Respirator

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A **respirator** is a device designed to protect the wearer from inhaling harmful dusts, fumes, vapors, or gases. Respirators come in a wide range of types and sizes used by the military, private industry, and the public. Respirators range from relatively inexpensive single-use, disposable masks to more robust reusable models with replaceable cartridges.

A half face particulate (air-purifying) mask is generally worn to protect the wearer from dust and paint fumes.

There are two main categories: the *air-purifying respirator* which forces contaminated air through a filtering element, and the *air-supplied respirator* in which an alternate supply of fresh air is delivered. Within each category, different techniques are employed to reduce or eliminate noxious airborne contaminants.

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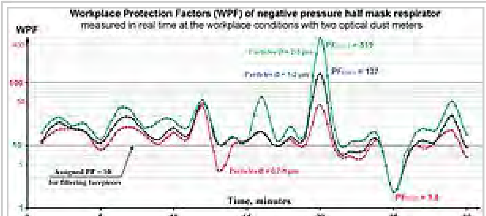

Workplace PF of filtering facepiece, measured in real time with two optical dust meters. In-facepiece dust concentration is changed dozens of times in a matter of minutes due to changes of the size of the gaps between the mask and face. Source[1]

Early development of respirators

The history of protective respiratory equipment can be traced back as far as the first century, when Pliny the Elder (circa A.D. 23-79) described using animal bladder skins to protect workers in Roman mines from red lead oxide dust.[2] In the 16th century, Leonardo da Vinci suggested that a finely woven cloth dipped in water could protect sailors from a toxic weapon made of powder that he had designed.[3] Alexander von Humboldt introduced a primitive respirator in 1799 when he was working in Prussia as a mining engineer.

Practically all the early respirators consisted of a bag placed completely over the head, fastened around the throat with windows through which the wearer could see. Some were rubber, some were made of rubberized fabric, and still others of impregnated fabric, but in most cases a tank of compressed air or a reservoir of air under slight pressure was carried by the wearer to supply the necessary breathing air. In some devices certain means were provided for the adsorption of carbon dioxide in exhaled air and the rebreathing of the same air many times; in other cases valves were provided for exhalation of used air.

The first US patent for an air purifying respirator was granted to Lewis P. Haslett in 1848[4] for his 'Haslett's Lung Protector,' which filtered dust from the air using one-way clapper valves and a filter made of moistened wool or a similar porous substance. Following Haslett, a long string of patents were issued for air purifying devices, including patents for the use of cotton fibers as a filtering medium, for charcoal and lime absorption of poisonous vapors, and for improvements on the eyepiece and eyepiece assembly. Hutson Hurd patented a cup-shaped mask in 1879 that became widespread in industrial use, and Hurd's H.S. Cover Company was still in business in the 1970s.

Inventors were also developing air purifying devices in Europe. John Stenhouse, a Scottish chemist, was investigating the power of charcoal, in its various forms, to capture and hold large volumes of gas. He put his science to work in building one of the first respirators able to remove toxic gases from the air, paving the way for activated charcoal to become the most widely used filter for respirators. British physicist John Tyndall took Stenhouse's mask, added a filter of cotton wool saturated with lime, glycerin, and charcoal, and invented a 'fireman's respirator,' a hood that filtered smoke and gas from air, in 1871; Tyndall exhibited this respirator at a meeting of the Royal Society in London in 1874. Also in 1874, Samuel Barton patented a device that 'permitted respiration in places where the atmosphere is charged with noxious gases, or vapors, smoke, or other impurities.' German Bernhard Loeb patented several inventions to 'purify foul or vitiated air,' and counted among his customers the Brooklyn Fire Department.


Woodcut of Stenhouse's mask

Chemical warfare

The Second Battle of Ypres was the first time Germany used chemical weapons on a large scale on the Western Front in World War I. 168 tons of chlorine gas was released on 22 April over a four-mile (6 km) front. Around 6,000 troops died within ten minutes from asphyxiation. The gas affects the lungs and the eyes causing respiration problems and blindness. Being denser than air it flowed downwards forcing the troops to climb out of trenches.

