
INTERNATIONAL SOCIETY FOR RESPIRATORY PROTECTION

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Keynote Presentation

LESSONS LEARNED FROM TOKYO SUBWAY INCIDENT AND KOBE EARTHQUAKE

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Nineteen ninety five was the year of ordeals for Japanese, who are suffering from economic depression. Not only did the Kobe (Hansin) earthquake occur in the HANSIN area where earthquakes have been rare, but the Kobe earthquake was also too severe to compare to the past big earthquakes. Therefore it became the catastrophe which brought tremendous damage and the death of 5,500 people.

March 20 is a solemn day for the Buddhists, but the people of the crazy AUM Cult generated the deadly toxic sarin gas in the Tokyo subway station or in the subway train. They not only created chaos but also killed many people.

Though these two incidents brought fear to civil people, it was consoling that useless chaos didn't occur because the defense agencies including fire service, police and the self defense force were well equipped with adequate respirators.

On the assumption of the incident of the especially deadly toxic chemicals, well prepared self contained breathing apparatus in combination with protective clothing received great reliance from the rescuers regarding the measures for sarin gas in the premise of the subway with worst ventilation.

In Japan it is believed that crimes and incidents seldom happen, but this faith collapsed. On the contrary, such a spirit has been generated that each person tries to defend himself. This is the only achievement through these two incidents.

Dinner Speaker

THE NEWTSUIT

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Man's venture into the deep ocean to work or to explore has been hampered by the efforts of pressure. A system has recently been developed which eliminates pressure on the working diver—a "zero-decompression" suit. The patented "Newtsuit" has made the 'bends a thing of the past and models of this unique submarine-that-you-wear' are now in use in many parts of the world for both commercial and military applications. The inventor talks on how the suit was developed and a look into the future.

CHANGES IN PROTECTION EFFICIENCY IN THE USE OF DUST RESPIRATORS

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Introduction

Dust respirators are made available for use at the workplace in Japan after they have been approved by national certification for each specific type. Dust respirators have thus to carry an approval mark indicating that the particular type has been approved. This national certification system ensures putting into use of respirators with appropriate quality. At each workplace exposing the workers to dust, the regular use of respirators having passed the national testing is obligatory.

This certification system, however, is effective only when a new type of respirator is put into the market, and does not ensure its appropriate use at each dust-exposed workplace. Our and others' experiences show that the efficiency of a dust respirator decreases as the air flow resistance increases due to dust particles caught in dust filters. Maintenance work for taking off deposited dust can often reduce the dust filters. Therefore, the changes in the efficiency of dust respirators were examined by measuring the dust collection efficiency in their actual use at foundries, iron-and-steel mills and machine shops. A new simple method of examining the changes in respirator efficiency has been developed.

Method

A new method has been worked up to measure dust concentrations in the normal atmospheric air prior to and after its passing through the filtering portion of a dust respirator. Air is sampled through a small pipe either from the air just in front of the respirator or from an inner portion of the respirator in which the air that has passed through the filters is present. The measurement of dust concentrations in the sampled air was done by a light-scattering particle counter. The method has the merit of being applied only with the normal atmospheric air instead of the specifically prepared air with high dust concentrations. The comparison of the dust concentrations of the two air samples from a respirator gave the efficiency of dust collection of the filters in the actual usage position. This efficiency corresponded to the protection efficiency.

Results

The protection efficiency was determined in the case of dust respirators that had been used by workers in arc-welding and polishing sections of a foundry. As routine maintenance techniques, group 1 workers were removing dust on the filters at an interval of 1–2 days without an effort to remove the accumulating dust.

The protection efficiency of respirators used by group 1 was as low as 80–95%, with only a slight change in airflow resistance (8 mmH₂O/40l). The protection efficiency in the case of group 2 respirators was maintained at a level above 95%, while the airflow resistance was in the range between 6–30 mmH₂O/40l.

In both the groups, respirators were found to have some maintenance problems such as inappropriate fixing of filters and contaminations of respiratory valves by accumulating dust.

The results suggested the inadequacy of the dust removal techniques applied by means of compressed air, as in the case of group 1. It was considered advisable to promote the frequent exchange of respirator filters rather than practicing removal of accumulating dust. The exchange of the filters should take place at regular intervals (every half-a-day, daily or every 2-several days) depending on the dust type or dust levels to which the workers are exposed.

Similar investigation on the protection efficiency of mechanical filters were also done in iron-and-steel mills and shops. The results showed the applicability of the proposed method. The results also pointed to the advisability of exchanging filters at brief regular intervals instead of applying dust removal techniques.

Conclusions

The dust collection efficiency of dust respirators could be validly measured by means of the newly proposed testing method. The method which applied the normal atmospheric air to obtain test samples

has proven practicable and reliable. The method is easy to apply in field conditions. The protection efficiency of filters decreased significantly when workers were practicing the removal of dust accumulating on the filters by means of compressed air techniques. Such a decrease was not noted when filters were regularly exchanged at an interval of 1-2 days in the case of a foundry.

These results show that maintenance procedures of filters used in dust respirators are critical in ensuring their high protection efficiency. It is suggested to apply the proposed method for monitoring the efficiency of dust respirators in actual use. An effective maintenance procedure should be to encourage the exchange of filters at brief regular intervals. The exchange interval should be as brief as 1-2 days depending on dust levels.

CHARACTERISTICS OF SELF-CONTAINED SELF-RESCUERS UNDER HEAVY EXERCISE

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Self-Contained Self-Rescuers for Japanese coal mines must be approved by the National Institute for Resources and Environment. The characteristic tests are done by using the lung simulator at the Institute. The testing condition is that the breathing volume is 30 L/min, the exhaled carbon dioxide is 4%, and so on. This condition is equivalent to light work load. But in the case of an escape under an emergency, the wearer would run fast and the breathing volume and the metabolic rate would be much higher than the testing condition. We can't evaluate the performance of SCSRs under the heavy working condition by the present characteristic test, and it is very important to know what is the most serious problem of the stressors related to SCSRs. We investigated the characteristics of SCSRs under heavy work load and the effects of the stressors on the human body.

Three units of SCSRs were evaluated by subject tests. The units were one bottle type and two KO2 type. They were made for Japanese coal mines and their service time was 30 minutes. A subject wore the units and walked on a treadmill. The speeds or slope of the treadmill increased every two minutes, and the subject continued walking and breathing through the units as long as he could at each test. One unit permitted the subject to continue walking as long as he did without any respirator. But breathing through the other two units, he could not continue walking until the same level that he reached without the respirator. He tried to keep breathing through the respirator after he stopped walking, but he couldn't because of acute distress. By comparing the values of inhaled temperature, breathing resistance and carbon dioxide among three units, it was revealed that sudden increase in inhaled carbon dioxide of the other two units was the reason for the termination of the tests.

High inhaled temperature, breathing resistance and inhaled carbon dioxide are the main physiological stresses of SCSRs. We also investigated how these stressors effected the human body.

To investigate the effect of inhaled temperature, we made the apparatus that supplied air for subjects to breathe. The dry and wet bulb temperature of the air were controlled correctly. Twelve subjects walking on the treadmill inhaled the air of various dry and wet bulb temperatures. The subjects also inhaled the air that included 3% carbon dioxide. It has been demonstrated that the tolerable maximum temperature for inhalation depended on the wet bulb temperature, that the increase in breathing volume reduced the maximal temperature a little, and that inhaled carbon dioxide did not affect the temperature except for its effect on breathing volume.

To study the physiological effects of breathing resistance and inhaled carbon dioxide, we constructed the measuring system of breathing volume and metabolic rate under various breathing conditions. Subjects breathed through an orifice and/or breathed the air including 3% carbon dioxide, and walked on the treadmill until exhausted. Their breathing volume, metabolic rate, and so on, were measured continuously by the measuring system. It has been demonstrated that breathing resistance reduced oxygen uptake at heavy work rate and diminished maximum work level. Inhaled carbon dioxide also reduced the maximum work level. There was closed correlation between subjective distress and alveolar carbon dioxide concentration.

ON REPEATED USE OF WATER-REPELLENT FILTERS BY CLEANING WITH AN ELECTRIC WASHING MACHINE

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Filters of replaceable type dust respirators are generally replaced when pressure drop increases by clogging. If the filters can be reused keeping their own performance, it is helpful for economy and resource saving. Water-repellent filters have great potential for reusability by cleaning with water. An electric washing machine is a convenient tool for the purpose of cleaning them with water.

We examined the effect of an electric washing machine with which we cleaned the filters loaded arc welding fumes. Loading fumes and cleaning were alternately repeated, and the samples were tested for pressure drop, filtering efficiency and damage. For inspection of the samples we introduced a new filter test which was designed for installation at actual workplaces. Indoor dust was used for measuring filtering efficiency.

As a result of the test, the filters loaded welding fumes were restored to the brand-new state by cleaning with an electric washing machine. We determined that the filters can be used repeatedly and that the new filter tester is effective for detecting the deterioration of the filters.

A NEW SOLUTION TO RESPIRATORY PROTECTION IN UNDERGROUND MINE REFUGE STATIONS

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Preamble

In underground mining operations, standard emergency procedures require miners to take refuge in a safe have if they are isolated by a mine fire, explosion or other mine emergency. Refuge stations, which are chambers excavated out of the rock near the active work area, provide this safe have. Fire walls and steel doors protect the occupants from the hostile environment created by the fire or explosion while compressed air lines, a water supply, communications linkages and other facilities provide life support and basic comforts to the trapped miners.

There is a recognized risk that some of these life supports are vulnerable to disruption; by the fire or explosion itself, or because of unrelated events. In the case of the remote compressed air supply, this is a matter of grave concern.

To address this concern initiatives were taken in Manitoba, supported by industry, industry associations, and government in both Manitoba and Ontario, to develop, to demonstrate on an operational scale, and to bring to production an alternative means of providing breathable air to the occupants of the refuge station, which would

- Maintain oxygen and carbon dioxide levels at or close to normal and within nationally established safe limits.
- Be immune to disruption from events external to the refuge station.
- Operate independently of external power supplies or other utilities for at least 24 hours.
- Be simple to use, rugged and durable in a mine environment, and affordable within the context of a mine safety program.

The culmination of these initiatives is the "REFUGE ONE" air centre, which meets all of the above parameters. Its successful development and full scale prototype demonstration has led to the installation of four production units in a Canadian underground hardrock mine, and widespread interest through the Canadian and international mining communities.

