

RESPIRATOR ARTICLE ABSTRACTS

We review the articles published in the American Industrial Hygiene Association Journal (*AIHJ*) and the Applied Occupational and Environmental Hygiene Journal for information that is applicable to the field of respiratory protection; we then publish abstracts of these articles. We appreciate the cooperation of the American Industrial Hygiene Association and the American Conference of Governmental Hygienists in allowing us to do this.—Ed.

"Physiological Responses of Firefighting Students During Simulated Smoke-Diving in the Heat" by Sirpa Lusa, Veikko Louhevaara, Juhani Smolander, Mika Kivimäki and Olli Korhonen, *American Industrial Hygiene Association Journal*, May 54(5):228-231, 1993.

While wearing a self-contained breathing apparatus and fire-protective clothing, 35 healthy firefighting students aged 19-27 years performed smoke-diving (entry into a smoke-filled room) during a simulated shipboard fire. The mean ($\pm$ SD) ambient temperature inside the simulator was $199 \pm 12^\circ\text{C}$ and the task lasted 17 ± 4 min. All subjects were fit according to their maximal oxygen consumption, which was 52.4 ± 5.2 mL/min/kg (4.08 ± 0.45 L/min). During the smoke-diving the average heart rate was 150 ± 13 beats/min ($79 \pm 6\%$ of maximal heart rate attained in a cycle-ergometer test), and the peak heart rate was 180 ± 13 beats/min ($95 \pm 6\%$ of maximal heart rate). The estimated oxygen consumption was 2.4 ± 0.5 L/min ($60 \pm 12\%$ of maximal oxygen consumption). Neither ability to tolerate stress (as determined by the instructors) nor previous experience in smoke-diving tasks seemed to influence the heart rate or estimated oxygen consumption during the experiment. Smoke-diving was physically very demanding even for the young and fit subjects, showing the importance of regular evaluation of the health and physical fitness of every firefighter who has to carry out smoke-diving tasks.

"Estimating Service Lives of Organic Vapor Cartridges" by Gerry O. Wood, *American Industrial Hygiene Association Journal*, January 55(1):11-15, 1994.

Procedures were developed for estimating service lives of air-purifying organic vapor respirator cartridges, including methods for untested compounds and use conditions (concentration, temperature, and airflow rate). Correlations of adsorption capacities and adsorption-rate coefficients based on equilibrium and breakthrough curve data were reviewed. These correlations were combined using the Reaction Kinetic (modified Wheeler) equation to estimate breakthrough times. The proposed estimation procedure showed 95% confidence intervals of up to $\pm 50\%$ when no breakthrough data were assumed. It is shown how even limited breakthrough curve data for one vapor/carbon combination can be used to substantially improve the accuracy of the estimation. Only dry conditions (below 50% relative humidity) have been considered so far.

"Stachybotrys Atra Corda May Produce Mycotoxins in Respirator Filters in Humid Environments" by Anna-Liisa Pasanen, Marjo Kikulin, Seija Berg, Eeva-Liisa Hintikka, *American Industrial Hygiene Association Journal*, January 55(1):62-65, 1994.

This paper examines the growth and toxin production of *Stachybotrys atra*, a cellulose-decomposing fungi, in two respirator filters with different ratios of cellulose and fiberglass at relative humidities of air (RH) 78-100% for 86 days. The results show that *S. atra* can grow only in filter material of high cellulose content. *S. atra* grew slightly at RH 84-89% but did not produce toxins. Under saturated conditions, *S. atra* grew and produced satratoxin H regardless of variation in temperature. The present study indicates that *S. atra* can grow on cellulose-containing filter material and produce toxins in the filter under humid conditions.

