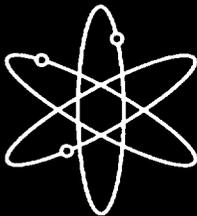
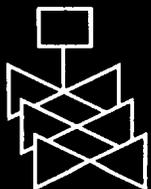
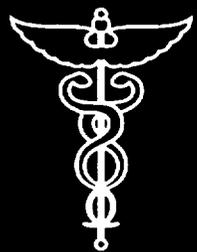


# Manual of Respiratory Protection Against Airborne Radioactive Material



Radiation Safety Associates, Inc.



U.S. Nuclear Regulatory Commission  
Office of Nuclear Reactor Regulation  
Washington, DC 20555-0001



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# Manual of Respiratory Protection Against Airborne Radioactive Material

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## **ABSTRACT**

This Manual provides information to assist respirator users and program staff in establishing a respiratory protection program that is in compliance with NRC regulations. It may also be of use to managers, supervisors, engineers and workers who may need to understand respirators, their uses, and their limitations. Chapter 1 provides a brief history of respirator regulations and discusses the applicability of OSHA's respiratory protection rules at an NRC-licensed facility. Chapter 2 covers evaluations to determine whether or not the use of respirators results in doses that are as low as reasonably achievable, and factoring hazards other than radiological hazards into decision making. Chapter 3 addresses respiratory protection procedures and programs, while Chapter 4 gives extensive information on respirators and related equipment including care, use and storage of this equipment. Chapter 5 offers advice on user-related issues such as medical evaluation, training and fit testing. Finally, Chapter 6 supplies information about personnel safety issues that may be related to respiratory protection, and addresses both radiological and non-radiological topics. A list of references and resources is included at the end of each chapter, which also provides e-mail addresses for various sources of information.

Appendices describe the human respiratory system, particle collection mechanisms, a method for calculating effective protection factors for supplied-air respirators in a tritium environment, forms for medical screening and for reporting medical status, and a copy of the "Rainbow Passage" for use during fit testing.

Front matter includes a list of acronyms and abbreviations, a list of NRC circulars, bulletins and notices related to respiratory protection, and a list of outdated NRC guidance documents on this topic.

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## FOREWORD

This document, NUREG/CR-0041, Revision 1, "Manual of Respiratory Protection Against Airborne Radioactive Material," is issued as a technical supplement to the 1999 revision of Subpart H "Respiratory Protection and Controls to Restrict Internal Exposure In Restricted Areas" of 10 CFR 20, and to Regulatory Guide 8.15, "Acceptable Programs for Respiratory Protection," Revision 1, October 1999. It imposes no new requirements. Rather, it is intended to provide licensees with technical assistance on establishing and administering programs, to provide licensees with the technical bases for industry good practices, offer suggestions for program content, and present facts about problems previously experienced in respiratory protection programs. References to existing sources of useful information are used extensively.

The goal of every respiratory protection program is to protect the health of workers from injury caused by the inhalation of harmful materials, by exposure to inadequate oxygen concentration or poor quality breathing air, or by the inappropriate use of protective equipment. It is expected that the material provided in this Manual will contribute useful technical information to help achieve that goal.

## ACKNOWLEDGEMENTS

Material for this Manual was accumulated from many sources over many years. While the people who have contributed material or suggestions are too numerous to thank specifically here, they know who they are. Bob da Roza deserves special recognition for his assistance. Several other individuals reviewed portions of this material and shared their insights. They also have the author's thanks.

Alan K. Roecklein, NRC project officer for this project, Sami Sherbini and James E. Wigginton, technical monitors, deserve a great deal of credit for the successful completion of this Manual. Their technical competence, thoroughness and knowledge of the regulatory arena contributed greatly to the quality of this Manual.

Several of the drawings used were obtained from sites on the Internet, which are cited in the References and Resources section at the end of each chapter. Line drawings of equipment were solicited from all the respirator manufacturers listed in NIOSH's Certified Equipment List. Mine Safety Appliances Company of Pittsburgh, Pennsylvania was the only one who came through with useable material. While use of drawings of their equipment does not constitute a recommendation by NRC, we thank MSA for contributing to the information provided in this Manual. Finally, thanks to Kurt Newton for his assistance in creating and manipulating graphics, and to Sharyn Mathews, for editorial and manuscript production assistance.

## ACRONYMS AND ABBREVIATIONS

ACGIH	American Conference of Governmental Industrial Hygienists
AEC	Atomic Energy Commission
AI	Alveolar interstitial region of the respiratory tract
ALARA	As low as is reasonably achievable
ALI	Annual limit on intake
AMAD	Activity median aerodynamic diameter
ANSI	American National Standards Institute
APF	Assigned protection factor
APR	Air-purifying respirator
CDC	Centers for Disease Control
CDE	Committed dose equivalent
CEDE	Committed effective dose equivalent
CF	Constant flow or continuous flow
CFR	Code of Federal Regulations
CGA	Compressed Gas Association
DAC	Derived air concentration
DDE	Deep dose equivalent
DHHS	Department of Health and Human Services
DOE	Department of Energy
DOL	Department of Labor
DOP	Diethyl phthalate
EMT	Emergency medical technician
EPA	Environmental Protection Agency
ERDA	Energy Research and Development Administration
FF	Fit factor
HEPA	High-efficiency particulate air
HHE	Health hazard evaluation
IDLH	Immediately dangerous to life or health
LPN	Licensed practical nurse
MMAD	Mass median aerodynamic diameter
MPC	Maximum permissible concentration

MSHA	Mine Safety and Health Administration
NFPA	National Fire Protection Association
NIOSH	National Institute for Occupational Safety and Health
NP	Negative pressure
NRC	Nuclear Regulatory Commission
OSHA	Occupational Safety and Health Administration
PAPR	Powered air-purifying respirator
PC	Protective clothing
PD	Pressure demand
PEL	Permissible exposure limit
PP	Positive pressure
pp	Partial pressure
PPE	Personal protective equipment
QLFT	Qualitative fit test
QNFT	Quantitative fit test
RD	Recirculating demand (closed-circuit SCBA)
REL	Recommended exposure limit
RG	Regulatory Guide
RN	Registered nurse
RP	Recirculating positive pressure (closed-circuit SCBA)
RPA	Respirator program administrator
RPM	Radiation protection manager
SAR	Supplied-air respirator
SCBA	Self-contained breathing apparatus
SCUBA	Self-contained underwater breathing apparatus
SG	Steam generator
TC	Tested and certified
TEDE	Total effective dose equivalent
TLV	Threshold limit value
USP	United States Pharmacopoeia
WGBT	Wet bulb globe temperature

## NRC Respirator-Related Circulars, Bulletins and Notices

Document Number	Title	Date
78-03	Potential Explosive Gas Mixture Accumulations Associated with BWR Offgas System Operations	February 8, 1978
78-07	Protection Afforded by Air-Line Respirators and Supplied-Air Hoods	June 12, 1978
79-08	Interconnection of Contaminated Systems with Service Air Systems Used as the Source of Breathing Air	March 28, 1979
79-09	Occurrences of Split or Punctured Regulator Diaphragms in Certain Self-Contained Breathing Apparatus	June 22, 1979
79-15	Bursting of High Pressure Hose and Malfunction of Relief Valve and "O"-Ring in Certain Self-Contained Breathing Apparatus	August 8, 1979
80-03	Protection From Toxic Gas Hazards	March 6, 1980
80-19	NIOSH Recall of Recirculating-Mode (Closed Circuit) Self-Contained Breathing Apparatus (Rebreather)	May 6, 1980
81-26, PART 1	Use of Recirculating-Mode (Closed Circuit) Self-Contained Breathing Apparatus (Rebreathers)	August 28, 1981
81-26, PART 2	Use of the Chemical "DOP"	August 28, 1981
81-26, PART 3	Placement of Personnel Monitoring Devices for External Radiation Exposure	August 28, 1981
81-26, PART 4	Personnel Entry Into Inerted Containment	August 28, 1981
81-26, PART 5	Evaluation of Instrument Characteristics When Using Portable Radiation Survey Instruments	August 28, 1981
82-28	Hydrogen Explosion While Grinding in the Vicinity of Drained and Open Reactor Coolant System	July 23, 1982
82-36	Respirator Users Warning for Certain Five-Minute Emergency Escape Self-Contained Breathing Apparatus	September 2, 1982
83-21	Defective Emergency-Use Respirator	April 15, 1983
83-67	Emergency-Use Respirator Material Defect Causes Production of Noxious Gases	October 11, 1983
83-68	Respirator User Warning: Defective Self-Contained Breathing Apparatus Air Cylinders	October 11, 1983
84-24	Physical Qualification of Individuals to Use Respiratory Protective Devices	April 5, 1984
84-34	Respirator User Warning: Defective Self-Contained Breathing Apparatus Air Cylinders	April 23, 1984
84-56	Respirator Users Notice for Certain 5-Minute Emergency Escape Self-Contained Breathing Apparatus	July 10, 1984

<b>Document Number</b>	<b>Title</b>	<b>Date</b>
84-60	Failure of Air-Purifying Respirator Filter to Meet Efficiency Requirement	August 6, 1984
85-06	Contamination of Breathing Air Systems	January 23, 1985
85-48	Respirator Users Notice: Defective Self-Contained Breathing Apparatus Air Cylinders	June 19, 1985
85-60	Defective Negative-Pressure, Air-Purifying, Full Facepiece Respirators	July 17, 1985
85-87	Hazards of Inerting Atmospheres	November 18, 1985
86-24	Respirator Users Notice: Increased Inspection Frequency for Certain Self-Contained Breathing Apparatus Air Cylinders	April 11, 1986
86-43	Problems with Silver Zeolite Sampling of Airborne Radioiodine	June 10, 1986
86-46	Improper Cleaning and Decontamination of Respiratory Protection Equipment	June 12, 1986
86-103	Respirator Coupling Nut Assembly Failures	December 16, 1986
88-100	Memorandum of Understanding Between NRC and OSHA Relating to NRC-Licensed Facilities (53 FR 43950, October 31, 1988)	December 23, 1988
89-47	Potential Problems With Worn or Distorted Hose Clamps on Self-Contained Breathing Apparatus	May 18, 1989
90-01	Importance of Proper Response to Self-Identified Violations by Licensees	January 12, 1990
94-16	Recent Incidents Resulting in Offsite Contamination	March 3, 1994
94-70	Issues Associated with Use of Strontium-89 and Other Beta Emitting Radiopharmaceuticals	September 29, 1994
94-89	Equipment Failures at Irradiator Facilities	December 28, 1994
95-01	DOT Safety Advisory: High Pressure Aluminum Seamless and Aluminum Composite Hoop-Wrapped Cylinders	January 4, 1995
97-66	Failure to Provide Special Lenses for Operators Using Respirator or Self-Contained Breathing Apparatus During Emergency Operations	August 20, 1997
98-20	Problems With Emergency Preparedness Respiratory Protection Programs	June 3, 1998
2000-07	National Institute for Occupational Safety and Health Respirator User Notice: Special Precautions for Certain Self-Contained Breathing Apparatus Air Cylinders	April 10, 2000

**Generic Communications**

The NRC does not provide a list of outdated communications in this category. Generic communications generally serve the purpose of alerting industry to some type of current problem, and are therefore not intended to be current forever. Licensees should refer to these documents for any useful information they may contain.

## Outdated NRC Guidance Documents

The health physics positions (HPPOS) and the answers provided in question and answer guidance (Q&A) listed below should no longer be used. The issues addressed have been affected by changes in the regulations, consensus standards and industry practices, and other documents. If the NRC staff updates the HPPOS data base, the affected documents will either be deleted or undergo significant revision.

### HPPOS

- 94: Regulations now prohibit beards. Background information still pertinent.
- 116: Same as 94 above. Technical rationale for not wearing facial hair is still valid, but regulations now prohibit beards.
- 117: Regulations concerning medical screening have changed. Frequency may be a function of wearer's age.
- 146: Regulations and guidance have changed for recirculating-mode SCBA.
- 162: Note that Regulatory Guide 8.15 (Rev. 1) allows contact lens use.
- 175: This is not completely consistent with upcoming guidance in ANSI-Z88.10 "Respirator Fit Testing."
- 219: The basic information is not incorrect, but licensees should refer to Section 5.1.3 of Regulatory Guide 8.15 (Rev. 1).
- 225: The old footnote (g) to 10 CFR 20 Appendix B established restrictions on the use of half-facepiece respirators. These restrictions have been removed.

### Q&As

- 131: The requirement for users to perform a user seal check upon donning a face-sealing respirator now has updated references.
- 386: Interim Policy Period is over; transition is complete.
- 418: The parenthetical discussion note on OSHA medical approvals is not consistent with the 1999 revision to 10 CFR 20 Subpart H, which allows dust masks to be used on a voluntary basis (assuming no credit) with no medical screening or fit testing. See Regulatory Guide 8.15, Rev. 1, section 4.8.

# 1 INTRODUCTION

## 1.1 History of Respirator Regulation

### *Federal Laws*

The *Atomic Energy Act of 1946* briefly acknowledged the potential peaceful benefits of atomic power. But it did not allow for private, commercial application of atomic energy. The act established the five-member Atomic Energy Commission (AEC) to manage the nation's atomic programs.

In the *Atomic Energy Act of 1954*, the government ended its monopoly on technical data and made the growth of a private commercial nuclear industry an urgent national goal. The AEC was assigned to continue the weapons program, promote the private use of atomic energy for peaceful applications, and protect public health and safety from the hazards of commercial nuclear power.

Congress passed the *Energy Reorganization Act of 1974*, which divided the AEC into: the Energy Research and Development Administration (ERDA) to manage the nuclear weapons, naval reactors, and energy development programs; and the Nuclear Regulatory Commission (NRC) to regulate the possession and use of byproduct, source, and special nuclear material. Finally, the *Department of Energy Organization Act of 1977* brought the federal government's energy-related agencies and programs into a single agency. The Department of Energy (DOE), activated on October 1, 1977, assumed the responsibilities of the Federal Energy Administration, the Energy Research and Development Administration, the Federal Power Commission, and parts and programs of several other agencies. The NRC continues to regulate byproduct, source and special nuclear material. NRC does not, and did not in

the past, regulate accelerator-produced radioactive materials or radiation-producing machines. NRC's regulations are contained in *Title 10* of the Code of Federal Regulations.

### *Federal Regulations*

Prior to 1994, the regulations contained in 10 CFR 20.103 addressed respiratory protection program requirements and use of respirators, and limited internal doses resulting from radioactive materials indirectly by limiting the intakes (i.e., MPC-hours) independent of doses resulting from external doses. Initially the table of protection factors was included in Regulatory Guide 8.15 "Acceptable Programs for Respiratory Protection," but was later incorporated into Appendix A of Part 20. Some additions and changes were made over the years to these respirator regulations, but the dose-limitation methodology only changed when the current version of 10 CFR 20 took effect in 1994. The 1994 change requires that internal and external doses be combined into a single dose called total effective dose equivalent (TEDE). It also requires that ALARA principles be applied to this quantity rather than optimizing external and internal doses separately, as was the case in the older regulations. The program requirements (Subpart H and Appendix A to 10 CFR 20) carried over into the "new" Part 20 almost unchanged. Significant changes to Subpart H and Appendix A were made in 1999. This NUREG provides a technical basis to support implementation of the 1999 changes.

## *Regulatory Guide 8.15*

The original Regulatory Guide 8.15, “Acceptable Programs for Respiratory Protection,” was published in October 1976 and remained unchanged until October 1999, when Revision 1 was published to support the 1999 revision to 10 CFR 20 Subpart H and Appendix A. The NRC believes that the current rule, supported by guidance in Regulatory Guide 8.15, provides licensees with a great deal of flexibility in implementing a high-quality respiratory protection program.

### *NUREG-0041*

The NRC issues documents called NUREGs for various purposes. NUREGs do not contain “new regulations” as the name might imply. Like regulatory guides, they do not contain any legally binding requirements.

NUREG-0041 was published in 1976 in conjunction with Regulatory Guide 8.15. It was an excellent effort on the part of the authors and virtually all nuclear respiratory protection programs use it as a foundation, but since it is based on 1970s technology and practice, it has become less and less useful in recent years.

Revision 1 to NUREG-0041 is intended to update the areas of interest identified in the original version, provide supplementary guidance in areas not covered in the original, and provide licensees with the benefit of experience gained in respiratory protection programs over the past 25 years.

## *ANSI Standards*

These consensus standards, issued by the American National Standards Institute<sup>1</sup>, contain specifications applicable to various aspects of a licensee’s operation and are sometimes referenced in Federal Regulations and NRC Regulatory Guides. ANSI is a non-governmental independent organization, although government representatives sit on many of the committees. A consensus standard is one that is developed by interested parties. These include major respirator users, respirator manufacturers, government agencies, trade unions, military services, etc. Of particular interest here is ANSI Z88.2-1992, “Practices for Respiratory Protection.” The NRC’s position on this ANSI standard is contained in Regulatory Guide 8.15 Revision 1.

### **1.2 Applicability of OSHA’s Respiratory Protection Rules**

There are four categories of hazards that may be associated with NRC-licensed facilities:

- Radiation risk produced by radioactive materials;
- Chemical risk produced by radioactive materials;
- Facility conditions that affect the safety of radioactive materials and thus present an increased radiation risk to workers. For example, these might produce a fire or an explosion, and thereby cause a release of radioactive material or an unsafe reactor condition; and
- Facility conditions that result in an occupational risk, but do not affect the safety of licensed radioactive materials. For example, there might be exposure to toxic non-radioactive materials and other industrial hazards in the workplace.

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<sup>1</sup> 11 West 42<sup>nd</sup> Street, New York, NY 10036. A complete list of ANSI Standards may be found at [www.ANSI.org](http://www.ANSI.org).

Generally, the NRC has jurisdiction over the first three categories listed above, and OSHA has jurisdiction over the fourth hazard. Under the terms of the memorandum of understanding (MOU) that exists between the NRC and OSHA, the NRC reports to the licensee and to OSHA any observed violations in the fourth category. Likewise, OSHA will inform the appropriate NRC Regional Office of matters under the NRC's jurisdiction when they come to the attention of OSHA through complaints or inspections.

The NRC does not conduct inspections focused on industrial safety in the course of inspections of radiological and nuclear safety, but NRC personnel may identify safety concerns within the area of OSHA responsibility, or may receive complaints from an employee about OSHA-covered working conditions. The NRC, however, does not make decisions regarding activities under the purview of OSHA.

The NRC has made every effort to make the Subpart H program compatible with the OSHA program. Complying with OSHA program requirements will result in satisfying most of the NRC requirements, with the exception of those few differences specifically identified in Regulatory Guide 8.15, Revision 1, paragraph 6.8. The converse is not true, however. Complying only with NRC requirements will not satisfy all OSHA requirements because the NRC's program is a small subset of the OSHA program. The NRC believes that if a licensee implements a respiratory protection program that complies with 10 CFR 20 requirements, the program will be consistent with all applicable OSHA requirements.

The NRC recognizes that most licensees generally experience very low levels of airborne radioactive material during normal operations, and that any need for a respiratory protection program would be dictated by the presence of airborne industrial contaminants. In this case, an OSHA program would be

needed rather than an NRC program. If an ALARA analysis results in a licensee decision that respirators would not be needed to limit the intake of airborne radioactive material, but respirators are assigned to protect against other industrial contaminants, then the presence of low levels of radioactive material could be considered incidental, and an OSHA program would be adequate to protect workers. It is important to note that even if a respiratory protection program is not required by the NRC, a licensee must still monitor for intake of radioactive material in accordance with 10 CFR 20.1502(b). Also, if a licensee is "taking credit" for the protection against airborne radioactive material even if the respirators are worn for industrial protection, then the licensee must also comply with the applicable Subpart H rules.

Licensees should consider the need for establishing a respiratory protection program based on a prospective analysis of the potential for worker exposures to airborne radioactive material during normal operations and during credible abnormal occurrences. NRC regulations require that licensees use procedures and controls to achieve occupational doses that are ALARA. It would be a licensee decision, based on an ALARA analysis, whether or not to use respirators to reduce exposure even further. Other controls, such as limiting duration of exposure, are permitted.

Licensees should also determine whether or not an emergency situation could reasonably be expected to arise that would require the use of respirators by facility workers responding to the emergency conditions. If so, then the licensee should establish an NRC-required respiratory protection program, and determine how extensive that program must be. The NRC staff believes that any respiratory protection program that meets Part 20 requirements should provide a good basis for respiratory use in emergency situations.

The assigned protection factors published by the NRC apply only in a respiratory protection program that meets the requirements of 10 CFR 20, Subpart H. They are applicable only to airborne radiological hazards and may not be appropriate to circumstances when chemical or other respiratory hazards exist instead of, or in addition to, radioactive

hazards. Selection and use of respirators for such circumstances must comply with Department of Labor regulations. In the case where both radiological and non-radiological airborne hazards exist, primary consideration should be given to the more hazardous component.

### References and Resources

1. Department of Health and Human Services, National Institute for Occupational Safety and Health, 1095 Willowdale Road, Morgantown, WV 26505-2888. Phone: 304-285-5907; Fax: 304-285-6030.
2. Dooley, Lawrence M. and Francis L. Barresi. "Workers' Perception of Respirator Use and Internal Dose: A Humanist's Perspective." *Radiation Protection Management*, Vol. 11, No. 6 (Nov./Dec. 1994), pp. 29-32. <<http://www.radpro.com>>
3. U.S. Nuclear Regulatory Commission, Washington, DC 20555, <<http://www.nrc.gov>>.

## 2 ALARA REQUIREMENT

### 2.1 Introduction

The term “respiratory protection” does not necessarily mean “use of respiratory protective devices.” Engineering and work practice controls are generally regarded as the most effective methods to control exposure to airborne radioactive materials. The use of respirators is the least satisfactory method of respiratory protection because:

- Respirators provide adequate protection only if they are properly fitted (face-sealing devices);
- Respirators provide adequate protection only if they are properly worn;
- Respirators protect only the employees who are wearing them, rather than reducing or eliminating the hazard from the workplace as a whole (which is what engineering and work practice controls do);
- Respirators are generally uncomfortable to wear, cumbersome to use, and interfere with vision and communication in the workplace, which can often be critical to maintaining safety and health; and
- The costs of operating a compliant respiratory protection program are substantial — including regular medical examinations, fit testing, training, and the purchasing and maintaining of equipment.

### 2.2 ALARA Evaluation

The NRC does not intend that licensees develop a new ALARA program or procedures to address respirator use. Rather, respiratory protection-related ALARA considerations should be factored into the existing evaluation method as one more dose-related variable. The NRC intends that respirator-related ALARA requirements should be incorporated into the existing ALARA program. For example, if the

existing ALARA program requires that a check-list be completed during the processing of each radiation work permit to determine whether or not a formal ALARA review is needed, then factors that impact internal dose should be included on such a check-list. If the existing ALARA program requires that a formal ALARA evaluation be performed for a task if the anticipated collective dose might exceed 1 person-rem TEDE, the dose projection used in making this determination should include both internal and external dose.

As part of an overall hazard evaluation process, licensees should include non-radiological factors when deciding if respirators should be used. Licensees should take into account potential unintended consequences of assigning a specific type of respirator. For example, assignment of a negative-pressure air-purifying respirator in a high-temperature, high-humidity work environment might have much more negative impact on overall worker safety than an incremental increase in external dose.

### 2.3 Estimating ALARA Benefit

An article entitled “Dose Expansion from Using Respirators”<sup>1</sup> provides information on methods that licensees may use in performing ALARA evaluations. While this article was written before the current revision of 10 CFR 20 became effective and therefore, still uses the maximum permissible concentration (MPC) terminology, the principles presented are still valid.

Licensees should take into account *total risk to workers* when establishing radiological controls for various tasks. An article, “Optimizing

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<sup>1</sup> Greenwood, Regis A. and Thomas J. O’Dou. “Dose Expansion from Using Respirators.” *Radiation Protection Management*, Vol. 9, No. 4 (July/August 1992), pp. 22-29.

Worker Protection: The Practical Application of Risk Analysis,"<sup>2</sup> illustrates the place of radiation dose within the larger framework of industrial safety. Consideration should be given to industrial safety concerns such as heat stress, which might be aggravated by the use of respirators, and the increased likelihood of industrial accidents when workers must climb ladders or work on scaffolding while wearing respirators.

If the difference in a worker's TEDE between using or not using respirators is small, the decision to use or not use respirators should be based on other considerations since either option could be considered to be in the spirit of ALARA. At low DDE rates, respirator-induced inefficiency will have little impact on total dose estimations.

## 2.4 Techniques for Limiting Respirator Use

Listed here are some techniques that licensees might consider, to limit the use of respirators.

- Containment systems that prevent the release of radioactive material into the work environment;
- Use of filtered ventilation systems;
- Decontamination of the work area prior to work;
- Spraying areas or components with a water mist to prevent contamination from becoming airborne; and
- Using contamination fixatives such as strippable paint prior to work.

## 2.5 Examples of ALARA Dose Estimations

In the following examples, the subscript "w" indicates "with respirators." The subscript "w/o" means "without respirators." Acronyms for dosimetry terms can be found in the List of

<sup>2</sup> Williams, Michael C. "Optimizing Worker Protection: The Practical Application of Risk Analysis," *Health Physics*, Vol. 59 (1990), pp. 925-929.

Acronyms and Abbreviations in the front of this Manual.

CEDE<sub>w</sub> is estimated as follows:

$$\frac{\text{CEDE}_{w/o}}{\text{APF}}$$

Respirator-induced worker inefficiency is assumed to be 15% in all of these examples. Worker inefficiency caused by respirator use is covered in section 2.8 below.

The percentage difference between CEDE<sub>w</sub> and CEDE<sub>w/o</sub> can be calculated as follows:

$$\frac{(\text{CEDE}_{w/o} - \text{CEDE}_w)}{\text{CEDE}_{w/o}} \times 100$$

RPA's are reminded that these are only examples of TEDE estimations. No generalizations or decisions about a licensee's program should be made based on these specific examples.

### *Example 1—High external dose rate and high airborne concentration*

The average airborne contamination concentration in a work area is estimated to be 30 times the DAC for the mix of radionuclides present based on historical data. The deep-dose equivalent rate in the work area is 200 mrem/h, and the job is projected to last for 1 hour.

### *Evaluation 1: Without respirators*

$$\text{DDE}_{w/o} = \frac{200 \text{ mrem}}{\text{h}} \times 1 \text{ h} = 200 \text{ mrem}$$

$$\text{CEDE}_{w/o} = 30 \text{ DAC} \times 1 \text{ h} \times \frac{2.5 \text{ mrem}}{\text{DAC} \cdot \text{h}} = 75 \text{ mrem}$$

$$\text{TEDE}_{w/o} = 275 \text{ mrem}.$$

*Evaluation 1: with respirators*

With full-facepiece respirators (APF = 100), using a 15% worker inefficiency factor:

$$\begin{aligned}DDE_w &= \frac{200 \text{ mrem}}{h} \times 1.15 \text{ h} = 230 \text{ mrem} \\CEDE_w &= \frac{30 \text{ DAC}}{100} \times \frac{2.5 \text{ mrem}}{\text{DAC} - h} \times 1.15 \text{ h} \approx 1 \text{ mrem} \\TEDE_w &= 231 \text{ mrem}.\end{aligned}$$

The difference (275 - 231 = 44 mrem) is in favor of respirator use. The decision to NOT use respirators could be justified in this case if added worker stress is significant, or if other safety issues are involved.

*Example 2—High external dose rate and low airborne concentration*

The average airborne contamination concentration in a work area is estimated to be 2 times the DAC for the mix of radionuclides present based on historical data. The deep-dose equivalent rate in the work area is 180 mrem/h, and the job is projected to last 4 hours.

*Evaluation 2: Without respirators*

$$\begin{aligned}DDE_{w/o} &= \frac{180 \text{ mrem}}{h} \times 4 \text{ h} = 720 \text{ mrem} \\CEDE_{w/o} &= 2 \text{ DAC} \times 4 \text{ h} \times \frac{2.5 \text{ mrem}}{\text{DAC} - h} = 20 \text{ mrem} \\TEDE_{w/o} &= 720 + 20 = 740 \text{ mrem}.\end{aligned}$$

*Evaluation 2: with respirators*

With full-facepiece respirators (APF = 100), using a 15% worker inefficiency factor:

$$\begin{aligned}DDE_w &= \frac{180 \text{ mrem}}{h} \times 4.6 \text{ h} = 828 \text{ mrem} \\CEDE_w &= \frac{2 \text{ DAC}}{100} \times 4.6 \text{ h} \times \frac{2.5 \text{ mrem}}{\text{DAC} - h} = 0.23 \text{ mrem} \\TEDE_w &= 828 \text{ mrem}.\end{aligned}$$

The difference (828 - 740 = 88 mrem) is in favor of no respirator use. Therefore, respirators should not be used unless there are other factors involved.

*Example 3—Low external dose rate and high airborne concentration*

The average airborne contamination concentration in a work area is estimated to be 20 times DAC for the mix of radionuclides present based on historical data. The deep-dose equivalent rate in the work area is 3 mrem/h. The job is projected to last 2 hours.

*Evaluation 3: without respirators*

$$\begin{aligned}DDE_{w/o} &= \frac{3 \text{ mrem}}{h} \times 2 \text{ h} = 6 \text{ mrem} \\CEDE_{w/o} &= 20 \text{ DAC} \times 2 \text{ h} \times \frac{2.5 \text{ mrem}}{\text{DAC} - h} = 100 \text{ mrem} \\TEDE_{w/o} &= 106 \text{ mrem}.\end{aligned}$$

*Evaluation 3: with respirators*

With full facepiece respirators (APF + 100), using a 15% inefficiency factor:

$$\begin{aligned}DDE_w &= \frac{3 \text{ mrem}}{h} \times 2.3 \text{ h} = 7 \text{ mrem} \\CEDE_w &= \frac{20 \text{ DAC}}{100} \times 2.3 \text{ h} \times \frac{2.5 \text{ mrem}}{\text{DAC} - h} \approx 1 \text{ mrem} \\TEDE_w &\approx 8 \text{ mrem}.\end{aligned}$$

The difference (106 – 8 = 98 mrem) is in favor of respirator use. A reasonable judgment in this case would be that respirators should be used unless there are other safety factors involved.

*Example 4—Low external dose rate and low airborne concentration*

The average airborne contamination concentration in a work area is estimated to be 2 times the effective DAC for the mix of radionuclides present based on historical data. The deep dose equivalent rate in the work area is 10 mrem/h. The job is projected to last 2 hours.

*Evaluation 4: without respirators*

$$DDE_{w/o} = \frac{10 \text{ mrem}}{h} \times 2 \text{ h} = 20 \text{ mrem}$$

$$CEDE_{w/o} = 2 \text{ DAC} \times 2 \text{ h} \times \frac{2.5 \text{ mrem}}{\text{DAC} - h} = 10 \text{ mrem}$$

$$TEDE_{w/o} = 30 \text{ mrem}.$$

*Evaluation 4: with respirators*

With half-facepiece respirators (APF=10), using a 15% inefficiency factor:

$$DDE_w = \frac{10 \text{ mrem}}{h} \times 2.3 \text{ h} = 23 \text{ mrem}$$

$$CEDE_w = \frac{2 \text{ DAC}}{(10)} \times 2.3 \text{ h} \times \frac{2.5 \text{ mrem}}{\text{DAC} - h} \approx 1 \text{ mrem}$$

$$TEDE_w \approx 24 \text{ mrem}.$$

Since there is no real difference in projected dose whether or not respirators are used, a reasonable judgment would be that respirators should not be used.

**2.6 ALARA Evaluation—Records**

For tasks that require a formal ALARA review, no additional documentation on the use or non-

use of respirators should be needed, as long as that review includes adequate information about how CEDE was considered.

For tasks that do not require a formal ALARA review but where the work area contains airborne radioactivity to the extent that it is posted “Caution Airborne Radioactivity Area,” then a record should be made that justifies the use or non-use of respirators for that job. A notation on a work document (e.g., a radiation work permit) is acceptable if it contains sufficient detail. Licensees might consider preparing a series of relatively generic justifications (based on historical information) for a variety of commonly encountered work situations. The work document could then simply reference the applicable justification.

**2.7 Exceptions to Respirator-ALARA Requirement**

Optimization of radiation dose is not the only test that should be applied in a radiological workplace. The concept of “worker safety” should also encompass consideration of hazards from falls or injuries due to tangling of airlines or use of bulky equipment, heat-related stress or illness, problems created by workers not being able to adequately communicate, and other problems that are caused by respirator use. The NRC intends to encourage licensee judgement in the decision to require the use of respirators where they may not be justified by an ALARA analysis, or to not use them when their use would reduce dose but decrease worker industrial safety.

Listed below are a few valid considerations that the RPA may take into account that would suggest either that respirators *should* be worn even though they are not justified by an ALARA analysis, or that respirators *should not* be worn even though TEDE will be higher than if they were used:

- Heat stress to workers. Some respirators provide body cooling that could mitigate an otherwise significant heat exposure.

Conversely, some types of respirators might make a heat stress situation worse;

- Type and quantity of protective clothing needed for a job. This could also have heat stress implications;
- Environmental conditions and how they might influence the decision to use or not use respirators;
- Skill and experience level of the workers involved; and
- Post-work consequences of not using respirators, such as the need for personal decontamination, skin-dose assessments, responding to portal monitor alarms, psychological strain on workers who are contaminated, and so on.

## 2.8 Respirator-Induced Inefficiency

It is widely recognized that the use of protective clothing, including respirators, generally reduces worker efficiency. Generally, the more complex the task, or the more coordination needed among respirator wearers, the greater the inefficiency. It should also be recognized that respirators are used in conjunction with protective clothing, which also contributes to worker inefficiency. Often, when higher levels of protective clothing are needed, more protective respirators are also used. A worker assigned to wear both cloth and plastic protective clothing will probably also use a supplied-air hood, both for respiratory protection and body cooling. The more-protective respirators often slow a worker down more than a less protective device. Worker efficiency can also be degraded significantly when the work environment is very cold, or is hot and humid. There are numerous other variables.

The NRC believes that use of an inefficiency factor of up to 15% is reasonable when respirators are worn. This factor may be used by licensees when making ALARA decisions on respirator use. Recognizing the numerous variables involved, however, licensees may use larger factors, but the licensee should have adequate justification.<sup>3</sup> Such justification could consist of prior field experience, professional judgment, time-motion studies, mock-up exercises, or other sources. Licensees should reevaluate the inefficiency factor used as work progresses in the same way that protective clothing requirements might be reevaluated, and modify the inefficiency factor as appropriate. The NRC also recognizes that shifting from using respirators to not using respirators (or vice versa) part way through a job might not be cost-effective in terms of re-instructing workers, modifying work permits, or altering communications equipment requirements, etc., and therefore, might not be ALARA. Future evaluations of similar jobs, however, should benefit from the lessons learned.

## 2.9 Dose Estimation

The appropriate method for dose estimation is to determine the concentration actually breathed by the worker by dividing the average airborne concentration in the work area during the work period by the assigned protection factor of the respirator being used. This method is illustrated in Section 2.5. Bioassays may also be used to assess intakes, especially if relatively high intakes are a possibility, or if respirator failure is suspected. Bioassay measurements also provide an on-going evaluation of the effectiveness of the airborne radioactive material measurement and control program, as well as an evaluation of the effectiveness of the respiratory protection program.

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<sup>3</sup> Lee, Roy. "The Effects of Respiratory Protection on Worker Efficiency." *Radiation Protection Management*, Vol. 11, No. 5 (September/October 1994), pp. 28-42.

Radiation workers should not be subjected to an excessive number of bioassay measurements to quantify minor intakes of

radioactivity. Such practice might produce undue psychological stress on the workers.

## References and Resources

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8. Cardarelli, R., K.L. Mossman, *et al.* "The Effect of Respiratory Protection on Worker Efficiency—ALARA Considerations." *Health Physics*, Vol. 50—Supplement 1 (June 1986), pp. S49-S50.
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10. Johnson, A.T., C.M. Grove and R.A. Weiss. Respirator Performance Rating Tables for Non-Temperate Environments." *American Industrial Hygiene Association Journal*, Vol. 53 (September 1992), pp. 548-555.
11. Williams, Michael C. "Optimizing Worker Protection: The Practical Application of Risk Analysis," *Health Physics*, Vol. 59 (1990), pp. 925-929.
12. Lee, Roy. "The Effects of Respiratory Protection on Worker Efficiency." *Radiation Protection Management*, Vol. 11, No. 5 (Sept/Oct 1994), pp. 28-42. <<http://www.radpro.com>>
13. Electric Power Research Institute, "Effects of Respirators on Worker Efficiency." EPRI TR-105350, Final Report, June 1995.

## 3 PROCEDURES AND PROGRAMS

### 3.1 Written Procedures

The NRC regulations supported by Regulatory Guide 8.15, Revision 1, specify the written procedures that are necessary in a respiratory protection program. Given here are a few suggestions for inclusion in those procedures.

A program should be established that identifies those positions with supervisory and technical responsibilities in the respiratory protection program including the Respirator Program Administrator (RPA); specifies minimum training and retraining requirements for each position; and identifies the minimum qualifications for appointment or assignment to these positions. The radiological and non-radiological respiratory protection programs may have different Administrators, so long as adequate communication and coordination exists between the programs. (This is an exception to ANSI Z88.2-1992, paragraph 4.5.1.)

The job description of each position in the respirator program should include a minimum level of training and/or experience related directly to respiratory protection that a person should have prior to filling such a position.

Recommendations for the contents of a respirator user-training program are contained in Chapter 5 of this Manual. This training should include the requirement for each respirator user to inspect the respirator prior to donning and to perform a user seal check each time a face-sealing respirator is donned.

Written guidelines should be established that limit respirator-induced stresses on workers. First, each respirator wearer should be informed that (s)he may stop work and exit the work area at any time for relief from respirator use. This may be precipitated by equipment malfunction, physical or psychological

distress, procedural or communications failure, significant deterioration of operating conditions, or any other condition that might require such relief. This is commonly referred to as "self-determination." Second, procedural controls should be established that take into account environmental factors in the work place that might present a risk to respirator wearers. These time limitations do not necessarily have to be stated in terms of a specific maximum number of continuous hours, or hours in a day or in a week that a person may work in a respirator. Time limitations may be based on a heat stress assessment performed prior to or during specific jobs. More specific information is provided in Chapter 6 of this document.

### 3.2 Separate Policy Statement Not Required

Previous versions of the NRC's regulations required licensees to develop and promulgate a policy statement on respirator use. The policy statement committed licensees to the use of process or other engineering controls, instead of respirators; defined what was meant by routine, non-routine, and emergency use of respirators; and described the periods of respirator use and steps to be taken for relief from respirator use. While these commitments and issues need to be addressed in the licensee's respiratory protection program, they are to be included in the written procedures. No separate document (policy statement) needs to be produced or maintained.

### 3.3 Evaluation of Use of Process or Other Engineering Controls

During routine work activities, process or engineering controls should be implemented when practicable for most situations where otherwise respirators would have to be worn.

If workers are assigned to use respirators to perform routine tasks, the results of an evaluation should be available to show why engineering controls were not considered to be ALARA.

In situations where respirators are used infrequently or in a non-routine manner, re-evaluations should be performed periodically to ensure that the engineering controls remain unwarranted.

Areas where emergency situations have developed, or could reasonably be expected to develop, that would require respirator use should be identified. Consideration should be given to staging emergency-use respirators of the appropriate type(s) near these areas.

All principles used in an ALARA evaluation, including cost, may be used in determining the reasonableness of implementing engineering controls for the reduction of airborne radioactivity. The evaluations and re-evaluations described above should be part of an on-going process. Procedures and programs should be formally reviewed periodically to ensure that they address the licensee's current situation. Documentation that such an evaluation has been performed could be an entry on a radiological work permit (RWP), or an entry in a logbook.

### **3.4 Use of Solvents for Decontamination**

It is commonly believed that the use of solvents will cause surface contamination to become airborne as the solvent evaporates. Similarly, it is believed that if contaminated surfaces are wetted with water and heated, the water vapor will carry particulate contaminants into the air. Unless the radioactive contaminant is chemically bonded to the water or solvent molecule (e.g., T<sub>2</sub>O), or unless the boiling point of the radioisotope is exceeded, none of the contamination will become airborne due to the evaporation of any of these liquids. Rapid evaporation (i.e., boiling) is the principle used in

radioactive liquid waste evaporators. If there were significant carry-over or volatilization of radioactive contaminants, such a system would not work.

## **3.5 Respirator Selection**

### **3.5.1 Prerequisites**

Once a determination has been made that respirators are appropriate for a particular job, certain prerequisites should be satisfied.

First, during non-emergency situations, use of respiratory protective devices is permitted only in atmospheres where the radiological hazards have been identified and assessed. If there is significant loose surface contamination in the work area, and the planned work activities are such that some significant fraction of the loose contamination is likely to become airborne, the estimated average potential concentration should also be considered when selecting the respirator for the job. Potential airborne contamination from specific work activities—such as opening the interiors of contaminated piping systems or ventilation systems—should also be considered when selecting respirators.

Second, each respirator wearer must have been medically evaluated, trained, and fit-tested (for face-sealing devices), and the dates of these must be current. The respirators used must be NIOSH-approved or NRC-accepted devices, must have been inspected and sanitized since the device was last used, and must meet all the other criteria stated in 10 CFR 20 Subpart H.

Third, non-radiological hazards and potential hazards that might exist in addition to radiological hazards should also be assessed. The respirator assigned should be adequate to protect the wearer from all such hazards. For example, air-purifying respirators do not supply air or oxygen and therefore may not be used in an area where airborne radioactivity occurs in conjunction with an oxygen-

deficient atmosphere. Oxygen deficiency is described in Chapter 6 of this document.

### **3.5.2 Selection (APF)**

The assigned protection factor (APF) of the respirator selected for use during a particular job should be as high as practical to minimize internal dose, taking into account ALARA considerations and other factors. If the expenditure of resources needed to set up and use the device with the higher APF cannot be justified, or if the device with the higher APF would have a negative impact on overall worker safety or dose, or if another good reason exists, then a device with a smaller APF could be chosen. Examples of some work place conditions that might influence the selection of a specific type of respirator are:

1. Temperature;
2. Humidity;
3. Ambient noise;
4. Need for clear, precise communication;
5. Entry into a confined space;
6. Need to climb caged ladders; and
7. Need for mobility.

## **3.6 Application of Assigned Protection Factors**

### **3.6.1 Meaning of Assigned Protection Factor (APF)**

The assigned protection factor (APF) is not a measured value, but rather an assigned number for a type or class of respirators. The current APFs were set by the ANSI Z88.2-1992 Committee. Data on the fit factors obtained with different types of respirators and the protection factors these respirators provided under actual working conditions were reviewed when available. The distributions of protection factors provided by these respirators under working conditions were then examined for each respirator type, and the 5<sup>th</sup> percentile of these distributions calculated. The 5<sup>th</sup> percentile is the value of

the protection factor that is higher than 5% of the protection factors measured for that type of respirator under working conditions. Stated differently, 95% of the protection factors were higher than the 5<sup>th</sup> percentile values. These 5<sup>th</sup> percentile values were then assigned to the respective respirator types as the assigned protection factors (APFs). For cases where little or no working condition data was available, the APFs were selected by comparison and extrapolation from similar respirator types for which data was available.

When the APF of a respirator is evaluated in relationship to the APFs of other devices, decisions can be made regarding the degree of protection afforded to the wearer by the respirator—the higher the APF, the greater the protection. The APF can be viewed as the minimum degree of protection the device should provide to a properly trained and fit-tested (for face-sealing devices) wearer, who is wearing and using the respirator properly, under normal conditions of use in the field. It is recognized that most devices will provide a higher degree of protection to most wearers than is indicated by the APF.

APF should not be confused with the number obtained during quantitative respirator fit testing (QNFT). The number that results from quantitative fit testing is called a fit factor (FF). Minimum acceptable fit factors are often stated in terms of multiples of the APF (e.g., 10 times the APF). Even though an individual achieves a Fit Factor of 1,000 or 3,000 during fit testing, credit may only be taken for the APF listed in Appendix A to 10 CFR 20 for the respirator type in question. Application can be made to the Commission for use of protection factors higher than the listed APFs.

### 3.6.2 Estimating Dose When Using Respirators

Worker dose may be estimated by either of the following methods:

- A. Divide the measured concentration by the APF of the respirator used. Then divide this concentration by the applicable DAC to obtain the multiple of the DAC assumed to be breathed by the respirator wearer with credit taken for the APF of the device. The measured concentration should be as representative as possible of the average value of the airborne radioactive material concentration during the work period for which the dose is being estimated. This number, then, is the estimated number of DAC-hours of exposure accumulated by each respirator wearer during each clock-hour of exposure. See the example below.

#### *Example*

Given:  $C_{\text{measured}} = 3\text{E-}6 \mu\text{Ci/mL}$ ;  $\text{APF} = 100$ ;  
 $\text{DAC} = 1\text{E-}8 \mu\text{Ci/mL}$ ; and  $t_{\text{exposure}} = 4 \text{ h}$ .

Calculate DAC-hours of exposure.

$$\frac{3\text{E-}6 \mu\text{Ci/mL}}{(100)(1\text{E-}8 \mu\text{Ci/mL})} = 3 \text{ DAC-h per clock hour}$$

$$4 \text{ clock hours} \times \frac{3 \text{ DAC-h}}{\text{clock hour}} = 12 \text{ DAC-h}$$

$$12 \text{ DAC-h} \times \frac{2.5 \text{ mrem}}{\text{DAC-h}} = 30 \text{ mrem.}$$

- B. Perform bioassay to determine the quantity of radioactivity in the exposed person's body.

### 3.6.3 Use of APFs Greater than Part 20 Appendix A Values

Licensees who perceive the need to use an APF for a device which is greater than that listed in Appendix A to 10 CFR 20 may apply to the Commission for permission to do so. This application should contain the following information:

- Describe the situation for which the higher APF is needed;
- Explain why other NIOSH-approved devices that have sufficiently high APFs are not suitable for the licensee's situation; and
- Demonstrate that the device is capable of providing the requested level of protection under the proposed conditions of use.

Data submitted to demonstrate that higher protection factors can be achieved with the device may be developed by the manufacturer of the device, by the licensee, or by a suitably qualified and reliable third party.

### 3.7 Qualifications of Program Personnel

#### 3.7.1 The Respirator Program Administrator (RPA)

The RPA should have knowledge of respiratory protection topics sufficient to supervise the respiratory protection program properly. He or she should have the ability, training and experience to evaluate the total workplace hazard, recommend engineering controls if appropriate, specify respiratory protection if control cannot otherwise be obtained, and decide against the use of respirators if conditions warrant. No academic degree or professional certification is required.

### 3.7.2 Technical Support Personnel

Persons performing technical functions in a respirator program should have specific documented training in the area(s) in which they have duties. This should be a combination of classroom training and on-job training under supervision. These persons should demonstrate a sufficient level of knowledge and skill before they are permitted to perform these tasks unsupervised. Examples of these technical job functions are fit testing, training, maintenance and repair, quality assurance inspection and testing, equipment issue, equipment decontamination and the like. Certain maintenance jobs, such as work on SCBA regulators, require specialized training provided or certified by the equipment manufacturer.

