Chemical and Biological Hazard Prevention

Studies and Research Projects

REPORT **R-804**

Development of a Control Banding Method for Selecting Respiratory Protection Against Bioaerosols

Jacques Lavoie
Eve Neesham-Grenon
Maximilien Debia
Yves Cloutier
Geneviève Marchand

irsst

The Institut de recherche Robert-Sauvé en santé et en sécurité du travail (IRSST), established in Québec since 1980, is a scientific research organization well-known for the quality of its work and the expertise of its personnel.

OUR RESEARCH is *working* for you !

Mission

To contribute, through research, to the prevention of industrial accidents and occupational diseases and to the rehabilitation of affected workers;

To disseminate knowledge and serve as a scientific reference centre and expert;

To provide the laboratory services and expertise required to support the public occupational health and safety network.

Funded by the Commission de la santé et de la sécurité du travail, the IRSST has a board of directors made up of an equal number of employer and worker representatives.

To find out more

Visit our Web site for complete up-to-date information about the IRSST. All our publications can be downloaded at no charge.
www.irsst.qc.ca

To obtain the latest information on the research carried out or funded by the IRSST, subscribe to Prévention au travail, the free magazine published jointly by the IRSST and the CSST.
Subscription: www.csst.qc.ca/AbonnementPAT

Legal Deposit
Bibliothèque et Archives nationales du Québec
2013
ISBN: 978-2-89631-703-5 (PDF)
ISSN: 0820-8395

IRSST – Communications and Knowledge Transfer Division
505 De Maisonneuve Blvd. West
Montréal, Québec
H3A 3C2
Phone: 514 288-1551
Fax: 514 288-7636
publications@irsst.qc.ca
www.irsst.qc.ca

Chemical and Biological Hazard Prevention

Studies and Research Projects

REPORT **R-804**

Development of a Control Banding Method for Selecting Respiratory Protection Against Bioaerosols

Jacques Lavoie[1], Eve Neesham-Grenon[2], Maximilien Debia[2], Yves Cloutier[1,] Geneviève Marchand[1]

[1]Prévention des risques chimiques et biologiques, IRSST
[2]Département de santé environnementale et santé au travail, Université de Montréal

Clic Research
www.irsst.qc.ca

A PDF version of this publication is available on the IRSST Web site.

This study was funded by the IRSST. The conclusions and recommendations are solely those of the authors.
This publication is a translation of the French original; only the original version (R-766) is authoritative.

The translation of this study into English was undertaken in response to a request from, and thanks to funding by, the CSA Group.

English site: http://www.csagroup.org/us/en/home
French site: http://www.csagroup.org/ca/fr/accueil

PEER REVIEW

In compliance with IRSST policy, the research results published in this document have been peer-reviewed.

ACKNOWLEDGEMENTS

The authors want to thank all the members of the expert committee who participated in this project. They are: Ali Bahloul, specialist in modeling and ventilation, and Claude Ostiguy, specialist in control banding for nanoparticles, at the Institut de recherche Robert-Sauvé en santé et en sécurité du travail; Simon Smith, specialist in respiratory protection at 3M; Sophie Therrien and Riadh Benziane at Hôpital Sacré-Cœur de Montréal; Michel Gagné at the Commission de la santé et de la sécurité du travail; and Luc Bhérer, occupational health physician at the Agence de santé et des services sociaux de la Capitale-Nationale and at the ministère de la Santé et des services Sociaux du Québec.

SUMMARY

The selection of a respirator against bioaerosols can be a complex task, due to the lack of occupational exposure limits and toxicological data, as well as the limitations of the current sampling techniques and the wide variety of bioaerosols. Under these circumstances, a qualitative risk evaluation and management method provides an alternative to the quantitative methods used in occupational hygiene. This report proposes a control banding method for selecting respiratory protection against infectious and non-infectious bioaerosols applicable to all workplaces and intended for occupational hygienists and other occupational health and safety practitioners, as well as for experts who are members of learned societies. This model, which is follow-up to the *Guide on Respiratory Protection against Bioaerosols*[1], published by the Institut de recherche Robert-Sauvé en santé et en sécurité du travail (IRSST) in 2007, is based on bioaerosol-related knowledge and on approaches to control banding developed mainly for chemical contaminants and nanoparticles. The model is presented in the form of a matrix consisting of the four risk groups used in biosafety and of five exposure levels. The cross-tabulation of a risk group and a given exposure level corresponds to an assigned protection factor that allows the user to choose an appropriate respirator. The exposure level is itself the result of the sum of the scores assigned to the control levels and to the bioaerosol generation rates. Respiratory protection is therefore chosen on the basis of the danger represented by the bioaerosol, the workplace control level, and the type of activities carried out in the workplace. The model is simple to use and generally agrees with the opinions and recommendations of experts. This approach is in no way intended to replace the work of the occupational hygienist and should be used only by individuals with a sufficient level of knowledge and experience, in the context of an overall workplace risk assessment and management approach.

[1] http://www.irsst.qc.ca/media/documents/PubIRSST/RG-497.pdf

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

1. CONTEXT

The health risks associated with occupational bioaerosol exposure are relatively well known and the importance of properly protecting workers against these agents is often underestimated, in the same way as for chemical and physical agents [2]. The evaluation of workplace bioaerosol exposure risk is a complex task, considering the great diversity of bioaerosols, the limitations of the measurement methods available, and the lack of occupational exposure limits (OEL) [1]. In this context, the choice of appropriate respiratory protection against bioaerosols can be difficult using a quantitative approach. The development of a qualitative approach is therefore an interesting alternative.

In 2007, the Institut de recherche Robert-Sauvé en santé et en sécurité du travail (IRSST) published the *Guide on Respiratory Protection against Bioaerosols* [2]. The purpose of this guide is to orient the choice of respirators against infectious and non-infectious bioaerosols in hazardous situations for workers in different industries. In addition, it recommended that the choice of respiratory protection against infectious bioaerosols be based on the decisions of experts. These experts are often affiliated with learned societies, such as Québec public health authorities and their professional subcommittees in health and medicine (e.g., Comité des infections nosocomiales du Québec [CINQ, the Québec nosocomial infections committee]), the Public Health Agency of Canada (PHAC) or, at the international level, the Centers for Disease Control and Prevention - National Institute for Occupational Safety and Health (CDC-NIOSH), and the World Health Organization (WHO). However, the opinions issued by these experts can vary significantly for similar risk situations. The current project, whose objective is to facilitate the choice of respiratory protection, is therefore completely relevant. This project complements the guide previously published by the IRSST, by providing occupational hygienists and other occupational health and safety (OHS) practitioners with a qualitative tool that is easy to use and that integrates control banding, thus allowing the appropriate respiratory equipment against infectious and non-infectious bioaerosols to be chosen. The results of this project may be used by expert members of learned societies in developing or updating standards, guides and recommendations related to respiratory protection against bioaerosols.

Control banding is not intended to replace traditional risk evaluation and management methods when they are possible and available, but is instead a complement to them. The means of control hierarchy must be applied at all times, meaning that priority be given to contaminant elimination or reduction at source in order to reduce to a minimum the environmental exposure of workers; as a complement, since collective and organizational means are sometimes insufficient, protective means and equipment must be used [3]. According to section 45 of the *Regulation respecting occupational health and safety* [4], the respirator must be selected, adjusted, used and cared for in accordance with CSA Z94.4-93 [5], as mentioned in the *Guide des appareils de protection respiratoire utilisés au Québec* [6]. The use of an appropriate respirator must be part of a respiratory protection program developed and applied in accordance with the above-mentioned standard and be the subject of periodic monitoring and evaluation [3]. The tool presented in this document cannot be used in the presence of an atmosphere that is oxygen-deficient (concentration below 19.5%) or presenting a risk of fire or explosion, in the case of an emergency situation or a situation immediately dangerous to life or health (IDLH), or in the presence of chemical contaminants.

2. STATE OF KNOWLEDGE, EXISTING APPROACHES, AND OBJECTIVES

2.1 Control banding

Control banding is a qualitative or semi-quantitative approach for managing health and safety risks. It was developed some twenty years ago by OHS professionals in the pharmaceutical industry for evaluating the risk of contaminants without an OEL or for which there are few toxicological data [7]. Subsequently, it was adapted to chemical contaminants [8,9] and, more recently, to nanoparticles [10,11]. This approach generally consists of a system of scores assigned to the risk levels and exposure levels classified by bands, in order to select means of exposure prevention and control in relation to the scores obtained following their multiplication or addition. Control banding has been the subject of several articles and analyses [12-14].

According to Maidment [15], the key to success in the development of a control banding program is the importance of limiting the number of factors in the model in order to reduce its complexity and facilitate its application by non-experts. The risk evaluation principle of the control banding model is based on simplified modeling techniques and methods for calculating weighted scores [16]. This evaluation includes three main aspects [16]:

1. Classification of substances according to the risk level
2. Assessment of workers' exposure: potential exposure and risk assessment
3. Selection of the control and prevention approach based on a risk score calculated by combining the risk and exposure indexes

Control banding has been successfully used in the above-mentioned fields for many years. Studies have shown its value and usefulness as a tool for risk evaluation and management, by mainly comparing the results obtained to the recommendations of occupational hygienists or even to workplace measurements [9,17-19]. The international OHS community is in agreement that it is an approach which is expected to improve, which will be increasingly used, and which will increase workers' protection and reduce the health effects of contaminants [16].

2.2 Work of McCullough and Brosseau

The model of McCullough and Brosseau was developed for selecting respirators against infectious bioaerosols in hospitals [20]. Even though it was not developed by using a control banding approach, it contains some aspects of it. It is therefore of great interest in the application of a control banding approach for the selection of respiratory protection against bioaerosols.

The assigned protection factor (APF), which is associated with a respirator, is based on a risk group (RG) and an exposure level (C). The model adapted to the Québec regulatory context is found in Figure 1 where each of the bands in this figure corresponds to a given APF [20].