The Challenge

Over the last half century, industry, diligence, and commitment to safety have dramatically reduce the fatalities and injuries that were once perceived as normal occurrences in mining. In Canada nowa-

days, mining does not rank anywhere near the top of the list of dangerous industries as measured by fatalities and lost time accidents. However, catastrophic events which have occurred in the past such as the Glace Bay, Sunshine, Hollinger and Westray mine disasters are there to remind us that the underground mine is a very unstructured workplace and that the safety of the mine worker hangs in a fragile balance between our ability to engineer safety and protection into the mine workings and the unpredictability of the natural hazards and forces which exist in the surrounding mine environment. Fortunately not all mine fires or explosions result in loss of life because workers are trained to react to mine emergencies and are supported by the efforts of mine rescue personnel who voluntarily put their own lives at risk to preserve the lives and health of their colleagues. For example, on October 6th of 1990, at a mine in northern Manitoba, a fire in an underground conveyor gallery quickly destroyed air, water, electricity, and communication lines which passed through the conveyor gallery and trapped 38 miners underground. Fortunately, the miners were able to congregate in a refuge station where, following emergency procedures they partially opened a compressed air valve to provide breathable air to the refuge station. However, the result of this simple action was entirely unexpected. Instead of breathable air entering the refuge station, the draft caused by the fire sucked air out through the damaged line placing the miners in a very precarious position. Fortunately, mine rescue teams arrived shortly thereafter and escorted all 38 miners to the surface without injury. The fire continued to burn for 19 hours, destroying 2,000 feet of conveyor system and disrupting operations for several months.

RESPIRATORY PROTECTION FOR MILITARY PERSONNEL AGAINST INDUSTRIAL CHEMICALS

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An incident in the former Republic of Yugoslavia has made the military aware that toxic chemicals stored at industrial sites form a potential threat towards military personnel. These chemicals may be used as actual chemical warfare agents or may be released as a result of collateral damage. For operations out of area there is a need for operational rules to assess this threat and to take the necessary precautions including respiratory protection. The protection provided by military gas masks and filter canisters against a number of industrial chemicals is limited, while the provision of a separate canister is logistically burdensome and may confuse the user. Ideally, a single filter against both industrial agents and chemical warfare agents should be available. The present study involves both a risk analysis and the testing of industrial and military canisters against both classes of agents.

A method to assess the threat involves the definition of a hazard distance. to determine the hazard distance the dosage as a function of distance from a given source is compared with the protective characteristics of mask and filter. A similar procedure involves the calculation of a safe source strength at a given distance. An estimation of the dosage is made using the following scenarios and assumptions:

1. Troops are stationed or operating in the vicinity of an industrial site where chemicals are stationed in bulk quantities. The surrounding area is rather flat.
2. The release of the chemicals is instantaneous and from a very compact source. Volatile chemicals that form the most serious threat can be released instantaneously, for instance, by means of explosives. This is obviously a worst case situation. Current dispersion models show that the maximum concentrations at a given distance depend on the rate of release and that dosages are proportional to the released amount. However, it is recognized that for very large quantities this assumption is not very realistic, since in those cases the concentration would become extremely high. For very flammable substances the risk of ignition resulting in an explosion is not taken into account.

The concentrations and dosages were calculated by means of the computer simulation package RAP developed at PML. Calculations were performed for a mean meteorological condition (D3) and a very stable weather condition (F2). The results show that the passage time of a cloud will only be a few minutes at distances up to several kilometres. Even at 15 km the passage time barely exceeds 15 minutes. Hence, this will leave little time for evacuation and the relevant question is whether the protection factor of the mask is adequate and the capacity of the filter is sufficient.

The protection factor of a military mask appears not to be decisive, as it has been developed for a class of much more toxic compounds albeit released in much smaller quantities. The only relevant parameter is the capacity. In Table 1 the capacity of three types of filters against a selection of commonly used chemicals are given. Given this capacity, the source strength that can be handled at a distance of 500 meters for the weather type D3 was calculated and is shown in the same table.

Table 1. The capacity ($\text{mg}/\text{min}/\text{m}^3$) and safe source strength (tonnes) at a distance of 500 m for three types of canisters and different chemicals ($C_0 = 0.5\%$ (v/v), 30 L/min, RH = 80%, T = 21°C).

Type of canister	Capacity ($\text{mg} \cdot \text{min} \cdot \text{m}^{-3}$) and safe source strength (tonnes) for				
	Ethylene oxide	Cl_2	HCN	SO_2	NH_3
A2B2E2K2NO2	98000 (27)	720000 (1%)	240000 (65)	280000 (76)	180000 (46)
NBC canister 1 100 g ASC	44000 (12)	230000 (63)	150000 (41)	140000 (38)	27000 (7)
NBC canister 2 120 g ASC/TEDA	72000 (17)	380000 (103)	190000 (52)	220000 (60)	28000 (7)

It is concluded that the capacity offered by an NBC canister against some types of industrial chemicals is quite reasonable. In view of the amounts present in industry, the capacity against ammonia seems to be inadequate. The adsorption capacity for volatile organics is rather low. However, the risk of these chemicals at some distance from the source is put into perspective by the fact that ignition is very likely once the lower explosion limit has been reached.

Testing different EN class industrial canisters according to military specification has shown that these in general do not offer protection against cyanogen chloride unless the carbon is impregnated with chromium salts. The protection against other types of agents (HCN, nerve gases) meet the NATO requirement.

The development of a single canister against both chemical warfare agents and industrial chemicals seems to be feasible. It can be achieved by adding capacity for ammonia to the military canister. This will undoubtedly increase the weight and pressure drop of the canister, but offers a significant logistic advantage. Since a number of types of NBC masks are fitted with two canister connectors, an alternative approach might be found in fitting the mask with two NBC canisters.

Is AMBIENT AEROSOL AN APPROPRIATE CHALLENGE AGENT FOR QUANTITATIVE RESPIRATOR FIT TESTING?

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The particle size range of aerosol challenge agents used for quantitative respirator fit testing has been the subject of numerous research projects. With few exceptions, the particle sizes investigated have ranged from a few tenths of a micrometer up to several micrometers. Most quantitative respirator fit testing in the United States is currently being performed with instrumentation using naturally occurring ambient aerosol having a number-mean size typically below 0.1 micrometer. The purpose of this study was to extend previous research investigating the effect of particle size on fit factor values to include particle sizes ranging from 0.03 micrometers to 0.60 micrometers which are typically found in naturally-occurring ambient aerosol.

The experiment utilized a TSI Model 3934 Scanning Mobility Particle Sizer (SMPS) to evaluate the particle size distributions outside a half-mask respirator and compare them to the distributions measured penetrating through leaks in the face seal of the respirator. A half-mask respirator was mounted onto a headform inside an aerosol chamber where a steady concentration of polydisperse aerosol was maintained and measured with the SMPS system. When necessary, face seal leaks were created by inserting fine wires between the headform and the respirator. Each measured aerosol distribution was divided into narrow-sized bins by the SMPS system resulting in the particle concentration as a function of particle size for each test. The particle concentrations measured outside the respirator were divided by those measured inside the respirator during the same test to determine the fit factor for each particle size bin.

The test results indicate that respirator leakage represented by fit factor values between 100 and 300 were independent of particle size for particles ranging from 0.03 micrometer to 0.6 micrometer. Variations in the fit factors were typically less than 15% throughout the experimental particle size range for each test.

The results from this experiment show that the lower particle size limit can extend down to 0.03 micrometers for the challenge aerosol when performing quantitative fit testing with particle counting instrumentation. Previous research indicates the existence of an upper size limit between 1.0 and 2.0 micrometers before losses start to bias the calculated fit factor. Both results indicate accurate calculation of quantitative fit factors when using particles sizes typically found in naturally-occurring ambient aerosol as the challenge agent for quantitative fit testing.

REPLACEMENT OF CARBON TETRACHLORIDE—CONCLUSIONS

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Introduction

Respirator filters are subject to approval testing for performance. This is normally undertaken by a regulatory agency which tests the filters according to a standard protocol. Carbon tetrachloride is currently used as the agent for organic vapour filter testing in these standards worldwide. However, it has been identified as contributing to ozone depletion, and its usage will be severely curtailed from 1996. The approach of this ban, and the concomitant increase in price has spurred efforts in various countries to seek an alternative to carbon tetrachloride for respirator filter testing.

Replacement Criteria

Carbon tetrachloride offers certain desirable properties as a filter test agent. It is nonflammable, available with good purity, originally at low price, is water immiscible and readily detectable by an infrared spectrophotometer. It has been considered "typical" of organic solvents, against which organic vapour filters will see service. Its undesirable properties are its effect on the environment as a contributor to ozone depletion, and the toxic effects—it is a carcinogen, mutagen, teratogen and neurotoxic.

Performance Considerations and Tests

Assessments have been made at Racal Filter Technologies, with testing along the lines of the standard organic vapour test procedures of NIOSH or Europe. These indicated suitable candidates in the following classes: linear alkanes, branched alkanes, cycloalkanes, aromatic hydrocarbons, esters and ketones. Results showed that a number of compounds of reasonable cost and low toxicity were suitable for consideration. Later work has concentrated on refining the selection. In particular, further study has taken into consideration the needs for approval of filters for mixed applications.

Filters may be designed for removal of more than one type of contaminant. The commonest of these are filters for acid gases and organic vapours. In Europe, the combination of protection against organic vapours, inorganic/acid gases and ammonia is not uncommon. The removal of non-organic gases is achieved usually by the addition of chemicals to the surface of the carbon by impregnation, usually from aqueous solution, followed by drying to various extents. Filters for service with such combinations are therefore likely to contain some adsorbed moisture. In fact, for removal of acid gases or ammonia, a

certain level of water is beneficial. This water will itself adversely affect the removal of many organic vapours, so it is important that an organic vapour test agent reflect this, to indicate the potential for early vapour penetration in the workplace if too much adsorbed water is present.

To address this, studies were undertaken using a standard filter type and test conditions (5000 ppm challenge, 57 LPM air at 80% R.H., on a 270 cc charcoal fill), with the filters tested as manufactured, or factor **pre-humidifying** the filter to constant weight at 80% R.H. The **pre-humidification** caused a reduction in breakthrough time for standard test conditions in all cases, but the extent of the change varied. The percentage drops (relative to the "non-humidified" break times) were: octane - 13%, butanone - 28%, ethyl acetate - 35%, heptane - 36%, acetone - 46%, hexane - 58%, carbon tetrachloride - 79%, cyclohexane - 88%, pentane - 92%. It is notable that the effect on both **alkanes** and ketones diminishes with increasing molecular weight. Cyclohexane and pentane are illustrated to be more affected by the presence of adsorbed water than carbon tetrachloride, and therefore to be satisfactorily discriminating regarding adsorbed water.