### 3.7.3 Staying Abreast of New Developments

Since this Manual was first published in 1976, rapid advancements have occurred in the field of respiratory protection. It is important that the RPA and respirator program supervisors stay abreast of new developments such as advances in technology, current issues, and changes in regulations. This can be done by periodically attending lectures, seminars or training courses on the topic. Some other sources of information are:

- The *Federal Register* prints all changes in federal regulations, and various abstracting services identify changes to health and safety regulations.
- Health and safety professional societies, through their publications, keep members apprised of new developments. A few of these are the American Industrial Hygiene Association (AIHA), National Fire Protection Association (NFPA), American Society of Safety Engineers (ASSE), International Society for Respiratory Protection (ISRP), the American Conference of Governmental Industrial Hygienists (ACGIH), the National Safety Council (NSC), and the Health Physics

Society (HPS). Membership in one or more of these organizations is recommended for RPAs. Contact information is included in the References and Resources section at the end of this chapter.

- Publications from NIOSH, NRC, and OSHA often contain information on topics related to respirators and respiratory protection.

## 3.8 Appropriate Uses of Respirators

It is not the intention of the Commission to eliminate the use of respiratory protection devices by licensees, but to limit their use to those situations or occasions where it is justifiable based on an evaluation of the significant risks involved. The situations listed below are examples of times when the use of respirators is appropriate. This list may not be all-inclusive, but merely illustrates the types of situations where the use of respirators, at least in the initial phases of work, may be justified.

### 3.8.1 When Indicated by ALARA Evaluation

Respirators may be used when the results of an ALARA evaluation show that the use of respirators will save significant radiation dose and the increased risk from non-radiological hazards are outweighed by the radiological risk avoided by the dose reduction.

### 3.8.2 For Emergency Entry into an Unassessed Environment

Entry into an environment where the hazards have not been assessed presents some potentially serious problems. It is recognized that the TEDE from even a very high concentration of airborne radioactive material is unlikely to create an environment (from airborne hazards alone) that is immediately dangerous to life or health (IDLH) in case of

respirator failure. However, two other very important factors should be considered before personnel are permitted to enter an unassessed environment.

First, it should be established that concurrent *non*-radiological hazards do not exist that might jeopardize the life or health of individuals entering the area. If such a concurrent hazard exists or might exist (e.g., confined space, oxygen-deficiency, poisonous or toxic gas), additional steps have to be taken in accordance with the applicable regulations, to ensure the safety of the entering personnel. Second, external radiation dose rates, or potential dose rates, especially during accident conditions, should be taken into account. When feasible, the TEDE of the entering personnel should be kept within the regulatory limits.

If high dose rates and/or relatively long exposure times are anticipated, licensees are reminded of the following portions of the Code of Federal Regulations that address radiation doses in emergency situations:

- In 10 CFR 20.1001, *Purpose*, subparagraph (b) states (in part) that “nothing in this part shall be construed as limiting actions that may be necessary to protect health and safety.”
- Licensed facilities where an emergency plan is required should review 10 CFR 50.47, *Emergency plans*, subparagraph (b). This states (in part) “The onsite and,” with certain exceptions “offsite emergency response plans for nuclear power reactors must meet the following standards:  
(11) Means for controlling radiological exposures, in an emergency, are established for emergency workers. The means for controlling radiological exposures shall include exposure guidelines consistent with EPA

Emergency Worker and Lifesaving Activity Protective Action Guides.”<sup>1</sup>

- In paragraph 10 CFR 50.54 *Conditions of licenses*, subparagraph (x) states “A licensee may take reasonable action that departs from a license condition or a technical specification (contained in a license issued under this part) in an emergency when this action is immediately needed to protect the public health and safety and no action consistent with license conditions and technical specifications that can provide adequate or equivalent protection is immediately apparent.” Subparagraph (y) continues with “Licensee action permitted by paragraph (x) of this section shall be approved, as a minimum, by a licensed senior operator, or, at a nuclear power reactor facility for which the certifications required under §50.82(a)(1) have been submitted, by either a licensed senior operator or a certified fuel handler, prior to taking the action.”

### **3.8.3 During the Initial Phase of an Operation**

When the potential for significant increase in airborne contamination is high during the first part of a work activity, even though airborne radioactivity measured prior to the start of work is low, respirators may be used until the potential source of airborne radioactivity has been contained or removed.

### **3.8.4 While Process or Engineering Controls are Being Implemented**

Respirators may be used while such controls are being designed, ordered, fabricated or installed.

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<sup>1</sup> “Manual of Protective Action Guides and Protective Actions for Nuclear Incidents.” US EPA, 400-R-92-001, May 1992.

### **3.8.5 Where a Professional Judgment Mandates Such Use**

Professional judgment of licensee staff should always be the determining factor in circumstances that are not easy to analyze quantitatively with regard to respirator use.

### **3.9 Inappropriate Uses of Respirators**

Using respirators for the following reasons is normally considered inappropriate use of these devices.

#### **3.9.1 Unjustifiable Work in Atmospheres IDLH**

Workers should not routinely be permitted to enter IDLH environments. Such entries should be specifically justified. Licensees should be reluctant to permit entries into IDLH environments unless all other reasonable alternatives have been considered. A procedure should be in place (e.g., confined-space entry) to guide the work. One such incident is described in IE Information Notice 81-26.<sup>2</sup>

#### **3.9.2 Compensation for Poor Work Practices**

The assignment of respirators to prevent workers from rubbing or touching their faces with contaminated gloves, or otherwise compensating for inadequate training or poor work practices is not proper.

#### **3.9.3 Eye Protection Only**

Assigning respirators primarily for the purpose of protecting the eyes from direct injury, or

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<sup>2</sup> IE Information Notice 81-26: "Compilation of Health Physics Related Information Items, Part 4: Personnel Entry into Inerted Containment."

primarily for the purpose of providing beta particle shielding to limit radiation dose to the lens of the wearer's eyes should not be permitted. Eye protection can be provided more appropriately with safety glasses or face shields that impose fewer constraints and less stress on the wearer.

#### **3.9.4 Surface Contamination Levels**

Assignment of respirators due only to the presence of loose surface contamination in excess of certain concentrations without additional justification should be avoided. Automatically requiring the use of respirators because loose surface contamination in the work place is greater than some arbitrary concentration (e.g., 100,000 dpm/100 cm<sup>2</sup>), without additional justification, may not be considered ALARA. If an evaluation shows that the contamination is in loose, powdery form and likely to become airborne under the conditions of the work to be performed, respirator use might be considered ALARA depending on anticipated concentrations and exposure times. If the contamination is wet or oily and not likely to become airborne, then respirators might not be needed. In the respirator-use evaluation, consideration should also be given to other factors that would affect the potential for the contamination to become airborne. Some examples of such factors would be whether the contamination is dry and powdery; whether it is in the immediate work area or not; whether the exposed individuals will be inspecting or making measurements, or performing more aggressive work. In short, the ability or likelihood of the radioactive material going airborne should be factored into the decision to use or not use respirators.

#### **3.10 Airborne Particle Production**

Mechanical processes such as grinding, welding, flame cutting, brazing, sawing, flapper-wheeling, and other similar types of activities performed on contaminated or

irradiated components will produce airborne contamination in the form of particles. The sizes of these particles range from very large to very small. Large particles, well outside the so-called respirable size range, are of such (relatively) large mass that they will quickly settle out of the air and onto surfaces, and will not be airborne for very long. However, a sufficient fraction of the particles thus produced are small enough to remain airborne for long periods and to be inhaled by workers.

For high-temperature operations such as welding, flame cutting, and brazing on radioactive or contaminated metal, the temperatures are much higher than in the friction-related processes described above. In these higher temperature processes, particles of metal and any contaminants that may be present on the metal will be vaporized. As these vapors cool and condense, very small particles called “fumes” are formed. Airborne vapors and fumes are very small and may remain airborne for a significant period of time. Small particles such as these in the range of 0.1  $\mu\text{m}$  MMAD are well within the so-called respirable range

and therefore, easily able to be drawn into the alveolar-interstitial (AI) region of a worker's respiratory system. Insoluble particles deposited in this region of the lung will remain in deep lung for relatively long periods of time. This is because the deep lung, the alveolar sacs, and the alveolar airways have no rapid or effective clearance mechanism as do the upper portions of the human respiratory system. Therefore, all personnel performing welding, flame cutting, brazing, or other high temperature work on any metals, radioactive or not, should be provided with some type of respiratory protection—engineered controls or respirators—for protection from the fumes.

If the metal is also radioactive, the CDE and CEDE may need to be estimated and added to the individual's dose record.

Refer to Appendix A of this Manual for a discussion of the human respiratory system and other information about particle collection mechanisms.

## References and Resources

1. "Manual of Protective Action Guides and Protective Actions for Nuclear Incidents." US EPA, 400-R-92-001, May 1992.
2. 2. IE Information Notice No. 81-26: "Compilation of Health Physics Related Information Items, Part 4: Personnel Entry into Inerted Containment." U.S. Nuclear Regulatory Commission, August 28, 1981.
3. Nelson, T.J. "The Assigned Protection Factor According to ANSI." *AIHA Journal*, 57: 735-740 (1996).

## Associations and Organizations

The American Society of Safety Engineers (ASSE)  
1800 E. Oakton St.  
Des Plaines, IL 60018  
(847) 699-2929; Fax: (847) 768-3434  
<[www.asse.org](http://www.asse.org)>

American Industrial Hygiene Association (AIHA)  
2700 Prosperity Ave., Suite 250  
Fairfax, VA 22031  
(703) 849-8888; Fax (703) 207-3561  
<[www.aiha.org](http://www.aiha.org)>

National Fire Protection Association (NFPA)  
1 Batterymarch Park  
Quincy, MA 02269-9101  
(617) 770-3000; Fax: (617) 770-0700  
<[www.nfpa.org](http://www.nfpa.org)>

International Society for Respiratory Protection (ISRP)  
Hazards Control Department  
Lawrence Livermore National Laboratory  
P.O. Box L-379  
Livermore, CA 94551  
<[www.isrp.com](http://www.isrp.com)>

American Conference of Governmental Industrial Hygienists, Inc.  
1330 Kemper Meadow Dr., Suite 600  
Cincinnati, OH 45240  
(513) 742-2020 ; Fax: (513) 742-3355  
<[www.acgih.org](http://www.acgih.org)> (Web site contains links to many safety-related organizations.)

National Safety Council  
1121 Spring Lake Drive  
Itasca, IL 60143-3201  
(630) 285-1121; Fax: (630) 285-1315  
<[www.nsc.org](http://www.nsc.org)>

Health Physics Society (HPS)  
1313 Dolley Madison Boulevard, Suite 402  
McLean, Virginia 22101  
(703) 790-1745; Fax: (703) 790-2672  
<[www.hps.org](http://www.hps.org)>

### **Web Sites**

1. U.S. Nuclear Regulatory Commission,  
<[www.nrc.gov](http://www.nrc.gov)>
2. U.S. Environmental Protection Agency,  
<[www.epa.gov](http://www.epa.gov)>
3. National Institute for Occupational Safety and Health (NIOSH),  
<[www.cdc.gov/niosh/respinfo.html](http://www.cdc.gov/niosh/respinfo.html)>
4. Occupational Safety and Health Administration (OSHA),  
<[www.osha-slc.gov/html/subject-index.html](http://www.osha-slc.gov/html/subject-index.html)>

## 4 EQUIPMENT

### 4.1 Introduction

Since NUREG-0041 was published in 1976, significant advances in respiratory protection technology have taken place. In the sections below, operational descriptions of commonly used types of respiratory protection devices are provided, and the major advantages and limitations of each are listed. Devices that incorporate a combination of these devices into a single piece of equipment are also described. There is no single type of respirator that is best for use in all situations. The Respirator Program Administrator (RPA) should understand the advantages and limitations of each type of respirator in order to purchase appropriate devices, and to assign the proper devices in various field applications.

The National Institute for Occupational Safety and Health (NIOSH) tests and certifies respiratory protection devices that meet specified design and operational criteria. A list of the manufacturers and model numbers of such devices are available from NIOSH.<sup>1</sup> With the exception of the exemption for supplied-air suits, the NRC requires that only NIOSH-approved equipment be used in a radiological respiratory protection program, unless an exemption has been granted as described in 10 CFR 20.1703(b). In addition, the licensee should use, maintain, and store these devices in such a manner that the approval is not voided.<sup>2</sup> This means that each device should be used in accordance with the manufacturer's

<sup>1</sup> Available from Publications Dissemination, DSST, National Institute for Occupational Safety and Health, U.S. Department of Health and Human Services, 4676 Columbia Parkway, Cincinnati, OH 45226.

<<http://www.cdc.gov/niosh/homepage.html>>. (Select "Databases" then "Certified Equipment List.")

<sup>2</sup> Steinmeyer, K. Paul. "NIOSH Approval Requirements for Respiratory Protection Equipment." *Radiation Protection Management*, Vol. 14, No. 5 (September-October 1997), pp. 48-52.

instructions and that they be repaired when necessary and maintained in "like-new" condition with allowance made for superficial signs of wear.

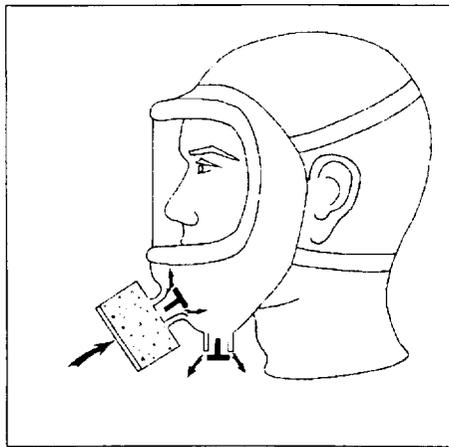
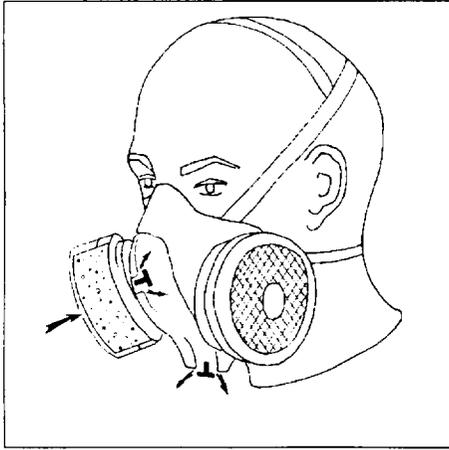
The licensee should also provide adequate equipment or material as necessary to supplement respiratory protective equipment for the purpose of reducing the likelihood that respirator use might contribute to workplace accidents or injury. Examples of this type of equipment would be spectacle adapters, welding adapters, voice amplification equipment, material or equipment to prevent or reduce fogging of respirator lenses, and body-cooling equipment in high temperature/high humidity environments.

Effective respirator use presumes a thorough knowledge of the capabilities and limitations of the device being used. This applies not only to the RPA and respirator users, but also to their supervisors, work planners, emergency planners, and trainers.

### 4.2 The Respiratory Inlet Covering

The respiratory inlet covering is the component of a respiratory protection device that isolates the breathing zone of the respirator wearer and protects it from the contaminants in the ambient air. Five general types of inlet coverings are commonly used in the nuclear industry. These are:

- Tight-fitting facepieces;
- Loose-fitting facepieces;
- Hoods;
- Helmets; and
- Suits.



**Figure 4-1. Half-facepiece with replaceable cheek-mounted filter cartridges, and a full-facepiece with chin-mounted filter canister.**



**Figure 4-2. Loose-fitting facepiece with a powered air-purifying device.**

#### 4.2.1 Tight-Fitting Facepieces

Tight-fitting facepieces are those that depend on a seal between the facepiece and the face of the wearer to protect the respiratory tract. This class includes single-use disposable respirators (also referred to as dust masks), half-facepiece respirators and full-facepiece respirators. Contaminants are excluded from the wearer's respiratory tract by the face-to-facepiece seal in combination with either filtered ambient air, or air supplied from another source such as a pressurized air cylinder or a breathing air compressor. Drawings of two of these devices are shown in Figure 4-1.

#### 4.2.2 Loose-Fitting Facepieces

Loose-fitting facepieces form only a partial seal with the face and do not completely cover the head or shoulders of the wearer. These devices often include a hard hat or a bump cap in their design. Respiratory protection systems that utilize a loose-fitting facepiece always operate in the positive-pressure mode. The wearer breathes either filtered ambient air that is blown into the facepiece (i.e., a powered air-purifying respirator), or compressed air supplied from another source (e.g., a constant-flow supplied-air respirator). A drawing of one of these devices is shown in Figure 4-2.

#### 4.2.3 Hoods

Hoods completely cover the head and neck of the wearer. These are seen in two configurations. The first, usually used with a supplied-air device, is designed with a double shroud or bib on the front and on the back. The inner shroud (both front and back) is to be tucked into the protective clothing. The outer shrouds are designed to be secured to the outside of the protective clothing by means of a belt, which also acts as an attachment point for an air pressure reducer and the air supply hose. The inner shroud directs the air exhaust

from the hood down over the wearer's torso and provides effective body cooling.

The second type incorporates a knit or elastic collar or neck dam that stays in close contact with the wearer's neck. Short front and back shrouds are usually also present. See Figure 4-3.

Hoods always operate in a positive-pressure mode. The wearer breathes either filtered ambient air that is blown into the facepiece (i.e., a powered air-purifying respirator), or compressed air supplied from another source (e.g., a continuous-flow supplied-air respirator). A drawing of one of these devices is shown in Figure 4-4.

#### 4.2.4 Helmets

Helmets are hoods that offer head protection for the wearer. They may be designed with long shrouds or with a knit or elastic neckband. Like hoods, these always operate in a positive-pressure mode and include a hard hat or a bump cap in their design. The wearer breathes either filtered ambient air that is blown into the helmet (i.e., a powered air-purifying respirator), or compressed air supplied from another source (e.g., a continuous-flow supplied-air respirator). A drawing of one of these devices is shown in Figure 4-5.

#### 4.2.5 Suits

Suits are one- or two-piece whole body covers that are usually made of waterproof material. The respiratory inlet covering of a suit is similar to a hood. A supplied-air suit is shown in Figure 4-6.

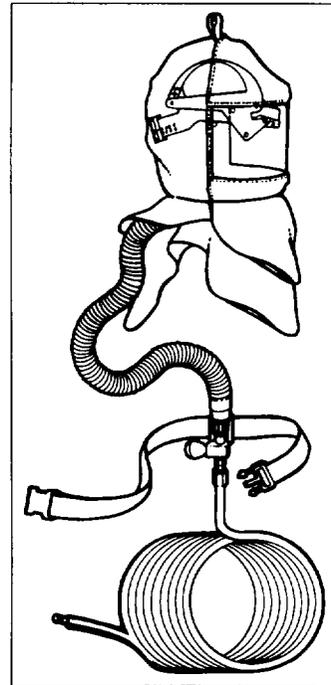


Figure 4-3. Supplied air hood, short shroud.



Figure 4-4. Supplied-air hood, long shroud.

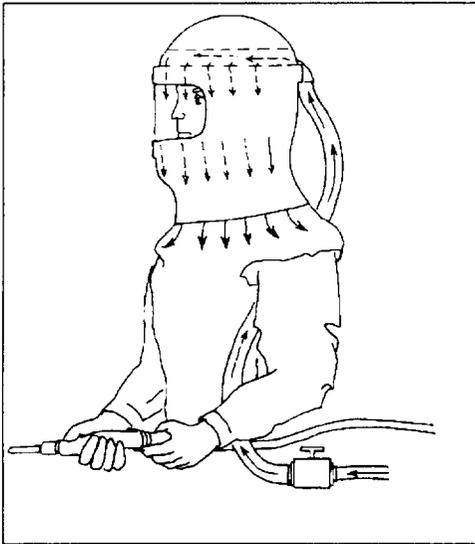


Figure 4-5. Supplied-air helmet.

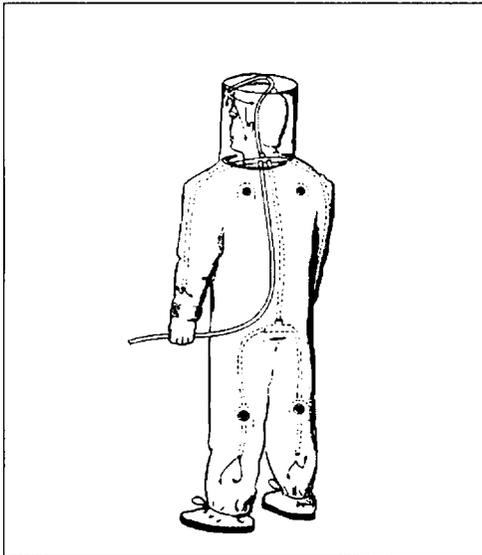


Figure 4-6. One-piece supplied-air suit.

### 4.3 Classification of Respirators

Respirators can be classified in a variety of ways. Some of these are by:

- Respiratory inlet covering,
- Source of breathing air, and
- Mode of operation.

Table 4-1 shows how respirators may be classified according to the respiratory inlet coverings described above.

A second way in which respirators may be classified is by the source of the breathing air provided to the wearer. Table 4-2 below shows respirators classified according to their source of breathing air.

Respirators may also be classified by their mode of operation. Table 4-3 below shows how respirators may be classified in this way. Complete descriptions of these various modes of operation are provided below.

It is common practice to combine these various classifications to accurately describe a specific respiratory protection device. Some examples would be:

- Half-facepiece, negative pressure, air-purifying respirator;
- Full-facepiece, positive-pressure, air-purifying respirator; and
- Full-facepiece, pressure-demand, SCBA.

### 4.4 Negative-Pressure Air-Purifying Respirators (APRs)

#### 4.4.1 Negative-Pressure Devices—General

Negative-pressure air-purifying respirators, both half- and full-facepiece, are the most commonly used of all respiratory protection devices. They remove contaminants from ambient air by filtration, absorption or adsorption of the contaminants, depending on the contaminant and on the cartridges or canister selected. This type of device is usually the least costly to purchase but, except for the disposable types, requires periodic maintenance and filter replacement. Of all the types of respiratory protection devices available, they weigh the least and allow maximum mobility to the wearer. They do not, however, supply oxygen and depend on the quality of filtered ambient air to sustain the wearer. Therefore, they cannot be used for fire fighting or in other oxygen-deficient environments.

**Table 4-1. Classification of respirators by type of respiratory inlet covering.**

Tight-Fitting Facepiece		Loose-Fitting Facepiece	Hood/Helmet	Suit
Half-Facepiece	Full-Facepiece	Air-purifying PP	Air-purifying PP	Supplied air CF
Air-purifying NP	Air-purifying NP	Supplied air CF	Supplied air CF	
Air-purifying PP	Air-purifying PP		Escape only SCBA	
Supplied air D, CF, PD	Supplied air D, CF, PD			
	SCBA D, PD			
	SCBA RD, RP			

PP = positive pressure (air-purifying)  
 D = demand  
 NP = negative pressure  
 RP = recirculating positive pressure (closed-circuit SCBA).

CF = continuous flow (supplied-air)  
 PD = pressure demand  
 RD = recirculating demand (closed-circuit SCBA)

**Table 4-2. Classification of respirators by source of breathing air.**

Air Purifying (AP)	Supplied-Air Respirator (SAR)	SCBA
Disposable dust masks, NP	Elastomeric half-facepiece, D, CF, PD	Full facepiece, D, PD
Half facepiece, NP	Full facepiece, D, CF, PD	Full facepiece, RD, RP
Full Facepiece, NP	Hood, CF	
Hood/helmet w/filter and blower, PP	Helmet, CF	
Loose-fitting facepiece, PP	Suit, CF	

PP = positive pressure (air-purifying)  
 D = demand  
 NP = negative pressure  
 RP = recirculating positive pressure (closed-circuit SCBA).

CF = continuous flow (SAR)  
 PD = pressure demand (SAR and open-circuit SCBA)  
 RD = recirculating demand (closed-circuit SCBA)

Table 4-3. Classification of respirators by mode of operation.

Negative Pressure (AP and SAR Demand)	Positive Pressure (Powered Air-Purifying)	Continuous Flow (SAR)	Pressure-Demand (SAR)	Pressure-Demand (Open circuit SCBA)	Recirculating Positive Pressure (Closed circuit SCBA)
Disposable dust mask	Elastomeric half-facepiece w/filter and blower	Elastomeric half facepiece	Elastomeric half facepiece	Full facepiece	Full facepiece
Reusable half facepiece	Full facepiece w/filter and blower	Full facepiece	Full facepiece		
Elastomeric half facepiece	Hood/helmet w/filter and blower	Hood/Helmet			
Full Facepiece	Loose-fitting facepiece w/filter and blower	Suit			

AP = air-purifying

SAR = supplied-air respirator

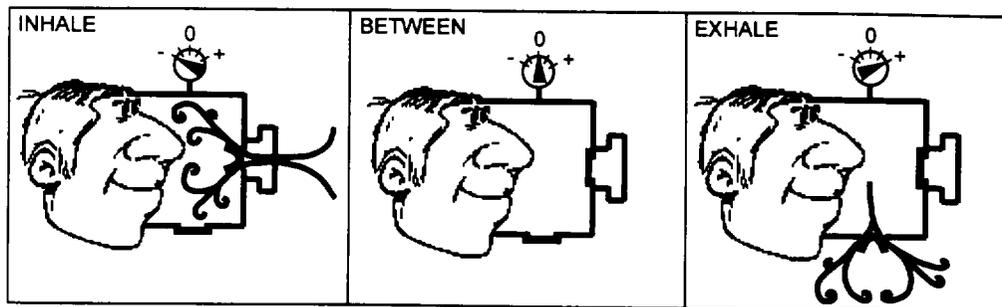


Figure 4-7. Negative-pressure respirator operation.

Negative pressure respirators must always utilize a tight-fitting facepiece. In a negative-pressure device, the air pressure inside the facepiece is negative with respect to the air pressure outside the device during inhalation. This differential pressure causes the exhalation valve to close, and ambient air to pass through the facepiece filter and inhalation valve to equalize the pressure inside. This also means that if there is a leak in the face-to-facepiece seal area, or if there is a hole in the facepiece, some contaminated air will be drawn into the

inlet covering through this unprotected pathway during the negative pressure portion of the breathing cycle. Upon exhalation, air pressure inside the facepiece is greater than ambient, so the inhalation valve is forced closed, the exhalation valve is opened by the pressure in the facepiece, and the exhaled air is discharged. The inhalation valve prevents back-flow of exhaled air through the filter. Some respirators are designed with no exhalation valves, and some are not equipped

with inhalation valves. Negative-pressure facepiece operation is illustrated in Figure 4-7.

Obviously, the fit of the facepiece on the wearer's face is of critical importance to the proper operation of respiratory protection devices that operate in this mode. Of all the modes of respirator operation, the negative-pressure mode is the least protective of the wearer. If properly fitted and used, however, negative-pressure respirators provide adequate protection in relatively low concentrations of airborne contaminants.

#### **4.4.2 Quarter-Facepiece Respirators, Negative Pressure Mode**

Quarter-facepiece respirators seal over the bridge of the nose, around the cheeks, and between the point of the chin and the lower lip. It has been observed that the fit becomes unstable when the wearer moves around in the work place, especially when the wearer talks. These devices have always been, and continue to be prohibited in an NRC-regulated respirator program (10 CFR 20 Appendix A, footnote e). Good alternatives such as half-facepiece respirators are readily available.

#### **4.4.3 Half-Facepiece Respirators—General**

Half-facepiece respirators seal over the bridge of the nose, around the cheeks, and under the chin. Traditionally, half-facepiece respirators are made of rubber or an elastomeric material (e.g., silicone rubber), have at least two adjustable elastic head straps (4-point suspension), and usually use two replaceable filter cartridges mounted opposite the cheeks of the wearer. In recent years, two somewhat different designs have come onto the market. Some of these have a standard rubber or elastomeric facepiece with filters attached, but the filters are not replaceable. These devices are considered to be half-facepiece respirators. In the others, called "filtering facepiece"

respirators, the filter medium is an integral part of the facepiece structure and is not replaceable.

NRC divides half-facepiece respirators into two categories: dust masks and half-facepieces. General industry (e.g., OSHA, ANSI) does not make this distinction. More information about the differences between dust masks and half-facepieces may be found in Regulatory Guide 8.15, Revision 1, October 1999. An experienced respirator program administrator should be able to distinguish between these single-use, filtering facepiece dust masks and those that qualify as half-facepiece respirators in an NRC-regulated program.

#### **4.4.4 Dust Masks, Negative Pressure Mode**

All dust masks are "filtering facepieces," meaning that the filter medium is an integral part of the facepiece and is not replaceable. Dust masks are generally considered to be single-use disposable respirators. The filter medium is relatively thin, they usually don't contain an exhalation valve, and the head straps are usually not adjustable. Any filtering facepiece that does not meet the definition of a half-facepiece (see 4.4.5 below) is a dust mask.

Appendix A to 10 CFR 20 does not assign an APF to "filtering facepieces" that are not equipped with elastomeric face seals and at least two adjustable straps, unless the licensee can demonstrate a fit factor of at least 100 by use of a quantitative or validated or evaluated qualitative fit test. If the device can be fit-tested to demonstrate a fit factor of at least 100, then an APF of 10 may be used. Although stated differently, this is essentially the condition that ANSI would require of disposables. The NRC believes that some devices such as dust masks may not retain good fit under conditions of use in the workplace.

The NRC and OSHA also permit the use of dust masks and other disposables, if requested

by a worker, without the requirement to perform medical screening or fit tests. Fit-testing is only required if APF credit is taken for use of the device in estimating intake or dose, suggesting that the intent is to limit intake of radioactive material.

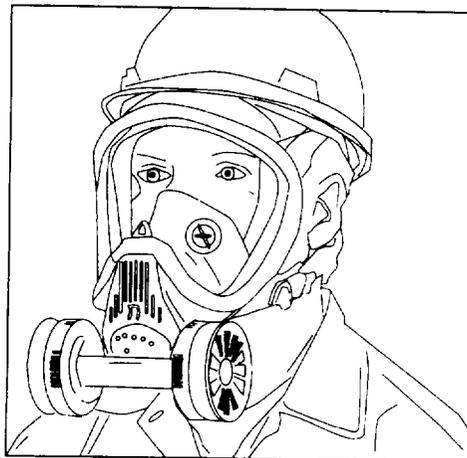
Anticipated applications of dust masks would be situations where a respirator is not necessary, but is requested by a worker (i.e., voluntary respirator use). This type of respirator can limit intakes of nuisance dusts when use of a more protective device cannot be justified in an ALARA analysis.

#### 4.4.5 Half-Facepiece Respirators, Negative Pressure Mode

Half-facepiece respirators, as recognized by the NRC, may be the traditional rubber facepiece with replaceable filter cartridges, a rubber facepiece with filter cartridges that can't be replaced, or they may be filtering facepieces. In order for a filtering facepiece to be considered a half-facepiece respirator, it must have *both* of two design characteristics. Seal-enhancing rubber or elastomeric material must be applied to the *entire* face-to-facepiece seal area (by the manufacturer), and an *adjustable* four-point (minimum) suspension strap system must be part of the design. Most of the devices that qualify as half-facepiece respirators also have exhalation valves, but an exhalation valve, while desirable, is not an essential design component.

#### 4.4.6 Full-Facepiece Respirators, Negative Pressure Mode

Full-facepiece respirators seal across the forehead between the hairline and the eyebrows; down over the temples between the eyes and the ears; then down and around the jaw and chin. Full-facepiece respirators are made of rubber or an elastomeric material (e.g., silicone rubber), have a four- or five-point suspension system, and use either two cheek-mounted filter



**Figure 4-8. Full-facepiece with replaceable, cheek-mounted filters.**



**Figure 4-9. Full-facepiece with replaceable, chin-mounted filter.**

cartridges, or one chin-mounted filter canister. Figures 4-8 and 4-9 show examples of these respirators. The filters are traditionally replaceable, but a somewhat different design is manufactured with non-replaceable filters installed.

#### 4.4.7 Advantages and Limitations of Negative Pressure Air-Purifying Respirators

Tables 4-4 through 4-6 summarize the major advantages and limitations of the various types of negative-pressure air-purifying respirators.

**Table 4-4. Advantages and limitations of dust masks (negative-pressure, air-purifying respirators).**

Dust Masks	
Advantages	Limitations
<ul style="list-style-type: none"> <li>• Relatively inexpensive</li> <li>• Little or no impact on worker vision or mobility</li> <li>• Add little or no cardiopulmonary stress or heat stress</li> <li>• Little impact on verbal communication</li> <li>• Create very little solid radioactive waste.</li> <li>• Voluntary use requires no medical screening or fit testing.*</li> <li>• Minimal wearer training required</li> <li>• Will not affect worker mobility</li> </ul>	<ul style="list-style-type: none"> <li>• Negative-pressure device</li> <li>• No APF credit unless fit testing and medical screening performed, low APF (<math>\leq 10</math>)</li> <li>• Should not be available to untrained individuals</li> <li>• Should ensure they are not mistakenly substituted for a more protective device</li> <li>• Protection from particulates only</li> <li>• May be difficult to perform user seal check</li> </ul>

\* If no APF is applied.

**Table 4-5. Advantages and limitations of half-facepieces (negative-pressure, air-purifying respirators).**

Half Facepiece (NP, APR)	
Advantages	Limitations
<ul style="list-style-type: none"> <li>• Relatively inexpensive</li> <li>• Little or no impact on worker vision or mobility</li> <li>• Small and easy to maintain</li> <li>• Little interference with worker mobility</li> <li>• Many different filters are available</li> <li>• Easy to use with minimum training</li> <li>• Light weight, small size</li> <li>• Easy to maintain</li> </ul>	<ul style="list-style-type: none"> <li>• May impact verbal communication</li> <li>• Low APF (<math>\leq 10</math>)</li> <li>• Can add cardiopulmonary stress or heat stress</li> <li>• Negative-pressure device</li> <li>• Breathing resistance increases with use, especially in dusty environments</li> <li>• Fit test required</li> </ul>

**Table 4-6. Advantages and limitations of full-facepiece, negative-pressure, air-purifying respirators.**

Full Facepieces (NP, APR)	
Advantages	Limitations
<ul style="list-style-type: none"> <li>• Little impact on worker mobility</li> <li>• Good APF (<math>\leq 100</math>)</li> <li>• Relatively small and easy to maintain</li> <li>• Many different filters are available</li> <li>• Relatively easy to use with proper training</li> </ul>	<ul style="list-style-type: none"> <li>• Expense</li> <li>• Vision restricted</li> <li>• Can add cardiopulmonary stress or heat stress</li> <li>• Impact verbal communication</li> <li>• Negative-pressure device</li> <li>• Breathing resistance increases with use, especially in dusty environments</li> <li>• Fit test required</li> <li>• More extensive maintenance needed</li> </ul>



Figure 4-10. Powered air-purifying respirator with full facepiece.

## 4.5 Powered Air-Purifying Respirators (PAPRs)

### 4.5.1 General

These devices may utilize either a tight-fitting facepiece, a loose-fitting facepiece, a hood, or a helmet as a respiratory inlet covering. Powered air-purifying respirators include one or more filters, a battery-operated blower, a rechargeable battery, and a flexible breathing tube that transfers air from the blower discharge to the respiratory inlet covering. Due to their weight, batteries are usually mounted on the wearer's waist. Filters and blower may be waist-mounted, or facepiece-mounted for devices that use a facepiece. When the blower motor is energized, ambient air is drawn through the filters and blown into the respiratory inlet covering continuously, maintaining the pressure in the respiratory inlet covering above atmospheric pressure. The excess air is discharged through one or more exhalation valves (full-facepiece between the face and the facepiece [loose-fitting facepiece]) or past the neck dam and/or front and rear shrouds (hood or helmet types). In case of leakage in the respiratory inlet covering, filtered air is much more likely to leak *out* rather than contaminated air leaking *in*. Figure 4-10 shows a powered air-purifying respirator with a full facepiece in use. Operation of a positive-pressure device is illustrated in Figure 4-11.

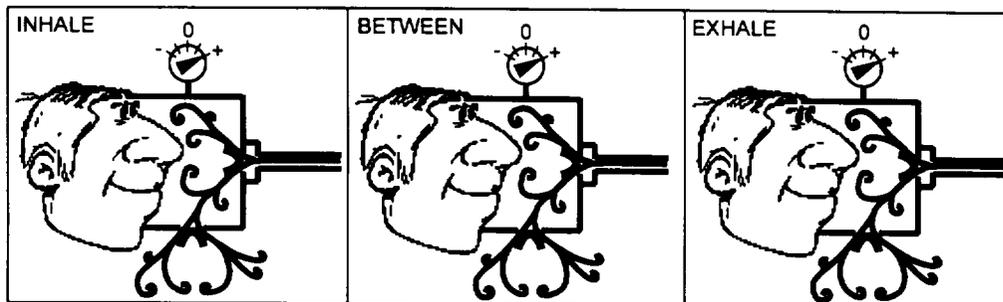


Figure 4-11. Positive-pressure (PAPR) respirator operation. Air supply is filtered ambient air.

This type of operation is referred to as the “positive pressure” or PP mode. This distinguishes it from the various modes of operation of supplied-air respirators described below (i.e., demand, constant-flow and pressure-demand).

It is *possible*, but not likely, for a respirator user to over-breathe or out-breathe a positive pressure device. This means that a person breathing very heavily could, at the peak of a strong inhalation, cause the pressure inside the respirator inlet covering to become negative with respect to the contaminated ambient air. This would only be the case for a very short time, however, and it is unlikely that a person could maintain this breathing volume (high work rate) for more than a few breaths. The minimum flow rate to a facepiece-equipped PAPR is 115 lpm (4 cfm), and to a hood- or helmet-equipped device it is 170 lpm (6 cfm). Several manufacturers have designed their devices to exceed these minimum requirements so that at the end of a work shift when the battery is no longer fully charged, the blower still delivers greater than the minimum air flow. Over-breathing is less of a concern with a PAPR that utilizes a tight-fitting facepiece, since additional air drawn into the facepiece would come through the PAPR filters. This would not be the case with non face-sealing PAPRs.

The initial cost of a PAPR is substantially more than a negative-pressure device. Continuing maintenance costs include recharging the battery between uses, and periodically discharging and recharging the batteries to ensure that the blower will deliver enough respirable air to the respiratory inlet covering. A battery has a limited useful life and cannot be recharged indefinitely and battery replacement can be expensive. Air blowers may need to be replaced if they fail. Some hood type devices require some pre-use assembly or replacement of the hood, breathing tube, and possibly other parts making them more maintenance intensive.

Other possible disadvantages, depending on the specific device, include weight, bulk, complex design, the need for ongoing maintenance, and at least daily replacement of air-purifying elements. Out-of-doors use presents special problems if hot or very cold air is supplied to the respiratory inlet covering. Filters may not be available for hazards other than airborne particulates.

#### **4.5.2 Advantages and Limitations of Positive Pressure Air-Purifying Respirators**

Tables 4-7 through 4-9 summarize the major advantages and limitations of facepiece-type, hood-type, and helmet-type positive-pressure air-purifying respirators. The advantages and limitations of loose-fitting facepieces are similar to those of hoods, except that the APF is 25.

#### **4.5.3 Respirator Filters**

##### *NIOSH Regulations*

On July 10, 1995, the requirements for certification of respirators were moved from 30 CFR 11 (Mine Safety and Health Administration) to 42 CFR 84<sup>3</sup> (Department of Health and Human Services). The role of NIOSH in the testing and certification of respirators is discussed below. The only substantive changes made so far during the shift in respirator approval regulations involve air-purifying respirators, and deal primarily with how filters for non-powered air purifying respirators are classified. Formerly, respirator filters had been categorized as “dust/mist,” “dust/mist/fume,” etc. The 42 CFR 84 system establishes nine classes of air-purifying particulate filters, categorized as to their efficiency and resistance to oil aerosols.

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<sup>3</sup> The full text of 42 CFR 84 “Respiratory Protective Devices” can be found at <http://www.cdc.gov/niosh/respinfo.html>.

**Table 4-7. Advantages and limitations of facepiece-type, positive-pressure, air-purifying respirators.**

<b>Facepiece-Type Positive Pressure Air-Purifying Respirator</b>	
<b>Advantages</b>	<b>Limitations</b>
<ul style="list-style-type: none"> <li>• Little impact on worker mobility</li> <li>• Reduced breathing resistance</li> <li>• Usually very comfortable for wearer</li> <li>• Positive-pressure device</li> <li>• High APF (<math>\leq 1000</math>)</li> <li>• May reduce cardiopulmonary stress or heat stress</li> <li>• Relatively easy to use with proper training</li> <li>• Long use duration</li> </ul>	<ul style="list-style-type: none"> <li>• Expense</li> <li>• Vision restricted</li> <li>• Impact verbal communication</li> <li>• Air blowing in wearer's face may be uncomfortable, especially in hot or cold environment</li> <li>• Fit test required</li> <li>• Much more extensive maintenance needed</li> <li>• Use in dusty environments may reduce airflow rate due to filter loading</li> <li>• Not for use in IDLH</li> </ul>

**Table 4-8. Advantages and limitations of hood-type, positive-pressure, air-purifying respirators.**

<b>Hood-Type Positive Pressure Air-Purifying Respirator</b>	
<b>Advantages</b>	<b>Limitations</b>
<ul style="list-style-type: none"> <li>• No fit test required</li> <li>• May be used by workers with facial hair or deformities</li> <li>• Many hoods provide better vision than facepiece- or helmet types</li> <li>• Little impact on worker mobility</li> <li>• Reduced breathing resistance</li> <li>• Usually very comfortable for wearer</li> <li>• Positive-pressure device</li> <li>• High APF (<math>=1000</math>)</li> <li>• May reduce cardiopulmonary stress or heat stress</li> <li>• Relatively easy to use with proper training</li> <li>• Long use duration</li> <li>• Adaptable to voice amplifiers and communications systems</li> </ul>	<ul style="list-style-type: none"> <li>• Expense</li> <li>• Vision restricted</li> <li>• Impact verbal communication</li> <li>• Air blowing into wearer's breathing zone may be uncomfortable, especially in hot or cold environments</li> <li>• Much more extensive maintenance needed</li> <li>• Use in dusty environments may reduce airflow rate due to filter loading</li> <li>• Not for use in IDLH</li> </ul>

**Table 4-9. Advantages and limitations of helmet-type, positive-pressure, air-purifying respirators.**

<b>Helmet-Type Positive Pressure Air-Purifying Respirator</b>	
<b>Advantages</b>	<b>Limitations</b>
<ul style="list-style-type: none"> <li>• No fit test required</li> <li>• May be used by workers with facial hair or deformities</li> <li>• Little impact on worker mobility</li> <li>• Reduced breathing resistance</li> <li>• Usually very comfortable for wearer</li> <li>• Positive-pressure device</li> <li>• High APF (<math>=1000</math>)</li> <li>• May reduce cardiopulmonary stress or heat stress</li> <li>• Relatively easy to use with proper training</li> <li>• Long use duration</li> <li>• Adaptable to voice amplifiers and communications systems</li> </ul>	<ul style="list-style-type: none"> <li>• Expense</li> <li>• Vision restricted</li> <li>• Impact verbal communication</li> <li>• Air blowing into wearer's breathing zone may be uncomfortable, especially in hot or cold environments</li> <li>• Much more extensive maintenance needed</li> <li>• Use in dusty environments may reduce airflow rate due to filter loading</li> <li>• Not for use in IDLH</li> </ul>

**Table 4-10. New filter categories, 42 CFR 84.**

Minimum Efficiency	Not for Use in Oil Aerosol Environments**	Oil-Resistant††	Oil-Proof‡
95%	N95	R95	P95
99%	N99	R99	P99
99.97%	N100	R100	P100

\* Tested with NaCl aerosol

† Use time restrictions may apply

‡ Tested with DOP, MMAD=0.3µm

Table 4-10 summarizes these new filter categories. NIOSH intends to revise the other sections of 42 CFR 84 one module at a time.

Manufacturers could no longer manufacture or ship 30 CFR 11-approved respirators after July 10, 1998. By this date, respirator manufacturers had received a new approval number for each of their devices. If these re-approved facepieces are identical to those approved under 30 CFR 11, then the new category filters may be used with the old facepieces. If the manufacturer redesigned the facepiece, however, before submitting it to NIOSH for approval, then the old facepieces may not be used with the new 42 CFR 84-approved filters. These old facepieces will continue to be approved devices only for as long as 30 CFR 11-approved filters are available for them. RPAs should verify that their equipment has been re-approved under 42 CFR 84.

### *HEPA Filters*

Previous versions of NRC regulations required the use of so-called HEPA (high-efficiency particulate air) filters on air-purifying respirators used for protection against airborne particulate radionuclides. The term "HEPA filter" was never defined or used by NIOSH in 30 CFR 11, and this continues to be true in 42

CFR 84. The former, 30 CFR 11, required dust-fume-mist filters to pass a DOP (dioctyl phthalate) test, and the DOP had to be thermally generated. Therefore, they met all the requirements for a high efficiency (HEPA) filter, but the term was never used. The term HEPA probably came out of the air cleaning industry. NIOSH now (42 CFR 84) only talks about percent filter efficiency, and specifies the challenge aerosol to be used and the acceptable range of particle sizes.

High efficiency particulate air (HEPA) filter is defined as "a filter that is at least 99.97% efficient in removing monodisperse particles of 0.3 micrometers in diameter." The equivalent NIOSH 42 CFR 84 particulate filters are the N100, R100, and P100 filters. Although NIOSH has revised the particulate filter descriptions under the new 42 CFR Part 84 respirator certification regulation, and does not use the term HEPA, this definition is included here because "HEPA filter" is used widely in the literature and in some of OSHA's substance-specific standards.

The use of "thermally generated dioctyl phthalate (DOP)" also presents some problems, including operator exposure to the DOP vapors (a possible carcinogen) and rather complex test equipment. The thermal generation process requires the DOP oil to be heated and vaporized then cooled, forming condensation nuclei of approximately 0.3 µm mass median aerodynamic diameter (MMAD). Under 42 CFR 84, N-type filters will be tested with sodium chloride aerosol (count median diameter = 0.075±0.020 µm), and R- and P-types will be tested with DOP particles produced in a non-thermal process (count median diameter = 0.185±0.020 µm). These count median diameters translate to a mass median aerodynamic diameter (MMAD) of 0.3 µm. Manufacturers may still test filters with hot DOP, however.

### *Limitations of Respirator Filters*

NIOSH approves respirator filter cartridges and canisters for some maximum concentrations of contaminant (e.g., 20 mg/m<sup>3</sup>). If actual or anticipated concentrations exceed that value, a more protective device, such as a supplied-air respirator should be selected.

## **4.6 Supplied-Air Respirators (SARs)**

### **4.6.1 General**

Supplied-air respirators (SARs) and self-contained breathing apparatus (SCBA) belong to a class of respirators called “atmosphere-supplying respirators.” They may operate in any one of three possible modes: demand (negative-pressure), constant flow, or pressure-demand. SCBA are discussed later in this chapter. All airline-supplied respirators, regardless of mode of operation, require a protected breathing air source and an air distribution system, which is expensive. The user is then tethered to this air supply by a hose. One big advantage of airline respirators is that they may be used for long continuous periods.