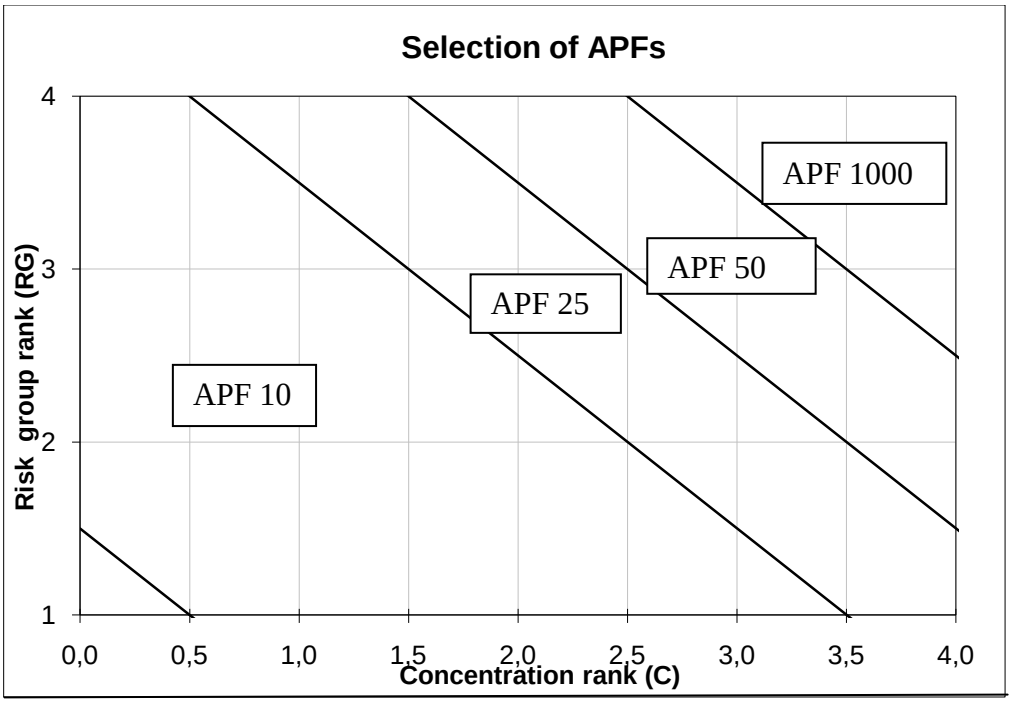

Figure 1 : Identification of the APF corresponding to the risk group and exposure level (based on the model of McCullough and Brosseau)

According to McCullough and Brosseau [20], since there is no occupational exposure limit (OEL) for bioaerosols, the exposure level (C for concentration of the contaminant or bioaerosol) should take into account two aspects of the work environment: 1) the control level (ventilation rate, Q); and 2) the aerosolization potential of the biological contaminant and the activities carried out (generation rate, G). It should be mentioned that the aerosolization potential has greater weight than the ventilation rate, particularly when microorganism emissions are involved (coughing, sneezing, medical care, etc.), where ventilation rates have little impact.

Furthermore, low ventilation rates can contribute to increased bioaerosol concentrations in the work environment due to the lack of dilution. Riley and Nardell [21] presented a model that takes into account the infectious potential of bioaerosols in the ambient air, referring to the Wells-Riley equation [22]. This model has been extensively used in the analysis of ventilation strategies associated with airborne infectious events in clinical environments [23]. It is based on an equation that is very useful for understanding the relationship between the number of new infections (C), the number of susceptible people (S), the infectious agents (I), the number of airborne infection doses added to the air (q, by unit of time) for a case at the infectious stage, pulmonary ventilation per susceptible person (p, in volume by unit of time), the exposure time (t), and the volume of fresh air (Q):

$$C = S(1 - e^{-Iqpt/Q}) \qquad \text{(equation 1)}$$

Equation 1 shows the impact of an increase in the volume of fresh or disinfected air on airborne infection rates. An increase in the volume of fresh air (Q) reduces the exposure level due to its dilution effect [24]. McCullough and Brosseau [20] proposed the following classification for

ventilation rates (Q) according to the standard of the *American Society of Heating, Refrigerating and Air-Conditioning Engineers (*ASHRAE) in force in 1991 [24] (Table 1).

Table 1: Classification of ventilation rates (Q) according to ASHRAE - Standards for hospitals

Locations	Minimum ACH*	Ventilation rate (Q) rank
Operating room	25	5
Autopsy, isolation room	12	4
Intensive care, recovery room	6	3
Patient room, sterile storeroom	4	2
Storeroom for clean linen or equipment	2	1

*ACH = Air changes per hour

The other aspect of the work environment to be considered involves the activity rate or aerosol generation rate that can potentially contaminate the air. The generation rate is a function of the quantity (number) of bioaerosols generated and represents the contribution of a particular source to its concentration in the air [20]. It is very difficult to precisely measure the generation rates for infectious aerosols originating from humans. McCullough and Brosseau instead suggest using a method that qualitatively classifies generation rates according to the source or the activity (Table 2). As an example, a person with tuberculosis can be considered as a source whose generation rate varies with the activity. Thus, if the person is sleeping and not coughing, he will expel less *Mycobacterium tuberculosis* into the environment than if he is undergoing respiratory therapy.

The rank or band corresponding to the exposure rate (C) is therefore equal to the quotient of the rank of the generation rate (G) by the rank of the ventilation rate (Q). It is expressed by the following equation:

$$C_{rank} = (G_{rank}/Q_{rank}) \qquad \text{(equation 2)}$$

This "C" value is found on the abscissa in Figure 1. It should be noted that, according to this relationship, any increase in the ventilation rank will reduce the exposure rate. This situation does not always correspond to reality in workplaces where a worker's exposure often depends on his proximity to a contaminant source, which can affect and counteract the desired effect of general ventilation.

Table 2: Generation rate (G) in relation to the source and the human activity

Human sources of infectious bioaerosols*	Type of activities	Generation rate (G) rank
Not speaking, not coughing and not sneezing	Manipulation without possibility of generation (e.g., preparation of microscope slide)	1
Coughing or sneezing with mouth covered	Manipulation with low risk of generation (e.g., culturing)	2
Coughing or sneezing with mouth uncovered	Manipulation with high risk of accidental generation (e.g., centrifugation)	3
Respiratory therapy, autopsy, dissection	Deliberate aerosolization (e.g., research work)	4

***** Applies to people who are infected or suspected of being infected

2.3 CSA Z94.4-11

Equation 2 presented above is used by the CSA in the most recent revision of its Z94.4 standard in the context of a control banding approach to the choice of respiratory protection against bioaerosols [25].

In this approach, the user is provided with a selection tool consisting of two wheels. One wheel applies to health care environments (Figure 2) and the other to general work environments (Figure 3). Each wheel is divided into four quarters corresponding to four risk groups (R1 to R4). Each quarter is subdivided into 16 sections corresponding to the intersects between the

generation rate (G1 to G4) and the control level (C1 to C4). Each section contains a number and a colour corresponding to the minimum acceptable protection level (Figure 4).

The user first identifies the work environment in which the bioaerosol is present. He then selects the appropriate wheel (health care or general), determines the risk group to which the bioaerosol belongs, and determines the generation rate and the control level. The user is able to choose an appropriate respirator based on the acceptable protection level obtained, with each protection level being associated with a minimum APF [25].

Risk group	
No diseases or adverse health effects	R1
Rarely serious, prevention / therapy exists	R2
Serious / lethal, prevention or therapy possible	R3
Serious / lethal, prevention or therapy unavailable	R4

Generation rate	
Patient not coughing or sneezing	G1
Patient coughing and sneezing with mouth covered	G2
Patient coughing and sneezing with mouth uncovered	G3
Medical procedures generating aerosols	G4

Control level	
Poorly ventilated; < 3 ARH*	C1
Corridor or patient room; 3 to 6 ARH	C2
Negative pressure, laboratory, autopsy room; 6 to 12 ARH	C3
Surgery > 12 ARH	C4

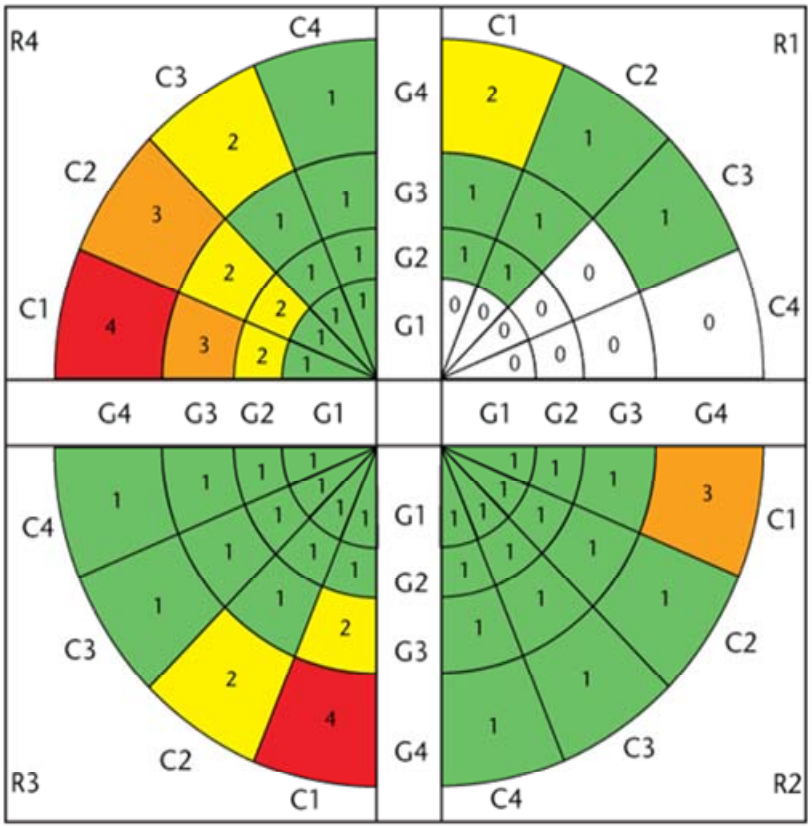

Figure 2

* For the control level, ARH means "air renewals per hour," equivalent to ACH.