"Development of a Dichotomous-Flow Quantitative Fit Test for Half-Mask and Full-Facepiece Respirators" by Usha Krishnan, Klaus Willeke, Arvydas Juozaitis, Matti Lehtimäki and Krzysztof Szewczyk, *American Industrial Hygiene Association Journal*, March 55(3):223-229, 1994

A new method to quantitate the fit of elastomeric half-mask and full-facepiece air-purifying respirators was developed. In this method the two flows, cartridge flow and leak flow, are separate. The air-purifying cartridges of the respirator are attached to a reference respirator. A selected flow equivalent to the inhalation flow of the wearer is drawn through the cartridge pair. A feedback system consisting of a pressure controller and a control valve is used to set the pressure drop in the mask on the subject's face equal to the pressure drop in the reference mask. The face seal leak flow is measured while the subject holds his or her breath for a short period of time. The ratio of total flow (cartridge flow + leak flow) to leak flow is a measure of fit and is defined as the flow fit factor. Aerosol fit factors and flow fit factors were determined using sampling probes in three mask locations: top, center, and bottom. A Kruskal-Wallis test showed that aerosol fit factors obtained from the three locations were significantly different from each other ($p = 0.0001$) while the corresponding flow fit factors were not. Aerosol fit factors obtained with the center probe had the least variability. The coefficient of variation in aerosol fit factors ranged from 5.4% for the center probe to 19% for the bottom probe. The coefficient of variation in flow fit factors was much lower, ranging from 1.7% for the top probe to 2.2% for the center and bottom probes.

"Estimated Workplace Protection Factors for Positive-Pressure Self-Contained Breathing Apparatus" by Donald L. Campbell, Gary P. Noonan, Timothy R. Merinar and Judith A. Stobbe, *American Industrial Hygiene Association Journal*, April 55(4):322-329, 1994

An analytical model is presented that estimates the distribution of workplace protection factor (WPF) values for positive-pressure respirators. Input for the model is (1) the instantaneous facepiece pressure measured as a function of time and (2) the distribution of WPF values for a negative-pressure version of the respirator. As an example application, the model was applied to 57 measurements of facepiece pressure made in a previous National Institute for Occupational Safety and Health study called "Firesmoke." That study involved professional firefighters wearing positive-pressure self-contained breathing apparatus (SCBA). During Firesmoke, there were four donnings in which facepiece pressure momentarily went negative one or more times during use. The purpose of the effort described here was to assess the significance of these momentary negative excursions in facepiece pressure. To that end, an analytical model was developed that estimates the ratio of the mass of contaminant that enters the facepiece during these negative excursions to that which would be expected to enter a negative-pressure respirator utilizing the same facepiece. Thus, the performance of a positive-pressure SCBA can be determined relative to the performance of a negative-pressure respirator with the same

facepiece—either a negative-pressure SCBA or a negative-pressure air-purifying respirator. The NIOSH-assigned protection factor (APF) for a negative-pressure full facepiece is 50; the APF for a positive-pressure SCBA is 10,000. The results of the application of this analytical model are consistent with the current NIOSH APF for a positive-pressure SCBA.

"Variation in Quantitative Respirator Fit Factors Due to Fluctuations in Leak Size During Fit Testing" by Usha Krishnan, Klaus Willeke, Arvydas Juozaitis, Toshihiko Myojo, Glenn Talaska, and Rakesh Shukla, *American Industrial Hygiene Association Journal*, April **55**(4):309–314, 1994

