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Guide on respiratory protection against bioaerosols: Recommendations on its selection and use

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Chemical Substances and Biological Agents

Studies and Research Projects

TECHNICAL GUIDE **RG-501**

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Recommendations on its selection and use

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PREFACE

The recommendations stated in this document apply to all people in charge of workers' respiratory protection against bioaerosols, whether infectious or not.

These recommendations summarize the state of knowledge of researchers at the Institut de recherche Robert-Sauvé en santé et en sécurité du travail (IRSST, Robert Sauvé Occupational Health and Safety Research Institute), in close collaboration with a follow-up committee made up of people working in occupational health and safety. This follow-up committee carried out the following role: to become familiar with the document's objectives; to ensure that the objectives meet the identified needs; and to decide on the feasibility of the selection process in order to ensure that the proposed protective measures are useful and relevant.

These recommendations in no way constitute a management plan for a possible pandemic. They are a complement to the Guide pratique de protection respiratoire (practical guidelines on respiratory protection) published by the IRSST (Lara and Vennes, 2003) to help in determining appropriate respiratory protection against bioaerosols, when the situation requires it. It is the responsibility of employers to ensure that risks involving respiratory protection are managed internally.

CONTEXT

All the recommendations specifically relate to respiratory protection against bioaerosols. For other types of exposure (direct or indirect contact with the body), other means of protection must be considered : wearing sealed goggles or visor, gloves and coveralls, hand washing, vaccination, etc.

The content of this document may eventually be updated to include the following aspects:

- the emergence of new infectious bioaerosols;
- updated recommendations of committees of experts;
- new knowledge on the toxicity of non-infectious bioaerosols, on fungal toxins (e.g., mycotoxins) and nanobacteria;
- new identification and counting methods used in microbiology such as genomic aerobiology;
- studies on the protection factors of respirators against bioaerosols;
- how to evaluate the mechanical filtration efficiency of filter materials against biological particles.

CHAPTER 1 **Introduction**

Microorganisms are present everywhere in our environment: water, soil, air, plants, animals and humans. When their presence in air is involved, they are called “airborne microorganisms” or “bioaerosols” (Goyer et al., 2001).

The American Conference of Governmental Industrial Hygienists (ACGIH) defines bioaerosols as being airborne particles consisting of living organisms, such as microorganisms (e.g., viruses, bacteria, molds, protozoa), or originating from living organisms (e.g., toxins, dead microorganisms or fragments of microorganisms) (ACGIH, 1999).

The European guideline 200/54/CE of September 18, 2000, on the risks of exposure to so-called “biological” agents in the workplace, includes microorganisms in this category, including those that are genetically modified, cell cultures, and human endoparasites likely to cause infection, allergy or poisoning (INRS, 2004).

There is growing interest in the risks of exposure to infectious bioaerosols for everyone who has a role to play in occupational health and safety (OHS). Choosing and using respiratory protection can be key decisions, among other things, in cases of exposure to severe acute respiratory syndrome (SARS), tuberculosis, avian or pig flu, anthrax, etc.

Since no general document on the respiratory protection of workers against bioaerosols existed, the members of the technical committee of the board of directors (3.33.1) of the CSST (Québec workers’ compensation board), in the context of reviewing Schedule I of the Regulation respecting occupational health and safety (Order in council 885-2001), asked the IRSST to develop a guide on this subject. In Québec, this same concern had been addressed by the Comité ministériel sur les mesures de précaution contre le syndrome respiratoire aigu sévère (SRAS) (2004b) (Ministerial committee on precautions against SARS).

This is the framework for this document. Its objective is to guide in the selection of respirators against bioaerosols in hazardous situations for workers in different sectors: hospitals, household waste sorting centres, wastewater treatment centres, agriculture, food and beverage processing, etc.

This document first includes a brief description of respirators, air filtration mechanisms and the assigned protection factors for respirators, completed by information on their fit, seal and care. It then presents the respiratory protection required for infectious and non-infectious bioaerosols.

At the end of the document are a few examples on the choice and use of respirators for various work contexts. The appendices contain a decision tree for selecting a respirator against bioaerosols as well the current standards and regulations.

CHAPTER 2 **Respirators**

According to Lara and Vennes (2003), a respirator is a device used for protecting an individual against a risk of alteration of his/her health due to the inhalation of air contaminated by gases, vapors and aerosols (or bioaerosols) or to a lack of oxygen.

There are three categories of respirators: air-purifying (filtration), atmosphere-supplying (supplied-air or self-contained), and those combining supplied air and air purification. Their characteristics are described in the IRSST's Guide pratique de protection respiratoire by Lara and Vennes, published in 2003.

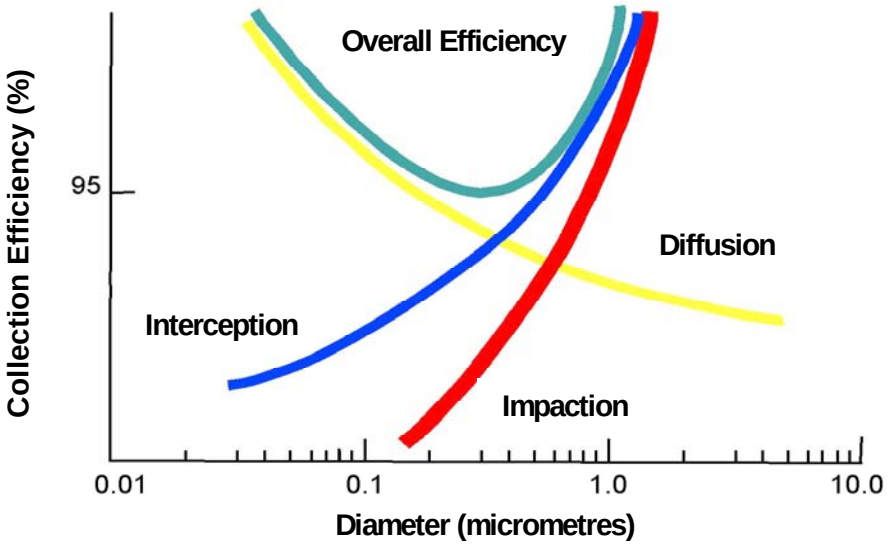
According to McCullough and Brosseau (1999), the choice of respirator is guided by the contaminant's physical nature and concentration. In the majority of situations, aerosols, including bioaerosols, require filtration. This is why the present guide essentially deals with air-purifying filter respirators, with this mechanism being sufficient to protect workers in most situations that involve contamination due to bioaerosols.

In the case of biological weapons, it is highly probable that the types of bioaerosols present, as well as their concentrations are unknown. It is then appropriate to use a self-contained breathing apparatus system (SCBA) (CDC, 2001b).