Figure 2. Control banding approach for bioaerosols in health care facilities (with permission of the CSA)

Risk group	
No diseases or adverse health effects	R1
Rarely serious, prevention or therapy exists	R2
Serious / lethal, prevention or therapy possible	R3
Serious / lethal, prevention or therapy unavailable	R4

Generation rate	
Low release of bioaerosol / pathogen; vacuuming with HEPA filter	G1
Medium release of bioaerosol / pathogen; soaking then shoveling	G2
High release of bioaerosol / pathogen; misting then shoveling	G3
Very high release of bioaerosol / pathogen; dry sweeping	G4

Control level	
Indoors – poorly ventilated ≤ 1 ARH	C1
Indoors – ventilation 1< ARH ≤ 4 Outdoors – no wind	C2
Indoors – ventilation 4< ARH ≤ 6 Outdoors – low wind	C3
Indoors – ventilation > 6 Outdoors – moderate wind	C4

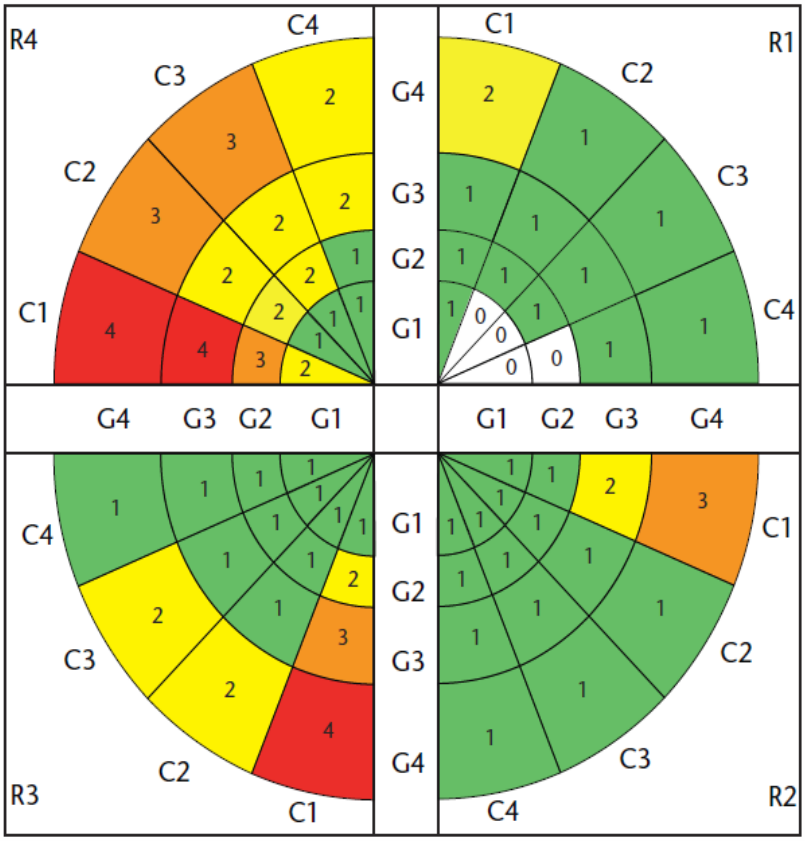

Figure 3. Control banding approach for bioaerosols in general workplaces (with permission of the CSA)

Acceptable level						Air-purifying options	APF	Atmosphere-supplying options
0	1	2	3	4	5			
					5	No air-purifying option available	10000	SCBA (pressure-demand) full-facepiece SCBA (pressure-demand) tight-fitting hood Multi-functional SCBA/airline
				4 to 5		Powered air-purifying full-facepiece Powered air-purifying helmet/hood with SWPF study	1000	Airline (continuous-flow) full-facepiece Airline (pressure-demand) full-facepiece Airline (continuous-flow) helmet/hood with SWPF study
			3 to 5			Powered air-purifying half-facepiece Air-purifying (negative-pressure) full-facepiece	50	Airline (pressure-demand) half-facepiece Airline (continuous-flow) half-facepiece
		2 to 5				Powered air-purifying loose-fitting facepiece/visor Powered air-purifying helmet/hood without SWPF study	25	Airline (continuous-flow) loose-fitting facepiece/visor Airline (continuous-flow) helmet/hood without SWPF study
	1 to 5					Air-purifying (negative-pressure) half-facepiece (including filtering facepieces)	10	No atmosphere-supplying option available
						No respiratory protection required	<1	No respiratory protection required

Figure 4. Hierarchy of respiratory protection

2.4 Objectives

The objective of this research project is to develop and validate, in collaboration with a committee of experts, a control banding method for the selection of respiratory protection against the infectious and non-infectious bioaerosols encountered in different work environments.

3. DESCRIPTION OF THE PRESENT APPROACH

3.1 Methodology

The present approach has been based on control banding models applied to chemical substances [8,9] and nanoparticles [10,11], the work of McCullough and Brosseau [20], the new CSA Z94.4-11 standard [25], as well as the international classification of microorganisms according to their pathogenic character [25-29]. A 4 X 5 model was developed, consisting vertically of the four risk groups used in biosafety, and horizontally of 5 exposure levels. The control levels and the generation rates were classified into five bands, each corresponding to a score. The sum of the control level and generation rate scores provides an exposure level which, once it is cross-tabulated with the microorganism risk groups, is associated with an APF that makes it possible to choose a sufficiently safe respirator. The bands, weightings and scores were validated by a committee consisting of experts in risk management (including control banding), occupational hygiene, microbiology, the behaviour of aerosols (including bioaerosols), fluid mechanics (for means of control), respiratory protection against bioaerosols, and occupational medicine. Case studies were carried out, in which the APFs obtained with the proposed model for different work situations were compared to the existing recommendations for the same situations (see Chapter 5).

3.2 Description of the bands

3.2.1 Risk group

Bioaerosols are defined in this document as being airborne particles containing living organisms, such as viruses, bacteria, moulds and protozoa, and/or substances or products originating from these organisms (e.g., toxins, dead microorganisms or fragments of microorganisms) [30]. Like all other aerosols, bioaerosols are defined by their particle size and behave according to aerosol physics [2,20].

Microorganisms are classified according to their pathogenic character into four risk groups [25-29]. In addition to the microorganism's pathogenic character, these risk groups take into account the infectious dose, the mode of transmission, the host, the availability of preventive measures, and the availability of an effective treatment [27]. There are three infectious risk groups (RG 2 to RG 4) and one non-infectious risk group (RG 1). The four risk groups are, in the present approach, equivalent to the control bands used in other control banding approaches. Table 3 summarizes the classification retained and provides several examples of microorganisms belonging to each group. For a more exhaustive list, refer to Appendix I of this document.

Table 3: Classification of microorganisms according to their risk group [25-29]

Risk group	Description	
1	Def.	*Low risk for individuals and communities* A biological agent not likely to cause diseases in healthy workers. Non-infectious bioaerosols are in this category.
	Ex.	*Bacillus subtilis, Escherichia coli K12*, the majority of moulds
2	Def.	*Moderate risk for individuals, low for communities* Pathogenic agent that can cause disease in humans but that, under normal circumstances, is not likely to pose a serious threat. Effective treatments and preventive measures exist that limit the risk of propagation.
	Ex.	**Bacteria:** *Salmonella* spp., *Legionella* spp., *Chlamydia* spp., *Clostridium* spp., *Vibrio cholerae, Listeria* spp., *Streptococcus* spp., *Helicobacter pylori* **Fungal agents:** *Blastomyces dermatitidis, Cladosporium bantianum, Cryptococcus neoformans, Microsporum, Penicillium marneffei* **Parasites:** *Entamoeba histolytica, Giardia lamblia, Leishmania* spp., *Plasmodium* spp., *Schistosoma* spp., *Toxoplasma, Trypanosoma* **Viruses:** Hepatitis A, B, C, D and E, Epstein Barr, types A, B and C influenza, human papilomavirus, mumps, measles, polio (all types)
3	Def.	*High risk for individuals, low for communities* Pathogenic agent whose potential for an infection is real and that generally causes a serious or lethal disease for humans. Curative treatments sometimes exist.
	Ex.	**Bacteria:** *Mycobacterium tuberculosis, Brucella* spp., *Yersinia pestis* **Fungal agents:** *Coccidioides immitis, Histoplasma capsulatum* **Viruses:** Hantavirus, Rift Valley fever, Japanese encephalitis, Yellow fever, types 1 and 2 HIV **Prions:** Creutzfeldt-Jakob disease, kuru agents
4	Def.	*High risk for individuals and for communities* Pathogenic agent that generally causes a very serious disease in humans and for which no treatment exists. This group consists only of viruses.
	Ex.	Crimean-Congo haemorrhagic fever, Ebola, Marburg, Lassa, Herpes B or simian herpes, haemorrhagic fever agents, and undefined viruses

Table 3 does not specify the mode of transmission (inhalation, contact, etc.) and the classification may not be up to date. It is the responsibility of the user to ensure the validity of the information available to him. Table 4 provides a list of pathogenic organisms (RG 2 to RG 4)

and infectious diseases that can be transmitted by aerosolization. They are examples and not an exhaustive list.