Aside from moisture effects introduced during manufacture, there can potentially be an influence from moisture in the filtered air. All current test protocols call for testing with humid air. NIOSH and Japanese standards currently use 50% R.H., European standards use 70% R.H. A study of a range of test humidities from 22 to 80% relative indicated a very small effect of humidity on breakthrough performance of four potential replacements for a standard type of filter over a ten-fold vapour concentration range.

Studies and Selections by Approvals Authorities

Discussions with NIOSH indicated that a programme of evaluation of a range of candidates—pentane, hexane and heptane and ethyl acetate—had been undertaken. The conclusions were that pentane and hexane were comparably representative, but that pentane was preferable because lower concentrations could be used, with reduced overall toxic hazard. The revised test conditions have been issued in letter form. NIOSH will continue to use carbon tetrachloride as long as possible, and is continuing experimental work in this area. The new proposed procedure removes **prehumidification** requirements, but calls for test conditions of 50 and 80% R.H. NIOSH will allow laboratories to use alternatives to pentane if correlation to pentane can be demonstrated. The recent issue of the revised test standard covering all respiratory protection products - 42 CFR 84 still includes tests using carbon tetrachloride, however.

After preliminary selection, a round-robin test plan was organized among European and one Canadian laboratory to provide data to choose between butanone (methyl ethyl ketone) and cyclohexane. Cyclohexane was chosen, and is now being incorporated into the latest revisions for standards EN 141 (filter canisters), and EN 146 and 147 for powered air purifying respirators.

A NON-DESTRUCTIVE ACTIVATED CARBON FILTER TESTER

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Introduction

Filters for respiratory protection against gases and vapours incorporate a bed of activated carbon, normally in a granular form. In the standard process of manufacture, a bed is formed by depositing activated carbon granules into the filter body by a method to maximize the packing density, and securely retaining this in place. If adequate carbon of good quality is used, the filter will perform with maximum design capability for gas and vapour adsorption.

There is the potential for problems to arise during filter manufacture. There may be flaws in the filter body, and possibly faults in production, such as disruption of the bed before securing, inadequate securing, use of insufficient carbon or of carbon of poor quality. Prolonged exposure of partially completed filters to humid air before packaging can occur, and if so may reduce the adsorptive capacity of the filter.

The currently available general method for assessing manufactured filter carbon bed integrity and condition is by drawing samples and performing destructive gas tests.

The Non-Destructive Gas-Life Tester

The use of a non-destructive gas tester potentially enables the elimination of destructive quality assurance tests, and opens the possibility of 100% on-line quality assurance testing. An apparatus has been designed and evaluated to develop this concept. The method of operation is to retain the filter inside a small enclosure, and to feed a clean dry air stream continuously through this. A small volume of high purity ethane is injected into the air stream, and a portion of effluent is passed to a hydrocarbon analyzer sensitive to ethane. The detector response is shown on a chart recorder, and analyzed electronically.

The principle behind the operation of the non-destructive gas life tester is the chromatographic effect resulting from the poor adsorption of ethane on activated carbon. When the pulse of ethane is introduced to the carbon bed, the ethane is adsorbed, but then flushed off again under the continuing passage of clean air. The adsorption-desorption process spreads an applied square wave-form pulse into a rounded peak. Faults are indicated by a deviation in the form of the peak from that noted for filters shown to be good by subsequently passing a destructive gas test. If there is a carbon packing fault, such as a channel in the bed (which permits air flow to miss the full adsorptive capacity of the bed), a small ethane pulse appears ahead of the main peak. If there is a fault such as carbon of low volume or poor quality, the full ethane pulse appears early.

The complete ethane pulse peak normally takes several minutes to elute—the times depending on the input pulse size and air flow rate. However, a discriminating indication of carbon bed integrity could be obtained by observing the appearance of the first small concentration of ethane in the effluent. Tests were made at a range of ethane test volumes, air flow rates and detector sensitivities, on good filters and those with deliberately introduced faults. These were followed by destructive gas tests, so that the necessary conditions for good discrimination of carbon bed quality could be established. Test conditions were adjusted so that a positive or negative indication of filter quality could be obtained in about 20 seconds, a test rate which is suitable for 100% on-production line filter testing.

In order to establish any effect that the ethane may have on impregnated activated carbons, tests were conducted on sample filters employing such a carbon which were filled with ethane in ten-fold excess of the normal test volume, and then subjected to environmental storage, and tested with standard gases. No effect on test results for gases removed by impregnants was noted. Peak concentrations of ethane likely to be eluted during normal usage of the filters were measured, and found to be negligible compared with hazardous levels.

The advantages of this non-destructive test method over existing sampling and destructive gas test methods are:

1. potential for 100% testing of product.
2. non-destructive—so that no finished product has to be scrapped due to testing;
3. reduction or elimination of use of costly and toxic test gases.

It has been demonstrated that the non-destructive tester can be used to provide these benefits without deleterious effect on filter performance or use. A fully automated on-line non-destructive filter test system derived from this study has recently been installed on a new production line and has been shown to be effective.

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EFFECTS OF DIFFERENT **INSPIRATORY** AIRWAY RESISTANCES ON PERFORMANCE TIME DURING STEADY-STATE EXERCISE OF 80% $\text{VO}_{2\text{MAX}}$

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The resistance to breathing inherent to respiratory protective masks adversely affects physical performance. Considerable attention has been paid to this factor in past research investigations but, at most, results have provided only limited insight into defining quantitative limits on inspiratory and expiratory breathing resistances. Technological advances in materials and mask concepts, coupled with the continued demand by users for less ventilatory restrictive masks stress the need to quantitate the

levels of breathing resistances that minimally impact performance before new mask systems are fabricated and marketed for use. Therefore, the purpose of this study was to determine the effects of specific inspiratory airflow resistances on performance. This study systematically measured performance time at five levels of inspiratory resistance in an attempt to define the performance decrements associated with each specific level of inspiratory resistance tested.

Nine volunteers (5 males and 4 females, mean age 25.8 ± 4.8 yr) ran to a voluntary end point during steady-state treadmill exercise of 80% $\text{VO}_{2\text{max}}$ at room temperature ($20\text{--}24^\circ\text{C}$) with and without added inspiratory airway resistance. Each volunteer received a thorough briefing on the nature and objective of the study and was advised of the medical risks and safety precautions involved. Half-masks (Hans Rudolph, model 7900) modified to provide the levels of inspiratory resistance to be tested were worn for all trials. Plastic, doughnut shaped disks were inserted within the inspiratory ports of the half-masks to provide the different inspiratory resistance levels. The diameter of the opening in the center of disks was different for each disk pair to elicit the desired inspiratory resistance levels. Subjects inspired against resistances of 0 (the control condition using an unaltered mask), 20, 30, 40, and 50 mm H₂O measured at a flow of 1.4 l s^{-1} in randomly administered trials. These levels mimic a stepwise reduction from the H₂O inspiratory resistance level found in many military negative pressure respirators. Expiratory resistance was held constant at 11 mm H₂O (at 1.4 l s^{-1}).

Heart rate was monitored continuously by recording a bipolar 3-lead ECG (Quinton Q3000 ECG Monitor) during the five experimental conditions. Ventilatory measurements of tidal volume, breath frequency, and minute ventilation were obtained from a flowmeter (KL Engineering K-520 transducer, KTC-3-D compensator) mounted to the end of expiratory tubing attached to a mixing chamber. Respired gas concentrations were measured from the mixing chamber with a medical gas analyzer (Perkin-Elmer MGA 1100). Oxygen consumption was calculated every minute of exercise and treadmill speed and/or grade was adjusted accordingly to maintain subject intensity between 80–85% of $\text{VO}_{2\text{max}}$. Mask inspiratory and expiratory pressures were measured using a variable reluctance pressure transducer (Celesco, LCVR). The measure of performance was exercise time and subjective ratings of breathing apparatus comfort (BAC) and perceived exertion (RPE) were obtained from subjects every other minute of exercise. Subjects also completed state-anxiety inventories pre- and post-exercise.

Average performance times were similar for resistance conditions of 0, 20, and 30 mm H₂O, however endurance during the 40 mm H₂O trial (9.8 ± 4.8 min) was significantly reduced compared to the 30 mm H₂O condition (13.5 ± 5.8 min). Performance time for the 50 mm H₂O (5.2 ± 4.2 min) decreased significantly compared to the 40 mm H₂O resistance condition. Subjective ratings of BAC indicated significantly greater breathing discomfort during the 50 mm H₂O trial compared to the 0, 20, and 30 mm H₂O conditions at minutes 1, 3, and 5 of exercise. However, RPE values were similar for all conditions at these times. State-anxiety increased significantly from pre- to post-exercise for resistance conditions of 30, 40, and 50 mm H₂O but no significant differences were observed between conditions. These findings demonstrate that steady-state exercise of 80% $\text{VO}_{2\text{max}}$, an intensity reported to limit exercise duration due to ventilatory factors, is significantly limited when breathing against inspiratory airway resistances of 40 mm H₂O and greater. Therefore, to minimize respiratory encumbrance of respirators, filters with inspiratory resistances below this threshold should be utilized by mask designers whenever possible, especially when wearers will be subjected to high work intensities. This information will also serve as a guide for mask design engineers by quantifying the effects of specific inspiratory resistance levels on performance.

MEASURING INTERACTIVE FLOWS IN VIRTUAL REALITY

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The current revisions of the European PAPR Standards, EN146 and EN147, for the first time include requirements for the performance of gas filters when used with PAPR devices. During the preparation of test methods to verify the requirements, the Standards Committee recognized that, in the case of tight fitting full facemask or half mask PAPR devices (EN147), the average air flow through a

filter would/could be greatly influenced by the interaction between the wearers breathing rate, PAPR motor/fan characteristics and filter pressure drop. Such an interaction would be even more significant in the new technology breath responsive PAPR devices.

To take account of this potential interaction when defining the realistic average constant flow at which to assess filter gas life, the concept of interactive flow rate was introduced into the revision of EN147. Interactive flow rate relates the pressure-flow characteristics of a filter to the dynamic pressure generated within a working PAPR device.

When a new requirement is introduced into an European Standard, it is incumbent upon Test Houses to produce and verify the accompanying new test method to assure its suitability and then to ensure uniformity and consistency of application across the European Laboratories.

Racal Health and Safety Test Centre, one of the independently accredited European Test Laboratories, has used virtual instrument software to produce a computer programme to measure interactive flow rates, giving a visual representation of the interaction between pressure generated within the turbo and breathing rate. The programme computes the interactive flow rate data in real time.