2.1 Air filtration mechanism

Bioaerosols that are living or dead, on solid or liquid substrates, behave in the air or on surfaces in the same way as other particles (Brousseau et al., 1997; Qian et al., 1997; CDC, 2001b; Lee et al., 2004). The fact that a particle is biologically active or not biological does not seem to affect either its retention by a filter or the deposition of the particle on the filter. As with inert particles, there may be re-aerosolization of a very small portion of the bacteria collected by the filter, following a cough or a violent sneeze by the carrier (Qian et al., 1997). Furthermore, particle filtration efficiency depends on the velocity, size, shape and the electrostatic and hygroscopic interactions of the particles (Hinds, 1982; Yassi and Bryce, 2004).

Figure 1 Filtration efficiency based on particle diameter



To properly understand filtration efficiency, it is important to know that several mechanisms affect the behavior of solid or liquid particles in the air: diffusion, sedimentation, impaction, interception and the electrostatic force. Three of them are critically important in how a particle is collected by a filter, namely interception, inertial impaction, and diffusion by Brownian motion (Yassi and Bryce, 2004; Willeke and Baron, 1993).

An increase in the size of a particle increases its capacity to be filtered by interception and inertial impaction, while a reduction in its size increases its collection by involving the diffusion mechanism (Willeke and Baron, 1993). As a result, there exists an intermediate particle size that brings two or more mechanisms into play, which operate simultaneously, without predominance. The total efficiency curve in Figure 1 indicates the range in which the particle's potential for penetration through the mechanical filter is at its maximum, and conversely, the one in which the filtration efficiency is at its minimum (Yassi and Bryce, 2004; Willeke and Baron, 1993).

For each type of filter, there is a particle diameter that minimizes the collection efficiency. Several well-known institutions consider the 0.3-micrometre (µm) particle as being the one that penetrates the deepest based on tests on respirator filters (Ruzer and Harley, 2005). Furthermore, it is the basic parameter for certification tests carried out on respirators in European standard EN149: 2001, NIOSH 42 CFR Part 84, and Australian Standard AS1716 (Yassi and Bryce, 2004).

The N95 filter respirator retains 95% of the most penetrating particles, meaning 0.3-micrometre (µm) particles, while the N99 retains 99%, and the N100, close to 100%. Filters in class N can be used in the presence of oil-free solid contaminants. There are also two other classes of filters, R (for one work shift) and P (for prolonged use), which are appropriate if there is oil present in the air (Lara and Vennes, 2003). Note that these designations, N95, N99 and others, must obtain NIOSH 42 CFR Part 84 approval. Table 1 groups them.

Table 1 Filter class designation according to NIOSH 42 CFR Part 84 approval

Minimum efficiency	Oil-free particles	Presence of oil in the particles (for one work shift - 8 hrs)	Presence of oil in the particles (for prolonged use)
95%	N95	R95	P95
99%	N99	R99	P99
99.97%	N100	R100	P100

The respirators must fit well. In addition, their seal must be checked before each use, except for some loose-fitting models (e.g., powered air-purifying respirator with loose-fitting facepiece/visor or supplied-air) (CDC, 2001b; Lara and Vennes, 2002, 2003).

2.2 Assigned protection factor (APF)

An assigned protection factor is given to each category of respirator in relation to its efficiency (Lara and Vennes, 2002, 2003). This factor is defined as being the ratio of the concentration of the contaminant measured outside (C_o) and inside (C_i) the respirator. The higher the assigned protection factor, the better the protection provided by the device.

$$APF = C_o / C_i$$

APFs were established by laboratory tests on well-shaved people trained in wearing respirators. For each class of filter, they determine the expected level of protection for a respirator under optimum use conditions. The various assigned protection factors are identified in two IRSST guides (Lara and Vennes, 2002, 2003).

To select a respirator with an appropriate APF, the risk coefficient (RC) must first be identified. It is the relationship between the concentration of the contaminant measured in the environment and the permissible exposure value (PEV) for chemical contaminants (Lara and Vennes, 2003). This same relationship is established from the tolerated background level, which can be considered equivalent to the PEV for non-infectious bioaerosols (Goyer et al., 2001). The concepts of risk coefficient and tolerated background level are defined in greater detail in section 3.2.1 of this document.

The important aspect to be remembered is the following: the APF must always be greater than the risk coefficient, based on the given situation in the workplace.

2.3 Fit, seal and care of respirators

Fit tests

Except for models with a loose-fitting facepiece/visor (such as some powered air-purifying or supplied-air respirators that do not require fitting), respirators must be properly adjusted to the user. They must be put on in such a way that they form a tight seal with the face to prevent contaminated air from entering the filtering facepiece around its periphery (Lara and Vennes, 2003).

Tests and devices help in selecting a respirator model and in verifying whether the fit is appropriate. Some types of tests “qualitatively” evaluate the fit by assessing the subjective perception of the odor or taste of a product (saccharine, bitrex or other) in an test chamber. Also, electronic instruments, such as the TSI Portacount and the Dynatech Fit Tester 3000, will fulfill the same objectives, quantitatively. The IRSST’s Guide pratique de protection respiratoire (2003) explains in greater detail the difference between the qualitative and quantitative tests.

The equipment must also be chosen, fit, used and cared for according to CSA standard Z94.4-93 Selection, Use, and Care of Respirators. In addition, a respiratory protection program must be developed and applied by complying with this standard.

Seal checks

The seal of filtering facepieces should be checked before each use. These seal checks are of two types: positive pressure and negative pressure (CDC, 1994; Lara and Vennes, 2003; Comité ministériel sur les mesures de précaution contre le syndrome respiratoire aigu sévère (SRAS), 2004b).

In the case of a negative pressure test, the following guidelines must be followed:

- put on the respirator and tighten the straps (if adjustable) without it being uncomfortable;
- block the filter or the filtering surface with your hands without deforming it, for a short period of time;
- disconnect the hose or shut off the air supply if it is a powered or supplied-air respirator;
- inhale gently to create a vacuum and check whether the respirator flattens somewhat; if not, there is a leak in the face seal or in a component.

A positive pressure test, which must be carried out after the negative pressure seal checks, has only two steps:

- lightly cover the filter or the filtering surface with your hands without crushing it or deforming it;
- gently exhale into the facepiece.

If the seal is good, the facepiece will bulge slightly. If not, the respirator must be re-ajusted.

Care of respirators

A respirator's non-disposable components must be stored and cared for according to the manufacturer's recommendations, by considering the precautions pertaining to biological hazards. They must be stored and cared for, mainly in the case of an infectious bioaerosol, in such a way as to eliminate or minimize any risk of contamination of the users and transmission of infections.

In this same context, when a powered air-purifying respirator (PAPR) equipped with high efficiency filters could be used, a safe filter changing procedure must be implemented (Comité ministériel sur les mesures de précaution contre le syndrome respiratoire aigu sévère (SRAS), 2004b). Non-disposable respirators must be cleaned and disinfected according to the official procedures (OSHA, 2006). McCullough and Brosseau (1999) recommend that the filter of a powered air-purifying respirator be changed after each use in hantavirus-contaminated environments. The disposable components must be properly stored in compliance with certain guidelines. The advice of committees of experts must be referred to in establishing a safe procedure.

