*atmosphere*

MDPI

*Review*

# Workplace Biological Risk Assessment: Review of Existing and Description of a Comprehensive Approach

**Sarah Burzoni [1,*], Philippe Duquenne [1], Gautier Mater [1] and Luc Ferrari [2]**

[1] French National Research and Safety Institute for the Prevention of Occupational Accidents and Diseases (INRS)–1, rue du Morvan–CS 60027, 54519 Vandœuvre-Les-Nancy, France; philippe.duquenne@inrs.fr (P.D.); gautier.mater@inrs.fr (G.M.)

[2] Institut Jean Lamour, UMR 7198 CNRS–Université de Lorraine, 2 allée André Guinier–Campus Artem, 54011 Nancy CEDEX, France; luc.ferrari@univ-lorraine.fr

* Correspondence: sarah.burzoni@inrs.fr

Received: 2 June 2020; Accepted: 29 June 2020; Published: 13 July 2020


**Abstract:** Biological risks potentially affect workers in multiple occupational sectors through their exposure to pathogenic agents. These risks must be carefully assessed to prevent adverse health effects. This article identifies and critically analyzes approaches that manage the qualitative evaluation of biological risk (EvBR) as part of occupational health and safety prevention, for which no standard method yet exists. Bibliographic and computing references were searched to identify qualitative EvBR approaches, which were then analyzed based on defined criteria, such as the risks studied and the type of assessment. Approaches proposing the most representative types of assessment were analyzed. EvBR approaches in an occupational setting were identified in 32 sources. "Workstation analysis" combined with "assessment by risk level" were the most common approaches. The predominant risk descriptors (RDs) were defined in a characterized and quantifiable way, and a variety of hazard levels and exposure indices were created. Overall, the risk was determined by summing or multiplying the hazard level and exposure indicators. The results confirmed that no methodological consensus currently exists regarding the EvBR and no approach has yet been described that integrates all the parameters to allow for a full assessment of biological risk. Based on the detailed analysis of the existing data, the present paper proposes a general approach.

**Keywords:** assessment; qualitative; biological risk; occupational exposure; risk descriptors; analysis by risk level

## 1. Introduction

Biological agents are defined by the European directive "2000/54/EC—biological agents at work" as micro-organisms (including genetically modified ones), cell cultures, and human endoparasites [1]. Micro-organisms are ubiquitous in the environment and have colonized all ecological niches [2–6]. In particular, biological agents occur in many working sectors where two types of situations can be found: (i) the deliberate use of biological agents for which the agents are known as they are involved in the work, for example, in industrial processes, such as food production, or research microbiology and biotechnology laboratories; and (ii) the unintentional presence of biological agents for which the presence of micro-organisms is linked to or a consequence of the activity itself, such as for healthcare professions, or is due to the characteristics of the activity, which allows for the survival or growth of microbial communities, for example, in the cotton industry or effluent treatment plants.

Thus, occupational exposure to bacteria, fungi, and viruses, as well as to the associated microbial compounds (endotoxins, allergenic proteins, etc.) and toxins (e.g., mycotoxins) has been demonstrated

in numerous working situations [7]. Routes of exposure include the inhalation of airborne microbial entities (i.e., bioaerosols), contact with the mucous membrane and skin, stings and cuts, and wounds. Such exposures were found for occupations involving contact with the public or products of human origin, agriculture, agrifood business, the pharmaceutical industry, the mechanical industry waste treatment and elimination, healthcare, and maintenance [8–11].

The vast majority of micro-organisms are harmless or even essential for life [12], where some present advantages for humans, for example, in the production of food products or biotechnology [13]. However, others can have a detrimental effect on workers' health [14–18]. Thus, occupational exposure to micro-organisms has been associated with four types of health disorders. First, the infection may occur following penetration of the body's defenses by the biological agent and its subsequent multiplication. Examples of infection are Covid-19 (severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) [19]), viral hepatitis (Hazara [20], hepatitis A, etc.), tuberculosis (*Mycobacterium tuberculosis* (Koch's bacillus)), and legionnaire's disease (e.g., *Legionella*) [21]. Second, immuno-allergic diseases, where the immune system mounts an extreme and inappropriate response (e.g., asthma (*Aspergillus fumigatus* [22]), allergic rhinitis, etc.). Third, diseases linked to microbial components or toxins produced by some biological agents, such as molds and bacteria (e.g., sewer worker's syndrome and toxic shock syndrome [23,24]). Finally, biological agents can induce occupational cancers. This disease, which manifests itself after infection, is the result of uncontrolled human cell multiplication (e.g., secondary liver cancer due to viral hepatitis (hepatitis B and C)) [25]. Beyond the four main risk families, exposure to bioaerosols or microbial compounds, such as (1,3)-β-D glucans, endotoxins, and mycotoxins, can also cause irritant effects, such as mucous membrane irritation syndrome (MMIS) [26–28].

Every year, 320,000 occupational deaths worldwide are estimated to be linked to transmissible diseases, where 5000 of these occur in the European Union [29]. According to the French research, development, studies, and statistics directorate (Dares), more than 4.8 million (22%) workers declare that they are exposed to biological agents as part of their occupational activities. In French public hospitals, the proportion increases to 76% of workers but is lower in other sectors: 37% in the agricultural sector and 35% in local government services (LGS). The highest exposure levels are estimated to be in the healthcare, social activities, home care, hotel-restoration-food, care of green areas, or waste and pollution treatment sectors [30].

In the context of occupational risks, one of an employer's regulatory obligations is that they must take all the necessary measures to protect the health and safety of workers by enacting the general principles of prevention (Directive 89/391/EC) [31]. Risk is the probability that a person will suffer harm or adverse health effects when exposed to danger, i.e., a potential source of harm. In the workplace, several types of risk coexist, such as chemical, physical, psychological, and biological risks. Biological risks correspond to the exposure of workers to micro-organisms or their components, such as bacteria, viruses, microscopic fungi, and endoparasites. Risk assessment is one of the fundamental provisions of the regulatory prevention principles. For activities that may induce a risk of exposure to biological agents, minimum requirements are mandatory when performing this assessment (Directive 2000/54/EC) [1]. In France, these provisions are transposed respectively to Articles L. 4121-1 and R. 4121-1 and, R. 4421-1 to R. 4427-5 of the French Labour Code.

Two steps are used to assess the risk: qualitative and quantitative risk assessment. The qualitative risk assessment is based on the analysis of the work carried out and the operating conditions. Therefore, it requires identifying the tasks performed by the employees. Overall, it involves estimating the risk associated with a task by considering the independent variables associated with the risk level, named "risk descriptors" (RDs), for example, the danger, the duration and frequency of exposure, the physicochemical properties, the conditions of implementation (the type of process, temperature, etc.), and the means of prevention. These risk descriptors can be used in an evaluation approach called "evaluation by level of risk" or "control banding"; this consists of a rating system assigned to the danger descriptors and exposure descriptors, which are classified progressively by bands or by

level to determine a level of risk according to the scores obtained following their multiplication or their summation. The result obtained then makes it possible to characterize the risk inherent in the work task. This approach is carried out upstream of a quantitative approach and makes it possible to prioritize risks according to their priority actions and to develop an action plan based on the results. The quantitative risk assessment is complementary and secondary to the qualitative evaluation and makes it possible to determine, in numerical terms, the level of exposure via measurements. Methods that can be used for the measurement of microbial concentration are numerous [32,33] and the quantitative exposure of workers to micro-organisms, their compounds, and their metabolites has been extensively documented during the last decade, especially for bioaerosols [33–37]. The relationship between the exposure levels and the response in terms of health effects has been investigated for most microbial groups and specific compounds of microbiological origin (allergens and toxins) that are involved in immunological and toxicological risks. Thus, for some microbial enzymes, such as fungal alpha amylase, the exposure–response relationships are known from multiple studies (in humans and animals), and health-based exposure limits have been proposed [38,39]. Similar proposals were also made for airborne endotoxins [40], and the effects of food-borne aflatoxins on aflatoxicosis and liver cancer are also well documented [41]. However, recent reviews of epidemiological [18] and animal studies [42] concluded that the published data are not sufficient for establishing health-based exposure limits values for most of the components of microbial bioaerosols. Therefore, there is no occupational exposure limit (OEL) value for airborne biological agents and the interpretation of non-infectious bioaerosol exposure data in terms of biological risks is still uncertain. For biological agents involved in infectious risk, the quantitative risk assessment is also difficult due to the lack of a minimal infectious dose value or exposure–response relationships for most agents. Furthermore, many agents are responsible (*Legionella pneumophila*, influenza virus, etc.) for outbreaks, and epidemiological studies with accurate exposure assessment strategies that can distinguish inter-human transmission from other sources are missing.

Although the quantitative evaluation has many benefits but also limitations, qualitative risk assessment, also known as initial risk assessment, is nevertheless a prerequisite for any prevention approach. However, the evaluation of biological risk (EvBR) presents inherent difficulties, such as the complexity of taking an inventory of the biological agents that are potentially present in the workplace, knowledge of the pathogenicity of these agents, and establishing their dose–effect relationships [15,43]. Furthermore, the lack of visibility, the delay in analysis of this type of risk due to priority given to other risks, and occupational health and safety officers' lack of knowledge are major obstacles to the consideration of risks [44]. However, the importance of treating the biological risk, in its entirety and in cooperation with health and safety professionals, was stated following a survey performed by the European Occupational Safety and Health Administration [45]. The results of this survey underlined the limited knowledge and information available on biological risks due to the difficulty in assessing them. In the healthcare sector, such as in research and analysis laboratories, the pharmaceutical industry, and care institutions, biological risks are known to exist and are taken into account [34,46]. Nevertheless, in other fields of activity, these risks remain poorly understood by the majority of workers that are likely to be exposed and by their employers.

Harmonized risk assessment approaches have been developed for chemical risks [47–52] and risks related to nanomaterials [53–57], where these are considered reference methods at the international level. For biological risk, assessment approaches have been proposed, but to date, no standard methodology has been adopted. Thus, to define the structure and components of a qualitative assessment methodology for biological risk, this work is broken down into two objectives:

- To describe existing approaches by carrying out an inventory and a critical analysis of existing and published qualitative biological risk assessment procedures in the workplace (this review does not consider implementing or testing the identified approaches).

- Moreover, at the end of this analysis, a structure of the most appropriate approach is proposed and appropriate criteria that constitute a qualitative EvRB approach that is as exhaustive as possible are identified.