Table 4: Pathogens and infectious diseases with the potential of being transmitted by air (adapted from ASHRAE (2009) and Tang et al. (2006))

Disease/pathogen	Transmission route
Anthrax (*Bacillus anthracis*)	Inhalation of spores
Arenavirus	Inhalation of small airborne particles originating from rodent feces
Aspergillosis *(Aspergillus fumigatus*)	Inhalation of airborne conidia (spores)
Blastomycosis (*Blastomyces dermatitidis*)	Conidia, inhaled in dust that contains spores
Brucellosis (*Brucella*)	Inhalation of airborne bacteria
Chickenpox/shingles	Liquid aerosols or airborne propagation of vesicular fluid or secretions from the respiratory tract
Coccidioidomycosis (*Coccidioides)*	Inhalation of infectious arthroconidia
Adenovirus	Transmitted by liquid respiratory aerosols
Enterovirus (Coxsackie virus)	Propagation by liquid aerosols
Cryptococcosis (*Cryptococcus neoformans)*	Presumed inhalation
Human parvovirus	Contact with infected respiratory secretions
Rotavirus	Possible respiratory propagation
Norwalk virus	Airborne transmission by fomites
Hantavirus	Presumed transmission by aerosols from rodent excrement
Histoplasmosis (*Histoplasma capsulatum*)	Inhalation of airborne conidia
Influenza	Airborne transmission predominates
Lassa virus	Contact with airborne infected rodent excrement
Legionellosis (*Legionella pneumophilia)*	Epidemiological data support airborne transmission
Lymphocytic choriomeningitis	Oral or respiratory contact with feces, food or dust contaminated with the virus
Measles	Airborne transmission by propagation of liquid aerosols
Melioidosis (*Burkholderia pseudomallei*	Inhalation of soil dust
Meningitis (*Neisseria meningitidis*)	Respiratory liquid aerosols originating from the nose and throat
Meningitis (*Haemophilus influenzae*)	Infection by liquid aerosols and nose and throat discharge
Meningitis (*Streptococcus pneumoniae*)	Propagation of liquid aerosols and contact with respiratory secretions
Mumps	Airborne transmission or propagation of liquid aerosols
Nocardia	Acquired by inhalation
Paracoccidioidomycosis (*Paracoccidioïdes brasiliensis*)	Presumed inhalation of contaminated dust or soil
Whooping cough (*Bordetella pertussis*)	Direct contact with the discharge from the mucous membranes of the respiratory tract of airway-infected people

Disease/pathogen	Transmission route
Plague (*Yersinia pestis*)	Rarely by liquid aerosols originating from human patients. In the event of deliberate use, bacilli could possibly be transmitted in aerosol form.
Pneumonia (*Streptococcus pneumoniae*)	Transmission by liquid aerosols
Pneumonia (*Mycoplasma pneumoniae*)	Probable inhalation of liquid aerosols
Pneumonia (*Chlamydia pneumoniae*)	Possibilities include airborne transmission
Psittacosis (*Chlamydia psittaci*)	By inhalation of the agent from dried droppings, secretions, and dusts in the feathers of infected birds
Q fever (*Coxiella burnetii*)	Commonly from airborne dissemination of Coxiella in dust
Rabies	Airborne transmission has been demonstrated in a cave where bats nested, as well as in the laboratory, but this is very rare.
Rhinitis/common cold (rhinovirus, coronavirus, parainfluenza, respiratory syncytial virus)	Presumed inhalation of liquid aerosols
German measles	Transmission by liquid aerosols
Smallpox	Transmission by liquid aerosols
Sporotrichosis (*Sporothrix schenckii)*	Presumed occurrence of pulmonary sporotrichosis by inhalation of conidia
Tuberculosis (*Mycobacterium* spp.)	Transmission by liquid aerosols

It is important to note that a microorganism that is known not to cause respiratory problems may nevertheless represent a health risk for workers who inhale it if it is in bioaerosol form, for example, if it is swallowed. Also, a pathogenic agent actually considered as non-transmissible through the air may prove to be transmissible as knowledge evolves. It is therefore recommended that all microorganisms with a potential for workplace aerosolization and belonging to the same group be considered as representing an equivalent health risk for workers, regardless of the mode of transmission. Also, prolonged and continuous exposure to high concentrations of RG 1 bioaerosols may, despite their non-infectious nature, lead to serious and irreversible health problems such as sensitization and the development of occupational diseases (e.g., extrinsic allergic alveolitis, asthma, organic dust toxic syndrome (ODTS), baker's lung, farmer's lung, mushroom worker's lung, sewage worker's syndrome, etc.) [1,2,32-36]. Concentrations of bioaerosols characteristic of various work environments are presented in the document of Lavoie et al. [2]. The present approach was developed from the standpoint of protecting workers against the risks associated with exposure to RG 1 bioaerosols as much as to RG 2 to RG 4 aerosols.

3.2.2 Exposure level

According to Brouwer [37], there are two different control banding approaches for characterizing the exposure level: the scoring system where points are assigned to the different bands and then added, and the binary system (yes/no) where the bands are defined according to a decision tree. For the present approach, the principle of score adding was preferred because it takes better account of the reality associated with localized or point sources often observed in workplaces. Even ideal general ventilation does not reduce a worker's exposure if the worker is located near the source, if there are projections, or if he blocks or protects the source by disturbing the ambient air flow profiles. A risk is always present in these situations and can never be reduced to

zero by general ventilation in this additive model, as is the case in the models of McCullough and the CSA, where ventilation divides the risk [20,25] (see equation 2).

As in the CSA's approach [25], the exposure level is a function of the control level and generation rate. The control level corresponds to the type and rate of ventilation in the workplace (indoors versus outdoors, number of air changes per hour (ACH), etc.). The number of ACH must correspond to the actual number of air changes and not the number indicated in the plans and specifications. The description of what constitutes an appropriate evaluation of the performance of ventilation systems and their capacity goes beyond the objectives of this study. It is recommended that qualified professionals in ventilation system engineering or contractors specialized in this field be consulted as needed for such an evaluation. Table 5 presents the control bands and the corresponding scores.

Table 5: Control level (Q)

Points	Control level bands
2.0	ACH* ≤ 2; no or low ventilation, confined or other similar situations
1.5	2 < ACH ≤ 6; general ventilation or open windows or other similar situations
1.0	6 < ACH ≤ 12; room at negative pressure; laboratory ventilation; isolation chamber; displacement ventilation or other similar situations
0.5	ACH > 12; mechanized operations; operations in a laboratory hood; some hospital departments (bronchoscopy, operating room; etc.); outdoor work or other similar situations
0	Operations in a laminar flow hood; closed circuit sources or other similar situations

* ACH = Air changes per hour

The generation rate corresponds to the aerosolization (suspension) potential of the bioaerosols. It depends on the type of activity performed, the process, the proximity of the sources, etc. Table 6 presents the generation rate bands and the corresponding scores.

Table 6: Generation rate (G)

Score	Generation rate bands	
	Probability of inhalation	**Examples**
8.0	Very high	Uncontrolled aerosolization of the biological contaminant; proximity to emission sources; work in the emission plumes; medical procedures producing aerosols or other similar situations
6.0	High	High aerosolization; decontamination work; care given to an infectious patient coughing or sneezing with mouth uncovered or other similar situations
4.0	Moderate	Moderate aerosolization; contact with the biological contaminant; long distance from the source; infectious patient coughing or sneezing with mouth covered or other similar situations
2.0	Low	Low aerosolization; personnel assigned to other care tasks
0	None	No aerosolization

It is important to note that the items in the different bands are mutually exclusive. The exposure level is the result of the weighted sum of the control level (Table 5) and the generation rate (Table 6) scores for a maximum score of 10. The weighting factors used are 20% of the total score from the control level and 80% from the generation rate. This weighting was chosen in order to take reality better into account because it is logical to think that the generation rate and the proximity of the source contribute more significantly to the overall exposure level than does the control level. It is an empirical choice but one that is supported by this project's committee of experts. This weighting has already been included in the scores presented in Tables 5 and 6.

A total score between 0 and 2 (first band) is considered as a very low exposure level, from 2.5 to 5 (second band) as a low level, from 5.5 to 7 (third band) as a medium level, from 7.5 to 9 (fourth band) as a high level, and from 9.5 to 10 (fifth band) as a very high exposure level (Table 7).

Table 7: Exposure levels

	Exposure level (sum of the control level and generation rate scores)				
Band	1	2	3	4	5
Level	Very low	Low	Medium	High	Very high
Score	0 – 2	2.5 – 5	5.5 – 7	7.5 – 9	9.5 – 10

3.3 Selection model

The exposure level band matches an APF to the risk group band. The respirator is then selected on the basis of the APF. Table 8 summarizes the model. In situations of simultaneous exposure to several biological contaminants, the highest APF takes precedence. The tool's implementation procedure is presented in detail in Appendix II.

Table 8: Model for selecting the minimum assigned protection factor (APF) corresponding to the risk group and exposure level

		Exposure level				
		1 Very low (0 – 2)	**2** Low (2.5 – 5)	**3** Medium (5.5 – 7)	**4** High (7.5 – 9)	**5** Very high (9.5 – 10)
Risk group	**1**	None	10	10	10	25
	2	None	10	10	25	50[1]
	3	None	10	25	50[1]	1000
	4	1000	1000	1000	1000	1000

[1] NIOSH's APF of 50 is equivalent to the APF of 100 in the *Guide des appareils de protection respiratoire utilisés au Québec*[6].

4. VALIDATION AND APPLICATION OF THE PRESENT APPROACH

Validation by case studies has been recognized as the method of choice for evaluating control banding approaches [17,37]. Validation consists here of doing a comparative analysis between the APFs obtained with the proposed model and the existing recommendations for the same work situations.

4.1 SARS virus (Risk group (RG) 3)

A) Personnel responsible for patient triage in the emergency room of a hospital where SARS is present

- Control level (Q)=1.5 (general ventilation); generation rate (G)=2.0 (low aerosolization); exposure level (Q+G)=3.5 (low/band 2); APF 10
- Recommendation of the *Comité ministériel sur les mesures de précaution contre le SRAS* [38]: half-facepiece with disposable N95 filter (APF 10)

Same recommendations in both cases.

B) Personnel providing care to an infected patient

- Q=1.0 ($6 < ACH \leq 12$); G=6.0 (care given to an infectious patient coughing or sneezing with mouth uncovered); Q+G=7.0 (medium/band 3); APF 25
- Recommendation of the *Comité ministériel sur les mesures de précaution contre le SRAS* [38]: half-facepiece with disposable N95 filter (APF 10) alone or under a PAPR with disposable full hood (APF 50 to 1000)

The government department committee issued this recommendation during the SARS epidemic, when the virus was unknown, which explains the more conservative APF recommended by the committee. The recommendation would probably be different today.