In the case of air-purifying respirators (or filters), it is preferable in the presence of bioaerosols to use disposable components and to discard them after use in order to avoid possible microbial proliferation in the filter as well as the immediate risks of contamination (Lavoie and Allard, 2004; Lavoie et al., 2004; Lavoie and Dunkerley, 2002; Lavoie and Guertin, 2001; CDC, 2001b; Lavoie, 2000).

When a respirator is removed, specific precautions must be taken, even if it is disposable, due to the risk of hand contamination by the infectious bioaerosols (Comité ministériel sur les mesures de précaution contre le syndrome respiratoire aigu sévère (SRAS), 2004b).

General information on fit and seal checks as well as information relating to respirator care can be found in the Guide pratique des appareils de protection respiratoire (Lara and Vennes, 2003).

It is important to note that any damaged, moistened or deformed non-disposable facepiece must be changed or repaired.

CHAPTER 3 **Respiratory protection against bioaerosols**

The sizes of bioaerosols are in the order of 0.02 to 0.25 µm for viruses, 0.3 to 15 µm for bacteria, and 1 to 50 µm for the majority of molds and yeasts (AIHA, 2000; Goyer et al., 2001).

According to Lee et al., (2005), most bacteria and molds are between 0.7 and 10 µm in size. The filtration efficiency of N95 filtering facepieces or half-facepieces should be greater than 99.5% for the majority of these sizes.

Evaluation of biological hazards and workers' respiratory protection must be based on the type of bioaerosol involved.

Two classes of biological hazards exist, based on the characteristics of the microorganisms making up a bioaerosol. They are:

1. infectious hazards (e.g., viruses, pathogenic bacteria);
2. non-infectious hazards (e.g., non-pathogenic bacteria and molds).

Infectious bioaerosols must be living to cause infections, which are defined as being the result of the penetration and development in a living being of microorganisms that can cause lesions by multiplying and eventually by secreting toxins or by spreading through the bloodstream (unofficial translation of definition in Le petit Larousse illustré, 2006).

The non-infectious bioaerosol category contains microorganisms found in the environment in general, which, even when dead, can produce immunological or toxic reactions when inhaled. Molds are a perfect example of these microorganisms.

3.1 Protection against infectious bioaerosols

Table 2 presents the infectious doses of some microorganisms (AIHA, 2000; Public Health Agency of Canada, 2005). Unless otherwise indicated, they apply to humans.

Table 2 Infectious doses of microorganisms or diseases and inoculation routes

Microorganisms or diseases	Infectious doses of microorganisms[1]	Inoculation routes
Histoplasma capsulatum	10 (mice)	Inhalation
Mycobacterium tuberculosis, Mycobacterium bovis	10	Inhalation
Coxsackie A21 virus (Enterovirus)	18 or fewer	Inhalation
Influenza	>790	Inhalation
Bacillus anthracis	8,000-50,000	Inhalation
Q fever (*Coxiella burnetii*)	10	Inhalation
Tularemia (*Francisella tularensis*)	5-10 10^6 - 10^8	Inhalation Ingestion
Adenovirus	>150	Intranasal
Respiratory syncytial virus	> 100-640	Intranasal
Syphilis	57	Intradermal
Malaria	10	Intravenous
Typhoid fever	10^5	Ingestion
E. coli	10^8	Ingestion
Enterohaemorrhagic *E. coli* 0157: H7	10	Ingestion
Bacillus cereus	10^6 or 10^5 per gram	Ingestion
Campylobacter jejuni	500 or fewer	Ingestion
Clostridium perfringens	10^5/gram of food	Ingestion
Hepatitis A virus	Estimated at 10-100 viruses	Ingestion, intravenous, others

[1]When not specified, the dose is the number of organisms.

Wearing a respirator does not protect us from all infectious bioaerosols. Some infections can be transmitted only by contact and not through the air. Other means of protection must then be used, such as vaccination, quarantine, etc.

For protection against diseases that can be contracted by bioaerosol inhalation, an appropriate and properly fitting respirator must be worn. In the hospital environment, among others, it is often the responsibility of local committees of experts such as the infection prevention and control committee, in close collaboration with occupational health and safety departments, to decide on the need for protection and the appropriate type of respirator. Decisions can also be made at higher levels should there be potential risks of epidemic or pandemic.

Molds and yeasts, generally classified as non-infectious bioaerosols, can travel without the help of a carrier. This is not the case for infectious bioaerosols, which, for the most part, are carried by larger diameter aerosols in the form of droplets (liquid particles) and dusts (solid particles).

During a sneeze, close to two million droplets can be expelled at a velocity of 100 m/sec (200 miles/hour), compared to fewer than 100,000 droplets from a cough . This significant difference is based on the origin of the secretions, which is deeper in the case of a cough (Yassi and Bryce, 2004). Several are large enough to contain thousands of microorganisms (ACGIH, 1999).

During the expulsion, the diameters of the droplets vary between 1 and 2,000 µm, 95% of which are in the order of 2 to 100 µm. However, they dry very rapidly. The drying times for 100 and 50 µm droplets in air at 50% relative humidity are 1.3 and 0.3 seconds, respectively (Lenhart et al., 2004b). This highlights the fact that relative humidity plays a role in the size and survival of infectious aerosols (Yassi and Bryce, 2004).

The size of infectious bioaerosols is probably between 0.1 and 10 µm (Yassi and Bryce, 2004; ACGIH, 1999). It even appears that the majority of viruses and bacteria that cause respiratory diseases in humans are usually inside bioaerosols with diameters greater than 5 µm.

All droplets and solid particles can contain microorganisms, proteins, mixtures of saliva, mucus and cell debris, which are carriers of respiratory infections (ACGIH, 1999).

Yassi and Bryce (2004) recommend specific precautions against measles, varicella and smallpox viruses due to their small size, which is close to 0.3 microns. In fact, in the case of viruses, the possibility will have to be considered that they can be carried by liquid particles (droplets) with initially large diameters but which, after drying, could shrink to the 0.3-micron size. Neglecting this aspect could lead to an inappropriate choice of respiratory protection for preventing the transmission of infections. This phenomenon and its impacts must be kept in mind in the prevention process.

Bioaerosols consisting of solid or liquid particles smaller than 10 µm in diameter remain suspended in the air for a sufficient time (a few hours) and are likely to be inhaled (Yassi and Bryce, 2004; ACGIH, 1999; Hinds, 1982). Table 3 indicates the time required for a bioaerosol to be deposited by sedimentation from a height of three metres.