## 2. Materials and Methods

### *2.1. Fields of Investigation and Research Criteria*

The overall approach undertaken to carry out an inventory of existing biological risk assessment approaches consisted of identifying and retrieving sources of information on this topic. The sources utilized were:

- Bibliographic references, including:
    - Scientific articles listed on the PubMed portal (whose last research update was carried out in March 2020; https://www.ncbi.nlm.nih.gov/pubmed/) based on the Preferred Reporting Items for Systematic Reviews and Meta-Analyses guidelines (PRISMA) [58]. The terms used in combination were "agents," "assessment," "airborne," "bioaerosol," "biological," "biologic*," "exposure," "hazard," "methodology," "occupational," "pathogens," "professional," and "risk," alongside the "AND" operator. The asterisk (*) is a truncation. It allows replacing a letter or a set of letters in a word. The use of this truncation for "biologic*" allows to be sufficiently exhaustive to write the search request. These terms were searched for in the title and abstract. The research considered articles in English and French without a specific period. The summary of the research process is presented in Table S1 [59].
    - Grey literature: Book chapters and publications generally longer than scientific articles that were published by public or private institutions in the field of occupational risk prevention, and multimedia sources, such as websites. Searches were done using Google and Google Scholar search engines. The terms used in these searches were those used for scientific articles.
- Moreover, to provide a more complete bibliography, the searches were extended to computing references. These corresponded to software tools in the field of the EvBR, with an interface allowing for the conversion and treatment of digital information. These applications were integrated into the study to identify the risk descriptors that they can use rather than to understand the algorithm used. The searches were carried out:
    - Through a security software provider and by contacting industrial users;
    - By contacting industrialists encountered during training;
    - On Google and Google Scholar search engines.

To be retained in our analyses, the sources had to meet the following criteria:

- A qualitative approach to biological risk assessment;
- An assessment of the situations leading to exposure during the use or handling of micro-organisms and/or a description of conditions when they are unintentionally present in the workplace;
- An assessment of the occupational health risks for workers.

No restrictions were set on the activity sector, the biological agents, or the type of risk or hazard identified. However, sources relating to the assessment of sanitary risks affecting human and animal health, as well as those linked to bioterrorism and biological safety, were excluded as they were considered beyond the scope of this article. These sources involved considering analysis or the development of parameters that cannot be extrapolated or that are out of the scope of application of a straightforward occupational risk-assessment approach. In detail:

- Sanitary risk refers to a risk to public health, which may be immediate or long-term and of variable likelihood. The identification and analysis of the risks linked to a phenomenon (flooding, contamination, etc.) generally make it possible to predict the impact of a sanitary risk on public health [60].
- Assessments linked to studies of bioterrorism and examining the intentional or potential use of micro-organisms (anthrax, smallpox, etc.) for terrorist means to cause disease or death in humans, animals, or plants [61].
- Assessments linked to biological safety through defining all the means and practices that aim to protect and prevent risks of loss, stealing, hijacking, or inappropriate use of strains of highly pathogenic micro-organisms or toxins that present a danger to humans [62].

### *2.2. Analysis of Sources*

Beyond the analysis of the existing approaches, this work made it possible to take stock of the available methods, their characteristics, their mode of operation, and the conditions of their implementation. Biological risk assessment approaches exist and the purpose of this work was to establish what they offered in terms of performing a risk assessment study in a workplace and to analyze the criteria they consider during that assessment. The analysis and characterization of the sources describing the EvBR were performed with the help of a list of criteria. This list was created following an analysis of nationally promoted methods to assess chemical risk [63]. The main criteria are listed in Table S2**.**

Sources describing a similar type of frequently used EvBR were more extensively analyzed by studying:

- The stages proposed in the various approaches;
- The risk descriptors, systems by which these variables were attributed, and their treatment modes.

## 3. Results

### *3.1. Collection and Description of the Sources of Information Gathered*

In the scientific literature, 1141 national and international publications were retrieved through the PubMed portal using the keywords mentioned above. After excluding articles beyond the scope of this study, 76 publications were retained for further analysis. Following our analysis, three of these references were retained (Table S1). Searches on Google and Google Scholar with the same keywords identified 22 references in the grey literature. Of the five manufacturers that were identified by the safety and security software provider, two were inclined to be contacted to discuss the use and deployment of this program within their institution. Based on this, three computer tools were selected following the exchanges with the industrialists met during training. The computer tools used by manufacturers are proprietary software, where it was only possible to use this software on the condition that the identity of those producing and using them remained anonymous. Regarding these tools, two computer applications were identified by performing searches using Google and Google Scholar search engines. Figure 1 shows the source selection process.

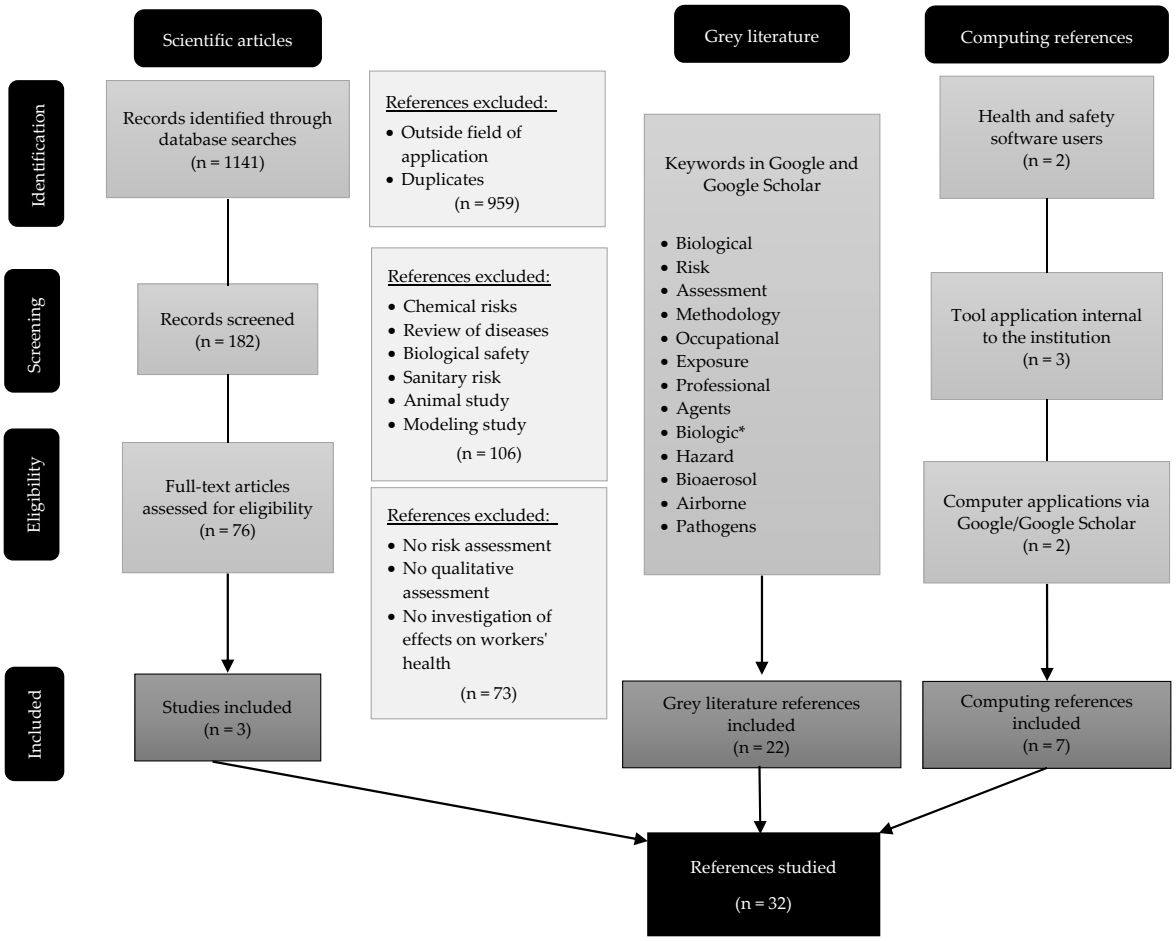



**Figure 1.** The process used to select the sources used for proposing a qualitative approach to assess biological risks in an occupational setting.

As a result, 32 references of interest to this study published since 2001 were identified. No relevant documents were published before 2001. Their names and authors are grouped in Table 1, their characteristics are listed in Table 2, and the results are presented in Figure 2.

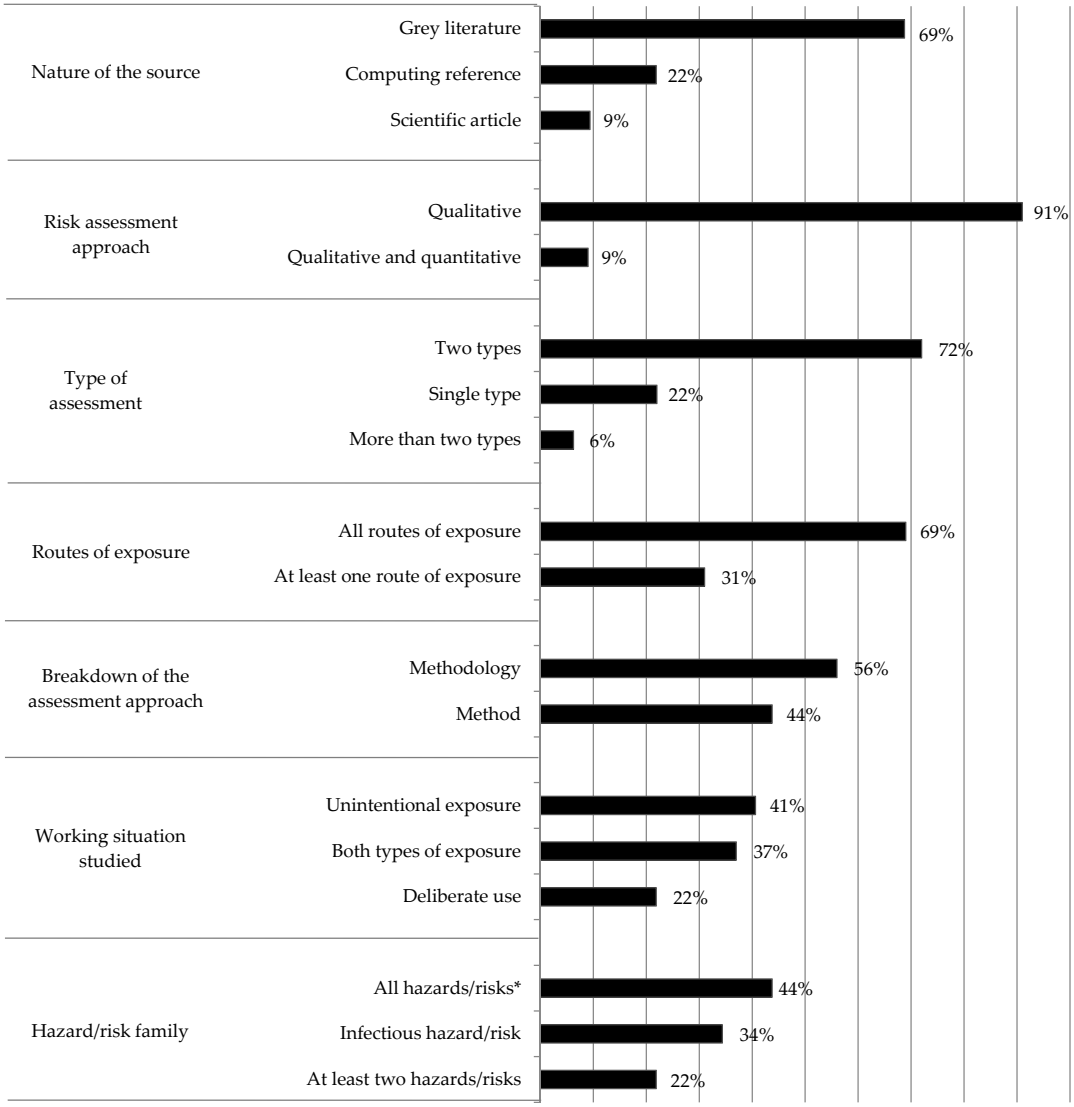
**Table 1.** List of sources for the qualitative assessment of biological risk in the workplace.