4.2 Tuberculosis (RG 3)

A) Entry into the room of an infected patient

- Q=1.0 (negative pressure); G=4.0 (infectious patient coughing or sneezing with mouth covered); Q+G=5.0 (low/band 2); APF 10
- Recommendation of the *Centers for Disease Control and Prevention* (CDC) [39]: half-facepiece with disposable N95 filter (APF 10)

Same recommendations in both cases.

B) Bronchoscopy on an infected patient or a patient suspected of being infected

- Q=0.5 (bronchoscopy department); G=8.0 (medical procedure producing aerosols (very high aerosolization rate)); Q+G=8.5 (high/band 4); APF 50 (NIOSH) or 100 (Québec)
- Recommendation of the CDC [39]: PAPR (APF 25 to 1000, depending on facepiece)

The APF may be higher or lower depending on the facepiece chosen.

C) Autopsy on a patient with tuberculosis or suspected of having tuberculosis

- Q=1.0 ($6 < ACH \leq 12$); G=6.0 (high probability of aerosolization); Q+G=7.0 (medium/band 3); APF 25
- CDC recommendation [39]: PAPR (APF 25 to 1000, depending on facepiece); recommendation of Nolte et al. [40]: N95 minimum (minimum APF 10); recommendation of McCullough and Brosseau [20]: APF 25

This example shows the diversity in the existing recommendations.

4.3 Hantavirus (RG 3)

A) Telephone installers, plumbers, electricians who may come in contact with rodents or rodents' nests

- Q=2.0 (no ventilation); G=2.0 (low probability of contact with biological contaminant); Q+G=4.0 (low/band 2); APF 10
- Recommendation of the CDC [41]: N100 filtering half-facepiece (APF 10) or PAPR with filtering half-facepiece (APF 25 to 1000, depending on the facepiece) for anyone who cannot wear the N100 filtering half-facepiece. N100 is recommended due to the size of this virus which is close to the size of the most penetrating particles [41].

Same recommendations in both cases.

B) People who frequently handle or are exposed to wild rodents (zoologists, exterminators, etc.)

- Q=2.0 (no ventilation); G=6.0 (high probability of inhalation); Q+G=8.0 (high/band 4); APF 50 (NIOSH) or 100 (Québec)
- Recommendation of the CDC [41]: N100 filtering half-facepiece (APF 10) or PAPR with filtering half-facepiece (APF 50)

Same recommendation or more conservative recommendation with the present approach.

4.4 Anthrax (*Bacillus anthracis)* (RG 3)

A) Personnel doing mail sorting

- Q=1.5 (general ventilation); G=2.0 (low probability of contact with biological contaminant); Q+G=3.5 (low/band 2); APF 10
- Recommendation of the CDC [42]: half-facepiece with disposable N95 filter (APF 10)

Same recommendations in both cases.

B) Personnel collecting samples of *Bacillus anthracis* in a post office

- Q=1.5 (general ventilation); G=4.0 (moderate probability of contact with biological contaminant); Q+G=5.5 (moderate/band 3); APF 25
- Recommendation of the CDC [42]: PAPR with full facepiece (APF 1000)

The bacterium Bacillus anthracis, now classified as RG 3, was classified RG 4 at the time the CDC issued the recommendation (biological weapon), which explains the APF of 1000.

4.5 Legionellosis (*Legionella pneumophilia)* (RG 2)

Cleaning of a spa

- Q=1.5 (general ventilation); G=4.0 (contact with biological contaminant); Q+G=5.5 (medium/band 3); APF 10
- Recommendation of McCullough and Brosseau [20]: APF 10

Same recommendations in both cases.

4.6 Histoplasmosis (*Histoplasma capsulatum)* (RG 3)

A) Inspection, sampling, etc.

- Q=0.5 (outdoor work); G=2.0 (low aerosolization); Q+G=2.5 (low/band 2); APF 10
- Recommendation of Lenhart et al. [43]: half-facepiece with disposable N95 filter (APF 10)

Same recommendations in both cases.

B) Outdoor cleaning and work

- Q=0.5 (outdoor work); G=4.0 (moderate aerosolization); Q+G=4.5 (low/band 2); APF 10
- Recommendation of Lenhart et al. [43]: PAPR with non-fitted facepiece (APF 10)

Same recommendations in both cases.

C) Chimney cleaning, work in attics or henhouses

- Q=2.0 (no ventilation); G=6.0 (high aerosolization); Q+G=8.0 (high/band 4); APF 50 (NIOSH) or APF 100 (Québec)
- Recommendation of Lenhart et al. [43]: full facepiece with disposable N95 filter (APF 50)

Same recommendations in both cases.

4.7 Pig house (RG 1 bioaerosols)

Personnel assigned to animal care

- Q=2.0 (no ventilation); G=8.0 (very high aerosolization); Q+G=10.0 (very high/band 5); APF 25
- Recommendation of Lee et al. [44]: APF 25

Same recommendations in both cases.

4.8 Recycling plant (RG 1 bioaerosols)

Recycling plant worker

- Q=1.5 (general ventilation); G=6.0 (high aerosolization); Q+G=7.5 (high/band 4); APF 10
- Recommendation of Lavoie and Guertin [45]: APF 10

Same recommendations in both cases.

4.9 Water treatment (RG 1 bioaerosols)

Filter press cleaner

- Q=1.5 (general ventilation); G=6.0 (high aerosolization); Q+G=7.5 (high/band 4); APF 10
- Recommendation of Lavoie [46]: APF 10

Same recommendations in both cases.

4.10 Influenza virus A(H1N1) (RG 3)

Personnel cleaning an infected patient's isolation room in a hospital

- Q=1.0 (room at negative pressure); G=4.0 (long distance from the source, moderate aerosolization); Q+G=5.0 (low/band 2); APF 10
- Recommendations of the *Comité sur les infections nosocomiales du Québec* (CINQ) [47]: Surgical or procedure mask.

This example shows that experts' recommendations exist that we consider inadequate. A surgical or procedure mask is not a respirator, has no APF and does not properly protect workers against the inhalation of infectious contaminants.

4.11 Peat moss (bioaerosols in RG 1)

Packaging of peat moss

- Q=1.5 (general ventilation); G=8.0 (uncontrolled aerosolization); Q+G=9.5 (very high/ band 5); APF 25
- Duchaine et al. [48] recommend respiratory protection without specifying an APF (therefore a minimum APF of 10).

No comparison possible.

4.12 *Chlamydia psittaci* (Psittacosis) avian strain (RG 2)

Poultry processing plant

- Q=1.5 (general ventilation); G=2.0 (low probability of inhalation); Q+G=3.5 (low/band 2); APF 10
- Noone [49] recommends respiratory protection without specifying an APF (therefore a minimum APF of 10).

No comparison possible.

In summary, comparison of the proposed model and the existing recommendations shows that the result is identical in twelve of the nineteen examples and sub-examples. As mentioned above, certain recommendations were made in a context in which the bioaerosol was not well known or was classified in a more hazardous RG, resulting in recommended APFs higher than those obtained with the proposed model. These comparisons also show the diversity in the existing recommendations, as well as the lack of precision or prudence of certain recommendations. This particularly justifies the development of a control banding model for the choice of respiratory

protection against bioaerosols that minimizes the differences between the recommendations from the different sources and allows OHS practitioners to be more autonomous.

5. SCOPE AND LIMITATIONS OF THE PRESENT APPROACH

Control banding is a qualitative or semi-quantitative approach for evaluating and managing OHS risks for substances that lack exposure standards or validated measurement methods, as is the case with bioaerosols. This approach establishes links between risk evaluation and control and allows efforts to be focused on the choice and implementation of control strategies rather than on exposure measurement.

Control banding does not verify compliance with an OEL, establish the exposure profile of workers, or perform environmental monitoring. Instead it is an approach that lies upstream from these actions. It must be part of a broader framework for evaluating and managing workplace risks. Control banding has been successfully used in the fields of nanotechnologies and chemical and pharmaceutical products for many years. Studies have shown its value and usefulness as a tool for risk evaluation and management, by primarily comparing the results obtained to the recommendations made by occupational hygienists or even to workplace measurements [9,17-19]. The international OHS community is of the opinion that it is an approach that will be improved and whose use will become increasingly widespread. This same community anticipates that control banding will increase worker protection and reduce contaminant-related health effects [16].

When this approach is used to select respiratory protection against bioaerosols, it requires a certain level of knowledge; otherwise it is preferable to call on experts in order to validate the choice of respirator. Also, this preventive approach follows the current state of knowledge. The information provided in this report is based on up-to-date evidence at the time the report was written. Bioaerosol classification into the four risk groups is subject to changes. It is therefore important that the user ensure the accuracy of the information in his possession. As well, as we saw in the example on anthrax in post offices, this approach is not developed for choosing respiratory protection against biological weapons. In this case, maximum protection should apply.

The present approach is different from that in CSA standard Z94.4-11. It generalizes risk management in all workplaces, without distinguishing between health care environments and other environments. As an example, for general workplaces, the CSA does not recommend any respirator for RG 1 (non-infectious) bioaerosols with a low generation rate (G1) and ventilation rates from 1 to 6 ACH (control levels C2 to C4). In comparison, the approach presented in this report recommends an APF of 10 for the same conditions. For RG 4 bioaerosols, APFs of 10 are recommended by the CSA approach for health care environments if the number of air changes per hour is greater than 12. According to the Public Health Agency of Canada, the only laboratory in the country authorized to handle this type of microorganism (Group 4), the minimum APF used is 1000[2], which the present approach takes into account.

The CSA approach also tends to recommend lower APFs for health care environments, for the four groups of bioaerosols. Thus, according to their approach, some workers may be less protected in relation to their work environment, which is avoided with our approach. Also, the mathematical model used in the CSA approach sometimes has the APF jump from 1 to 3 or from

[2] Bourget, S. *Communication personnelle*. 2012. Pathogen Regulation Directorate, Public Health Agency of Canada.