Variation in fit factors during quantitative respirator fit testing was studied for a high degree of fit (aerosol fit factors > 1000) and a low degree of fit (aerosol fit factors < 1000). In a controlled human study, fit factors were determined sequentially for three different exercises by (1) an aerosol fit test (using a portable condensation nuclei counter and room aerosol as the test agent) and (2) the newly developed dichotomous-flow fit test (Dichot). For the higher level of respirator fit, the aerosol fit factors were 30 to 60 times the corresponding flow fit factors, and for the lower level of respirator fit they were 2 to 4 times the flow fit factors. A coefficient of variation (CV) of 84% (GSD 1.6) for the higher respirator fit and 178% (GSD 2.2) for the lower respirator fit data was observed in the human study when aerosol fit factors for the three exercises were pooled. In a similar mannequin study, the center sampling probe gave aerosol fit factors with a CV of 5.4% (GSD 1.05). The flow fit factors for all three exercises pooled had a CV of 36% (GSD 1.3) for the higher respirator fit and 40% (GSD 1.5) for the lower respirator fit data, while the mannequin study gave flow fit factors with a CV of 2.2% (GSD 1.02). Thus, the variation in fit factors obtained in the human study was much higher than that obtained in a mannequin study. However, the variation in the aerosol method relative to the flow method, in the human study, is of the same order of magnitude as in the mannequin study. This suggests that the higher variation in the human tests is mainly due to variations in facesal leak size and not to increased systematic errors. It was estimated that the fluctuations in facesal leak size for the subject with the high fit factor varied between 0.5 mm and 0.7 mm, and between 1.0 mm and 1.3 mm for the subject with the low fit factor. Thus, the fit factor determined for a human cannot be expected to be constant even for the most perfect test system.

"Visual Field Loss While Wearing Full-Face Respiratory Protection" by Sanford D. Zelnick, Roy T. McKay and James E. Lockey, *American Industrial Hygiene Association Journal*, April, **55**(4):315-321, 1994

The loss of visual field was quantified for 21 test subjects while they wore three full-face respirators. Changes in visual field were quantified for each type of respirator using a modified Goldmann projection perimeter. The loss of visual field was determined by calculating the area under the curve while wearing a respirator to that while wearing no respirator. Distinct patterns of visual field loss were apparent for the different style respirators. Analysis of the patterns could lead to the design of full-face respirators with improved visual qualities, which could improve worker safety for certain occupations. This technique also could be of help when selecting models of respiratory protection when certain visual fields must be maintained.

"The Effects of Respirator Use on Workers' Productivity in a Mentally Stressing Task" by Majid Jaraiedi, Wafik H. Iskander, Warren R. Myers and Rebecca Giorcelli Martin, *American Industrial Hygiene Association Journal*, May, **55**(5):416–424, 1994

This article quantitatively determines the effect of wearing half-facepiece respirators, the most widely used type in industry, on worker productivity and efficiency in a mentally stressing task. An experiment investigated the performance of 10 subjects in a task simulating inspection of printed circuit

boards. Accuracy and mean reaction time were tested automatically. Paced and unpaced task simulations were used to evaluate the effect of wearing the respirator on response times and the accuracy of subjects' responses for different product complexities and quality levels. The results indicated that wearing the respirator, in general, did not affect the speed or accuracy of subjects performing simulated inspection tasks. Pacing the task resulted in longer response times but did not affect accuracy. More complex products resulted in longer response times but also did not affect accuracy. High product quality resulted in longer response times and a higher miss rate. In terms of accuracy and reaction times a statistically significant difference was found in the performance of subjects.

"A Validation Study of Respirator Fit Testing by Controlled Negative Pressure," by Clifton D. Crutchfield, Alyson M. Ruiz, and Mark D. Van Ert, *Applied Occupational and Environmental Hygiene*, May, 9(5):362–366, 1994

Respirator fit testing is a fundamental part of a respiratory protection program. The development of a quantitative respirator fit test method based on controlled negative pressure (CNP) provides an alternative to standard aerosol fit test methods that is faster and less dependent on ambient test conditions. This study was conducted to evaluate the performance of a controlled negative pressure system using the method of validation protocol proposed in the American National Standards Institute (ANSI) Respirator Fit Test Methods Standard.

The study procedure involved measuring 100 pairs of sequential fit tests using a generated aerosol system and a controlled negative pressure system. A study population of 25 subjects was tested with both half-mask and full-face air purifying respirators. Additional fit test series were accomplished with each mask type by inserting leak sources between each subject's cheek and respirator face seal. The leaks were used to achieve a distribution of fit test results above and below the test acceptance criterion of a fit factor of 100.