The paper will describe the concept and principles of interactive flow rate, the development of the software programme, showing examples of its use with single and multiple filter PAPR devices and the differences between constant flow and breath responsive devices. The work by Racal Health and Safety to develop a '**transfer standard**'—an item of test equipment that is transferred between all European Test Laboratories to verify test procedures will also be described.

MEANING, DEFINITION AND USE OF '**PROTECTION FACTORS**'—THE EUROPEAN VIEW

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In response to increasing concern that a common understanding of the term '*protection factor*' did not exist, the European Committee of ISRP held an open forum to debate the issue. It became clearly evident from the forum that confusion did exist, which did little to enhance the health and safety of those using respiratory protective devices. In response to this concern the European Committee prepared a discussion document outlining the current definitions and requested comments on these and on a proposal to reduce the number of terms to just three. This presentation reviews the comments received and introduces European consensus of the meaning, definition and use of the term—**protection factor**.

FILTER DEGRADATION UNDER **DOP** LOADING PER 42 CFR 84

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This article reports the DOP loading results of several filter media under the testing conditions specified in 42 CFR 84. While remaining a constant breathing resistance, meltblown and needlepunched filters degrade markedly in filtration efficiency when subjected to DOP loading. On the contrary, HEPA filters made of glass fibers appear to sustain a stable DOP penetration.

All DOP loading tests were performed using TSI model 8130 (TSI Inc., St. Paul, Minnesota). DOP mass concentration was 120 milligram per cubic meter with an average particle size of 0.3 micrometers. The face velocity of the challenging aerosol was 7 centimeter per second. Each filter medium was sub-

jected to a DOP loading for 20 minutes. During the 20 minute period, approximately 200 milligrams of DOP was loaded onto a filter sample. The penetration and breathing resistance of the sample were measured every minute.

Several types of filter media were challenged. Figure 1 shows the penetration of a composite filter material versus DOP loading time. The filter material consists of one layer of needlepunched and one layer of meltblown. At the end of 200 milligram loading, its penetration increased over 40 times.

Five HEPA cartridge products were tested under DOP loading. Those five HEPAs are currently on the market. Figure 2 is the penetration of the five HEPAs, while Figure 3 plots the corresponding breathing resistance versus loading time.

In summary, the current HEPA cartridge respirators seem to meet the requirements as P-100 respirators per 42 CFR 84. However, needlepunched and meltblown filter media may degrade dramatically in filtration efficiency under DOP loading.

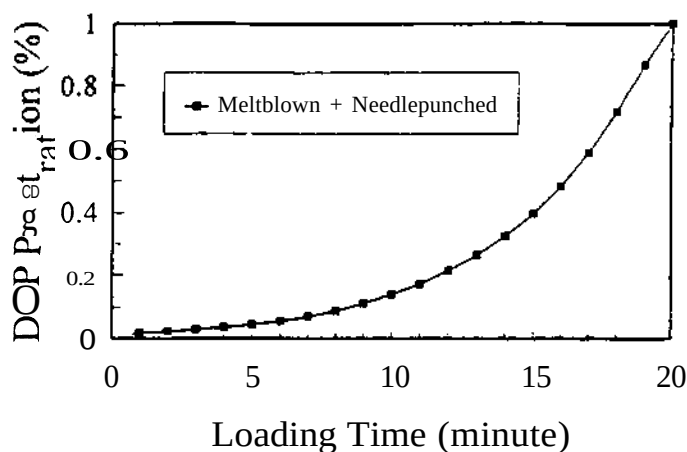


Fig. 1, Penetration vs. DOP loading time, needlepunched + meltblown composite

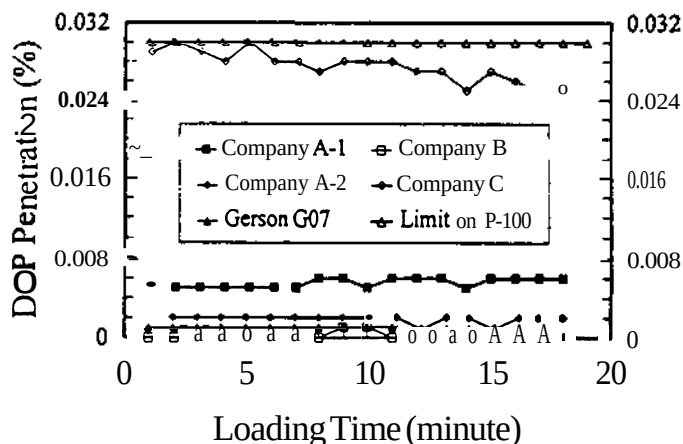


Fig. 2, Penetration vs. DOP loading time, five commercial HEPA cartridges

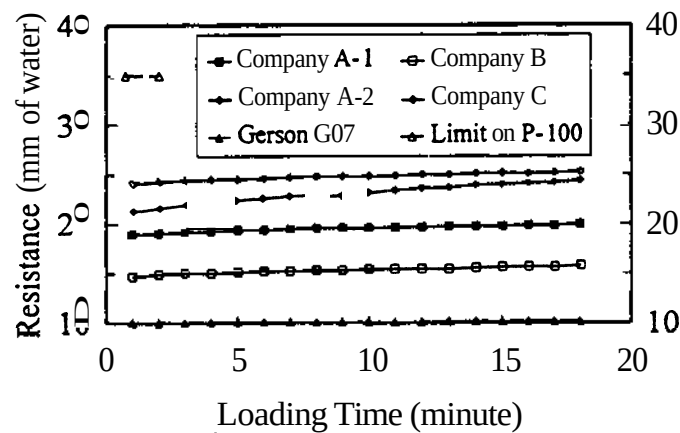


Fig. 3, Resistance vs DOP loading time, the five commercial HEPA cartridges

A NEW METHOD FOR VALIDATING RESPIRATOR FIT TEST SYSTEMS

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Generated aerosol systems have historically been used to validate the performance of other types of quantitative and qualitative respirator fit test systems. The generated aerosol method is currently considered to be the "gold standard" for fit testing, although no studies have been published to prove that generated aerosol systems can effectively measure respirator leakage. A major portion of the published literature and a substantial number of comparison studies with pressure-based fit test systems indicate that aerosol-based systems do not detect leakage introduced into respirators with good efficiency. The determination of respirator leakage is fundamental to respirator fit and performance measurement. The proposed new method for validating fit test systems is based on performing a pair of fit tests both before and after a known amount of leakage is introduced into the respirator. The ability of the fit test system to detect the known leakage serves as a validation measure that can be traced to primary calibration standards.

The capability of the proposed new validation protocol has been demonstrated in two separate comparison studies involving a controlled negative pressure and an ambient aerosol fit test system. One study utilized half-mask respirators worn by human subjects, while the other study included both half-mask and full-face respirators mounted on a breathing machine-headform system. In both studies, the validation protocol provided a means of determining the accuracy and precision with which each system measured the known leakage introduced into each respirator between sequential fit tests. The results of the two studies are summarized.

EFFECT OF LEAK LOCATION ON MEASURED RESPIRATOR FIT

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A difference in leak detection as a function of leak location was observed during a study conducted to assess how well current models of quantitative fit test systems can detect known amounts of leakage introduced into respirators. The basic study design consisted of introducing known leaks (matched

hypodermic needles) at three fixed locations into factory-probed half-mask and full-face respirators mounted on a headform-breathing machine system. The fixed leak locations included the bridge of the nose, the cheek, and the chin. Baseline leakage into each respirator was determined by conducting a fit test with all fixed leak sources capped. The leakage through each fixed leak source was then measured by performing a fit test with each fixed leak source uncapped individually. Study objectives included determining 1) how well each quantitative fit test system could measure the known leakage introduced into the respirator, and 2) whether the location of the leak had any effect on the leak measurement.

An ambient aerosol fit test system (Portacount Plus, TSI, St. Paul, MN) and a controlled negative pressure (CNP) fit test system (FitTester 3000, Dynatech Nevada, Carson City, NV) were used to make repeated measurements of the fixed leak sources. The ambient aerosol system detected an overall average of 40.3% of the known leakage introduced into test respirators, with a coefficient of variation of 46.9%. The Portacount's detection of known leakage increased in comparison to results from a similar study conducted with human subjects. The increase in leak detection was attributed to the absence of aerosol lung deposition in the bellows of the breathing machine. An analysis of variance showed significant differences in aerosol system measurements of leakage as a function of leak location ($p < 0.04$). An inverse relationship was observed in leak detection as a function of leak location in half-mask and full-face respirators. The CNP system detected an overall average of 98.4% of the known leakage through the same hypodermic needles, with a coefficient of variation of 4.3%. CNP system results were not affected by leak location.

RESPIRATORY PROTECTION: INTEGRATION AND IMPLEMENTATION OF MULTIPLE REGULATORY SOURCES

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The effective integration and successful implementation of a respiratory protection program (RPP) directed under the authority of the United States Department of Energy (DOE) presents unique administrative challenges. The standards that regulate respiratory protection within the DOE community constitute a regulatory amalgam that is often imposing and complex. Regulations include but are not limited to:

- OSHA; 29 CFR 1910.134, "Respiratory Protection"
- OSHA; 29 CFR 1910.1001-1101, Substance Specific Regulations
- ANSI; Z88.2-1980, "Practices for Respiratory Protection"
- ANSI; Z88.2-1992, "American National Standard for Respiratory Protection"
- ANSI; Z88.6-1984, "Respiratory Use—Physical Qualifications for Personnel"
- DOE Draft Order on "Contractor Respiratory Protection Program (Issued 12/17/92)"
- DOE Radiological Control Manual (April, 1994)
- DOE 10 CFR 830 Nuclear Safety Management
- DOE 10 CFR 835 Occupation Radiation Protection

Each regulatory standard contains unique provisions that must be acknowledged. The strategic development necessary for effective implementation into a workable program is an important step for successful integration. The formation of an Advisory Council may assist in obtaining important perspectives from various organizations impacted by policies of the RPP. Procedures, policies, and administrative approaches must acknowledge the diversity of activities within the DOE Complex by maintaining flexibility and consideration for operation efficiency and cost.

The underlying themes of the presentation may be summarized as follows:

- Examination of multiple regulatory standards and identification of unique provisions.
- Best management practices which may be integrated into a RPP to strengthen its overall positive impact on worker safety and health. In the absence of a mandated requirement to comply with a specific regulation some of the beneficial provisions of the regulation may be implemented voluntarily at reasonable cost.