Eventually reserve Canadian troops held the front, being away from the attack, using urine-soaked cloths as primitive respirators. A Canadian soldier realized that the ammonia in urine would react with the chlorine, neutralizing it, and that the water would dissolve the chlorine, allowing the soldiers to breathe through the gas. This is the first recorded response and defense against chemical attacks using respirators.

Modern respirator technology

Cross-section of a disposable NIOSH P95 filter pad used in metalworking operations. Even "clean" industrial processes often generate large amounts of harmful particulate matter and require breathing protection.

All respirators have some type of facepiece held to the wearer's head with straps, a cloth harness, or some other method. The facepiece of the respirator covers either the entire face or the bottom half of the face including the nose and mouth. Half-face respirators can only be worn in environments where the contaminants are not toxic to the eyes or facial area. For example, someone who is painting an object with spray paint could wear a half-face respirator, but someone who works with chlorine gas would have to wear a full-face respirator. Facepieces come in many different styles and sizes, to accommodate all types of face shapes, and there are many books and references available for determining which kind of hazard requires what type of respirator.

Fit testing respirators

All respirators function by forming a seal on the users face with the respirator itself. This is essential, as respirators are designed to come in contact with all air flowing through them, which is then delivered to the user. Fit testing uses simple equipment that places the users face and head into a hood, into which flavored mist is sprayed. Usually either bitter or sweet in flavor, with bitter flavors being favored for the almost involuntary reaction of users. Following a standard procedure, the user then breathes through the chosen respirator, and indicates whether they can detect the mist. If they cannot, the filter has passed the basic requirement of a face seal and the user also understands how to fit the mask.

While the user may not detect the sweet or bitter indicator, which indicates a proper fit, this test does not provide any indication as to whether the equipment is appropriate for the hazard.

Air-purifying respirators

Air-purifying respirators are used against particulates (such as smoke or fumes), gases, and vapors that are at atmospheric concentrations less than immediately dangerous to life and health. The air-purifying respirator class includes:

- negative-pressure respirators, using mechanical filters and chemical media
- positive-pressure units such as powered air-purifying respirators (PAPRs)
- Escape Only respirators or hoods such as Air-Purifying Escape Respirators (APER) for use by the general public for chemical, biological, radiological, and nuclear (CBRN) terrorism incidents.


Protective filter mask worn by NYPD officer

Full hood, half- or full-facepiece designs of this type are marketed in many varieties depending on the hazard of concern. They use a filter which acts passively on air inhaled by the wearer. Some common examples of this type of respirator are single-use escape hoods and filter masks. The latter are typically simple, light, single-piece, half-face masks and employ the first three mechanical mechanisms in the list below to remove particulates from the air stream. The most common of these is the disposable white N95 variety. The entire unit is discarded after some extended period or a single use, depending on the contaminant. Filter masks also come in replaceable-cartridge, multiple-use models. Typically one or two cartridges attach securely to a mask which has built into it a corresponding number of valves for inhalation and one for exhalation.

The American National Standard for Air-Purifying Respiratory Protective Smoke Escape Devices was established to define both test criteria and approval methods for fire/smoke escape hoods. ANSI/ISEA 110 provides design guidance to Respiratory Protective Smoke Escape Devices (RPED) manufacturers in the form of a detailed set of performance requirements and testing procedures. Key sections of the standard cover certification, labeling, design, performance, conditioning and testing requirements.

ANSI/ISEA 110 was prepared by members of the ISEA RPED Group, in consultation with testing laboratories and was reviewed by a consensus panel representing users, health and safety professionals and government representatives.

ANSI/ISEA Standard 110[5] contains general requirements for certification – including ISO registration for the manufacturer, independent process and quality control audits and follow-up inspection programs – and a comprehensive schedule of performance requirements and associated test methods.

The U.S. Consumer Product Safety Commission is using ANSI/ISEA 110 as the benchmark in their testing of fire escape masks, stating on their website, “Emergency escape masks have the potential to reduce consumer-related deaths and injuries by assisting in egress from fires, provided they perform effectively and reliably."

