during a breathing cycle, within an inner oro-nasal mask. By decoupling the respiration from the main body of the respirator it allows the ocular region of the mask to remain at a constant positive pressure through the supply of small quantities of air through an inbuilt blower, which substantially reduces the risk of inward leakage through the face seal. Initial testing has shown that by integrating the dual cavity technology into a standard negative pressure respirator unprecedented levels of protection are achieved, even when the volunteer purposely breaches the face seal for one, the pressure within the eye space, and hence protection, can be monitored using Real Time Fit pressure sensor which alerts the user to a breach in the face or oronasal seal, creating a high level of user confidence in the respirator.

Keywords: respirator, face seal, respirator design, dual cavity

INTRODUCTION

In the event of a chemical or biological threat or event, emergency responders/military personnel could be required to enter a chemical and biological (CB) contaminated area. Recent advances in instrumentation, such as the development of the Respirator Battlefield Evaluation System (RBES), now permit the performance of respirators to be measured under realistic conditions, with subjects performing operationally relevant tasks, using the Standard Military Protocol (SMP) [Christiansen et al., 2006; van der Gijp and Steenweg, 2004].

Subsequent studies have highlighted the susceptibility of present respirator technology to various forms of mask failure e.g. leakage during a specific exercise, such as digging, shown in Figure 1A, or prolonged levels of reduced protection, shown in Figure 1B. The latter is of particular concern as the wearer is generally unaware of any compromise in mask performance.

These studies concluded that if the required levels of protection are to be guaranteed throughout the period of exposure, a secondary means of protection is necessary to overcome periodic and sometimes frequent breaches in the respirator face seal. The conventional approach to overcoming breaches in the face seal involves pressurising the face piece using a man-mounted blower unit. However, these are often bulky, can use significant amounts of power and require a multiple number of replacement filter canisters. Consequently, this approach does not always offer an acceptable solution.