Study results show that the controlled negative pressure system exceeded the ANSI validation criteria in the areas of test sensitivity, test specificity, and predictive value of a pass. The CNP system did not pass any respirators that were subsequently rejected by the aerosol system. The CNP system did not meet the ANSI criterion for predictive value of a fail. Thirty respirators with induced leakage exceeding 530 ml/min were rejected by the CNP system but subsequently passed the generated aerosol fit test.

"Chinese-Language Labeling of Cartridges for Air-Purifying Respirators," by W. Lo and S. P. Levine, *Applied Occupational and Environmental Hygiene*, May, 9(12):961, 1994

Personal protective equipment (PPE) is used for worker protection all over the world. The United States and other English-speaking countries are the leading manufacturers of these products and labeling and color coding of PPE hardware follow conventions of the countries of origin.

In the case of cartridges for air-purifying respirators, the color codes indicate the purpose of the cartridge. Advertising materials, translated into the language of the end-user country, are also useful. At times, cartridge instructions are also available in the local language.

However, the label on the cartridge itself is almost always printed in English (Figure 1a). Therefore, those who do not speak English may be at a disadvantage in the correct application of cartridges for air-purifying respirators. This is a situation that can endanger workers through misuse of PPE devices.

To avoid this potential risk, labels should be printed in the local language (Figure 1b). However, because the cartridges must remain sealed in gas-tight packages before use, local agents are unable to

apply new labels written in the local language. Therefore, the PPE manufacturers should apply labels in the end-user language prior to shipment.

Incentives for manufacturers to translate labels into Chinese are twofold:

1. The Chinese-language market in East Asia numbers 15 billion persons, which exceeds the English-language market.
2. Local legislation or regulations may be written in an effort to ban PPE devices without labels in the local language.

These observations may be applicable to all PPE devices, as well as to other devices in the field of industrial hygiene and safety.

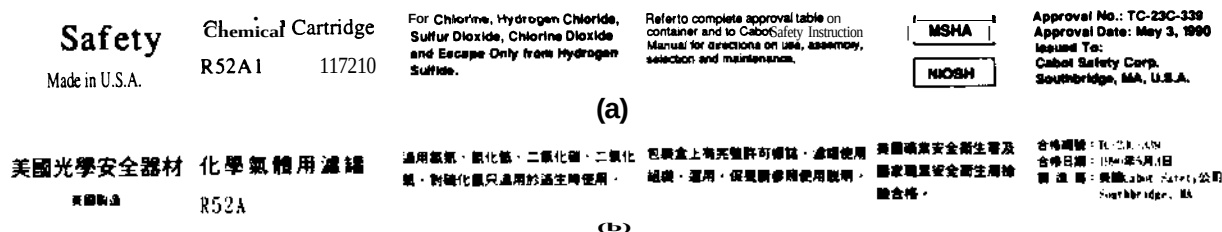


FIGURE 1. (a) English-language label from an air-purifying cartridge sold in the Republic of China. (b) Proposed Chinese-language label for the same cartridge.

"Modeling Respirator Penetration Values with the Beta Distribution: An Application to Occupational Tuberculosis Transmission" by Mark Nicas, *American Industrial Hygiene Association Journal*, June, 55(6):515-524, 1994

The lognormal distribution typically is used to model variability in respirator penetration values. The lognormal model is a good descriptor where the average penetration value is low, but may be a poor descriptor where the average penetration values could be predicted to exceed unity. In this regard, the beta distribution offers greater flexibility than the lognormal in modeling penetration values over the physically plausible interval [0,1]. The beta distribution also is shown to be mathematically convenient for describing the risk of airborne transmission of tuberculosis among a respirator-wearing population. Infection can occur following inhalation of respirable particles, termed droplet nuclei, carrying viable *Mycobacterium tuberculosis* bacilli. Based on the expected number of infectious doses inhaled, the Poisson probability model traditionally is used to predict an individual's risk of infection. This article synthesizes the beta distribution as applied to average penetration values among a respirator-wearing population, and the Poisson distribution, as applied to an individual's infection risk, to describe the population risk of *M. tuberculosis* infection.

