Supplemental Information—Protection Afforded by PAPRs

Definitions

Powered air-purifying respirator (PAPR)[1] = an air-purifying respirator that uses a blower to force the ambient air through air-purifying elements to the inlet covering.
Assigned protection factor (APF)[2] = the workplace level of respiratory protection that a respirator or class of respirators is expected to provide to employees when the employer implements a continuing, effective respiratory protection.

Mechanism of Air-Purifying Respirators (PAPRs)

PAPRs 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.
Assigned Protection Factors (APF) for PAPRs[3]:

- Half mask = 50
- Full facepiece = 1,000
- Helmet/Hood = 25/1,000
- Loose-fitting face piece = 25

The protection factor is determined experimentally by measuring facepiece seal and exhalation valve leakage, indicating the relative difference in concentrations of substances outside and inside the facepiece that can be maintained by the respirator.[i] For example, a PAPR APF of 50 means that a worker could wear the respirator and be protected in atmospheres containing chemicals at concentrations up to 50 x higher than the appropriate limits. The minimum filter efficiency for the PAPR100 is ≥ 99.97% and PAPR95 is ≥ 95%.[4]

To be certified as a PAPR by The National Institute for Occupational Safety and Health (NIOSH), the blower must provide a constant airflow of at least 115 L/min (4 ft^3/min) for a tight-fitting face piece (half-face or full face PAPR) or at least 170 L/min (6 ft^3/min) for a loose-fitting face piece, helmet, or hood.[5]

CBRN protection is a PAPR that provides protection from a detailed list of chemicals, including chemical warfare agents, biological agents and radiological agents that have been represented by testing against the 10 Test Representative Agents (TRA), dioctyl phthalate (DOP) and Live Agent Testing (LAT).[6]

[1]Occupational Safety and Health Administration. (2009) Assigned Protection Factors for the Revised Respiratory Protection Standard. U.S. Department of Labor.
[2] Occupational Safety and Health Administration. Regulations (Standards - 29 CFR). https://www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=STANDARDS&p_id=12716. Last Update June 2011. Accessed August 2015.
[3] Occupational Safety and Health Administration. (2009) Assigned Protection Factors for the Revised Respiratory Protection Standard. U.S. Department of Labor.
[4] National Institute for Occupational Safety and Health. (2007) Proposed Concept: Powered Air-Purifying Respirator (PAPR) Standard Subpart P Centers for Disease Control and Prevention, Atlanta, GA.
[5] UNC. (2013) Powered Air Purifying Respirators. http://ehs.unc.edu/training/self_study/resp_new/container.php?page=22. Last Update December 2013. Accessed August 2015.
[6] National Institute for Occupational Safety and Health. (2007) Proposed Concept: Powered Air-Purifying Respirator (PAPR) Standard Subpart P Centers for Disease Control and Prevention, Atlanta, GA.

Known PAPR Failure Rates

- From a 1984 U.S. Nuclear Regulatory Commission Office of Inspection and Enforcement report, Three Mile Island (TMI) personnel tested new, used MSA Company's Ultra and PAPR filters.[7]
    - After testing filters at 85 L/min flowrate and rejecting filters in excess of 0.025% leakage, they determined an overall failure rate of less than 5% averaged over several cases (36 filters/case).
    - Most failures were marginal or only slightly in excess of the NIOSH leakage requirement.
    - After adjusting their standards and rejecting filters in excess of 0.02% leakage, the failure rate dropped to 2% for new, unused filters.
- PAPRs with a tight-fitting facepieces and full facepieces have < 2% face-seal leakage under routine conditions.[8]
- PAPRs with loose-fitting facepieces, hoods or helmets have < 4% face-seal leakage under routine conditions.[9]
- In a 2011 study of two PAPRs from two reputable manufacturers, leakage volumes were measured as 2-10% of the tidal volume tested; if no contaminant (fog) reached the mouth, the protection factors for these respirators would be found to be extremely high.[10]
    - These tests were performed using tight-fitting PAPRs: the 3M Breathe-Easy PAPR and the SE 400 breathing demand PAPR.
        - The 3M Breathe-Easy PAPR has a blower that is supposed to supply a constant 114 L/min flow rate to the face piece.
        - The SE 400 PAPR is a breathing-demand device with a blower that adjusts to the breathing flow rates of the wearer.
    - For each of the tests, the Krug breathing machine was operated at 40 breaths/min and with a tidal volume of about 2.25 L.

Indicators of PAPR Failure[11]

- Each PAPR shall have a monitor to indicate the condition of the power source. It shall be readily detectable to the wearer during use without manipulation of the respirator and not affect protection and performance.
- Each PAPR shall have an active indicator which alerts the user to low pressure in the breathing zone. It shall be readily detectable to the wearer during use without manipulation of the respirator and not affect protection and performance.
- Each PAPR shall have readily accessible switches and controls designed to prevent accidental shutoff.
- Low pressure indicator
    - A low pressure indicator will actively and readily indicate when pressure inside the respiratory inlet covering falls below ambient pressure during more than 12 consecutive breaths during blower operation.

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[7] U.S. Nuclear Regulatory Commission Office of Inspection and Enforcement. (1984) IE Information Notice No. 84-60: Failure of Air-Purifying Respirator Filter to Meet Efficiency Requirement.

[8] Boss MJ, Day DW (2003) *Biological Risk Engineering Handbook: Infection Control and Decontamination*: Lewis Publishers.