| N° | Authors and Year of Publication | Title or Name of Source |
|---|---|---|
| | **Bibliographical References** | |
| 1 | Forestier D., Lecornet E., Mosqueron L., and Lambolez, L. (2012) [64] | Exposure to bioaerosols for wastewater treatment plant workers: Prioritization of the areas and tasks involving the greatest exposure, and prevention |
| 2 | Pichenot O., Barbe A., Thiriet S., Benhassine R., Dion J.J., and Reveil J.C. (2008) [65] | Assessment of the professional biological risks of dialysis technicians |
| 3 | Nuebling M. and Hofmann F. (2001) [66] | Task profile and risk of occupational hepatitis. A infection in sewerage workers |
| 4 | Touche, S. (2008) [67] | Évaluation et prévention des risques biologiques en laboratoires d'analyses médicales. Présentation d'un guide méthodologique |
| 5 | Académie de Grenoble (2010) [68] | Prévention des risques biologiques—Risques biologiques au laboratoire de génie biologique |
| 6 | ANSES's Committee for the Control of Biological Risks in Laboratories (CMRBL) (2011) [69] | Methodological guide to the assessment of biological safety and security risks |
| 7 | Bonnard R. (2001) [43] | Le risque biologique et la méthode d'évaluation du risque |
| 8 | Réseau Ressources Risque Biologique (3RB)- Education nationale /INRS (2016) [70] | Evaluation des risques: éléments de méthodes |
| 9 | Goyer N., Lavoie J., Lazure L., Marchand G., Allard R., and Bhérer L. (2001) [71] | Bioaerosols in the workplace: evaluation, control and prevention guide |
| 10 | Lavoie, J., Neesham-Grenon E., Debia M., Cloutier, Y., and Marchand, G. (2013) [72] | Development of a control banding method for selecting respiratory protection against bioaerosols |
| 11 | Cheneval E., Busque, M.-A., Ostiguy C., Lavoie J., Bourbonnais, R., Labrèche F., and Zayed J. (2017) [73] | Green Jobs in Quebec: Definition and Assessment of Potential Chemical and Biological Risks to Workers' Health |
| 12 | U.S. Department of Health and Human Services (2009) [74] | Biosafety in Microbiological and biomedical laboratories (5th Edition) |
| 13 | Advisory Committee on Dangerous Pathogens (HSE) (2003) [75] | Infection at work: Controlling the risks—A guide for employers and the self-employed on identifying, assessing and controlling the risks of infections in the workplace |
| 14 | Advisory Committee on Dangerous Pathogens (HSE) (2005) [76] | Biological agents: Managing the risks in laboratories and healthcare premises |
| 15 | Health & Safety Service (HSE) (2015) [77] | Bio COSHH (Bio Control of Substances Hazardous to Health) Risk Assessment |
| 16 | Belgian Biosafety Server (2014) [78] | Biological Risk Assessment Sheets |
| 17 | Health Canada (2004) [79] | The Laboratory Biosafety Guidelines (3rd edition) |
| 18 | Government of Alberta (2011) [80] | Best Practices for the Assessment and Control of Biological Hazards—Best Practices Guidelines for Occupational Health and Safety in the Healthcare Industry |
| 19 | Health Service Executive (HSE Ireland) (2011) [81] | Guidance for Developing a Biological Agents Risk Assessment for the Healthcare Sector |
| 20 | Société française d'hygiène hospitalière (2007) [82] | Prévention des risques infectieux dans les laboratoires d'analyse de biologie médicale |
| 21 | Centre National de la Recherche Scientifique (CNRS) (2017) [83] | Risques biologiques–Les cahiers de prévention (4 ème édition) |
| 22 | European Agency for Safety and Health at Work (EU-OSHA) (2010) [84] | Risk assessment for biological agents (E-facts 53) |
| 23 | Institut National de Recherche et de Sécurité (INRS) (2014) [85] | Les risques biologiques en milieu professionnel |
| 24 | Institut National de Recherche et de Sécurité (INRS) (2009) [86] | Laboratoires d'analyses médicales—Evaluation et prévention des risques infectieux |
| 25 | World Health Organization (2004) [87] | Laboratory Biosafety Manual—Third Edition |
| | **Computing References** | |
| 26 | Institut de recherche Robert-Sauvé en santé et en Sécurité du Travail (IRSST) (2015) [88] | A support tool for choosing respiratory protection against bioaerosols |
| 27 | Caskey S., Gaudioso J., and Salerno R., (2009) [89] | Biosafety Risk Assessment Methodology |
| 28 | User in the soil remediation sector | Proprietary software to assess biological risk |
| 29 | User in the biotechnology research and development sector | Proprietary software to assess biological risk |
| 30 | User in the research laboratory sector | Proprietary software to assess biological risk |
| 31 | User in the medical biology laboratory sector | Proprietary software to assess biological risk |
| 32 | User in the food product manufacturing sector | Proprietary software to assess biological risk |

**Table 2.** Relationship of sources and qualitative assessment of biological risks in occupational settings.

| Reference No. | | 1 [64] | 2 [65] | 3 [66] | 4 [67] | 5 [68] | 6 [69] | 7 [43] | 8 [70] | 9 [71] | 10 [72] | 11 [73] | 12 [74] | 13 [75] | 14 [76] | 15 [77] | 16 [78] | 17 [79] | 18 [80] | 19 [81] | 20 [82] | 21 [83] | 22 [84] | 23 [85] | 24 [86] | 25 [87] | 26 [88] | 27 [89] | 28 | 29 | 30 | 31 | 32 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Nature of Source | Scientific Article | X | X | X | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | Grey Literature | | | | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | | | | | | |
| | Computing Reference | | | | | | | | | | | | | | | | | | | | | | | | | | X | X | X | X | X | X | X |
| Breakdown of Approach | Method | | | | X | | | X | | X | | | X | X | X | | X | X | X | | | X | X | X | X | X | | | | | | |
| | Methodology | X | X | X | | X | X | | X | | X | X | | | | X | | | | X | X | | | | | | X | X | X | X | X | X | X |
| Qualitative Approach | | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X |
| Quantitative Approach | | X | | | | | | X | | X | | | | | | | | | | | | | | | | | | | | | | |
| Type | | T1 T4 | T1 T4 | T1 T4 | T1 T3 | T1 T4 | T1 T2 T4 | T1 | T1 T4 | T1 | T1 T4 | T1 T4 | T1 | T1 | T1 T3 | T1 T4 | T1 | T1 T3 | T1 T3 | T1 T4 | T1 T3 T4 | T1 T3 | T1 | T1 | T1 T3 | T1 T3 | T1 T4 | T1 T4 | T1 T4 | T1 T4 | T1 T4 | T1 T4 |
| Occupational Situations Studied | Deliberate Use | | | | | | X | X | X | X | X | | X | | X | X | X | X | | | | X | X | X | | X | | X | | X | X | X | X |
| | Unintentional Presence | X | X | X | X | X | | X | X | X | X | X | X | X | X | | | | X | X | X | X | X | X | X | | X | | X | | X | X | X |
| Includes an Inventory of Biological Agents | | | | | | | X | | | | | X | | | X | X | X | X | | X | | X | | | | | X | X | | X | | | |
| Related to a Single Activity Sector | | X | X | X | X | X | X | | | | | X | X | | | X | X | X | X | X | X | X | | | X | X | | X | X | X | X | X | X |
| Covers Several/All Activity Sectors | | | | | | | | X | X | X | X | | | X | X | | | X | | | | | X | X | | | X | | | | | | X |
| Includes | Analysis of Tasks/Operations | X | X | X | X | X | X | | X | X | X | | X | X | X | | X | X | X | X | X | X | X | X | X | X | | | X | X | X | X | X |
| | Ranking of Risks | X | X | X | | X | X | X | X | | X | X | | | | X | | | | X | X | | X | X | | | | X | X | X | X | X | X |
| | Development of a Plan of Action/Prevention | X | X | X | | X | X | X | X | X | X | | X | X | X | X | X | X | X | X | X | | X | X | X | X | | | X | X | X | X | X |
| Hazards/Risks | Infectious | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X |
| | Immuno-allergic | X | | | X | | | | X | X | X | X | | | X | | X | | X | X | | X | X | X | | | X | X | X | X | X | X | X |
| | Toxic | X | | | X | | | X | X | X | X | X | | | X | | X | | | X | | X | X | X | | | X | X | X | X | X | X | X |
| | Carcinogenic | X | | | X | | | | X | X | X | X | | | | | | | | X | | X | X | X | | | | X | X | X | | X | X |
| Considers Exposure by | Inhalation | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X |
| | Skin Contact | X | X | X | X | X | X | X | X | | | | X | X | X | X | | X | X | X | X | X | X | X | X | X | | | X | X | X | X | X | X |
| | Digestive | X | X | | X | X | | X | X | | | | X | X | X | X | | X | X | X | X | X | X | X | X | X | | | X | X | X | X | X | X |
| | Eye Contact | X | X | | X | X | X | X | X | | | | X | X | X | X | | X | X | X | X | X | X | X | X | X | | | X | X | X | X | X | X |
| | Inoculation | | | | X | X | X | X | X | | | | | X | X | X | | X | X | X | X | X | X | X | X | X | | | X | X | X | X | X | X |
| Integrates the Implementation of Means to Control Risks in General | | | X | | | | X | | X | X | | | X | | | X | | | X | X | X | X | X | X | X | | | X | X | X | X | X | X |
| Integrates the Availability of Collective Protective Equipment | | | X | | X | | X | | | | X | X | X | | | X | | | X | X | X | X | X | | | X | X | X | X | X | X | X | X |
| Integrates the Availability of Personal Protective Equipment | | | X | | X | | X | | | | | | X | | | X | | | X | | X | X | X | | | | | X | X | X | X | X | X |

T1—Workstation analysis. T2—Systemic approach. T3—Conformity analysis. T4—Assessment by risk level (control banding).




*: All hazards/risks included infectious, immune-allergic, toxic, and carcinogenic hazards/risks.