The limitations of supplied-air respirators are the potential consequences of a loss of the source of respirable air supplied to the respiratory inlet covering, and tangling problems associated with the attached air hose. Such loss may be caused by cutting, burning, kinking, or crushing the supply air hose, by air compressor failure, or by depletion of the respirable air in a storage tank. Possible loss of respirable air supports the NIOSH recommendation against airline respirator use in IDLH atmospheres. SARs are never used for fire fighting because the air hose is vulnerable to damage. (Combination devices, such as an airline respirator with an auxiliary self-contained air supply, could be used in such atmospheres because the auxiliary self-contained air supply can be used for escape.

These devices are covered later in this chapter.) The trailing air supply hose of the airline respirator limits the wearer’s mobility. The maximum hose length allowed by NIOSH is 300 feet. Some devices are certified for shorter hose lengths. This may make the airline respirator unsuitable for those who move frequently between widely separated work stations.

### **4.6.2 Demand Mode Supplied-Air Respirators (Negative Pressure)**

Respirators that operate in the demand mode are negative-pressure devices and require the use of a face-sealing respiratory inlet covering. A regulator is mounted either on the wearer’s waist and connected to the facepiece by a breathing tube, or it is mounted directly on the facepiece. As the wearer inhales, the pressure inside the facepiece becomes negative with respect to atmospheric pressure. This pressure differential causes an exhalation valve installed in the facepiece to close, preventing ambient air from entering the facepiece. It also moves a rubber diaphragm in the regulator, which bears on a lever, which opens an admission valve. As the admission valve opens, breathing air from a remote source flows through the valve and into the respiratory inlet covering. When pressure inside the facepiece equals atmospheric pressure at the end of inhalation, the diaphragm moves away from the admission valve lever and the air stops flowing to the facepiece. When the wearer begins to exhale, air pressure inside the facepiece exceeds atmospheric pressure, and the exhalation valve in the facepiece opens, allowing exhaled air to exit the facepiece without disturbing the face seal.

### 4.6.3 Advantages and Limitations of Negative Pressure, Demand, Supplied-Air Respirators

Table 4-11 summarizes the major advantages and limitations of supplied-air respirators operating in the demand mode.

**Table 4-11. Advantages and limitations of facepiece-type, demand supplied-air respirators.**

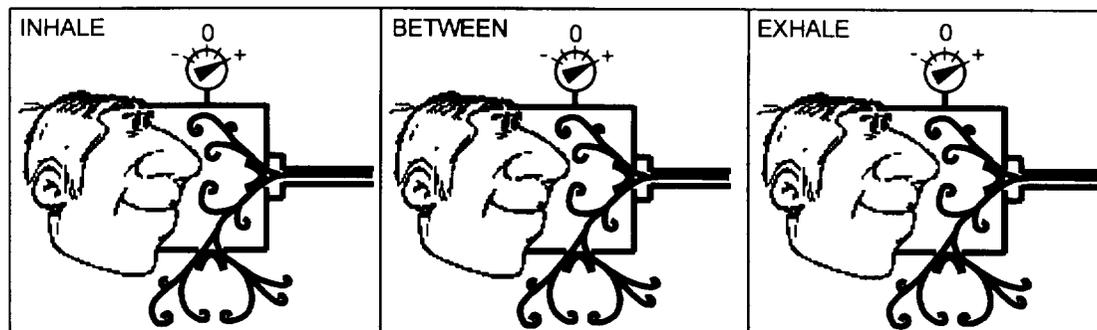
Half- and Full-Facepiece Demand Supplied-Air Respirators	
Advantages	Limitations
<ul style="list-style-type: none"> <li>• None</li> </ul>	<ul style="list-style-type: none"> <li>• More expensive than APR</li> <li>• Air supply system required</li> <li>• Vision restricted</li> <li>• Limited cooling in hot environments</li> <li>• Impact verbal communication</li> <li>• Negative-pressure device</li> <li>• Low APF</li> <li>• Mobility restricted due to air umbilical</li> <li>• Fit test required</li> <li>• More extensive maintenance needed than for APR</li> <li>• Not for use in IDLH</li> <li>• Could be mistaken for a more protective device</li> </ul>

### 4.6.4 Constant Flow Mode (CF)

The term “constant flow” or “continuous flow” is applied to supplied-air respirators that deliver breathing air to a respiratory inlet covering in a continuous stream. The inlet covering may be a face-sealing device, a hood or a helmet. The air is supplied from a secure air source such as a bank of cylinders or from a compressor through an air distribution header. As with positive-pressure devices, if the respiratory inlet covering is compromised, the supplied air is much more likely to leak *out* rather than contaminated air leaking *in*. Constant-flow respirators are almost always used in conjunction with a compressor-supplied air distribution system.



**Figure 4-12. Constant-flow supplied-air respirator with a full facepiece.**



**Figure 4-13. Constant flow respirator operation.**

The large volume of air required to operate these devices usually exclude their use with air supplied by a bank of pressurized cylinders. Mobility is limited by the 300-foot maximum length of the attached air hose. Figure 4-12 shows a constant-flow SAR in use. Operation of a constant-flow device is illustrated in Figure 4-13.

It is *possible*, but not likely, for a respirator user to over-breathe or out-breathe a constant-flow SAR. This means that a person breathing very heavily could, at the peak of a strong inhalation, cause the pressure inside the respirator inlet covering to become negative with respect to the contaminated ambient air. This would only be the case for a very short time, however, and it is unlikely that a person could maintain this breathing volume (high work rate) for more than a few breaths. The minimum flow rate to a facepiece-equipped SAR is 115 lpm (4 cfm), and to a hood- or helmet-equipped device it is 170 lpm (6 cfm).

#### 4.6.5 Advantages and Limitations of Supplied-Air-Respirators

Tables 4-12 through 4-14 summarize the major advantages and limitations of facepiece-type, hood-type, and helmet-type supplied-air respirators.

#### 4.6.6 Pressure-Demand Mode

Supplied-air respirators (airline) and SCBA can both operate in the pressure-demand mode. Pressure-demand operation always requires a tight-fitting facepiece. A pressure greater than atmospheric is maintained inside the facepiece throughout the breathing cycle. Because the exhalation valve is spring loaded in the closed position, air is prevented from being exhausted until facepiece pressure exceeds the spring tension. The regulator also has a spring that forces the regulator to deliver air to the facepiece until the pressure is just below the set point of the exhalation valve.

Therefore, if a person wearing a pressure-demand device holds his breath momentarily, no air will flow through the regulator and the facepiece will contain a slight pressure. As the wearer begins to inhale, the facepiece pressure begins to decrease but remains greater than ambient pressure. This decrease is sensed by the regulator, which begins to supply air to the facepiece, maintaining the positive pressure. As exhalation begins, the increasing pressure in the facepiece exceeds the set point of the exhalation valve, the valve opens, and air is exhausted from the system. Thus, through all phases of the breathing cycle, the pressure inside the facepiece is greater than atmospheric pressure. Any leakage past the

**Table 4-12. Advantages and limitations of facepiece-type, constant-flow supplied-air respirators.**

Half- and Full-Facepiece Constant Flow Supplied-Air Respirators	
Advantages	Limitations
<ul style="list-style-type: none"> <li>• Less complicated operation and maintenance than pressure-demand devices.</li> <li>• High APF</li> </ul>	<ul style="list-style-type: none"> <li>• More expensive than APR</li> <li>• Vision restricted</li> <li>• Limited cooling in hot environments</li> <li>• Impact verbal communication</li> <li>• Mobility restricted due to air umbilical</li> <li>• Loss of air supply requires removal of facepiece</li> <li>• Fit test required</li> <li>• More extensive maintenance needed</li> <li>• Limited body cooling in high-temperatures</li> <li>• May be uncomfortable for long durations</li> <li>• Not for use in IDLH</li> </ul>

**Table 4-13. Advantages and limitations of hood-type, constant-flow, supplied-air respirators.**

Hood-Type Constant Flow Supplied-Air Respirators	
Advantages	Limitations
<ul style="list-style-type: none"> <li>• Many hoods provide better vision than facepiece- or helmet types</li> <li>• High APF</li> <li>• No fit test required</li> <li>• Less expensive than pressure-demand devices</li> <li>• Less complicated operation and maintenance than pressure-demand devices</li> <li>• Hoods are often single-use items</li> <li>• Provide excellent body cooling in high-temperature and/or high humidity areas</li> <li>• Adaptable to voice amplifiers and communications systems</li> </ul>	<ul style="list-style-type: none"> <li>• More expensive than APR</li> <li>• Impact verbal communication</li> <li>• Mobility restricted due to air umbilical</li> <li>• Requires a protected breathing air source and an air distribution system</li> <li>• Air blowing into wearer's breathing zone may be uncomfortable, especially in hot or cold environments</li> <li>• Not for use in IDLH</li> </ul>

face-seal area or through a defect in the facepiece would cause the pressure to decrease to below the regulator set point, and the regulator would supply additional air to the facepiece. In this situation, the respirator wearer would immediately know that there was an air leak in the system because the regulator would be supplying air continuously and not just during the inhalation phase of the respiration cycle. Figure 4-14 shows a positive-demand SAR in use, and Figure 4-15 illustrates pressure-demand respirator operation.

**Table 4-14. Advantages and limitations of helmet-type, constant-flow, supplied-air respirators.**

Helmet-Type Constant-Flow Supplied-Air Respirator	
Advantages	Limitations
<ul style="list-style-type: none"> <li>• High APF</li> <li>• Less complicated operation and maintenance than pressure-demand devices</li> <li>• Head protection</li> <li>• May provide body-cooling in high-temperature and/or high humidity areas.</li> <li>• Very good protection provided</li> <li>• Less complicated operation and maintenance than pressure-demand devices</li> <li>• Adaptable to voice amplifiers and communications systems</li> </ul>	<ul style="list-style-type: none"> <li>• More expensive than APR</li> <li>• Vision restricted</li> <li>• Impact verbal communication</li> <li>• Requires a protected breathing air source and an air distribution system</li> <li>• Mobility limited by length of attached air hose</li> <li>• Consumes large volume of air</li> <li>• Not for use in IDLH</li> </ul>

It is *possible* for a respirator user to over-breathe or out-breathe a SAR operating in the pressure-demand mode. This means that a person breathing very heavily could, at the peak of a strong inhalation, cause the pressure inside the facepiece to become negative with respect to the contaminated ambient air. This would only be the case for a very short time, however, and it is unlikely that a person could maintain this breathing volume (high work rate) for more than a few breaths.

Pressure-demand operation is considered to be the most protective mode of operation available at this time. Since wearers of

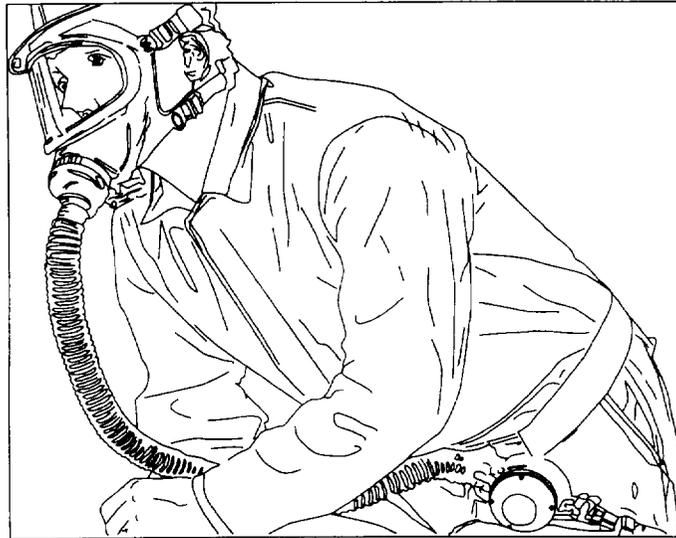


Figure 4-14. Pressure-demand supplied-air respirator with full facepiece.

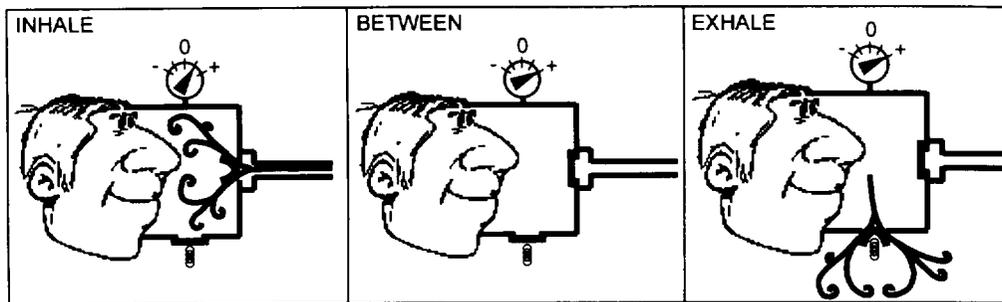


Figure 4-15. Pressure-demand respirator operation.

Table 4-15. Advantages and limitations of full-facepiece, pressure-demand, supplied-air respirators.

Full-Facepiece Pressure-Demand Supplied-Air Respirators	
Advantages	Limitations
<ul style="list-style-type: none"> <li>• No better protection available</li> <li>• Less expensive than SCBA</li> <li>• Less complicated operation and maintenance than SCBA</li> </ul>	<ul style="list-style-type: none"> <li>• Expense</li> <li>• Vision restricted</li> <li>• Limited cooling in hot environments</li> <li>• Impact verbal communication</li> <li>• Mobility restricted due to air umbilical</li> <li>• Fit test required</li> <li>• More extensive maintenance needed</li> <li>• Requires protected breathing air source and air distribution system</li> <li>• Not for use in IDLH</li> </ul>

pressure-demand devices have to exhale with some force to overcome the spring tension in the exhalation valve, this fact should be brought to their attention during training. The slight effort expended during exhalation is the indication that the system is operating properly.

#### **4.6.7 Advantages and Limitations of Pressure-Demand, Supplied-Air Respirators**

Table 4-15 summarizes the major advantages and limitations of full-facepiece supplied-air respirators operating in the pressure-demand mode.

### **4.7 Self-Contained Breathing Apparatus (SCBA)**

#### **4.7.1 Introduction**

While SCBAs are essentially just another type of supplied-air respirator, they are always considered to be in a special category of atmosphere-supplying devices since they are almost always the respirator of choice for entry into IDLH and other truly hazardous environments. The primary differences between them and other SARs are:

- The air supply source is totally under the control of the wearer;
- They are equipped with an emergency regulator bypass in case of regulator failure; and
- They are equipped with a low-pressure alarm.

SCBAs are the most complex type of respiratory protection device available. They require a good deal of upkeep and testing in order to ensure that they will operate properly when they are needed. They also require that the user be highly trained to use the device properly.

The constant-flow mode of operation is not adaptable to SCBA operation, due to the large volume of air consumed by CF systems. The limited air supply in the user-carried cylinder would be expended quickly. The emergency escape feature on open-circuit SCBA, however, turns the device into a CF device by bypassing the regulator and supplying cylinder air directly to the facepiece.

There are two general categories of SCBA: open circuit and closed circuit. Devices in both categories are available that operate in the demand mode. As described above, the demand mode of operation is the least protective of all the modes of operation available. NRC advises against the use of demand SARs and SCBAs by assigning them relatively low APFs in Appendix A to 10 CFR 20. Since demand devices look much like pressure-demand devices, individuals might perceive them to be more protective than they really are and attempt to use them in situations in which a device with a much higher APF is needed. The NRC requires that fire brigades at nuclear power facilities operating prior to January 1, 1979, be equipped with full-facepiece, positive-pressure SCBAs (10 CFR 50, Appendix R, Section III.H). Also, ANSI specifically prohibits the use of demand SCBA in emergency situations such as fire fighting. Little additional information is provided in this document about demand-mode SCBA.

#### **4.7.2 Open-Circuit, Pressure-Demand SCBA**

In an open-circuit, pressure-demand SCBA, all the breathing gas is carried on the back of the wearer. Exhaled air is expelled from the device through the exhalation valve on the facepiece. The combination of spring tensions in the regulator and in the exhalation valve cause a pressure greater than ambient to be maintained inside the facepiece at virtually all times during the inhalation-exhalation cycle. If a small air leak occurs in the system, or if the



**Figure 4-16. Open-circuit, pressure-demand SCBA.**

face-to-facepiece seal is disrupted or compromised, a sufficient pressure and volume of air exists in the cylinder to maintain a positive pressure inside the facepiece. The wearer will be aware of the leak because the regulator will be passing air continuously into the facepiece. Thus, even with a significant air leak, the device is likely to continue to provide a high level of protection to the wearer during egress. Figure 4.16 shows an open-circuit, pressure-demand SCBA in use.

In case of a regulator malfunction, a valve under the control of the wearer can be opened that causes air from the cylinder to bypass the regulator and be delivered directly to the facepiece. This changes the mode of operation to constant flow, and the air in the cylinder will be rapidly depleted. This emergency bypass capability, however, is designed to provide sufficient air to the wearer to permit escape from a hazardous environment without removing the facepiece.

The weight of most SCBAs may make them unsuitable for strenuous work, and their bulk may make them inappropriate for use in a constricted space. The limited service life makes them unsuitable for routine use for long continuous periods, though airline-SCBA

combination devices (described below) resolve this limitation. The relatively short service life of open-circuit type devices may limit them to use where the wearer can go conveniently and quickly from a hazardous atmosphere to a safe atmosphere to change the tank of air. A supply of extra air cylinders is usually necessary, and a means of refilling the tanks must be available. This adds to the operating expense.

The rated duration of use for these devices can be misleading. Since NIOSH rates these devices as 15-minute, 30-minute or 60-minute duration using a relatively low breathing rate, actual use time in a stressful situation or while performing heavy work may only be about 50% of the rated duration. If leakage occurs or if the face-to-facepiece seal is seriously compromised, the useful duration will be even shorter. A warning alarm is activated when this device reaches 20% of full capacity, reminding the user to exit the area to replenish the air supply. The wearer should exit the area as soon as the alarm sounds.

Recent changes made to the National Fire Protection Association (NFPA) specifications for open-circuit pressure-demand regulators make it much less likely that devices that meet the NFPA standard can be over-breathed.

#### **4.7.3 Advantages and Limitations of Open-Circuit Pressure-Demand SCBA**

Table 4-16 summarizes the major advantages and limitations of open-circuit pressure-demand SCBA. These devices all utilize full facepieces as the respiratory inlet covering.

#### **4.7.4 Open-Circuit SCBAs with a Donning Switch**

There is a type of hybrid SCBA available that incorporates a so-called "donning switch" into its design. These are designed to operate in demand mode during donning and while removing the facepiece in a safe area. The

**Table 4-16. Advantages and limitations of full-facepiece, open-circuit, pressure-demand SCBA.**

<b>Full-Facepiece Open-Circuit Pressure-Demand SCBA</b>	
Advantages	Limitations
<ul style="list-style-type: none"> <li>• No better protection available</li> <li>• Less complicated operation and maintenance than closed-circuit, positive-pressure SCBA</li> <li>• Highest APF available (10,000)</li> <li>• Permitted for use in unassessed environments, fire fighting, IDLH</li> <li>• Allows comparatively free movement over an unlimited area</li> <li>• Less expensive than closed circuit SCBA</li> <li>• Requires less maintenance than the closed-circuit type</li> </ul>	<ul style="list-style-type: none"> <li>• Expensive</li> <li>• Actual service life may be only 50% of rated duration</li> <li>• Extra air cylinders needed</li> <li>• Source of high-pressure air needed</li> <li>• Bulk and weight</li> <li>• Unsuitable for routine use for long continuous periods</li> <li>• Relatively short service life</li> <li>• Open-circuit SCBA are more expensive to purchase than supplied air systems</li> <li>•</li> </ul>

donning switch in the demand mode prevents the rapid loss of air from the SCBA cylinder when the facepiece is not sealed to the wearer's face. After the wearer puts on the facepiece and is ready to enter the hazardous area, the donning switch is changed to the pressure-demand position and the regulator begins to operate in the pressure-demand mode. There are two potential problems with this type of device. The wearer will not have the benefit of a highly protective pressure-demand device if (1) the switch is mistakenly left in the donning position when the wearer enters a hazardous area or, (2) the switch is inadvertently or accidentally changed to the donning position while the worker is in a hazardous area.

Licensees who have demand-only SCBAs, or SCBAs with donning switches, especially those who might need to use them in a fire fighting application, should be aware that these devices do not meet the current NFPA standards.<sup>4</sup> These devices should either be modified to bring them up to the new standard or be replaced.

<sup>4</sup> National Fire Protection Association, "Open Circuit Self-Contained Breathing Apparatus for Fire Fighters," ANSI/NFPA 1981, 1997 edition.

#### **4.7.5 Closed-Circuit Positive Pressure Mode**

There is a second type of SCBA that operates in the "closed-circuit" (or "re-circulating") mode, meaning that exhaled air is retained in the system by use of a second hose attached to the facepiece. This second hose directs exhaled air into the back-mounted apparatus where the CO<sub>2</sub> is removed, O<sub>2</sub> is added, and the treated air is made available to be re-breathed by the wearer.

A closed-circuit positive-pressure SCBA (RP) is not a true pressure-demand device. Air exhaled by the wearer passes through a catalyst bed in the backpack that removes CO<sub>2</sub>, and is directed into a spring-loaded breathing bag that pressurizes it to some extent. O<sub>2</sub> from a pressurized cylinder in the backpack bleeds slowly into the breathing bag, re-oxygenating the air and increasing the pressure in the closed system. When the wearer inhales, the slightly pressurized air from the spring-loaded breathing bag provides the air. The oxygen bleed quickly increases the O<sub>2</sub> concentration in the breathing gas to greater than 35%. This makes these devices useful in applications such as high altitude work, or work in low atmospheric pressure environments that are oxygen deficient.

Since these devices were developed for mine rescue, long use times were essential. Unlike open-circuit SCBAs, if a closed-circuit device is rated for four hours, then a full four hours of use can be expected. These devices have also been adapted for use under water, primarily in military applications.

If an air leak occurs in the system, or if the face-to-facepiece seal is disrupted or compromised, the small volume of pressurized air in the breathing bag will quickly reach ambient pressure. The O<sub>2</sub> cylinder will begin venting into the breathing bag at a faster rate in an attempt to maintain system pressure, but if the leak is persistent, or very large, the device will quickly revert to the negative pressure mode of operation. The first sign the wearer might have of trouble could be the premature sounding of the low-oxygen warning alarm at 20% of capacity. The chemical reaction that removes CO<sub>2</sub> also increases the temperature of the air supplied to the wearer, which some users report is uncomfortable.

These devices also require more maintenance between uses than open-circuit devices, even if the same person is going to reuse it. The catalyst bed in the backpack has to be replaced after each use, and a pressurized oxygen cylinder, also inside the backpack, must be replaced. Therefore, a supply of catalyst material and a number of compressed oxygen cylinders must be maintained on site, and a local source for breathing-quality oxygen located.

#### 4.7.6 Advantages and Limitations of Full-Facepiece, Closed-Circuit, Recirculating Positive-Pressure SCBA

Table 4-17 summarizes the major advantages and limitations of full-facepiece, closed-circuit, recirculating positive-pressure SCBA.

**Table 4-17. Advantages and limitations of full-facepiece, closed-circuit, recirculating positive-pressure SCBA.**

Full-Facepiece Closed-Circuit Recirculating Positive-Pressure SCBA	
Advantages	Limitations
<ul style="list-style-type: none"> <li>• Very long use times</li> <li>• Highest APF available (10,000)</li> </ul>	<ul style="list-style-type: none"> <li>• Breathing air becomes warm during use</li> <li>• Bulk: 2 hoses attached to facepiece</li> <li>• Weight</li> <li>• Require more maintenance between uses than open-circuit</li> <li>• Supply of compressed oxygen cylinders needed</li> <li>• Source for breathing-quality oxygen needed</li> <li>• Supply of CO<sub>2</sub> absorbent needed</li> </ul>

### 4.8 Combination Devices

#### 4.8.1 Air-Purifying/Supplied-Air

Combinations of two (or conceivably even more) types of respirators are possible. One such device is a combination air-purifying respirator and airline-supplied respirator. When the device is connected to an air supply, the wearer breathes the remotely supplied-air usually in the continuous-flow mode of operation. When the air supply is disconnected, the wearer breathes ambient air through an attached filter and the device operates in the negative-pressure mode. (See Figure 4-17.)

#### 4.8.2 Supplied-Air/Short-Duration SCBA

Another combination is an airline-supplied respirator and self-contained breathing apparatus. This device allows the wearer to breathe air from a remote supply, but provides a 5- or 10-minute reserve air supply in a small cylinder, usually attached to the wearer's belt. If the device operates in the continuous-flow mode, the only way for this device to be used is for the wearer to enter the contaminated environment, perform the required work, and exit the area breathing air through the attached airline. The attached air cylinder would be employed only for escape in the event that the airline supply failed. The cylinder should be charged to a minimum of 90% of its full capacity prior to its use.

For pressure-demand devices with escape cylinders, if the use of the airline for entry and exit is not practical, the RPA may permit the wearer to enter a contaminated environment using the air in the belt-mounted cylinder, then connect to an airline supply at the work location. The air remaining in the cylinder is available for use during egress or in case the remotely supplied-air source fails. The RPA should ensure that the air expended during entry does not exceed 20% of the rated service life of the SCBA, and that the cylinder is charged to a minimum of 90% of its full capacity prior to its use. (See Figure 4-18.)

#### 4.8.3 Supplied-Air/SCBA

For applications where very long work times are required and exiting an area in case of air supply failure is not an option, a standard 30-minute or 60-minute SCBA might be combined with an airline-supplied respirator. For example, in the event of a casualty, the atmosphere inside the control room at a nuclear power plant might require the use of supplied-air respirators. A combination SAR/SCBA provides maximum protection over a long period of use. These combination

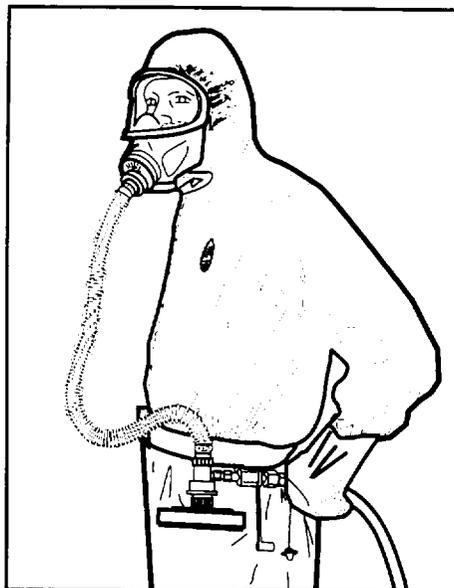


Figure 4-17. Combination supplied-air respirator and air-purifying respirator.



Figure 4-18. Combination pressure-demand airline and short-duration SCBA.

devices operate in the pressure-demand mode while in both configurations.

#### 4.8.4 NIOSH Certification

Each combination device must be NIOSH certified. Each device is issued only one certification number, and that number is for the mode of operation that provides the least protection. The NIOSH certificate, however, will contain information about both modes of operation, and the device is certified for use in both modes of operation.

An exception to this certification number policy is that devices that include SCBA capability are assigned a certification number for SCBA. All combination devices must be used within the limitations stated in the NIOSH certificate. More information about NIOSH approvals is contained in Section 4.9 below.

#### 4.8.5 Assigned Protection Factor

The Assigned Protection Factor applied to a combination device by the licensee should be for the respirator type and mode of operation as listed in Appendix A to 10 CFR 20. If this is not practical, licensees may apply the smaller APF for the entire duration of respirator use. If this would result in a dose assignment, post-exposure bioassay measurements may be made to quantify any actual intake.

#### 4.9 The Role of NIOSH in Respirator Programs

The NRC, OSHA and EPA all require that NIOSH-approved equipment be used, when available, as part of a compliance respiratory protection program. The National Institute for Occupational Safety and Health (NIOSH) was established in 1971 by the Occupational Safety and Health Act. The respirator certification work that NIOSH performs is a

direct offshoot of the approval of mine rescue breathing apparatus formerly done by the Bureau of Mines. Up until July 10, 1995, NIOSH tested and certified respiratory protection devices against the requirements of 30 CFR 11, and all NIOSH certifications were issued jointly with the Mine Safety and Health Administration (MSHA). On that date, the requirements for certification of respirators were moved from 30 CFR 11 (Mine Safety and Health Administration) to 42 CFR 84 (Department of Health and Human Services). Now most certifications are issued solely by NIOSH, a part of the Centers for Disease Control (CDC), which is part of the Department of Health and Human Services (DHHS). The Mine Safety and Health Administration (MSHA) still exists, regulates mining activity, and continues to issue joint respirator approvals with NIOSH for devices used in mine rescue and other mine emergencies, although MSHA's logo no longer appears on the approval label.

#### 4.9.1 Assigned Protection Factors (APF)

The instantaneous protection factor (PF) of a respirator can be defined as:

$$PF = \frac{\text{Ambient Airborne Concentration}}{\text{Concentration Inside Respirator}}$$

The *assigned* protection factor for each type of device is based on measured PFs achieved by a number of individuals under work-like conditions with a safety factor applied. Presumed particle removal efficiency (%) based on APF can be calculated as follows:

$$\text{Removal Efficiency (\%)} = 100 \left( 1 - \frac{1}{\text{APF}} \right)$$

See the discussion of APFs in section 3.6.1 of this Manual.

Particle removal efficiencies, provided by respirators having various APFs, are shown in Table 4-18 below.

**Table 4-18. Particle removal efficiencies for various assigned protection factors.**

Assigned Protection Factor (APF)	Minimum Particle Removal Efficiency (%)
10	90
25	96
100	99.0
1,000	99.9
3,333	99.97
10,000	99.99

Approximately 1/3 of tritium (<sup>3</sup>H) in gaseous (<sup>3</sup>H<sub>2</sub>) or vaporous (T<sub>2</sub>O) form is absorbed through the skin of an exposed person, so intake is not limited very effectively by using respiratory protection devices. Air-purifying respirators equipped with particulate filters are not effective against any gases or vapors. Even the protection provided by supplied-air respirators is dramatically reduced. See Table 4-19 below. Calculation of these APFs are provided in Appendix B of this document.

**Table 4-19. APFs for supplied-air respirators against tritium.**

APF	Tritium APF
10	2.5
25	2.78
100	2.94
1000	2.997
10,000	3.0

NIOSH recommends APFs for respirators certified under 30 CFR 11 in its "Guide to Industrial Respiratory Protection" and in the "Respirator Decision Logic." Other APFs can be found in ANSI Z88.2-1992. Assigned protection factors that are to be used against specific hazards can be found in Appendix A to 10 CFR 20 (radioactivity), 29 CFR 1001 Table 1 (asbestos), 29 CFR 1910.1025 Table 2 (lead), 29 CFR 1910.1028 Table 1 (benzene),

and other hazard-specific standards. No APFs are given in OSHA's main respiratory protection regulation (29 CFR 1910.134). NRC licensees are required to use the APFs provided in Appendix A to 10 CFR 20 for exposures to airborne radioactive material. When non-radiological airborne hazards are present, licensees should use APFs that are appropriate to the hazard, not (necessarily) those listed in Appendix A to 10 CFR 20.

#### 4.9.2 The NIOSH Approval Process

NIOSH approves entire assemblies, not individual components of respiratory protection systems. Therefore, there is no such thing as an "approved" regulator, an "approved" facepiece, or an "approved" filter. Components are only "approved" in so far as they are part of a complete, approved *assembly*. A respirator manufacturer seeking NIOSH approval would submit samples of the device along with drawings, user instructions, and other documentation, such as its QA program and the QC plan for the specific product. NIOSH would then test the devices in its laboratory against the requirements of 42 CFR 84. If the device met all the requirements, an approval number would be assigned.

NIOSH also has a follow-up surveillance program, including site audits of the manufacturer's facilities. They also obtain off-the-shelf devices periodically for re-testing. There is also a problem-investigation program, in which reports of problems received from regulatory agencies, labor organizations, respirator users, and respirator manufacturers, are investigated and resolved. Items of major interest or significance are widely distributed as "Respirator User Notices" or "Respirator User Warnings."<sup>5</sup>

<sup>5</sup> The most current NIOSH User Notices are available at <<http://www.cdc.gov/niosh/usersntc.html>>.

**Table 4-20. NIOSH approval categories.**

42 CFR 84 Device Type	Approval Schedule Sub-Part	Current Revision
SCBA	H	TC-13F
Gas Masks	I	TC-14G
Supplied Air	J	TC-19C
Non-Powered Air Purifying, Particulate	K	TC-84A
Chemical Cartridge	L	TC-23C
Dust, Fume, and Mist; Pesticide; Paint Spray	KK (Grand-fathered approval schedule)	TC-21C* (particulate) TC-23C* (Combination or chemical cartridge)
Powered Air-Purifying High Efficiency Respirators	KK	TC-21C (particulate) TC-23C (Combination or chemical cartridge)

\* None issued after July 10, 1998

The NRC, OSHA and EPA all require that NIOSH-approved equipment be used when available, as part of a compliant respiratory protection program. NRC, when requiring use of NIOSH-approved devices as part of a respiratory protection program, is simply employing an equipment testing and certification mechanism that is already in place.

NIOSH tests and approves respirators in the categories listed in Table 4-20. As stated above, if a submitted device meets the listed

criteria, it is granted a "TC" number. (The letters TC were originally "TCL" and stood for Testing and Certification Laboratory, Bureau of Mines. It was soon shortened to "TC"-Testing and Certification. The current official name of the NIOSH lab is the Certification and Quality Assurance Branch, Division of Respiratory Disease Studies, NIOSH.)

Formerly, negative-pressure air-purifying respirators were accompanied by a booklet containing a NIOSH approval certificate for each combination of facepiece and filter that the manufacturer offered. Under the new scheme, NIOSH has revised its approval label (which is usually an 8½" × 11" sheet of paper), and will issue multiple approval numbers for a facepiece and each of the filters or cartridges it is approved with, all on one label. The list of approved assemblies on the label was formerly a narrative paragraph, but will now be a matrix list. The approval label enclosed with a facepiece will list all the cartridges and canisters that may be used with the facepiece. The label on a box of cartridges will list all the facepieces for which the cartridge is approved. This matrix method is intended to be more user-friendly.

#### 4.9.3 Approval of Combination Devices

Combination devices are those which incorporate two modes of operation into one device. These are usually issued an approval number for the *less* protective mode of operation. For example, a combination air-purifying and supplied-air continuous flow respirator would be issued an approval number beginning TC-84A (i.e., a particulate, non-powered air-purifying respirator approval). Such devices are *also* approved for use in the other mode of operation, but this may not be apparent to the end user, who should rely on information from the manufacturer. Apply the assigned protection factor (APF) for the mode in which the device is operated. In this example (in an NRC program), APF=100

when used in the air purifying mode, and APF=1,000 when used in the constant-flow supplied air mode. Under the new method of approval, any combination device that includes a particulate filter since July 10, 1995 has been assigned a TC-84A approval number.

The exception to the rule is the combination SCBA-supplied air respirator (SAR). These are certified, and assigned an approval number as a self-contained breathing apparatus. There must be no confusion about what an SCBA is approved for.

#### 4.9.4 What NIOSH Does *Not* Approve

NIOSH does *not* approve a variety of equipment that is (or could be) used in conjunction with respiratory protection equipment. Examples of these would be:

- Breathing air distribution manifolds;
- Breathing air compressors;
- Breathing air-purification systems;
- Qualitative and quantitative fit test equipment; and
- Supplied air suits.

If an approval schedule for a type of equipment does not exist in 42 CFR 84, then no approval can be granted. In the case of breathing air compressors, air supply systems, distribution manifolds, etc., the RPA should still ensure that Grade D breathing air or better is delivered to the NIOSH-approved device.

#### 4.9.5 Proper Use and Maintenance of Approved Devices

Purchase of NIOSH-approved equipment is only the first step. The licensee should keep it in "like new" condition while allowing for a reasonable amount of wear. The old regulation stated [30 CFR 11.2(a)]: "Respirators, combinations of respirators, and gas masks shall be approved for use in hazardous atmospheres where they are maintained in an approved condition and are the same in all respects as those devices for which a

certificate of approval has been issued under this part." This paragraph was deleted from 42 CFR 84 because NIOSH has no authority to regulate end users of the equipment. NIOSH relies on the regulatory agencies that oversee respiratory programs to have adequate requirements in place to ensure that respirator users are issued high-quality working respiratory protection devices. This means that these devices should be inspected before and after each use, and that an experienced person should perform required repairs, determine which devices are excessively worn or broken, and repair or discard them. A few key inspection points are listed below. Additional information about inspecting respiratory protection systems should be available from the device manufacturer.

- Straps should not show any breaks, excessive wear or loss of elasticity;
- Broken or malfunctioning buckles should be replaced;
- Facepieces should not show excessive wear, craze lines, cracks, tears, or holes;
- Continued use of an elastomeric facepiece that is distorted from improper storage should not be permitted;
- Cracked or badly scratched lenses should be replaced;
- Incorrectly mounted lenses that distort the facepiece should be adjusted; and
- Broken or missing mounting clips, cracked or broken cartridge holders, components with badly worn threads, and missing gaskets should all be replaced before the respirator can be used again.

Where specific guidance from NIOSH does not exist, licensees should use, maintain, and repair respiratory protection devices in accordance with the manufacturer's instructions.

Most repairs can be accomplished by a person who is familiar with how the device is constructed and who is experienced in the use of devices of the type to be repaired. Manufacturer-provided training is not required for the less complex portions of respiratory protection systems such as facepieces. Repair

of some portions of pressure-demand supplied air respirator regulators, and several self-contained breathing apparatus components (e.g., regulators, alarm devices, cylinder valves, and possibly others) require manufacturer-certified training. These critical subassemblies are clearly identified in each manufacturer's literature.

When delivered, each NIOSH-certified device is usually accompanied by an approval label and an instruction manual. As stated above, the label contains a matrix showing all the components of the approved device. The instructions may include an exploded drawing that shows all the parts in the assembly along with their relative locations. Replacement and repair parts for a device should be ordered from this list, even if parts that appear to be identical are available from another source. The simple fact, for instance, that a filter cartridge or a gasket from one manufacturer's respirator fits on or in the facepiece of a different manufacturer, does not mean that it should be used.

If questions arise about which repairs may or may not be done in-house, about how the equipment is to be operated or stored, or about other technical matters, the best source of information is the manufacturer of the device. Reputable manufacturers should be willing to put their answers or explanations in writing. Manufacturers do not have the authority, however, to allow operation of their equipment outside the parameters stated in the NIOSH approval.

The 30 CFR 11 approval labels all contained cautionary statements such as:

- Not for use in atmospheres containing less than 19.5% oxygen; or
- Not for use in atmospheres immediately dangerous to life or health.

The new 42 CFR 84 labels contain an expanded list of these statements. For example:

- Use only the pressure ranges and hose lengths specified in the User's Instructions;
- Failure to properly use and maintain this product could result in injury or death;
- Never substitute, modify, add, or omit parts. Use only exact replacement parts in the configuration as specified by the manufacturer; or
- Refer to User Instructions and/or maintenance manuals for information on use and maintenance of these respirators.

#### 4.9.6 Form, Fit or Function

Another way in which respirators might potentially be misused and have their performance degraded involves the use of other types of protective, safety, or communications equipment in conjunction with the respiratory protection equipment. Regarding each such item, the following question must be asked: "Does use of this equipment affect or change the form, fit, or function of the respirator?" If the answer is "yes," then use of the device in question will probably result in a non-approved assembly.

For example, use of a non-manufacturer-supplied voice amplification device, in which the microphone and connectors attach to or through the facepiece body or lens (and thus change the form of the respirator), would result in a non-approved assembly. A similar device, however, which utilizes a throat microphone, and is not attached in any way to the respiratory device, would be permitted even if it is not supplied by the respirator manufacturer, because the respirator is not directly affected.

Anything that intrudes into the area where the respirator seals against the face will affect the fit of the device. This includes hair, cosmetics, standard spectacle temples, etc. A bone-conduction microphone held tight to the top of the head by the facepiece harness would also alter the fit of the respirator, and would

therefore not be allowed. Obviously, modification of any respiratory device in any way, except that done in accordance with the manufacturer's instructions, is likely to impact the NIOSH approval.

A minor exception to this involves the marking of respirators for purposes of accountability. The use of small numbered metal or plastic tags, attached to facepieces with plastic electrical fasteners or small metal S-hooks, present no problem as long as the tag does not interfere with the proper operation of the respirator. The "D" rings normally found on facepiece buckles are acceptable mounting points. Use of bar-coded labels applied to the lenses of full facepieces might be acceptable if they do not distract or obscure the vision of the wearers. Methods of marking which damage or weaken the respirator (e.g., branding a number into a facepiece or lens with a soldering iron) are not permitted.

#### **4.9.7 Other Ways in Which Devices Might Be Misused**

Air-supplied devices must be used with air that meets (as a minimum) the Grade D requirements of the Compressed Gas Association (CGA) as described in their Pamphlet G-7.1-1997 "Commodity Specification for Air." This requirement holds for airline-supplied devices and for SCBA.

Each airline-supplied device is approved for a certain minimum and maximum hose length, which is measured from the air distribution manifold to the inlet of the regulator assembly on the facepiece or on the wearer's belt. Such devices may be approved for various supply-hose lengths up to 300', with no section shorter than 25'. Specific devices might be approved for less than 300', and may have other limiting conditions or requirements added. Specific minimum and maximum air pressures supplied to the device are also part of the NIOSH approval. Formerly, all the different combinations of hose length and

supply pressure were listed on the approval label. Under the 42 CFR 84 approval method, the user will be referred to the manufacturer's instructions. Use of supply hose outside the approved range of lengths, or in an unapproved configuration, or at pressures outside the manufacturer's specifications is not permitted.

NIOSH approvals do not address the maximum length of hose from a primary air supply up to the point where the approved assembly is attached to it. Therefore, breathing air may be connected from a supply header or a bank of cylinders to the inlet of a distribution manifold using commercially available rubber hose and hose clamps, or threaded pipe and fittings. None of this has to be supplied by the respirator manufacturer, or meet any NIOSH approval criteria. The NIOSH approval starts where the approved respiratory protection device attaches to the air distribution manifold. The pressure at that point must be within the range specified in the manufacturer's user instructions.

#### **4.9.8 Conclusion**

Just because a respiratory protection device has a NIOSH approval doesn't necessarily mean that it will be the right device for a particular application. Respirator program administrators are strongly advised to obtain samples of devices they want to consider for purchase. These should be used in the workplace for a period a time and subjected to actual conditions of use. Some respirator wearers should participate in the evaluation of devices.

This evaluation should include an assessment of the ease of maintenance and other factors that are important in a well-run respiratory protection program. Performance of these devices should be evaluated when they are used in conjunction with other types of protective equipment. How does the respirator manufacturer address spectacle adapter kits?

Does the inside of the lens fog badly when used in a cold environment? Can a hard-hat be worn properly at the same time the respirator is being worn? How is voice amplification addressed by the manufacturer?

#### **4.9.9 Input to NIOSH**

Licenses should report any significant respirator defect or failure to the manufacturer, with a copy or supplemental phone call to NIOSH. Names and addresses of respirator manufacturers are available in the NIOSH Approved Equipment List. NIOSH may be contacted at:

NIOSH Division of Safety Research  
Testing and Certification Branch  
944 Chestnut Ridge Road  
Morgantown, WV 26505  
(304) 291-4361.

#### **4.10 Non-NIOSH-Certified Equipment**

##### **4.10.1 Exemptions for Non-NIOSH-Certified Devices**

If a licensee identifies the need for a respiratory protection device that is not NIOSH approved and not listed in Appendix A to 10 CFR 20, and where no such NIOSH-approved device is known to exist, the licensee may make application to the Commission to use a non-approved device. Commission approval is required whether or not APF credit will be used. The application should include the following information:

- An explanation of why no existing NIOSH-approved device meets the licensee's need; and
- Evidence that the material quality and performance characteristics of the proposed device are capable of providing adequate respiratory protection to the wearer under the proposed conditions of use while not subjecting the wearer to

undue physical or psychological stress, or to undue hazard.

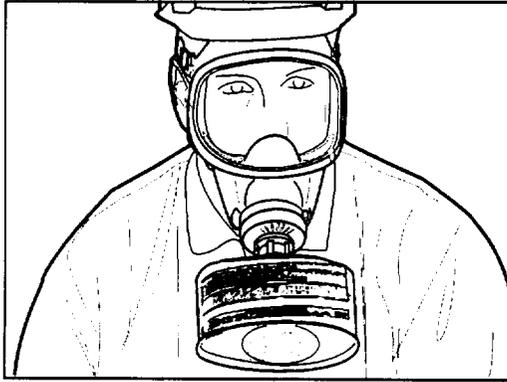
Such test information may be developed by the licensee, the equipment manufacturer, or by a reliable third party. The manufacturer of such a device should have previous experience with the design and manufacture of respiratory protection equipment. The licensee-applicant may use such devices under controlled circumstances to develop information for the exemption application.

Where an exemption for use of such a device has already been granted to a licensee by the Commission, subsequent applications by additional licensees may make use of test information previously submitted. At a minimum, for devices that have not yet been granted an exemption by the Commission, the licensee-applicant should be involved in at least one operational test of the device.

##### **4.10.2 Radioiodine Canisters**

The NRC has granted an exemption to a number of power reactor licensees to use an APF of 50 when using combination particulate/organic vapor chin-mounted canisters in areas where airborne radioiodine is present (see Figure 4-19). Licensees receiving such authorization were required to establish a more stringent quality assurance program and procedures for using these canisters. Although the APF for full-facepiece air-purifying respirators went from 50 to 100 in the 1999 revision of Appendix A to 10 CFR 20, licensees previously granted this exemption may still only utilize an APF of 50 for these radioiodine canisters, unless authorized in writing by the NRC to increase it. The granting of a blanket exemption by the NRC to all licensees to allow the use of an APF for these canisters against airborne radioiodine vapors is not anticipated.

A few licensees who have obtained the NRC's authorization to use this APF have reported small radioiodine uptakes in wearers of this



**Figure 4-19. Full-facepiece respirator with radioiodine canister attached.**

device. It has been postulated that the reason for this might be the stress that such a canister places on the facepiece seal when the wearer moves about in the work place. Consideration should be given to using these “iodine canisters” during quantitative fit testing (QNFT) of individuals to determine whether the added weight of the canister has any effect on the quality of the fit.

#### **4.10.3 Supplied-Air Suits**

One-piece and two-piece supplied-air suits are permitted for use in nuclear industry respiratory protection programs, but no protection credit may be taken except as described in 10 CFR 20.1705, “Application for use of higher assigned protection factors.” Additional information about this application is provided in Regulatory Guide 8.15, Revision 1. The NRC believes that, in certain nuclear industry applications (e.g., control-rod drive removal at boiling water reactors), these suits might be the best overall choice, taking into account respiratory protection, contamination control considerations, heat stress, and ALARA.

All requirements of the respiratory protection program apply to the use of these devices (e.g., medical screening, training, air quality,

maintenance and QA requirements) whether or not an APF is used.

#### **4.10.4 Past Use of Uncertified Devices**

As a general rule, use of non NIOSH-certified devices is not permitted in an NRC-regulated respiratory protection program. The NRC is aware that, in the past, a few licensees have deliberately used non NIOSH-approved disposable dust masks for certain tasks in an attempt to avoid medical screening, training, and/or fit testing requirements. The removal of the medical screening and fit testing requirements for the use of filtering facepieces without using an APF, and the minimal training now required for users of these devices, should give licensees the program flexibility necessary to maintain full compliance without imposing unnecessary burdens for a large number of workers.