- Examples of administrative approaches which establish compliance with regulatory requirements.

The presentation on regulatory reference implementation will provide a regulatory overview and examples of how various provisions could be administered. A basic design framework for program administration including planning, organizing, resources, and control will also be provided.

CANADIAN FORCES RESPIRATORY PROTECTION PROGRAM

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In early 1993, the Department of National Defence identified the lack of structured program for the respiratory protection of its military as well as its civilian employees.

During the past three years, different Directorate worked together to develop an all encompassing respiratory protection program, combined with an air purity testing element.

This has been a long and tedious project which is almost at the implementation stage. Bureaucracy, budget cuts, manpower requirements, lack of experience and/or expertise are but a few of the obstacles that had to be overcome.

We are proud of the work done to this point and would be willing to share it with others.

DEVELOPMENT AND IMPLEMENTATION OF AN INTEGRATED EXPOSURE ASSESSMENT, SAMPLE TRACKING, RESPIRATOR AND PERSONAL PROTECTIVE EQUIPMENT SELECTION, AND EXPOSURE COMMUNICATION

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Good safety and industrial hygiene practice and multiple regulations (including: 29 CFR 1910.132 and .134, DOE orders, and ANSI Z88.2) require proper documentation and control of respirator and other personal protective equipment use. Other standards, and good practices, necessitate tracking of occupational safety and health exposures, and other control methods. Additionally, occupational medical care providers need ready access to employee exposure information to conduct meaningful periodic evaluations and to assist in emergency and other health care management.

The Industrial Hygiene staff and Management Information Systems Team at Lawrence Livermore National Laboratory recognized an opportunity to develop a new system incorporating hazard and exposure assessment information, which also includes automated access to training, fit testing, job class, and existing exposure information. The system provides the following additional features:

- Identification and tracking of operations requiring exposure monitoring or other evaluation.
- Exposure assessment information, by worker, to health care practitioners conducting routine medical surveillance and respirator qualification examinations.
- A standardized format to communicate job hazards to workers.
- Avoids redundant entry and storage of information by integrating multiple databases.
- Ensures a consistent format and approach amongst industrial hygienists.

- Reflects currently trained and fitted respirator wearers.

Although there are multiple purposes served by this system, the emphasis of this presentation will be on the aspects associated with issues associated with the respiratory protection program. Other information regarding the software (Oracle) and hardware (DEC/Alpha with Macintosh interface) will also be addressed.

DESIGN OF A PROTOTYPE **ACTIVE-END-OF-SERVICE-LIFE** INDICATOR FOR AN AIR PURIFYING RESPIRATOR

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Air-purifying respirators are widely used to protect workers in an area that contains toxic gases which would be harmful to breathe. One of the major problems for use of the respirator is determining the service life of the cartridge. In 1984, NIOSH published standards for certification of Active-End-of-Service-Life-Indicators (AESLI) to encourage the development of the AESLI system. But to this date, no AESLI has been certified by NIOSH. For this reason a new AESLI for air-purifying respirators was designed.

This indicator combines a tin oxide semiconductor sensor with an adapter and an electronic circuit. By changing the adapter this indicator could be applied to any air-purifying respirators. Twenty-seven challenging chemicals, listed in the ASTM method F1001-89, at the concentration of 8 ppm, were individually tested. The sensor performance was investigated in terms of 90% response time (T90), 30% recovery time (R30), and signal response. Thirteen chemicals of acetone, aromatics, hydrocarbons, amines, amide, ester, mercapto, hydroxylics and heterocyclics had significant sensor-voltage response which was more than 0.8V as compared to the 50-min baseline voltage, i.e. 0.5V. The T90 and R30 of those significant chemicals were less than 60 sec. Other chemicals with higher red-ox potential were found not sensitively detected by this sensor.

There are other characteristics included in the AESLI *prototype* design: (1) The joint device according to the present invention functions for joining the filter cartridge to the mask body, so the degree of tightness at junctures is very important. In the AESLI, the related elements, except for sensors such as power supply and electric circuit, are instilled outside the joint device to avoid oversize and/overweight, and the degree of tightness of the joint device according to the present invention is accordingly improved. (2) There is no additional valve in the AESLI so that the improper working possibility caused by a valve is eliminated. (3) The sensor used in the adapter is for sensing the gas inhaled by the user. It can avoid the interference of the exhaled moisture, metabolin and other contaminants (for example, alcohol).

DEVELOPMENT OF A NOVEL PROTOTYPE FILTER FOR RESPIRATORY PROTECTION AGAINST **CHEMICAL/BIOLOGICAL WARFARE AGENTS**

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The U.S. Army Edgewood Research, Development and Engineering Center is pursuing new technology for the development of the next generation of respirators for the future warrior. As part of this exploratory development program, a contract task was initiated with Battelle to design, fabricate, and

evaluate a chest-mounted filter element for protection against chemical and biological warfare agents. The task led to the development and optimization of a unique, double-sided, 4.5 x 6.5 x 0.85 inch filter.

Both sides of the filter incorporated a filter element which consisted of layers of carbon-loaded media placed between layers of electrostatic filtration media. The two filter elements were separated by a plastic spacer that permitted air to flow to an airflow transition piece (ATP) which also served as the filter frame. The ATP is a novel design whereby the air that enters both sides of the filter into the center of the filter can be transported through a manifold into air ducts that lead to the mask face piece. Candidate polymeric materials were identified and evaluated to produce the ATP and the edge sealant for the filter media encapsulation molding process. Materials were selected based upon their softness, flexibility, adhesion and curing properties required by the filter element design. Molds were then designed to fabricate both the ATP and filter element.

Ninety prototype filter elements were fabricated and their performance evaluated for comparison against specific design criteria. The design criteria consisted of performance specifications for size, airflow resistance, aerosol filter efficiency, and vapor sorptive capacity. Vapor sorptive capacity was assessed by determining the gas life against dimethyl methyl-phosphonate (DMMP—a nerve agent simulant) and cyanogen chloride (CK). Specifically, the design criteria required that (1) the maximum size be 4.5 in. x 6.5 in. x 0.85 in., (2) the airflow resistance not exceed 45 mm H₂O (25 mm H₂O desired) at 85 lpm, (3) the aerosol filtration efficiency exceed 99.99% for 0.3 µm particles at 32 lpm, (4) the DMMP gas life exceed 110 min when challenged with 3000 mg/m³ of DMMP vapor at 32 lpm, and (5) the CK gas life exceed 30 min when challenged with 4000 mg/m³ CK under simulated breathing conditions of 25 lpm.

The prototype filter elements were not fully capable of meeting the design requirements. An airflow resistance of 25 mm H₂O at 85 lpm was achieved; however, the aerosol efficiency averaged only 0.44% and the DMMP and CK gas life averaged 79 min and 22 min, respectively. Additional prototype filters were constructed with six layers of carbon material. The DMMP and CK gas life met the performance criteria but the aerosol filtration efficiency, although greatly improved, was still below the requirement. The additional layers of material increased the airflow resistance to 32 mm H₂O.

Although the prototype filter elements were not capable of meeting all the design criteria, optimum performance was achieved within the size constraints and filtration media available. Improvements in the filtration media or additional surface area are needed for the filter to fully achieve the design performance specifications.

A SIGNIFICANT TECHNOLOGICAL ADVANCE IN SELF-CONTAINED BREATHING AIR APPARATUS

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Advances in the "state of the art" of self-contained breathing air apparatus (SCBA) have been limited due to the exclusive use of compressed air. Maximum safe limits for use of compressed air were reached with introduction of the fiber wrapped 4500 psig aluminum cylinders which allowed production of 60 minute units. The bulk and weight of these units limit their use for some applications.

NASA was faced with a unique problem in planning for potential rescue of shuttle crew personnel during final orbiter closeout activities with the space craft in a vertical position or during a landing incident. In these scenarios, rescue of crew personnel could require access through a twenty-inch hatch. A lightweight, low profile respirator which could supply breathing air for a minimum of 45 minutes was not commercially available; therefore, action was initiated at KSC to develop a suitable unit.

NASA has extensive experience with environmental control units which use liquid air to provide cooling and breathing air in whole body suits. Using this expertise, an advanced technology SCBA, which uses liquid rather than gaseous air, was developed and has been in use since 1986. Compared to a 60 minute compressed air SCBA, this unit is smaller, weighs less, and more than satisfies breathing air requirements for strenuous work. The NASA New Technology Office made this technology available for industrial enhancement; however, at that time its applicability for commercial use was impacted by the

logistical problems associated with providing the liquid air.

Techniques for making liquid air involve (1) liquefying breathing air by flowing it through tubing immersed in liquid nitrogen, (2) mixing and circulating measured quantities of liquid oxygen and liquid nitrogen and (3) flowing large quantities of liquid nitrogen and liquid oxygen through sized orifices into a large Dewar. None of these techniques are ideal for providing small quantities for various reasons. NASA has now developed and tested a new method of mixing and sampling liquid air in quantities as small as 100 liters. As with any technology change, the initial cost of equipment required for this process is a consideration; however, liquid oxygen and liquid nitrogen are commonly used by hospitals and industrial facilities and are therefore readily available in all areas.

This new technology advance is expected to open the door to commercial development and use of liquid air supplied long duration SCBAs which will enhance safety and reduce costs in fire fighting and hazardous materials clean-up operations. In addition, air packs using liquid air for breathing and body cooling in totally encapsulating suits have long been used in the Air Force and NASA Space program.

Availability of a liquid air supply will allow use of liquid air packs to supply breathing and cooling air in full body suits used in commercial applications. Many suits are available now which could be easily adapted for use with these packs.

This paper will review the design and operation of the NASA liquid air pack (LAP) and the mixing fixture with associated equipment used to blend liquid oxygen and liquid nitrogen to produce liquid air in small quantities.