Table 3 Behavior of bioaerosols in the air (Yassi and Bryce, 2004)

Diameter in µm	Time required for deposition from a height of 3 metres
100	10 sec.
40	1 min.
20	4 min.
10	17 min.
6 to 10	A few hours
0.06 to 6	Several hours

In fact, contrary to what is generally stated, where a distinction is made between micro-droplets (diameter ≤ 5 µm) and the largest droplets (diameter > 5 µm) which are assumed to be transported only over distances of less than 1 metre, it appears that solid or liquid particles between 6 and 10 µm can take a few hours before being deposited from a height of 3 metres (Lenhart et al., 2004b; Yassi and Bryce, 2004). The belief that droplets larger than 5 µm sediment before traveling a distance of one metre has no foundation (Lenhart et al., 2004b). The duration of suspension in the air must be taken into account, and a respirator chosen accordingly, in order to be well protected against an infectious bioaerosol.

3.1.1 Approach based on the significance of the risk and experts' recommendations

For infectious bioaerosols, the PEV and the tolerated background levels do not enter into the choice of a respirator because the infectious doses are unknown or inapplicable in most cases. In light of these facts, as recommended by CDC-NIOSH, the approach based on knowledge of the significance of the risk and experts' recommendations seems more appropriate (Lenhart et al., 2004a, 2004b).

This approach is a qualitative method that guides the choice of respiratory protection for an infectious inhalable bioaerosol and that requires a decision based on the judgment of several experts (Lenhart et al., 2004b). For example, different respirators will be chosen if the seasonal flu virus or the H5N1 avian influenza virus are involved. This method is used when the data are insufficient or unavailable for a quantitative approach to respirator selection.

The qualitative method has been used in recommending respirators for several types of exposure: to *Mycobacterium tuberculosis* (CDC 1994), *Histoplasma capsulatum* (Lenhart et al., 2004a), *Bacillus anthracis* (CDC, 2001a), to Hantavirus pulmonary syndrome (CDC, 2002), and to bioterrorism agents (CDC, 2001b).

Note that in cases where it is impossible to evaluate the significance of the risk involving an infectious inhalable bioaerosol, meaning when neither the agent nor its means of dissemination are known, the precautionary principle applies. The action rule allows a respirator to be selected whose APF is proportional to the perceived risk. For example, for protection against bioaerosols used as biological weapons, maximum respiratory protection must be favored (autonomous respirator with full-facepiece, positive pressure (SCBA)) (CDC, 2001b). Should the personnel in patient triage in a hospital admitting department be exposed to the SARS virus, the minimum protection required is a disposable N95 respirator (Comité ministériel sur les mesures de précaution contre le syndrome respiratoire aigu sévère (SRAS), 2004b).

Faced with the emergence of a virulent disease like SARS, the Comité ministériel sur les mesures de précaution contre le SRAS in Québec recommended the use of a NIOSH certified disposable N95 filtering half-facepiece respirator, that must be properly fit and used in conjunction with other necessary protective equipment (eye protection, gloves, coveralls, etc.), to prevent transmission, among other things, to the people assigned to ambulance transport and emergency department triage.

Situations can also arise that require respirators with efficiencies better than that of N95 (N99, N100, etc.) or of different classes (P or R) (OSHA, 2006). The Centers for Disease Control and Prevention therefore recommend the use of N100 filters for protection against the hantavirus (see *Table 4*) or a powered air-purifying respirator equipped with P100 filters adapted to certain personal characteristics (having a beard, etc.) (CDC, 2002).

Table 4 presents different choices of respirators made by committees of experts.

Table 4 Respirator choices for protection against some infectious bioaerosols based on the significance of the risk and experts' recommendations

Infectious bioaerosols	Significance of the risk of exposure[1]	Examples of work	Minimum respirator required according to the experts	Comments	Source
Mycobacterium tuberculosis	Low	Entry into an infected patient's room	N95 filtering half-facepiece	The size of this bacterium is >1 µm and can be found on micro-droplets < 5 µm.	CDC, 1994 (retrieved in 2006)
	Average or high	Bronchoscopy on infected patient, autopsy	Powered air-purifying (with P100 filter)[2]	Based on the characteristics of the tasks, a respirator with appropriate APFs is recommended.	
Bacillus anthracis	Low	Personnel doing mail sorting	N95 filtering half-facepiece	N95 filtering half -facepiece sufficient against this bacterium >1 µm.	CDC, 2001a (retrieved in 2006)
	Average or high	Personnel sampling *Bacillus anthracis* in a post office	Powered air-purifying with full-facepiece (P100 filter)	-The spore was possibly biologically modified. - The infectious dose and the exposure levels are unknown. - The type of work of the investigators is non-stationary. APF as high as possible for this situation	
Hantavirus	Low	Telephone installers, plumbers, electricians who can be in contact with rodents or rodents' nests.	Type of respirator to be determined by case	For low risks, the employer must inform the workers about the dangers of infection. For those who handle animals, an N100 filtering half-facepiece is recommended due to the size of the virus and its survival in the environment (approximately 1 week). The powered air-purifying respirator is recommended for those who cannot wear the N100 filtering half-facepiece.	CDC, 2002 (retrieved in 2004)

Infectious bioaerosols	Significance of the risk of exposure[1]	Examples of work	Minimum respirator required according to the experts	Comments	Source
	Average or high	People who frequently handle or are exposed to wild rodents (zoologists, exterminators, etc.)	Half-facepieceN100 or powered air-purifying half-facepiece (with P100 filter)		
Histoplasma capsulatum	Low	Inspection, collection of samples, etc.	N95 filtering hal-facepiece	*H. Capsulatum* is a mold > 1 µm.	Lenhart, 2004a
	Average	Cleaning or work outdoors	Powered air-purifying with disposable N95 half-facepiece	APF of 50	
	High	Chimney cleaning, work in attics and poultry houses	Full-facepiece with N95 filters	APF of 100	
SARS	Low	Personnel in charge of patient triage in a hospital emergency room in the presence of SARS	Disposable N95 filtering half-facepiece	By analogy with other committees of experts (Health Canada and WHO) and according to the reference framework in risk management for health in the Québec public health network	Comité ministériel sur les mesures de précaution contre le syndrome respiratoire aigu sévère (SRAS), 2004b
	Average or high	Personnel caring for an infected individual	Disposable N95 filtering half-facepiece alone or under a powered air-purifying respirator with complete disposable hood based on the HSC's[5] decision	Higher exposure level (higher APF) and protection of the worker when removing his protection.	
Influenza pandemic (recommendations solely for health institutions)	Low	When entering an infected patient's room	Surgical mask[3] or procedure mask	The route of transmission of the virus is by droplets (>5 µm)[4] (analogies with CDC and WHO)	CINQ, 2006
	Average or high	Personnel doing procedures that can generate bioaerosols	N95 filtering half-facepiece	Possibility of transmission in the form of aerosols (≤5 µm)[4]	

[1]: When the significance of the risk has not been evaluated, the precautionary principle applies.
[2]: Powered air-purifying respirators are always used with P100 filters (HEPA filters).
[3]: A surgical or procedure mask is not a respirator.
[4]: In occupational hygiene, droplets are aerosols; [5]: HSC -= Health and Safety Committee

These examples demonstrate that experts' recommendations can vary and that several criteria have to be considered to make a judicious selection of respirators against infectious bioaerosols.