**Figure 2.** Characteristics of the sources proposing a qualitative EvBR (number of sources taken into consideration n = 32).

Approaches used for an EvBR were mainly found in the grey literature (69%) [43,67–81,83–87,90]. Half of these descriptions presented the elements to be considered when assessing the biological risk. The other half included directly useable elements, such as data collection tables or practical factsheets to facilitate the collection of the information required to assess the risk [53,70,75,77,80,81,83,84,86]. The computing references mainly corresponded to software that helps with assessing biological risks, which are used in companies [91]. Among all approaches identified, only 9% proposed a combination of qualitative and quantitative assessments. In contrast, 72% associated a main type of evaluation with a complementary secondary method. A total of 56% of the sources proposed a combination of "workstation analysis" and "assessment by risk level," while 69% considered all routes of exposure, where the respiratory route was common to all the approaches (Figure 2).

The proportions of approaches presented as a method (44%) [43,67,71,74–76,78–80,83–87] or a methodology (56%) [64–66,68–70,72,73,77,81,82] were similar.

#### 3.1.1. Methods

A method is a general approach. It is defined as the proposal of orderly and logical steps that allow for the collection of the information necessary for the evaluation and to integrate (or not integrate) risk descriptors contributing to the estimation of the risk.

References from the grey literature only presented methods. These methods were either based on a single type of "workstation analysis" or a combination of a "workstation analysis" with a "conformity analysis." Apart from these two methods [43,71], which combine qualitative and quantitative assessments, all the other sources used a qualitative approach for assessing biological risk. For example, some of these approaches were proposed by health and safety institutes, such as Health Canada [79], a Belgian public health institute: Belgian Biosafety Server [78], the Department of Health and Human Services in the United States [74], the Advisory Committee on Dangerous Pathogens of the Health & Safety Executive (ACDP–HSE) [75], the European Agency for Safety and Health at Work (EU-OSHA) [84], the French National Institute for the Industrial Environment and Risks (INERIS) [43], the French National Centre for Scientific Research (CNRS) [83], the French Research and Safety Institute for the Prevention of Occupational Accidents and Diseases (INRS) [85,86], and the Institut de recherche Robert-Sauvé en santé et en sécurité du travail (IRSST) [71].

These generalist approaches present the guidelines that are to be implemented to enhance biosafety at work. They describe the nature of the pathogenic agents, their hazards and risks, and present the elements that must be considered when performing risk assessment, such as identification of the hazards, characterization of the activity, and the definition of the operating conditions. Other sources are specific to particular activities, e.g., biological laboratories [67,79,86] or healthcare institutions [76,80], where a biological risk is known to exist.

#### 3.1.2. Methodologies

A methodology is a variation of a method but is more precise. It integrates distinct steps, risk descriptors, and methods of processing risk descriptors.

Qualitative methodologies for EvBRs were found in scientific articles, the grey literature, and in the form of computing references. In the large majority of cases, these methods combined "workstation analysis" as the main method with "analysis by risk level" as a secondary method [64–66,68–70,72,73,77,81,82]. Two other sources included a third type of analysis, which were classed as "systemic analysis" when it related to failure-mode, effects, and criticality analysis (FMECA) [69] or an "analysis of conformity" [82]. The methodologies described were mainly qualitative approaches. A single source combined qualitative and quantitative assessments [64]. Methodologies were mainly proposed by institutional health and safety organizations, such as the French Agency for Food, Environmental and Occupational Health & Safety (ANSES) [69], the Institut de recherche Robert-Sauvé en santé et en sécurité du travail (IRSST) [72,73], the Health Service Executive of Ireland (HSE) [81], and the French Society for Hospital Hygiene (SF2H) [82]. The other methodologies corresponded to feedback following the implementation of an EvBR approach in companies and presenting a description of the actions performed in an industrial setting, for example, within a multinational firm collecting and treating wastewater [64] or in a hospital department [65].

The approaches presented in the computing references were considered as methodologies since they presented concepts combining stages, RDs, and means of treatment, which were converted to be compatible with a computerized system (Figure 3).

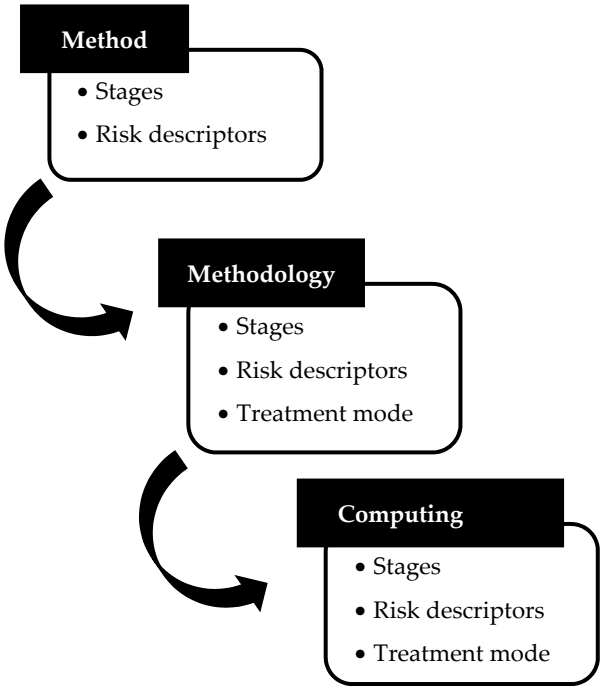



**Figure 3.** Definition of approaches used for the qualitative assessment of biological risk.

These references mainly presented tools for qualitatively assessing biological risks in an industrial setting [89,91]. They included an application [88], which was initially the subject of a guide [72], to help select appropriate respiratory protective devices used to manage exposure to aerosols. This application is also useful in healthcare and other sectors (agriculture, local authorities, industrial, etc.) as it provides information on the potential presence of biological agents in the different activity sectors and for individual work tasks.

All these tools link "workstation analysis" as the main type of analysis to "analysis by level of risk" as a secondary analysis. They are mainly used in companies and involve a variety of activity sectors. The industrial groups or companies produce some of them in-house, while companies producing risk-assessment software develop others. The latter can personalize the options and contents of the software application for the particular industrial sector, the specific activity, and to meet the requirement of the health/safety manager in the company.

The capacity to assess all working situations potentially leading to exposure to multiple micro-organisms or only a single micro-organism is not specific to the breakdown of the approach. Whatever the type of method or methodology, they can be used to assess the biological risk during deliberate use, when micro-organisms are intentionally present, and/or when they are present unintentionally. Similarly, whether one family of risks, at least two families, or all risks are taken into account depends on how the approach is broken down (Table 2).

This analysis revealed several progressive approaches for assessing biological risks in an occupational setting. In the absence of a methodological consensus, the methods assess the biological risk in different ways, do not address the same areas of application, and rely on distinct principles and criteria. The approaches are diverse and can be broken down heterogeneously. They can be used to assess all or individual working situations in which workers may be exposed and cover all or just one family of hazards or risks relating to micro-organisms. The assessment methods used are diverse, as are the risk descriptors and the treatment systems.

In the remainder of this article, we analyze the assessment approaches that are linked to both "workstation analysis" and "analysis by risk level."

### *3.2. Analysis of Approaches Involving "Workstation Analysis" and "Analysis by Risk Level"*

#### 3.2.1. Description of the Approaches

Sources combining the typologies "workstation analysis" and "risk level analysis" were studied. Two other sources also included a third type of analysis based on a "systematic approach" or "conformity analysis" and are also presented in this section.

The different steps in these approaches are listed (Table S3). They are similar and can be used to progressively collect the data required to assess the "risk level." The following common stages were observed:

- Identification of the hazards [69,77,81,82];
- Identification of risks [70,81,82];
- Identification or description of the means of control [69,70];
- Assessment of the exposure or risk [66,70,81,82,91].

While not explicitly broken down into structured steps, the different phases of the risk assessment process used in computing tools can also be defined. They are determined from incremental information inputs: the biological agent's hazard level, the frequency of exposure, the handling conditions, etc. (Table S3).

Risk descriptors can be classified into three categories:

- Subjective: the determinant is imprecisely defined and can be interpreted differently depending on the individual [65,66,68,77,81]. For example, the frequency of exposure can be qualified as "low" or "high."
- Identifiable: the determinant is defined or associated with example situations [65,68–70,72,73,82,88,91]. For example, a frequency of exposure that is qualified as "very rare" corresponds to an "exposure that may occur at most once a year, is unlikely, or is never encountered."
- Identifiable and quantifiable: the determinant is defined and can be associated with sample situations and/or with countable/quantifiable characteristics [64–66,69,70,72,73,81,82,88]. For example, the duration of the exposure is quantified or characterized by time intervals, such as "less than 30 min" or "from 30 min to 2 h."

A total of 79% of RDs were defined in an identifiable or in an identifiable and quantifiable manner.

"Intermediate" variables are created by the combination of two RDs [68,70,72,73,88]. For example, the "frequency of exposure to the hazard" combined with the "probability of occurrence of a hazardous event" defines an intermediate parameter, namely, the "probability of incurring consequences." This parameter is associated with the "severity of consequences" and can be used to estimate the "risk level" (Figure 4) [68].

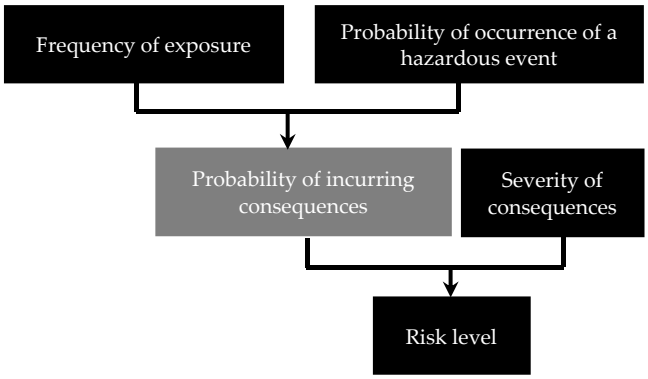



**Figure 4.** Representation of an exposure determinant considered as an "intermediate" parameter (grey box).

The risk level can be described, for example, as a "level of gross risk," a "level of controlled risk," or an "estimated risk level," especially for proprietary software (Table S3). The passage from one degree to another requires considering the existing implemented preventive measures that modulate the level of gross risk.

#### 3.2.2. Treatment Modes (Table S3)

The different levels of RDs classified into bands can be characterized as:

- Qualitative, involving the use of a qualificative adjective;
- Quantitative, associated with a point, index, or score;
- Qualitative and quantitative, combining an adjective with an index.