FIT TESTING: FACE TYPE, RESPIRATOR TYPE, AND LEAKAGE

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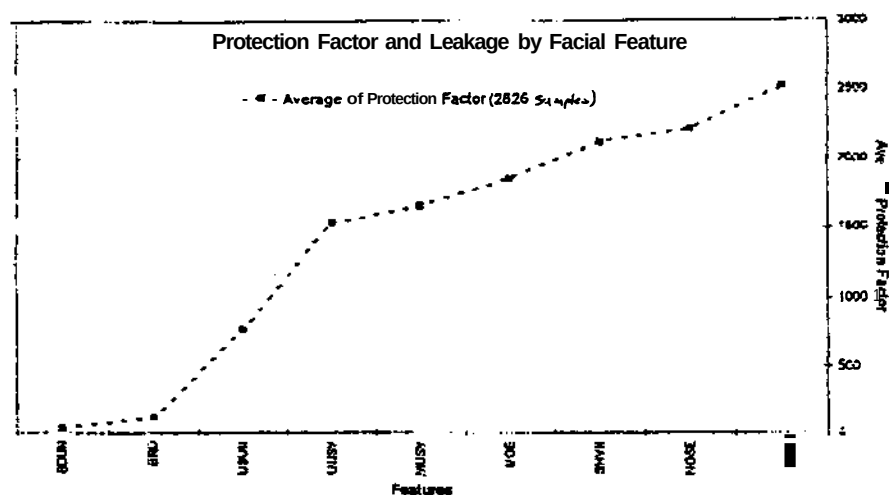
*Shaharin Yussof, Chris Winder, and Goran Berndtsson
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Individual respirator fit testing is required to ensure that respirator users are capable of achieving adequate protection factors. Fit testing may be carried out in a number of ways, but is best achieved under standard conditions.

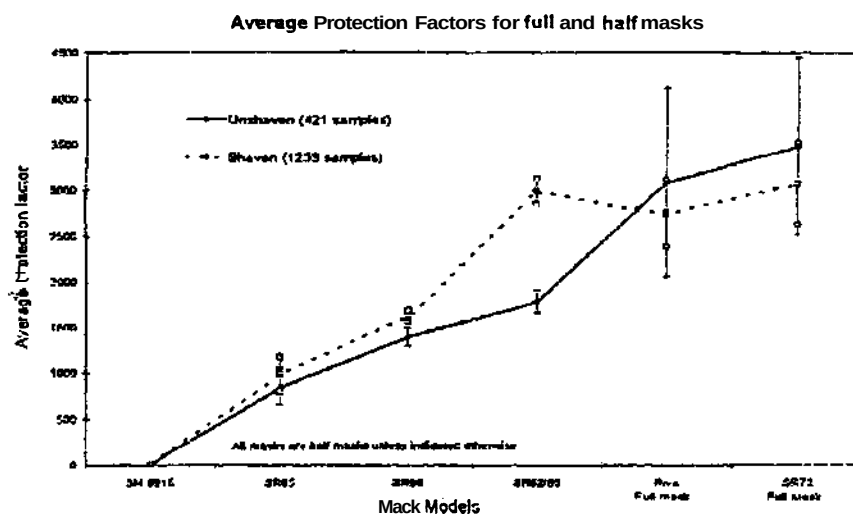
Safety Equipment Australia has been collecting subject data and fit test results since 1988, and has compiled a database containing 4,146 fit measurements of over 2,000 workers, most who have worked in the Australian primary aluminum smelting industry. The data collected comprises: demographic data; face dimension data; shaven/beard status; results of fitness sub-tests and overall leakage; respirator type used and calculation of protection factor. Analysis of this data shows:

- Analysis of face type data was in line with conventional wisdom, in that correlation of leakage test data and/or protection factor data showed that the highest protection factors tended to be from wearers with shaven faces (although some mustaches also received good protection from some respirators). Wearers with unusual facial features (unusual nose, scars) or with beard/unshaven faces tend to score lower protection factors (that is, there was more leakage).





- Analysis of individual protection factors suggests that the distribution is polynomial, although the magnitude of the first peak is quite variable, depending on face *type*.
- Analysis of data by respirator type also generally supported conventional wisdom:
 - Full face respirators tended to provide better protection factors, especially when the wearer was unshaven;
 - One of the half face respirators (the SR62) provided as good a protection factor as a full face mask as long as the wearer was shaven. Other half face respirators (the SR85 and SR90) offered lower protection factors for both shave and unshaven wearers;
 - Paper masks offer poor protection for any face or beard *type*.



The leakage test is presently based on five separate measurements. Comparison of leakage sub-test data indicates that each of the five sub-tests are highly correlated with each other, and that perhaps only one or two measures will provide data of similar quality.

In summary, respirators in the workplace offer good protection from occupational hazards, as long as shaven/beard status, mask *type* and fit are optimized. The provision of respirators to recognized standards and training in fit and use of respirators will also assist in this process.

Analysis of this database continues, for instance in the possible identification of features important in the design and use of respirators in the workplace.

A STUDY TO DETERMINE THE LUNG MINUTE AIR FLOWS AND PEAK **INSPIRATORY** FLOWS OF EMPLOYEES WORKING IN THE **POTLINE** OF AN ALUMINUM SMELTER IN NEW ZEALAND

*John Wallaart
New Zealand Aluminum Smelters*

A study has been made to determine the lung minute air flows and peak inspiratory flows of employees working in the potline of an aluminum smelter in New Zealand.

Data from a variety of routine tasks carried out were recorded and physiological effects considered. It is shown that on a number of subjects these values are higher than may have been previously considered.

The implications are critical in selecting personal protective equipment in heavy industry.

A COMPARISON OF **ANTHROPOMETRIC** PANELS USED FOR RESPIRATOR NOMINAL PROTECTION FACTOR EVALUATION

Milena Jovasevic and Bozidar Stojanovic

As an aid to the selection of RPD, the term "Nominal Protection Factor" (NPF) has been introduced into CEN Guidelines for selection and use of RPD (ON 259/93). The NPF is derived from the maximum permitted inward leakage of the whole device stated in certain standards or some of the inward leakage figures from relevant standards for different components. Using the mass balance of a contaminant penetrating the mask we can predict the NPF, as a function of filter efficiency, exhalation valve leakage and facepiece seal leakage.

When a filter penetration and exhalation valve leakage are negligible, we get a possibility for facepiece leakage testing. The results from this test could be expressed as the "Fit Factor". It is defined as a quantitative measure of the fit of a particular facepiece to a particular wearer. In addition, FF testing can be used with the intention of ranking different respirators of the same type by how they fit to the population of wearers or to audit the design characteristics of the facepiece. In this case each test subject wearing a respirator represents not only himself, but also other potential wearers from the population.

At present, there are various methods that have been used for selection of test subjects. In the European standards (EN) for the RPD, a panel of ten subjects have to be selected covering spectrum of facial characteristics of typical users. Australian standard requires a panel of ten people, of three major facial size grouping based on two key anthropometric measurements: bizygomatic breadth and menton-nasal root depression length. Using these anthropometric measures, Hack and McConville specified for full facepiece the anthropometric panel of 25 members, with the proportional distribution of subjects in ten anthropometric boxes. Similarly, they defined a panel for half-mask testing on the basis of face length and lip width, using 25 test subjects, too. In China, a panel of 25 persons, selected on the basis of mid-eye face length and bizygomatic face length, for full facepiece was established. Japan proposed a 10 person test panel for half mask, and QC test panel for full facepiece, both based on Hack's anthropometric measurements.

A recent facial dimensions survey from 14 countries shows that the coefficient of correlation of face length and face width was only about 0.2 and this is the reason for the use of two variables in the design of anthropometric panels. These two key dimensions are relatively easy to measure, and they correlate well with other facial dimensions in the corresponding planes. Because of the nature of facepiece-to-face interface, further criteria for a panel evaluation should be correspondent between selected face dimension and well defined facepiece dimension. The bizygomatic width corresponds to the maximum width of facepiece, but menton-nasion length do not correspond to any facepiece dimension. Reviewed panels encloses about 95% of the population. For convenience, each panel is subdivided into a matrix of a number size categories (8 subcategories in China, 10 in Japan and the U.S.A.). The number of test subjects to be selected for each subcategory of matrix corresponds to the percentage of this size subcategory of the population. Although these panels contribute to better selection of the subjects for fit testing, it seems that further research is necessary for better representation of the face-to-facepiece interface and the reevaluation of the minimal number of the test subjects.

In an attempt to obtain an anthropometric panel which would be more representative of the facepiece-to-face interface, we carried out an anthropometric survey of 423 male subjects from former Yugoslavia. The facial measurements chosen included several commonly used in the previous surveys. As a key dimension for full facepiece test panel, we selected two pairs of measurements: menton-crinion length vs. bizygomatic width, and menton-glabella length vs. frontal width, which represents the outer and inner sealing edge, respectively, and standard pair; face length vs. face width. The results were presented as three test panels, subdivided as a matrix four-by-three of ten size categories. Comparing these panels we concluded that a panel of menton-glabella length vs. frontal width is convenient for use due to better frequency distribution and correspondence to the inner sealing edge which is more important for mask fitting. The limits of menton-glabella length were 114.5-154.5 mm and frontal width 103.5-133.5 mm. Each subcategory in the matrix is 10 by 10 mm box. The number of subjects to be used in a subcategory is 3 or 30.

In this study, inward leakage of one half-mask respirator (UR) and one panoramic full face mask (B2) were tested using a standard CEN sodium chloride aerosol test method. Both of respirators had high efficiency particulate filters and high quality exhalation valves. The results are expressed as logarithmic values of fit factor, due to the known nature of fit factor log-normal distribution. The average value of individual FF means we call the nominal fit factor (NFF), which primary purpose is to rank the quality of face-to-facepiece sealing for population of wearers and respirators. Antilogarithm of NFF can be used for the calculation of the nominal protection factor of certain types of respirators.

Four series of fit factor tests were carried out using combinations of a number of subjects in the panel and replication: 1x30 (one subject by 30 replications), 10x3, 30x1, and 90x1. The results are summarized in the following table:

Type of panel	Nominal fit factor		Coefficient of variation (%)	
	B2	UR	B2	UR
1	4.113	3.784	5.3	9.4
10	4.382		8.7	
30	4.351	3.530	10.7	18.4
90	4.424		10.6	

The results indicate that there is no significant difference in the estimation of NFF when using the panels 10x3, 30x1, and 90x1. Obviously a EN 10-person panel is not adequate for accurate estimation of nominal fit or protection factor.

IMPLICATION OF ISO STANDARD SERIES **14000** IMPLEMENTATION TO THE FUTURE DEVELOPMENT OF RPE

Bozidar Stojanovic and Jovan Pejcinovic

Organizations of all kinds are increasingly concerned to achieve and demonstrate sound environmental performance. They do so in the context of increasingly stringent legislation, the development of economic and other measures. At the beginning of 1993, ISO established the new Technical Committee ISO/TC 207 on Environmental Management, with three subcommittees: (1) Environmental Management Systems, (2) Environmental Auditing, and (3) Environmental Labeling. The environmental standards are intended to enable any organization to establish an effective environmental management system, including the reduced environmental impact of products during their entire life cycle (design, production, marketing, use and disposal).