3.1.2. Criteria to be considered in selecting a respirator

According to Lenhart et al., (2004b), a respirator for use against infectious bioaerosols is selected by considering several criteria:

- the possibility of inhalation;
- the state of knowledge;
- the transmission routes;
- the level of exposure;
- the microorganism;
    - its classification by infectious risk group (groups I, II, III, IV, Health Canada)
    - its virulence
    - its infectious dose
    - its size
    - its survival
    - its means of dispersion
    - its suspension time in the air
    - the drying time for the vector and the bioaerosol
- the characteristics of tasks known to involve potential or real exposure to infectious bioaerosols;
- knowledge relating to APFs;
- the advantages and disadvantages of wearing respirators.

In a respiratory risk management plan, the recommendations can be accompanied by directions to be followed (e.g., steps for removing the respirator, waste management, etc.) and/or means of prevention. In the case of SARS, for example, to avoid indirect contamination of the person and his environment, a well-established sequence must be followed when removing the different personal protective equipment (PPE), and hand washing is a vital measure (OSHA, 2006; Comité ministériel sur les mesures de précaution contre le syndrome respiratoire aigu sévère (SRAS), 2004b). Disposable PPEs contaminated by infectious bioaerosols must be handled as biomedical waste (CINQ, 2006; OSHA, 2006; INRS, 2003; CDC, 2002).

In its guide for protecting employees from avian influenza viruses (2006), OSHA proposes the following PPE removal sequence:

- remove protective clothing, except for gloves, before removing the respirator and goggles;
- then remove gloves and wash hands thoroughly with soap and water (avoid all contact of hands with mouth and face);
- remove eye protection and place in a designated receptacle for subsequent cleaning and disinfection;
- remove the disposable respirator and discard;
- wash hands a second time;
- discard the disposable PPE, considered as contaminated material;
- clean and disinfect non-disposable PPEs as specified in the official procedures.

This sequence is to be validated internally, based on actual work practices.

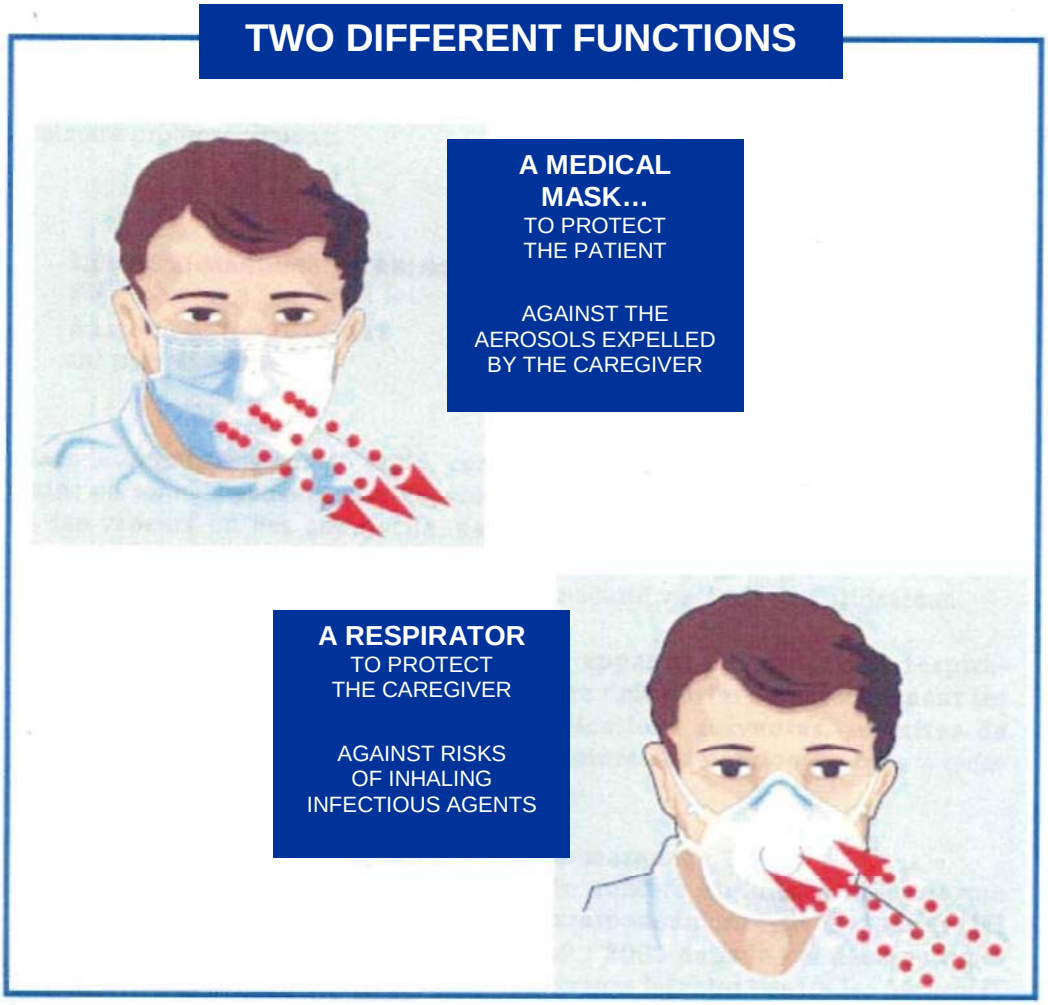
Also to be considered is the fact that some workers can be exposed simultaneously to harmful vapors and gases and to bioaerosols. Although prevention should be based in priority on measures of substitution, process modification, collection and ventilation at source, other respirators may be necessary. For example, in the case of simultaneous exposure to chemical substances and bioaerosols, two means must be combined: cartridges and filters.

3.1.3 Medical mask and respirator

Medical masks (procedure masks, surgical masks) are not respirators. They do not offer sufficient protection against the inhalation of bioaerosols because they cannot provide a close face seal (Yassi and Bryce, 2004; INRS, 2003; McCullough and Brosseau, 1999). In general, they are not made of sufficiently efficient filtering materials (Brosseau et al., 1997). The following figure (Figure 2) shows how a medical mask and a respirator function differently.

Despite the fact that a medical mask is a physical barrier against large droplets, secretions or excretions, its main function is to protect the patient against the aerosols expelled by the caregiver or a visitor (INRS, 2003; CDC, 1994; McCullough and Brosseau, 1999). In North America, all respirators must have NIOSH 42 CFR Part 84 approval (McCullough and Brosseau, 1999).

Figure 2 Medical mask and filtering facepiece respirator (source: INRS, 2003)



3.2 Protection against non-infectious bioaerosols

Although the inhalation dose-effect relationship has not been established for the majority of non-infectious bioaerosols, the scientific community agrees that some of these bioaerosols can cause health problems, particularly if they are present in sufficient concentration (Goyer et al., 2001; ACGIH, 1999).