### **4.11 Inventory, Inspection, and Storage**

#### **4.11.1 Facepieces**

Each time a respirator goes through the decontamination-sanitization cycle, the facepiece should be inspected and tested for gross leakage before being made available for reissue. The inspection and testing should be done by a person who is trained to perform this procedure, and who is approved by the RPA. Each component of the facepiece should be examined for presence and proper function. As a final check, any of the following methods may be used:

- The person doing the testing performs a user seal check, then re-sanitize the facepiece. This re-sanitization could utilize a non-alcohol wipe or a sanitizing spray;
- Perform a leak test using a test head and aerosol generator;
- Perform a leak test using a test head and a vacuum pump; or

- Rely on the end user to perform the required user seal check. Consider having this seal check performed at the point of issue so a defective respirator may be identified and replaced immediately.

Also see paragraph 4.12.4 below.

Respirator facepieces that are available for routine issue should be visually inspected at least every month. If such devices are stored in clear plastic bags, verify that no moisture condensation is visible on the inside of the bag. A few facepieces should be handled and examined each month but need not be removed from the bags as long as the licensee can determine that the device is ready for issue.

Respirator facepieces that are designated for emergency use, such as those staged at the Emergency Operations Center at a commercial power reactor facility, should be visually inspected at least every month as described above for respirators that are available for routine issue. A more thorough inspection should be conducted twice or three times per year where each facepiece is handled and inspected. Licensees should consider re-washing and re-sanitizing these emergency-use facepieces on an annual basis, or replacing them periodically with different facepieces that have been washed and sanitized more recently.

At the time each facepiece is issued, the qualified issuing person should inspect the device to ensure that all component parts are present, that the proper filter or canister is attached or provided, and that the lens is free from significant abrasions.

Each time a respirator is donned, the wearer should perform a user seal-check such as a positive-pressure check or a negative-pressure check. Respirator users must be trained to recognize the symptoms of a leaking facepiece during this seal check, and trained to obtain a properly working replacement prior to entering an airborne contamination area.

Store facepieces in a plastic, cloth or paper bag with straps fully extended and inside the facepiece. The licensee determines whether the filter is attached before storage or attached at the time of issue. The bag should be secured closed and contain an easily visible tag or sticker indicating the date the facepiece was last sanitized and fully inspected. The identity of the person who performed the inspection should also be indicated. Bagged full-facepieces should be stored on a flat surface, with the lens down. Half-facepieces should be stored in the same way with the support yoke down. Do not store facepieces with the face seal portion bearing the weight of the respirator. Do not stack respirator facepieces unless they are first placed in a rigid container. The original facepiece box is acceptable. Other methods of facepiece storage are acceptable as long as the seal area is protected from distortion and the device can be kept free of dust and dirt.

Respirators that are ready for issue should be in like-new condition with allowance made for superficial signs of wear.

#### **4.11.2 Associated Equipment**

Equipment used in conjunction with respirators (e.g., belt/mask-mounted air regulators, air-supply hoses, portable distribution manifolds, etc.) should be inventoried and functionally tested periodically, for instance, twice yearly or prior to issue (licensee's choice). During this inspection, the licensee should verify that these components are clean and in ready-to-use condition, and that there are a sufficient number of them available to meet the needs of the program during high-usage periods.

A functional test for an air hose would consist of connecting it to a source of breathing air, verifying that air flows through it, and that there are no leaks. An adequate inspection would consist of verifying that the quick-connect fittings are properly installed and

operate properly, and that the hose is not cut, nicked or abraded. Hoses should be in like-new condition. An acceptable way to store air hoses is in a coil with the quick-connect fittings connected together. This protects the inside of the hose from dirt and debris. Other acceptable methods of protecting the quick-connect fittings and the hose interior are to cover the ends with tape, small plastic bags or plastic caps. Air hoses that are ready for issue should be in like-new condition with allowance made for superficial signs of wear. Consider storing coils of hose inside a 55-gallon drum to protect them from damage. A functional test for a mask- or belt-mounted regulator would consist of connecting it to a source of breathing air and verifying that air flows through it. An adequate inspection would consist of verifying that any threaded connectors are in good condition, or that quick-connect fittings are properly installed and operate properly. Regulators that are ready for issue should be in like-new condition with allowance made for superficial signs of wear.

A functional test for an elephant trunk-style breathing tube would consist of blocking both ends and stretching the tube as far as it will go. This will collapse the breathing tube. If the tube stays collapsed for 15 seconds or more it is unlikely to have a significant leak. Other methods suggested by the manufacturer are acceptable.

Repair and replacement parts for respiratory protection devices should be inventoried and inspected periodically.

#### **4.11.3 Emergency-Use SCBA**

Emergency respiratory protection equipment (SCBA) should be visually inspected monthly, and donned and operationally tested quarterly. Licensees should attempt to use infrequently used SCBA on a rotating basis for training or during drills or exercises. Other respiratory protection devices designated for emergency use (e.g., single use, escape-only SCBA)

should be removed from any protective bag and examined thoroughly once per month. Filter respirators stored for emergency use are covered in 4.11.1 above.

#### **4.11.4 SCBA Cylinders**

SCBA cylinders should be inspected monthly to verify that they contain a minimum of 90% of their rated capacity.

Regulations regarding all pressurized gas cylinders are the responsibility of the U.S. Department of Transportation (DOT). There are currently three types of SCBA cylinders available on the market: steel, aluminum, and composite. Steel and aluminum cylinders can be distinguished from composite cylinders because they have smooth exteriors. Composite cylinders consist of a relatively thin aluminum shell that is reinforced by wrapping fibrous material around the outside. Some composite cylinders are fully reinforced from neck to bottom, others have only the cylindrical section reinforced. This second category is referred to as "hoop-wrapped" cylinders. To date, most composite cylinders have been reinforced with fiberglass, but beginning in 1997, some have been made using carbon fiber reinforcement.

Steel and aluminum cylinders must be depressurized, inspected, refurbished as necessary, and hydrostatically tested every five years. Composite cylinders must undergo this process every three years.

Composite cylinders have a maximum life of 15 years from the date of manufacture. After this, they must be replaced. It is possible that carbon fiber-wrapped composite cylinders may eventually have their useable lifetime extended, since there is a provision made by DOT that additional testing can be done after 15 years of service. The carbon fiber-wrapping technology will be 15 years old in the year 2012. Steel and aluminum cylinders may be used indefinitely as long as they continue to be

properly maintained and pass the hydrostatic test requirement.

#### 4.11.5 Equipment in Storage

It is accepted practice to designate a certain number of facepieces "in storage" to avoid having to inspect them monthly as is required for ready-to-issue facepieces. This is a reasonable procedure so long as the devices in storage are effectively prevented from being used. This could be accomplished by covering portions of the normally ready-to-issue facepiece storage shelves with cardboard or plastic sheets that are clearly labeled, "Do Not Use."

When in storage and not available for use, respirators and component parts of respiratory protection devices should be inspected annually to verify that they are stored in such a way as to prevent damage. Checks of items in storage should be performed to ensure that the facepiece rubber is not taking a set, that rubber parts are not hardening or deteriorating, that sorbent canisters have not exceeded their shelf life, and that breathing-air or oxygen cylinders contain sufficient pressure. These checks should be designed to ensure that if devices in storage are needed, they will be ready for use quickly. Devices in storage should also be inspected prior to being made available for issue.

Equipment in warehouse storage need not be routinely inspected at all. This includes equipment that was once in use, but that has been repackaged in order to prevent damage and returned to a warehouse for storage. Table 4-21 below summarizes NRC's interpretation of the types and frequencies of respirator inspections.

#### 4.11.6 Shelf Life

The concept of "shelf life" may not be appropriate for respirator facepieces, SCBA,

and related equipment. Thin rubber components such as inhalation and exhalation valves can lose their elasticity, however, and may need to be replaced periodically.

Respirator facepieces have been observed to last for many years if properly maintained, cleaned and stored. One licensee reports that facepieces that were in service in 1981 are still in use. Properly maintained and stored, SCBA are reported to have been in service for over 25 years. These have been maintained and overhauled periodically in accordance with the manufacturer's instructions, and have been upgraded as necessary to meet NFPA standards. At least one SCBA manufacturer has specified a 15-year SCBA regulator overhaul period for infrequently used devices. This is in contrast to a 3- or 5-year overhaul period specified for frequently used SCBA.

The most critical factors in extending the life of respiratory protection equipment are:

- Proper water and air temperatures when washing, rinsing and drying the devices;
- Avoiding contact with harmful solvents and chemicals;
- Storage to prevent rubber components from becoming distorted; and
- Storage with no residual moisture.

The NRC believes that a good visual and hands-on inspection of a respirator and its components will reveal which are still serviceable, and which need to be repaired or replaced. Shelf lives and other such arbitrary limitations on service life are better suited to critical components inside devices that are not readily available for periodic inspection.

It might be asked why annual inspection of facepieces in storage is recommended at all, since an inspection is required before a facepiece is taken out of storage and made available for issue. It is inspected again by the person issuing the respirator, and the respirator user is required to perform a user seal check upon donning the facepiece. NRC does not recommend an extensive annual inspection of

**Table 4-21. Summary of recommended inspection frequencies for respiratory protection devices.**

Intended Use	Equipment Type	Inspection Type and Frequency <sup>1</sup>
Emergency Use or Rescue	SCBA	Monthly: Visual <sup>2</sup> Quarterly: Functional <sup>3</sup> After use: Functional <sup>3,10</sup> Overhaul Regulator per Manufacturer
Emergency Use	SCBA cylinders	Monthly: Check Pressure Hoop-wound: Inspect, overhaul, hydro 3 yrs. Alum. and Steel: Inspect, overhaul, hydro 5 yrs.
Emergency Use	Elastomeric Facepieces other than SCBA	Monthly: Visual <sup>4</sup> 2-3 times per year: Thorough <sup>10</sup>
Escape Only	Escape-Only Devices	Monthly
Routinely Available for Use	Elastomeric Facepieces	1. After use: Thorough <sup>10</sup> 2. Monthly: Visual <sup>4</sup> 3. At time of issue by issuing person 4. User seal check on donning
Routinely Available for Use	Supplied-Air Hoods or Suits <sup>5</sup>	1. At time of issue by issuing person 2. User operational check after donning
Routinely Available for Use	Repair and replacement parts for NIOSH-certified device <sup>6</sup>	Quarterly: Visual <sup>6</sup>
Routinely Available for Use	Air reducers, air distribution boxes	Twice per year: Functional test <sup>7</sup>
In Storage <sup>8</sup>	Elastomeric Facepieces	1. Before being made available for issue: thorough <sup>10</sup> 2. If in storage for >1 year: Annual visual <sup>4</sup>
Warehouse stock <sup>9</sup>	All	No routine inspection required. Thorough inspection <sup>10</sup> before being made available for use, except hoods and suits <sup>5</sup> .

1 Less frequent inspections are acceptable if recommended and documented by the manufacturer.

2 Visual inspection of SCBAs should verify that all components are present, straps are adjusted to the full-out position, and the cylinder pressure is >90% of capacity.

3 A functional inspection of an SCBA should include donning the device to test the operation of all buckles and straps; opening the cylinder valve and pressurizing the regulator; donning the facepiece to test proper head harness operation, and taking a series of breaths to test the operation of the regulator and exhalation valve; ensure that the low-pressure alarm activates at 20% of full cylinder pressure. Re-sanitize the facepiece, return the facepiece and apparatus straps to the full-out position, and ensure that the cylinder pressure is >90% of capacity.

4 For facepieces stored in transparent bags, an adequate visual inspection would consist of ensuring that no moisture condensation was visible through the bag, and that the facepieces were stored in such a way as to not distort the seal area. For facepieces stored in non-transparent bags, the licensee should ensure that they are stored in such a way as to not distort the seal area, and should examine a few facepieces to ensure that they are not damp. In both of these cases this is intended to be a cursory inspection. Therefore each facepiece does not need to be examined individually.

5 Supplied-air hoods and suits that are still in the packaging as received from the manufacturer, need not be routinely inspected. An inspection by the issuing person should be done at or near the time of issue. Also, an operational performance check of the device should be performed after it has been donned by the wearer but before the wearer is exposed to airborne contaminants. Hoods or suits that are reused should be inspected prior to each use.

6 Equipment such as belt- or facepiece-mounted pressure reducers, air supply hose, air distribution boxes, replacement parts for NIOSH-certified systems, and the like. This equipment should be clean and stored where environmental conditions are not likely to have an adverse effect on them.

7 A functional test means verifying that these components operate. No measurement of pressure or flow is required.

8 This refers to facepieces located in or near the respirator issue area, but which are covered by some type of barrier to effectively prevent inadvertent use or easy access, and which have been declared "out of service."

9 Respirators that are new and still in the warehouse or in another long-term storage location need not be routinely inspected. Respirators that were in use at one time, but which have been properly repackaged and returned to warehouse storage, need not be routinely inspected.

10 Examine each component of each facepiece for presence and proper function. The person doing the testing should perform a user seal check, then re-sanitize the facepiece. Leak test using a test head and aerosol generator or vacuum pump is also acceptable.

devices in storage. It expects licensees to verify that stored respirators are, in fact, still available if needed, have not been pilfered or vandalized, have not been moved in such a way as to cause elastomeric parts to be bent or twisted out of shape, and that physical conditions in the storage area (e.g., temperature, humidity) are still satisfactory. Respirators in storage do not necessarily need to be removed from their containers for this periodic inspection.

## **4.12 Maintenance Program**

### **4.12.1 Purpose**

Inspection, testing, and repairing of respiratory protection devices by competent personnel is an essential element in a high quality respiratory protection program.

### **4.12.2 Qualifications of Respirator Maintenance and Repair Personnel**

Respirators and component parts of respiratory protection devices should be maintained and repaired only by persons specifically trained to perform this work. Such repairs and maintenance should be accomplished in accordance with the manufacturer's instructions, but training by the device manufacturer is not required.

Maintenance and repair of some components of certain devices require manufacturer-certified training. Some examples would be SCBA regulators and low-pressure alarms. The device manufacturer specifies these components.

### **4.12.3 SCBA Maintenance and Repair**

SCBA manufacturers specify the frequency at which their devices need to be overhauled and adjusted. Under certain circumstances, such as SCBAs staged for emergency use but rarely

used in fact, some manufacturers have informed licensees that these overhauls and adjustments may be performed less frequently for these "limited use" devices. This recommendation by manufacturers is consistent with regulatory requirements.<sup>6</sup>

### **4.12.4 Facepiece Leak Tests**

Leak-testing each facepiece on a test head after each decontamination and inspection cycle is not required. A licensee can take for granted the quality of a respirator that is ready for issue if all of the following are in place:

- An adequate maintenance, inspection and repair program has been followed;
- The person who issues the respirator is qualified to recognize that the device is in useable condition with all component parts present; and
- The individual respirator users perform a seal check each time a facepiece is donned and are able to distinguish a properly operating facepiece from a defective one.

Experience has shown that a properly maintained and inspected facepiece rarely develops significant leakage that cannot be identified during a user seal check. In view of this, the practice of mechanically leak testing each facepiece each time it is processed is not necessary and does not materially improve the quality of issued respirators, and is therefore not warranted. As a good practice licensees who have this equipment may choose to test some percentage of the facepieces coming through the decontamination-disinfection-inspection process, or they may choose to test respirators that have had repair work done on them before they are made available for issue. A user seal check performed by respirator maintenance personnel might also be considered.

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<sup>6</sup> Letter, LeMoine J. Cunningham, Chief, Radiation Protection Branch, NRR to John F. Schmidt, Chief Health Physicist, Nuclear Management and Research Council, August 26, 1992.

New facepieces, and facepieces that have been returned to warehouse storage, should be sanitized and leak checked before being put into service. See Table 4-21, footnote 9.

#### 4.12.5 Testing Respirator Filters

It is not required, nor is it necessary, to re-certify respirator filter efficiency prior to use. Respirator filter manufacturers have quality assurance (QA) and quality control (QC) programs approved by NIOSH to ensure that their filters or cartridges meet the certification criteria specified in 42 CFR 84.

#### 4.12.6 Reuse of Respirator Filters

In 1983, responding to a question from licensees, the NRC took the position that respirator filters had to be tested with a 0.3-micron, thermally generated DOP aerosol, and demonstrate  $\geq 99.97\%$  efficiency prior to use. This defaulting to the HEPA filter certification criteria was a conservative position taken, due to a lack of data on other test methods. Since that time, however, filter testing protocols with other aerosol media and/or generating techniques have been shown to provide adequate sensitivity to detect damage to a filter which would void its HEPA characteristics. Therefore, it is the NRC's current position that aerosol penetration testing of filters and canisters by licensees should be performed with a testing protocol capable of detecting significant filter damage or deterioration. It is not required, nor is it necessary, to re-certify the filter efficiency prior to use or reuse.<sup>7</sup>

Licensees who wish to reuse replaceable facepiece filters as described in Regulatory Guide 8.15, Revision 1 may perform the

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<sup>7</sup> Health Physics Position-226 (HPPOS-226). The health physics position was written in the context of 10 CFR 20.103, but it also applies to "new" 10 CFR 20.1703. See also the letter from L. J. Cunningham to S. K. Herweyer (TSI Incorporated) dated February 27, 1990.

required penetration test using corn oil aerosol, ambient dust particles, or any other aerosol for which a detection system is available. Aerosol penetration testing of filters prior to their reuse is necessary to detect damage, incurred during prior use, that may not be evident in a visual or pressure drop test.

An industrial hygienist or health care professional should address the issue of potential presence of microorganisms on respirator filters intended for reuse.<sup>8</sup>

#### 4.12.7 Equipment Calibration

Static pressure gauges, differential pressure gauges, flow meters, particle detectors and other components of devices or test equipment used in a compliance respiratory protection program should be calibrated either annually, or as specified by the manufacturer, or in accordance with licensee procedures.

The flow-restricting devices commonly used in constant-flow supplied air respirators are not considered to be regulators for purposes of periodic re-calibration. Periodic functional tests of these devices is adequate.

### 4.13 Quality Assurance

#### 4.13.1 Purpose

The purpose of quality assurance (QA) in a respiratory protection program is to prevent the use of defective or faulty devices. A proper and complete QA program should encompass inspection and/or testing of both new and used devices. Written procedures should be established to maintain uniformity of the program.

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<sup>8</sup> NIOSH Respirator User Notice, May 2, 1997 <<http://www.cdc.gov/niosh/respupdt.html>>.

#### 4.13.2 New Equipment

Quality assurance inspection and testing of new equipment is not intended to dispute the design but to find any instances of human error in the manufacture and assembly of the devices. Manufacturers of NIOSH-approved devices maintain rigid quality assurance programs for testing of newly manufactured devices and parts, but human error in testing may permit distribution of defective equipment. Thus, a QA program covering new equipment is needed.

##### *Facepieces*

Half-mask facepieces should be inspected to ascertain the following:

- Only half-facepieces with a 4-point suspension should be used;
- Integrity of valves and seats;
- Presence and integrity of cartridge gasket or gaskets (as required); and
- Integrity of facepiece (absence of tears, mold defects, etc.).

Full facepieces require more attention than the half-facepieces, owing to the intricacy of the valves and speaking diaphragm assembly available on most. Inspection of full facepieces should include the following:

- Straps and suspension;
- Integrity of facepiece (absence of tears, mold defects, etc.);
- Canister or cartridge mounts (cheek, chin, etc.);
- Canister or cartridge gaskets (where applicable);
- Integrity of inhalation and exhalation valves and seals;
- Speaking diaphragm assembly (diaphragm, diaphragm gasket, assembly tightness);
- Lens (absence of scratches, cracks, blemishes); and
- All clamps and connections (check for tightness).

Where leak-test equipment is available, licensees may choose to test some percentage of new facepieces as a good practice. New facepieces should be sanitized before being made available for use.

##### *Cartridges, Canisters, and Filters*

Cartridges, canisters, and filters should be visually inspected for damage caused by handling and shipping. The presence of proper labels should be verified.

##### *Powered Air-Purifying Respirators*

The facepieces on the units should be inspected and tested as suggested above. The blower should be checked for adequate airflow, and the corrugated breathing tube should be inspected for cracks or other defects and for tightness of connections.

##### *Hoods and Suits*

Hoods and suits should be checked for tears and defects in fabrication material, presence of zippers and snaps as required, and integrity of heat-sealed seams and air distribution and exhaust systems.

##### *Regulators*

Supplied-air regulators shall be visually inspected for damage, attached to an appropriate air supply, and tested for proper function.

##### *Compressors*

Compressors used to provide air for atmosphere-supplying respirators should be inspected and tested to ascertain the following:

- Proper and adequate intake filters;

- Presence of moisture trap or dryer;
- Sufficient reserve air storage (if present);
- Carbon monoxide alarm presence and proper function (if present);
- Adequate air output and presence of proper connectors for equipment to be used; and
- Heat alarm function (if present).

Oil-type compressors should only be used if fitted with either a continuous carbon monoxide monitor or high-temperature alarm. Diaphragm and water-seal pumps are recommended since they do not create an air supply contaminated with oil mist or carbon monoxide. Moisture criteria need to be met for air used to fill SCBA and other breathing-air cylinders.

#### *Airline Hose*

Airline hose should be inspected for the following:

- Contaminants (mold powder, ground rubber, etc.) inside the hose.
- Proper fittings and connections (i.e., not compatible with other gas or fluid systems); and
- Cuts, breaks, or weak spots in hose.

#### *Open-Circuit SCBA*

The self-contained breathing apparatus (SCBA), the most complicated of respiratory protective devices, requires more extensive inspection and testing than other types of devices. Owing to the intricacy of the parts of the SCBA, simple visual inspection is not sufficient to identify defective units. Inspection and testing of a SCBA should be done by individuals totally familiar with the particular device.

The facepiece, corrugated breathing tube and connectors should be inspected as described above. Special attention should be given to the pressure-demand exhalation valve operation.

Regulators and alarms of SCBA are to be visually inspected and a simple test performed to ascertain proper regulator function and integrity of the regulator diaphragm. The alarm should be activated to ascertain that its functions properly.

The following other parts of SCBA should be checked:

- Cylinder - check the pressure; check the cylinder valve for leaks; and inspect the cylinder valve lock for presence and function; and
- Backpack and harness assembly - Inspect the integrity of straps, buckles, and fasteners; and check the backpack cylinder lock assembly for function.

#### *Closed-Circuit SCBA*

The facepiece, corrugated breathing tubes and connectors should be inspected as described above. In addition, check the following:

- Breathing Bag - Visually inspect for tears and defects; then inflate and check for leaks; and
- CO<sub>2</sub> Sorbent - Make certain that used sorbent is removed from the unit before storage. (Do not refill with sorbent until immediately prior to use of unit.) Ensure that seals on sorbent containers are in place.

#### **4.13.3 SCBA Inspection**

It is virtually impossible to inspect and test self-contained breathing apparatus properly without actually donning the unit. New units should be donned, straps fully adjusted, and used for a period of time (e.g., 10 minutes) to verify that they operate properly. After this type of test, appropriate components should be sanitized, the straps fully extended, and the air cylinder replaced with one that is fully charged before the unit is made available for use.

#### **4.13.4 Inspection and Tests After Cleaning and Maintenance**

The procedures for inspecting and testing cleaned and repaired devices are the same as those outlined in the preceding new equipment section, in the equipment manufacturer's literature, and as described elsewhere in this Manual.

#### **4.14 Control and Issuance**

Licensees should maintain positive control over the issuance of all respiratory protection devices. Sufficient control should be established and maintained so that persons not authorized to wear such devices are effectively prevented from obtaining them.

By assigning serial numbers to individual reusable respirator facepieces, the licensee will be able to find out who wore a device that is discovered to be defective during the decontamination and inspection process, and consider performing an internal dose evaluation.

For disposable filtering facepiece respirators or dust masks with no APF assigned (see Regulatory Guide 8.15, Section 4.8), the NRC recognizes that these devices might be issued from sources other than a centralized respirator issue room. The licensee should take reasonable steps to see that only those individuals who have received the minimal required training for voluntary users be allowed to use these devices. Given the short duration of required training for users of these dust masks, and given that the medical screening and fit testing requirements are waived for users of these devices, licensees might consider providing this minimal training to all radiation workers.

A respirator can be reused by the same individual on the same day or during the same work shift as long as external contamination levels are manageable. Licensees should take precautions to keep the interiors of such devices

uncontaminated. Storage in a plastic bag bearing the identity of the user would be adequate.

#### **4.15 Recordkeeping**

Records of personal fit tests, medical screening, training, and issuance of respirators should be maintained in accordance with the requirements of 10 CFR 20.

Individual maintenance and repair records do not necessarily have to be kept on each respirator facepiece. The NRC does not believe that it is important to know on which date, for example, the coupling nut or exhalation valve was replaced on a given respirator, as long as each respirator is in like-new condition at the time of issue (see paragraph 4.1 of Regulatory Guide 8.15). Since little or no dose is likely to be saved by keeping these records, such detailed records are not cost-justified and therefore, not ALARA. A tag or sticker on the facepiece storage bag, containing the date of last inspection and the identity of the person who performed the inspection, is adequate documentation.

Procurement information should be maintained in so far as it enables the licensee to accurately determine the correct part number to be ordered for the equipment being maintained. Some manufacturers provide "exploded" views of their equipment with part numbers provided for each. Parts of some respiratory protection devices look very similar but are, in fact, different from one another. In order to maintain NIOSH approval for each device, it is important for the licensee to be able to identify and order the correct parts for respirators.

#### **4.16 Respirators Supplied by Contractors**

Contractors may be required or permitted to provide their own respiratory protection equipment or sources of breathing air to perform tasks at a licensee's site. This usually occurs when specialized work such as sand blasting or

diving is to be done since the licensee may not maintain this type of equipment in inventory. The reason need not be justified. It is the licensee's obligation to ensure that the systems used are NIOSH approved (where applicable), and are used and maintained in such a way that the NIOSH approval is maintained. Breathing air sources must deliver Grade D or better air. If such equipment is to be returned to a contractor that does not have an appropriate radioactive materials license, then the equipment must meet licensee's criteria for unrestricted radiological release. If contaminated, it may be shipped to another appropriately licensed facility.

It would be a rare case when contract personnel would need to use respirators for protection against airborne radioactive material at the site of a licensee where an NRC respiratory protection program is not in effect. If this situation were to occur, the licensee is still responsible to ensure that the contractor's program is in accordance with the requirements of 10 CFR 20 Subpart H. This could be accomplished by obtaining the services of a qualified consultant.

#### **4.17 Service Life Limitations**

NIOSH has noted<sup>9</sup> that the efficiency of P-series filters (i.e., oil-proof under the 42 CFR 84 approval terminology) may be significantly reduced with long-term use in the presence of oil aerosols. Such long-term exposure has resulted in the reduction in efficiency of P100 filters to efficiencies much less than that required for P95 filters. In some workplace situations, this reduction in efficiency is not accompanied by an increase in breathing resistance that would signal the user to replace the filter, or filter element. Since this reduction in filter efficiency varies significantly from model to model, licensees who use respirators in an oil aerosol environment are encouraged to

contact the manufacturers of any P-type respirators or respirator filters that they use to receive guidance on filter change frequency. This same notice states the current NIOSH service-time-limit recommendations for non-powered particulate filter respirators.

#### **4.18 Breathing-Air Supply and Distribution**

##### **4.18.1 Supply Systems**

Breathing air is usually supplied to a header by one or more compressors which draw air through an intake filter. An air dryer or moisture separator is usually incorporated to make the supplied air as dry as possible. Moisture inside an air system can cause corrosion inside pipes and other components. Rust particles can clog regulator orifices and cause other problems. In cold climates, moisture-laden air can also freeze as it is depressurized in a regulator.

A large-volume tank called a receiver is usually attached to the system. The compressor pressurizes the receiver along with the rest of the header. When the system reaches its maximum operating pressure, the compressor shuts off. The receiver supplies air to the header until header pressure reaches its minimum operating pressure. At this point, the compressor comes on and re-pressurizes the system. See Figure 4-20.

Other equipment that might be incorporated into an air system used for breathing air might be an air purification system, a CO monitor, and/or an O<sub>2</sub> monitor.

NIOSH does not certify breathing-air supply systems, and neither NIOSH nor the NRC require that a dedicated breathing-air system be used. The only requirement imposed by NIOSH and the NRC is that Grade D-quality (or better) air must be delivered to the NIOSH-certified respiratory protection system.

<sup>9</sup> NIOSH Respirator User Notice, May 2, 1997  
<<http://www.cdc.gov/niosh/respupdt.html>>.

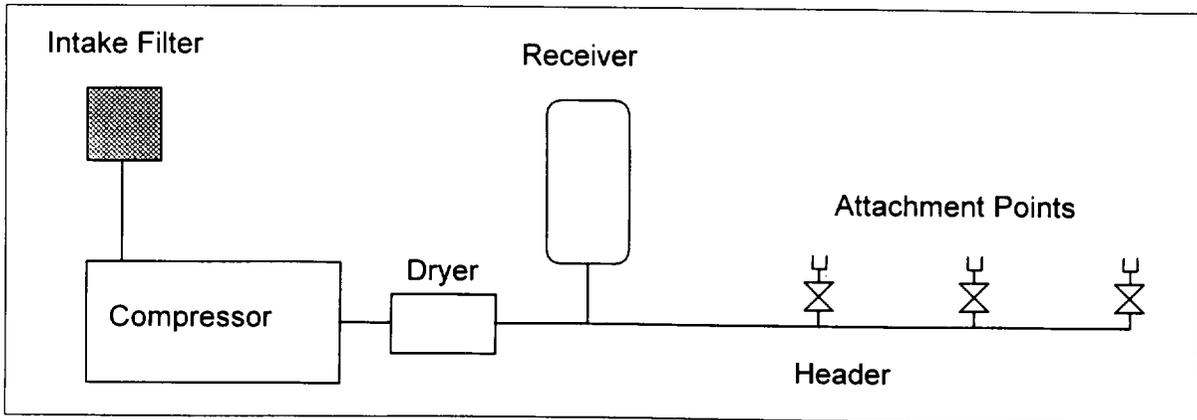


Figure 4-20. Typical breathing-air supply system.

#### 4.18.2 Distribution Equipment

At various locations along the air header, a “tee” and an isolation valve are installed so that air may be used from the header. A permanent or portable distribution manifold is then attached to the header near where supplied-air respirators will be used. Such a manifold usually consists of the following components:

- Particulate air inlet filter;
- Pressure relief valve (125 psig);
- One or more pressure regulators;
- One or more female quick-connect fittings; and
- A pressure gauge installed on the low-pressure side of each regulator.

NIOSH does not certify distribution manifolds. Therefore, these may be purchased as a unit from a vendor, or fabricated by the licensee. The filter is intended to trap rust particles and scale that might develop inside steel pipes, and therefore, does not have to meet any particular efficiency requirements. NIOSH sets a maximum pressure of 125 psi for air supplied to an SAR, so a relief valve would be set to open at this pressure in a system that operates at greater than 125 psi. Vendor-supplied units are usually configured

in a compact box that looks like a suitcase. If fabricated by the licensee, good practice dictates that this distribution box be made using clean, high quality materials. An engineer should review the design to ensure that the component and material specifications are adequate to provide sufficient pressure and volume air flow. The NIOSH-certified device is attached by quick-connect fitting to this manifold, and the manifold regulator is set to the pressure range specified by the NIOSH certification and manufacturer’s instructions. The hose (if any) used to connect the distribution box to the breathing air header is not restricted as far as length, diameter, material, type of connections and so on. The maximum hose length specified in the NIOSH certification does not apply to this hose. As with the components of the distribution manifold described above, there is no NIOSH approval requirement for these hoses. Good practice dictates that this connection be made using clean, high quality materials. Hoses used for this purpose should not be used for any other purpose to prevent them from becoming unfit for use with breathing air, and the hose connectors should be incompatible with other gas or fluid systems in the facility.

NIOSH approvals for SARs require that a minimum airflow be delivered to the respiratory inlet covering (4 cfm minimum for full facepieces, 6 cfm minimum for hoods and helmets). The certifications are written, however, so that the end user of the respiratory device is not required to measure the actual flow rate of air delivered to the device. Rather, an acceptable *pressure* range at the distribution manifold is specified for a given length of hose, number of hose sections, or for a specified number of quick-connect fittings. This works well when a single device is connected to a pressure regulator. It also works when two or more identical devices are connected to the outlet of a single pressure regulator as long as the hose lengths and/or number of quick-connect fittings are the same in each device. However, each time a device is added to a manifold supplied by a single regulator, the air pressure on the distribution manifold decreases, and has to be readjusted to meet the NIOSH

requirement. If two or more *different* devices are connected to the output of a single pressure regulator, or if the hose lengths and/or number of quick-connect fittings are different, it might be difficult (or impossible) to maintain a manifold pressure that meets the NIOSH requirement for all of the attached devices. If sufficient air pressure cannot be maintained to supply all the devices required, a second distribution regulator and manifold will be needed.

A distribution system that avoids these complications is one that contains a pressure regulator for each user. Such a device is illustrated in Figure 4-21.

Manufacturers of airline respirators include instructions specifying the range of air pressures required to produce the flow rates to the device required by the NIOSH certification standards. For a tight-fitting facepiece in the continuous-

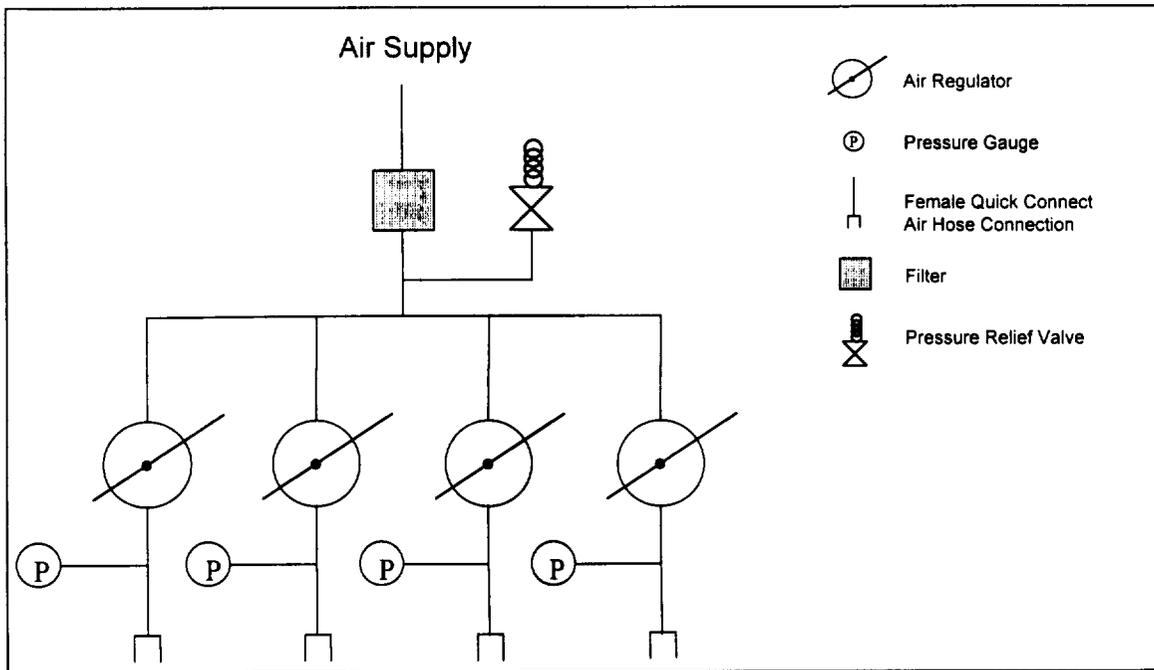


Figure 4-21. Recommended breathing-air distribution manifold configuration.

flow mode, this is 4-15 scfm. For hoods, it is 6-15 scfm. The air supply pressure required is based on the total length of supply hose used, and on the number of hose sections connected together. Each hose section incorporates a set of quick-connect fittings that cause a pressure drop. If a single device is used, and if the appropriate pressure is applied for the number of hose sections used, air flow to the user may be assumed to be within the required range.

Licensees are never required to measure the flow rate of air supplied to a facepiece or hood. The licensee may assume that if the device is used in accordance with manufacturer's instructions (e.g., minimum and maximum hose lengths, proper air pressure at the point that the device is attached to the breathing-air source), then the air-flow rate will fall within the acceptable range.

#### **4.18.3 Air Supplied to High-Pressure Breathing-Air Cylinders**

In addition to the Grade D requirement, OSHA requires [29 CFR 1910.134(i)(4)(iii)] that the moisture content in breathing-air cylinders not exceed a dew point of -50 °F (-45.6 °C) at one atmosphere pressure. Compressed Gas Association (CGA) G-7.1-1997, "Commodity Specification for Air," states that air in SCBA cylinders should not exceed a dew point of -65 °F (24 ppm v/v), or 10 °F lower than the coldest temperature expected in the area where the SCBA will be used. The NRC suggests compliance with the OSHA requirement for all cylinders and suggests meeting the CGA Grade L requirement for moisture content, if practical.

#### **4.18.4 Problems with Breathing-Air System Contamination**

Various problems have been encountered over the years regarding contamination of systems used to supply breathing air. In one incident,<sup>10</sup> a combination service-air/breathing-air system was used to provide the motive force to backwash a demineralizer filter element. The air system became contaminated when water from the liquid radioactive waste system leaked past a check valve and an air-operated ball valve.

In another instance,<sup>11</sup> radioactive gases from a reactor off-gas system leaked into the combination service-air/breathing-air system when the on-line and standby service air compressors failed and the system was depressurized.

In a third instance,<sup>12</sup> two workers became contaminated when they connected their respirators to an instrument air manifold. The initial surge of air contained dust and rust particles that were radioactive. The source of this contamination was not able to be determined.

Licensees are advised to take the necessary precautions to prevent contamination of the breathing air system. Routinely opening system low-point drains, and allowing some air to flow out of an attachment point before connecting a distribution manifold may be considered to clear condensation or debris from the header. Care should be taken to not cause airborne contamination during these venting operations. Periodic radiological surveys of the breathing air and of critical system components should also be performed.

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<sup>10</sup> IE Information Notice No. 79-08 "Interconnection of Contaminated Systems with Service Air Systems Used as the Source of Breathing Air," March 28, 1979.

<sup>11</sup> IE Information Notice No. 85-06 "Contamination of Breathing Air Systems," January 23, 1985.

<sup>12</sup> Ibid.

## 4.19 Emergency Entry and Escape Equipment (IDLH)

### 4.19.1 Equipment for Emergency Entry

Equipment approved for emergency entries into known or potential IDLH areas includes SCBA (pressure-demand and positive-pressure) and a combination supplied-air respirator with emergency escape air cylinder.

### 4.19.2 Equipment for Emergency Escape

One major consideration in choosing an escape respirator is the time required to don the device. Ideally, the escape device can be donned quickly during the time that the escape is being made.

A positive-pressure, self-contained breathing apparatus (SCBA) provides the best available protection for a relatively long period of time, but donning time is relatively long. Even a well-trained, calm person cannot don an SCBA quickly. An emergency, with its attendant anxiety, may cause even longer donning times. Standard SCBAs should probably not be relied upon for escape purposes unless workers in the area are already wearing them when the emergency occurs. Even if it is being worn, a full-sized SCBA may impede escape from a rapidly developing emergency, so its respiratory protection capabilities must be balanced against a delayed escape.

There are other types of atmosphere-supplying respirators specifically approved by NIOSH for escape. Most consist of a small compressed-air cylinder (3, 5, or 10 minutes) and a facepiece or hood. These can be quickly donned, but they are bulky, making them awkward to carry continuously. Another device consists of a nested coil of stainless steel tubing charged with breathing air to 5,000 psi. This air supply feeds into a light plastic hood that fits over the wearer's head.



Figure 4-22. Self-contained 5-minute escape device.

This device will supply 5 minutes of breathing air. (See Figure 4-22.)

If each worker cannot carry an escape device, relatively large numbers of these devices may need to be placed in accessible locations. A person in an area where an IDLH environment can occur should never be more than a few seconds away from an escape device. A combination airline respirator equipped with both an airline connection and a small tank of compressed air is useful for escape in case the main compressed-air supply fails. These are also classified as SCBAs by NIOSH.

## 4.20 Potential Respirator Program Weaknesses

Some potential weaknesses found in respirator programs, which apply primarily to power reactor licensees, but which might act as a reminder to other licensees, are listed below. (NRC Information Notices 98-20 and 99-05.)

- Requirements for members of the emergency response organization to be qualified to use respirators were eliminated;
- Key emergency response and operations personnel permitted to have facial hair, some of whom were committed to don SCBA within two minutes after initiation of an emergency;

- Key emergency response and operations personnel unfamiliar with the locations of emergency response SCBAs;
- Key operations personnel had not had hands-on training with SCBA in five years;
- Air cylinder pressure in some SCBAs was below 90% of rated pressure (industry standard), and some were at less than 80% of capacity;
- Failure to realize that certain areas of the plant might become IDLH areas under certain postulated (design-basis) conditions;
- Failure of certain key emergency response, staff, security and operations personnel to maintain their respirator qualifications (annual fit testing and medical screening);
- Facepiece sizes for which certain emergency response and operations personnel had been fit tested were not available at all SCBA locations; and
- Reactor operators had not been trained on how to change SCBA cylinders.

One other situation involved reactor operators who might be required to wear SCBA in the control room during an emergency. The back-mounted air cylinder made it impossible for operators to sit in any available control room chair. The need for chairs or stools without backs had not been anticipated.

#### **4.21 Decontamination and Sanitization of Facepieces; Contamination Control**

##### **4.21.1 Introduction**

Proper cleaning, sanitization and decontamination of respiratory protection devices is essential to their safe use. Even apparently mild cleaning techniques can unwittingly cause a loss of safety function. Manufacturers' recommendations for cleaning and decontaminating a respirator are found in the technical literature supplied with the device. Additional information on the appropriateness of a particular cleaning technique can be

obtained by contacting the respective manufacturer.

##### **4.21.2 Elastomeric and Plastic Components**

Respirators may be cleaned by hand or using an automated system. Care must be taken to use a cleaner and a sanitizing agent that will not have a deleterious effect on the rubber or plastic components of the device. Respirator manufacturers usually only provide instructions for hand-washing respirators. Licensees should apply the same principles if they choose to automate the process.

Instructions for cleaning respirators provided by some manufacturers indicate that the facepiece should be disassembled to some extent before being washed. This may be required after facepieces have been used in very dirty environments or when the nature of the contaminant dictates (e.g., biohazardous material). Based on long experience, NRC believes that most half-facepiece and full-facepiece respirators used in a radiological environment are lightly or moderately contaminated and are not really "dirty" in the traditional sense. These can be effectively decontaminated and sanitized without disassembly. Therefore full or partial disassembly is not necessarily required prior to decontamination or sanitization as long as the residual contamination guidelines are met and the sanitization is satisfactory. Heavily contaminated and physically dirty devices might require disassembly prior to cleaning. Another obvious exception would be for those facepieces equipped with electronic components that are part of a voice amplification system. It is the responsibility of the RPA to decide the best way to decontaminate and sanitize respirators and components.

Manufacturers' recommendations must be heeded with regard to maximum water temperatures used when cleaning or sanitizing the respirators. The upper temperature limit is usually 43 °C (110 °F), but this may be different

for some manufacturers. These temperature restrictions would also apply if heated air is used to dry the facepieces.

Most manufacturers specify their own brand of cleaning and/or sanitizing solution. Other alternatives are acceptable. A hypochlorite solution (50 ppm chlorine in water), an aqueous solution of iodine (50 ppm iodine in water), or commercially available cleaners of equivalent disinfectant quality are acceptable when used as directed, and if their use is not prohibited by the respirator manufacturer. Instructions for sanitizing respirators often state that the facepiece should be "immersed" in the sanitizing solution for a specified period of time. In a program that uses a modified automatic dishwasher to clean and sanitize facepieces, the spray of disinfectant solution inside the machine effectively immerses the facepieces and is appropriate for sanitizing them. Alcohol-impregnated towelettes or wipes should not be used on elastomeric facepieces. A description of an improper respirator cleaning process that resulted in the rapid deterioration of certain parts of the respirator is the subject of IE Information Notice No. 86-46.

Respirators being taken out of storage and being returned to service should be inspected and resanitized prior to issue. In this case, a survey for residual contamination would not be required if the facepieces had met the radiological criteria prior to being put into storage.

#### 4.21.3 SCBA Cylinders

NIOSH recommends<sup>13</sup> special attention and increased oversight and inspections for certain high-pressure aluminum seamless and aluminum composite hoop-wrapped cylinders made of aluminum alloy 6351-T6 by Luxfer. These cylinders may develop cracks in the neck and shoulder area, leading to greater-

<sup>13</sup> NIOSH Respirator User Notice, December 7, 1999 <[http://www.cdc.gov/niosh/3al\\_run.html](http://www.cdc.gov/niosh/3al_run.html)>.

than-normal loss of air during storage, and ruptures that may lead to serious injury or death. Additionally, short of catastrophic failures, the unexpected loss of air (and reduction of service time) could lead to reduced worker safety and less effective emergency response. Luxfer cylinders manufactured in the United States after 1988 use a different alloy and are not subject to the NIOSH notice. The affected cylinders are used on various NIOSH-approved SCBA, including various sizes and rated durations ranging from 5 to 30 minutes.<sup>14</sup> Licensees should review this information for applicability to their facilities and consider actions, if appropriate, to upgrade their self-contained breathing apparatus (SCBA) cylinder inspection program.

Stripping the paint from SCBA air cylinders to remove fixed contamination is not usually an acceptable practice. An important safety function will be lost if the cylinders are not repainted with the proper paint because the manufacturer-applied coating is designed to discolor at 350 °F to indicate that the cylinder has been exposed to excessive heat. Also, significant degradation of structural integrity can result if this decontamination technique is used on composite air cylinders. Commercial paint stripper will attack the bonding material of the reinforcing fiberglass wrapping.<sup>15</sup>

#### 4.21.4 Radiological Guidelines for Reuse

Dust masks (i.e., those that do not meet the definition of a half-facepiece) should be disposed of after each use. For subsequent

<sup>14</sup> See also NRC Information Notices 83-68, 84-34, 85-48, 86-24 and 2000-07 <<http://www.nrc.gov/NRC/reference.html>>.

<sup>15</sup> NIOSH Respirator Users Notice, July 30, 1996. "Safety Advisory on The Potential for Sudden Failures of Fiberglass-wrapped Composite Aluminum Cylinders Following Exposure to Acidic Chemical Cleaning Agents." <<http://www.cdc.gov/niosh/cylinder.html>>

exposures workers should obtain a new dust mask.

All other respirators may be reused by the same person on the same working day as long as the licensee has reasonable assurance that the interior portions of the device do not contain significant contamination. One of more of the following methods could be employed to achieve such assurance:

- Store device in a clean plastic bag between uses;
- Store device in an uncontaminated area;
- Wipe out device interior with a clean, damp cloth before reuse; and
- Survey device interior before reuse.

Establishing acceptance criteria for reuse of devices as described above are left to the discretion of the licensee.

#### 4.21.5 Radiological Guidelines for Reissue

Suggestions for limits on residual contamination inside the facepiece and on the face-seal area are provided in Table 4-22 below. Fixed contamination levels on the outside of the facepiece could be higher.