Although the environmental standards are not enforced in most countries, people from the RPE world would be prepared for the implications which may be expected after their implementation. This paper discusses possible consequences of the implementation ISO 14000 standards to the future of RPE: reduction of need for the RPE of high protection capacity, due to reduced emissions to air in many industries and agriculture, reduction in use of disposable respirators, due to limitations in their disposal, controlled disposal of used RPD, new criteria for selection of materials, recycling, and others.

In most states of Europe the main objectives in the environmental field are: to preserve, protect, and improve the quality of the environment, to contribute towards protecting human health, and to ensure a provident and rational utilization of natural resources. Organizations of all kinds in the developed countries are increasingly concerned to achieve and demonstrate sound environmental performance in compliance to main objectives. In contrast, mishandled environmental issues could seriously affect an operation, or even a company, through excessive costs or a damaged reputation. Alert organizations, therefore, wish to be able to demonstrate that industrial processes involved are operated responsibly and that products produced are environmentally sympathetic. They do so not only in context over stricter environmental legislation, but due to the need to develop and implement an environmental risk management strategy to maintain their competitive position and anticipate future legislative developments.

Due to heterogeneous levels of economic and social development among European countries, particularly in the relationships: West to East, there is a fundamental desire among policy-makers of Europe to 'level the playing field' in terms of the environmental context within which companies operate. But there exists an unfair advantage of firms operating in the states where there are lax environmental regulations. As a consequence, firms can produce at a lower unit cost by not having to take into account the true costs of adopting the best practical environmental standards.

A promising action which may contribute to harmonization of the environmental issues in Europe took place at the beginning of 1993, when ISO established the new Technical Committee ISO/TC 207 on Environmental Management, which included five subcommittees: (1) Environmental Management Systems, (2) Environmental Auditing, (3) Environmental Labeling, (4) Environmental Performance Evaluation, and (5) Life Cycle Assessment. Future environmental standards ISO series 14000 are intended to promote the design, production, marketing and use of products which have a reduced environmental impact during their entire life cycle, and to enable any organization to establish an effective environmental management system (EMS). Besides, these standards would improve the efficiency of combined Health, Safety and Environmental (HSE) management systems which exist in most organizations.

The standards on environmental management systems shares common management principles with ISO 9000, the internationally recognized quality systems standard. Basic principles in an environmental management system should be: environmental strategy and policy, environmental organization and communication, environmental impact assessment, environmental management program, environmental documentation, environmental audits, environmental management reviews, etc.

Although the environmental standards are not enforced in most countries, people from the RPE world would be prepared for the implications which may be expected after their implementation.

The companies, which properly design and implement environmental management systems, demonstrate that the quality of natural environment (air, water, and soil), as well as working environment, could be improved. Many industries, today, more successfully conduct elimination, substitution or reduction of the emissions of many types of toxic substances. Hence, the levels of the air contamination at the workplace and in the environment are lower and consequently the need for the respiratory protection equipment of high protection capacity become also lower.

The inclusion of the environmental aspects of product, production, and services in recent years by the national regulations of the developed countries introduced the principles of sustainability (control of the environmental impacts and the rational use of energy and materials) in the product quality. The ISO committee TC 207 drafted the "Guide for the Inclusion of Environmental Aspects in Product Standards" (ISO 14060) at the beginning of 1995, which represents an important basis for control of the environmental effects of products at the international level. This standard recommends the use of life cycle thinking and recognized scientific methodologies in developing product standards that incorporate environmental aspects.

The quality of RPE differs mainly in the dependence of the country of their origin (developed vs. undeveloped countries). There are various approaches to the concept of the same type of RPE, e.g. some producers pay attention mainly to the protection performances, others combine protection and comfort, while only few producers demonstrate a complex approach using adequate protection, comfort, safety and environmental aspects of the product quality. Existing European RPE standards do not include environmental aspects of the product quality. The life cycle analysis and "eco-balance" of each particular RPD would establish a new basis for the control of RPE, from product concept, design, selection of materials and technology of production, through use and maintenance to disposal and recycling. There should be expected further extension of the use of recyclable polymer materials, sophisticated techniques

of design and production, the reduction of the use of aluminum, activated carbon, HEPA filtering materials, and introducing the responsibility of RPE producers for the handling of used products.

The future of many producers, who are producing over a billion of the disposable halfmasks, millions of cartridges, hundreds of thousands of rubber half- and full-face masks per year, will be strongly influenced by the new ISO 14000 standards, particularly those who are not able to implement new scientific methodologies and environmental thinking in their business.

PERFORMANCE COMPARISON OF SECOND-GENERATION OXYGEN SELF-RESCUERS

Nicholas Kyriazi

On 21 June 1981, underground coal mine operators in the United States were required to make available to each miner a self-contained self-rescuer (SCSR). The regulations (30 CFR 75.1714) require that each person in an underground coal mine wear, carry, or have immediate access to a self-rescuer that provides an oxygen source. Previous to this was the requirement for a filter self-rescuer (FSR) which protects only against low levels of CO.

A performance study of the four, second-generation oxygen self-rescuers approved for use in the United States, mostly in underground coal mines, was undertaken as an assessment of present technology. The purpose of this study was to provide a side-by-side comparison of apparatus performance, unavailable elsewhere, for the benefit of both users and manufacturers. A previous such study was published in 1984 on the first generation of oxygen self-rescuers, deployed in underground coal mines beginning in 1981. The apparatus were tested on a breathing and metabolic simulator in the Life Support laboratories of the U.S. Bureau of Mines. All of the apparatus have been approved by the National Institute for Occupational Safety and Health (NIOSH) and the Mine Safety and Health Administration (MSHA). Parameters monitored during the testing were inhaled levels of CO₂ and O₂, inhaled wet- and dry-bulb temperatures, and breathing pressures. The metabolic demand placed on the apparatus represented the average demand of the 50th-percentile miner performing a 60-minute, man-test 4 from the Code of Federal Regulations, Title 30, part 11 (30 CFR 11). Results presented include apparatus service life, quantity of usable oxygen, and averages and peaks of monitored parameters.

In addition, a brief study evaluating the estimated impact of the underground environment was performed on three of the apparatus. The apparatus omitted in this study, the CSE SR-100, was studied previously (Report of Investigation 9328). The environmental simulation treatments performed on the apparatus were temperature extremes (71°C for 48 h (5) with a preheated convection oven and -45°C for 16 h) and shock and vibration.

The three 60-min-rated apparatus, the SR-100, OXY K plus, and Portal-Pack, are marketed to be direct replacements for their predecessors, the AU-9A1, OXY-SR 60B, and 60-min SCSR, respectively. The 10-min-rated M-20, however, is intended to be used in conjunction with the 60-min-rated Ocenco EBA 6.5. It was designed to be worn on the belt, replacing a belt-worn filter self-rescuer. While the others are also intended to be belt-worn, there has been some resistance to this among users even though they are much smaller than their predecessors which were mostly stored.

All of the apparatus are pendulum-flow, the inhalation of flow path being the reverse of the exhalation flow path, with no check valves. The three 60-min-rated apparatus all have volume-activated relief valves vs. the pressure-activated relief valve on the M-20. Of the three volume-activated relief valves, however, only the SR-100 and the OXY K plus purge excess gas before it has entered the chemical bed, thus sparing it somewhat. These two also had the lowest CO₂ levels. This could just as easily be the result of more effective CO₂ absorption by the chemical beds, however.

The Portal-Pack is the only unit with a heat exchanger in its breathing hose and had the largest breathing bag volume, approximately 13 L, over 40% larger in volume than the next largest. It also had the lowest average wet- and dry-bulb temperatures. The M-20, with the smallest breathing bag and no breathing hose to exchange heat, had the highest average wet- and dry-bulb temperature.

How TO ACHIEVE SIZE AND WEIGHT REDUCTIONS IN **SCSRs**

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and*

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Sometimes users are confused about how to regard the rated duration of an MSHA/NIOSH-approved 60-min. Self-Contained Self-Rescuer (SCSR), especially when an SCSR is used in a way which takes it outside of the test conditions under which it was approved. For instance, for a mine escape that takes a miner from the deepest point of penetration in the mine to the surface, how long will a 60-min. SCSR last? Just as important, is the related issue of how to achieve size and weight reductions in SCSR. A smaller, lighter weight SCSR will be easier to wear as personal protective equipment, and thus more acceptable to miners.

A model is presented which we believe can help provide practical and quantitative answers to these questions for SCSR that store oxygen as a solid chemical. We begin by showing how an ideal SCSR performs. By definition, an ideal SCSR delivers the same quantity of usable oxygen at all work rates. So, if work rate (rate of oxygen consumption) is plotted against duration, the resulting SCSR performance curve would be a hyperbola with the axes as asymptotes, since the quantity of usable oxygen is always conserved.

As might be expected, real SCSR perform otherwise. The results of laboratory tests and field trials show that, unlike ideal apparatus, usable oxygen is not conserved for real SCSR. Instead, usable oxygen is a variable that depends upon the work rate. Although the performance curve for a real SCSR is still a hyperbola, the asymptotes are no longer zero, indicating losses or inefficiencies. In other words, all of the oxygen stored in a real SCSR is not available to a user. Some oxygen is wasted due to overproduction and venting, or because it remains chemically unreacted in the bed.

The next step of our analysis is to account for these inefficiencies. We show how to modify the ideal performance model by introducing two loss parameters. The magnitudes of the loss parameters can be estimated from experimental data, and the loss parameters help explain how a real SCSR will perform across a range of work rates which lie outside of the approval test conditions.

Minimizing losses due to inefficiencies translates directly into SCSR size and weight reduction. So, we take a variation of parameters to estimate percentage decreases in size and weight due to small changes in the loss parameters, and then discuss how practical improvements might be made through engineering design.

THE THERMAL AGING STABILITY OF **DIOCTYL PHTHALATE (DOP)**

Zane N. Frund, Jr. and Ronald E. Thompson

Recently, concern has arisen that dioctyl phthalate (DOP) decomposes after prolonged use in the "hot smoke" DOP penetrometer. A controlled study was conducted to quantify the changes in the purity, structure, and (aerosol) particle size distribution of dioctyl phthalate (DOP) after prolonged heating in a "hot smoke" DOP penetrometer.

Several instrumental techniques were employed to investigate the properties of fresh and exposed DOP samples. These techniques included X-ray fluorescence, gas chromatography-mass spectrometry, Fourier Transform infrared analysis, UV-visible spectrometry and light scattering techniques.