[9] Ibid.

[10] Koh FC *et al* (2011) Inward leakage in tight-fitting PAPRs. *Journal of environmental and public health* 2011**:** 473143

[11] National Institute for Occupational Safety and Health. (2007) Proposed Concept: Powered Air-Purifying Respirator (PAPR) Standard Subpart P Centers for Disease Control and Prevention, Atlanta, GA.

    - This indicator is readily visible (via light) or detectable (via sound or vibration) to the user without manipulation of the respirator and shall not affect respirator protection and performance.
- Power indicator
    - Power can be supplied by local battery or external power supply.
    - PAPR using an external power supply that can be used for emergency escape must have a battery with a minimum life of 15 minutes. The switch from external power to emergency battery shall restore minimum required operating conditions within 15 seconds.
    - Each PAPR has an indicator to monitor the condition and source (battery or external) of power.
    - Each PAPR equipped with a local battery shall have an active low power warning. This warning indicator shall signal when the battery can no longer provide the unit with 15 minutes of additional adequate power to properly power the unit at the lowest recommended operating temperature and at the highest flow attainable. A PAPR with emergency battery power only does not require a low battery warning indicator.
    - All power indicators shall be readily visible (via light) or detectable (via sound or vibration) to the user without manipulation of the respirator and without affecting protection and performance.
- Battery life
    - Battery life time increments shall be in one hour increments (1-hour, 2-hours, 3-hours, etc.) with a minimum rating of one hour except for emergency escape batteries.
- ESLI (end-of-service-life indicator)[12]
    - End-of-service-life is when a respirator no longer works correctly. It is when the filtering medium can no longer provide the expected level of protection from harmful air contaminants, has reached its capacity for capture and retention of the contaminant, when breathing while wearing the respirator becomes too difficult, or when the respirator becomes damaged, contaminated, or the integrity of the respirator is no longer intact.
    - Demonstration that the ESLI is at its end point (e.g., color change is complete, warning signal activities, etc.), when the cartridge or canister has at least 10% of its service life remaining.
    - Some gas- and vapor-removing air-purifying respirators are also equipped with end-of-service-life indicators (ESLI). The ESLI are usually specific to only one contaminant. The ESLI gives the wearer an indication, often a color change, that the contaminant will no longer be able to be removed by the cartridge or canister and that the cartridge or canister should be replaced.
        - A passive ESLI shall be situated on the respirator so that it is readily visible by the wearer without manipulation of either the respirator or the indicator.
            - If the passive ESLI utilizes color change, the change shall be detectable to people with physical impairments such as color blindness (Example-light color to dark color).
            - If the passive indicator utilizes color change, reference colors for the initial color of the indicator and the final (end point) color of the indicator shall be placed adjacent to the indicator.
- Exhalation valve leakage[13]

[12] CDC. (2014) Respirator Trusted-Source Information. http://www.cdc.gov/niosh/npptl/topics/respirators/disp_part/RespSource3end.html. Last Update August 2011. Accessed August 2015.

[13] National Institute for Occupational Safety and Health. (2005) Concept: Proposed Industrial Powered, Air-Purifying Respirator (PAPR) Standard. Centers for Disease Control and Prevention, Atlanta, GA.

    - Dry exhalation valves and valve seats shall be subjected to a suction of 25 mm water column height while in a normal operating position.
    - Leakage between the valve and valve seat shall not exceed 30 milliliters per minute.
- Breathing resistance[14]
    - For all PAPRs, exhalation breathing resistance shall be measured in the nose/mouth area of the respiratory inlet covering with the blower operating.
    - Exhalation breathing resistance may not exceed 25.4 mm (1") water gauge above static at any flow rate with the respirator operating on a head form and the static reference point being between inhalation and exhalation breaths.

Respirator Protection Factor

The respirator "protection factor" has been defined as the ratio of the contaminant concentration outside the respirator to the contaminant concentration inside the face piece. Thus, a protection factor of 10 means that the concentration inside the mask is one-tenth that outside.[15]
The PF equals 100 divided by % respirator leakage (PF = 100/ % leakage).
(% leakage = 100/ APF)
(% leakage $_{\text{(half mask)}}$ = 100/ 10 = 10%) (% leakage $_{\text{(full face)}}$ = 100/ 50 = 2%)

The protection factor is calculated by the following equation:[16]
Leak rate of the face piece: Lm (%)
Penetration efficiency of filter: Lf (%)
Total leak rate of respiratory protective equipment: TIL (%); TIL (%) = Lm (%) + Lf (%)
Total protection factor of respiratory protective equipment: PF; PF = 100 / TIL (%)

For example, a half mask with an APF of 50 would have 2% leakage; a loose-fitting face piece with an APF of 25 would have 4% leakage.
4% = 100/25 (APF)

[14] Ibid.
[15] The Occupational Safety and Health Administration. (2014) Respirator Classification. http://www.med.navy.mil/sites/nmcphc/Documents/industrial-hygiene/RESPIRATOR-CLASSIFICATION.pdf. Last Update July 2014. Accessed August 2015.
[16] Matsumura Y (2012) Criteria for the Selecting a Respiratory Protective Equipment for Workers Engaged in the Disposal of Decontaminated Waste. Criteria for the Selecting a Respiratory Protective Equipment for Workers Engaged in the Disposal of Decontaminated Waste.