As shown in Table 5, these concentrations can fluctuate greatly from one work environment to another.

Table 5 Maximum concentrations of bioaerosols found in scientific literature for various workplaces (Goyer et al., 2001)

Workplaces	Total bacteria (CFU/m³)[a]	Gram negative bacteria (CFU/m³)[c]	Molds (CFU/m³)
Outdoors	10^2	10^1	10^3
Agriculture (normal)	10^7	10^3	10^{3-4}
Agriculture (moldy hay)	10^9	10^3	10^9
Bakery	-[b]	-[b]	10^{2-3}
Composting plant	10^5	10^2	10^4
Wastewater treatment plant	10^4	10^4	10^3
Mushrooms (compost)	10^6	-[b]	10^4
Mushrooms (culture)	10^3	-[b]	10^2
Household waste (collection)	10^4	10^3	10^4
Office building	10^2	10^1	10^{2-3}
Paper mill effluents	10^4	10^3	10^4
Cutting fluid	10^6	10^4	10^5
Humidifier	10^3	10^3	10^{2-3}
Cotton mill	10^5	10^4	10^3
Paper mill	10^6	10^{23}	10^3
Swine confinement building	10^6	10^{3-4}	10^4
Sawmill	10^4	10^{3-4}	10^6
Peat bog	-[b]	-[b]	10^8
Sugar processing	10^5	10^3	10^3
Household waste sorting	10^4	10^3	10^4
Tobacco plant	10^3	10^2	10^4

[a]: CFU/m^3 (colony forming units per cubic metre of air)
[b]: not documented
[c]: Gram negative bacteria are those that contain endotoxins in their exterior cell wall

As an example, concentrations of viable bacteria (that proliferate on gelose agar), in places where mushrooms are cultivated (compost), can reach 10^6 CFU/m³ of air (colony forming units per cubic metre of air). In a well-maintained office building, the same bacteria should not exceed a concentration of 10^2 CFU/m³ of air (Goyer et al., 2001). In some workplaces, when control at source is impossible and the concentrations of non-infectious bioaerosols are high, respirators may have to be used.

As with chemical contaminants, it is the concentrations ofr non-infectious bioaerosols present that allow the risk coefficient (RC) to be calculated, which, in turn, must dictate the choice of appropriate respirator, meaning one whose assigned protection factor (APF) is sufficient.

3.2.1 Risk coefficient (RC) method

Respirator selection based on the risk coefficient applies to non-infectious bioaerosols. This is because the scientific literature determines the tolerated background levels, for humans, that can be equivalent to the permissible exposure values (PEVs). These levels represent the thresholds below which the majority of individuals should not suffer from symptoms during exposure to non-infectious bioaerosols. As explained previously in section 2.2 for chemical contaminants, the RC is the relationship between the concentration of the contaminant in the ambient air (CC) and the PEV. For non-infectious bioaerosols, the tolerated background level replaces the PEV.

RC = CC/PEV or tolerated background level

As mentioned by Lara and Vennes (2003) in their Guide pratique de protection respiratoire, the RC must not exceed the APF value for the respirator. It is the RC that serves as a basis in choosing the type of respirator with the minimum appropriate APF.

Tolerated background level for molds

There are currently more than 100,000 species of molds in nature. Humans can easily be exposed to more than 200 species, several of which proliferate in a humid environment (Goyer et al., 2001).

Molds release their spores under the effect of significant air movement or as a reaction to unfavorable conditions such as a rapid increase or decrease in humidity or even in response to the need to reach a new source of food (Goyer et al., 2001).

Still according to Goyer et al. (2001), molds in our regions are active in the outdoor air from April to November and reach their peak of growth between July and the end of autumn. They persist despite the first frost, and although some can develop at temperatures below the freezing point, most are dormant. Snow cover considerably reduces the concentrations in the air, but does not kill molds. When the snow melts, they develop, mainly on dead vegetation. Also, temperature affects their rate of growth. Temperatures from 20 to 25^{o}C correspond to the ideal zone of growth for the majority of them. The document by Goyer et al. (2001) provides additional information on molds.

In summer, the active proliferation period, outdoor mold concentrations can easily reach between 1,000 and 10,000 CFU/m^3 of air (Lavoie and Allard, 2004; OSHA, 2002; Hyvärinen et al., 2001). These concentrations compare with those measured in several studies carried out in Québec on the fungal content of outdoor air (Lavoie et al., 2004; Lavoie and Dunkerley, 2002; Goyer and Lavoie, 2001a, 2001b; Lavoie and Guertin, 2001; Lavoie, 2000; Lavoie and Alie, 1997; Lavoie et al., 1996; Lavoie and Comtois, 1993).

The National Allergy Bureau (NAB), a division of the American Academy of Allergy, Asthma and Immunology (AAAAI), states that the majority of individuals sensitized to mold spores could suffer from symptoms when the concentrations exceed 13,000 spores/m³ of air (IICRC, 2003). From this perspective, the Institute of Inspection, Cleaning and Restoration Certification (IICRC), in their document IICRC S520 entitled Standard and Reference Guide for Professional Mold Remediation, recommends using 10,000 spores/m³ of air as the background level for determining the necessity for wearing a respirator (IICRC, 2003).

It should be mentioned that the unit for this limit is spores, which, contrary to infectious agents, do not have to be alive or viable to retain their immunological properties (Burge, 1995). Clearly, the concentrations of spores/m³ of air are slightly higher than those reported in CFU/m³ because, in addition to the viable or cultivable fraction, the non-viable fraction is also counted. It should also be mentioned that, based on the current state of knowledge, this tolerated background level is also valid for the health effects of mycotoxins (included in the spores of some molds) (IICRC, 2003).

Tolerated background level for bacteria

For all cultivable bacteria, the Scandinavian countries as well as the IRSST, following their research on waste collection and treatment, are currently proposing a tolerated background level of 10,000 CFU/m³ of air (Lavoie and Allard, 2004; Goyer et al., 2001; Lavoie and Alie, 1997; Poulsen et al., 1995a, 1995b; Malmros et al., 1992; Malmros, 1990).

The level set for viable Gram negative bacteria is ten times less, or 1,000 CFU/m³ of air (Lavoie and Allard, 2004; Goyer and al., 2001; Lavoie and Alie, 1997; Poulsen et al., 1995a, 1995b; Malmros et al., 1992; Malmros, 1990).

Tolerated background level for endotoxins

There are also Relative Limit Values (RLVs) for endotoxins (ACGIH, 1999). These toxins present in the external cell wall of Gram negative bacteria can have non-infectious effects on workers' respiratory health (ACGIH, 1999). Based on the logic expressed in this document, RLVs can be equated to the tolerated background levels in calculating the risk level.

The RLVs proposed by the ACGIH are:

- 30 times the background concentration measured in the air at the reference site for healthy individuals;

- 10 times the background concentration in the air at the reference site for people with related symptoms.