"ANSI Z88.2 (1992): Practices for Respiratory Protection" by Thomas J. Nelson, Donald P. Wilmes and Robert A. daRoza, *American Industrial Hygiene Association Journal*, July, 55(7):660-662, 1994

This article outlines changes to the ANSI Z88.2 standard for respiratory protection, which incorporates the latest information on the performance of respirators. Several major changes have been made in the standard since its last revision in 1980, such as revision of the list of assigned protection factors and changes in the requirements for breathing air, either from the immediate environment or from air supplies. The sections of the 1980 standard regarding written procedures and records have been rewritten to clarify their content. New material includes a selection guide, guidance for the testing of breathing air supplies and a requirement to fit test atmosphere-supplying respirators. The assigned protection factors listed in the standard incorporate information generated by a number of studies on respirator

performance that have been made in the last decade, including both workplace and laboratory studies. The revised standard clarifies the requirements for assuring that adequate breathing supplies are provided. An immediately dangerous atmosphere is defined as any atmosphere that deviates from 20.9% oxygen unless the reason for the change is known. In addition, specific guidance is given on the tests required for air supplies that come from purchased sources or are generated by compressors.

"Task Performance with Visual Acuity While Wearing a Respirator Mask" by Arthur T. Johnson, Cathryn R. Dooly and Elizabeth Y. Brown, *American Industrial Hygiene Association Journal*, September, 55(9):818-822, 1994

Forty-six subjects were required to perform a console-monitoring and two hand-eye coordination tasks while wearing masks with lenses clouded to give seven levels of visual acuity. The console-monitoring task performance was found to be the most sensitive to visual acuity, followed by the random hand-eye coordination task. These results can be used to help predict performance degradation when lenses become clouded due to condensation or particulate deposition.

"Fit Test for Filtering Facepieces: Search for a Low-Cost, Quantitative Method" by Toshihiko Myojo, Klaus Willeke and Chih-Chieh Chen, *American Industrial Hygiene Association Journal*, September, 55(9):797-805, 1994

Conventional fit-testing methods use HEPA filter cartridges to distinguish face-seal leakage from filter penetration and thereby test a respirator's ability to face-seal. These methods cannot be applied to low-efficiency filtering facepieces that also protect the wearer through aerosol particle retention by the filter material. Therefore, the ability of a filtering facepiece to face-seal is of interest to the developer for improving the design and to the user for finding the conditions for optimal face-seal. A unique difference has been found between the combined aerosol penetration through filter medium and leak site at low versus high flow rate. This feature has been used to differentiate face-seal leakage from filter penetration. A "fit index" has been introduced as the most sensitive indicator of fit. When normalized by reference to the aerosol penetration through the filter material, this index displays a unified behavior irrespective of the filter material used. The fit index is determined by relating the measured total aerosol concentration at a high flow rate to that at a low flow rate. Tests during normal breathing of a human subject compare well with the data obtained during breath-holding experiments. Available instruments may be used for this test, but need to be modified for tests on humans.

"Reliability of Respiratory Inductive Plethysmography for Measuring Tidal Volume During Exercise" by David M. Caretti, Paul V. Pullen, Leslie A. Premo and Wade D. Kuhlmann, *American Industrial Hygiene Association Journal*, October, 55(10):918-923, 1994

This study was designed to determine the reliability of measurements of respiratory volumes obtained with a respiratory inductive plethysmograph (RIP) during exercise. Tidal volumes (VT) from the RIP were compared with simultaneous flowmeter volumes in 8 healthy subjects at 5 incremental work rates of 60, 90, 120, 150 and 180 W during cycling and treadmill exercise. During cycling, average RIP and flowmeter values did not differ significantly at work rates below 180 W for 63% of the subjects. Average RIP and flowmeter VT were similar at work rates below 180 W for 50% of the subjects, and for 83% of the subjects at intensities below 150 W. The variability in these results may be attributed to several factors including RIP calibration errors and slippage of the RIP elastic bands containing the inductive coils. Correlations of breath-by-breath flowmeter and RIP VT were significant for subjects during cycling ($R = 0.73$, $P < 0.05$) and treadmill exercise ($R = 0.78$, $P < 0.05$). These findings suggest that the RIP should be considered a semi-quantitative method for measurements of tidal volume during exercise with and without respirator wear.