2 to 4, for example, without using the intermediate APF, for situations that are however intermediate (going from G3 to G4 or from C1 to C2, for example). This is not seen with the present approach.

It is important to mention that CSA standard Z94.4-11 is not the one referred to in the *Regulation respecting occupational health and safety*. Instead, Z94.4-93 is mentioned, which is currently in force in Québec [4]. Biological contaminants are not considered in it.

To make the present approach more accessible and easier to use, the development of a computer-based tool will be proposed following this project. This tool will also contain relevant information and computer links to support the procedure and to document the choices that will be made in it.

6. CONCLUSION

Knowing that bioaerosols are ubiquitous in workplaces and the harmful effects that they can cause on workers' health, it is essential to be able to identify the most hazardous situations and to choose the appropriate respiratory protection against these agents. Due to the limitations of the sampling methods and the lack of OELs for bioaerosols, control banding allows appropriate respiratory protection to be chosen and constitutes an interesting and complementary alternative to the quantitative methods of occupational hygiene. The hierarchy in the means of control must be applied at all times, meaning that contaminant elimination or reduction at the source must be favoured in order to reduce to a minimum the workers' environmental exposure; as a complement, when collective and organizational measures are not sufficient, personal protective means and equipment must be used.

The approach presented in this report was developed to respond to the questions of the people in charge of respiratory protection against bioaerosols in establishments and to provide them with a tool that is easy to use, regardless of the workplace. With this approach, the risks of exposure to infectious and non-infectious bioaerosols can be evaluated by providing recommendations for selecting the appropriate respirator and by identifying the most hazardous operations when workers are exposed to bioaerosols.

Validation by means of case studies has demonstrated a good agreement with the APFs cited in the scientific literature, particularly since the approach in this report is sensitive and conservative.

BIBLIOGRAPHY

1. Eduard, W., et al., *Bioaerosol exposure assessment in the workplace: the past, present and recent advances.* Journal of Environmental Monitoring, 2012. **14**(2): p. 334-339.
2. Lavoie, J., et al., *Guide on Respiratory Protection against Boaerosols: Recommendations on Its Selection and Use. Report RG-501*, 2007, Institut de recherche Robert-Sauvé en santé et en sécurité du travail (IRSST), Montreal, QC.
3. Roberge, B., *Manuel d'hygiène du travail: du diagnostic à la maîtrise des facteurs de risque*. 2004, Mont-Royal, Québec: Association québécoise pour l'hygiène, la santé et la sécurité du travail (AQHSST).
4. Gouvernement du Québec, *Regulation respecting occupational health and safety*, in *c. S-2.1, r. 13*2012, Les Publications du Québec.
5. Canadian Standards Association, *Selection, use and care of respirators:Occupational health and safety*, 1993, ACNOR: Rexdale, ON. p. 103.
6. Lara, J. and M. Vennes, *Guide des appareils de protection respiratoire utilisés au Québec*. 2e ed. 2003: Commission de la santé et de la sécurité du travail du Québec (CSST).
7. Sargent, E.V. and G.D. Kirk, *Establishing airborne exposure control limits in the pharmaceutical industry.* The American Industrial Hygiene Association Journal, 1988. **49**(6): p. 309-313.
8. Russell, R.M., et al., *An introduction to a UK scheme to help small firms control health risks from chemicals.* Annals of Occupational Hygiene, 1998. **42**(6): p. 367-76.
9. Marquart, H., et al., *'Stoffenmanager', a web-based control banding tool using an exposure process model.* Annals of occupational hygiene, 2008. **52**(6): p. 429-441.
10. Paik, S.Y., D.M. Zalk, and P. Swuste, *Application of a pilot control banding tool for risk level assessment and control of nanoparticle exposures.* Annals of Occupational Hygiene, 2008. **52**(6): p. 419-28.
11. Truchon, G. and Y. Cloutier, *Control banding et nanotechnologies.* Travail et Santé, 2009. **25**(1): p. 15-16.
12. Nelson, D.I. and D.M. Zalk, *Control banding: background, critique, and evolution.* Patty's Industrial Hygiene, 2010.
13. Zalk, D.M. and D.I. Nelson, *History and evolution of control banding: a review*. Journal of Occupational and Environmental Hygiene, 2008. **5**(5): p. 330-46.
14. National Institute for Occupational Safety and Health, *Qualitative risk characterization and management of occupational hazards: control banding (CB), a literature review and critical analysis*, 2009, CDC/NIOSH, Atlanta, GA. p. 118.
15. Maidment, S.C., *Occupational hygiene considerations in the development of a structured approach to select chemical control strategies.* Annals of Occupational Hygiene, 1998. **42**(6): p. 391-400.

16. Drolet, D., et al., *Stratégies de diagnostic sur l'exposition des travailleurs aux substances chimiques. Rapport R-665*, 2010, Institut de recherche Robert-Sauvé en santé et en sécurité du travail (IRSST), Montreal, QC.

17. Jones, R.M. and M. Nicas, *Evaluation of COSHH Essentials for vapor degreasing and bag filling operations.* Annals of Occupational Hygiene, 2006. **50**(2): p. 137-147.

18. Tielemans, E., et al., *Stoffenmanager exposure model: development of a quantitative algorithm.* Annals of occupational hygiene, 2008. **52**(6): p. 443-454.

19. Zalk, D.M., S.Y. Paik, and P. Swuste, *Evaluating the Control Banding Nanotool: a qualitative risk assessment method for controlling nanoparticle exposures.* Journal of Nanoparticle Research, 2009. **11**(7): p. 1685-1704.

20. McCullough, N.V. and L.M. Brosseau, *Selecting respirators for control of worker exposure to infectious aerosols.* Infection Control and Hospital Epidemiology, 1999. **20**(2): p. 136-144.

21. Riley, R.L. and E.A. Nardell, *Clearing the air: the theory and application of ultraviolet air disinfection.* American Journal of Respiratory and Critical Care Medicine, 1989. **139**(5): p. 1286-1294.

22. American Society of Heating, Refrigerating and Air-Conditioning Engineers, *Position Document on Airborne Infectious Diseases*, 2009, ASHRAE.

23. Sze To, G. and C. Chao, *Review and comparison between the Wells–Riley and dose-response approaches to risk assessment of infectious respiratory diseases.* Indoor Air, 2010. **20**(1): p. 2-16.

24. American Society of Heating, Refrigerating and Air-Conditioning Engineers, *Health Facilities*, in *1991 Application Handbook*. 1991, ASHRAE: Atlanta, GA.

25. Canadian Standards Association, *Selection, Use and Care of Respirators*, 2011, CSA: Mississauga, ON. p. 132.

26. Centers for Disease Control and Prevention & National Institutes of Health, *Biosafety in microbiological and biomedical laboratories*. 5th ed. 2009: US Department of Health and Human Services, Atlanta, GA.

27. Health Canada, *Laboratory biosafety guidelines, 3rd edition*, 2004, Minister of Public Works and Government Services, Ottawa, ON

28. National Institutes of Health, *NIH Guidelines for research involving recombinant DNA molecules*, 2011, NIH, Bethesda, MD.

29. European Parliament and Council of the European Union, *Directive 2000/54/EC of the European Parliament and of the Council of 18 September 2000 on the protection of workersfrom risks related to exposure to biological agents at work* 2000, Official Journal of the European Communities.

30. American Conference of Governmental Industrial Hygienists, *Bioaerosols: Assessment and Control*. 1999: ACGIH, Cincinnati, OH.

31. Tang, J., et al., *Factors involved in the aerosol transmission of infection and control of ventilation in healthcare premises.* Journal of Hospital Infection, 2006. **64**(2): p. 100-114.

32. Burge, H.A., *Bioaerosols*. Vol. 2. 1995, Ann Arbour: Lewis Publishers. 318.

33. Eduard, W., *Exposure to non-infectious microorganisms and endotoxins in agriculture.* Annals of Agricultural and Environmental Medicine, 1997. **4**(2): p. 179-186.

34. Goyer, N., et al., *Bioaerosols in the Workplace: Evaluation, Control and Prevention Guide. Technical Guide T-24*, 2001, Institut de recherche Robert-Sauvé en santé et en sécurité du travail (IRSST), Montreal, QC.

35. Lacey, J., *Aerobiology and health: the role of airborne fungal spores in respiratory disease.* Frontiers in Mycology, 1991: p. 157-185.

36. Lacey, J. and J. Dutkiewicz, *Bioaerosols and occupational lung disease.* Journal of Aerosol Science, 1994. **25**(8): p. 1371-1404.

37. Brouwer, D.H., *Control Banding Approaches for Nanomaterials.* Annals of Occupational Hygiene, 2012. **56**(5): p. 506-514.

38. Comité ministériel sur les mesures de précaution contre le syndrome respiratoire aigu sévère (SRAS), *Rapport final*, 2004, Ministère de la santé et des services sociaux: Québec. p. 49.

39. Centers for Disease Control and Prevention, *MMWR: Guidelines for preventing the transmission of Mycobacterium tuberculosis in health-care settings*, 2005, CDC, Atlanta, GA.

40. Nolte, K.B., D.G. Taylor, and J.Y. Richmond, *Biosafety considerations for autopsy.* The American Journal of Forensic Medicine and Pathology, 2002. **23**(2): p. 107-122.

41. Centers for Disease Control and Prevention, *MMWR: Hantavirus pulmonary syndrome-United States: updated recommendations for risk reduction*, 2002, CDC, Atlanta, GA.

42. Centers for Disease Control and Prevention, *Protecting investigators performing environmental sampling for Bacillus anthracis: personal protective equipment*, 2002, CDC, Atlanta, GA.

43. Lenhart, S.W., et al., *Histoplasmosis: protecting workers at risk (revised ed.)*, 2004, CDC/NIOSH/NCID, Cincinnati, OH. p. 32.

44. Lee, S.A., et al., *Respiratory protection provided by N95 filtering facepiece respirators against airborne dust and microorganisms in agricultural farms.* Journal of Occupational and Environmental Hygiene, 2005. **2**(11): p. 577-585.