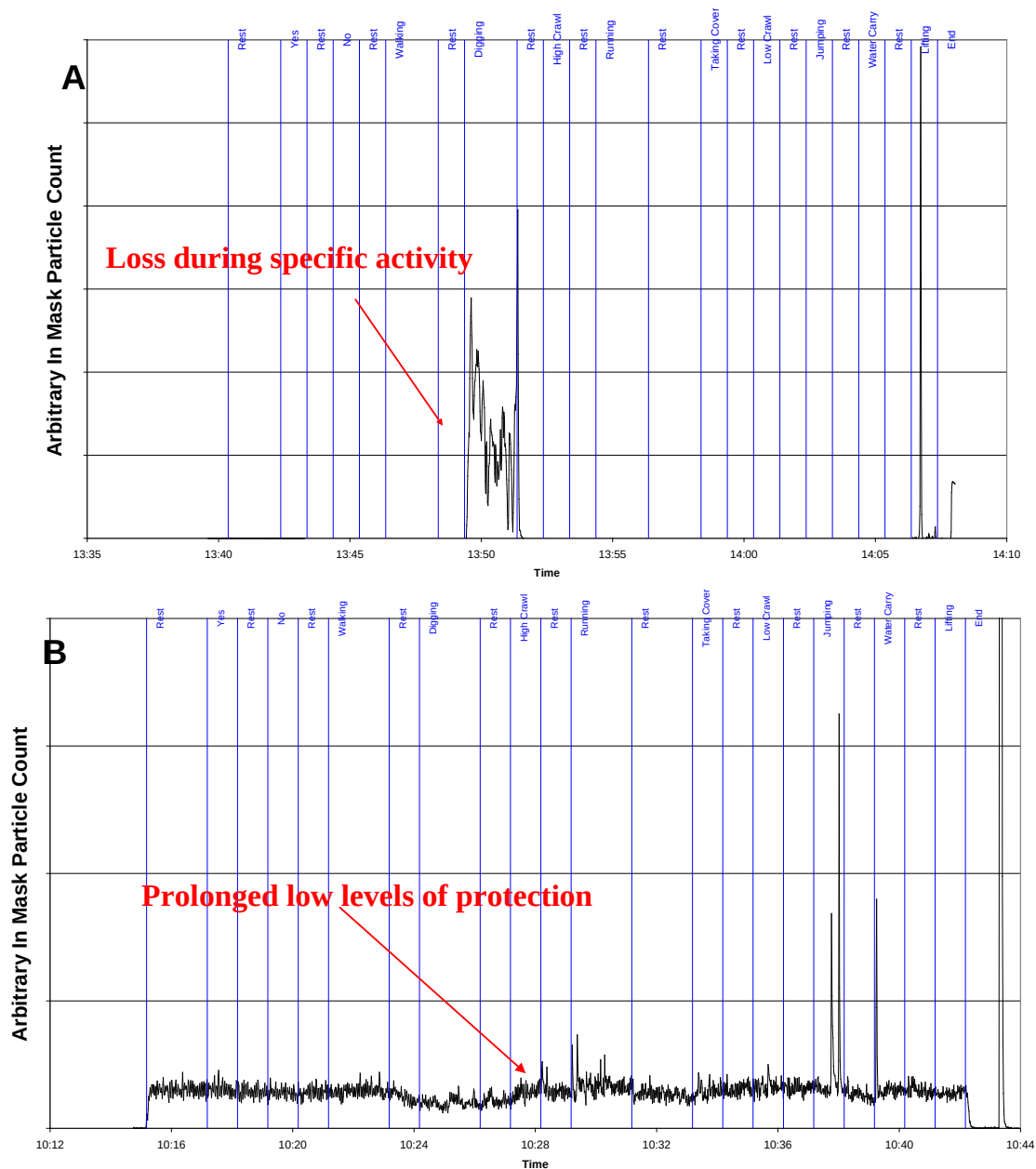


Figure 1. Continuous monitoring of in mask particle counts from a prototype respirator during Standard Military Protocol exercises. Figure 1A shows a breach in the respirator during the digging activity. Figure 1B shows a low level leakage in the respirator during all exercises.

DUAL CAVITY DEVELOPMENT

The need to provide consistently high levels of protection has been overcome with the development of dual cavity respirator technology by Dstl (Richardson, 2002) and its incorporation into a standard negative pressure respirator. The design of the modified respirator isolates the positive/negative pressure swings encountered during the breathing cycle, within an inner oro-nasal mask, shown in Figure 2.



Figure 2. A) Commercially available PAPR device. B&C) Internal modifications made to the standard negative pressure respirator to create the dual cavity prototype. The miniature blower unit can be seen in the lower right hand side of the B.

Confining respiration to the inner mask of the respirator allows the ocular region of the mask to be held at a constant positive pressure through the supply of a small quantity of filtered air from the miniature blower unit. Consequently, the risk of inward leakage through the face seal is substantially reduced. Air circulated within the eye space also provides a *perceived* reduction in physiological burden due to the induced cooling effect, as well as ensuring fog-free eye pieces. The air flow requirement for the eye space cavity remains minimal, requiring only $\sim 10 \text{ l}\cdot\text{min}^{-1}$ in comparison to the $\geq 150 \text{ l}\cdot\text{min}^{-1}$ delivered by commercial Powered Air Purifying Respirator (PAPR) devices. Moreover, the approach has the added benefit of an ergonomic, compact design with no externally mounted blower units or connections, as indicated in Figures 2 B and C.

Air Handling Options

During the development of dual cavity technology, various air management embodiments were investigated to generate the required level of positive pressure within the eye space. These included a valve arrangement allowing the breathing cycle and blower unit to use a single filter and the use of a separate filter for the blower unit.