The reference site for background sampling can be indoors or outdoors, depending on the season (ACGIH, 1999). For example, suppose that an average concentration of 1,000 endotoxin units (EU)/m³ of air was measured in a swine-confinement building, while the outdoor concentration (background) was 7 EU/m³ of air. This indicates a level 142 times greater than the background level. By wearing an N95 half-facepiece as described in Table 6, the concentration is reduced ten-fold (from 1,000 to 100 EU/m³ of air) and the RLV of 210 EU/m³ (30 times the background concentration of 7 EU/m³ of air) is respected for healthy individuals.

Minimum respiratory protection

Table 6, referring to the IICRC S520 guide, contains information on certain types of respirators and their assigned protection factors. This information is related to the concentrations of mold spores or viable bacteria that can be found in different work environments (IICRC, 2003).

Table 6 Maximum use concentrations and corresponding protection factors

Concentrations of molds in spores or total bacteria in CFU/m³(1)	**Assigned protection factor**	**Minimum respirator required**
100,000	10	Half-facepiece with disposable N95 filters
250,000	25	Powered air-purifying or supplied-air with loose-fitting facepieces/visor
500,000	50	Powered air-purifying with half-facepiece
>500,000-1,000,000	100	Full-facepiece with disposable N95 filters
>1,000,000-10,000,000	1,000	Powered air-purifying with hood and hose and equipped with a high efficiency filter (P100 or HEPA)(2)
> 10,000,000	10,000	Self contained with full-facepiece (SCBA), positive pressure

(1): For a recommended background level of 10,000 spores/m³ of air for molds and 10,000 CFU/m³ of air for total bacteria.
(2): For the model with hood and high efficiency filter according to 3M. The hood and hose will have to be disposable for protection against infectious bioaerosols.

The various modes of respirator operation are described in the Guide pratique de protection respiratoire by Lara and Vennes (2003), and in the Guide des appareils de protection respiratoire utilisés au Québec, Lara and Vennes (2002).

As a complement to this information, Appendix 1 contains the selection tree for a respirator against infectious and non-infectious bioaerosols.

CHAPTER 4 **Limits and scope of this guide**

Experts' recommendations for respiratory protection may sometimes seem exaggerated. If any doubt exists, and the available data are insufficient to come to a definite conclusion, the precautionary principle applies, particularly regarding an infectious context.

As for future research needs, interest should now focus on ways to sterilize disposable N95 respirators so that they can be reused in the event of pandemics. With the help of colleagues in infection prevention or occupational health, knowledge about the behavior of microorganisms in the air should be developed further regarding the reduction of risks of disease transmission. The creation of a multidisciplinary network of specialists in respiratory protection against bioaerosols could meet these needs.

CHAPTER 5 **Examples of choices of a respirator**

Personnel working in the room of a patient infected with the SARS virus

In this scenario involving the presence of an infectious bioaerosol, the approach based on the significance of the risk and on experts' recommendations applies. In this regard, the ministerial committee recommended that personnel wear a disposable N95 filtering half-facepiece respirator, alone or under another respirator providing greater protection, such as a PAPR, equipped with a disposable hose and hood. This recommendation related to operations at high risk of producing aerosols (intubation, induced sputum, etc.) (Comité ministériel sur les mesures de précaution contre le syndrome respiratoire aigu sévère (SRAS), 2004b). Such a device is distinguished by a protection factor greater than that for the filtering half-facepiece; it therefore provides more protection. The half-facepiece respirator is used to protect the wearer from risks of contamination when removing the powered respirator before leaving the patient's room. Anyone having to work in this context should follow the procedure defined by the ministerial committee.

Operator cleaning a filter press at a wastewater treatment plant

In this situation, the risk coefficient (RC) method applies, since infectious bioaerosols are not involved and the tolerated background levels equivalent to the PEVs are available. The RC must be below the APF in choosing the respirator. For this type of operation, the literature describes total viable bacteria concentrations in the order of 50,000 CFU/m³ of air (Goyer et al., 2001). The RC is therefore 5 (ambient air concentration of 50,000 CFU/m³ of air/tolerated background level of 10,000 CFU/m³ of air). Table 6 indicates that a disposable N95 filtering facepiece respirator (APF of 10) provides acceptable protection.

Peat moss packager

Since this work generally involves non-infectious bioaerosols, equipment selection is based on the risk coefficient method.

Evaluation of the air's fungal content, for a worker assigned to peat moss packaging, gives concentrations of 200,000,000 spores/m^3 of air (Duchaine et al., 2004). Using Table 6 as a basis, the worker should wear a respirator with a maximum APF, namely 10,000 (SCBA with full-facepiece at positive pressure). However, the characteristics of the tasks to be performed make this type of device unusable. As a result, after implementing control measures such as a local ventilation system and verifying its efficiency, the worker will be able to wear a PAPR (powered air-purifing respirator) with a hood and a P100 filter, if the new concentrations permit it. Because the bioaerosols present are not considered infectious, there's no need to use a disposable hood and hose.

GLOSSARY

Aerosol – Solid or liquid particle suspended in a gaseous medium such as air.

Assigned protection factor (APF) – Recommended value that provides an indication of the protection provided by a respirator. The higher this factor, the higher the protection provided the respirator.

Bioaerosols – Airborne particles consisting of living organisms such as microorganisms, or originating from living organisms, for example toxins, dead microorganisms or fragments of microorganisms (ACGIH, 1999).

CFU – Colony forming unit. It is the unit of measurement for viable microorganisms growing on gelose agars (culture media). One unit corresponds to one microorganism.

Diffusion – Mass transfer associated with the random movement of molecules or particles under the effect of a difference in concentration.

Droplet – Liquid particle.

Dust - Aerosol consisting of solid particles**.**

Endotoxins – Components of the exterior cell membrane of Gram negative bacteria, made up of lipopolysaccharides associated with proteins and lipids

Inertial impaction – Mechanism by which the particles that tend to travel in their original direction of movement will deviate from the lines of flow to impact on a surface. This tendency is even stronger when the particle is massive, its velocity is high, and the lines of flow diverge abruptly.

Infection – Result of the penetration and development in a living being of microorganisms that can cause lesions by multiplying and eventually secreting toxins or by spreading through the bloodstream.

Infectious dose – Quantity of microorganisms necessary to cause an infection in their host.

Interception – Phenomenon by which a particle is collected due to its physical size when it comes into contact with another particle or fiber.

Medical mask (for care, hygiene, anti-projection, procedure or surgical) – Their main function is to protect the patient against the aerosols expelled by a caregiver or visitor.

Mycotoxin – Secondary metabolite released by molds as defense against other microorganisms.

Particle – Small portion of solid or liquid material.

PEV (permissible exposure value) – According to the ROHS (Regulation respecting occupational health and safety, Schedule I), permissible limit of exposure for workers to an air contaminant.