**Table 4-22. Recommended contamination guidelines for facepiece interiors prior to reissue.**

	$\alpha$ (dpm per 100 cm <sup>2</sup> )	$\beta$ or $\beta\gamma$ (dpm per 100 cm <sup>2</sup> )
Total contamination <sup>a</sup> (direct survey)	<100	<5000
Removable contamination (wipe survey)	<20	<1000

<sup>a</sup> Small spots of contamination may be averaged over 100 cm<sup>2</sup> for comparison to the guideline values. Hot particles should be removed.

These same guidelines can be used for interiors of air hoses, breathing tubes, regulators, quick connect fittings and the like. Interiors of these components should be surveyed periodically, for example, once or twice per year or when contamination is suspected.

Allowable radiological guidelines for the reuse of other equipment in restricted areas (e.g., exterior of air hose, exterior of regulators, exterior of breathing tubes, exterior of SCBA cylinders, etc.) may be substantially higher than those suggested for facepiece interiors. While most loose contamination should be removed from these components before storage or reuse, total contamination guidelines can be established based either on total activity or on dose rate, and should be ALARA. If respiratory protection equipment containing fixed contamination is stored in areas other than restricted areas, ensure that the requirements of 10 CFR 20 are met with regard to posting and labeling. Equipment that is stored outside a restricted area<sup>16</sup> should have no detectable contamination.

At facilities where alpha contamination is possible but unlikely, surveying every 10<sup>th</sup> or 15<sup>th</sup> facepiece for alpha contamination is sufficient. Where both alpha and beta contamination are known to be present, each facepiece should be tested for both categories of contaminants, although a validated beta-gamma to alpha ratio may be used. At facilities that are licensed only for possession of beta- and/or beta-gamma-emitting isotopes, or for sealed alpha-emitting sources, or if a facility does not use alpha-emitting radionuclides, no alpha survey is required.

<sup>16</sup> Restricted area is defined in 10 CFR 20.1003 as an area, access to which is limited by the licensee for the purpose of protecting individuals against undue risks from exposure to radiation and radioactive materials. Most nuclear reactor sites use the term radiologically controlled area (RCA) instead.

If a licensee uses a direct measurement with a gamma-sensitive or beta-sensitive monitor to screen respirators for contamination prior to reissue, the MDA for the counter should be low enough to detect the activities specified with 95% confidence. If the sensitivity of the direct survey method is good enough to show compliance with the removable contamination guideline, no wipe survey need be performed. Where alpha contamination is involved, a beta-to-alpha ratio may be used so long as the ratio is satisfactorily established.

Equipment-to-detector survey distance should be the same as that used to establish the counting efficiency.

The guidelines suggested in this section should not be interpreted as being criteria for the release of respirators or other equipment to unrestricted areas or for unrestricted use.

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19. Health Physics Position-226 (HPPOS-226). The health physics position was written in the context of 10 CFR 20.103, but it also applies to "new" 10 CFR 20.1703. See also the letter from L. J. Cunningham to S. K. Herweyer (TSI Incorporated) dated February 27, 1990.
20. NIOSH Respirator User Notice, May 2, 1997 <<http://www.cdc.gov/niosh/respupdt.html>>.
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23. IE Information Notice No. 86-46. "Improper Cleaning and Decontamination of Respiratory Protection Equipment," June 12, 1986.

## 5 RESPIRATOR USERS

### 5.1 Medical Evaluation

The purpose of the respiratory protection program is to protect the health of workers. One component of that program is the medical evaluation. The use of a respirator imposes particular physiological demands on the wearer. These demands could jeopardize the health or even the life of a user who has certain medical conditions.<sup>1</sup> A medical evaluation is designed to identify these conditions so that they can be taken into account when deciding the proper respiratory protection for a worker without endangering his/her health or life. For some medical conditions the kinds of respirators that may be used might have to be limited. For more serious conditions such as those that might lead to the inability to breathe, cause a heart attack, vascular accident or seizure, the use of respirators might be precluded entirely.

Medical screening is not required for individuals who will only wear filtering facepiece respirators or dust masks with no APF as described in Regulatory Guide 8.15, Section 4.8. Also, no medical screening is required for personnel who are not respirator wearers but who might infrequently need to use an emergency escape respirator.

#### 5.1.1 The Licensee's Physician

The physician selected by the licensee should be made aware of the types of respiratory protection devices used by the licensee, and should have an opportunity to experience the stresses associated with wearing and using

these devices. (S)he should also be aware of the range of potential environmental conditions in which the respiratory devices might be worn (e.g., high temperature, high humidity), and the types of protective clothing that might typically be worn in conjunction with the respirators. In short, the licensee's physician should have an adequate knowledge of all the stresses respirator wearers might be subjected to in the workplace in order to make informed judgments about who should and should not be permitted to use respirators. This knowledge will also allow informed decisions to be made regarding individuals who might be permitted to use certain types of respirators but not others, who may wear respirators but perform only supervisory or light work, and who should not use any type of respirator.

The licensee's physician should determine which screening methods and tests are appropriate, should set the acceptance criteria for those methods and tests, and should periodically review the implementation of the program. The screening process should be sufficient (in the opinion of the licensee's physician) to identify any person who should not use respiratory devices for medical reasons, or who should be limited to the use of specific types of devices. The NRC regulations do not require a "hands-on" physical examination by a physician.

The licensee should choose a physician with an appropriate specialty (e.g., internal medicine, industrial medicine, family practice), and the licensee's physician should be licensed to practice medicine in the United States.

The physician should review the program implementation periodically during visits to the licensee's facility.

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<sup>1</sup> IE Information Notice No. 84-24: "Physical Qualification of Individuals to Use Respiratory Protective Devices," dated April 5, 1984, describes a fatality involving a worker who had been wearing a respirator, and provides guidance on medical screening programs for respirator users.

### **5.1.2 Establishing and Performing the Evaluation**

The licensee's physician should identify those physiological factors that are to be measured or asked about during the screening process. The screening should include a medical history questionnaire. The questionnaire should be designed to elicit information from the person being screened regarding critical conditions or diseases. The OSHA Respirator Medical Evaluation Questionnaire contained in Appendix C to 29 CFR 1910.134 is acceptable to NRC, and is Appendix C to this Manual. The physician may also use the results of measurements (e.g., spirometry testing, blood pressure, temperature, pulse) to supplement the questionnaire. Finally, ANSI Z88.6-1984, "Respirator Use—Physical Qualifications for Personnel,"<sup>2</sup> provides guidance that is acceptable to the NRC staff for the physician to use in determining medical fitness. Overall responsibility for the medical screening program always rests with the licensee's physician, who establishes the precise screening method.

The medical evaluation program should be carried out by the physician, or by a certified, medically trained individual such as a registered nurse (RN), licensed practical nurse (LPN), emergency medical technician (EMT), or someone who, in the judgment of the licensee's physician, has adequate experience, education, training, and judgment to administer the screening program. Appointment or approval of the medical screening program staff should be in writing from the licensee's physician.

The physician establishes, in writing, which answers to the medical history questions, and which measured parameters are acceptable and which are not. (S)he should be available by phone to resolve any implementation issues

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<sup>2</sup> This standard has been withdrawn by ANSI in anticipation of the issuance of an updated version, which will contain expanded guidance.

with the individual(s) who are administering the program at the licensee's facility, and should periodically review (on-site) the implementation of the program. The physician need not review or sign the records of each person who is screened and who meets the acceptance criteria. However, approval to use one or more types of respirator for an individual who fails to meet the minimum medical screening criteria should be signed by the licensee's physician.

Those individuals who fall outside the bounds of the established acceptance criteria may be examined by the determining physician, who can then make a medical judgement about which type(s) of respirator(s) the individual may or may not wear. Notification may be given to the Respirator Program Administrator (RPA) in the form of a Respirator User Medical Status form (see Appendix D to this document).

### **5.1.3 Psychological Factors**

It is generally very difficult to evaluate a wearer's psychological limitations by means of a routine medical examination. The licensee's physician should investigate any identified psychological conditions thoroughly to ascertain that the wearing of respiratory protection equipment will not aggravate an existing condition. Even under ideal conditions, a degree of anxiety is often encountered by respirator wearers, and this anxiety may become exaggerated during an emergency.

Most individuals, especially inexperienced respirator users, experience some level of psychological stress when using a respirator. Also, the normal increase in depth and frequency of respiration due to the additional dead-air volume resulting from the facepiece is often interpreted as a sign of anxiety. The licensee should obtain reasonable assurance that respirator users will not experience

unmanageable respirator-induced psychological stress to the extent that they run the risk of injuring themselves or their co-workers when respirators are worn. Questions regarding claustrophobia, extreme anxiety, respirator-related anxiety problems previously experienced, and other related conditions are therefore appropriate on the medical screening questionnaire.

Potential respirator wearers who are observed during training, especially the hands-on portion, to be overly anxious or agitated while wearing a respirator should be referred to the medical screening staff or to the determining physician for further evaluation. Likewise, those who exhibit similar behaviors during fit testing should be referred to the medical group.

This represents the actions expected of the licensee to screen out individuals who might experience psychological stress brought on by respirator use. The NRC recognizes that some individuals might be unwilling to answer medical screening questions candidly, which may lead to misinformation being provided on medical screening questionnaires.

#### **5.1.4 Timing of Medical Evaluations**

According to 10 CFR 20.1703(c)(5), the initial medical evaluation to determine a worker's fitness to use respirators must be accomplished prior to respirator fit-testing for tight-fitting facepieces and prior to the first field use for loose-fitting devices, since no fit-test is required for these types.

NRC regulations require that a worker must be re-evaluated medically every 12 months thereafter or at some other frequency established by the licensee's physician. ANSI Z88.6-1984 suggests a range for reevaluation from every 5 years for workers below age 35, to annually for workers over age 45. ANSI Z88.2-1992 concurs. Licensees are reminded

that OSHA requirements specify annual medical screening with no allowance for longer periods under any circumstances.

If necessary, a re-evaluation "grace period" of up to 90 days is considered to be reasonable.<sup>3</sup> In unusual circumstances, an otherwise fully qualified respirator user whose medical screening has expired within the past 90 days may be issued a respirator with the concurrence of the RPA. Licensees should not interpret this grace period to mean that re-screening can be accomplished every 15 months. For example, Health Physics Position 219 referred to above specifies that, if annual re-screening is indicated, three consecutive examinations should not exceed 39 months.

#### **5.1.5 Failure To Meet the Acceptance Criteria**

If an individual's screening results fall outside the range of the acceptance criteria, the licensee may choose to have the case referred to the licensee's physician for further evaluation. This evaluation might consist of a telephone conference with the individual being screened or with the on-site medical representative, a review of the written records, or possibly a hands-on examination. In this case the physician has three options:

- Permit unconditional use of respirators;
- Confirm the outcome of the screening and prohibit any use of respirators; or
- Permit use of one or more respirator types and prohibit the use of others.

Presumably, if conditional approval is granted to use only some types of respirators, these will be ones that involve less worker stress (e.g., supplied-air hoods or powered air-purifying respirators).

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<sup>3</sup> G.D. Kerr et al., "Health Physics Positions Data Base," Health Physics Position 219, NUREG/CR-5569, Revision 1, page 120, February 1994.

Alternatively, the physician might specify that respirators may be used by such an individual provided that only supervisory activities (rather than physical labor) be performed.

#### **5.1.6 Approval by Other Physicians**

Medical evaluations performed by a physician other than the licensee's physician may be acceptable as long as comparable screening tests and acceptance criteria are used for screening individuals. The licensee's physician should review the screening methods used by the other organization and approve or disapprove it in writing. This is also true of licensees who utilize a centralized records data base. If the respirator medical screening programs of all the participants in the data-sharing network have been cross-reviewed and approved, use of such data is acceptable in lieu of the licensee re-screening the individuals involved.

#### **5.1.7 Privacy of Medical Records**

Medical records and the results of medical screening tests should be kept confidential. The only information that should be transmitted from the medical department to the RPA is whether or not an individual may use respirators, or which devices may be used and which may not be. A simple medical status form is adequate (see Appendix D).

#### **5.1.8 Medical Status Forms**

Upon completion of each respirator medical screening, a "Respirator User Medical Status" form should be filled out. This form should contain enough information to clearly identify the screened person. It should then indicate one of three statuses:

1. Approved for use of *all* types of respirators;
2. *Not* approved for use of *any* respirator; or

3. Conditional approval. Approved for use of *some types* of respirators but not for others. The types allowed or prohibited should be specified.

An example of a form that may be used is provided in Appendix D to this Manual.

If the first or second option is indicated, the form need only be signed by the person performing the screening.

If the third option is indicated, the physician's specific instructions should be noted, and the form signed by the licensee's physician. Faxed copies are acceptable. A copy of the Respirator User Medical Status form should be sent to the RPA, and another should be given to the subject. The original should be retained in the subject's medical record.

## **5.2 Training**

### **5.2.1 Qualifications of Training Personnel**

Individuals performing respirator user training should have expertise in radiation protection and should themselves be experienced in using all the types of respirators that are the subject of the training. Ideally, they should also be trained in presentation skills, and have experience instructing classes or making oral public presentations.

### **5.2.2 Contents of Training Program**

A training program, including hands-on training, should be established and implemented for respirator users. Initial training for inexperienced respirator users and for first-time respirator users should take place before fit testing. Hands-on training may not need to be repeated annually for workers who use respirators frequently, but retraining sessions should review and at least demonstrate proper donning, performance of user seal checks, and removal procedures.

Retraining of workers who have not used respirators during the past year, or those who have used them infrequently, should include hands-on training.

Respirator inspection, donning, user seal checking, use and proper removal are mechanical skills. As such, they require a first-time trainee to actually perform these actions a number of times while being observed (and corrected as necessary) by an experienced respirator user/instructor in order to achieve an acceptable level of proficiency. This practice-under-instruction provides a high degree of confidence that when the worker dons a respirator in the field, it will likely be donned properly and will afford the predicted minimum degree of protection. Performing an action several or many times reinforces learning. The more correct repetitions of a task, the longer the trainee will maintain proficiency at performing that task unsupervised. As an analogy, consider a novice welder in training. If the novice were to observe an instructor performing and explaining even a simple weld, we would not expect the trainee to be able to perform such a weld correctly the first time without any practice. Simply presenting a demonstration of the respirator skills described above is not adequate training.

Topics addressed during respirator training should include the following for each device the trainees will use in the field and for emergency escape respirators:

1. Principles of operation;
2. Capabilities and limitations;
3. NIOSH approval requirement;
4. How to communicate clearly with fellow workers while using respirators;
5. Proper use of equipment associated with each device (e.g., voice amplification units, spectacle adapters);
6. Potential respirator-related problems, such as lens fogging in a full-facepiece respirator;
7. How to inspect each type of respiratory protective device to be used, and be

8. instructed to perform this inspection prior to donning a device;
8. For face-sealing devices, be instructed in how to perform a user seal check, and be instructed to perform this fit check each time this type of device is donned;
9. For non-face sealing device, be instructed in how to perform an operational check, and be instructed to perform this operational check each time this type of device is donned;
10. Be informed that each respirator user may leave the work area at any time for relief from respirator use in the event of equipment malfunction, physical or psychological distress, procedural or communications failure, significant deterioration of operating conditions, or any other conditions that might necessitate such relief.
11. Training should also include information about the types of physical or medical conditions that might indicate respirators should not be used, a description of respirator cleaning and sanitization program, a description of the inspection and maintenance programs, and the respirator issue procedure; and
12. Be advised that a new fit test should be requested if any of the changes listed in section 5.7 of this Manual apply to the respirator wearer.

### **5.2.3 Effective Respirator Training**

In the classroom portion of the program, each trainee should be given a respirator of the type that is the subject of the training. As the instructor describes the component parts and principles of operation, trainees are able to clearly identify each part while seeing how it operates. Trainees are also shown how the straps are tightened and loosened, check exhalation valve operation and so on. The instructor emphasizes that respirator users must always perform this visual inspection prior to donning.

Next, the instructor demonstrates the respirator donning, negative- and/or positive-pressure user seal check (see Figure 5-1), and removal procedure while the trainees watch. The demonstration should be repeated. Finally, the trainees don their own respirators while the instructor recites the donning instructions aloud. The instructor closely observes the trainees and corrects any mistakes. The instructor then recites the instructions for the negative- and/or positive-pressure user seal checks as the trainees perform the operations. Strong emphasis should be placed on how to correctly conduct one or more user seal checks. Trainees must learn to recognize the symptoms of a respirator malfunction that the checks are designed to detect, and must learn what action they should take if a facepiece fails a user seal check. The respirators are then removed in accordance with the instructor's verbal directions. Again, the instructor corrects any mistakes made by the trainees and provides positive reinforcement when they perform the tasks correctly. This positive reinforcement is important, since it must be clear to each trainee that he or she is in fact performing the task correctly. The instructor also solicits questions from the class to see if there were any problems or misunderstanding of instructions.

Finally, the trainees are told to don their respirators in the way that they have just practiced. The instructor observes them closely and corrects as necessary. Negative and/or positive-pressure user seal checks are then performed. During this hands-on training, with respirators on, each trainee should perform a series of activities such as operating a valve, reading a gauge or performing similar tasks that might be required in the workplace. This is also a good opportunity to let the trainees practice verbal communications with one another to get used to coping with the voice distortion imposed by the facepieces. After some period of respirator use, the trainees should remove the respirators as the instructor watches. Positive reinforcement should again be given for correct performance. Trainees should then don and

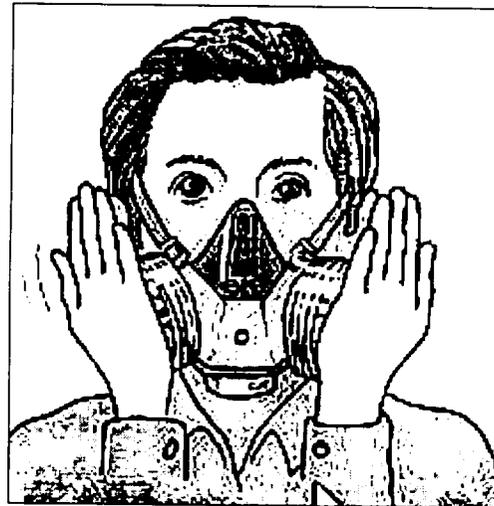
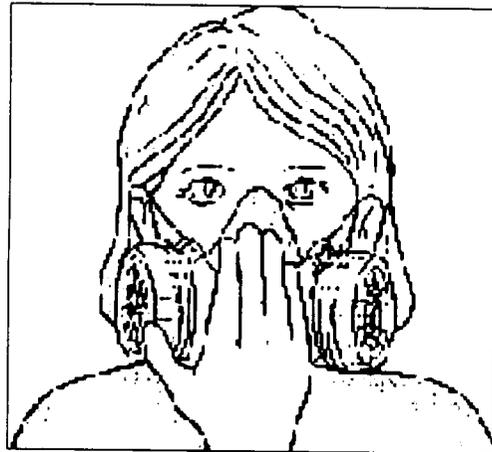


Figure 5-1. Positive-pressure (top) and negative-pressure (bottom) user seal checks.

remove the respirators correctly (without prompting) at least two more times while the instructor observes.

One thing to avoid, *especially* during initial respirator training, is a demonstration of how *not* to don or remove a respirator. While an instructor can make this very amusing, studies have shown that this negative training will be remembered as well as or better than the correct training. This would obviously be counterproductive.

Once effective training is complete, the trainee should be able to correctly don and use the respirator during the fit test.

#### **5.2.4 Training for Supervisors of Respirator Users**

In addition to respirator users, supervisors of respirator users should also receive training, even if they are not themselves respirator users. A list of topics for supervisor training can be found in ANSI Z88.2-1992, paragraph 8.1.1. These supervisors should also receive the hands-on training. If such supervisors are excluded from respirator use on medical grounds, they should at least observe the hands-on training. Fit testing for supervisors is not required unless they will be respirator users.

### **5.3 Fit Testing**

#### **5.3.1 Introduction**

Fit testing is, and probably always will be, a laboratory situation where the adequacy of a respirator fit is determined under ideal conditions. The physical stresses placed on the facepiece-to-face seal in the workplace are extremely variable in type and intensity.

A fit-testing program is to be implemented for all face-sealing respirators, even those that will be used only in a positive-pressure mode in the field. Each time fit testing is required, only a single satisfactory fit test need be performed for each facepiece. Separate fit tests are required for each manufacturer's model, size and facepiece material that the individual might use. For example, if a specific make, model and size facepiece is supplied in both carbon rubber and silicon rubber versions, and the user might be issued a facepiece made of either material, a separate fit test should be performed for the carbon rubber and silicon rubber facepieces.

Fit testing should always be performed with the facepiece operating in the negative-pressure mode, regardless of the mode of operation in which it will be used in the field. An adequate fit with a tight-fitting positive-pressure facepiece is important to prevent the possible ingress of contaminants, especially at high work rates. It is also important to ensure that the service-life of a SCBA is not reduced by the escape of compressed air past an inadequate face-to-facepiece seal.

In a properly administered fit-test program, adequate fit factors should be obtained for more than 99% of test subjects who are free of facial deformities that preclude an adequate respirator fit. For those individuals who are unable to achieve a fit factor 10 times the APF of the respirator, consideration should be given to a positive pressure face sealing device or to a device for which a face seal is not necessary. A new ANSI standard, Z88.10-200x, "Respirator Fit Test Methods," is in the final stages of review and should be published soon. Licensees should review this document after its publication for ways to improve their fit-testing program.

#### **5.3.2 Relationship Between Fit Testing and Training**

A few respiratory protection training programs have been observed in which respirator fit testing is utilized as a substitute for the "hands-on" portion of initial respirator user training (i.e., the training of those who have little or no experience in the use of respirators). Theoretically, where this situation prevails, inexperienced workers can satisfactorily complete initial radiation worker/respirator user training without ever having touched a respirator, or at least never having donned one under instruction.

Fit testing is not a substitute for hands-on training. Each person to be fit tested should be competent to properly don a facepiece and

perform at least one appropriate user seal check. No person, including the fit-test technician, should coach the subject during the respirator donning process, since no coach will be available in the workplace. If a person presents himself for a fit test and is unable to don a facepiece properly, no fit test should be administered, since the person has not been adequately trained. The fit test, then, is also a test of training effectiveness. The fit-test technician should observe the donning and user seal checking process to ensure that the device has been donned correctly. If it has not been, the fit test should not proceed. The individual should be referred to the appropriate person for retraining or for a refresher.

At a facility where budgets and staff may be shrinking, the RPA might be tempted to cut costs by presuming that the respirator fit test could be substituted for the hands-on portion of the training program. This would shorten the initial worker-training program, eliminate purchase and maintenance of respirators for use in training, and eliminate the need to sanitize the training respirators after each class. Without hands-on training, however, no effective training takes place, and much of the time spent in class talking about respirator use is wasted. The purpose of a fit test is to gain assurance that a trained and practiced worker who dons a respirator unassisted, as he or she would in the workplace, will obtain an acceptable respirator fit.

#### **5.4 Quantitative Fit Testing (QNFT)**

In a quantitative fit test, the test subject is exposed to a challenge aerosol while wearing a respirator and a sample of the air inside the facepiece is analyzed for the challenge aerosol. The concentration inside the facepiece is compared to the challenge concentration outside the facepiece, and a numerical "fit factor" is obtained. QNFT, then, provides a numerical value that is indicative of how well or how poorly a respirator fits a test subject. It

is an objective test that is very much under the control of the person conducting the test, and not the fit-test subject.

Historically, the challenge agent has been a mechanically generated aerosol mist of corn oil, dioctyl sebacate (DOS), or similar substance injected into a fit test chamber where the test subject is positioned. [Dioctyl phthalate (DOP) should not be used for QNFT since it is a suspected carcinogen.] The challenge concentration is maintained constant over the duration of the test. A newer test technology (Portacount™) uses ambient dust particles in the air as its challenge agent, thus eliminating the need for a test chamber and aerosol generator.

A QNFT program is more expensive to run than a qualitative fit test program (QLFT), because of the equipment that must be purchased and maintained. Additional training is also required for the operator of the fit-test equipment, and for those who interpret the test results.

In order for a licensee to use an APF >10 for any face-sealing respirator, QNFT is required and an adequate fit factor measured. Currently available QLFT methods are only capable of measuring a fit factor of 100. The requirement is that a fit test must measure a fit factor that is 10 times the APF of the tested respirator, or a fit factor of 500 for facepieces that will be used with positive-pressure devices.

Some respirators used for QNFT may need to be modified to perform the tests. While this modification voids the NIOSH approval for the device, no such approval is required for respirators used during fit testing, since occupational exposures to hazardous or radioactive materials are not involved. Some respirator manufacturers provide adapters that enable QNFT to be performed without permanently altering the facepiece.

A few licensees who have obtained the NRC's authorization to use an APF for combination particulate and organic vapor chin-mounted canisters, have reported some radioiodine uptakes in wearers of this device. It has been postulated that the reason for this might be the stress that such a canister places on the facepiece seal when the wearer moves about in the work place. Consideration should be given to using these "iodine canisters" during QNFT of individuals to determine whether the added weight of the canister has any effect on the quality of the fit. See Figure 4-19.

## 5.5 Qualitative Fit Testing (QLFT)

In a qualitative respirator fit test (QLFT), the test subject, while wearing an unmodified respirator with the proper cartridge(s) attached, is exposed to a challenge aerosol or vapor. If the challenge agent is not detected (i.e., smelled or tasted) by the test subject, the respirator is judged to fit adequately. Negative- and positive-pressure user seal checks are *not* qualitative fit tests.

There are some obvious drawbacks to this type of test. First, the test subject may report inaccurately. This may be caused by a misunderstanding of the test instructions or by a realization that a failed test might mean termination of employment. Second, depending on which challenge agent is utilized, some people may not be able to smell or taste it in the low challenge concentrations. One, isoamyl acetate (banana oil), will desensitize the olfactory nerves of a test subject if that subject is exposed to the vapors before the test is conducted. Another accepted challenge aerosol is sodium saccharine. Only one recognized challenge agent evokes an involuntary response from a test subject, and that is irritant smoke (stannic oxychloride). A QLFT program is less expensive to establish and run than a QNFT program, since very little equipment needs to be purchased and maintained.

A common misunderstanding about QLFT is that it takes less time to perform than a quantitative test. This is not the case. The exercise portion of the fit test protocol (i.e., which exercises are to be performed, how they are to be performed, and for how long) should be the same, no matter which test method is used.

### 5.5.1 Capabilities and Limitations of QLFT

Currently available QLFT methods are only considered capable of verifying a fit factor of 100. Therefore QLFT methods can only be used for facepieces for which an APF  $\leq 10$  will be used. For example, if a full facepiece air-purifying respirator is tested using QLFT, it may still be used in the field so long as an APF no greater than 10 is used. Since respirators that operate in a positive-pressure mode require a minimum fit factor of 500 before the APF listed in Appendix A to 10 CFR 20 can be applied, an APF of no more than 10 can be used for these devices in a program that utilizes QLFT exclusively.

### 5.5.2 Irritant Smoke

These tubes contain stannic chloride ( $\text{SnCl}_4$ ), which reacts with ambient humidity to liberate a white hydrochloric acid fume and tin compounds. This smoke is a strong irritant of the eyes, mucous membranes, and skin, and evokes an involuntary response from the person who inhales it. For this reason it is the least subjective QLFT method.

The National Institute for Occupational Safety and Health (NIOSH) conducted a Health Hazard Evaluation (HHE) in response to a request after four fire fighters reported experiencing either skin irritation or eye irritation as a result of qualitative fit tests using irritant smoke. The health risks associated with the use of irritant smoke were evaluated by conducting particle size analysis of the "smoke"

emitted from air flow indicator tubes, and by measuring the concentration of hydrogen chloride produced by these tubes. Count median diameters of the smoke ranged from 0.33 to 0.63  $\mu\text{m}$ . Concentrations of hydrogen chloride measured on a day with low relative humidity ranged from <1 ppm to 2,700 ppm. Concentrations of hydrogen chloride measured on a day with high relative humidity ranged from 100 ppm to 11,900 ppm. The highest concentration measured inside the test hood during multiple bulb squeezes was 14,400 ppm. Inhalation of hydrogen chloride at concentrations of 5 ppm or more is immediately irritating to the nose and throat. In addition to upper respiratory tract irritation, short-term exposure to relatively low concentrations can also cause coughing and choking. Inhalation exposure of male volunteers to hydrogen chloride at concentrations between 50 and 100 ppm for 1 hour were reported as barely tolerable, and 10 ppm was the maximal concentration acceptable for prolonged exposure. The NIOSH recommended exposure limit (REL), the OSHA permissible exposure limit (PEL), and the ACGIH threshold limit value (TLV) for hydrogen chloride are a ceiling limit of 5 ppm. The ACGIH TLV is based on the reports of respiratory irritation from short-term exposure to hydrogen chloride at 5 ppm and above. NIOSH has also established an immediately dangerous to life and health (IDLH) value of 100 ppm for hydrogen chloride. A concentration of 309 ppm has been reported as the level of hydrogen chloride causing a severe toxic endpoint in laboratory animals, including intolerable irritation, incapacitation, and unconsciousness. For these reasons, NIOSH suggests that licensees who use this QLFT method investigate other options.

## **5.6 Fit Test Protocols and Procedures**

### **5.6.1 Pre-Test Considerations**

Certain prerequisites must be met before any subject is allowed to wear a respirator, even

for fit testing. Major among these are medical screening and training in the use of the device(s) to be tested. Test subjects must also be clean-shaven for the fit test.

People who are waiting around for fit testing may try to distract the fit test subject. This distraction may cause the subject to make facial or other movements that are not part of the protocol. Eliminate the possibility of the subject "clowning" with others by performing the fit testing in a private area.

Subjects should perspire during the test in the same way that they will perspire in the workplace. Therefore, the facepiece should be donned approximately five minutes prior to the start of the test. This allows at least the facial perspiration process to begin prior to exposure to the challenge aerosol.

### **5.6.2 The Protocol**

The word "protocol" is used generally to denote a procedure that requires strict adherence. Therefore, the fit-test protocol that is established for use in a respiratory protection program should be used consistently when performing measurements of the quality of respirator fits. The protocol covers everything about the measurement portion of the fit test. Once established, it should be followed whether a qualitative or quantitative test is used. The protocol should include one or more procedures that provide instructions on equipment operation and testing, test documentation, exercises to be performed during the test, recordkeeping, and so on. If both QLFT and QNFT are used, then two (or more) protocols will be needed.

### **5.6.3 The Exercises**

The purpose of having a fit test subject perform various movements and exercises during respirator fit testing is to simulate those

movements which will likely take place on the job when respirators are being worn, and to see if the respirator provides adequate protection under these circumstances. It must be understood, however, that no respirator fit test can hope to duplicate all the possible workplace movements of a respirator wearer. It is also important to establish clearly *how* the chosen exercises are to be performed. If all test subjects perform each test exercise in approximately the same way, then valid comparisons can be made between the fit test results of different subjects, and between different types of respirators on the same test population.

The exercises selected, and how those exercises are performed during testing, should be designed to *challenge the respirator fit* under simulated conditions of use. This should be an aggressive test, and not just “for the record.” Fit-test protocols *should not* be designed simply to allow a high percentage of test subjects to “pass” the test.

Listed below are the eight exercises specified in the OSHA respirator standard (29 CFR 1910.134 Appendix A). Included are suggested instructions for performing each of the exercises to limit the variability between fit tests. Selecting the OSHA-required exercises is acceptable to the NRC.

1. *Normal Breathing.* Subject should stand without talking and breathe normally with arms at sides. Head should be facing forward, eyes front. This should be both the first and last exercise during the fit test.
2. *Deep Breathing.* In a normal standing position, take long, deep breaths. Do not breathe so rapidly as to cause hyperventilation, but attempt to simulate labored breathing in the workplace. Head should be facing forward, eyes front.
3. *Turn Head Side-to-Side.* While standing and breathing normally, turn the head as far to one side as possible, keeping the

shoulders square and the trunk of the body facing front. With the head turned, take one normal breath and let it out. Then turn the head quickly all the way to the other side, and hold it there through one inhalation/exhalation cycle. Repeat this for the required duration of the exercise. The head should be turned quickly from one side to the other, but not so fast as to cause whiplash or other injury. No breath should be taken in between the full left and full right positions. Be sure that the subject is not moving from the waist and facing his upper body left and right. The purpose of this exercise (and of the Head Up and Down exercise below) is to stretch the skin on the neck, chin, and sides of the face to see how badly those movements degrade the respirator seal.

4. *Move Head Up and Down.* While standing and breathing normally, move the head as far up as possible, keeping the shoulders square and the trunk of the body facing front. With the head elevated in this manner take in a normal breath and let it out. Then move the head all the way down, and hold it there through one inhalation/exhalation cycle. Repeat this for the duration of the exercise. The head should be moved quickly from one position to the other, but not so fast as to cause whiplash or other injury, or to cause the filter to hit the chest. No breath should be taken in between the full up and full down positions. Be sure that the subject is not moving from the waist and positioning his upper body up and down.
5. *Talk.* Usually test subjects are required to read “The Rainbow Passage” (Appendix E to this Manual). This is an elocution drill, requiring the person who reads it aloud to form all of the vowel and consonant sounds in the English language. An alternative (for people who have forgotten their glasses) is to have them count backwards from 100, or recite a poem that they know. Whatever the words used in this exercise, the important thing is for the

subject to speak clearly, trying to make himself understood to the fit test administrator. The subject *should not* take a deep breath and read or recite at a rapid and unintelligible rate. He should speak slowly and enunciate each word, just as he will have to do in the workplace to make himself understood while wearing a respirator.

6. *Grimace*. The test subject should breathe normally and grimace by smiling or frowning. During the smiling portion the corners of the mouth should turn upward, the brow should rise and the cheeks should broaden. When frowning, the brow should be knitted and the corners of the mouth turned downward in a scowl. The smile and frown should be alternated for the duration of the exercise. The grimace exercise is designed to break the face-to-facepiece seal to ensure that the seal is reestablished for the final two exercises. Therefore the fit factor results of the grimace exercise are not used to calculate the overall fit factor. *This exercise should not be used during QLFT.*
7. *Bend at Waist*.<sup>4</sup> While breathing normally, the subject should bend forward from the waist until the upper portion of the body is approximately parallel with the floor, as if trying to touch his toes. Keep the shoulders square. While in this position take in a normal breath and let it out. Then resume an upright position and repeat an inhalation/exhalation cycle. Continue alternating these two positions for the duration of the exercise. The movements should be accomplished quickly, but care must be taken not to bump the head or cause other injury. No breath should be taken in between the full up and full down positions.  
(*Jog in Place*. The feet should be lifted off the floor during this exercise, but it should not resemble an Olympic sprint. This

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<sup>4</sup> Jogging in place should be substituted for bending over at the waist in those test environments that do not permit bending.

exercise should induce rapid respiration, similar to what would be experienced while climbing stairs, lifting objects, and performing other strenuous tasks in the work place. The test subject should break a sweat during this exercise.)

8. *Normal Breathing*. As in 1. above.

#### 5.6.4 Duration of Exercises

The duration of each exercise (except for the grimace exercise) should be one minute. This applies to both QNFT and QLFT protocols. In quantitative fit testing, there is some time delay between when the sample air is drawn from the facepiece and when it is evaluated by the test instrument. This is a function of how long the sample tube is, and of the sample air-flow rate. This time delay may be significant. There may also be some time delay between sample analysis and the display of that analysis on a meter or chart recorder. This time delay is generally short. The manufacturer's instructions for the test equipment should supply this information. The duration of each exercise, then, should be one minute plus any sample evaluation time delay.

The grimace exercise, used only during QNFT, should only be performed for 15 seconds.

### 5.6.5 Acceptable Fit

The overall fit factor (FF) must meet or exceed the required fit factor for the type of device used. The fit factor for one or more exercises may be less than the minimum acceptable value as long as the overall fit factor is acceptable. The overall fit factor is calculated as follows:

$$FF_{\text{Overall}} = \frac{n}{\frac{1}{FF_1} + \frac{1}{FF_2} + \dots + \frac{1}{FF_n}}$$

Where n = the number of exercises performed

### 5.7 Retesting

The retest period does not need to be more frequent than annually. A retest grace period of ninety days is considered to be reasonable. Licensees should not interpret this grace period to mean that re-testing can be accomplished every 15 months. For example, three consecutive annual fit tests should not exceed 39 months.

Retesting should be accomplished prior to next respirator use when a potential respirator wearer, since the last fit test, has:

1. A weight change of 10% or more;
2. Significant facial injury or scarring in the area of the facepiece seal;
3. Significant dental changes (e.g., multiple extractions without prosthesis, acquisition of dentures);
4. Reconstructive or cosmetic surgery in the area of the facepiece seal;
5. Any other condition that might change the fit of a face-sealing respirator.

It is the responsibility of the individual respirator wearer to bring these conditions to the attention of the RPA.

Licensees are cautioned that some previous federal regulations applying to some non-radiological hazards (e.g., 29 CFR 1910.1001

Asbestos), and some proposed non-radiological respiratory protection regulations, have required or proposed re-testing at more frequent intervals, and have required or proposed more than one satisfactory fit test be achieved. NRC requires only one satisfactory fit test.

### 5.8 Minimum Acceptable QNFT Fit Factors

If quantitative fit testing is used to test facepieces that, in the field, will operate in the negative-pressure mode, a fit factor that is at least 10 times the APF (stated in Appendix A to 10 CFR 20) should be demonstrated before an individual is permitted to use that facepiece in the field. For combination devices (e.g., combination negative-pressure air purifying and continuous-flow airline device), the minimum acceptable fit factor is 10 times the APF for the negative-pressure mode of operation. If quantitative fit testing is used to test facepieces that in the field will operate *only* in the positive-pressure mode (e.g., powered air-purifying respirators), or in the continuous-flow mode (e.g., airline respirators), or in the pressure-demand mode (e.g., airline respirators, SCBA), a fit factor of at least 500 should be demonstrated with the facepiece operating in the negative pressure mode before an individual is permitted to use that facepiece in the field. Table 5-1 is provided below for convenience, but licensees are reminded that the source of APFs is Appendix A to 10 CFR 20. During training or operation, perceptible outward leakage of breathing gas from the face-to-facepiece seal area of any self-contained breathing apparatus is unacceptable, and the wearer should not be permitted to continue to use the device.

**Table 5-1. Respirator APFs and required minimum fit factors.**

<b>Respirator Type</b>	<b>Mode</b>	<b>APF</b>	<b>Required Fit Factor</b>
<b>AIR-PURIFYING</b>			
Single-use disposable	NP	1	NR
Facepiece, half mask	NP	10	100
Facepiece, full	NP	100	1000
Facepiece, half mask	PP	50	500
Facepiece, full	PP	1000	500
Helmet/hood	PP	1000	NR
Facepiece, loose-fitting	PP	25	NR
<b>ATMOSPHERE SUPPLYING</b>			
<b>Air-line respirator</b>			
Facepiece, half-mask	D	10	100
Facepiece, half-mask	CF	50	500
Facepiece, half-mask	PD	50	500
Facepiece, full	D	100	1000
Facepiece, full	CF	1000	500
Facepiece, full	PD	1000	500
Helmet/hood	CF	1000	NR
Facepiece, loose-fitting	CF	25	NR
Suit	CF	1	NR
<b>Self-contained breathing apparatus (SCBA)</b>			
Facepiece, full	D	100	1000
Facepiece, full	PD	10,000	500
Facepiece, full	RD	100	1000
Facepiece, full	RP	10,000	500

NR = Not required

**5.9 Sanitizing Respirators After Use in Fit Testing**

Licenseses have an obligation to provide each fit-test subject with a clean, sanitary respirator. Precisely how this is accomplished is left to the judgment of the RPA, but (s)he should consider consulting an industrial hygienist or nurse before deciding on the method to be used.

Licenseses may consider one of the following methods for use in their fit test programs.

1. Use a different facepiece for each subject, then wash and sanitize all used facepieces at the end of the day or shift. This requires a relatively large number of facepieces to be dedicated to fit testing.
2. At the end of each fit test, the test subject sanitizes the facepiece just used, making it ready for another test subject. This could be done by immersing the respirator in a

solution of water and one of the sanitizing solutions described in this manual, or by spraying such a solution into the inside of the facepiece. The facepiece should then be thoroughly rinsed in clean water, then shaken and towel dried.

3. Require each test subject to sanitize the facepiece that (s)he will use during the fit test. This could be done as described in 2. above.
4. Wiping the interior surfaces with a non-alcohol sanitizing towelette might be acceptable if the concurrence of an industrial hygienist is obtained.

Several respirator manufacturers have adapters available that will convert any of their facepieces into a fit-test respirator. If this is the case, personnel could be given ready-for-issue respirators for use in fit testing, then return them

to the respirator washing area when the fit test is complete.

## **5.10 Communication**

### **5.10.1 Need for Voice-Amplification Equipment**

Facepiece respirators are drawn up snug against the wearer's face to provide a proper facepiece-to-face seal. The limitation on jaw movement that results, combined with the muffling effect of the facepiece, can severely inhibit voice communication. Add to this the complications of the workplace, such as high ambient noise levels and the distance between workers, and communication attempts can become very stressful. Voice strain, hoarseness, and frustration are the primary physical manifestations, but the potential for accidents and mistakes is significantly increased when clear communication is difficult.

### **5.10.2 Respirator Manufacturer-Supplied Equipment**

Some respirators incorporate a speaking diaphragm into the facepiece that vibrates as the wearer speaks and helps to transmit the sound outside the facepiece. Mask-mounted microphones, connected to external amplifiers are also available for many respirators. The licensee must ensure that any voice amplification device is listed on the NIOSH list of approved subassemblies.

### **5.10.3 Non-Respirator Manufacturer-Supplied Equipment**

Other suppliers have available a variety of products offering communication aids to respirator wearers. These include throat-mounted microphones, in-the-ear microphone/receivers, cranial mikes, headset/boom devices, and all sorts of

combinations of communication equipment for all conditions of use. When using communications equipment supplied by companies other than the respirator manufacturer, care must be taken that use of the device does not void the NIOSH approval of the respirator. Generally speaking, equipment used in conjunction with a respirator cannot affect its form, fit or function. It cannot be attached to the respirator, and may not interfere with how the respirator fits on the face or head. For example, a bone conduction microphone worn under the head harness of a full facepiece (to hold it firmly in contact with the wearer's head to get maximum sound conduction) would likely void the NIOSH approval since it would interfere with the way the respirator is worn. A throat-mounted microphone would not void the approval, since it does not come into contact with the respirator in any way.

### **5.10.4 Other Options**

Hand signals can work well in situations where communications do not need to be very complex. Thorough planning of work and mock-up training may also limit the need to communicate on the job. Other possible alternatives to voice amplification equipment might be the use of signaling devices such as a horn or bell. These might be appropriate for communicating simple instructions or warnings to workers. The important considerations are worker safety and ALARA. The RPA should make the judgment about the adequacy of communication methods used.

## **5.11 Vision and Vision Correction**

In most full facepiece-type respirators, the worker's field of vision is limited. If care is not taken, the worker can literally walk into an accident.

Workers should be cautioned that if they are unable to safely perform their assigned tasks while wearing respirators without vision correction, then they should not be issued respirators until respirator spectacle adapters with proper corrective lenses are in hand, or unless they are wearing their contact lenses.

Licensees should ensure that individuals who need to wear corrective lenses while performing licensed duties (e.g., power reactor licensed operators), or while responding to an emergency (e.g., fire brigade members) should have proper corrective lenses available for conditions requiring use of a respirator or a self-contained breathing apparatus.<sup>5</sup>

Any spectacle adapter, even those not supplied by the manufacturer of the respirator, may be acceptable for use inside a full facepiece respirator. Any adapter may be used if the device does not interfere with the facepiece seal, if it does not cause any distortion of vision, damage the lens or the facepiece itself, or cause any physical harm to the wearer during use.

Contact lenses may be worn by wearers of full facepiece respirators, supplied-air hoods, helmets and the like. Licensees may not require workers to obtain contact lenses, and contact-lens wearers should not be forced to wear the contact lenses in lieu of a standard spectacle adapter. Contact-lens wearers should be informed during training that they should wear their contact lenses during the hands-on portion of the respirator training and during fit testing to ensure compatibility.

New contact-lens wearers (i.e., those with little or no experience wearing the contact lenses under any circumstances) might be instructed not to wear the new lenses while wearing a respirator until they have several weeks experience using the contact lenses. Wearing the contact lenses during training or fit testing

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<sup>5</sup> NRC Information Notice 97-66: "Failure to Provide Special Lenses for Operators Using Respirator or Self-Contained Breathing Apparatus During Emergency Operations."

should be viewed as an absolute minimum level of experience.

It is the obligation of the contact-lens wearer to make known to the licensee problems experienced with contact lenses and respirator use. The NRC's position on contact lens use with respirators is contained in Regulatory Guide 8.15, Section 5.7, and is consistent with the OSHA rule.

## **5.12 Use of Respirators in Low Temperatures**

### **5.12.1 Lens Fogging**

Lens fogging in negative-pressure, air-purifying respirators is a continual problem. Though respirator manufacturers are required by NIOSH to incorporate design features to reduce or eliminate the effect of fogging, most are less than fully effective. Most full-facepiece respirators have inlet ducts or air-directing devices that cause the inhaled air to be swept across the inside of the facepiece lens. This acts much like an automobile defroster, which clears off (with varying degrees of success) the accumulated condensation on the inside of the respirator lens. The cause, of course, is the warmed and moistened exhaled breath that comes into direct contact with the inside of the colder lens. As the ambient air temperature decreases, the intermittent lens-clearing provided during inhalation becomes less and less effective. At temperatures below the freezing point, lens frosting can occur, which can completely obliterate the wearer's vision. Workers are known to sometimes force deep and extended inhalations to provide clear vision. As long as they can hold their breath, the lens will stay relatively condensation-free. This cycle of deep inhalation followed by breath-holding is physically taxing and should be discouraged.

Nosecup inserts, available for most brands of full facepieces, are very effective at directing the moisture-laden exhaled breath away from the lens and into the exhalation valve. At temperatures below 32 °F, nose cups (or an alternative method of control) are required as part of a NIOSH-approved assembly in all self-contained breathing apparatus. Powered air-purifying devices and constant-flow airline devices also offer some reduction to the fogging problem.

There are some specialty products on the market that can effectively reduce or eliminate lens fogging. Plastic inserts that adhere directly to the inside of the lens and form a double-pane barrier are said to work very well. These would not have to be supplied by the facepiece manufacturer so long as they do not interfere with the facepiece seal, do not cause any distortion of vision, damage the lens of the facepiece or the facepiece itself, or cause any physical harm to the wearer during use. This judgment is to be made by the RPA.

Anti-fog solutions can be effective if applied in accordance with their instructions. Check with the respirator manufacturer regarding compatibility of these products with their facepieces.

SCUBA divers apply some saliva to the inside of their diving masks to limit fogging. As long as facepieces are cleaned and sanitized before being used by another person, this technique is acceptable in an NRC-regulated program.

#### **5.12.2 Exhalation Valve Freezing**

Very low temperatures can also cause the respirator exhalation valve, moistened with condensation or saliva, to freeze in the open

position, thus providing a pathway for gross leakage of contaminants into the facepiece.