"Adsorption Prediction of Binary Mixtures on Adsorbents Used in Respirator Cartridges and Air-Sampling Monitors" by Nader Vahdat, Peter M. Swearengen and James S. Johnson, *American Industrial Hygiene Association Journal*, October, 55(10):909-917, 1994

A mathematical method was developed for predicting the performance of respirator cartridges and air-sampling monitors in the presence of binary mixtures. This method uses only data for pure-component adsorption equilibrium to calculate the breakthrough curves of the two components in a binary vapor mixture. The Ideal Adsorbed Solution Theory was used to calculate the adsorption equilibria for the components in a binary mixture. The adsorption capacities were then used in expressions similar to the modified Wheeler equation for pure compounds to determine the breakthrough curves for the binary mixture. This technique applies to a wide variety of binary mixture/adsorbent systems. In the present study it was successfully applied to the adsorption of four binary mixtures of acetone and m-xylene on activated carbon, three binary mixtures of acetone and styrene on activated carbon, and a binary mixture of carbon dioxide and water vapor on a molecular sieve. The predicted breakthrough curves were in agreement with experimental data.

"Personnel Protection During Aerosol Ventilation Studies Using Radioactive Technetium (Tc^{99m})" by Rick D. Huff, Paula Horwitz, and Stephen J. Klash, *American Industrial Hygiene Association Journal*, December, 55(12):1144-1148, 1994

Two commercially available nebulizing devices used for ventilation studies were evaluated. The nebulizers use radioactive Technetium-99m (Tc^{99m}), a potential source of room air contamination. Ambient air concentrations of Tc^{99m} were monitored, as were the exposures of department personnel not performing ventilation studies. Room surfaces and air vents were examined to determine the extent of contamination in the examination room. Personnel were evaluated for contamination on clothing, hair and airways when hospital lab coats and latex gloves were the only protective apparel used. Though the maximum permissible concentrations of $4 \times 10^{-5} \mu Ci/c^3$ was not exceeded, preliminary results indicated levels as high as 11,000 disintegrations/min in the nasal passages of personnel. These findings clearly demonstrate the need for more effective personnel protective devices. Personnel contamination resulted primarily from the patient due to an inability to maintain a proper oral seal on the nebulizer mouth-piece. Conventional hospital surgical masks were ineffective in reducing internal deposition to tolerable levels. By comparison, levels were reduced by 19% ($p > 0.10$) through use of methods such as simple body substance isolation techniques and high-efficiency disposable respirators. Levels approaching 50 disintegrations/min or less were obtainable ($p < 0.001$), and overall levels of Tc^{99m} were reduced by 78%.

"Quantitative Respirator Fit Tests of Tucson Fire Fighters and Measurement of Negative Pressure Excursions During Exertion" by Jefferey L. Burgess and Clifton D. Crutchfield, *Applied Occupational and Environmental Hygiene*, January, 10(1):29-36, 1995

Pressure-demand self-contained breathing apparatus (SCBA) respirators are designed to maintain a positive pressure inside the facepiece at all times and therefore provide a high degree of respiratory protection. However, under conditions of high exertion fire fighters may overbreathe their respirators and transiently develop negative facepiece pressures. For pressure-demand respirators, facepiece leakage requires both negative pressure excursions and poor facepiece fit. Tucson Fire Department (TFD) fire fighters were studied to determine if this overbreathing poses a potential health threat, and if quantitative respirator fit testing could improve fire fighter safety. TFD fire fighters wear SCOTT® 4.5 unit pressure-demand SCBA. Controlled negative pressure (CNP) fit testing demonstrated low facepiece leakage (< 10 cc/min at -0.51 inches of water) in 78 percent of 102 TFD fire fighters and in 82 percent of 51 fire fighters fit for a large facepiece using a qualitative technique. The maximum leakage in a fire fighter fit for a large facepiece was 1530 cc/min. Treadmill testing of 10 fire fighters revealed that they