Precautionary principle – Action rule that allows a respirator to be chosen with an APF proportional to the perceived risk

RLV – Relative limit Values for endotoxins. The proposed RLVs are:

- 30 times the background concentration in the air at the reference site for healthy individuals;
- 10 times the background concentration in the air at the reference site for people with related symptoms.

Respirator – Intended to protect an individual exposed to a risk of alteration of his health caused by the inhalation of air contaminated by gases, vapors, aerosols (including bioaerosols), or by a lack of oxygen.

Risk coefficient (RC) – Allows the minimum assigned protection factor (APF) for a respirator to be defined in relation to the contaminant's concentration. It is determined from the contaminant's concentration in the air divided by the tolerated background level for non-infectious bioaerosols. The APF must be higher than this coefficient.

Sedimentation – Phenomenon of particle displacement under the effect of gravity .

Virulence – Ability of a pathogenic organism to multiply in a living organism, resulting in sickness.

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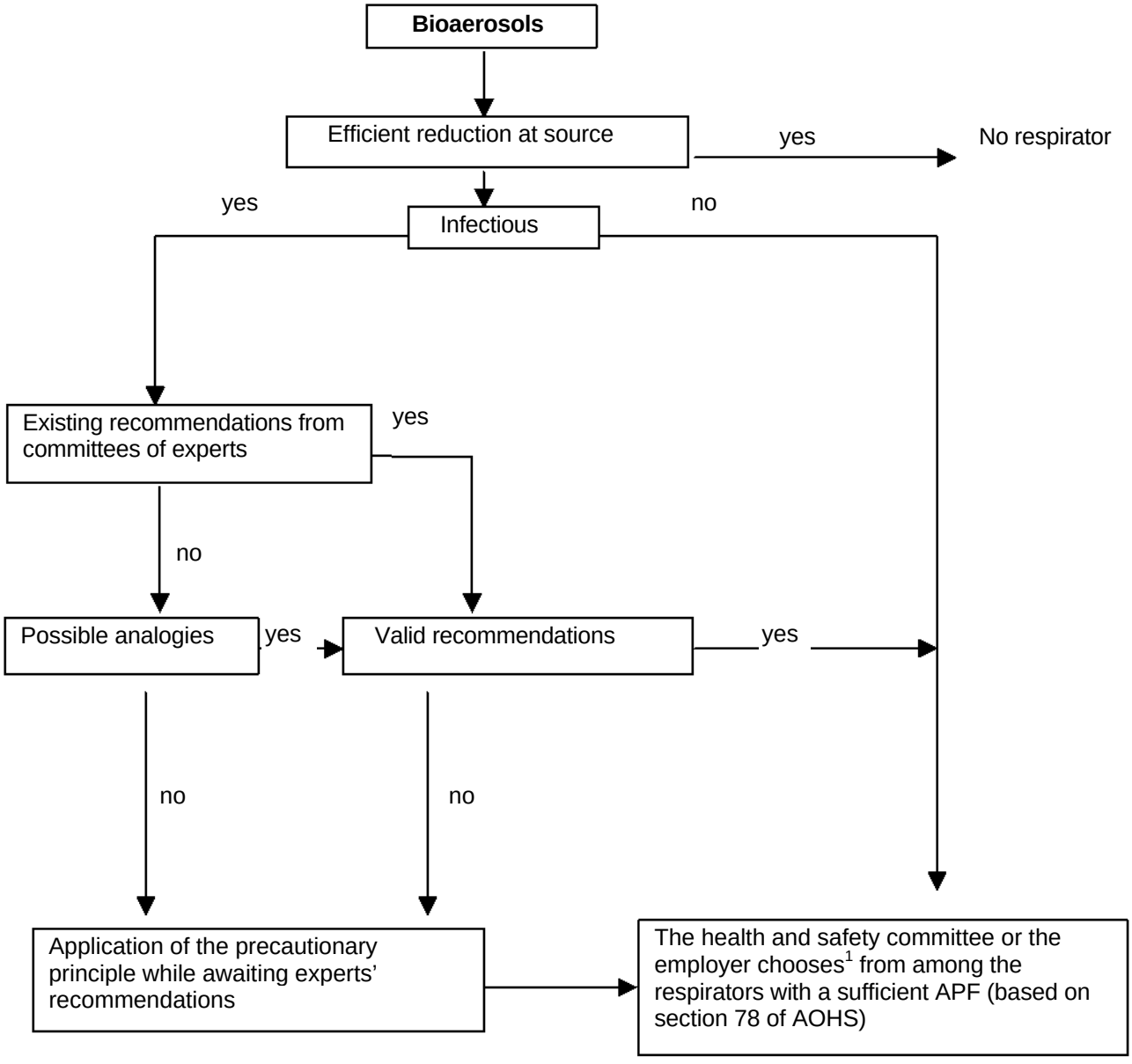
APPENDIX 1 **Decision tree for selecting a respirator against bioaerosols**



[1] The choice is based on the realities of the workplace.

APPENDIX 2 Standards and regulations

Section 1 of the Act respecting occupational health and safety of Québec (AOHS) defines a contaminant as solid, liquid or gaseous matter, a microorganism, a sound, a vibration, a radiation, heat or an odor, or any combination of these likely to alter in any way the health or safety of workers (AOHS, 2003). Employers and workers must know their obligations and their rights related to AOHS, as well as its pursuant Regulation respecting occupational health and safety (ROHS) (AOHS, 2003; ROHS, 2007). The rights and obligations concerning respiratory protection are particularly important in the presence of contaminants that are possible health hazards that cannot otherwise be controlled.

Although personal protective equipment (PPE) is vital for some workplaces or for performing certain tasks, it should however be remembered that the purpose of the AOHS is to eliminate, at source, hazards to the health, safety and physical integrity of workers (AOHS, 2003).

For respiratory protection against chemical contaminants, the ROHS prescribes more specific measures in sections 45 and 47. It states in particular that the employer must supply at no charge to the worker the respiratory protective equipment provided for in the *Guide des appareils de protection respiratoire utilisés au Québec* (Lara and Vennes, 2002) published by the IRSST (Québec occupational health and safety research institute) as it reads at the time that it is applied; the employer must ensure that the worker wears the equipment.

The equipment must be chosen, fit, used and cared for in compliance with CSA Standard Z94.4-93 Selection, Use and Care of Respirators. A respiratory protection program must be developed and applied in accordance with the standard. Furthermore, this program's specific requirements must also be followed for bioaerosols. In fact, other important organizations such as the Institut National de Recherche et de Sécurité (INRS) of France, the National Institute for Occupational Safety and Health (NIOSH), and the Centers for Disease Control and Prevention (CDC) recommend that a respiratory protection program be established when respirators are used, regardless of the contaminant involved (INRS, 2005; NIOSH, 1999).

In addition, according to section 78 of AOHS (2003), it is the responsibility of the establishment's health and safety committee to choose the respirators best adapted to the workers' needs.