Use of a powered air-purifying respirator or a continuous-flow, supplied-air respirator eliminates the potential for a frozen exhalation valve since these are positive-pressure devices and the exhalation valve is always in the open position during operation.

### **5.13 Wearer Comfort and Acceptance**

Comfort relates to the degree of physical distress to the respirator wearer. Everyone who wears a respirator may be expected to experience some discomfort. Distress associated with the job environment tends to be accentuated by wearing a respirator: vision is restricted, breathing is more difficult, ventilation across the face is limited, equipment may be cumbersome and restrict movement, and wearing the respirator may add to the adverse effects of temperature extremes. Other factors also adversely affect wearer acceptance. An improperly fitted mask may create intolerable pain spots. Improperly designed or malfunctioning valves may cause uncomfortable restrictions to breathing or produce an irritating flicking and popping sound. Limitations on the wearer's ability to communicate may be unpleasant and add to the hazards. All these factors contribute to the physical discomfort that affects the willingness to wear and make proper use of respirators. However, if proper attention is paid to these factors in selecting equipment, most people may be provided with respirators that do not cause undue distress and that provide effective protection. The more comfortable a respirator is, the more likely that it will be worn properly and for the duration of the work.

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## 6 SAFETY

### 6.1 Face-to-Facepiece Seal Integrity

The single most important thing that a respirator wearer has control over is the integrity of the face-to-facepiece seal. Respirators that rely partially or completely on a face-to-facepiece seal may never be worn by individuals who have facial or other hair that intrudes into the area where the facepiece is supposed to contact or seal to the face. This applies to both men and women, and to both positive- and negative-pressure devices. Also, the fit of some loose-fitting facepieces might be adversely affected by facial hair. This should be evaluated by the RPA.

Cosmetics, medicines, ointments and any other material applied to the face in the area where the facepiece seals to the face precludes respirator use while such material remains in place. Acne scars and other permanent facial deformities should be dealt with during fit testing. If the test subject is able to meet the fit-test criteria, then respirator use may be allowed. Skin eruptions, boils, and other transitory skin conditions should contraindicate respirator use while the condition is manifest, but only until the skin has recovered.

Protective hoods should be worn *over* the respirator suspension straps. Skull caps, surgeon caps and the like should not be worn under the suspension straps. Hard hats and other protective equipment and protective clothing, if worn, should not interfere with the form, fit or function of the respirator. Even spectacle adapters that utilize an ultra-thin head band of elastomeric material to hold them in place on a worker's face may not be used in an NRC-regulated respiratory protection program.

This prohibition against any material or substance over which the wearer has control in the area where a tight-fitting or loose-fitting

respirator is designed to contact or seal to the face of the wearer is intended to be all-inclusive. NOTHING should exist between the skin of the respirator wearer and the sealing surface of the facepiece. There are no exceptions. OSHA and ANSI also have strong prohibitions against facepiece seal interference.

### 6.2 Standby Rescue Persons

Standby rescue persons are needed in two cases. First, standby rescuers should be present when a respiratory protection device is used that would be difficult or impossible for the wearer to remove unaided in case of failure of the air supply. Individuals using this type of equipment are in a confined space. Since one standby person could conceivably assist several persons, the ratio need not necessarily be 1 to 1. Standby rescue persons are also required when individuals enter an IDLH environment. In certain circumstances, such as the fatality involving a diver in an inerted condensate storage tank described below, *two* standby persons were not enough to pull the unconscious diver up and out of the tank. The respirator program administrator (RPA) or other competent persons are to decide the appropriate ratio of standby workers to those entering the IDLH area. Making equipment—such as tripods and power winches—available might also be considered in certain circumstances. The purpose of a standby rescue person is not to simply fulfill a legal requirement. Rather, it is to be able to effect a rescue if that becomes necessary.

Licensees should refer to OSHA's requirements for entry into permit-required confined spaces (29 CFR 1910.146), and requirements for entry into IDLH environments (29 CFR 1910.134(g)(3)).

### 6.3 Un-Assessed Environments

An air sample does not necessarily need to be taken in each area prior to each entry by personnel. Areas where the licensee is reasonably certain that airborne contamination concentrations are low need not be sampled prior to each entry. This should already be addressed in the licensee's air sampling program.

When prompt entry into an area is necessary and there is reason to believe that significant levels of airborne radiological contamination might be present, entry may be made by personnel equipped with any appropriate respiratory protection device, so long as the area is known to not be IDLH due to the presence of non-radiological hazards. Good practice suggests that the device selected in this situation have as high an APF as practicable, consistent with ALARA and good safety practice. This decision should be made by the RPA or other competent individual.

If entry is to be made into an un-assessed area that could reasonably be expected to contain an IDLH environment, then it should be considered to be IDLH for purposes of assigning respirators and standby personnel. RPAs are encouraged to err on the side of caution in these situations.

### 6.4 Emergency Escape

The emergency escape devices envisioned here are those that would either be carried by workers or staged at critical locations inside work areas for use during escape from an environment in which respirators are normally not required. In radiological environments these could be any of the devices listed in Appendix A to 10 CFR 20. For potentially IDLH environments, only those certified by NIOSH for use in IDLH environments should be used. These devices are identified on the NIOSH certificate. Devices should be selected so that they are easy to don and use, and do

not slow the workers down as they are making their escape. When deciding how many of these devices to stage in a potentially IDLH area, licensees should take into account the fact that many more devices will be needed than the number of individuals who might be present when an emergency occurs. A person in a potentially IDLH area should never be far from an escape device.

Emergency escape devices staged or carried into areas could be negative-pressure devices equipped with particulate or other types of chemical cartridges or canisters. They might also be small, constant-flow, self-contained breathing apparatus with a simple bag-type respiratory inlet covering.

The decision about which type(s) of emergency escape respirators to stage or have workers carry into these areas should be based on the potential hazards in the area and the potential concentration based on the worst credible accident scenario.

Potential wearers of these devices should have sufficient training to enable them to know when to use the devices, how to don and use the device correctly and efficiently, and how to make their escape. They should also be informed that these devices are for escape only, and are not to be used for fire fighting, search and rescue, or other entries into hazardous areas.

No medical screening or fit testing is required for personnel who are not respirator wearers, but who might—in an emergency—need to use an emergency escape respirator.

## 6.5 Breathing Air

### 6.5.1 Breathing-Air Systems

Licensees are required by 10 CFR 20.1703(g) to supply air of Grade D quality or better as described by the Compressed Gas Association (CGA) to each supplied-air respirator. Section 6.5.2 addresses breathing-air quality. Licensees who utilize a service-air or instrument-air system as a source of breathing air need to maintain extra vigilance to prevent radiological and non-radiological contamination of the system. Licensees in this situation should consider the use of removable spool pieces in the pipes leading to fluid systems that are connected to the air system to prevent back-flow into the air system when not in use. If this is not practicable, a check valve between two isolation valves, or two isolation valves with an open leak-off between can be used. The use of check valves alone is the least desirable option in this situation because of their tendency to eventually develop leaks. IE Information Notice 79-08 describes an incident where both a check valve and a ball valve leaked and allowed the contamination of a breathing-air system. IE Information Notice 85-06 describes two similar air system contamination incidents. A complete list of respirator-related generic communications has been included at the front of this Manual.

Caution should be exercised if temporary air compressors, powered by internal combustion engines, are utilized to supplement the installed air compressors, or used where no installed air system is operational. In these cases, the licensee should ensure that the engine exhaust is not drawn into the compressor intake.

Licensees should not permit use of breathing-air supply hoses, regulators or other components for non-breathing-air applications. Quick-connect fittings used for breathing-air equipment should be incompatible with quick-connect fittings used for other purposes at the facility. This is an OSHA requirement [29 CFR 1910.134(i)(8)].

### 6.5.2 Breathing-Air Quality

The breathing-air supply should meet certain minimum quality requirements. These are specified in the CGA pamphlet G7.1-1997 "Commodity Specification for Air." This document also describes acceptable test methods for measuring the parameters. Documentation of analytical results and test methods should be retained. If analysis results are provided by a vendor, the licensee should take steps to assure the accuracy of the reported results.

### 6.5.3 Moisture Content in Breathing-Air Cylinders

The allowable moisture content in breathing-air cylinders is addressed in the OSHA regulations [29 CFR 1910.134(i)(4)(iii)]. This requires that the moisture content in the cylinder does not exceed a dew point of  $-50^{\circ}\text{F}$  ( $-45.6^{\circ}\text{C}$ ) at 1 atmosphere pressure. CGA G-7.1-1997 states that air in SCBA cylinders should not exceed a dew point of  $-65^{\circ}\text{F}$  (24 ppm v/v), or  $10^{\circ}\text{F}$  lower than the coldest temperature expected in the area where the SCBA will be used. Licensees should comply with the OSHA requirement as a minimum, and should meet the CGA Grade L requirement for moisture content if practical.

### 6.5.4 Testing Frequency

Guidelines for the frequency at which breathing-air supply systems should be tested are provided in Regulatory Guide 8.15, "Acceptable Programs for Respiratory Protection," Revision 1 (October 1999). As long as reasonable precautions are taken to protect the air inlet, an air system supplied from a non-oil-lubricated compressor that is used exclusively to supply breathing air is less likely to become contaminated than a combination service-air/breathing-air system. It is reasonable, then, to test the air quality less frequently in a dedicated system. In systems that utilize

compressors that are oil-lubricated, additional potential sources of contamination are present and more frequent testing is indicated. Air systems that are used daily or several times in a week to supply breathing air should be tested more frequently than a system used infrequently. Systems used infrequently to supply breathing air should be tested before each use, then at some reasonable frequency during the time it is in use. A system that is due for testing, but which is not in use, need not be activated for purposes of air-quality testing, so long as the testing is accomplished before the system is used again to supply breathing air. Likewise with combination service-air/breathing-air systems. If the system is not being used to supply breathing air it need not be tested periodically (e.g., monthly or quarterly) for Grade D quality, so long as the testing is done prior to its next use as a source of breathing air. Results from these "prior to next use" tests should be in hand, however, before the system is used to supply breathing air.

The air from compressors used to supply breathing air to cylinders should also be tested periodically. This applies to SCBA cylinders and to larger cylinders (e.g., 280 ft<sup>3</sup> or 300 ft<sup>3</sup>), and to cylinders filled by the licensee and to those filled by a vendor. If the air is tested and shown to meet the quality criteria at the beginning of the filling process, it is reasonable to assume that cylinders may be filled for the following 24 hours without retest. Other reasonable retest periods may be acceptable.

### **6.5.5 Test Methods**

The test methods described in CGA G7.1-1997 are acceptable to the NRC staff. Air-quality tests performed using detector tubes filled with color-reactive chemicals that are sensitive to oxygen and the various possible contaminants are acceptable, if performed in accordance with the manufacturer's instructions. Licensees who use this method for routine air-quality verification should have

the air tested several times per year using more rigorous analytical methods (e.g., gas chromatography).

### **6.5.6 Sampling Breathing Air for Radiological Contamination**

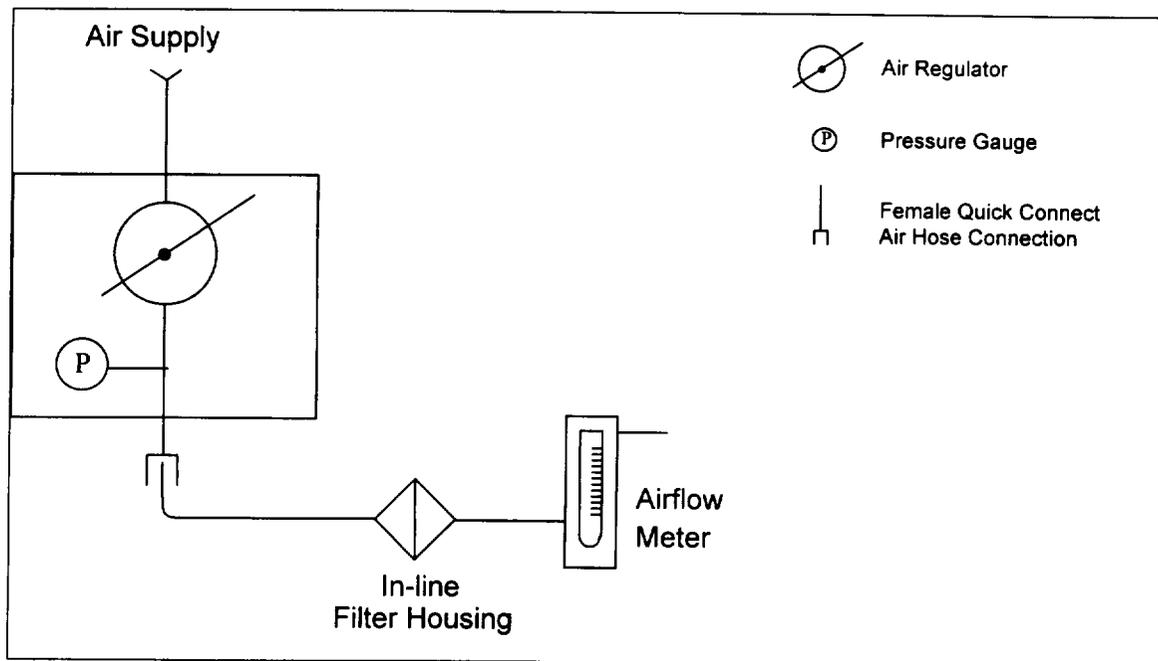
Licensees should take steps to protect breathing-air manifolds, quick-connect fittings and other potential places where radiological contaminants might enter a breathing-air system. Caps, plastic bags, and tape have been used successfully in this application. Wipe samples should be taken at the air-connection points that might be contaminated prior to attaching a respirator supply hose. The breathing air should be sampled periodically for radiological contaminants. One possible sampling method is illustrated in Figure 6-1.

### **6.5.7 Oxygen Purity Requirements**

When any respiratory protection device uses an oxygen supply rather than an air supply (e.g., closed-circuit SCBA), that oxygen should meet the United States Pharmacopoeia (USP) requirements for medical or breathing oxygen.

## **6.6 Use of Higher or Lower APFs**

Licensees who want to use APFs larger than the ones listed in Appendix A to 10 CFR 20 must first apply to NRC and be granted permission (10 CFR 20.1705). Such applications should be in the form of a letter accompanied by a brief report. The report should describe the situation for which the higher APFs are needed and include the reason that an existing NIOSH-certified device with a larger APF is not suitable. It should demonstrate that the proposed respiratory protection equipment provides these higher levels of protection under the intended



**Figure 6-1. Sample collection design for a radiological sample of the breathing-air supply.**

conditions of use. This demonstration can be based on testing done by the licensee or the licensee's representative, or on testing performed by the manufacturer of the device. If only manufacturer testing has been done, a licensee representative should have observed or participated in such testing.

Use of lower APFs for negative-pressure devices is permitted but not encouraged. Assigning a lower APF because a worker is unable to achieve a sufficiently high fit factor is not a good reason, and a different size facepiece should be tried. Furthermore, if an individual is unable to obtain a fit factor of >500 on a facepiece that will be used with a SCBA, that individual should not be permitted to use the SCBA for fire fighting, emergency response, rescue, or in IDLH atmospheres.

No permission from or notification of the NRC is required or suggested for using lower APFs, but a record should be made and retained. An acceptable record could be made on the radiation work permit, as an annotation on a

work procedure, or in a brief memo retained in the work package.

## 6.7 Limiting Duration of Respirator Use

### 6.7.1 Introduction

One of the most difficult tasks that an RPA has is to decide maximum duration of respirator use, or how long a worker should be asked to wear a respirator without a break.

The primary reason for limiting the occasions when respirators might be used, and for limiting the duration of each respirator use, is personal safety. Each time an individual dons a respirator, some increment of risk is incurred. This risk could be the result of a limited or distorted field of vision, a diminished ability to hear or be understood clearly, tangling of an air-supply hose, inability to exit through a narrow opening, and so on. Limiting respirator use is part of a holistic approach to worker safety and should

include *all* aspects of personnel protection in the workplace.

NRC regulations require<sup>1</sup> that each worker be instructed that (s)he is permitted to exit a work area for relief from respirator use in the event of equipment malfunction, physical or psychological distress, procedural or communication failure, significant deterioration of operating conditions, or for any other reason without obtaining prior supervisory permission. This, however, does not always provide a sufficient degree of assurance that workers will not exceed their subjective stress limit. Some individuals will persist at a task until they are well beyond the point at which they should have sought relief. This may result from peer pressure or from a misunderstanding of material presented during training. Listed below are some things that should be taken into account in determining maximum respirator use times.

### 6.7.2 Establishing Time Limits

In addition to the ability of each worker to obtain relief from respirator use at any time (10 CFR 20.1703(d)), licensees should set reasonable time limits on respirator use that apply to all workers. Factors that should be taken into account in setting these time limits should include consideration of the following as a minimum:

- Ambient temperature and humidity;
- Energy expended by the worker performing the task;
- Weight, thickness, permeability of anti-contamination clothing;
- Number of layers of anti-contamination clothing;
- Additional protective equipment worn;
- Work rate;
- Regional climate;
- Time of day;
- Time of year; and
- Other appropriate factors.

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<sup>1</sup> 10 CFR 20.1703(d).

Licensees should establish reasonable limits on the time any individual should be expected to wear a respirator and on the number of times or hours per day or per week respirator use should be permitted. Since the stress and strain placed on workers by negative-pressure face-sealing respirators is generally much greater than for other types of devices (e.g., positive pressure), time limits on the use of negative-pressure respirators will usually be the most restrictive. These guidelines may impose limits using combinations of the following methods.

- Maximum continuous use time (e.g., no more than 30 or 60 or 120 minutes at a time);
- Maximum use time per hour (e.g., 15 or 30 or 45 minutes per hour);
- Maximum daily use times (e.g., no more than 2 or 4 or 5 hours per day); or
- Maximum weekly use times (e.g., no more than 10 or 15 or 20 hours per week).

For example, under a given set of circumstances (e.g., work rate, workplace temperature and humidity) a licensee might decide to limit each worker's use of negative-pressure respirators as follows:

- No more than 90 minutes at a time with a 30-minute break between uses;
- No more than three 90-minute respirator use periods should be assigned in any working shift; and
- The maximum weekly respirator use time should be 18 hours.

Under a different set of circumstances, another licensee might limit respirator use to 30 minutes per hour, not to exceed six use periods in a working shift. Other reasonable methodologies for limiting respirator use times may be acceptable. The time limits used in the examples above should not be interpreted as NRC's suggestions or recommendations.

### 6.7.3 Variables

Different types of respirators impose various degrees of discomfort or stress on workers. The maximum use time for a worker performing moderately demanding work while wearing a full-facepiece air-purifying respirator in a hot, humid work area might be only 15 minutes every hour. A worker in a supplied-air hood or powered air-purifying respirator in a less stressful work environment and working at a slower rate might have a much longer effective work time. The NRC recognizes these variables and relies on the judgment of the RPA and other competent persons to set reasonable limits or guidelines.

### 6.8 OSHA Requirements

The ideal situation for licensees who must comply with the regulations of both OSHA and NRC when designing and implementing a respiratory program would be for the regulations to be compatible. This would allow a single program to be implemented rather than require that two different programs be run in parallel. The NRC believes that this has effectively been accomplished with the 1999 amendment to 10 CFR 20 Subpart H and Appendix A, and Revision 1 to Regulatory Guide 8.15. The differences between the OSHA and NRC requirements pointed out in Regulatory Guide 8.15, Revision 1, Section 6.8 are believed to be slight.

### 6.9 Radiological Hazard Evaluation

Air sample results may be used to determine which respirator (if any) should be assigned in a given work area. Air samples that are representative of the air breathed by workers may be used to estimate and assign CDE and CEDE.

### 6.9.1 Air Sampling

Pre-exposure air sampling is *not required* in an emergency. The word "emergency" should be clearly defined by the licensee so that all personnel in decision-making positions understand what *is* and what *isn't* an emergency. True emergency situations would certainly include lifesaving, rescuing injured personnel, fire fighting, prevention of overexposure of an individual(s) to radiation, stopping or preventing a significant uncontrolled release of radioactive material.

Appropriate air sampling or assessment *is* required in most other situations, at least where airborne radioactive material might exceed certain concentrations. The licensee should refer to Regulatory Guide 8.25 "Air Sampling in the Workplace," Rev. 1, June 1992, and to NUREG-1400, "Air Sampling in the Workplace," September 1993 for information on acceptable air sampling practices.

### 6.9.2 Noble Gases

As stated in footnote f to Appendix A in 10 CFR 20, exposure to noble gases is not considered to be a significant respiratory hazard. Only a small fraction of the TEDE is delivered by the gas in the lungs, while the majority comes from the cloud of gas in which the worker is present. Therefore, protective actions for these contaminants should be based on external (submersion) dose considerations (e.g., limiting exposure time). Noble gas concentrations should not be factored into DAC calculations for the purpose of deciding whether or not to assign respirators.

### 6.9.3 Tritium Vapors

A discussion of airborne tritium and how the APFs of various respirators are affected by it is included in paragraph 4.9.1 above.

Tritium, normally found in the form of water vapor ( $^3\text{H}_2\text{O}$ ) but sometimes present in gaseous form, requires special consideration. Air-purifying respirators provide little protection against airborne gases and vapor. Therefore if airborne tritium is present in the work area in sufficient concentration to require use of respiratory protection devices, then an atmosphere-supplying device should be selected. Unfortunately, approximately one-third of tritium intake occurs by absorption through the skin, so that by simply protecting the respiratory tract, only two-thirds of the job has been done. Therefore, the assigned protection factors allowed for atmosphere-supplying devices are lower for tritium than for other contaminants. These are provided in Table 4-19.

In situations where tritium is detectable in significant concentrations in addition to airborne particulates, separate protection factors may need to be tracked or applied at the same time. The APF from Appendix A to 10 CFR 20 would be applied for the particulate component of the air, and a greatly reduced APF would be applied for the tritium component. The APF for tritium could, for the sake of simplicity, also be applied to the airborne particulate component.

Whole body-covering suits might be considered for some additional protection against skin absorption of tritium; however, most plastic suits are not impervious to tritium and a great deal of success should not be anticipated. The prudent course of action is to track DAC exposure hours using the reduced APF as outlined above. By use of post-exposure bioassay, actual exposure can be determined and the DAC-hour totals can be adjusted based on this bioassay information.

## 6.10 Non-Radiological Hazard Evaluation

In addition to radioactive respiratory hazards, there are non-radioactive respiratory hazards present in the nuclear industry that could present a hazard to personnel and the facility,

reduce the ability to maintain effective control over operations, and hinder efforts to mitigate consequences of safety system malfunction. Damage control and repair teams should be able to perform essential emergency duties at any time to restore plant systems and stabilize the plant so that recovery operations can take place when needed. Methods used to evaluate and control non-radioactive respiratory hazards are essentially the same as those used for radioactive hazards. Even a brief, unprotected exposure to some non-radiological respiratory hazards can lead to immediate permanent injury or death (e.g., rupture of a chlorine cylinder). Such conditions could occur during an emergency in a nuclear facility.

Some of these non-radiological hazards that may affect the selection of a respiratory protection method are the existence of an explosive gas mixture, oxygen deficiency, high ambient temperature, low ambient temperature and low atmospheric pressure. The concurrent use of other safety equipment can also affect the selection. Safety glasses or goggles, a hard hat, hearing protection, communications equipment, and protective clothing can all affect the choice of respiratory protection method. Physical work locations may contain narrow passageways, ladders, or scaffolding that may dictate a less protective respirator to increase mobility and decrease chances of an industrial accident or injury.

All of these potential hazards need to be considered when selecting a respiratory protection method.

### 6.10.1 Physical Stresses

Some physical discomfort associated with respirator use is unavoidable, no matter how much effort goes into product selection, materials of construction and fit testing. A few specific sources of discomfort (e.g., over-tightened head harness, or hair caught between straps and buckles) can be overcome by

effective training. Other sources of discomfort will always be present: inhaling or exhaling against pressure, an itching nose, or perspiration in the eyes. Even more discomfort is experienced by those suffering from allergies or a cold, dental aches, and facial skin conditions.

It is common that full protective clothing (PCs) is required when respirators are used. Air-purifying respirators, especially, used in conjunction with PCs, greatly reduce the evaporative cooling process and contribute greatly to heat stress. This, in turn, can impact a worker's efficiency, thereby increasing work time and radiation dose.

Supplied-air hoods, if used properly, are especially useful in mitigating heat stress. With the inner shroud (front and back) tucked inside the PCs, the exhausted air is directed down over the worker's torso. This allows evaporative cooling to take place over a major portion of the body, and keeps core body temperature within acceptable limits.

Continuous-flow facepiece respirators are not nearly as effective at cooling the wearer as are air-fed hoods. Since only the face is cooled, core body temperature can rise to dangerous levels while the person's temperature sensors (located principally on the face) are not providing a warning.

Certain facepiece materials (e.g., silicone) tend to be more comfortable to wear for extended periods of time. Some facilities have instituted worker comfort assessments during the fit-testing process. The additional physical stresses associated with respirator use are the primary reason that respirator wearers are required to pass an initial medical screening and a periodic re-screening.

## 6.10.2 Increased Breathing Resistance

While wearing negative-pressure, air-purifying respirators, inhalation resistance is attributable to the air-purifying element and the flow channels within the facepiece itself. As dirt builds up on the filter, breathing resistance increases. This resistance can range from 20 mm water pressure for the highest efficiency particulate filters, to about 50 mm water pressure for chin-mounted adsorber canisters (e.g., a "radioiodine" canister) over their useful service lives. Even at the minimum values, this additional resistance during the time of use can become a significant burden to the wearer. Since we inhale by contracting our intercostal and diaphragm muscles, these muscles fatigue faster as the inhalation resistance increases.

The use of positive-pressure respirators (airline-supplied or air-purifying) might mitigate this problem, but the different stresses imposed by these devices would need to be evaluated. For instance, many inexperienced wearers of pressure-demand, airline-supplied devices or pressure-demand SCBA become apprehensive when they realize that exhalation is more difficult in these devices.

Occasionally, they will remove the device and report that the exhalation valve is defective. This is most often observed when a heavy work rate is involved. The best solution to this problem is to point out this operating characteristic of pressure-demand devices during hands-on training. For air-purifying devices, the amount of time spent in respirators should be limited, air-purifying elements should be changed when increased breathing resistance is noticed, and lighter weight non-sorbent filters should be used whenever possible.

### 6.10.3 Increased Dead-Air Volume

When an individual inhales, the air that initially reaches the alveolar region of the lung is the oxygen-depleted air that remains in the wearer's upper airways (nose, trachea, bronchi, etc.) from the previous exhalation. It is the newly inspired air that follows this "dead air" that is the primary source of oxygen. If a respirator is worn, an additional volume of oxygen-depleted air from the previous exhalation remains inside the facepiece. This respirator dead-air volume, added to the anatomic dead-air volume, requires the wearer to inhale *both* volumes of O<sub>2</sub>-depleted air before any oxygen-rich air enters the lungs. The wearer of a negative-pressure respirator, then, *must* breathe more deeply and/or more frequently to provide the same amount of oxygen to his lungs. This increased depth and frequency of breathing when a negative-pressure respirator is donned is often misinterpreted as an anxiety response when in fact, it is physiological.

#### *Example*

##### **No Respirator Worn**

Anatomic dead air volume	150 cc
<u>Required fresh air volume</u>	<u>350 cc</u>
Total Inhaled Volume	500 cc

##### **Wearing a Negative-Pressure Full Facepiece**

Anatomic dead air volume	150 cc
Facepiece dead air volume	150 cc
<u>Necessary fresh air volume</u>	<u>350 cc</u>
Total Inhaled Volume	650 cc

This 30% increase in air volume necessary per inhalation adds to the breathing effort required by the wearer, and can lead to early fatigue. Adding dead air volume to an individual by use of a respirator also increases the temperature of the inhaled gas and increases the partial pressure of carbon dioxide in the lungs. Since our rate and depth of respiration is determined, in large part, by the level of

CO<sub>2</sub> in our blood, these elevated levels may lead to mild hyperventilation.

In situations where stress and fatigue caused by a respirator's dead air volume become a significant factor, powered air-purifying respirators and continuous-flow airline respirators are effective in keeping the facepiece full of oxygen-rich air. If use of these devices is not feasible, the increased physiological stress caused by negative-pressure respirators should be considered in establishing maximum work times or work-rest cycles.

### 6.10.4 Additional Weight and Size

SCBA can weigh as much as 35 pounds with a fully charged air cylinder. This weight is usually well distributed and held close to the user's body, and the back frame and shoulder straps are designed to be as comfortable as possible. This weight, however, exerts stresses on wearers that should be taken into account during medical screening and training.

Most full-facepiece respirators weigh only 1 to 3 pounds, which may seem insignificant. If the majority of the weight is in a large chin-mounted canister extending well out from the face, however, fatigue can result in muscles in the neck and upper back. This might lead the RPA to select facepieces that include cheek-mounted rather than chin-mounted filters, at least for some applications.

Respiratory protection equipment unnaturally enlarges a worker's profile, necessitating caution when climbing or walking through tight spaces, looking through viewing ports, or handling bulky equipment. Balance is affected as well, and even simple tasks sometimes require extra concentration. Many normal physical activities need to be altered to accommodate the new profile and can result in strained muscles, additional overall stress, and accelerated fatigue. When unsuccessful maneuvers result in bumping into objects, or

facepiece dislodgment, damage to the respirator or physical injury to the wearer can result.

These respirator weight- and size-related problems can be mitigated to some extent by selecting the lightest-weight and smallest-profile model or type of respirator available that will provide the necessary level of protection. An adequate training program will give respirator wearers experience using the devices in various environments. Consider these factors when establishing maximum work times or work-rest cycles.

### **6.10.5 Limited Mobility**

Respiratory protection devices that require an umbilical cord (e.g., airline respirators) present obvious limitations to mobility of the wearer. Gaining access to a work area sometimes requires as much effort as performing the actual task. Consider using airline hose reels or festooning systems to keep the hoses tended and out of the way. The NIOSH approval for all airline-supplied respirators specifies a maximum air-hose length of 300 feet. It also requires the use of a belt, to which the regulator and supply hose are attached. This belt takes the strain of the air hose off the facepiece or hood.

One strategy for reducing the effect of these air hose-related problems is to provide a breathing air source as close as possible to the work area, and use of a combination air-purifying/airline-supplied respirator system. Another option is to provide a second individual as air-hose tender to manage the hose and keep it from tangling. Selection of a different type of respirator, such as a powered air-purifying device, will eliminate the umbilical problem altogether as long as it will adequately address the airborne contaminant present in the area.

### **6.10.6 Psychological Distress**

Many workers experience simple anxiety when wearing a respirator. This may be partly caused by the additional dead-air volume added by the negative-pressure facepiece, by mild claustrophobia, or by concern over the work environment. Whatever the reasons, it is very common even among experienced respirator wearers for the pulse to quicken and the breathing rate to increase. Whether slight or severe, respirator use increases the psychological stress on the wearer.

The best defense against respirator-induced psychological distress is to maximize worker familiarity with the respiratory equipment and with the work environment. Training should illustrate how the devices operate; what they can and cannot do as far as protecting the wearer; how they should be donned, doffed, and worn; how they are cleaned, sanitized, maintained and stored. This should give the worker confidence in the equipment's capabilities and in the care taken by respirator program personnel to ensure that each respirator issued is clean and working properly. Finally, the respirator fit-testing process, if performed and explained properly, should clearly show the worker that the respirator is an effective protective device if worn correctly.

## **6.11 High-Temperature Work Areas (Heat Stress)**

Heat stress is a complex interaction among environmental factors, clothing and protective devices used, and work demands as they impact on work performance, safety, and health. The most obvious manifestation of physiological strain is sweating, which is accompanied by increases in heart rate and body temperature. As exposures to heat stress become more significant and the physiological strain increases, the ability to perform physical and mental work diminishes. A heat-stressed person cannot work as hard as, and is more

likely to make mistakes than, a non heat-stressed worker. As physical and mental performance decrease, the likelihood of an accident increases. Ultimately, if the heat exposure continues unabated and the normal physiological responses to heat stress are insufficient to protect the worker, a heat-related disorder will occur.

### 6.11.1 Heat-Related Disorders

The five most commonly described heat-related disorders are:

- Rash;
- Cramps;
- Syncope;
- Exhaustion; and
- Stroke.

*Heat rash* is caused by obstruction of the sweat glands brought on by chronically wet skin. The symptoms are itchy skin with small red spots and an unusual sensitivity to radiant heat. To treat heat rash, allow intermittent relief from the hot environment. Heat rash can be prevented by keeping the skin clean, and periodically allowing the skin to dry.

*Heat cramps* are caused by profuse sweating and hard work. They are associated with an excessive loss of salts and are manifested as painful muscle cramps in legs, arms or abdomen. The cramps may occur during or after exertion. Massage cramping muscles to obtain relief, and give water orally. Prevent heat cramps by supplementing electrolyte intake by using sport drinks or some other method.

*Heat syncope* (pronounced “sin-ka-pee”) is brought on when a worker maintains one work posture (e.g., standing or squatting) for too long a time. This allows blood to pool in the legs, away from the head. Standing or sitting up quickly will cause a dizzy feeling or a brief fainting spell of less than 30 seconds duration. Treat heat syncope by allowing the worker to rest lying down. Administer water or other

suitable fluid orally. To prevent or reduce heat syncope, instruct workers to flex their leg muscles several times before moving from a stationary position, and to stand or sit up slowly.

*Heat exhaustion* is often precipitated by heavy sweating, which causes dehydration. If a person is already dehydrated due to an illness (e.g., vomiting or diarrhea), the onset of heat exhaustion will be hastened. The symptoms are a general feeling of fatigue or weakness, uncoordinated actions, headache, thirst, and weak pulse. The treatment is simply to rest in a cool environment. Prevent heat exhaustion by drinking water or other suitable fluids frequently, and by adding salt to food.

*Heat stroke* is a life-threatening condition. It may be brought on by a pre-existing illness (e.g., fever or flu), an abnormal intolerance to heat stress, excessive exposure to heat stress, or by drug or alcohol abuse. A person in heat stroke will have difficulty recognizing surroundings or people and may exhibit irrational or unexpected behavior. The skin will be dry. Convulsions or unconsciousness for periods greater than 30 seconds may also occur. Treat heat stroke by immediately and aggressively lowering the person’s body temperature. This can be accomplished by wetting the skin and clothing and increasing the airflow by using fans, ventilation trunks, or by manual fanning. Ice packs may also be used if available. Transport the victim immediately to an emergency medical facility, even if the victim reports feeling better. Prevent heat stroke by training personnel to recognize the symptoms of heat-related disorders in themselves and in others, and by allowing the workers to participate in the determination of heat stress exposures. Maintaining a healthy life-style will also reduce the likelihood of heat stroke.

Lightly salting food at mealtimes should be encouraged during training as both treatment for and prevention of some heat disorders. Those individuals on salt-restricted diets

should consult their personal physicians regarding the advisability of exposure to heat stress and the supplementing of salt intake. Salt tablets, however, should *never* be used.

### 6.11.2 Evaluation of Heat Stress

Before countermeasures can be selected, the heat stress should be evaluated. The evaluation process should measure or estimate three factors.

- Environmental heat sources and factors;
- Metabolic heat (generated internally while working); and
- Clothing requirements.

*Environmental heat* sources include convection, which is reflected in air temperature and air movement, and radiant heat, which depends on the temperatures of surrounding walls, equipment and other surfaces. An important environmental factor is air humidity, which affects the body's ability to cool itself by evaporation of perspiration. Air temperature alone is not a very good predictor of heat stress potential.

An empirical index of environmental heat that was developed to account for these environmental factors is the wet bulb globe temperature (WBGT) index. The wet bulb temperature (a water-dampened wick surrounds the thermometer bulb) is always lower than air temperature, but it will increase with increasing levels of humidity. The globe temperature (a thermometer inside a hollow, black-painted globe) depends on air motion, air temperature, and the temperature of the solid surroundings (radiant heat). It rises and falls with the degree of convection and radiant heat that may be present. In locations away from direct sunlight, the "indoor" WBGT is the sum of 70% of the wet bulb temperature and 30% of the globe temperature.

$$\text{WBGT}_{\text{indoor}} = 0.7(\text{wet bulb temp}) + 0.3(\text{globe temp.})$$

For work in direct sunlight, the "outdoor" WBGT is used. This is the sum of 10% of the dry bulb air temperature (which accounts for solar heating), 20% of the globe temperature, and 70% of the wet bulb temperature.

$$\text{WBGT}_{\text{outdoor}} = 0.7 (\text{wet bulb temp}) + 0.2 (\text{globe temp}) + 0.1 (\text{dry air temp})$$

Because of the heavy weighing on wet bulb temperature, the WBGT value is almost always much less than the dry bulb air temperature.

*Metabolic heat*, or body heat generated by work demands, is most easily estimated from tables of typical activities. Tables are provided for estimating work demands in terms of energy expenditure rate (kilocalories per hour or kcal/h). Light work, such as instrument repair or supervision, ranges from 100 to 200 kcal/h. Moderate work, typical of most maintenance tasks, ranges from 200 to 325 kcal/h. Heavy work, requiring a great deal of physical effort (e.g., continuous shoveling, mopping, installing shielding) ranges from 325 to 450 kcal/h.

Also important in gauging metabolic heat is the anticipated work-rest regimen. It should be estimated what percent of a worker's time in the potential heat stress area will actually be spent working, and what percent will be spent resting or at least not working (and not generating additional metabolic heat).

*Clothing requirements*, the third factor used to determine the level of heat stress, mostly affect the body's ability to cool by sweat evaporation. Multiple layers of clothing or vapor-barrier clothing significantly reduce the ability to evaporate perspiration, and therefore cause greater physiological strain.

Adjustments should be made to the WBGT index when clothing other than a single layer of light summer-type clothing is worn (e.g., in an uncontaminated area). When one layer of anti-contamination clothing is worn add 2 °C

to the WBGT reading. Add 4 °C when 2 layers of PCs are worn.

If vapor-barrier clothing is worn (full plastic PCs), the WBGT index is not an appropriate estimator of heat stress, since evaporative cooling has been eliminated for workers wearing this type of garb. In this case, use only the air temperature and the globe temperature in the following relationship.

$$\text{Adjusted dry bulb temp.} = 0.5 (\text{globe temp.}) + 0.5 (\text{air temp})$$

The environmental heat measurement (WBGT or Adjusted Dry Bulb temperature, as appropriate), the estimate of metabolic heat (e.g., moderate work, 50% work, 50% rest), and protective clothing requirements are then all factored together to determine whether or not a potential for heat stress exists. Several examples of how this is done are given below. The environmental heat measurement (WBGT or Adjusted Dry Bulb temperature, as appropriate), the estimate of metabolic heat (e.g., light work  $\approx$  100-200 kcal/h, heavy work  $\approx$  325-450 kcal/h), and protective clothing requirements are then all factored together to

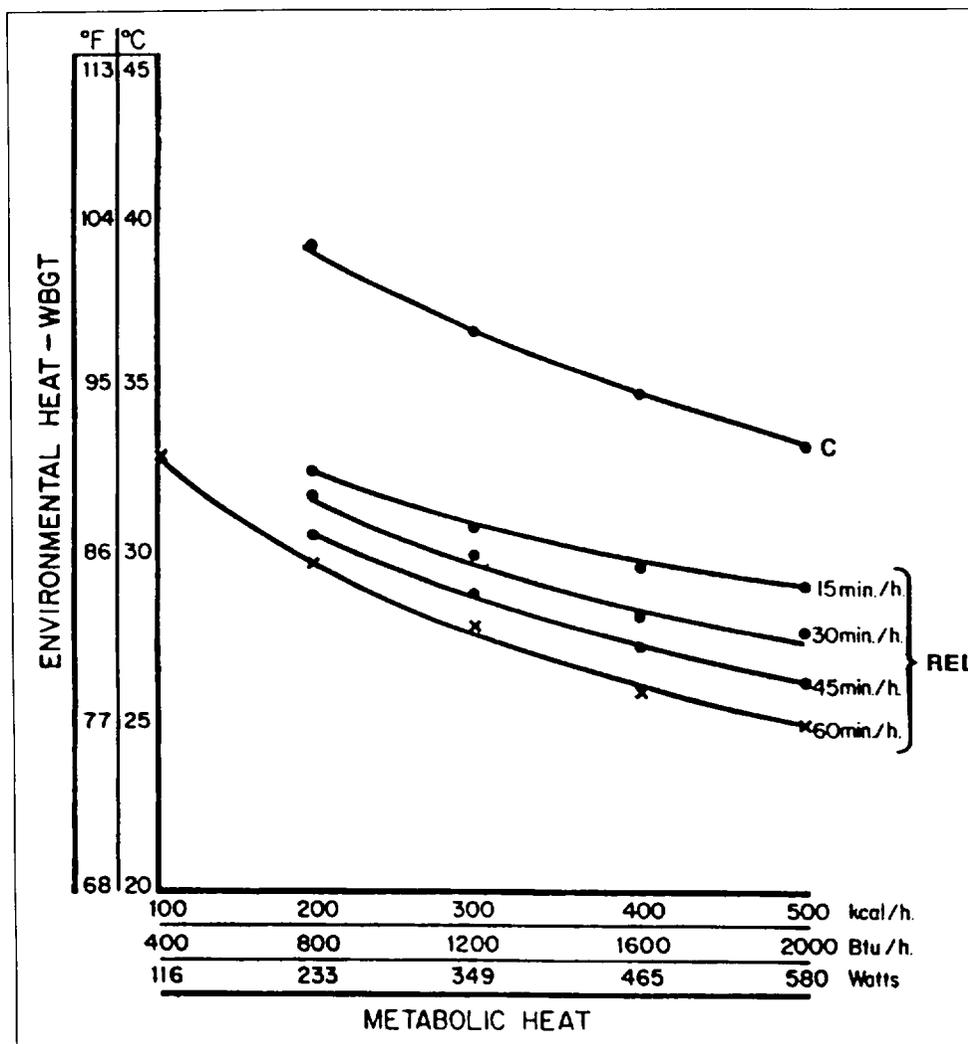


Figure 6-2. NIOSH-recommended exposure limit (REL) for heat stress.

determine whether or not a potential for heat stress exists. Several examples of how this is done are given below. When interpreting Figure 6-2, if the coordinate of the measured environmental heat load and the estimated metabolic heat production occurs above the ceiling limit curve (C), work should not be performed until action is taken to reduce one or both of the heat factors. If the coordinate falls between two of the curves (e.g., between 45 min/h and 60 min/h) then the work-rest regimen indicated by the upper (more restrictive) curve should be followed.

### Examples

**Situation 1.** The WBGT index for a work area has been measured at 30 °C. You estimate that the workers will be performing work in the high end of the “moderate” range. Since this is a contaminated area, they will be wearing one set of PCs.

**Assessment 1.** Since 1 set of PCs will be worn, 2 °C should be added to the WBGT reading, making this adjusted value 32 °C. On Figure 6-2, draw a horizontal line at the 32 °C point. Since the work to be performed will be at the high end of the moderate range, draw a vertical line at about 325 kcal/h. These two lines intersect *below* the 15 min/h work-rest curve but *above* the 30 min/h curve. Therefore the work can take place beginning with 15 minutes of work followed by 45 minutes of rest. These workers, however, will be in a potential heat stress situation, and appropriate engineering controls, and/or protective countermeasures should be considered. These are discussed below. As work progresses, the work-rest cycle can be adjusted based on how well or how poorly the workers react to the heat stress.

**Situation 2.** The WBGT index for a work area has been measured at 26°C. You estimate that the workers will be performing work in the middle of the moderate range. Since this is a

highly contaminated area, they will be wearing 2 sets of PCs.

**Assessment 2.** Since 2 sets of PCs will be worn, 4°C should be added to the WBGT reading, making this adjusted value 30 °C. On Figure 6-2, draw a horizontal line at the 30°C point. Since the work to be performed will be in the center of the moderate range, draw a vertical line at about 265 kcal/h. Since these two lines intersect *below* the 30 min/h work-rest curve but *above* the 45 min/h, the work can take place beginning with 30 minutes of work followed by 30 minutes of rest each hour. These workers, however, will be in a potential heat stress situation, and appropriate engineering controls, and/or protective countermeasures should be considered as described below. As work progresses, the work-rest cycle can be adjusted based on how well or how poorly the workers react to the heat stress. (Note that in this situation, if the protective clothing requirements could be reduced to one set, the point on Figure 6-2 where the environmental heat intersects with the metabolic heat would be below the 60 min/h curve and the work situation would no longer involve heat stress.)

**Situation 3.** The work to be accomplished must be performed in full plastic PCs. The WBGT index, therefore, does not apply. Instead the Adjusted Dry Bulb temperature should be used. This temperature is 41°C. You estimate that the workers will be performing work at the low end of the moderate range.

**Assessment 3.** On Figure 6-2, draw a horizontal line at the 41°C point. Since the work to be performed will be at the low end of the moderate range, draw a vertical line at about 210 kcal/h. Since these two lines intersect *above* the ceiling limit curve, the work should not take place. Some combination of engineering controls, and/or protective countermeasures should be implemented before this work begins. These are discussed below.

### 6.11.3 Complicating Factors

*Physical condition.* The WBGT heat stress index is designed for a "Standard Worker" weighing 154 pounds and having a body surface area of 19.4 ft<sup>2</sup>. What about the effects of heat stress on workers who are outside these standard parameters upon which Figure 6-2 is based? The overriding consideration in predicting a person's tolerance to heat stress is physical condition. Parameters such as body weight, sex, and personal habits have an effect only insofar as they impact overall physical fitness. The more physically fit a worker is, the better he/she will be able to tolerate a heat stressful situation. While there is no way to quantify these differences, some generalizations can be made which may be taken into account when work in high temperatures is required.

*Body fat.* An overweight worker will generally have more of a problem in a heat stressful work environment than one who is of average weight. Carrying additional weight means that more energy must be expended to perform any given task. Thus, metabolic heat generation is greater. Also, the fatty layer of tissue acts as an insulator, making heat dissipation from muscles and other deeper-lying tissues more difficult. In addition, the body surface area-to-weight ratio (ft<sup>2</sup> to pounds) becomes less favorable for heat dissipation. That is, the overweight worker's body has less surface area per pound of body weight, and the body's primary heat removal method (through the skin) is less effective.

*Age.* There is some information that workers over 40 years of age will perform less well in a high temperature situation than younger workers.

*Gender.* There appears to be no difference in tolerance to heat stress between women and men of the same physical size. This tolerance does not seem to vary over the menstrual cycle.

*Alcohol use.* The use of alcoholic beverages before (or during) work in the heat should not be permitted. Alcohol use is clearly associated with heat stroke, and increases the risk of other heat-related illnesses. It also reduces a worker's tolerance to work in high temperatures.

*Drug use.* Many drugs, both prescription and otherwise, can negatively affect heat tolerance. A worker who is taking medication should be under the supervision of a physician who understands the potential ramifications of the drugs on heat tolerance. At the very least, workers taking prescription medication should be required to work into heat exposure situation gradually (i.e., short exposures) until the limits of their capacity to work in a high-temperature environment are established. Generally speaking, the drugs of most concern are those which affect the central nervous system (tranquilizers, anti-depressants, stimulants), cardiovascular reserve, and body hydration (diuretics).