The Safety Equipment Institute (SEI) is a private, non-profit organization that administers a non-governmental, third-party certification program and tests and certifies a broad range of safety and protective products used occupationally and recreationally. SEI certification programs are voluntary and available to any manufacturer of safety and protective equipment seeking to have product models certified by SEI.

Mechanical filter respirators

Mechanical filter respirators retain particulate matter when contaminated air is passed through the filter material. This was the method used by early inventors such as Haslett and Tyndall. Wool is still used today as a filter, along with other substances such as plastic, glass, cellulose, and combinations of two or more of these materials. Since the filters cannot be cleaned and reused and therefore have a limited lifespan, cost and disposability are key factors. Single-use, disposable as well as replaceable cartridge models are common.

Mechanical filters remove contaminants from air in the following ways:

1. by particles which are following a line of flow in the airstream coming within one radius of a fiber and adhering to it, called *interception*;
2. by larger particles unable to follow the curving contours of the airstream being forced to embed in one of the fibers directly, called *impaction*; this increases with diminishing fiber separation and higher air flow velocity
3. by an enhancing mechanism called *diffusion*, which is a result of the collision with gas molecules by the smallest particles, especially those below 100 nm in diameter, which are thereby impeded and delayed in their path through the filter; this effect is similar to Brownian motion and increases the probability that particles will be stopped by either of the two mechanisms above; it becomes dominant at lower air flow velocities
4. by using certain resins, waxes, and plastics as coatings on the filter material to attract particles with an electrostatic charge that holds them on the surface of the filter material;
5. by using gravity and allowing particles to settle into the filter material (this effect is typically negligible); and
6. by using the particles themselves, after the filter has been used, to act as a filter medium for other particles.

Considering only particulates carried on an air stream and a fiber mesh filter, diffusion predominates below the 0.1 μm diameter particle size. Impaction and interception predominate above 0.4 μm. In between, near the 0.3 μm most penetrating particle size (MPPS), diffusion and interception predominate.

Filtering half mask with exhalation valve (class: FFP3)

For maximum efficiency of particle removal and to decrease resistance to airflow through the filter, particulate filters are designed to keep the velocity of air passing through the filter medium as low as possible. This is achieved by manipulating the slope and shape of the filter to provide larger surface area.

A substantial advance in mechanical filter technology was the HEPA filter. A HEPA filter can remove as much as 99.97% of all airborne particulates with aerodynamic diameter of 0.3 micrometres or greater.

The National Institute for Occupational Safety and Health in the United States defines the following categories of particulate filters:[6]


A video describing N95 certification testing

Oil resistance	Rating	Description
Not oil resistant	N95	Filters at least 95% of airborne particles
	N99	Filters at least 99% of airborne particles
	N100	Filters at least 99.97% of airborne particles
Oil Resistant	R95	Filters at least 95% of airborne particles
	R99	Filters at least 99% of airborne particles
	R100	Filters at least 99.97% of airborne particles
Oil Proof	P95	Filters at least 95% of airborne particles
	P99	Filters at least 99% of airborne particles
	P100	Filters at least 99.97% of airborne particles

European standard EN 143 defines the following classes of particle filters that can be attached to a face mask:

Class	Filter penetration limit (at 95 L/min air flow)
P1	Filters at least 80% of airborne particles
P2	Filters at least 94% of airborne particles
P3	Filters at least 99.95% of airborne particles

European standard EN 149 defines the following classes of “filtering half masks” (also called “filtering face pieces”), that is respirators that are entirely or substantially constructed of filtering material:

Class	Filter penetration limit (at 95 L/min air flow)	Inward leakage
FFP1	Filters at least 80% of airborne particles	<22%
FFP2	Filters at least 94% of airborne particles	<8%
FFP3	Filters at least 99% of airborne particles	<2%

Both European standards test filter penetration with both dry sodium chloride and paraffin oil aerosols, after storing the filters at 70 °C and −30 °C for 24 h each. The standards also include tests on mechanical strength, breathing resistance and clogging. EN 149 also tests the inward leakage between the mask and face (ten human subjects perform five exercises each and for eight of these individuals the average measured inward leakage listed above must not be exceeded).