Indices can be combined by summing or multiplying their values; for example, "intrinsic severity," "extrinsic severity," "probability of occurrence of an event," and "detectability," where all of which have values from 1 to 5 and can be multiplied to produce the "risk priority index," which will be ranked in bands [69]. The same mathematical mode of treatment can be used to rank the different working situations assessed. A matrix combining RDs can also be used as a mode of treatment. Matrices do not involve a mathematical system but propose a logical means of combining RDs. The combination of two RDs with high indices results in a priority risk index. Hazard and exposure level indices can be combined to define a gross risk. The intermediates and results obtained by combining RDs are defined as bands and are associated with:

- Risk levels, e.g., "high," "medium," or "low" [73,77,81];
- Priorities for actions, e.g., "strong," "moderate," or "weak" priorities depending on the risk index obtained [64,68,82];
- An assigned protection factor and a corresponding respiratory protection device [73,88].

An examination of the approaches jointly proposing "workstation analysis" and "analysis by risk level" revealed the diversity of the RDs, systems of attribution, and modes of treatment that can be used.

## 4. Discussion

Qualitative risk assessment in the workplace is a prerequisite for risk prevention and the implementation of preventive measures. In this context, the present review identified and analyzed existing EvBR approaches in an occupational setting. These approaches represent the results of evolution in the development of methods for the EvBR. However, in contrast to chemical risks [47–52] and risks related to nanomaterials [53–57], the qualitative assessment methods for biological risk have not yet been developed. In addition, there is no universal, standardized approach, and without a harmonized consensus, they can only be distinguished from one another based on their intrinsic characteristics (Table 2).

To contribute to the development of methods for the assessment of exposure to biological agents, a complementary study was carried out to define the structure of the most appropriate and most complete possible approach [45]. It was with this in mind that this census and critique of the data was performed. Relying on an analysis of the approaches studied, the characteristics of this methodology were identified from criteria that compose a shared core. None of the sources studied included all the criteria but each one uses some of them (Table 2). In addition, the computing tools, which have different characteristics, appear to be closer to a complete approach.

Thus, on the one hand, we have proposed the structure of an approach to risk assessment, and on the other hand, have relied on the control banding approach [92,93] to define hazards and RDs.

### *4.1. A Qualitative Methodology in Redaction Form*

Two types of approach breakdown were distinguished. The 14 methods identified defined guidelines and good practices to be implemented when performing an assessment. Their generalized approach makes them adaptable to a wide range of applications and provides the variability required to meet the needs of several fields. However, although the assessment methods recommend data that should be taken into account, they do not explain how this data should be collected, treated, or interpreted. In addition, no data treatment system is presented that would allow for the highest-risk situations to be identified or to rank situations. The 18 methodologies identified have the advantage of being more structured and more precise. Their approach is more structured and more explicit in terms of both the steps to be followed and the information to be collected. In addition, they are associated with two types of analysis, namely, "workstation analysis" and "assessment by risk level," the combination of which presents the advantages described later. The "qualitative" criterion, shared by all the approaches studied, can be used to estimate risk by collecting information and by examining the activities of the workers observed. This approach does not require expertise in atmospheric metrology nor investment to acquire specific material.

An assessment approach must be as accessible as possible to anyone involved in risk management. It appears obvious that the seven software tools identified can simplify the treatment of the information gathered to obtain a result, which is a risk level in this case. These tools have the advantage of being adaptable: the RDs and associate risk level bands can be selected and personalized. Nevertheless, these tools require knowledge and expertise in the field of biological risk, as well as training for their use. In addition, the acquisition or development of this type of tool necessitates a financial investment. An approach to assess risks that is available in written form, for example, as a document associated with factsheets or tables to be completed, can facilitate data collection, implementation of the assessment approach, and has a wider availability [68,69,77,84].

### *4.2. Hazard Descriptors*

The step of creating an inventory of the biological agents potentially present in the work environment, which was proposed by 11 approaches (Table 2), provides knowledge of the potential dangers and risks incurred by workers. This inventory, which must be as complete as possible, can be carried out in fields where the biological agents present are known and voluntarily used, for example, in the food sector or research laboratories [69,77]. In addition, in these use conditions, the quantities of biological agents involved are known and generally identifiable. This criterion can thus be integrated into the risk estimation. When biological agents are present unintentionally, establishing an inventory and quantification of the biological agents requires extensive analysis of the literature relating to the most likely biological agents, as well as measuring the concentrations and the diseases most frequently encountered for each activity [73,81]. Once this inventory stage has been completed and quantities involved have been estimated, the two types of working situations leading to exposure can be assessed.

Once the biological agents present in the workplace have been identified, all the risks that may result in exposure to these biological agents must be taken into account, as proposed in 14 of the approaches analyzed. The infectious risk is the best-known risk in an occupational setting and was assessed in all the approaches. Considered an "acute" risk, the infectious risk is determined based on knowledge of the pathogenicity of the micro-organisms and existing regulatory classifications. To propose a global biological risk methodology, it is necessary to take into account the set of biological effects, namely, infectious, allergenic, toxic, and carcinogenic effects. Biological agents are classified by a level of pathogenicity in the range from 1 to 4; groups 2, 3, and 4 are considered pathogenic biological agents.

The immuno-allergic and toxic effects do not have a classification by level of risk but they are the subject of a report on the margin of the infectious classification [1]. Given the other possible effects, it seems necessary that the risk assessment should not be limited solely to the infectious effect on which the risk level classification of the micro-organisms is based. Therefore, by considering allergenic

effects or the ability to produce toxins [94–96], "chronic" toxicity is also taken into account in the proposed EvBR.

### *4.3. Exposure Descriptors (Table 2)*

As proposed in 22 approaches, all the routes of assimilation into the human body must be taken into consideration. This overall approach allows for all the forms of contamination with micro-organisms to be considered. Although inhalation is the main route of penetration into humans, other routes of contamination can damage a person's health. Skin contact, cutaneous projections, and inoculations are routes of penetration that must be considered in the assessment approach.

Considering the existing technical and organizational preventive measures that are described in the 14 approaches studied present two advantages. The first is that it can be used to determine the status of what has already been implemented. The second is that the risk level of the working situation can be broken down into a "gross" risk level without these measures and a "residual" risk level once preventive measures have been implemented. A few sources propose these different "risk levels" by taking into account the existing (or not) technical and organizational preventive measures. Beyond diagnosing workers' exposure, this approach also provides a close assessment of the real circumstances and conditions in the workplace by considering the existing preventive measures. In addition, in the context of the implementation of corrective or preventive measures, these approaches can be used to re-assess the risk and thus provide useful feedback on the efficacy of the measures implemented.

### *4.4. Risk Assessment Combining "Workstation Analysis" and "Assessment by Risk Level"*

The approaches studied propose various types of assessments. The seven approaches combining "workstation analysis" and "conformity analysis" can be used to answer a series of questions relating to the design of workplaces, appropriate manipulation conditions, equipment, etc. [76,79,80,83,86,87]. Proposed in particular for research laboratories, they have the advantage of asking the right questions about the conditions required to handle biological agents safely [97]. However, this type of typology assesses the differences between the situation observed and the design and use requirements. It does not constitute an assessment of the work situation. The 18 approaches that combined "workstation analysis" with "assessment by risk level" are not highly subjective and are simpler to implement [72]. Used in several fields, the progressive approach relies on an identification system, which attributes levels by classifying RDs into bands [50,52,73,98,99]. Thus, the exposure in the real working situation can be observed by selecting the levels of each exposure determinant. The application and feasibility of this grading system have been tested in the field [64–66] and in the software tools studied.

### *4.5. Identifiable or Quantifiable Determinants, Attribution Systems, and Simple Treatment Modes*

The RDs, hazard levels, and exposure levels must be defined as objectively as possible and must be understood and correctly interpreted. As they generate less confusion than subjectively defined RDs, "identifiable" or "identifiable and quantifiable" definitions are more precise. Once clearly defined, these terms can be associated with quantitative notions to allow for a better definition of the hazard or exposure level in the working situation assessed.

The association of the level of danger, corresponding to the dangerousness of the micro-organisms or the mixture of micro-organisms, and the level of exposure, which is the combination of exposure descriptors, such as the duration and frequency of exposure, physicochemical properties, conditions of implementation (type of process, temperature, etc.), and means of prevention, gives a level of risk. To achieve this result, the system classifying the hazard and exposure levels in bands, as well as the treatment methods, must be simple to understand and use (Figure 5). For example, indices or number-based scores for the different levels are easy to use. These numbers can then be added or multiplied to facilitate their combination. This simple treatment produces a quantitative result, which represents and ranks the "risk level" of a working situation. This result can also be associated with a priority-of-action band, which is given a color code to facilitate perception of the risk level

and the priorities. For example, situations representing a "high risk level" can be indicated in red, while those with a "low risk level" are indicated in green to facilitate risk perception [95].

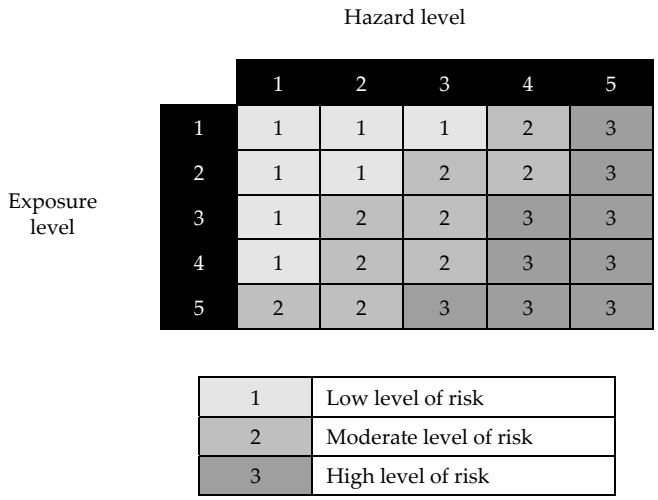



**Figure 5.** Estimation and coding of risk levels based on the hazard levels and exposure levels measured in a working situation.

### *4.6. The Contribution of Quantitative Assessment to Risk Assessment*

A quantitative approach can be used to characterize exposures by expressing it as a numbered value determined from concentration measurements. A major effort has been made in recent decades to quantify biological agents in occupational environments. Thus, airborne concentrations of microbial agents have been fully documented in numerous occupational settings for (i) specific microbial groups, including culturable bacteria, fungi, and actinomycetes [35,100–102]; (ii) vegetal structures, such as pollen [103]; (iii) viruses [104]; (iv) microbial compounds, such as endotoxin [33,105], (1-3)-β-D-glucans [106], allergens [107], and ergosterol [108]; and (v) microbial toxins, such as mycotoxins [109].

Additionally, the number of published scientific works aimed at determining the composition of occupational environments in microbial taxa has increased sharply in recent years. Studies were carried out by characterizing the biodiversity of microbial communities through the cultivation of micro-organisms, followed by the identification of isolates using macroscopic and microscopic observations, biochemical tests, and chemical methods, such as fatty acid methyl ester (FAME) and matrix-assisted laser desorption/ionization time of flight (MALDI-TOF) analyses [110]. Non-culture-based biodiversity studies are usually carried out using a polymerase chain reaction (PCR), followed by the sequencing of DNA and bioinformatic analysis of sequences [111–113].