*Individual variation.* Different individuals exhibit a wide variation in responses to heat environments. Sometimes the same individual may perform well in some heat-stressful situation and poorly in others. About half of these situations can be related to differences in body size and physical fitness. The reasons for the rest are not understood.

*Acclimatization.* When workers are first exposed to a hot work environment, they will usually show signs of distress and discomfort. They will also develop increased deep body temperatures and heart rates. They may complain of headaches, giddiness or nausea. Some may also faint on first exposure. On repeated exposure to high temperatures there is a marked adaptation, resulting primarily from the body's increased sweating efficiency. This means that the acclimatized worker will start sweating sooner, produce larger quantities of perspiration, and the electrolyte concentration in the sweat will be reduced (less loss of electrolytes). After five daily

exposures to high temperature of 100 or more minutes per day, a worker will be approximately 80% acclimatized. (The 100 minutes need not be one single exposure.) Full acclimatization will be achieved in approximately ten days. Little of the acclimatization will be lost during 1 or 2 days off. Absence of heat exposure for a week or more, however, results in significant loss of the beneficial adaptation. After a one-week absence, heat acclimatization can be regained in 2-3 days upon return to the heat work environment. A worker absent due to illness will probably need 1 day of re-acclimatization for each day absent. A physically fit worker will generally acclimatize faster and maintain it better than a worker who is in poorer condition. This means that it would probably be better to assign one work crew to a high-temperature job of long duration, and let them work the job until completion. Changing work crews daily would inhibit acclimatization of all workers and increase the overall heat stress to all workers.

*Respirator use.* Another question involves the use of respirators in a high-temperature environment. The fact is that there is no convincing evidence that filter respirator use increases the heat stress on a worker. A respirator will, however, add to the workers subjective strain, and due to increased discomfort may shorten the worker's tolerance time in the work area. If the use of respiratory protective devices is required in a heat stressful work situation, some less stressful device should be chosen if possible. The advantages and disadvantages of different types of respiratory protection devices are discussed elsewhere in this Manual.

#### **6.11.4 Reducing Heat Stress**

Four methods of heat stress reduction are discussed here. They are:

- Engineering controls;
- Personnel protective equipment (PPE);

- Administrative controls; and
- General countermeasures.

#### *Engineering Controls*

Reduction of work load and/or work rate will reduce the metabolic heat production and therefore, decrease worker stress. This probably has the greatest potential for stress reduction. Any mechanical assistance that can reduce workload should be considered. For instance, the use of slings and chain falls to raise a large valve bonnet, or the use of pneumatic drivers to tighten nuts, will reduce the physical work required by workers.

Reduction of air temperature and humidity are next in order of effectiveness. Dilution ventilation and air conditioning have been successfully applied to heat stress problems in the nuclear industry.

Increasing air velocity is the least effective of the engineering controls. Unless the temperature and/or the humidity of the air are also reduced, very little actual lessening of heat stress will be realized. Another consideration is that the increased airflow might cause surface contamination to become airborne, potentially increasing internal dose and possibly requiring the use of respirators. In any event, the heat stress problem could be greatly complicated by increasing airflow in a highly contaminated area.

Reduction of radiant heat can be effective if radiant heat is a contributor to the problem. Simple heat shields can be erected for short-duration jobs. Insulation of radiant heat sources can be considered for the long term. Surface emissivity is frequently overlooked. The shinier a surface, the lower its emissivity and therefore, the less able it is to radiate heat to nearby workers. This is the reason that "mirror" insulation is used in some applications.

## *Personal Protection*

Personal protection in the form of personal cooling (and possibly reflective clothing) is recommended for conditions when:

- The minimum expected safe time exposure is less than 60 minutes;
- The WBGT index exceeds the ceiling limit; or
- Vapor barrier clothing is used by exposed personnel.

Personal protective equipment can be grouped into four categories.

- Ice vests;
- Air cooled systems;
- Circulating liquid systems; and
- Vortex air coolers.

The first three are far more effective overall than the fourth.

*Ice vests* permit a great deal of mobility, with typical service times on the order of one to two hours. While these require some additional personnel support and the availability of a freezer, they have proven to be well worth the effort. The incidence of heat-related illness can be expected to decrease, and increased worker stay times enhance productivity. Once the ice in the vest is substantially melted, the differential temperature between the vest and the wearer's body decreases, quickly reducing its effectiveness. At this point, the vest becomes a liability due to its weight, absence of cooling effect, limiting the evaporation of perspiration from the wearer's torso, and acting as an insulator to retain metabolic heat.

*Supplied air hoods*, if used properly, are especially useful in mitigating heat stress. With the inner shroud (front and back) tucked inside the PCs, the exhausted air is directed down over the worker's torso. This flow of dry air promotes evaporation of perspiration over a major portion of the body, and the temperature drop caused by depressurization of the air provides additional body cooling,

keeping core body temperature within acceptable limits.

Continuous-flow facepiece respirators are not nearly as effective as air-fed hoods. In fact, since only the face is cooled, deep body temperature can rise to dangerous levels while the person's temperature sensors (located principally on the face) are saying that everything is fine.

*Circulating liquid systems* are similar to ice vests, in that they are worn as a vest or suit. A liquid flows through capillary tubes built into the garment, absorbing heat. The liquid is usually cooled by equipment near the work area, requiring the worker to be connected by umbilical to the cooling system for the garment to work. These garments weigh a good deal less than a fully loaded ice vest.

*Vortex air coolers* take advantage of the fact that air temperature drops when it is depressurized. Air is depressurized in a vortex cooler, which can be compared to a tube-and-shell heat exchanger. Air being supplied to the wearer passes through one or more tubes in the belt-mounted heat exchanger while some air is allowed to be depressurized around the outside of these breathing-air tubes, thus cooling the air that will be breathed. The air exhausted from the vortex tubes might contribute to airborne contamination levels. Licensees are reminded that a respirator system must be NIOSH-certified with the vortex cooler. A vortex cooler should not be added into a system that is not NIOSH-approved to include the cooler.

## *Administrative Controls*

*Self-determination.* Each worker may decide when he or she has reached a point where relief is needed from a high temperature work situation. The individual worker should understand that there are differences among workers for heat tolerance and that each individual should end an exposure at the first

symptoms of weakness, fatigue, nausea, or other signs of heat-related disorders. This is a central tenet of managing heat stress and should be emphasized during training.

*Check time (CT)* is a control that requires each worker to make an explicit decision to continue working rather than only an implicit decision to stop (self-determination). Its value is based on the heat stress conditions and is a minimum expected safe exposure time. At the check time, and at intervals afterward, the workers are asked (1) if they are experiencing any symptoms of heat disorders and (2) if they can continue. An explicit decision is thus requested.

*Recovery allowance and work/rest cycles* are designed to allow sufficient recovery from previous heat stress exposures before a subsequent exposure is undertaken. Work/rest cycles are suggested for long-term exposures to heat stress in the NIOSH documentation as seen in Figure 6-2. If rest breaks are provided for in the work cycle, the WBGT action threshold can be increased.

*Scheduling* hot work during a time of lower heat stress is a commonly recognized control method. Working hot jobs on back shifts when air temperatures are cooler, or scheduling the work to be accomplished in late fall through early spring are examples of this strategy.

*Clothing requirements* can be reviewed and possibly reduced to lower the heat stress. This may require area or equipment decontamination or other efforts. NRC regulations place limits on doses to personnel. They do not specify maximum contamination levels or prohibit skin contamination.

*A buddy system* provides for mutual observation and assistance in the event of a heat disorder.

*Personal monitoring* means that physiological measurements may be taken to alert individuals to excessive physiological strain. Advice about maximum oral temperature and

heart rate, and for heart rate recovery, should be obtained from a physician or industrial hygienist. Equipment is commercially available that can monitor both body temperature and heart rate continuously, without interfering with the work.

### *General Countermeasures*

*Medical screening* should be accomplished prior to first exposure and periodically thereafter for workers who will be exposed throughout the year. This could easily be incorporated into the periodic respirator medical screening, but the examining physician should be aware that the workers will be exposed to heat stress. This will allow medications and medical conditions that might not otherwise be of concern to be given special consideration due to the potential for exposure to heat stress.

*Training* sufficient to provide exposed individuals with the knowledge required to deal effectively with heat stress should be provided prior to first heat stress exposure. Annual retraining is recommended. This can be accomplished during annual radiation worker re-qualification, in first aid classes, or during safety meetings. Adequate heat stress training requires only 30 minutes per year. The recommended training content includes:

- Sources of heat stress;
- Physiological responses;
- Recognition of and first aid for heat disorders;
- Engineering controls;
- Use of personnel protective equipment;
- Administrative controls; and
- General countermeasures.

*Fluid replacement* is essential to restore the water lost by perspiration. Ideally, water is replaced frequently (e.g., 3-4 times per hour). In restricted areas<sup>2</sup> where eating and drinking

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<sup>2</sup> Referred to as radiologically controlled areas (RCAs) at most reactor facilities.

may be prohibited by the license, workers should be encouraged to pre-hydrate (drink more than usual before the heat exposure), and then to drink additional water afterwards. The NRC does not prohibit workers from drinking inside the restricted area or RCA. Regulations place limits on TEDE and require that doses be kept ALARA. Licensees have successfully established programs that make potable water available in contaminated areas while keeping the likelihood of ingestion of radioactive material to a minimum. Consider the use of squeeze bottles or single-use paper cups. A weight loss of more than 0.2 kg (0.44 pounds) per day is probably indicative of dehydration.

A typical diet probably contains all the salts and other nutrients that are necessary to cope successfully with heat stress, but lightly salting food at mealtimes can be encouraged during training as both treatment for and prevention of some heat disorders. Those individuals on salt-restricted diets should consult their personal physicians regarding the advisability of exposure to heat stress and supplementing salt intake. Salt tablets should *never* be used. Large doses of salt will absorb and hold water, preventing it from getting to the body tissues where it is needed, and will also irritate the stomach lining. There are, however, a number of specially developed commercial drinks (e.g., sports drinks) that contain various electrolytes and nutrients. During exposures to heat stress, it is the water in these drinks that is most important. Because these drinks are flavored, they may be more acceptable to the work force, thus encouraging water replacement. Other flavored drinks (e.g., dilute iced tea or lemonade) can also be used to promote water replacement by making the drink more palatable.

## 6.12 Toxic and Nuisance Atmospheres

### 6.12.1 Common Toxic Gases and Vapors at Nuclear Facilities

Some common toxic materials that could present personnel hazards at nuclear facilities are discussed below. In particular, the physiological effect of brief exposure to high concentrations will be discussed, which relates to the IDLH concentrations. The IDLH values have been taken from the NIOSH Pocket Guide to Chemical Hazards (DHHS-NIOSH Publication 97-140, June 1997). Bulk releases of these gases mix slowly with air, especially if their specific gravity is much different than that of air, which is 1. This is especially hazardous in low-lying areas.

*Chlorine* is an extremely toxic gas. Adverse symptoms can occur after several hours of unprotected exposure, even at concentrations of 1 ppm. Chlorine has a sharp, penetrating odor above 3-5 ppm. Low concentrations cause general irritation of the respiratory system, whereas higher concentrations (50 ppm for 20 minutes, or 1000 ppm for 1 minute) can be fatal. The IDLH concentration is 10 ppm. Chlorine has a specific gravity of 2.49. Chlorine is commonly used at nuclear facilities to inhibit marine growth in plant cooling systems during plant operations. Several events involving chlorine releases are described in IE Circular 80-03. Guidance for providing protection of power plant control room operators is provided in NRC Regulatory Guide 1.95.

*Hydrogen fluoride* (HF) is a highly toxic liquid (hydrofluoric acid) or gas with a strong, irritating odor. Its sharp, penetrating odor ordinarily prevents voluntary inhalation of toxic quantities. Contact with skin causes very painful and medically serious burns. Liquid contact with eyes can cause immediate blindness. Exposure to high concentrations will result in pulmonary edema, and burns of the skin, eyes, and upper respiratory tract. Exposure to low concentrations of HF gas will

result in irritation of the eyes, nose, throat, and the upper respiratory tract, and it will cause nasal congestion and bronchitis. With an IDLH of 30 ppm (0.003% by volume), HF is a highly dangerous substance. HF gas has a specific gravity of 0.69. It is noncombustible but difficult to contain as it corrodes most substances except lead, wax, polyethylene, and platinum. It may be present in uranium hexafluoride (UF<sub>6</sub>) processes.

*Hydrogen sulfide* (H<sub>2</sub>S) may be a byproduct from the decomposition of organic material. It is a colorless gas with a strong and easily detectable odor of rotten eggs. However, H<sub>2</sub>S will quickly deaden the olfactory nerves. Exposure to high concentrations can quickly result in death due to respiratory paralysis (apnea). Other physiologic effects are coma, convulsions, irritation of the eyes with conjunctivitis and pain, lacrimation, photophobia, corneal vesiculation, irritation of the respiratory system, dizziness, headaches, fatigue, insomnia, and gastrointestinal effects. Hydrogen sulfide has an IDLH concentration of 100 ppm (0.1% by volume), and because of its pronounced and rapid physiologic effects in high concentrations, potential exposure should be given careful consideration. H<sub>2</sub>S may be created due to decaying marine growth in circulating cooling systems when these systems are shut down and drained for periodic inspections. H<sub>2</sub>S is also flammable. It is heavier than air (specific gravity of 1.19), and may travel a considerable distance to an ignition source, and flash back. It is dangerously reactive with fuming or strong nitric acid and other oxidizers.

*Uranium hexafluoride* (UF<sub>6</sub>) is a highly corrosive vapor with properties similar to HF, and is considered the most toxic of the common uranium compounds, excluding the radioactive aspects. If released to the atmosphere, UF<sub>6</sub> combines with moisture in the air and produces HF. There has not been an IDLH level uniquely established for UF<sub>6</sub>, but due to its close relationship with HF, which may also be present, protective measures taken

for HF should be sufficient for UF<sub>6</sub>. This, of course, excludes the radioactive aspects that may be present with the UF<sub>6</sub>. UF<sub>6</sub> is a liquid at room temperature, and has a dense vapor.

*Other uranium compounds*, including such as UO<sub>2</sub>F<sub>2</sub>, UCl<sub>4</sub>, UO<sub>2</sub>(NO<sub>3</sub>)<sub>2</sub> · 6H<sub>2</sub>O, U<sub>3</sub>O<sub>8</sub>, UF<sub>4</sub>, and UO<sub>2</sub> present less of a hazard than UF<sub>6</sub>. As a group, soluble uranium and its soluble compounds present a danger of kidney damage when inhaled or ingested. Generically, uranium and its compounds (both soluble and insoluble) have been assigned an IDLH level of 10 milligrams per cubic meter of air (mg/m<sup>3</sup>). An intake of 300 mg of soluble uranium is considered to be lethal within 30 days to 50% of those who receive that intake (LD<sub>50/30</sub>).

Although airborne uranium compounds present an internal radiation problem, the limits of intake of soluble uranium compounds are based on chemical toxicity rather than radioactivity. A soluble uranium compound deposited in the lung transfers rapidly to the bloodstream. Although a large fraction is quickly excreted, a sufficient amount may remain in the kidneys to cause chemical damage. On the other hand, an insoluble uranium compound may remain in the lung indefinitely.

Exposure to high concentrations of uranium compounds can result in conjunctivitis, shortness of breath, coughing, chest rales, nausea, vomiting, skin burns, red blood cell disorders, casts in urine, albuminuria, high blood urea nitrogen, and lymphatic cancer.

*Solvents and solvent-containing materials.* There are numerous petroleum and chlorinated solvents that may be present in a nuclear facility, either as a pure solvent, or as part of a paint and coating formulation. Unless properly stored and controlled, these may present a fire and toxicity hazard. Many of the organic solvents are flammable and their vapors are also explosive.

### 6.12.2 Inert Gases

*Hydrogen (H<sub>2</sub>)* is a colorless and odorless gas. It may be present in the pure gaseous form as a coolant for electrical generators, in reactor coolant systems, waste gas treatment systems for both PWR and BWR, or as a byproduct of other processes such as the treatment of makeup water (mixing strong bases and acids).

Hydrogen does not have an IDLH limit or concentration and is considered a simple asphyxiant. A high concentration will only result in an oxygen-deficient atmosphere being created through displacement of the ambient oxygen. Hydrogen has a very low specific gravity of 0.07. It has no other physiologic effect. However, in combination with O<sub>2</sub>, H<sub>2</sub> is highly explosive.<sup>3</sup>

*Nitrogen (N<sub>2</sub>), Argon (Ar), and Helium (He)*, three inert gases, have been lumped together as they are frequently used as inerting agents in enclosed spaces. Their only physiologic effect is asphyxiation; therefore, oxygen deficiency is the major consideration. The specific gravity of each is:

Nitrogen	0.97
Argon	1.38
Helium	0.14

Therefore, high-concentration pockets of argon would be found in low areas whereas helium would be found near the ceiling.

*Carbon dioxide (CO<sub>2</sub>)*, a colorless and odorless gas, will be most commonly present in fire suppression systems. It has an IDLH concentration of 50,000 ppm (5% by volume). It is a relatively nontoxic gas and the physiologic effect at lower concentrations is to increase the breathing rate. The response to increased carbon dioxide concentration varies with the individual, but 5% to 10% usually

causes a headache in addition to increased breathing rate. As used in fire suppression systems, the major hazard will be the possibility of an oxygen-deficient atmosphere being suddenly created. Carbon dioxide tends to stay in low-lying areas, since its specific gravity is 1.52.

From 1975 through 1999, there were a total of 63 deaths and 89 injuries resulting from accidents involving the discharge of CO<sub>2</sub> fire suppression systems. Four are summarized below.

1. In September, 1985, an inadvertent initiation of the carbon dioxide fire suppression system at a nuclear power reactor caused the release of approximately 10 tons of cardox (liquid carbon dioxide under pressure) into one of the four diesel generator fuel oil storage tank rooms. The affected room pressurized and carbon dioxide leaked into adjacent areas where several workers were overcome. Twenty-three people were transported to nearby hospitals with one individual listed in serious condition upon arrival. The plant was evacuated, and search and rescue teams reported some difficulty in accounting for all construction personnel during the search to ensure all persons had been evacuated. There were no fatalities.

2. On January 15, 1999, an inadvertent discharge of the CO<sub>2</sub> fire suppression system occurred in the cable spreading room of a nuclear power plant. The cable spreading room is located in the control building directly below the control room. The actuation was caused when a non-licensed plant equipment operator trainee in the service building blew dust off a printed circuit board located in the cable spreading room CO<sub>2</sub> control panel located in the service building. There were no plant personnel in the cable spreading room at the time of the discharge. Shortly after the discharge, CO<sub>2</sub> was found to have migrated down into the switchgear rooms located directly below the cable spreading room. Approximately 37 minutes after initiation, the

<sup>3</sup> See the following for descriptions of events related to hydrogen gas detonations at nuclear reactor facilities: IE Bulletin 78-03; IE Information Notice 82-28; and IE Information Notice 86-43. A complete list of respirator-related NRC bulletins, circulars and notices is included in the front of this Manual.

licensee used a portable instrument to measure the concentration of CO<sub>2</sub> in one of the control building stairwells (which allows access to the control room, the cable spreading room and the switchgear rooms). The reading was off-scale high, indicating that the CO<sub>2</sub> concentration was in excess of 50,000 parts per million (ppm). The current NRC Regulatory Guide 1.78 recommended toxicity limit for CO<sub>2</sub> is 10,000 ppm.<sup>4</sup> On the basis of this indication, the licensee declared the area uninhabitable. Approximately 2 hours after the CO<sub>2</sub> discharge, operators aligned the control building purge system to remove CO<sub>2</sub> from the switchgear rooms. The switchgear rooms were selected for purging first because they contained important plant equipment, such as the auxiliary shutdown panel. The purge system is a non-safety-related system designed to remove CO<sub>2</sub> and smoke from various control building areas. Placing the purge system in service diverted air from the control room to the switchgear rooms, which lowered the pressure in the control room relative to the cable spreading room. This lowering of pressure in the control room may have allowed CO<sub>2</sub> from the cable spreading room to migrate up through penetrations into the control room. When the concentration of CO<sub>2</sub> reached 5,000 ppm in the control room, the operators donned self-contained breathing apparatus (SCBA) as required by their procedures. The concentration of CO<sub>2</sub> in the control room reached a peak level in excess of 17,000 ppm before it began to decrease. The operators wore SCBA for approximately 6 hours until the CO<sub>2</sub> was successfully purged from the control room. It was discovered during this incident that the chairs in the control room

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<sup>4</sup> The current NRC toxicity limit for CO<sub>2</sub>, specified in Regulatory Guide 1.78, is 10,000 ppm. Plant personnel exposed to CO<sub>2</sub> need to be protected by self-contained breathing apparatus before this concentration is reached. In the proposed revision to Regulatory Guide 1.78, the toxicity limit for CO<sub>2</sub> was raised to 40,000 ppm. This new limit is based on the Immediately Dangerous to Life and Health (IDLH) concentration of CO<sub>2</sub>, established by the National Institute for Occupational Safety and Health (NIOSH).

were not suited for occupants who were wearing SCBA, so the operators were on their feet for hours. This resulted in a great deal of unnecessary stress and strain on the operators involved.

3. At a nuclear power reactor on March 22, 1992, the licensee performed a special test of the CO<sub>2</sub> fire suppression system in the cable spreading room. This test was conducted to check corrective actions taken following a CO<sub>2</sub> discharge in 1990. At the time of this test, the reactor had been shutdown and defueled. As a result of this test, CO<sub>2</sub> had intruded into the control room; this intrusion led to an unacceptable reduction in area oxygen level within a few minutes. Oxygen levels of 17% (at chest level) and 15% (at floor level) were recorded; these levels were below the plant acceptance criterion of 19.5%. Essential control room personnel donned self-contained breathing apparatus (SCBA) and were able to remain in the control room. The lowered oxygen levels were caused by increased pressure in the cable spreading room, which is directly beneath the control room. Sealed penetrations between the two rooms leaked under the high differential pressure.

4. On July 28, 1998, at a national laboratory, during preparation for electrical system preventive maintenance, a high-pressure CO<sub>2</sub> fire suppression system unexpectedly actuated. The room in which workers were located was filled instantly with CO<sub>2</sub>, creating whiteout conditions. Workers did not have the means of escaping safely. Emergency exit training was not provided; exit pathways were not clear; and, emergency breathing apparatus, exit pathway lighting, and emergency ventilation were not available. The accident resulted in one fatality, several life-threatening injuries, and significant risk to the safety of the initial rescuers.

## 6.13 Oxygen-Deficient Environments

### 6.13.1 Oxygen Deficiency

Oxygen is the component of the atmosphere we breathe that is necessary to sustain life. The earth's atmosphere (air) is composed of the gases listed in table 6-1.

**Table 6-1. Relative percent volume and the partial pressures of the gases that comprise air.**

Gas	Volume %	Partial Pressure mm Hg at Sea Level
Nitrogen	78.1	593
Oxygen	20.9	159
Argon	0.9	7.1
Other*	0.1	---

\* Carbon dioxide, neon, krypton, helium and water vapor.

Oxygen deficiency is a hazard because the amount of oxygen that can be transferred from the alveoli to the blood is reduced. An atmosphere that is, or might be, deficient in oxygen should always be a matter of concern. Such atmospheres may result from a reduction in ambient atmospheric oxygen content by displacement or consumption, from reduced atmospheric pressure, or from a combination of these. Breathing oxygen-poor air can cause physiological problems that if severe enough can impair a worker's judgment and motor skills, and potentially lead to permanent injury or death.

The susceptibility to reduced oxygen varies somewhat among individuals. The range of oxyhemoglobin saturation at a given oxygen partial pressure shown in Figure A.1 in ANSI Z88.2-1992 presumes that exposed individuals have a red blood cell count within the normal range. A low count will decrease the oxygen available to the brain. Licensees might consider including a red blood cell count in the respirator medical screening program, and investigating any history of anemia, for those

individuals who will be exposed to oxygen-deficient environments.

### 6.13.2 Causes of Oxygen-Deficient Environments

An oxygen-deficient environment can be created in two ways:

- Reduction of the percent oxygen by volume in the air in the work environment; or
- Reduction of the atmospheric pressure in the work area, which has the same effect as increasing the elevation above sea level.

#### *Reduction of the Percent Oxygen by Volume*

This situation can result from the oxygen being displaced by another gas, or by the consumption of oxygen by fire or other methods of oxidation, or removal by other methods. It is the most common form of an oxygen deficiency hazard, warranting extreme care when entering confined spaces, especially when inert gases are in use (e.g., TIG welding, tank inerting, etc.) Oxygen can be consumed during fires, by oxidation of organic matter, oxidation of iron (rust) in a tank, controlled burning operations (flame cutting, brazing, etc.), other chemical reactions, and simply by people breathing. For this reason, confined spaces should be clearly identified, entry into them tightly controlled, and work in them closely monitored.

Oxygen-deficient atmospheres are most often found in enclosed or inerted spaces such as a pit (even though the top may be open), or a tank. In an emergency at a nuclear facility, an oxygen-deficient atmosphere may be created by a sudden release of a gas or vapor into an enclosed space thereby displacing the oxygen. A fire or other rapid chemical reaction will have the same result. Decomposition of organic matter in an enclosed space that

consumes the available oxygen is another potential source of oxygen deficiency. An atmosphere that contains very little oxygen (less than 6% by volume at sea level) can be considered totally inert. The hazards to an unprotected individual in this environment are catastrophic, with a person being incapacitated after only a few breaths. Death will most certainly occur within 4-6 minutes without timely rescue.

Several incidents involving oxygen-deficient environments are described below.

1. In September, 1976, at a commercial nuclear power plant, two workers were killed in a recirculation pit (sump) by asphyxiation from argon inerting gas used to support welding on stainless steel piping. After the welding was completed, gas leakage from the faulty argon purge-pipe connection filled the pit. When a workman entered the pit to remove the purge connection he was overcome by the inerted atmosphere. He and one of two fellow workers attempting rescue were killed. A licensee safety review of the incident revealed several work practice deficiencies including:

- Local ventilation for the pit was available, but not used before entry;
- Although the equipment was available, oxygen air sampling was not performed; and
- A "buddy system" for the first entry into a confined space was not employed.

2. At another nuclear power reactor in August, 1985, with the plant in a cold, shutdown condition, a nitrogen inerting blanket was placed on a moisture separator reheater. The nitrogen leaked past several shut valves into the main condenser. A non-licensed operator, while walking down the condensate system, stopped near the open condenser manway. The operator lost consciousness because of an apparent local IDLH area created by nitrogen escaping the condenser. An accompanying assistant provided prompt and effective rescue/first aid

and the operator was transported to the hospital. No permanent injury resulted from the incident. As a result of a licensee review of the lessons learned from the event, the licensee has improved its hazards controls program for using inerting gases by increasing atmospheric sampling, providing appropriate hazard postings to alert workers, and analyzing the potential effect on associated systems (e.g., potential leak paths).

3. A health physics technician at a nuclear power reactor was overcome by an oxygen-deficient atmosphere in a steam generator (SG). The secondary-side of SGs are often nitrogen-inerted to minimize oxygen uptake during non-operational periods. In this case, the wrong SG was purged of its inerting atmosphere, and an HP technician (when entering the still-inerted SG) was overcome. Another HP technician on the scene promptly pulled the asphyxiated technician from the IDLH area. No lasting injuries resulted from this event.

#### *Reduced Atmospheric Pressure*

This situation always occurs with increasing altitude, and/or with decreasing atmospheric pressure, and can be brought about in a reactor containment vessel that is under a partial vacuum. The oxygen percent by volume may remain at 20.9%, but the  $ppO_2$  will be lower than normal and the body's ability to utilize the  $O_2$  will therefore be reduced. It's the *partial pressure* of oxygen ( $ppO_2$ ), *not* the oxygen percentage, that drives it from the air in the lungs, through the walls of the alveoli and into the bloodstream.

The partial pressure (pp) of oxygen (or any gas) equals its fractional concentration times the total atmospheric pressure. Atmospheric pressure at sea level is 760 mm Hg. Since air contains approximately 21%  $O_2$ , then the  $ppO_2$  at sea level is

$$760 \text{ mmHg} \times 0.21 = 160 \text{ mmHg} .$$

**Table 6-2. Oxygen partial pressure (mm Hg) at various altitudes.**

	Sea Level	5,000 feet	10,000 feet	14,000 feet
ppO <sub>2</sub> (mm Hg)	160	133	110	95

The ratio of these gases to one another is the same, whether measured at sea level or on the top of Mt. Everest. The partial pressure of oxygen decreases, however, as elevation increases, since atmospheric pressure decreases.

As shown in Table 6-2, the greater the altitude, the lower the atmospheric pressure and the lower the ppO<sub>2</sub>. We know that people live and work at high altitudes, and do so with little or no physiological effect, because they are acclimated. The human body can adapt to the reduced ppO<sub>2</sub> levels, up to an elevation of roughly 17,000 feet, by making compensating changes to its respiratory, cardiovascular and hematopoietic systems. Complete acclimatization requires about four weeks residence at the ambient ppO<sub>2</sub>.

When people who are not acclimated work in areas of reduced ppO<sub>2</sub>, they will quickly experience a feeling of fatigue. A given work rate in an environment of reduced ppO<sub>2</sub> produces a higher breathing rate, a greater heart rate, and possible other symptoms of fatigue that, under normal conditions (i.e., near sea level), would not be customary at that work load. If a worker moves from a location at sea level to take a job at a facility at a high elevation, that worker will become acclimated within several weeks. During these weeks of acclimation the worker is not considered to be at risk from oxygen deficiency. The more significant situation would be when workers are required to work inside structures that are well below atmospheric pressure. Due to the relatively short exposure to these low-pressure work environments, their bodies are not able to acclimatize.

### *Comparisons—Reduced Atmospheric Pressure*

1. The Federal Aviation Administration requires that the cabins of passenger-carrying aircraft be pressurized when they go above 12,500 feet altitude.
2. Some un-acclimatized people experience several effects of oxygen deficiency (e.g., headache, lightheadedness) at elevations above 5,000 feet (e.g., Denver, Colorado).
3. At altitudes comparable to Pike's Peak (elevation 13,000 feet) and Quilcha, Chile (elevation 17,000 feet), sustained physical activity is difficult.<sup>5</sup>
4. Permanent habitation is nearly impossible above 17,000 feet. Mountain climbers use supplementary oxygen above this elevation.<sup>5</sup>
5. The summit of Mount Everest is 29,028 feet above sea level.

### **6.13.3 Oxygen Deficiency Immediately Dangerous to Life or Health (IDLH)**

#### *Definition of IDLH*

The definition of IDLH based on O<sub>2</sub> deficiency has three parts.<sup>6</sup>

1. If an area is a confined space and the air contains less than the normal 20.9% O<sub>2</sub>, the area is considered IDLH unless the reason for the O<sub>2</sub> reduction is understood and is under control.
2. Any space or area in which the O<sub>2</sub> is less than 12.5% (95 mm Hg ppO<sub>2</sub>) at sea level atmospheric pressure (or the equivalent ppO<sub>2</sub> for other elevations), the area or space is IDLH.
3. If total atmospheric pressure is less than 8.6 psia (450 mm Hg barometric pressure) the area or space is IDLH. This pressure is equivalent to a 14,000-foot altitude. Any combination of reduced percentage of O<sub>2</sub> and reduced atmospheric pressure that

<sup>5</sup> McArdle, W.D., F.I. Katch and V.L. Katch. *Exercise Physiology*. Second edition. Philadelphia: Lea and Febiger, 1986.

<sup>6</sup> ANSI Z88.2-1992, Section 7.3.1.

leads to an O<sub>2</sub> partial pressure of less than 95 mmHg makes the area IDLH. (Recall that barometric pressure times O<sub>2</sub> fraction equals the ppO<sub>2</sub>. For example, 450 mm Hg × 0.21 = 94.5 ≈ 95 mm Hg.)

Potential O<sub>2</sub> deficiency due to reduced oxygen percent and due to increased elevation/reduced atmospheric pressure *both* apply *at all times*. For the remainder of the discussion of oxygen deficiency, refer to Figure 6-3 for information on the relationship between percent oxygen and elevation (atmospheric pressure). For example, O<sub>2</sub> deficiency at sea level is defined as an O<sub>2</sub> content of 16% or less. At 6,000 feet, O<sub>2</sub> deficiency begins at 20% O<sub>2</sub>. This is the “sea-level equivalent” O<sub>2</sub> deficiency point at 6,000 feet. The information for Figure 6-3 was taken from ANSI Z88.2-1992 Table 2.

### Confined Space

Any confined space that contains less than 20.9% oxygen should be considered IDLH. A possible exception to this is discussed in Section 6.13.4 below. In this case it is only the percent O<sub>2</sub> that is the problem, and atmospheric pressure is the same both inside and outside the confined space. If entry into such a confined space is necessary, SCBA would be required (as long as atmospheric pressure remains greater than 450 mm Hg) since it is technically an IDLH area. Classification of areas as IDLH based on low atmospheric pressure is discussed below. In IDLH situations, an SAR would provide adequate oxygen, but in case of air-supply failure the wearer would be exposed to a potentially lethal atmosphere. SCBA provides escape capabilities that a standard SAR does not.

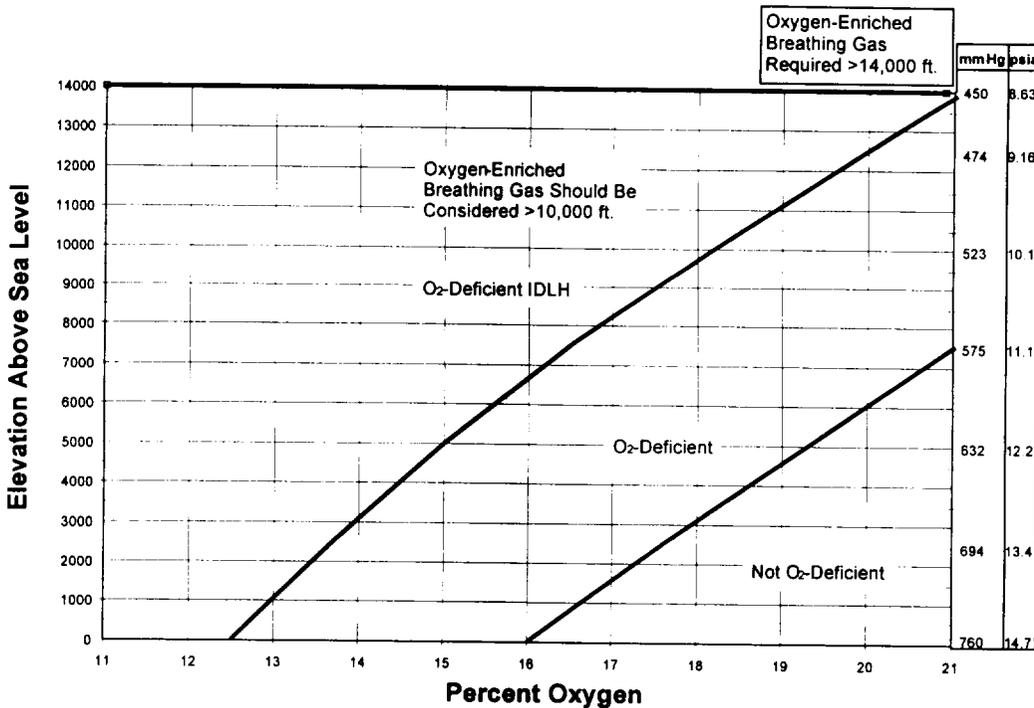


Figure 6-3. Oxygen deficiency and the relationship between percent O<sub>2</sub> and elevation (atmospheric pressure), after ANSI Z88.2—1992, Table 2. See also Appendix F.

### *IDLH—O<sub>2</sub> Concentration Less Than 12.5% Sea-Level Equivalent*

Areas where the oxygen concentration is less than 12.5% sea-level equivalent (see Figure 6-3) are also considered to be immediately dangerous to life or health (IDLH). This means that a person in this environment using an atmosphere-supplying respirator would suffer some effects of hypoxia if the respirator failed. These effects could, depending on how far below 12.5% the level was, either hinder his escape (which might lead to permanent injury or death), or might cause his rapid unconsciousness and death. An oxygen content less than 12.5% (or atmospheric pressure less than 450 mm Hg), corresponds to an oxygen partial pressure of 48 mm Hg in the alveoli of the lungs.<sup>7</sup> Under these conditions, the hemoglobin of the alveolar blood is 83% saturated with oxygen. The relationship between percent O<sub>2</sub> saturation of hemoglobin and partial pressure of O<sub>2</sub> in the alveoli is not linear. As alveolar ppO<sub>2</sub> decreases below 48 mm Hg, the percent hemoglobin saturation decreases precipitously and symptoms of oxygen deficiency quickly become manifest.

Again referring to Figure 6-3, the IDLH point of 12.5% O<sub>2</sub> at sea level is equivalent to 13% O<sub>2</sub> at 1,000 feet and to 14% at 3,000 feet. As explained above, SCBA is required for entries into IDLH areas because of its escape capabilities.

### *IDLH—Atmospheric Pressure Less Than 8.6 psia (450 mm Hg)*

An atmospheric pressure of 8.6 psia (450 mm Hg) corresponds to an elevation of 14,000 feet above sea level. This results in a ppO<sub>2</sub> of 95 mm Hg. Under these conditions, even though the percent O<sub>2</sub> is 20.9%, a person's judgment and coordination become very poor, and other symptoms and injuries may result. Individuals

<sup>7</sup> ANSI Z88.2-1992, Figure A.1.

working at or below this atmospheric pressure will not be afforded any protection by a SAR or open-circuit SCBA, since the problem is lack of pressure to drive the available O<sub>2</sub> across the alveolar boundary and into the blood. The only realistic solution to this problem is to utilize an oxygen-enriched source of breathing gas.

### *O<sub>2</sub>—IDLH at NRC-Licensed Facilities*

While it has been reported<sup>8</sup> that a 30-minute exposure to 4E+6 DAC of Class W <sup>239</sup>Pu or to 2E+6 DAC of Class Y <sup>239</sup>Pu will produce deterministic (nonstochastic) effects consistent with the definition of IDLH, the term IDLH does not realistically apply to most situations involving exposures to airborne radioactive material. The IDLH definition obviously applies to certain non-radiological hazards at an NRC-licensed facility. IE Information Notice 81-26, Part 4 describes a situation where a licensee permitted three workers wearing SCBA devices to enter a fully nitrogen-inerted reactor drywell (approximately 3% O<sub>2</sub> by volume). The purpose of the entry was to locate the source of a primary system leak. Exposure of these individuals to this IDLH environment was for operational reasons, to avoid having to shut the plant down, ventilate the drywell for several hours, and then test the air before entry. In this case, the standby rescue personnel were not able to maintain the proper level of communication with the work party and were positioned on the other side of an airlock and unable to render immediate assistance in case of the malfunction of a worker's SCBA. Descriptions of several other incidents involving oxygen-deficient environments are contained in IE Information Notice 85-87. A complete list of respirator-related NRC bulletins, circulars, and notices is included in the front of this Manual.

<sup>8</sup> Bianconi, Charles J. "Selection of Respiratory Protection Devices for Use in Very High Concentrations of Airborne Plutonium." *Operational Radiation Safety*, August 2000, pp. S41-S43.

### *Misinformation About IDLH*

Licenses should note that a number of older documents, the original NUREG-0041 (1976) included, list exposure to airborne radioactive materials in their definitions of what constitutes an IDLH environment. This is no longer considered valid and licenses may ignore such incorrect guidance in administering their respiratory protection programs.

### **6.13.4 Oxygen Deficiency Non-IDLH**

#### *Non-IDLH—Confined Spaces*

Workers entering a confined space where measured O<sub>2</sub> concentration is less than 20.9% but more than 16% at sea level<sup>9</sup> should use a supplied-air respirator (SAR) under most circumstances. Entry *may* be made without respiratory protection only under unusual circumstances. Licenses should provide supplemental area ventilation if no respirators are used. For example, if after supplemental ventilation has been initiated, two O<sub>2</sub> measurements taken 20 minutes apart inside the confined space indicate that the O<sub>2</sub> concentration is increasing and is greater than 16%, the licensee could conclude that the additional ventilation is correcting the problem and an entry without respiratory protection devices may be made. SARs should still be used if they will have no significant impact on radiation dose or on overall safety. In a situation such as this, licenses should follow their confined space entry procedure, which should include continuing periodic O<sub>2</sub> sampling inside the confined space, protection of the air supply, and arrangements to assist or rescue individuals making such an entry in case the situation deteriorates.

<sup>9</sup> ANSI Z88.2-1992, Section 7.3.3.

#### *Non-IDLH—Reduced Percent O<sub>2</sub>*

Oxygen deficiency non-IDLH can be defined as an area where the oxygen content is greater than 12.5% at sea level (or atmospheric pressure greater than 450 mm Hg, equivalent to an elevation of 14,000 feet—the IDLH level), but less than 16% at sea level (or atmospheric pressure less than 575 mm Hg, equivalent to an elevation of 7,500 feet). See Figure 6-3.

This classification is for an oxygen content that will produce noticeable effects on non-acclimated healthy worker, yet is not IDLH. The hemoglobin of the alveolar blood is 92% saturated with oxygen at the upper end of this classification, and 84% at the lower end. See ANSI Z88.2-1992, Figure A.1. To aid the non-acclimatized worker, and to allow for the uncertainty in the IDLH point among individuals, a supplied-air respirator should be used in this oxygen concentration range.

#### *Non-IDLH—Reduced Atmospheric Pressure*

The containment buildings of seven commercial nuclear power reactor plants are maintained at sub-atmospheric pressures (approximately 11 to 9 psia or 10,000 to 12,750 ft elevation) while the reactors are operating. (Note that the actual elevation of the plant is immaterial if containment pressure is measured in psia.) This exposes personnel entering those containment buildings to an oxygen-deficient environment.<sup>10</sup> Using 9 psia as the lowest operating pressure, three potential scenarios are possible (refer to Figure 6-3.):

1. O<sub>2</sub> = 20.9%;
2. O<sub>2</sub> less than 20.9% but greater than 20.2%;  
or
3. O<sub>2</sub> less than 20.2%.

<sup>10</sup> U.S. Nuclear Regulatory Commission, memorandum of March 14, 1985 from LeMoine J. Cunningham. Subject: Breathing Apparatus for Entry into Subatmospheric Containments.

In the first case, when the O<sub>2</sub> is consistently at 20.9%, an entry would expose workers to an O<sub>2</sub>-deficient environment even though the O<sub>2</sub> level is at its atmospheric maximum. The usual approach to entering an O<sub>2</sub>-deficient environment—assignment of SARs—is not a solution in this case because the ambient air already contains the same percent O<sub>2</sub> as a breathing air system would supply. The O<sub>2</sub> deficiency is due to reduced atmospheric pressure, which reduces the ppO<sub>2</sub> and thus reduces the body's ability to utilize the oxygen. Short of repressurizing the containment building to more than 575 mm Hg (less than 7,500 ft elevation), the only solution is to increase the O<sub>2</sub> content of the breathing gas supplied to the workers.

The second case is similar to the first, except that a lower-than-normal percent O<sub>2</sub> makes the situation more potentially hazardous since the IDLH level based on O<sub>2</sub> deficiency occurs at about 20.2%. Assignment of SARs or open-circuit SCBAs will marginally improve the situation by increasing the O<sub>2</sub> to 20.9%, but the workers will still be in an O<sub>2</sub>-deficient environment, and the level of stress they are exposed to will be increased by the respirators. Use of atmosphere-supplying respirators is not an effective solution to this problem. Also, ANSI Z88.2-1992 Table 2 recommends that if respirators are assigned for use at altitudes 10,000 feet or higher because the O<sub>2</sub> level is less than 20.9%, that those devices should provide O<sub>2</sub>-enriched breathing gas. The NRC concurs with this recommendation. A minimum of 23% O<sub>2</sub> is needed at 10,000 feet. The O<sub>2</sub>-enriched breathing gas issue is discussed in section 6.13.6 below.

While entry into a confined space which is O<sub>2</sub>-deficient may be made without respiratory protection under unusual circumstances (*see Non-IDLH—Confined Spaces* above), it is not advisable in the two situations described here.

In the third case, the workers would be exposed to an IDLH environment based on O<sub>2</sub> deficiency. As was the case above with SARs,

open-circuit SCBAs only provide air at 20.9% O<sub>2</sub> and are ineffective at protecting workers from oxygen deficiency at this atmospheric pressure. Use of oxygen-enriched breathing gas is the only solution to entries into an IDLH environment under these circumstances.

### 6.13.5 Entry into an IDLH Environment

Entry made into an IDLH (or potentially IDLH) environment is an extremely hazardous and potentially life-threatening operation and should only be undertaken in exceptional circumstances. A few such exceptional circumstances would be:

- Life-saving;
- Fire fighting;
- Stopping or preventing major release of radioactive material; or
- Stopping or preventing major property damage.

These entries should be made in accordance with written procedures.

Entries into IDLH environments<sup>11</sup> should be made only by individuals equipped with SCBAs operated in the pressure-demand mode (or positive-pressure mode for closed-circuit SCBA). Persons making such entries should use the "buddy system." The buddies should always have one another *in sight*. This in-sight criterion might not be possible in a fire-fighting situation, so in this case, some other accountability system should be used.

There should be standby rescue persons equipped with SCBAs outside the IDLH area, but immediately ready to enter the area to rescue a person who is in trouble. The number of standby rescue persons should be sufficient to accomplish a rescue in a timely fashion if the occasion arises. In one incident, a diver entered a condensate storage tank at a nuclear power plant to perform a pre-maintenance

<sup>11</sup> Except for IDLH based on O<sub>2</sub> deficiency caused by decreased atmospheric pressure discussed previously.

inspection. He apparently did not recognize that a nitrogen blanket existed in the tank and entered without breathing apparatus. The diver lost consciousness and fell into the water. A standby diver and the safety line tender tried to pull the diver out of the tank but they were unsuccessful. The standby diver, also unaware of the nitrogen blanket, jumped into the tank without safety line or breathing apparatus, to attempt a rescue. The standby diver disappeared beneath the water and died in his rescue attempt. The first diver was later rescued and revived. In this case, even *two* individuals were not enough to extract the first diver.

The NRC issued an information notice<sup>12</sup> in 1981 describing a non-emergency entry into a fully inerted boiling water reactor (BWR) containment. It contains more information about the NRC's position on exposing personnel to IDLH environments.

#### **6.13.6 Entry into a Reduced-Pressure Reactor Containment Building**

The reduced pressure of a sub-atmospheric-pressure containment building with absolute pressure of 9 psia is the equivalent of an altitude of approximately 12,750 feet. Thus, oxygen deficiency is a legitimate concern. A positive-pressure, open-circuit SCBA, although providing protection against any airborne contaminants which may be present in the space, will not protect against the oxygen-deficient atmosphere present because of the reduced atmospheric pressure. This is because the open circuit SCBA regulator, by design, reacts to the ambient pressure and will provide breathing air at a pressure only slightly above ambient. This still results in insufficient oxygen being available to the wearer. Therefore, the atmosphere supplied to the wearer of an open-circuit SCBA with

typical grade D air specifications will technically and realistically be oxygen-deficient.