Chemical cartridge respirators

Chemical cartridge respirators use a cartridge to remove gases, volatile organic compounds (VOCs), and other vapors from breathing air by adsorption, absorption, or chemisorption. A typical organic vapor respirator cartridge is a metal or plastic case containing from 25 to 40 grams of sorption media such as activated charcoal or certain resins. The service life of the cartridge varies based, among other variables, on the carbon weight and molecular weight of the vapor and the cartridge media, the concentration of vapor in the atmosphere, the relative humidity of the atmosphere, and the breathing rate of the respirator wearer. When filter cartridges become saturated or particulate accumulation within them begins to restrict air flow, they must be changed.[7]

If the concentration of harmful gases is immediately dangerous to life or health, a US law[8] and NIOSH[9] prohibits the use of any air-purifying respirators.

Combined gas and particulate respirator filter for protection against acid gases, the type of BKF (БКФ). It has transparent body and special sorbent that changes color after the saturation. This color change may be used for timely replacement of respirators' filters (like End of Service Life Indicator ESLI).

Powered air-purifying respirators (PAPRs)

The purpose of a PAPR is to take air that is contaminated with one or more types of pollutants, remove a sufficient quantity of those pollutants and then supply the air to the user. There are different units for different environments. The units consist of a powered fan which forces incoming air through one or more filters for delivery to the user for breathing. The fan and filters may be carried by the user or with some units the air is fed to the user via tubing while the fan and filters are remotely mounted.

The type of filtering must be matched to the contaminants that need to be removed. Some respirators are designed to remove fine particulate matter such as the dust created during various woodworking processes. When used in combination with the correct filters they are suitable for working with volatile organic compounds such as those used in many spray paints. At the same time filters that are suitable for volatile substances must typically have their filter elements replaced more often than a particulate filter. In addition there is some confusion over terminology. Some literature and users will refer to a particulate filtering unit as a dust mask or filter and then use the term respirator to mean a unit that can handle organic solvents.

Self-contained breathing apparatus (SCBA)

An SCBA typically has three main components: a high-pressure tank (e.g., 2200 psi to 4500 psi), a pressure regulator, and an inhalation connection (mouthpiece, mouth mask or face mask), connected together and mounted to a carrying frame. There are two kinds of SCBA: open circuit and closed circuit.

Open-circuit industrial breathing sets are filled with filtered, compressed air, the same air we breathe normally. The compressed air passes through a regulator, is inhaled by the user, then exhaled out of the system, quickly depleting the supply of air. Most modern SCBAs are open-circuit. An open-circuit SCBA has a full-face mask, regulator, air cylinder, cylinder pressure gauge, and a harness with adjustable shoulder straps and belt which lets it be worn on the back. Air cylinders are made of aluminum, steel, or of a composite construction (usually fiberglass-wrapped aluminum.) Commonly an SCBA will be of the "positive pressure" type, which supplies a slight steady stream of air to stop toxic fumes or smoke from leaking into the mask. Not all SCBAs are positive pressure; others are of the "demand" type, which only supply air on demand (i.e., when the regulator senses the user inhaling). All fire departments and those working in toxic environments need to use the positive pressure SCBA for safety reasons.

The closed-circuit type filters, supplements, and recirculates exhaled gas: see rebreather for more information. It is used when a longer-duration supply of breathing gas is needed, such as in mine rescue and in long tunnels, and going through passages too narrow for a large open-circuit air cylinder.

Educational textbook

There are different respirators designs, and their design differences have a significant impact on the resulting degree of protection. So, the use of high quality and certified (approved) respirator under conditions, for which its design is not intended, may not preserve the health of workers. Therefore, the industrialized countries have requirements for employer containing specific instructions for selection and use of RPD, enshrined in national legislation. And in accordance with these requirements of the law were developed tutorials with information on how to meet these requirements:

- *Nancy Bollinger, Robert Schutz et al.* NIOSH Guide to Industrial Respiratory Protection. (http://www.cdc.gov/niosh/docs/87-116/pdfs/87-116.pdf) — NIOSH. — Cincinnati, Ohio: DHHS (NIOSH) Publication No. 87-116, 1987. — 305 p.