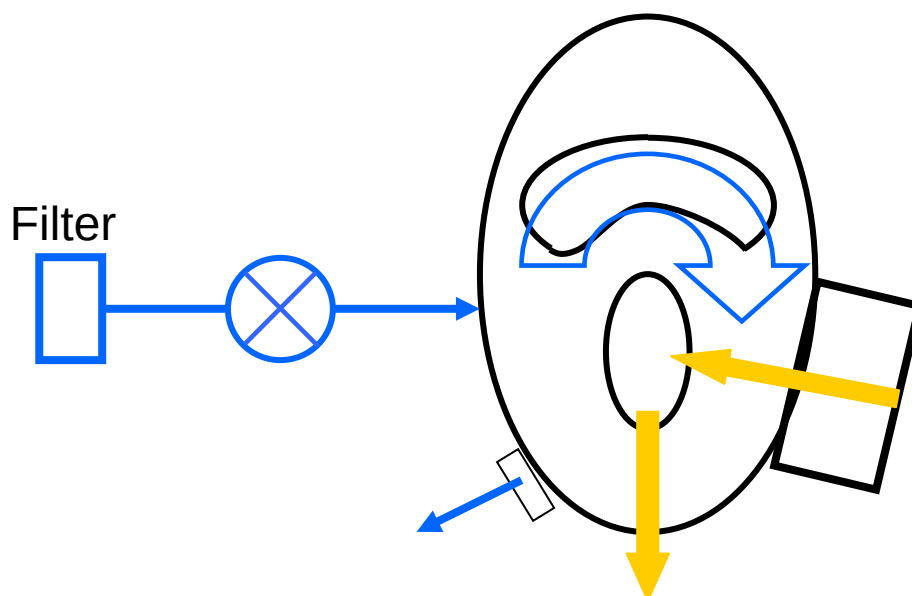


Figure 3. The air handling option finally down selected for the production of the dual cavity respirator. The fan has a separate filter to allow the air to be constantly replenished within the eye space.

Preliminary trials of these air management options showed that the dual cavity respirator gave unprecedented levels of respiratory protection when using a separate filtration element, as shown in Figure 3. This air handling arrangement allows the filtered air within the outer cavity to be constantly replenished throughout the breathing cycle; therefore this arrangement has been embedded within the standard negative pressure respirator to create a dual cavity prototype.

Real time fit indication

The positive pressure within the outer cavity is controlled using an integral, low power centrifugal fan unit (~ 0.5 W), which injects filtered air into the eye space. The pressure can easily be monitored using a sensor which provides feedback on the pressure conditions within the eye space, creating a real time fit indicator. Figure 4 shows a prototype of this real-time fit indicator, designed and co-developed by Dstl and UK industry.

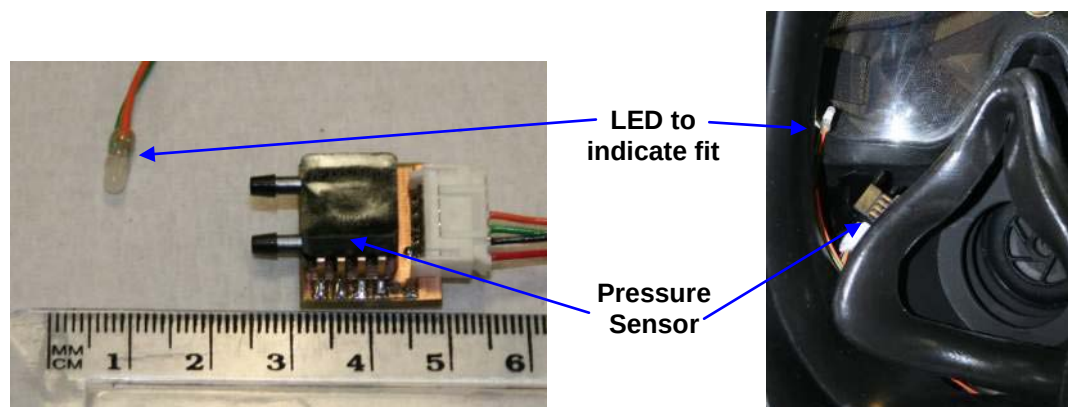


Figure 4. Real Time Fit Indicator.

A single, dual colour LED has been connected to the pressure sensor and can easily be used to indicate the sealing characteristics of the respirator. Table I indicates the meaning of each colour and any remedial action required.

Table I. Truth Table Indicating Fit of the Dual Cavity Respirator

LIGHT COLOUR	CAUSE	REMEDIAL ACTION
RED	NEGATIVE PRESSURE IN OUTER CAVITY	ADJUST ORO-NASAL SEAL
OFF	ATMOSPHERIC PRESSURE IN OUTER CAVITY	ADJUST FACE SEAL
GREEN	POSITIVE PRESSURE IN OUTER CAVITY	SATISFACTORY FIT

This indicator could be used as an initial fitting tool to ensure optimum protection is attained during the donning process, or used to alert the user that the respirator needs adjusting during use.

DUAL CAVITY PERFORMANCE

A series of laboratory based measurements were carried out using a negative pressure respirator fitted with dual cavity components. The unmodified negative pressure respirator was used as a control. The tests involved volunteers carrying out a series of head movements wearing both respirators in turn. The head movements were: Normal Breathing (NB), Head Side to Side (HSS), Head Up and Down (HUD), Bending over moving Head Side to Side (BOHSS), Speaking the rainbow passage and Deep Breathing (DB). In the case of the modified mask, the volunteers were asked to breach the outer face seal using two fingers for one minute at the end of the series of exercises.