45. Lavoie, J. and S. Guertin, *Evaluation of health and safety risks in municipal solid waste recycling plants.* Journal of the Air and Waste Management Association, 2001. **51**(3): p. 352-360.

46. Lavoie, J., *Évaluation de l'exposition aux bioaérosols dans les stations de traitement des eaux usées.* Vecteur Environnement, 2000. **33**(3): p. 43-50.

47. Comité sur les infections nosocomiales du Québec (CINQ), *Mesures de prévention et contrôle de l'influenza pandémique pour les établissements de soins et les sites de soins non traditionnels.*, 2006, Direction des risques biologiques, environnementaux et occupationnels, Institut national de santé publique du Québec. p. 63.

48. Duchaine, C., et al., *Santé respiratoire des travailleurs et qualité de l'air des tourbières du Québec possédant des systèmes de dépoussiérage. Rapport R-363*, 2010, Institut de recherche Robert-Sauvé en santé et en sécurité du travail (IRSST), Montreal, QC. p. 138.

49. Noone, P., *Psittacosis in poultry workers and trichloramine occupational exposure limits in swimming pools.* Occupational Medicine, 2012. **62**: p. 392-393.

APPENDIX I

Directive 2000/54/EC of the European Parliament and of the Council on the protection of workers from risks related to exposure to biological agents at work [29]

COMMUNITY CLASSIFICATION
(Article 2, second paragraph, and article 18)

BACTERIA and similar organisms
NB: For biological agents appearing on this list, "spp." refers to other species which are known pathogens in humans.

Organism	Risk group
Actinobacillus actinomycetemcomitans	2
Actinomadura madurae	2
Actinomadura pelletieri	2
Actinomyces gereneseriae	2
Actinomyces israelii	2
Actinomyces pyogenes	2
Actinomyces spp.	2
Arcanobacterium haemolyticum (Corynebacterium haemolyticum)	2
Bacillus anthracis	3
Bacteroides fragilis	2
Bartonella baciliformis	2
Bartonella quintana (Rochalimaea quintana)	2
Bartonella (Rhochalimaea) spp.	2
Bordetella bronchiseptica	2
Bordetella parapertussis	2
Bordetella pertussis	2 V
Borrelia burgdorferi	2
Borrelia duttonii	2
Borrelia recurrentis	2
Borrelia spp.	2
Brucella abortus	3
Brucella canis	3
Brucella melitensis	3
Brucella suis	3
Burkholderia mallei (Pseudomonas mallei)	3
Burkholderia pseudomallei (Pseudomonas pseudomallei)	3
Campylobacter fetus	2
Campylobacter jejuni	2
Campylobacter spp.	2
Cardiobacterium hominis	2
Chlamydia pneumoniae	2
Chlamydia trachomatis	2
Chlamydia psittaci (avian strains)	2
Chlamydia psittaci (other strains)	3
Clostridium botulinum	2 T
Clostridium perfringens	2
Clostridium tetani	2 T, V
Clostridium spp.	2
Organism	**Risk group**

Corynebacterium diphtheriae	2 T, V
Corynebacterium minutissimum	2
Corynebacterium pseudotuberculosis	2
Corynebacterium spp.	2
Coxiella burnetii	3
Edwardsiella tarda	2
Ehrlichia sennetsu (Rickettsia sennetsu)	2
Ehrlichia spp.	2
Eikenella corrodens	2
Enterobacter aerogenes/cloacae	2
Enterobacter spp.	2
Enterococcus spp.	2
Erysipelothrix rhusiopathiae	2
Escherichia coli (with the exception of non-pathogenic strains)	2
Escherichia coli, verocytotoxigenic strains (e.g., O157:H7 or O103)	3 (**) T
Flavobacterium meningosepticum	2
Fluoribacter boiemanac (Legionella)	2
Francisella tularensis (type A)	3
Francisella tularensis (type B)	2
Fusobacterium necrophorum	2
Gardnerella vaginalis	2
Haemophilus ducreyi	2
Haemophilus influenzae	2
Haemophilus spp.	2
Helicobacter pylori	2
Klebsiella axytoca	2
Klebsiella pneumoniae	2
Klebsiella spp.	2
Legionella pneumophila	2
Legionella spp.	2
Leptospira interrogans (all serovars)	2
Listeria monocytogenes	2
Listeria ivanovii	2
Morganella morganii	2
Mycobacterium africanum	3 V
Mycobacterium avium/intracellulare	2
Mycobacterium bovis (except BCG strain)	3 V
Mycobacterium chelonae	2
Mycobacterium fortuitum	2
Mycobacterium kansasii	2
Mycobacterium leprae	3
Mycobacterium malmoense	2
Mycobacterium marinum	2
Mycobacterium microti	3 (**)
Mycobacterium paratuberculosis	2
Mycobacterium scrofulaceum	2
Mycobacterium simiae	2
Mycobacterium szulgai	2
Mycobacterium tuberculosis	3 V
Mycobacterium ulcerans	3 (**)
Mycobacterium xenopi	2
Mycoplasma caviae	2
Mycoplasma hominis	2
Mycoplasma pneumoniae	2
Organism	**Risk group**

Neisseria gonorrhoeae	2
Neisseria meningitidis	2 V
Nocardia asteroides	2
Nocardia brasiliensis	2
Nocardia farcinica	2
Nocardia nova	2
Nocardia otitidiscavianum	2
Pasteurella multocida	2
Pasteurella spp.	2
Peptostreptococcus anaerobius	2
Plesiomonas shigelloides	2
Porphyromonas spp.	2
Prevotella spp.	2
Proteus mirabilis	2
Proteus penneri	2
Proteus vulgaris	2
Providencia alcalifaciens	2
Providencia retigeri	2
Providencia spp.	2
Pseudomonas aeruginosa	2
Rhodococcus equi	2
Rickettsia akari	3 (**)
Rickettsia canada	3 (**)
Rickettsia conorii	3
Rickettsia montana	3 (**)
Rickettsia typhi (Rickettsia mooseri)	3
Rickettsia prowazekii	3
Rickettsia rickettsii	3
Rickettsia tsutsugamushi	3
Rickettsia spp.	2
Salmonella arizonae	2
Salmonella enteritidis	2
Salmonella typhimurium	2
Salmonella paratyphi A, B, C	2 V
Salmonella typhi	3 (**) V
Salmonella (other serovars)	2
Serpulina spp.	2
Shigella boydii	2
Shigella dysenteriae (type 1)	3 (**) T
Shigella dysenteriae (other than type 1)	2
Shigella flexneri	2
Shigella sonnei	2
Staphylococcus aureus	2
Streptobacillus moniliformis	2
Streptococcus pneumoniae	2
Streptococcus pyogenes	2
Streptococcus suis	2
Streptococcus spp.	2
Treponema carateum	2
Treponema pallidum	2
Treponema pertenue	2
Treponema spp.	2
Vibrio cholerae (including El Tor)	2
Vibrio parahaemolyticus	2
Organism	**Risk group**

Vibrio spp.	2
Yersinia enterocolitica	2
Yersinia pestis	3 V
Yersinia pseudotuberculosis	2
Yersinia spp.	2
VIRUSES (*)	
Adenoviridae	2
Arenaviridae	
LCM-Lassa-virus complex (old world arena viruses):	
Lassa virus	4
Lymphocytic (strains)	3
Lymphocytic choriomeningitis virus (other strains)	2
Mopeia virus	2
Other LCM-Lassa complex viruses	2
Tacaribe-Virus-complex (new world arena viruses):	
Guanarito virus	4
Junin virus	4
Sabia virus	4
Machupo virus	4
Flexal virus	3
Other Tacaribe complex viruses	2
Astroviridae	2
Bunyaviridae	
Belgrade (also known as Dobrava)	3
Bhanja	2
Bunyamwera virus	2
Germiston	2
Oropouche virus	3
Sin Nombre (formerly Muerto Canyon)	3
California encephalitis virus	2
Hantaviruses:	
Hantaan (Korean haemorrhagic fever)	3
Seoul (virus)	3
Puumala virus	2
Prospect Hill virus	2
Other hantaviruses	2
Nairoviruses:	
Crimean-Congo haemorrhagic fever	4
Hazara virus	2
Phleboviruses:	
Rift Valley fever	3 V
Sandfly fever	2
Toscana virus	2
Other *bunyaviridae* known to be pathogens	2
Caliciviridae	
Hepatitis E virus	3 (**)
Norwalk-virus	2
Other *Caliciviridae*	2
Corohaviridae	2
Filoviridae	
Ebola virus	4
Marburg virus	4
Flaviviridae	
Organism	**Risk group**

Australia encephalitis (Murray Valley encephalitis)	3
Central European tick-borne encephalitis virus	3 (**) V
Absettarov	3
Hanzalova	3
Hypr	3
Kumlinge	3
Dengue virus type 1 to 4	3
Hepatitis C virus	3 (**) D
Hepatitis G virus	3 (**) D
Japanese B encephalitis	3 V
Kyasanur Forest	3 V
Louping ill	3 (**)
Omsk (a)	3 V
Powassan	3
Rocio	3
Russian spring-summer encephalitis (TBE) (a)	3 V
St. Louis encephalitis	3
Wesselsbron virus	3 (**)
West Nile fever virus	3
Yellow fever	3 V
Other flaviviruses known to be pathogens	2 V
Hepadnaviridae	
Hepatitis B virus	3 (**) V, D
Hepatitis d virus (Delta) (b)	3 (**) V, D
Herpesviridae	
Cytomegalovirus	2
Epstein-Barr virus	
Herpesvirus simiae (B virus)	3
Herpes simplex viruses types 1 and 2	2
Herpes virus varicella-zoster	2
Human B-lymphotropic virus (HBLV-HHV6)	2
Human herpes virus 7	2
Human herpes virus 8	2 D
Orthomyxoviridae	
Influenza viruses types A, B and C	2 V (c)
Tick-borne *orthomyxoviridae*: Dhori and Thogoto	2
Papovaviridae	
BK and JC viruses	2 D (d)
Human papillomaviruses	2 D (d)
Paramyxoviridae	
Measles virus	2 V
Mumps virus	2 V
Newcastle disease virus	2
Parainfluenza viruses, types 1 to 4	2
Respiratory syncytial virus	2
Parvoviridae	
Human parvovirus (B 19)	2
Picornaviridae	
Acute hemorrhagic conjunctivitis virus (AHC)	2
Coxsackie viruses	2
Echo viruses	2
Hepatitis A virus (human enterovirus type 72)	2 V
Polioviruses	2 V
Rhinoviruses	2
Organism	**Risk group**