all had facepiece negative pressure excursions (mean negative pressure 0.071 ± 0.024 inches of water; mean duration of negative pressure excursions $3.41 \pm 2.04\%$). Application of the maximum measured negative pressure excursion during treadmill testing to the worst facepiece leakage rate measured during CNP fit testing resulted in a calculated protection factor of 4000. All other fire fighters fit for a large facepiece had a calculated protection factor of over 10,000. While not essential, CNP respirator fit testing can provide important information for fire fighters using pressure-demand SCBA.

"Exposure Assessment and Respirator Selection in the Cleaning of Crude Oil Process Vessels" by Kate T. H. Durand, Peter S. J. Lees and David G. Kem, *Applied Occupational and Environmental Hygiene*, February, **10**(2):120-124, 1995

The processes in the oil production industry are generally closed systems. The workers who clean and maintain process vessels, however, are exposed to the hazards of crude oil and confined spaces. Although respiratory protection is often used by these workers, exposures have not been documented and respirator selection procedures using detector tubes to measure benzene concentrations have not been validated. This study evaluates the effectiveness of this approach to respirator selection by examining actual exposures of a group of vessel workers and assessing the adequacy of protection that was provided. Personal breathing zone samples and area samples were collected by active adsorptive sampling during the cleaning of oil separators. Area air samples were also collected prior to entry into the vessels in conjunction with detector tube sampling conducted by safety personnel. Adsorptive air sampling indicated that exposure concentrations ranged from nondetectable to 5.8 ppm, averaged over the duration of an entry. Although there were inconsistencies in the relationship between measured benzene concentrations and selected respiratory protection, workers were always adequately protected according to the requirements of the Occupational Safety and Health Administration benzene standard.

"Heat Strain Assessment for Workers Using an Encapsulating Garment and a Self-Contained Breathing Apparatus" by Pierre C. Dessureault, Richard B. Konzen, Newton C. Ellis, and Daniel Imbeau, *Applied Occupational and Environmental Hygiene*, March, **10**(3):200-208, 1995

This study evaluated the physiological response of subjects wearing a Tyvek®-Saranex® totally encapsulating suit and self-contained breathing apparatus (SCBA) while working under four environmental conditions. The work was performed on an ergometer connected to a measuring unit that maintained the work load at 255 W (220 kcal/h). Five young male cyclists (mean age = 28.7 years), familiar with the use of a SCBA and an encapsulating suit, were scheduled to perform this work under all four environmental conditions in a randomized series. A control session without the SCBA and the suit was performed at the end of the experiment in a cool environment. Each session was conducted in an environmental chamber and was scheduled to last 90 minutes, that is, three periods composed of 25 minutes of work each, followed by a 5-minute rest period. Physiological measurements included heart rate, six-point skin temperature (arm, chest, back, neck, lateral thigh, and medial thigh), and rectal temperature. Dry bulb temperature (T_{db}) was varied from 30.5° to 32.5°C and globe temperature (T_g) from 30.5°C to 40°C. Air velocity was constant at 1 m/s and relative humidity was kept between 35 and 45 percent. Measurement of all parameters was obtained every 2 minutes. The average rectal temperature increase varied from 0.28°C (when $T_{db} = 30.5^\circ\text{C}$ and $T_g = 30.5^\circ\text{C}$) to 1.30°C (when $T_{db} = 32.5^\circ\text{C}$ and $T_g = 40^\circ\text{C}$). The results showed that heart rate and skin temperature are well correlated with the rise in rectal temperature. A regression analysis showed that dry bulb temperature, globe temperature, and their two-way interaction along with time, are good predictors of the rise in rectal temperature [coefficient of correlation (R^2) - 0.77]. The successive addition to the model of heart rate ($R^2 = 0.82$) and skin temperature at the chest ($R^2 = 0.85$) improved an already good model fit.