The quantitative assessment of microbial communities and microbial compounds, as well as biodiversity studies, improves knowledge of the micro-organisms present in a given professional environment. Therefore, it provides essential input for the qualitative approach for EvBRs. However, in the current state of knowledge, the quantitative approach alone does not allow for biological risks to be assessed with sufficient precision. Indeed, the health effects of micro-organisms on workers depend on the species and the compounds to which workers are exposed, where a recent literature review on that issue concluded "that none of the analyzed studies provided suitable dose–response relationships for derivation of exposure limits" [18]. Helpful guideline values, which are generally not health-related, were published for bacteria and molds in general, but they vary from country to country. For example, the values that can be described as acceptable at the workplace for molds are $10^3$ CFU/m$^3$ in Switzerland [114], $5 \times 10^4$ CFU/m$^3$ in the air of household waste sorting centers in Germany [115], and $10^4$ spores/m$^3$ in Canada [116]. Thus, research is therefore still needed regarding quantifying exposure levels to define realistic indicator parameters that can be measured for quantitative risk

assessment in a given working sector, to develop standardized measurement methods for indicator parameters that allow for identifying the real risk potential of exposures, and to carry out studies combining different measurement methods with valid dose–response outputs.

Additionally, the quantification of exposure levels can be used to quantify only what is sought or measurable, and it provides a snapshot of the working situation for a given period, generally during a working shift or a specific task. These metrological campaigns require technical knowledge and have a controlled level of expertise. Furthermore, a financial cost must be borne by the company.

Finally, the complementarity of the quantitative assessment with the qualitative assessment, namely, the two steps used to assess the risk, was highlighted by three of the references studied [43,64,71].

## 5. Limitation and Interests

One of the limits of this work could be the non-exhaustiveness of the inventory of sources related to procedures for assessing biological risk in the workplace. This theme is still underdeveloped [45,117], which is why the identification of sources presenting this type of evaluation was not easy. On the one hand, the listed bibliographic references revealed that the publications concerning the evaluation of biological health risks, or those related to bioterrorism or biological safety, were the subject of a large number of references in comparison to those on the evaluation of biological risk in the workplace. One explanation is the place and importance of considering health risks, particularly in the context of the prevention of epidemics or other effects on the health of the population [118,119]. Another one is the increase in the number of assessment-related tools related to bioterrorism, especially after the events of 11 September 2001 [120,121]. Finally, the existence and application of diversified measurement and analysis techniques for micro-organism measurement campaigns [15,122,123] or the increasing development of modeling systems [124–126] may also explain why published data are scarce. In the context of this work, the grey literature is presumably infinite. It is not possible to review all guidelines issued by private companies about occupational risk prevention, and internal documents are not generally accessible. Moreover, a database from a copyright library or an appropriate publishing database could have been consulted but the use of search engines, such as Google and Google Scholar, made it possible to achieve our objectives in terms of finding our bibliographic references.

On the other hand, regarding finding users of health and safety software, only one provider was contacted and few manufacturers use this type of software to assess biological risks.

The evaluation of biological risks is admittedly a recognized difficulty for experts, as evidenced by the lack of sources on this subject. However, the strength of this unconventional research is that it has incorporated various sources of biological risk assessment, such as conceptual approaches, notably proposed by regulatory agencies; professional methodologies; and computer applications. These are functional approaches whose evaluation principle is based on the regulatory provisions of the country in which they are developed. This work made it possible to draw up a representative inventory of the existing situation in terms of the qualitative assessment of biological risk. In addition, the analysis of these sources made it possible to define the structure of an approach by describing the components of the risk, descriptors of the danger, and descriptors of the exposure. The proposal of such a methodology is a first step. The following steps will focus on the construction of such a methodology, its implementation, and validation to verify its feasibility. This methodology can thus evolve with scientific and technical advances in the field of biological risk in the workplace.

## 6. Conclusions and Perspectives

Critical analysis of the 32 sources considering the initial or qualitative assessment of the biological risk in an occupational setting indicates that today, there is no universal approach that exhaustively integrates all the criteria through which this risk can be fully assessed. By analyzing existing approaches and formalizing the findings, we defined the main characteristics of a complete EvBR methodology. The proposed approach was inspired by all the studied approaches, and therefore contains similarities

with them, but allows for defining a comprehensive approach. The proposed approach has the following features:

- A qualitative methodology in the form of writing because it is a more structured approach that facilitates its availability and the collection of data during its implementation.
- It takes into account the hazard descriptors by carrying out an inventory of the microorganisms that are potentially present and of all the hazards.
- It takes into account exposure descriptors, such as routes of exposure, as well as technical and organizational preventive measures.
- It is based on a risk assessment that combines the "analysis of workstations" and "assessment by level of risk," which is a progressive approach that allows for classifying the descriptors of hazards and experiences classified into bands through observation.
- It presents identifiable or quantifiable descriptors that are more precise and more understandable and includes a simple points system that is easier for users to implement.

Based on these elements, a methodology is being developed for a particular sector of activity, namely, composting waste. This sector is the subject of a certain number of studies relating to bioaerosols and metrological campaigns. The next works, which will consist of defining a qualitative methodology in this sector of activity, will make it possible to compare the results obtained from such an approach to the results from the quantitative evaluations. Currently, this approach is in the testing phase for real work situations in companies. Based on the generated feedback, improvements will be made to this methodology to ensure its feasibility in the field, with the ultimate goal being to contribute to the development of a method of biological risk assessment in the workplace.

**Supplementary Materials:** The following are available online at http://www.mdpi.com/2073-4433/11/7/741/s1, Table S1: Summary of the research process using the PubMed bibliographic database. Table S2: Characteristics of the approaches used to assess biological risk. Table S3: Characteristics of assessment approaches that combine "workstation analysis" and "assessment by risk level."

**Author Contributions:** Conceptualization S.B., L.F., P.D., and G.M.; methodology, S.B., P.D., and G.M.; investigation, S.B., L.F., and P.D.; formal analysis, S.B., L.F., and P.D.; validation, L.F., P.D., and G.M.; visualization, S.B.; writing—original draft preparation, S.B. and P.D.; writing—review and editing, L.F., P.D., and G.M. All authors have read and agreed to the published version of the manuscript.

**Funding:** This research received no external funding.

**Conflicts of Interest:** The authors declare no conflicts of interest.

## References

1. Journal officiel. Directive 2000/54/CE du Parlement Européen et du Conseil du 18 Septembre 2000 Concernant la Protection des Travailleurs Contre les Risques liés à L'exposition à des Agents Biologiques au Travail. *Journal Officiel*, 18 September 2020; 25.
2. Li, K.; Bihan, M.; Yooseph, S.; Methe, B.A. Analyses of the microbial diversity across the human microbiome. *PLoS ONE* **2012**, *7*, e32118. [CrossRef] [PubMed]
3. Eldor, A.P. *Soil Microbiology, Ecology and Biochemistry*, 4th ed.; Academic Press: Cambridge, MA, USA, 2015.
4. Gibbons, S.M.; Gilbert, J.A. Microbial diversity–exploration of natural ecosystems and microbiomes. *Curr. Opin. Genet. Dev.* **2015**, *35*, 66–72. [CrossRef]
5. Fröhlich-Nowoisky, J.; Kampf, C.J.; Weber, B.; Huffman, J.A.; Pöhlker, C.; Andreae, M.O.; Lang-Yona, N.; Burrows, S.M.; Gunthe, S.S.; Elbert, W.; et al. Bioaerosols in the Earth system: Climate, health, and ecosystem interactions. *Atmos. Res.* **2016**, *182*, 346–376. [CrossRef]
6. Snelling, W.J.; Joshi, P.; Pande, V. Microbial diversity of aquatic ecosystem and its industrial potential. *J. Bacteriol. Mycol.* **2016**, *3*, 177–179.
7. Dutkiewicz, J.; Cisak, E.; Sroka, J.; Wójcik-Fatla, A.; Zajac, V. Biological agents as occupational hazards–selected issues. *Annals Agric. Environ. Med.* **2011**, *18*, 286–293.