- *Linda Rosenstock et al.* TB Respiratory Protection Program In Health Care Facilities. Administrator's Guide. (http://www.cdc.gov/niosh/docs/99-143/pdfs/99-143.pdf) — DHHS (NIOSH) Publication No. 99-143. — Cincinnati, Ohio, 1999. — 120 p.
- *Nancy Bollinger et al.* NIOSH Respirator Selection Logic. (http://www.cdc.gov/niosh/docs/2005-100/pdfs/2005-100.pdf) — DHHS (NIOSH) Publication No. 2005-100. — Cincinnati, Ohio, 2004. — 39 p
- Respiratory protective equipment at work. A practical guide. 4 ed. (http://www.hse.gov.uk/pubns/priced/HSG53.pdf) — HSE (UK). — Norwich: Crown, 2013. — 59 p. — ISBN 978 0 7176 6454 2.
- BGR/GUV-R 190 Benutzung von Atemschutzgeraten. (http://publikationen.dguv.de/dguv/pdf/10002/R-190.pdf) — Deutsche Gesetzliche Unfallversicherung e.V. (DGUV), Medienproduktion. — Berlin (BRD), 2011. — 174 p.
- *Jaime Lara, Mireille Vennes*. Guide pratique de protection respiratoire. (http://www.irsst.qc.ca/media/documents/PubIRSST/R-319.pdf) — Institut de recherche Robert-Sauvé en santé et en sécurité du travail (IRSST). — Montréal (Canada), 2002. — 56 p. — ISBN 2-550-37465-7
- Occupational Safety & Health Administration, Respiratory Protection Training Video (https://www.osha.gov/SLTC/respiratoryprotection/training_videos.html#video)

See also

- Air filter
- Gas mask
- HEPA
- Pocket mask
- Poison gas in World War I
- Atmospheric particulate matter
- Cartridges and canisters of air-purifying respirators
- Surgical mask
- Smoke hood
- Respirator Assigned Protection Factors
- Respirators testing in the workplaces

References

1. Lee, Shu-An, Sergey Grinshpun (2005). "Laboratory and Field Evaluation of a New Personal Sampling System for Assessing the Protection Provided by the N95 Filtering Facepiece Respirators against Particles". *The Annals of Occupational Hygiene*. Oxford, UK: British Occupational Hygiene Society. **49** (3): 245–257. doi:10.1093/annhyg/meh097. ISSN 0003-4878.
2. "OSHA Technical Manual (OTM) Section VIII: Chapter 2, Respiratory Protection". United States Department of Labor Occupational Safety and Health Administration. 1999-01-20. Retrieved 2013-09-13.
3. "Women in the US Military – History of Gas Masks". Chnm.gmu.edu. 2001-09-11. Retrieved 2010-04-18.
4. Christianson, Scott (2010). *Fatal Airs: The Deadly History and Apocalyptic Future of Lethal Gases that Threaten Our World.* ABC-CLIO. ISBN 9780313385520.
5. "International Safety Equipment Association". Safetyequipment.org. Retrieved 2010-04-18.
6. Metzler, R; Szalajda, J (2011). "NIOSH Fact Sheet: NIOSH Approval Labels - Key Information to Protect Yourself" (PDF). *DHHS (NIOSH) Publication No. 2011-179*. Centers for Disease Control and Prevention. ISSN 0343-6993.
7. The document describes the methods used previously and currently used to perform the timely replacement of cartridges in air purifying respirators.
8. OSHA standard 29 CFR 1910.134 (http://www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=STANDARDS&p_id=12716) "Respiratory Protection"
9. Bollinger, Nancy; et al. (1987). *NIOSH Respirator Selecion Logic*. DHHS (NIOSH) Publication No. 87-108. Cincinnati, Ohio: National Institute for Occupational Safety and Health. p. 32.