The amount of oxygen enrichment necessary to adequately protect a respirator user in a reduced-pressure environment will be dependent upon the containment's total pressure. If, for example, a sub-atmospheric containment's atmospheric pressure is 9 psia (465 mm Hg), the percentage of oxygen in the breathing gas must be increased to approximately 35%. This is calculated by dividing ppO<sub>2</sub> at sea level by the atmospheric pressure in the work environment, in this case

$$\frac{760 \text{ mm Hg} \times 0.209}{465 \text{ mm Hg}} = 0.342 = 34.2\%$$

Therefore, by providing breathing air with 35% O<sub>2</sub>, the SCBA wearer will be assured of having sufficient oxygen to maintain normal bodily function. However, operating open-circuit SCBA's with other than grade D-quality air voids the equipment's NIOSH certification. One nuclear utility has applied to the NRC in accordance with 10 CFR 20.1703(b) for permission to use oxygen-enriched breathing gas in its SCBAs for entry into sub-atmospheric containments. The licensee contracted with the National Aeronautics and Space Administration (NASA) and Lawrence Livermore National Laboratory (LLNL) to conduct controlled testing. NASA's White Sands Test Facility (WSTF) examined ignition and combustion within the SCBA regulator, and the compressive heating of hoses and regulator soft goods (e.g., O-rings). The test results showed that the SCBA materials did not promote ignition up to an oxygen concentration of 51% at 4,500 psig. However, with hydrocarbon contaminants present (not normally found in a well-maintained SCBA) some non-catastrophic failures occurred under worst-case conditions, but only during initial pressurization of the apparatus. Further testing revealed that the manufacturer-supplied silicon facepiece used with the SCBA met the

<sup>12</sup> IE Information Notice No. 81-26 Part 4, "Personnel Entry Into Inerted Containments," August 28, 1981.

National Fire Protection Association's flame and heat test. Based on the results of these tests, the NRC granted the licensee's request to use oxygen-enriched breathing air with SCBAs specifically designated for use inside the reduced-pressure containment structures.

A closed-circuit, positive-pressure SCBA's operation is also affected by reduced ambient pressure, since the regulator senses the lower ambient pressure. Due to design characteristics of closed circuit apparatus, the recirculating breathing gas *starts out* at 40-60% oxygen enrichment and over the course of the service life may reach upwards of 80-90% oxygen enrichment. The carbon dioxide evolved during respiration is chemically "scrubbed" from the circulating gas.

Routine or emergency entries should not be made into sub-atmospheric containment buildings without breathing apparatus that provides an oxygen-enriched supply of breathing air.

### 6.13.7 Confined Spaces

There is a distinct possibility in a nuclear facility that occasionally, an emergency entry may have to be made into what is called a "confined space." This may include enclosures that have limited openings for entry or exit, such as storage tanks, stacks, pits, reactor vessels, ventilation and exhaust ducts, and any open-topped space that is more than 4 feet in depth and not equipped with adequate ventilation.

Considering that such an enclosure may also be oxygen-deficient and/or contain a high concentration of radioactive and/or non-radioactive airborne contaminants, the environment should be considered as IDLH, and attendant respiratory protection required for entry and work until it has been properly sampled and ventilation established, or until an adequate surveillance and control program has been established. In addition to the

respiratory requirements, special precautions should be taken to ensure the safety of the workers when working in confined spaces. These include continuous communications, standby rescue personnel, and use of signal lines and/or lifelines. Additional procedures should exist for the use of SCBA for entry into Limited Egress/Confined Space (LE/CS) during emergencies. These procedures should allow for the larger space required by persons wearing SCBA, require standby rescuers to have SCBAs, and provide for removal of people by lifeline if necessary.

It is only human nature to attempt immediate rescue of a disabled person before evacuating an area. At the onset, it is unlikely that the extent or severity of an emergency will be known. Remaining in the emergency area to effect a rescue while wearing inadequate or no respiratory protection may jeopardize everyone involved. The following quote concerning emergencies in confined spaces is applicable to other emergency situations. "An important consideration in responding to an emergency is to avoid making the situation worse by placing yourself in danger. For example, an unconscious person in a confined space usually cannot be rescued by a single person. Proper equipment and assistance generally are needed to retrieve such a person. Under no circumstances should you independently enter a confined space, even if someone else is in danger or if you believe it is safe to enter. The entry of an ill-equipped rescuer without proper knowledge of the situation could result in two fatalities rather than one...."<sup>13</sup> The rescue of injured, trapped, or incapacitated workers in an emergency that may involve hazardous environments is usually more successful when left to trained personnel.

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<sup>13</sup> Los Alamos National Laboratory. "Health and Safety Guide." LALP-82-39. <<http://lib-www.lanl.gov/la-pubs/00212245.pdf>>

#### **6.14 Use of Respirators by Non-Licensee Personnel**

##### *Firefighters*

When an outside fire department responds to a fire or other emergency at a licensee's facility, the licensee may presume that the firefighters meet the respiratory protection program requirements that apply to them. They may use their own equipment or the licensee's equipment. No retrospective evaluation of fit testing, medical screening or training needs to be done. An APF of 10,000 may be used for dose assessment if one is required.

Radiological release of the firefighters' equipment after the emergency should be in accordance with the licensee's procedures.

It is suggested that licensees coordinate with local emergency response organizations to work out potential problem areas before an emergency occurs. Some of these areas might be compatibility of SCBA air cylinders, availability of replacement cylinders, site familiarization, and the on-site capability for refilling these cylinders.

##### Divers

While diving operations are a very specialized application of respiratory protection, they are much more of a planned occurrence than is fire fighting. Therefore, licensees should take the opportunity to verify the diving contractor's compliance with 29 CFR 1910 Subpart T, Commercial Diving Operations (29 CFR 1910.401-1910.441).

##### *Other Contractors*

The requirements of a licensee's respiratory protection program should apply to contractors and permanent employees alike. If a contractor provides specialized respiratory protection equipment for a specific task (e.g., sand-blasting) the RPA should examine the equipment to ensure that it meets the licensee's criteria for NIOSH approval, like-new condition, etc., described elsewhere in this Manual.

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13. IE Information Notice 81-26, Part 4, "Personnel Entry Into Inerted Containment" (August 1981), is another useful reference which discusses a non-emergency entry into a fully inerted BWR containment at power. The notice discusses the entry hazards, provides guidance, and lists other pertinent references.
14. IE Information Notice 85-87, "Hazards of Inerting Atmospheres" (November 18, 1985).
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# APPENDIX A

## The Human Respiratory System and Particle Collection Mechanisms

The human respiratory system (Figure A-1) can be divided into four sections<sup>1</sup>:

- The extrathoracic (ET) region includes the anterior nose (ET<sub>1</sub>), and the posterior nasal passages, larynx, pharynx, and mouth (ET<sub>2</sub>);
- The bronchial region (BB) consisting of the trachea and the left and right bronchi;
- The bronchiolar region (bb) consisting of the bronchioles and terminal bronchioles; and
- The alveolar-interstitial region (AI) consisting of the respiratory bronchioles, the alveolar ducts and sacs with their alveoli, and the interstitial connective tissue.

### *Extrathoracic (ET) Region*

Air is normally inspired through the nose and pharynx into the larynx. In case of a nasal obstruction, or when breathing demands exceed the nasal airflow capacity, additional air is inspired through the mouth. The ET region humidifies and increases the temperature of inspired air.

### *Bronchial (BB) Region*

The BB region consists of the trachea, the main bronchi, and six more generations of sub-branches off the bronchi. The region also includes associated lymph vessels and lymph nodes. The BB region conducts air from the ET region into the bb and AI regions where O<sub>2</sub>-CO<sub>2</sub> exchange takes place. These

conducting airways are tubes lined by ciliated respiratory mucosa and contain variable amounts of muscle and/or cartilage in their walls.

### *Bronchiolar (bb) Region*

This is the second half of the air conducting system and contains the next seven branches (generations) of the bronchial tree called the bronchioles. The last set of these are called terminal bronchioles. These are also lined with mucous. Bronchi are distinguished from bronchioles primarily by the presence of cartilage in their walls. All airways beyond the terminal bronchioles contain alveoli, where most of the gas exchange in the lungs takes place. Each person's lungs contain between 25 million and 100 million bronchioles.

### *The Alveolar-Interstitial (AI) Region*

The AI region contains the final ten generations of the bronchial tree, which are the respiratory bronchioles and the alveolar ducts. It also includes the interstitial lymphatic tissues and lymph vessels, and the bronchial lymph nodes. Gas exchange, the main function of this region, occurs in the alveolus where the thin laminar capillary blood flow and inspired air are separated only by a thin tissue layer. Gas exchange takes 0.25 seconds or 1/3 of the total transit time of a red cell. The oxygen-rich air in the lungs transfers oxygen to the red blood cells in the capillaries, and CO<sub>2</sub> from the same red blood cells is transferred to the air in the alveoli. Hemoglobin on the red blood cells attracts O<sub>2</sub> when oxygen is plentiful, and attracts CO<sub>2</sub> when carbon dioxide is plentiful. The driving

<sup>1</sup> International Commission on Radiological Protection (ICRP). "Human Respiratory Tract Model for Radiological Protection." Publication 66. Oxford: Pergamon Press. 1994.

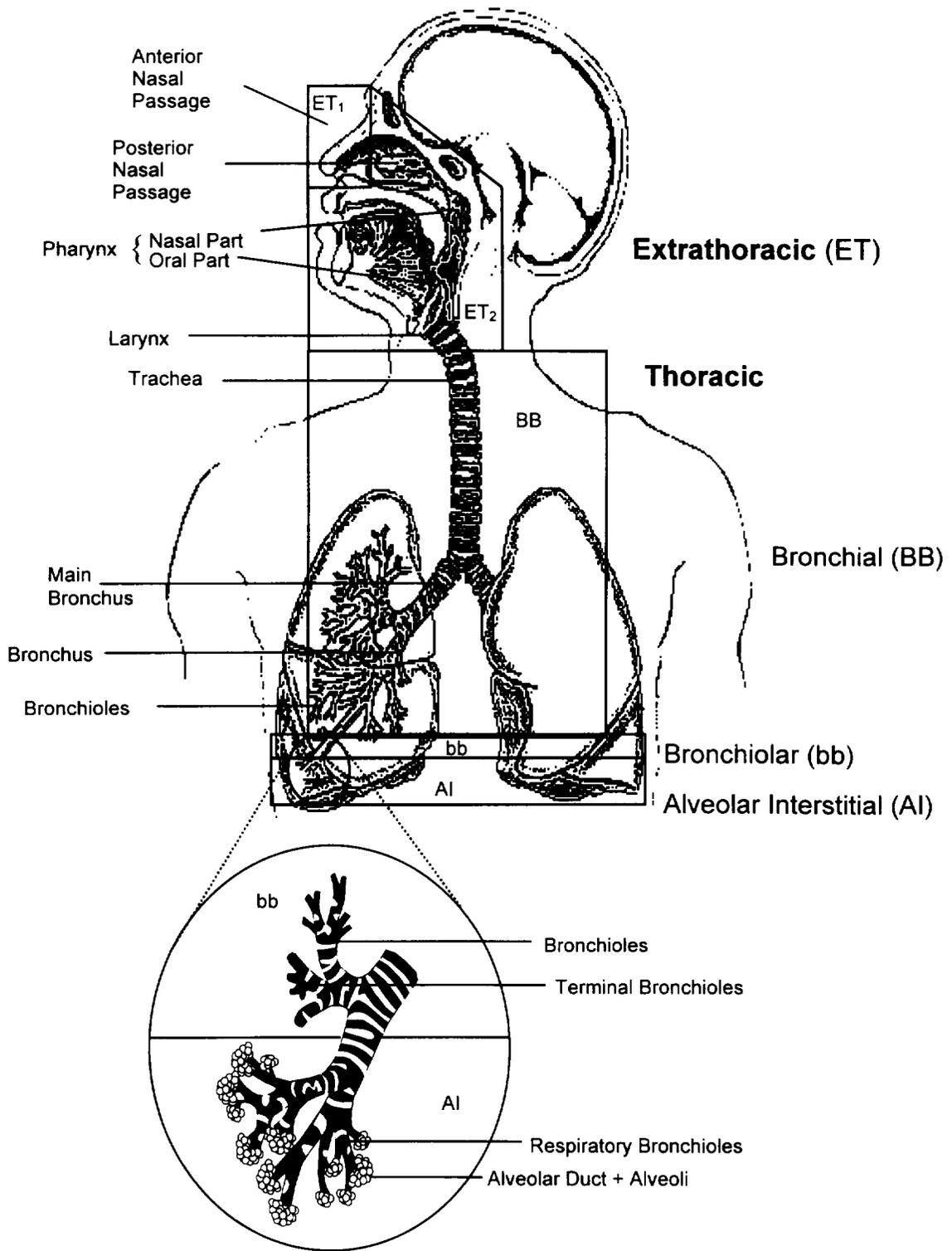


Figure A-1. The human respiratory system model, after ICRP Publication 66, 1994.

force in both of these transfers is the partial pressure of each gas. Gas will always move from an area of higher pressure to an area of lower pressure. The greater the pressure differential the faster the transfer will be. See Table A-1 below. The entire blood volume of the body passes through the lungs each minute in the resting state (i.e., 5 liters per minute).

The total surface area of the adult lung varies from about 300 ft<sup>2</sup> (28 m<sup>2</sup>) while at rest to about 1,000 ft<sup>2</sup> (93 m<sup>2</sup>) at deep inspiration (equivalent to the size of a tennis court). In contrast the skin surface of an adult is roughly 20 ft<sup>2</sup> (1.9 m<sup>2</sup>). Each person's lungs contain about 300 million alveoli. The alveolar walls, which separate the alveolar gas from the capillaries, are only 1 or 2 cells thick, while

the epidermis and dermis are several millimeters thick. The large area of the respiratory system means that most inhaled contaminants will be transferred to the blood quickly. Also, oxygen deficiency will act quickly on an individual. The delicate nature of the alveolar sacs means that they can be easily damaged. Approximately 10,000 liters of air are inspired per day.

*Particle Deposition in the Lung*

Particles in an air stream, such as dirt or dust particles in the air breathed by a worker, can vary in size from 0.001 μm to as much as 100 μm. Particle sizes are given in terms of their activity median thermodynamic diameter

**Table A-1. Partial pressures of the various breathing gas constituents in inhaled air at sea level compared to alveolar gas.**

Gas	PP Inhaled Air (mm Hg)	Direction of Flow	PP Alveolar Gas (mm Hg)
O <sub>2</sub>	159	→	110
N <sub>2</sub>	593	→	569
H <sub>2</sub> O (vapor)	3.8	←	47
CO <sub>2</sub>	0.2	←	40

**Table A-2. Fractional deposition (%) of various size particles in each region of the respiratory tract for nose breathers.**

Activity Median Diameter (μm)	ET <sub>1</sub>	ET <sub>2</sub>	BB	bb	AI
0.001	40	40	8	10	0.4
0.005	18	20	6	30	30
0.01	9	11	3	20	50
0.05	3.5	3.8	1	7.5	34
0.1	3.5	3.5	0.8	5	22
0.5	14	18	1	2	12
1.0	20	25	1.5	1.5	10
5	35	40	2	1.4	5
10	35	40	1.5	0.7	2.5
50	26	26	0.18	0.04	0.08
100	26	26	0.04	-0-	-0-

(AMTD) for very small particles, or their activity median aerodynamic diameter (AMAD) for larger particles. This is a measure of how fast they will drop out of a volume of air and no longer be airborne (i.e., settling velocity). Particles will be collected with varying degrees of efficiency in the various portions of the respiratory tract depending on their aerodynamic diameters. Table A-2 and Figure A-2 show the deposition fractions by particle size in the respiratory compartments for nose breathers. Table A-3 and Figure A-3 provide the same information for mouth breathers. Note that mouth breathers consistently draw a higher percentage of particles from 0.1 to 100  $\mu\text{m}$  AMAD into the AI compartment.

As can be seen in Table A-2 and Figure A-2, large particles are relatively easy to remove from air inhaled through the nose. They tend to travel in a straight line due to inertia, so many are collected on the mucous-covered nasal hairs, or impact the mucous-covered

walls of the ET<sub>2</sub> region as the air stream changes velocity and direction.

Very small particles are also relatively easy to collect. Since they have negligible mass, they have virtually no inertia. So in contrast to the straight-line travel of large particles, very small particles travel in a torturous path even when entrained in a moving stream of air. This erratic movement increases their probability of coming into contact with the walls of the upper airways and being collected. This erratic movement is referred to as Brownian motion.

*Small Particle Collection—Brownian Motion*

In 1827 the English botanist Robert Brown noticed that pollen grains suspended in water jiggled about under the lens of the microscope, following a zigzag path. Even more remarkable was the fact that pollen grains that

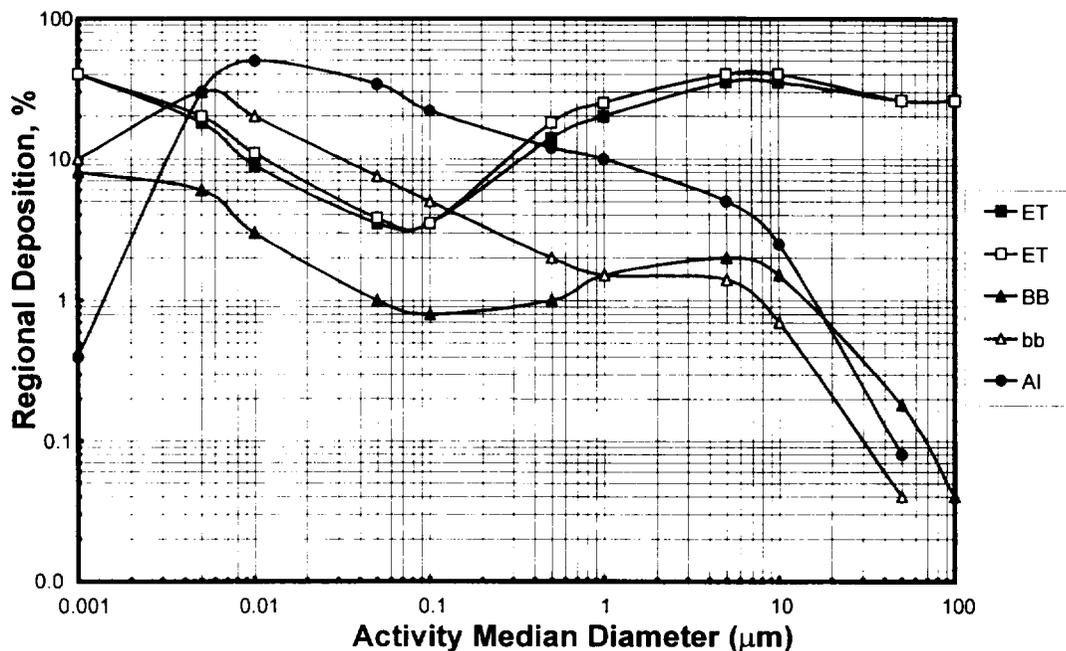
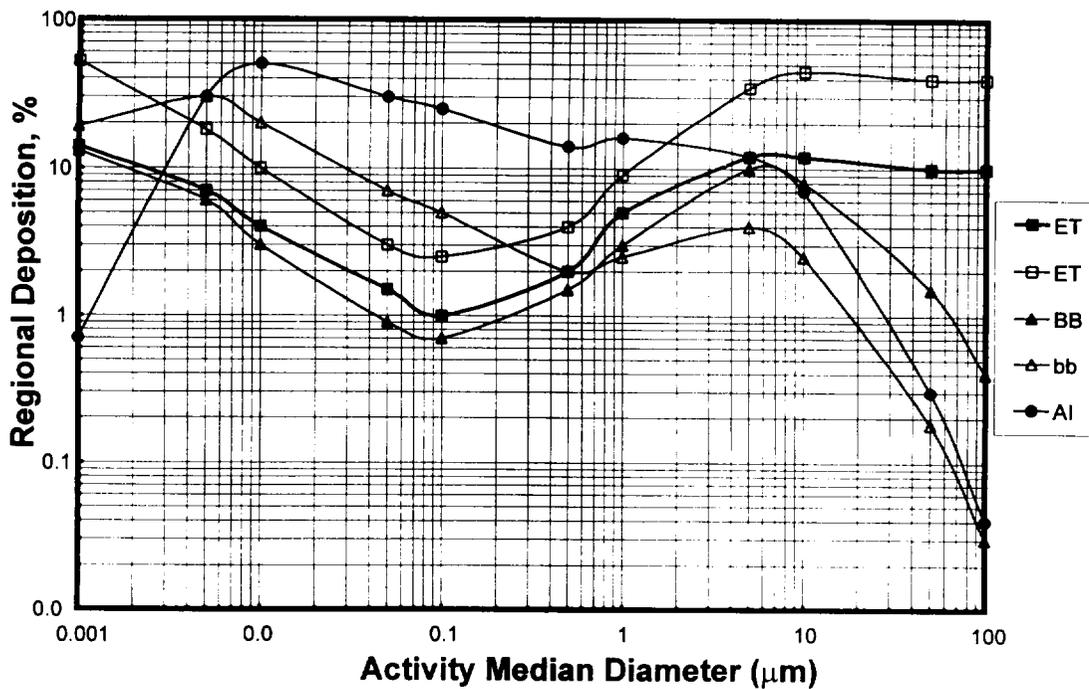


Figure A-2. Fractional deposition (%) of various size particles in each region of the respiratory tract for nose breathers.

**Table A-3. Fractional deposition (%) of various size particles in each region of the respiratory tract for mouth breathers.**

Activity Median Diameter ( $\mu\text{m}$ )	ET <sub>1</sub>	ET <sub>2</sub>	BB	bb	AI
0.001	14	52	13	19	0.7
0.005	7	18	6	30	30
0.01	4	10	3	20	50
0.05	1.5	3	0.9	7	30
0.1	1	2.5	0.7	5	25
0.5	2	4	1.5	2	14
1.0	5	9	3	2.5	16
5	12	35	10	4	12
10	12	45	8	2.5	7
50	10	40	1.5	0.18	0.3
100	10	40	0.4	0.03	0.04



**Figure A-3. Fractional deposition (%) of various size particles in each region of the respiratory tract for mouth breathers.**

had been stored for a century moved in the same way. In 1889 G.L. Gouy found that the “Brownian” movement was more rapid for smaller particles (e.g., we do not notice Brownian movement of cars, bricks, or people). In 1877, Desaulx correctly theorized that a suspended particle is constantly and randomly bombarded from all sides by molecules of the fluid in which it is suspended. If the particle is very small, the hits it takes from one side will be stronger than the bumps from the other side, causing it to jump. These small random jumps are what make up Brownian motion. Einstein developed the first mathematical theory of Brownian motion in 1905 and received the Nobel Prize for his effort. Brownian motion increases the likelihood of very small particles coming into contact with the fibers of a respirator filter, or a mucous-covered nasal hair, or the mucous membrane that lines the upper regions of the respiratory tract, and being removed from the inspired air.

#### *Large Particle Collection—Impaction*

Brownian motion has little effect on large particles in a moving air stream, and their greater mass means that they have more inertia than small particles, so they tend to travel in a straight line. They will continue to travel in a straight line even if the airway turns (e.g., in the ET<sub>2</sub> Region). If a large particle impacts a filter fiber, or a mucous-covered nasal hair, or the mucous membrane that lines the upper regions of the respiratory tract, it is likely to be collected. Very large particles (>100 μm) have so much mass that they will not remain airborne for very long. Even if they are inhaled few of them will get past the ET region.

#### *Particle Size Summary*

As a general rule, very large particles in an air stream are easy to collect due to inertia, and very small particles are easy to collect due to

Brownian motion. An examination of the collection probability versus particle size reveals that particles roughly in the range of 0.3 μm MMAD are the most difficult to remove by filtration. This was the basis for choosing dioctyl pthalate (DOP) as the challenge medium for respirator filters. When DOP oil is vaporized and the vapor is cooled, the size of the tiny oil droplet formed, called the condensation nucleus, has an MMAD of roughly 0.3 μm.

#### *Defense Mechanisms of the Lung*

The Extrathoracic Region (ET<sub>1</sub>) is equipped with a pre-filter—the nasal hairs—which are especially effective at removing very large and very small particles from inhaled air. Particles deposited in the anterior portion of the ET region cause an increase in mucous production and are usually removed by sneezing or nose blowing. In the posterior portion of this region (ET<sub>2</sub>) the air channels narrow (which increases the air velocity) and change direction several times. The air stream again turns 90° as it passes through the pharynx and larynx and enters the trachea. These changes in velocity and direction cause entrained particles to impact with the walls of the nasal cavity and pharynx and to be collected on the mucous membrane. The particles captured in the ET<sub>2</sub> region also cause an increase in mucous production, which leads to coughing. This particle-laden mucous may be spit out, but is most often swallowed. Particles trapped in the ET region have a clearance half-time of a few minutes to a few hours.

The lining of the Bronchial Region (BB), and to a lesser extent the Bronchiolar Region (bb), contain ciliated cells. Dust particles in the air are collected when they come in contact with the mucous-covered walls. These particles stimulate the trachea and bronchi to produce more mucous. The small hair-like cilia covering the walls of much of these regions move in such a way as to sweep the dirt-laden mucous to the top of the trachea. Cilia beat at

1,000 to 1,500 cycles per minute resulting in the movement of the mucus blanket at 0.5 to 1 mm per minute in small airways and 5 to 20 mm per minute in the trachea and main bronchi. All material that accumulates in these airways is removed in about 24 hours. Together the ciliated cells and the mucous blanket constitute the so-called mucociliary escalator. From the top of the trachea the dirt-laden mucous is either swallowed or expectorated. Clearance half-times from these regions range from 2 hours to 70 days.

Alveolar macrophages constitute a small percentage of the cells in alveoli, but they represent the main defense mechanism in the AI Region. They are part of the mononuclear phagocyte system and are derived primarily

from monocytes (a type of white blood cells). Macrophages wander through the lung and are the only alveolar clearance mechanism for particulate material that has escaped the collectors in the upper regions of the respiratory tract. To leave the lungs, these cells with their captured particles may either migrate to the nearest bronchiole and exit via the mucociliary escalator, or they may exit via the blood vessels or lymphatic system. They may also accumulate in the regional lymph nodes. Clearance half-times for particles in the AI region range from a month to nearly 20 years.

## **References and Resources**

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## APPENDIX B

### Calculation of Effective Tritium APF for SAR

Given:

$s$  = intake through skin

$I_o$  = intake through lung *without* respiratory protection

$I_w$  = intake through lung *with* respiratory protection

$$\text{Effective Protection Factor} = PF_{\text{Eff}} = \frac{S + I_o}{S + I_w}$$

$$\text{and } I_w = \frac{I_o}{APF}$$

$$\text{Thus, } PF_{\text{Eff}} = \frac{S + I_o}{S + \frac{I_o}{APF}} = \frac{(S + I_o) APF}{(S)(APF) + I_o}$$

If 1/3 of tritium is absorbed through the skin, let  $S = 1$  and  $I_o = 2$ .

$$PF_{\text{Eff}} = \frac{3 APF}{APF + 2}$$

$$\text{If the APF} = 10, PF_{\text{Eff}} = \frac{3 \times 10}{10 + 2} = \frac{30}{12} = 2.5$$

$$\text{If the APF} = 100, PF_{\text{Eff}} = \frac{3 \times 100}{100 + 2} = \frac{300}{102} = 2.94$$

$$\text{If the APF} = 1,000, PF_{\text{Eff}} = \frac{3 \times 1,000}{1,000 + 2} = \frac{3,000}{1,002} = 2.99$$

$$\text{If the APF} = 10,000, PF_{\text{Eff}} = \frac{3 \times 10,000}{10,000 + 2} = \frac{30,000}{10,002} = 2.999$$

# APPENDIX C

## Respirator Medical Screening Questionnaire

(From 29 CFR 1910.134 Appendix C.

Use of this questionnaire is mandatory in an OSHA respiratory protection program.)

**To the employer:** Answers to questions in Section 1, and to question 9 in Section 2 of Part A, do not require a medical examination.

**To the employee:** Can you read (circle one): Yes/No

Your employer must allow you to answer this questionnaire during normal working hours, or at a time and place that is convenient to you. To maintain your confidentiality, your employer or supervisor must not look at or review your answers, and your employer must tell you how to deliver or send this questionnaire to the health care professional who will review it.

**Part A. Section 1. (Mandatory) The following information must be provided by every employee who has been selected to use any type of respirator (please print).**

1. Today's date: \_\_\_\_\_
2. Your name: \_\_\_\_\_
3. Your age (to nearest year): \_\_\_\_\_
4. Sex (circle one): Male/Female
5. Your height: \_\_\_\_\_ ft. \_\_\_\_\_ in.
6. Your weight: \_\_\_\_\_ lbs.
7. Your job title: \_\_\_\_\_
8. A phone number where you can be reached by the health care professional who reviews this questionnaire (include the Area Code) : \_\_\_\_\_
9. The best time to phone you at this number: \_\_\_\_\_
10. Has your employer told you how to contact the health care professional who will review this questionnaire (circle one): Yes/No
11. Check the type of respirator you will use (you can check more than one category):
  - a. \_\_\_\_\_ N, R, or P disposable respirator (filter-mask, non-cartridge type only).
  - b. \_\_\_\_\_ Other type (for example, half- or full-facepiece type, powered-air purifying, supplied-air, self-contained breathing apparatus).

12. Have you worn a respirator (circle one): Yes/No.  
If "yes" what type(s) \_\_\_\_\_

**Part A. Section 2. (Mandatory) Questions 1 through 9 below must be answered by every employee who has been selected to use any type of respirator (please circle "yes" or "no").**

1. Do you currently smoke tobacco, or have you smoked tobacco in the last month: Yes/No
2. Have you ever had any of the following conditions?
  - a. Seizures (fits): Yes/No
  - b. Diabetes (sugar disease): Yes/No
  - c. Allergic reactions that interfere with your breathing: Yes/No
  - d. Claustrophobia (fear of closed in places): Yes/No
  - e. Trouble smelling odors: Yes/No
3. Have you ever had any of the following pulmonary or lung problems?
  - a. Asbestosis: Yes/No
  - b. Asthma: Yes/No
  - c. Chronic bronchitis: Yes/No
  - d. Emphysema: Yes/No
  - e. Pneumonia: Yes/No
  - f. Tuberculosis: Yes/No
  - g. Silicosis: Yes/No
  - h. Pneumothroax (collapsed lung): Yes/No
  - i. Lung Cancer: Yes/No
  - j. Broken ribs: Yes/No
  - k. Any chest injuries or surgeries: Yes/No
  - l. Any other lung problem that you've been told about: Yes/No
4. Do you currently have any of the following symptoms of pulmonary or lung illness?
  - a. Shortness of breath: Yes/No
  - b. Shortness of breath when walking fast on level ground or walking up a slight hill or incline: Yes/No
  - c. Shortness of breath when walking with other people at an ordinary pace on level ground: Yes/No
  - d. Have to stop for breath when walking at your own pace on level ground: Yes/No
  - e. Shortness of breath when washing or dressing yourself: Yes/No
  - f. Shortness of breath that interferes with your job: Yes/No
  - g. Coughing that produces phlegm (thick sputum): Yes/No
  - h. Coughing that wakes you early in the morning: Yes/No
  - i. Coughing that occurs mostly when you are lying down: Yes/No
  - j. Coughing up blood in the last month: Yes/No
  - k. Wheezing: Yes/No
  - l. Wheezing that interferes with your job: Yes/No
  - m. Chest pain when you breathe deeply: Yes/No
  - n. Any other symptoms that you think may be related to lung problems: Yes/No

5. Have you ever had any of the following cardiovascular or heart problems?
- a. Heart attack: Yes/No
  - b. Stroke: Yes/No
  - c. Angina: Yes/No
  - d. Heart failure: Yes/No
  - e. Swelling in your legs or feet (not caused by walking): Yes/No
  - f. Heart arrhythmia (heart beating irregularly): Yes/No
  - g. High blood pressure: Yes/No
  - h. Any other heart problem that you've been told about: Yes/No.
6. Have you ever had any of the following cardiovascular or heart symptoms?
- a. Frequent pain or tightness in your chest: Yes/No
  - b. Pain or tightness in your chest during physical activity: Yes/No
  - c. Pain or tightness in your chest that interferes with you job: Yes/No
  - d. In the past two years, have you noticed your heart skipping or missing a beat: Yes/No
  - e. Heartburn or indigestion that is not related to eating: Yes/No
  - f. Any other symptoms that you think may be related to heart or circulation problems: Yes/No
7. Do you currently take medication for any of the following problems?
- a. Breathing or lung problems: Yes/No
  - b. Heart trouble: Yes/No
  - c. Blood pressure: Yes/No
  - d. Seizures (fits): Yes/No
8. If you've used a respirator, have you ever had any of the following problems? (If you've never used a respirator, check the following space and go to question 9:
- a. Eye irritation: Yes/No
  - b. Skin allergies or rashes: Yes/No
  - c. Anxiety: Yes/No
  - d. General weakness or fatigue: Yes/No
  - e. Any other problem that interferes with your use of a respirator: Yes/No
9. Would you like to talk to the health care professional who will review this questionnaire about your answers to this questionnaire: Yes/No.

**Questions 10 to 15 below must be answered by every employee who has been selected to use either a full-facepiece respirator or a self-contained breathing apparatus (SCBA). For employees who have been selected to use other types of respirators, answering these questions is voluntary.**

10. Have you ever lost vision in either eye (temporarily or permanently): Yes/No
11. Do you currently have any of the following vision problems?
- a. Wear contact lenses: Yes/No
  - b. Wear glasses: Yes/No
  - c. Color blind: Yes/No
  - d. Any other eye or vision problem: Yes/No

12. Have you ever had an injury to your ears, including a broken eardrum: Yes/No
13. Do you currently have any of the following hearing problems?
- a. Difficulty hearing: Yes/No
  - b. Wear a hearing aid: Yes/No
  - c. Any other hearing or ear problem?: Yes/No
14. Have you ever had a back injury?: Yes/No
15. Do you currently have any of the following musculoskeletal problems?
- a. Weakness in any of your arms, hands, legs, or feet: Yes/No
  - b. Back pain: Yes/No
  - c. Difficulty fully moving your arms and legs: Yes/No
  - d. Pain or stiffness when you lean forward or backward at the waist: Yes/No
  - e. Difficulty fully moving your head up or down: Yes/No
  - f. Difficulty fully moving your head side to side: Yes/No
  - g. Difficulty bending at your knees: Yes/No
  - h. Difficulty squatting to the ground: Yes/No
  - i. Climbing a flight of stairs or a ladder carrying more than 25 lbs: Yes/No
  - j. Any other muscle or skeletal problem that interferes with using a respirator: Yes/No

**Part B. Any of the following questions, and other questions not listed, may be added to the questionnaire at the discretion of the health care professional who will review the questionnaire.**

1. In your present job, are you working at high altitudes (over 5,000 feet) or in a place that has lower than normal amounts of oxygen: Yes/No. If "yes," do you have feelings of dizziness, shortness of breath, pounding in your chest, or other symptoms when you're working under these conditions: Yes/No.
2. At work or at home, have you ever been exposed to hazardous solvents, hazardous airborne chemicals (e.g., gases, fumes, or dust), or have you come into skin contact with hazardous chemicals: Yes/No. If "yes," name the chemicals if you know them: \_\_\_\_\_
3. Have you ever worked with any of the materials, or under any of the conditions, listed below:
- a. Asbestos: Yes/No
  - b. Silica (e.g., in sandblasting): Yes/No
  - c. Tungsten/cobalt (e.g., grinding or welding this material): Yes/No
  - d. Beryllium: Yes/No
  - e. Aluminum: Yes/No
  - f. Coal (for example, mining): Yes/No
  - g. Iron: Yes/No
  - h. Tin: Yes/No
  - i. Dusty environments: Yes/No
  - j. Any other hazardous exposures: Yes/No If "yes," describe these exposures: \_\_\_\_\_

4. List any second jobs or side businesses you have: \_\_\_\_\_  
\_\_\_\_\_

5. List your previous occupations: \_\_\_\_\_

6. List your current and previous hobbies: \_\_\_\_\_  
\_\_\_\_\_

7. Have you been in the military services? Yes/No  
If "yes," were you exposed to biological or chemical agents (either in training or combat): Yes/No

8. Have you ever worked on a HAZMAT team? Yes/No

9. Other than medications for breathing and lung problems, heart trouble, blood pressure, and seizures mentioned earlier in this questionnaire, are you taking any other medications for any reason (including over-the-counter medications): Yes/No.

If "yes," name the medications if you know them:  
\_\_\_\_\_

10. Will you be using any of the following items with your respirator(s)?

- a. HEPA Filters: Yes/No
- b. Canisters (for example, gas masks): Yes/No
- c. Cartridges: Yes/No

11. How often are you expected to use the respirator(s) (circle "yes" or "no" for all answers that apply to you)?

- a. Escape only (no rescue): Yes/No
- b. Emergency rescue only: Yes/No
- c. Less than 5 hours per week: Yes/No
- d. Less than 2 hours per day: Yes/No
- e. 2 to 4 hours per day: Yes/No
- f. Over 4 hours per day: Yes/No

12. During the period you are using the respirator(s), is your work effort:

- a. Light (less than 200 kcal per hour): Yes/No. If "yes," how long does this period last during the average shift: \_\_\_\_\_ hrs \_\_\_\_\_ mins.

Examples of a light work effort are sitting while writing, typing, drafting, or performing light assembly work; or standing while operating a drill press (1-3lbs.) or controlling machines.

- b. Moderate (200 to 350 kcal per hour): Yes/No. If "yes," how long does this period last during the average shift: \_\_\_\_\_ hrs \_\_\_\_\_ mins. Examples of a light work effort are sitting while nailing or filing; driving a truck or bus in urban traffic; standing while drilling, nailing, performing assembly work, or transferring a moderate load (about 35 lbs.) at trunk level; walking on a level surface about 2 mph or down a 5-degree grade about 3 mph; or pushing a wheelbarrow with a heavy load (about 100 lbs.) on a level surface.

c. Heavy (above 350 kcal per hour): Yes/No. If "yes," how long does this period last during the average shift: \_\_\_\_\_ hrs. \_\_\_\_\_ mins.

Examples of heavy work are lifting a heavy load (about 50 lbs.) from the floor to your waist or shoulder; working on a loading dock; shoveling; standing while bricklaying or chipping castings; walking up an 8-degree grade at about 2 mph; climbing stairs with a heavy load (about 50 lbs.).

13. Will you be wearing protective clothing and/or equipment (other than the respirator) when you're using your respirator: Yes/No If "yes," describe this protective clothing and /or equipment: \_\_\_\_\_

14. Will you be working under hot conditions (temperature exceeding 77 °F): Yes/No

15. Will you be working under humid conditions: Yes/No

16. Describe the work you'll be doing while you're using your respirator(s): \_\_\_\_\_  
\_\_\_\_\_

17. Describe any special or hazardous conditions you might encounter when you're using your respirator(s) (for example, confined spaces, life-threatening gases):  
\_\_\_\_\_

18. Provide the following information, if you know it, for each toxic substance that you'll be exposed to when you're using your respirator(s): Name of the first toxic substance: \_\_\_\_\_

Estimated maximum exposure level per shift: \_\_\_\_\_

Duration of exposure per shift: \_\_\_\_\_

Name of the second toxic substance: \_\_\_\_\_

Estimated maximum exposure level per shift: \_\_\_\_\_

Duration of exposure per shift: \_\_\_\_\_

Name of the third toxic substance: \_\_\_\_\_

Estimated maximum exposure level per shift: \_\_\_\_\_

Duration of exposure per shift: \_\_\_\_\_

Name of the fourth toxic substance: \_\_\_\_\_

Estimated maximum exposure level per shift: \_\_\_\_\_

Duration of exposure per shift: \_\_\_\_\_

The name of any other toxic substances that you'll be exposed to while using your respirator: \_\_\_\_\_

19. Describe any special responsibilities you'll have while using your respirator(s) that may affect the safety and well being of others (for example, rescue, security): \_\_\_\_\_  
\_\_\_\_\_

**APPENDIX D**  
**Respirator User Medical Status Form**

**Respirator User Medical Status**  
(Name of Licensee)

Name \_\_\_\_\_ SSN \_\_\_\_\_

Date of Screening \_\_\_\_\_ Screening Administrator \_\_\_\_\_

**Results of Screening**

- Approved for use of ALL TYPES of Respirators
- NOT Approved for ANY Respirator Use
- CONDITIONALLY APPROVED (Complete the section below.)

Signature of Screening Administrator \_\_\_\_\_

---

**Conditional Approval Supplementary Information**

Describe the limitations on respirator use for this individual:

Physician's Signature \_\_\_\_\_ Date \_\_\_\_\_  
(Required for conditional approval only.)

---

*(A form like this could be forwarded from the medical department to the RPA to verify respirator user status. The confidential medical records can then be maintained in the medical department.)*

## **APPENDIX E**

### **The Rainbow Passage**

*(Used for the talking exercise during respirator fit testing.)*

### **The Rainbow Passage**

When the sunlight strikes raindrops in the air, they act like a prism and form a rainbow. The rainbow is a division of white light into many beautiful colors. These take the shape of a long round arch, with its path high above and its two ends apparently beyond the horizon. There is, according to legend, a boiling pot of gold at one end. People look, but no one ever finds it. When a man looks for something beyond his reach, his friends say that he is looking for the pot of gold at the end of the rainbow.

*(Repeat for the duration of the exercise.)*

# APPENDIX F

Oxygen Deficiency and the Relationship Between Percent O<sub>2</sub> and Elevation  
(Atmospheric Pressure), after ANSI Z8.2—1992, Table 2.

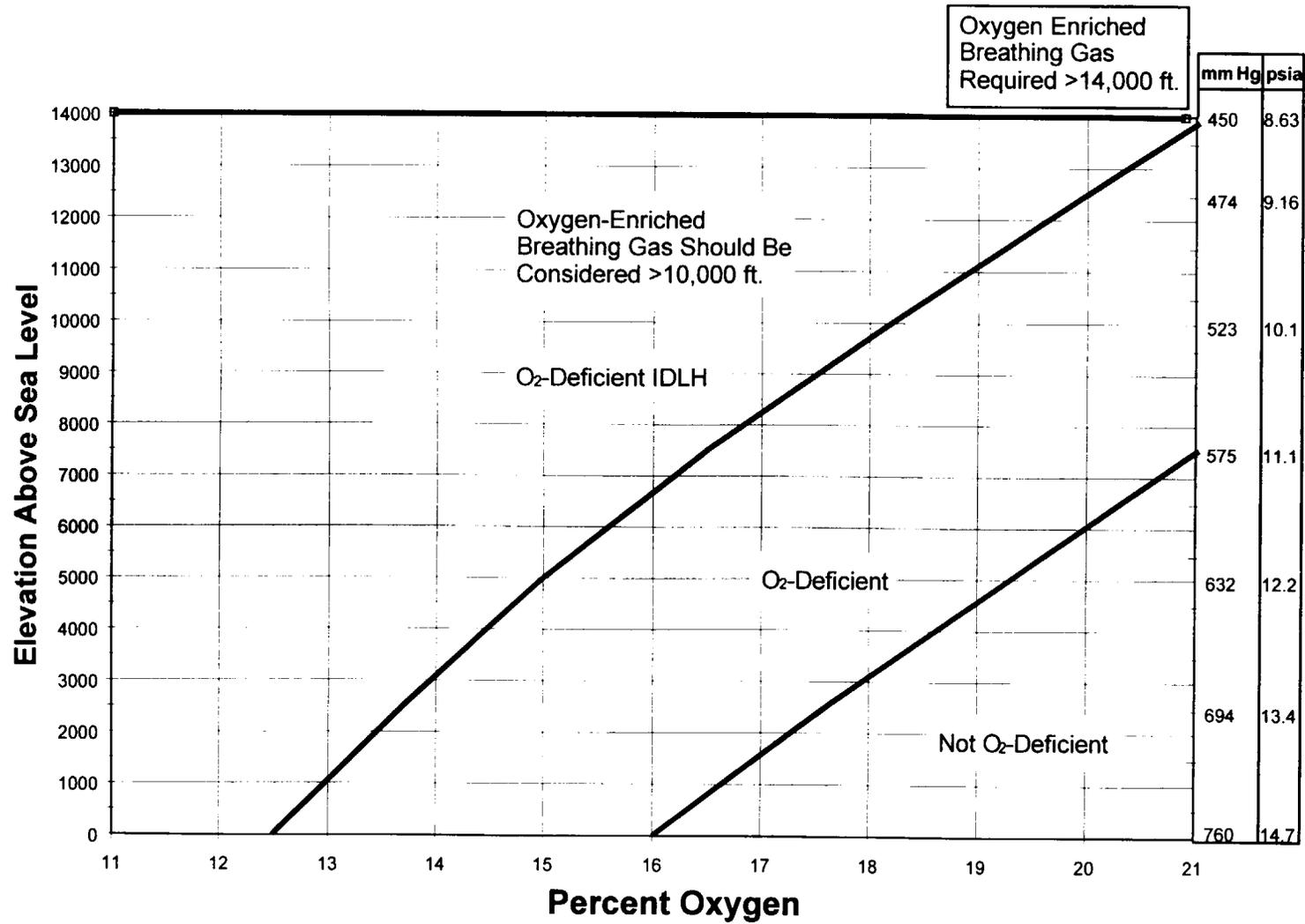


Figure 6-3. Oxygen deficiency and the relationship between percent O<sub>2</sub> and elevation (atmospheric pressure), after ANSI Z8.2—1992, Table 2.

**BIBLIOGRAPHIC DATA SHEET**

(See instructions on the reverse)

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10. SUPPLEMENTARY NOTES

11. ABSTRACT (200 words or less)

This Manual provides information to assist respirator users and program staff in establishing a respiratory protection program that is in compliance with NRC regulations. It may also be of use to managers, supervisors, engineers and workers who may need to understand respirators, their uses, and their limitations. Chapter 1 provides a brief history of respirator regulations and discusses the applicability of OSHA's respiratory protection rules at an NRC-licensed facility. Chapter 2 covers evaluations to determine whether or not the use of respirators results in doses that are as low as reasonably achievable, and factoring hazards other than radiological hazards into decision making. Chapter 3 addressed respiratory protection procedures and programs, while Chapter 4 gives extensive information on respirators and related equipment including care, use and storage of this equipment. Chapter 5 offers advice on user-related issues such as medical evaluation, training and fit testing. Finally, Chapter 6 supplies information about personnel safety-issues that may be related to respiratory protection, and addressed both radiological and non-radiological topics.

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unlimited

14. SECURITY CLASSIFICATION

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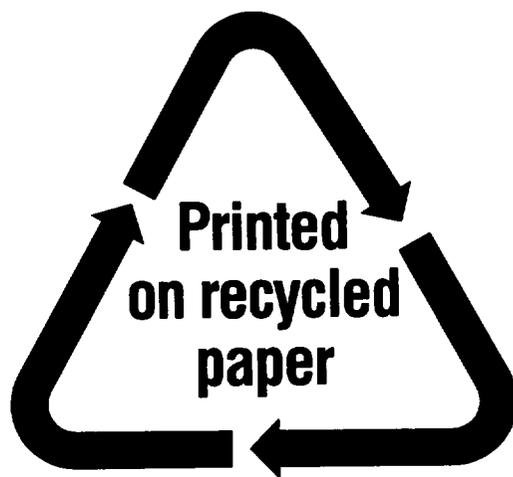
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