The in-mask particle count (oro-nasal mask) and in-mask pressure (eye space) were recorded simultaneously using the Respirator Battlefield Evaluation System (RBES [1,2]). The RBES operates two TSI Portacounts in parallel, which allows the challenge and in-mask particle count to be recorded simultaneously. The exercises were performed within a test chamber containing a sodium chloride aerosol challenge.

An example set of results from each mask is shown in the following figures.

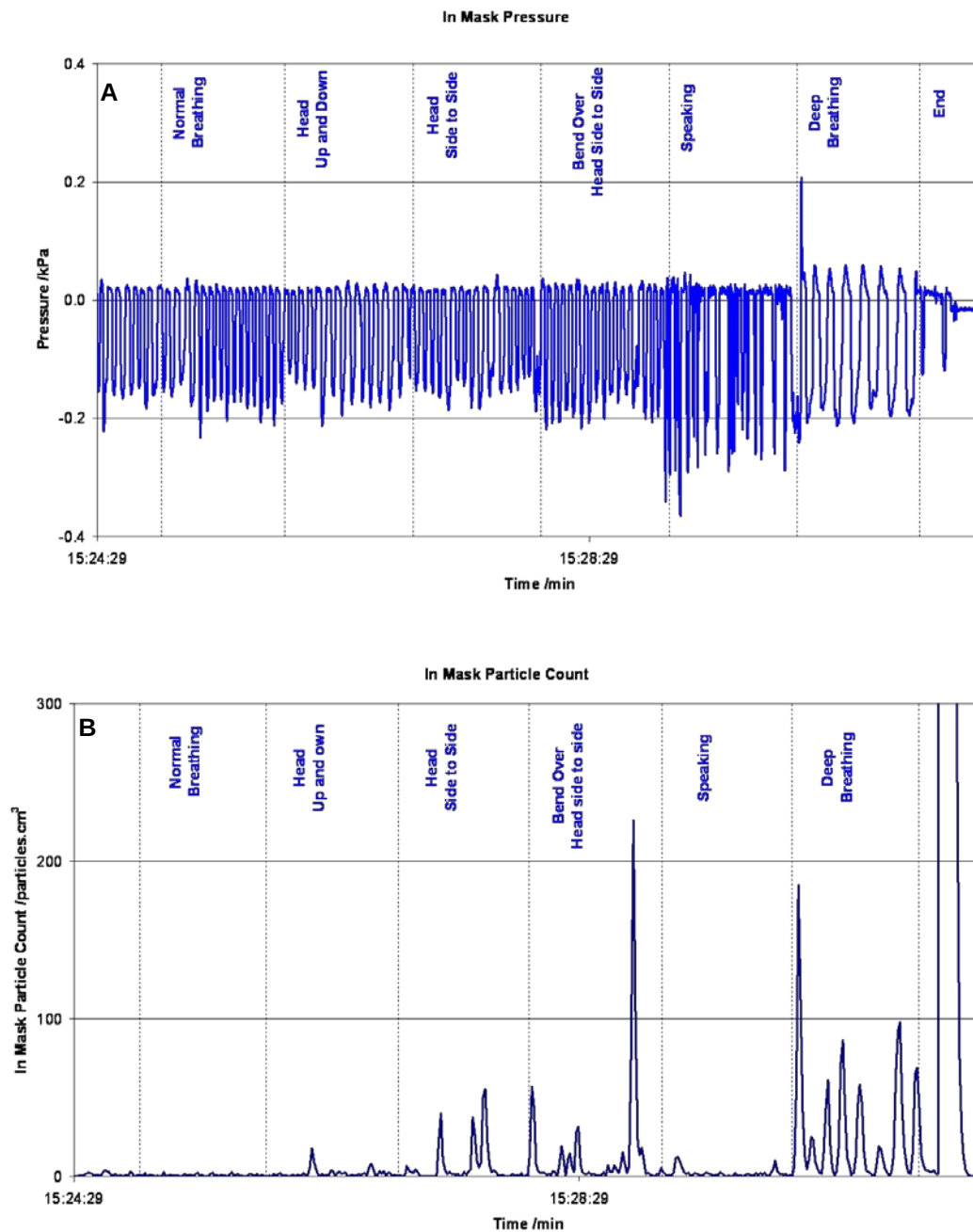


Figure 5. A) In-mask pressure (kPa) of the negative pressure control respirator during a series of head movement exercises. B) In-mask particle count (particles.cm³) measured during the same period as that of the pressure measurements.