Further reading

- Savage, Robert C. Woosnam; Hall, Anthony (2002). *Brassey's Book of Body Armor*. Brassey's. ISBN 1-57488-465-4.
- Palazzo, Albert (2000). *Seeking Victory on the Western Front: The British Army and Chemical Warfare in World War I*. University of Nebraska Press. ISBN 0-8032-8774-7.
- Cheremisinoff, Nicholas (1999). *Handbook of Industrial Toxicology and Hazardous Materials*. Marcel Dekker. ISBN 0-8247-1935-2.
- NIOSH respirators main page (http://www.cdc.gov/niosh/topics/respirators/)
- NIOSH respirator fact sheet (http://www.cdc.gov/niosh/npptl/topics/respirators/factsheets/respfact.html)
- What’s Special about Chemical, Biological, Radiological, and Nuclear (CBRN) Air-Purifying Respirators (APR)? (http://purl.fdlp.gov/GPO/gpo41712) NIOSH Fact Sheet

- NIOSH-Approved Disposable Particulate Respirators (Filtering Facepieces) (http://www.cdc.gov/niosh/npptl/topics/respirators/disp_part/)
- TSI Application note ITI-041: Mechanisms of Filtration for High Efficiency Fibrous Filters (http://www.tsi.com/uploadedFiles/Product_Information/Literature/Application_Notes/ITI-041.pdf)
- British Standard BS EN 143:2000: Respiratory protective devices – Particle filters – Requirements, testing, marking
- British Standard BS EN 149:2001: Respiratory protective devices – Filtering half masks to protect against particles – Requirements, testing, marking

External links

Wikimedia Commons has media related to ***Respirators***.

- 3M Safety Respirator Classification Guide (http://solutions.3m.com/wps/portal/3M/en_US/PPESafetySolutions/PPESafety/Personal_Protective_Equipment/Respirators/)
- Mine Safety Appliance Company (MSA) Respirator Classification Guide (http://webapps.msanet.com/ResponseGuide)
- The Invention of the Gas Mask (http://www33.brinkster.com/iiiii/gasmask/page.html)
- CDC Protective Masks Fact Sheet (http://www.cdc.gov/niosh/npptl/topics/respirators/factsheets/respfact.html)
- Canadian Centre for Occupational Health and Safety (CCOHS)> Respirator Selection (http://www.ccohs.ca/oshanswers/prevention/ppe/respslct.html)
- For CBRN defense responders: The following links are ideal respirator selection logic and competitive bid research information pages for use by all end-users, especially respiratory protection program managers, safety officers, industrial hygienists, CBRN defense specialists, and grant writers seeking funding from the United States Department of Homeland Security (DHS) or other public safety sources:
  - APR (http://www.cdc.gov/niosh/npptl/topics/respirators/cbrnapproved/apr/): Respirator manufacturer approvals for NIOSH-certified air-purifying respirator with CBRN Protections (CBRN APR). This link covers APR and Air-Purifying Escape Respirators (APER) certified by the NIOSH's National Personal Protective Technology Laboratory (NPPTL), Pittsburgh, PA, to Chemical, Biological, Radiological, and Nuclear (CBRN) protection NIOSH standards. CBRN APR are tight-fitting, full-face respirators with approved accessories and protect the user breathing zone by relying on user negative pressure, fit testing and user seal checks to filter less than Immediately Dangerous to Life and Health (IDLH) concentrations of hazardous respiratory compounds and particulates through NIOSH CBRN Cap 1, Cap 2 or Cap 3 canisters for CBRN APR- or CBRN 15- or CBRN 30-rated APER.
  - PAPR (http://www.cdc.gov/niosh/npptl/topics/respirators/cbrnapproved/papr/default.html): Respirator manufacturer approvals for NIOSH-certified powered air-purifying respirator with CBRN Protections (CBRN PAPR-loose fitting or tight fitting)
- OSHA videos on respiratory protection (http://www.osha.gov/video/respiratory_protection/index.html)

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