8. Herr, C.; Bittighofer, P.M.; Bünger, J.; Eikmann, T.; Fischer, A.B.; Grüner, C.; Idel, H.; zur Nieden, A.; Palmgren, U.; Seidel, H.J.; et al. Effect of microbial aerosols on the human. *Schr. Ver Wasser Boden Lufthyg* **1999**, *104*, 403–481.
9. Radon, K.; Nowak, D. Atemwegs- und Lungenerkrankungen in der Europäischen Landwirtschaft. *Pneumologie* **2003**, *57*, 444–448. [CrossRef] [PubMed]
10. Rim, K.-T.; Lim, C.-H. Biologically Hazardous Agents at Work and Efforts to Protect Workers' Health: A Review of Recent Reports. *Saf. Health Work* **2014**, *5*, 43–52. [CrossRef]
11. Yilmaz, I.; Oner Erkekol, F.; Secil, D.; Misirligil, Z.; Mungan, D. Cat and dog sensitization in pet shop workers. *Occup. Med.* **2013**, *63*, 563–567. [CrossRef]
12. Cho, I.; Blaser, M.J. The human microbiome: At the interface of health and disease. *Nat. Rev. Genet.* **2012**, *13*, 260. [CrossRef]
13. Hazelwood, L.A.; Daran, J.M.; Van Maris, A.J.; Pronk, J.T.; Dickinson, J.R. The Ehrlich Pathway for Fusel Alcohol Production: A Century of Research on *Saccharomyces cerevisiae* Metabolism. *Appl. Environ. Microbiol.* **2008**, *74*, 2259–2266. [CrossRef] [PubMed]
14. Douwes, J.; Thorne, P.; Pearce, N.; Heederik, D. Bioaerosol health effects and exposure assessement: Progress and prospects. *Ann. Occup. Hyg.* **2003**, *47*, 187–200. [PubMed]
15. Eduard, W.; Heederik, D.; Duchaine, C.; Green, B.J. Bioaerosol exposure assessment in the workplace: The past, present and recent advances. *J. Environ. Monit.* **2012**, *14*, 334–339. [CrossRef] [PubMed]
16. Gehin, D.; Faure, M.; Duquenne, P.; Simon, X.; Vallte, D.; Montjoffre, F. Fabrication de saucissons secs et pneumopathie d'hypersensibilité–Point des connaissances et étude de poste. *Doc. Pour Médecin Trav. (DMT)* **2009**, *120*, 437–452.
17. Srikanth, P.; Sudharsanam, S.; Steinberg, R. Bio-aerosols in indoor environment: Composition, health effects and analysis. *Indian J. Med. Microbiol.* **2008**, *26*, 302–312. [CrossRef] [PubMed]
18. Walser, S.M.; Gerstner, D.G.; Brenner, B.; Bünger, J.; Eikmann, T.; Janssen, B.; Kolb, S.; Kolk, A.; Nowak, D.; Raulf, M.; et al. Evaluation of exposure–response relationships for health effects of microbial bioaerosols—A systematic review. *Int. J. Hyg. Environ. Health* **2015**, *218*, 577–589. [CrossRef] [PubMed]
19. Shereen, M.A.; Khan, S.; Kazmi, A.; Bashir, N.; Siddique, R. COVID-19 infection: Origin, transmission, and characteristics of human coronaviruses. *J. Adv. Res.* **2020**, *24*, 91–98. [CrossRef]
20. Surtees, R.; Ariza, A.; Punch, E.K.; Trinh, C.H.; Dowall, S.D.; Hewson, R.; Hiscox, J.A.; Barr, J.N.; Edwards, T.A. The crystal structure of the Hazara virus nucleocapsid protein. *BMC Struct. Biol.* **2015**, *15*, 1–3. [CrossRef] [PubMed]
21. Engelbrecht, M.; van Rensburg, A.; Rau, A.; Yassi, A.; Spiegel, J.; O'Hara, L.; Bryce, E.; Nophale, L. Tuberculosis and blood-borne infectious diseases: Workplace conditions and practices of healthcare workers at three public hospitals in the Free State. *S. Afr. J. Infect. Dis.* **2015**, *30*, 23–28. [CrossRef]
22. Crameri, R. Recombinant *Aspergillus fumigatus* allergens: From the nucleotide sequences to clinical applications. *Int. Arch. Allergy Immunol.* **1998**, *115*, 99–114. [CrossRef] [PubMed]
23. Duquenne, P.; Ambroise, D.; Görner, P.; Clerc, F.; Greff-Mirguet, G. Exposure to Airborne Endotoxins among Sewer Workers: An Exploratory Study. *Ann. Occup. Hyg.* **2014**, *58*, 283–293. [PubMed]
24. Liebers, V.; Raulf-Heimsoth, M.; Brüning, T. Health effects due to endotoxin inhalation (review). *Arch. Toxicol.* **2008**, *82*, 203–210. [CrossRef] [PubMed]
25. Perz, J.F.; Armstrong, G.L.; Farrington, L.A.; Hutin, Y.J.; Bell, B.P. The contributions of hepatitis B virus and hepatitis C virus infections to cirrhosis and primary liver cancer worldwide. *J. Hepatol.* **2006**, *45*, 529–538. [CrossRef] [PubMed]
26. Herr, C.E.; Zur Nieden, A.; Jankofsky, M.; Stilianakis, N.I.; Boedeker, R.H.; Eikmann, T.F. Effects of bioaerosol polluted outdoor air on airways of residents: A cross sectional study. *Occup. Environ. Med.* **2003**, *60*, 336–342. [CrossRef] [PubMed]
27. Sykes, P.; Jones, K.; Wildsmith, J.D. Managing the potential public health risks from bioaerosol liberation at commercial composting sites in the UK: An analysis of the evidence base. *Resour. Conserv. Recycl.* **2007**, *52*, 410–424. [CrossRef]
28. Fung, F.; Hughson, W.G. Health effects of indoor fungal bioaerosol exposure. *Appl. Occup. Environ. Hyg.* **2003**, *18*, 535–544. [CrossRef]
29. Driscoll, T.; Takala, J.; Steenland, K.; Corvalan, C.; Fingerhut, M. Review of estimates of the global burden of injury and illness due to occupational exposures. *Am. J. Ind. Med.* **2005**, *48*, 491–502. [CrossRef]

30. Cavet, M.; Coutrot, T.; Rivalin, R. *Les Risques Professionnels en 2010: De Fortes Différences d'exposition Selon les Secteurs*; Dares Analyses: Corbevoie, France, 2013; p. 12.
31. Journal Officiel. *Directive 89/391/CEE du Conseil, du 12 juin 1989, Concernant la Mise en Oeuvre de Mesures Visant à Promouvoir L'amélioration de la Sécurité et de la Santé des Travailleurs au Travail 1989*; Journal Officiel des Communautés européennes: Luxembourg, 12 June 1989; pp. 0001–0008.
32. Reponen, T. Methodologies for assessing bioaerosol exposures. In *Encyclopedia of Environmental Health*; Nriagu, C.J.O., Ed.; Elsevier: Burlington, NJ, USA, 2011; pp. 722–730.
33. Duquenne, P.; Marchand, G.; Duchaine, C. Measurement of Endotoxins in Bioaerosols at Workplace: A Critical Review of Literature and a Standardization Issue. *Ann. Work Expo. Health* **2012**, *57*, 137–172.
34. Corrao, C.R.; Mazzotta, A.; La Torre, G.; De Giusti, M. Biological risk and occupational health. *Ind. Health* **2012**, *50*, 326–337. [CrossRef]
35. Oppliger, A.; Duquenne, P. Chapter 8—Highly contaminated workplaces. In *Environmental Mycology in Public Health: Fungi and Mycotoxins Risk Assessment and Management*; Viegas, C., Ed.; Academic Press: Amsterdam, The Netherlands, 2016; pp. 79–105.
36. Schlosser, O.; Robert, S.; Debeaupuis, C.; Huyard, A. Inhalable dust as a marker of exposure to airborne biological agents in composting facilities. *Waste Manag.* **2018**, *81*, 78–87. [CrossRef]
37. Robertson, S.; Douglas, P.; Jarvis, D.; Marczylo, E. Bioaerosol exposure from composting facilities and health outcomes in workers and in the community: A systematic review update. *Int. J. Hyg. Environ. Health* **2019**, *222*, 364–386. [CrossRef] [PubMed]
38. Health Council of the Netherlands. *Fungal Alpha-Amylase (Derived from the Fungus Aspergillus Oryzae)—Health-Based Recommended Occupational Exposure Limit*; Health Council of the Netherlands: The Hague, The Netherlands, 2014; p. 96.
39. Nielsen, G.D.; Larsen, S.T.; Hansen, J.S.; Poulsen, L.K. Experiences from occupational exposure limits set on aerosols containing allergenic proteins. *Ann. Occup. Hyg.* **2012**, *56*, 888–900. [PubMed]
40. Health Council of the Netherlands. *Endotoxins. Health-based Recommended Occupational Exposure Limit*; Health Council of the Netherlands: The Hague, The Netherlands, 2010.
41. IARC. *IARC Monogrpah 100F—Aflatoxins*; International Agency for Research on Cancer: Lyon, France, 2018; pp. 225–248.
42. Zamfir, M.; Gerstner, D.G.; Walser, S.M.; Bünger, J.; Eikmann, T.; Heinze, S.; Kolk, A.; Nowak, D.; Raulf, M.; Sagunski, H.; et al. A systematic review of experimental animal studies on microbial bioaerosols: Dose-response data for the derivation of exposure limits. *Int. J. Hyg. Environ. Health* **2019**, *222*, 249–259. [CrossRef] [PubMed]
43. Bonnard, R. *Le Risque Biologique et la Méthode d'Evaluation du Risque*; Institut National de l'Environnement Industriel et des Risques (INERIS): Verneuil-en-Halatte, France, 2001; p. 70.
44. Le Bâcle, C. Les risques biologiques en milieu professionnel. *Hygiène Sécurité Trav.* **2007**, *207*, 85–96.
45. Brun, E. *Expert Forecast on Emerging Biological Risks Related to Occupational Safety and Health*; Office for Official Publications of the European Communities: Brussels, Belgium, 2007.
46. Coelho, A.C.; García Díez, J. Biological Risks and Laboratory-Acquired Infections: A Reality That Cannot be Ignored in Health Biotechnology. *Front. Bioeng. Biotechnol.* **2015**, *3*, 56. [CrossRef]
47. Arndt, R.; Packroff, R.; Gorner, B.; Guhe, C.; Lechtenberg-Auffarth, E.; Lotz, G.; Tischer, M. An easy-to-use workplace control scheme for hazardous substances-A guidance for small and medium enterprises to comply with the new German Ordinance on hazardous substances for hazardous chemical agents without an occupational exposure limit value. *Gefahrst. Reinhalt. Luft.* **2005**, *65*, 13.
48. Balsat, A.; de Graeve, J.; Mairiaux, P. A structured strategy for assessing chemical risks, suitable for small and medium-sized enterprises. *Ann. Occup. Hyg.* **2003**, *47*, 549–556.
49. HSE. *COSHH Essentials: Easy Steps to Control Chemicals—Control of Substances Hazardous to Health Regulations*; Health and Safety Executive (HSE): London, UK, 2003.
50. Marquart, H.; Heussen, H.; Le Feber, M.; Noy, D.; Tielemans, E.; Schinkel, J.; West, J.; Van Der Schaaf, D. 'Stoffenmanager', a web-based control banding tool using an exposure process model. *Ann. Occup. Hyg.* **2008**, *52*, 429–441.
51. Russell, R.M.; Maidment, S.C.; Brooke, I.; Topping, M.D. An introduction to a UK scheme to help small firms control health risks from chemicals. *Ann. Occup. Hyg.* **1998**, *42*, 367–376. [CrossRef]