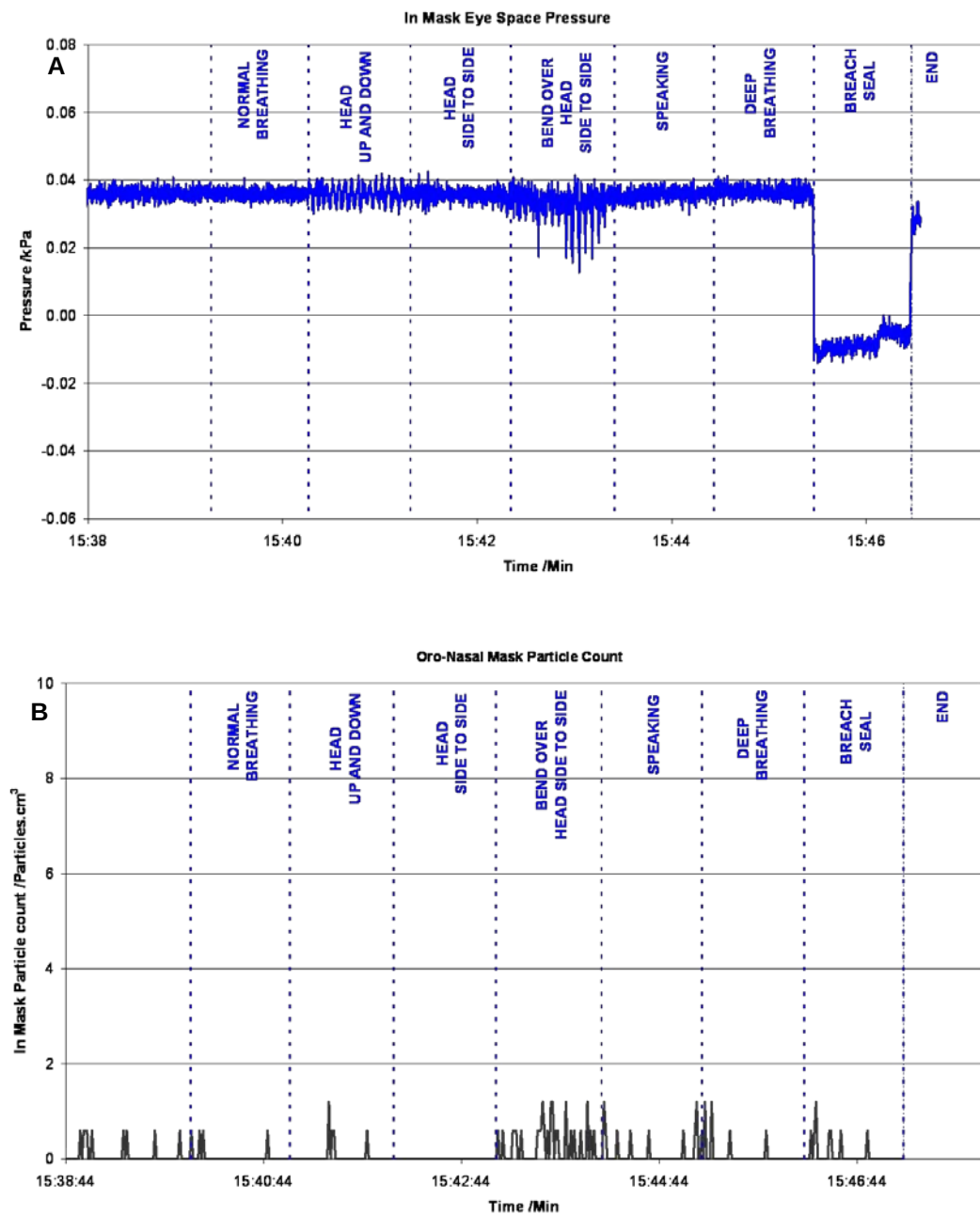


Figure 6. A) In mask pressure (kPa) of the dual cavity respirator during a series of head movement exercises. B) In mask particle count (particles.cm³) measured during the same period as that of the pressure measurements.

The in-mask pressure shown in figures 5 & 6 show that the unmodified respirator displays pressure swings within the eye space, as would be expected for a typical negative pressure respirator. The in-mask particle count, again typical of a negative pressure respirator, is shown in Figure 5B. However, the modified dual cavity mask shows a consistent positive pressure of approximately 0.03 kPa, except during the breach seal exercise (Figure 6A). Upon breaching the seal the pressure drops when the filtered air is simply exiting the mask through the large breach. However, during the loss of positive pressure in the eye space, there is no observable loss of protection within the oro-nasal mask, with the particle count staying consistent with the previous exercises (Figure 6B).