Poxviridae	
Buffalopox virus (e)	2
Cowpox virus	2
Elephantpox virus (f)	2
Milker's node virus	2
Molluscum contagiosum virus	2
Monkeypox virus	3 V
Orf virus	2
Rabbitpox virus (g)	2
Vaccinia virus	2
Variola (major and minor) virus	4 V
Whitepox virus ('Variola virus')	4 V
Yatapox virus (Tana and Yaba)	2
Reoviridae	
Coltivirus	2
Human rotaviruses	2
Orbiviruses	2
Reuviruses	2
Retroviridae	
Human immunodeficiency viruses	3 (**) D
Human T-cell leukemia viruses (HTLV), types 1 and 2	3 (**) D
SIV (h)	3 (**)
Rhabdoviridae	
Rabies virus	3 (**) V
Vesicular stomatitis virus	2
Togaviridae	
Alphaviruses:	
Eastern equine enccphalomyelitis	3 V
Bebaru virus	2
Chikungunya virus	3 (**)
Everglades virus	3 (**)
Mayaro virus	3
Mucambo virus	3 (**)
Ndumu virus	3
O'nyong-nyong virus	2
Ross River virus	2
Semliki Forest virus	2
Sindbis virus	2
Tonate virus	3 (**)
Venezuela equine encephalomyelitis	3 V
Western equine encephalomyelitis virus	3 V
Other known alphaviruses	2
Rubivirus (rubella)	2 V
Toroviridae	2
Unclassified viruses	
Equine morbillivirus	4
Hepatitis viruses not yet identified	3 (**) D
Unconventional agents associated with the transmissible spongiform encephalopathies (TSEs):	
Creutzfeldt-Jakob disease	3 (**) D (d)
Variant Creutzfeldt-Jakob disease	3 (**) D (d)

Organism	**Risk group**

Bovine spongiform encephalopathy (BSE) and other related animal TSEs (i)	3 (**) D (d)
Gerstmann-Sträussler-Scheinker syndrome	3 (**) D (d)
Kuru	3 (**) D (d)

(*) See introductory note 7, at the end of Appendix I.
(**) See introductory note 8, at the end of Appendix I.
(a) Tick-borne encephalitis.
(b) Hepatitis D virus is pathogenic in workers only in the presence of simultaneous or secondary infection caused by hepatitis B virus. Vaccination against hepatitis B virus will therefore protect workers who are not affected by hepatitis B virus against hepatitis D virus (Delta).

(c) Only for types A and B.

(d) Recommended for work involving contact with these agents.

(e) Two viruses are identified: one a buffalopox type and the other a variant of the Vaccinia virus.

(f) Variant of cowpox virus.

(g) Variant of Vaccinia.

(h) At present there is no evidence of disease in humans caused by the other retroviruses of simian origin. As a precaution containment level 3 is recommended for work with them.

(i) There is no evidence in humans of infections caused by the agents responsible for other animal TSEs. Nevertheless, the containment measures for agents categorised in risk group 3 (**) are recommended as a precaution for laboratory work, except for laboratory work relating to an identified agent of scrapie where containment level 2 is sufficient.

D: List of workers exposed to this biological agent to be kept for more than 10 years after the end of last known exposure.

T: Toxin production.

V: Effective vaccine available.

PARASITES

Organism	**Risk group**
Acanthamoeba castellani	2
Ancylostoma duodenale	2
Angiostrongylus cantonensis	2
Angiostrongylus costaricensis	2
Ascaris lumbricoides	2 A
Ascaris suum	2 A
Babesia divergens	2
Babesia microti	2
Balantidium coli	2
Brugia malayi	2
Brugia pahangi	2
Capillaria philippinensis	2
Capillaria spp.	2
Clonorchis sinensis	2
Clonorchis viverrini	2
Cryptosporidium parvum	2

Cryptosporidium spp.	2
Cyclospora cayetanensis	2
Dipetalonema streptocerca	2
Diphyllobothrium latum	2
Dracunculus medinensis	2
Echinococcus granulosus	3 (**)
Organism	**Risk group**
Echinococcus multilocularis	3 (**)
Echinococcus vogeli	3 (**)
Entamoeba histolytica	2
Fasciola gigantica	2
Fasciola hepatica	2
Fasciolopsis buski	2
Giardia lamblia (Giardia intestinalis)	2
Hymenolepis diminuta	2
Hymenolepis nana	2
Leishmania brasiliensis	3 (**)
Leishmania donovani	3 (**)
Leishmania ethiopica	2
Leishmania mexicana	2
Leishmania peruviana	2
Leishmania tropica	2
Leishmania major	2
Leishmania spp.	2
Loa loa	2
Mansonella ozzardi	2
Mansonella perstans	2
Naegleria fowleri	3
Necator americanus	2
Onchocerca volvulus	2
Opistorchis felineus	2
Opistorchis spp.	2
Paragonimus westermani	2
Plasmodium falciparum	3 (**)
Plasmodium spp. (human and simian)	2
Sarcocystis suihominis	2
Schistosoma haematobium	2
Schistosoma intercalatum	2
Schistosoma japonicum	2
Schistosoma mansoni	2
Schistosoma mekongi	2
Strongyloides stercoralis	2
Strongyloides spp.	2
Taenia saginata	2
Taenia solium	3 (**)
Toxocara canis	2
Toxoplasma gondii	2
Trichinella spiralis	2
Trichuris trichiura	2
Trypanosoma brucei brucei	2
Trypanosoma brucei gambiense	2
Tryponosoma brucei rhodesiense	3 (**)
Trypanosoma cruzi	3
Wuchereria bancrofti	2

(**) See introductory note 8, at the end of Appendix I.
A: Possible allergic effects.

INTRODUCTORY NOTES

7. Member States are to ensure that all viruses which have already been isolated in humans and which have not been assessed and allocated in this Annex are classified in group 2 as a minimum, except where Member States have proof that they are unlikely to cause disease in humans.

8. Certain biological agents classified in group 3 which are indicated in the appended list by two asterisks (**), may present a limited risk of infection for workers because they are not normally infectious by the airborne route. Member States shall assess the containment measures to be applied to such agents, taking account of the nature of specific activities in question and of the quantity of the agent involved, with a view to determining whether, in particular circumstances, some of these measures may be dispensed with.

APPENDIX II

Implementation of the selection tool

When a bioaerosol is present or suspected of being present in the work environment, the procedure to be followed is:

1. Determine the risk group to which the bioaerosol belongs. As needed, consult the databases of the following organizations or refer to the list in Directive 2000/54/CE [29] (Appendix I of this document):

   - Public Health Agency of Canada: http://www.phac-aspc.gc.ca/lab-bio/res/psds-ftss/index-eng.php
   - American Biological Safety Association: http://www.absa.org/riskgroups/index.html

2. Determine the control banding level in relation to the type of ventilation and the ventilation rate (estimate the number of ACH as needed).

Points	Control banding levels
2.0	ACH* ≤ 2; no ventilation; confined spaces or other similar spaces
1.5	2 < ACH ≤ 6; general ventilation or open windows or other similar situations
1.0	6 < ACH ≤ 12; room at negative pressure; laboratory ventilation; isolation room; displacement ventilation or other similar ventilation
0.5	ACH > 12; mechanization of operations; operations in a laboratory hood; some hospital departments (bronchoscopy, operating room; etc.); outdoor work or other similar work
0	Operations in a laminar flow hood; closed circuit sources or other similar situations

3. Determine the generation rate band in relation to the type of work performed, the activities, processes, etc.

Points	Generation rate bands	
	Probability of inhalation	**Examples**
8.0	Very high	Uncontrolled aerosolization of the biological contaminant; proximity to emission sources; work in emission plumes; medical procedures producing aerosols or other similar situations
6.0	High	High aerosolization; decontamination work; care provided to a infectious patient coughing or sneezing mouth uncovered or other similar situations
4.0	Moderate	Moderate aerosolization; contact with the biological contaminant; distance far from the source; infectious patient coughing or sneezing mouth uncovered or other similar situations
2.0	Low	Low aerosolization; personnel assigned to other care
0	None	No aerosolization

4. Calculate the exposure level by adding the control level and generation rate scores.

	Exposure level (sum of the control level and generation rate scores)				
Band	1	2	3	4	5
Level	Very low	Low	Moderate	High	Very high
Score	0 – 2	2.5 – 5	5.5 – 7	7.5 – 9	9.5 – 10

5. Find the minimum APF at the intersect of the exposure level and the risk group in the model.

		Exposure level				
		1 Very low (0 – 2)	**2** Low (2.5 – 5)	**3** Medium (5.5 – 7)	**4** High (7.5 – 9)	**5** Very high (9.5 - 10)
Risk group	**1**	None	APF 10	APF 10	APF 10	APF 25
	2	None	APF 10	APF 10	APF 25	APF 50[1]
	3	None	APF 10	APF 25	APF 50[1]	APF 1000
	4	APF 1000	APF 1000	APF 1000	APF 1000	APF 1000

[1] NIOSH's APF of 50 is equivalent to the APF of 100 in the *Guide des appareils de protection respiratoire utilisés au Québec* [6]

6. Select (using the *Guide des appareils de protection respiratoire utilisés au Québec*) a respirator with the required APF [6].

Warning

This tool must not be used if:

1) It is an emergency situation or an immediate-danger-to-life-or-health situation,
2) The oxygen level in the air is below 19.5%,
3) There is a risk of fire or explosion, or
4) Chemical contaminants are present.