Testing and analysis revealed that DOP experiences negligible decomposition (99.11% for fresh vs. 98.49% for exposed) after prolonged heating (336 hours at $167 \pm 2^\circ\text{C}$). Analysis also indicated that the brown color is due to the presence of a trace quantity (a few tenths of a percent) of a high molecular weight hydrocarbon produced primarily by the reaction of the 2-ethylhexanol impurity within the fresh DOP.

Finally, gas chromatography and light scattering measurements revealed that insignificant differences exist between the purity and the character (distribution of particle sizes, geometric mean diameter and standard deviation) of the aerosol particles generated from the fresh and exposed DOP samples.

MSA's Chemical R&D Group conducted a controlled study to quantify the changes in the purity, structure and (aerosol) particle size distribution of DOP after prolonged heating in a "hot smoke" DOP

penetrometer. The DOP penetrometer is an instrument that vaporizes DOP oil at approximately 167°C and subsequently condenses the vapors into an aerosol or smoke of known particle size. By careful control of air flows and temperatures, the particle diameter of the aerosol is adjusted to be monodisperse at 0.3 microns. The aerosol is used to test the efficiency of filter media in respiratory protection devices, such as respirators, gas masks, and air purifying systems. The details of this investigation and analysis of the results are presented in this report.

ANALYSIS OF THE FAILURE MECHANISMS AS CRITERION FOR DEVELOPMENT OF INDIVIDUAL RESPIRATORY PROTECTIVE SYSTEMS

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Gas masks are used today as the most important equipment for respiratory protection for either military or industrial applications. The masks have various problems which limit their use in the long run. The mask as a concept is based on facial sealing, which requires special adjustment and training; it is characterized by physiological limitations which derive from breathing resistance, heat stress, skin irritation, and functional impediments of stress, pain, and discomfort.

While the mask is worn during activities such as deep breathing, head movement, talking and light exertion, an "under pressure" is formed inside the mask. This under pressure condition causes leakage through the sealing area and thus reduces the protection factor.

This failure mechanism may be corrected by two elements alone or by their integration:

- a. Addition of a blower unit will supply constant air flow and reduce the under pressure inside the protection system. This will reduce also the leakage as well as allow inflow of air that will help in flushing the contaminants which penetrated the system.
- b. Neck sealing (hood concept) will substantially improve the sealing and will reduce the effective leakage area.

The use of one of these elements or a combination of both will result in higher protection reliability, especially in dynamic situations, and will reduce failures caused by repeated donnings. The combination of hood and blowers provides better physiology and increases comfort in usage.

EFFECTS OF A **NOSECUP** ON RESPIRATOR PERFORMANCE IN SELECTED OPEN-CIRCUIT SELF-CONTAINED BREATHING APPARATUS

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The effect of nose cups on respirator performance in three National Fire Protection Association-compliant open-circuit positive pressure SCBAs was investigated. Six men performed a continuous, variable work rate protocol which consisted of three exercise periods of 5, 15, and 20 minutes each while wearing an SCBA without a facepiece. Average oxygen consumption, minute ventilation, and expired peak flow were 3.38 ± 0.13 , 79.1 ± 10.6 , and 254.4 ± 29.1 for the 5-min period; 2.21 ± 0.09 , 48.7 ± 5.1 , and 182.4 ± 36.3 for the 15-min period; and 1.00 ± 0.09 , 25.8 ± 7.2 , and 113.6 ± 32.4 for the 10-min period, respectively (all units a min^{-1} , STPD, and mean $\pm$ S.D.). The same exercise tests were then performed with subjects wearing three different model SCBAs without and with a nose cup. Time to alarm, minimum and average inspired CO_2 concentration, tidal volume, and breathing frequency were measured for each test. Time to alarm was significantly reduced without versus with a nose cup [30.0 min (without) versus 34.1 min (with), $p < 0.05$]. Minimum and average inspired CO_2 concentrations, as well as the volume of re-inspired CO_2 , were significantly greater without a nose cup than with a nose cup across all exercise intensities ($p < 0.005$). Inspired minute volume was significantly greater ($p < 0.05$) without a nose cup than with during the 3.0 lpm bout but not during the 0.5 or 2.0 lpm bout. The 14% increase in

time to alarm seen with the use of a nose cup is most likely explained by the significantly lower inspired CO₂ concentration and volume of re-inspired CO₂.

FIELD TRIALS OF RESPIRATORS UNDER WINTER CONDITIONS

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Field trials and examination of properties that may depend on the weather conditions are part of the test program prior to procurement of most NBC equipment for military use in Norway. In several cases unexpected problems due to low temperature and snow have been observed and influenced the acquisition program and avoided the obtaining of equipment unsuitable for Norwegian winter climate.

In connection with the procurement of a new respirator for the armed forces in Norway, the test program included compatibility testing related to equipment and procedures, laboratory testing of properties related to materials and components and measuring of protection factors and last but not least, field trials to test wearing and application properties under realistic conditions.

Important factors that may be influenced by the cold weather are visibility and field of view due to ice or mist on eyeglasses, problems with mist related to sight correction, stiffness and problems with ice influencing the protection factor and breathing resistance. Results and experience with the tested respirators will be discussed in order to suggest solutions where winter conditions in little or no way influence the properties of the respirator.

A METHOD FOR PROJECTING THE PROTECTIVE CAPACITY OF A **PWSCSR** WITH TIME IN SERVICE

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The service life of self contained rescuers (SCSR) is generally based on comprehensive studies regarding aging in air, at elevated temperatures, under compression, and other stressors placed on each component. For all practical purposes, these tests do not include estimating the SCSR's ability to withstand being carried on a daily basis in a harsh underground mining atmosphere over a finite time period. Of particular concern is knowing if the chemical canister is maintaining the protective capacity for which it was approved.

Currently, the life supporting capacity of field deployed SCSRs is assessed by collecting a small sample of units from a given population. The sample units are evaluated using live test subjects and/or on a metabolic simulator. The results obtained from the field units are compared with new units. Because these tests are expensive in time and money, the sample size of new and field units is kept small. The conclusions made from these tests do not imply that the protective capacity of the SCSR meets the standards of certification.

The model SR-10G is classified as A Person Wearable SCSR and has been carried daily by miners for better than five years. During this time CSE Corporation has been collecting data and developing a more practical nondestructive test to predict the condition of the chemicals used to produce oxygen and remove carbon dioxide. The method has been used to assess the protective capacity of more than 1,800 field deployed units selected from a population of more than 12,000 units. The test assesses degradation of the chemicals contained within the unit and projects if the unit can remain in service for the rest of its projected service life.

This paper discusses the correlation developed to project expected performance standards for new SR-100s, the procedures used to generate chemical bed degradation in the laboratory, a correlation relating chemical degradation with performance capacity and the non-invasive test method used to evaluate chemical bed degradation.

A SIMULATED WORKPLACE PROTECTION FACTOR STUDY
OF THE E.D. **BULLARD** MODEL 77 AND MODEL 88
ABRASIVE-BLASTING SUPPLIED-AIR RESPIRATORS

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Current OSHA-assigned protection factor (APF) values for continuous-flow loose-fitting hood/helmet respirators are too restrictive. In arriving at these APF values, OSHA has used the NIOSH "Respirator Decision Logic," which groups this type of respirator in a class with other types of loose-fitting-facepiece style respirators. This combination has resulted in a very significant underestimate of the APF for continuous-flow loose-fitting hood/helmet respirators. Experimental data used by NIOSH to recommend this value did not contain performance data for the hood/helmet type of respirator. The current value used by OSHA/NIOSH also disagrees with the ANSI Z88.2-1992 APF recommendation for this type of respiratory protection.

The E.D. Bullard Company retained the Lawrence Livermore National Laboratory to carry out an evaluation of their continuous-flow loose-fitting hood/helmet respirators Model 77 and Model 88. An evaluation protocol was developed to use the traditional respirator fit-test exercises as well as a series of exercises designed to simulate typical work activities of the abrasive blasters. The specific exercise protocol is listed in Table 1 and each exercise was carried out for two minutes.

Table 1. Abrasive blasting respirator evaluation protocol.

While standing on feet:

- Normal breathing
- Bending at waist and touching toes with hands
- Raising arms above head
- Bending at knees
- Twisting at waist, while holding rod and raising and lowering arms
- Running in place
- Normal breathing

While lying on back (abrasive-blasting movements):

- With hands together, move hands from side to side
- With hands together, move hands from above head and touch toes
- Roll side to side
- Roll over onto belly and back by throwing one leg over the other

While lying on belly:

- With hands in front of subject, move hands up and down

The protection factor during each set of exercises was measured using a forward-light-scattering photometer and a polyethylene glycol 400 aerosol. The pressure differential between the inside and outside of the respirator was also measured during each set of exercises.

Four test subjects were evaluated using six different respirators (three each of two models) for a total of 24 complete tests. Results from these tests indicate a small number of negative excursions within the respirator, which did not correlate with any detectable decrease in the calculated protection factor. Overall calculated protection factors for the Bullard Model 77 and Model 88 were greater than 40,000. These results will be analyzed in more detail, and they support the need for OSHA/NIOSH to significantly increase the APF for continuous-flow loose-fitting hood/helmet respirators.

SELF CONTAINED SELF RESCUER REQUIREMENTS IN MINING AROUND THE WORLD: A **MANUFACTURER'S** PERSPECTIVE

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Hazards in underground mining around the world are very similar regardless of the geographical location, type of ore mined or the sizes of the mine. These hazards may include fire and explosion hazards, electrical hazards, and roof and rib control hazards just to name a few.

Even more similar than the hazards themselves, is how the miners must protect themselves from the hazards. In the event of an explosion, a fire or a lack of fresh air, the miner is protected by some form of self-rescue respiratory device while egressing the mine. This device can be either a simple filter type respirator or a self contained self rescuer.

It seems rather obvious that if the hazard is the same worldwide and the appropriate protection is the same worldwide (i.e., protection of the human respiratory tract) then it is only logical that the respiratory equipment requirements would be the same worldwide—not only in what the miner should wear, but the methodology used to approve a particular respiratory device.

After researching mining safety regulations in many countries around the world, it was surprising to find such a wide spectrum of respiratory requirements for such similar mining hazards.

Federal mining regulations require that every underground coal miner in the U.S. be equipped with an MSHA/NIOSH-approved 60-min. duration Self-Contained Self-Rescuer (SCSR), a closed-circuit breathing apparatus designed to supply a miner with a breathable atmosphere in the aftermath of a mine explosion or fire. Besides getting an SCSR approved, a manufacturer must also stipulate a service life policy that states how long, and under what circumstances, before his SCSR must be removed from service.

This presentation outlines a practical, scientific method for determining SCSR service life.