Comparing results from the modified and unmodified respirators it can be seen that the addition of the dual cavity technology increases the protection by at least an order of magnitude, as shown in Figure 7.

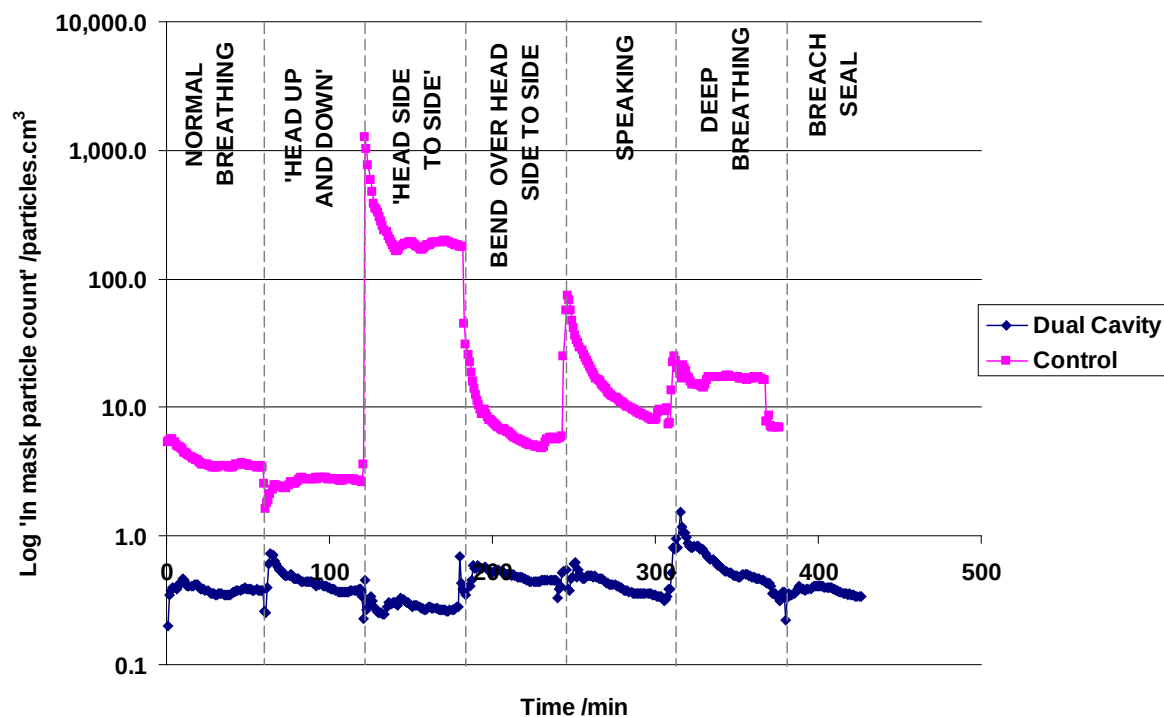


Figure 7. The average in – mask particle count for all volunteers using both the unmodified respirator as a control (shown in pink) and the dual cavity respirator (shown in blue).

CONCLUSIONS

Compared with a negative pressure control respirator, a dual cavity respirator can enhance the level of protection by approximately 1 - 2 orders of magnitude. This is because the positive pressure is maintained within the eye space throughout the laboratory exercises. There is also no observable inward leakage into the oro-nasal mask whilst the face seal was deliberately breached for a period of 1 minute.

The dual cavity concept also has the benefit of providing the user with an added level of user confidence regarding fit indication. The technology allows real time feedback of the pressure in the eye space, and hence fit, to be relayed back to the user. This could be used as a tool to indicate breaches in either oro-nasal or face seal whilst undergoing fit testing.

Acknowledgements

We would like to acknowledge the Defence Threat Reduction Agency for funding this study.

REFERENCES

- The Development of a Methodology to Measure Simulated Workplace Protection for High Performance Military Respirators. A. F. Christiansen, G. S. Richardson, L. Steenweg and G. H. Williams. ISRP 2006 Conference Abstract.
- Respirator Performance During Military Field Trials. S. van der Gijp and L. Steenweg. JISRP. 2004, Vol 21; Part 3/4, pages 135-141.
- A Dual-Seal Respirator Concept for Increased Respiratory Protection. G. S. Richardson. ISRP 2002 Conference Abstract.