52. Vincent, R.; Bonthoux, F.; Mallet, G.; Iparraguirre, J.F.; Rio, S. Méthodologie d'évaluation simplifiée du risque chimique: Un outil d'aide à la déscision. *Hygiène Sécurité Trav.* **2005**, *200*, 39–62.
53. ANSES. *Development of a specific Control Banding Tool for Nanomaterials*; Agence Nationale se Sécurité Sanitaire de L'alimentation de L'environnement et du Travail (ANSES): Maisons-Alfort, France, 2010; p. 50.
54. Hristozov, D.; Zabeo, A.; Alstrup Jensen, K.; Gottardo, S.; Isigonis, P.; Maccalman, L.; Critto, A.; Marcomini, A. Demonstration of a modelling-based multi-criteria decision analysis procedure for prioritisation of occupational risks from manufactured nanomaterials. *Nanotoxicology* **2016**, *10*, 1215–1228. [CrossRef] [PubMed]
55. Kuempel, E.D.; Geraci, C.L.; Schulte, P.A. Risk assessment and risk management of nanomaterials in the workplace: Translating research to practice. *Ann. Occup. Hyg.* **2012**, *56*, 491–505. [PubMed]
56. Liao, C.M.; Chiang, Y.H.; Chio, C.P. Model-based assessment for human inhalation exposure risk to airborn nano/fine titanium dioxide particules. *Sci. Total Environ.* **2008**, *407*, 165–177. [CrossRef] [PubMed]
57. Ricaud, M.; Witschger, O. *Les Nanomatériaux—Définitions, Risques Toxicologiques, Caractérisation de L'exposition Professionnelle et Mesures de Prévention*; Insitut National de Recherche et Sécutité (INRS): Paris, France, 2012; p. 52.
58. Moher, D.; Liberati, A.; Tetzlaff, J.; Altman, D.G.; Prisma Group. Preferred Reporting Items for Systematic Reviews and Meta-Analyses: The PRISMA StatementThe PRISMA Statement. *Ann. Intern. Med.* **2009**, *151*, 264–269. [CrossRef] [PubMed]
59. Boehm, A.B.; Graham, K.E.; Jennings, W.C. Can We Swim Yet? Systematic Review, Meta-Analysis, and Risk Assessment of Aging Sewage in Surface Waters. *Environ. Sci. Technol.* **2018**, *52*, 9634–9645. [CrossRef] [PubMed]
60. Setbon, M. Les risques sanitaires. *Médecine/Sciences* **2000**, *16*, 1203–1206. [CrossRef]
61. Rotz, L.D.; Khan, A.S.; Lillibridge, S.R.; Ostroff, S.M.; Hughes, J.M. Public health assessment of potential biological terrorism agents. *Emerg. Infect. Dis.* **2002**, *8*, 225–230. [CrossRef] [PubMed]
62. Chyba, C.F. Toward biological security. *Foreign Aff.* **2002**, *81*, 122–136. [CrossRef]
63. Triolet, J.; Héry, M. Les méthodes d'évaluation des risques chimiques. *Une Anal. Crit.* **2009**, *216*, 11–22.
64. Forestier, D.; Lecornet, É.; Mosqueron, L.; Lambolez, L. Exposure to bioaerosols for wastewater treatment plant workers: Prioritization of the areas and tasks involving the greatest exposure, and prevention. Environnement. *Risques Santé* **2012**, *11*, 137–148.
65. Pichenot, O. Assessment of the professional biological risks of dialysis technicians. *Hygiènes* **2008**, *5*, 407–415.
66. Nuebling, M.; Hofmann, F. Task profile and risk of occupational hepatitis. *A Infect. Sewerage Work. Int. Arch. Occup. Environ. Health* **2001**, *74*, 589–593. [CrossRef] [PubMed]
67. Touche, S. *Évaluation et Prévention des Risques Biologiques en Laboratoires d'analyses Médicales. Présentation d'un Guide Méthodologique*; Association Nationale Médecine du Travail d'Ergonomie du Personnel des Hôpitaux (ANMTEPH): Lausanne, Switzerland, 2008; p. 31.
68. Académie de Grenoble. *Prévention des Risques Biologiques–Risques Biologiques au Laboratoire de Génie Biologique*; Académie de grenoble: Grenoble, France, 2010; Academie de Grenoble. Biotechnologies–ST2S. Available online: https://sti-biotechnologies-pedagogie.web.ac-grenoble.fr/ (accessed on 27 March 2020).
69. CMRBL (Comité de Maîtrise des Risques Biologiques en Laboratoire). *Methodological Guide to the Assessment of Biological Safety and Security Risks*; Agence Nationale de Sécurité Sanitaire de L'alimentation, de L'environnement et du Travail (ANSES): Maisons-Alfort, France, 2012; p. 32.
70. 3RB (Réseau Ressources Risque Biologique). Evaluation des Risques: Éléments de Méthodes. 2016. Available online: http://www.esst-inrs.fr/3rb/afftexte.php?p1=cotation_risque (accessed on 27 March 2020).
71. Goyer, N. Bioaerosols in the workplace: Evaluation, control and prevention guide. In *Studies and Research Projects; Technical Guide T-24*; Institut de Recherche Robert-Sauvé en Santé et en Sécurité du Travail (IRSST): Montréal, QC, Canada, 2001; p. 94.
72. Lavoie, J.; Neesham-Grenon, E.; Debia, M.; Cloutier, Y.; Marchand, G. *Development of a Control Banding Method for Selecting Respiratory Protection against Bioaerosols*; Rapport R-804; Institut de Recherche Robert-Sauvé en Santé et en Sécurité du Travail (IRSST): Montreal, QC, Canada, 2013.
73. Cheneval, E.; Busque, M.A.; Ostiguy, C.; Lavoie, J.; Bourbonnais, R.; Labrèche, F.; Zayed, J. *Green Jobs in Quebec: Definition and Assessment of Potential Chemical and Biological Risks to Workers' Health*; Institut de recherche Robert-Sauve en Sante et en Securite du Travail (IRSST): Montreal, QC, Canada, 2017.

74. U.S. Department of Health and Human Services. *Biosafety in Microbiological and Biomedical Laboratories*; Centers for Disease Control and Prevention: Atlanta, GA, USA, 2009; p. 438.
75. Advisory Committee on Dangerous Pathogens. *Infection at Work: Controlling the Risks—A Guide for Employers and the Self-employed on Identifying, Assessing and Controlling the Risks of Infections in the Workplace*; Health and Safety Executive (HSE): Norwich, UK, 2003; p. 80.
76. Advisory Committee on Dangerous Pathogens. *Biological Agents: Managing the Risks in Laboratories and Healthcare Premises*; Health and Safety Executive (HSE): Norwich, UK, 2005; p. 80.
77. Health & Safety Service. *Bio COSHH Risk Assessment*; Health & Safety Service: Newcastle upon Tyne, UK, 2015; p. 28.
78. Belgian Biosafety Server. *Biological Risk Assessment Sheets*; Belgian Biosafety Server: Brussels, Belgium, 2016; Belgain Biosafety Server. Assessement of Biological Risk. Available online: https://www.biosafety.be/ (accessed on 27 March 2020).
79. Health Canada. *The Laboratory Biosafety Guidelines*; Santé Canada: Ottawa, ON, Canada, 2004; p. 136.
80. Government of Alberta. *Best Practices for the Assessment ans Control of Biological Hazards—Best Practices Guidelines for Occupational Health and Safety in the Healthcare Industry*; Health Canada: Ottawa, ON, Canada, 2011; p. 200.
81. HSE. *Guidance for Developing a Biological Agents Risk Assessment for Healthcare Sector*; Health Service Executive (HSE): Dublin, Ireland, 2011; p. 34.
82. Société Française d'Hygiène Hospitalière. Prévention des risques infectieux dans les laboratoires d'analyse de biologie médicale. *Hygiènes* **2007**, *XV*, 405–524.
83. CNRS (Centre National de la Recherche Scientifique). *Risques Biologiques: Les Cahiers de Prévention*; Centre National de la Recherhce Scientifique: Meudon, France, 2017; CNRS. Cahier de Prévention "Risques Biologiques". Available online: http://www.dgdr.cnrs.fr/SST/CNPS/guides/risquebio.htm (accessed on 27 March 2020).
84. EU-OSHA. *Risk Assessment for Microbiological Agents (E-facts-53)*; Agence Européenne Pour la Santé et la Sécurité au Travail: Bilbao, Spain, 2010; p. 14.
85. INRS. *Les Risques Biologiques en Milieu Professionnel*; Institut National de Recherche et de Sécurité (INRS): Paris, France, 2014; p. 47.
86. INRS. *Laboratoires D'analyses Médicales: Evaluation et Prévention des Risques Infectieux*; Institut National de Recherche et de Sécurité (INRS): Paris, France, 2009; p. 57.
87. WHO. *Laboratory Biosafety Manual*, 3rd ed.; World Health Organization (WHO): Geneva, Switzerland, 2004; p. 234.
88. IRSST. *A Support Tool for Choosing Respiratory Protection against Bioaerosols*; Institut de Recherche Robert-Sauvé en Santé et en Sécurité du Travail (IRSST): Montréal, QC, Canada, 2015.
89. Caskey, S.; Gaudioso, J.; Salerno, R. *Biosecurity Risk Assessment Methodology (BioRAM) v. 2.0 (Version 00)*; U.S. Department of Energy—Office of Scientific and Technical Information: Livermore, CA, USA, 2009.
90. Société Française de Microbiologie. *Manuel de Sécurité et de Sûreté Biologiques*; Société Française de Microbiologie (SFM): Paris, France, 2014; p. 224.
91. Sandia National Laboratories. *Biosafety Risk Assessement Methodology*; Sandia Nationak Laboratories: Livermore, CA, USA, 2010; p. 69.
92. NIOSH. *Qualitative Risk Characterisation and Management of Occupational Hazards: Control Banding (CB), a Literature Review and Critical Analysis*; CDC/NIOSH: Atlanta, GA, USA, 2009; p. 118.
93. Zalk, D.M.; Nelson, D.I. History and Evolution of Control Banding: A Review. *J. Occup. Environ. Hyg.* **2008**, *5*, 330–346. [CrossRef] [PubMed]
94. Journal officiel. *Arrêté du 27 Décembre 2017 Relatif à la liste des agents Biologiques Pathogènes et aux Mesures Techniques de Prévention à Mettre en Oeuvre dans les Laboratoires où les Travailleurs sont Susceptibles d'être Exposés à des Agents Biologiques Pathogènes*; Journal Officiel: Paris, France, 27 December 2017; p. 3.
95. Ausschuss für Biologische Arbeitsstoffe (ABAS). *TRBA 400 Handlungsanleitung zur Gefährdungsbeurteilung und für die Unterrichtung der Beschäftigten bei Tätigkeiten mit biologischen Arbeitsstoffen*; Bundesanstalt für Arbeitsschutz und Arbeitsmedizin (BAuA): Dortmund, Germany, 2017.
96. Gouvernement du Canada. *Fiche Technique Santé-Sécurité: Agents Pathogènes, et Evaluation des Risques*; Gouvernement du Canada: Montréal, QC, Canda, 2017.

97. Journal officiel. *Arrêté du 16 Juillet 2007 Fixant les Mesures Techniques de Prévention, Notamment de Confinement, à Mettre en Œuvre dans les Laboratoires de Recherche, D'enseignement, d'analyses, D'anatomie et Cytologie Pathologiques, les Salles D'autopsie et les Etablissements Industriels et Agricoles où les Travailleurs sont Susceptibles d'être Exposés à des Agents Biologiques Pathogènes*; Journal Officiel: Paris, France, 16 July 2007; p. 13106.
98. RIVM. *The Stoffenmanager Nano Module*; National Institute for Public Health and the Environment (RIVM): Bilthoven, The Netherlands, 2017.
99. Brouwer, D. Control Banding Approaches for Nanomaterials. *Ann. Work Expo. Health* **2012**, *56*, 506–514.
100. Haas, D.; Unteregger, M.; Habib, J.; Galler, H.; Marth, E.; Reinthaler, F.F. Exposure to bioaerosol from sewage systems. *Water Air Soil Pollut.* **2010**, *207*, 49–56. [CrossRef]
101. Pearson, C.; Littlewood, E.; Douglas, P.; Robertson, S.; Gant, T.W.; Hansell, A.L. Exposures and health outcomes in relation to bioaerosol emissions from composting facilities: A systematic review of occupational and community studies. *J. Toxicol. Environ. Health Part B* **2015**, *18*, 43–69. [CrossRef]
102. Szymanska, J. Dental bioaerosol as an occupational hazard in a dentist's workplace. *Ann. Agric. Environ. Med.* **2007**, *14*, 203–207. [PubMed]
103. Peden, D.; Reed, C.E. Environmental and occupational allergies. *J. Allergy Clin. Immunol.* **2010**, *125* (Suppl. 2), S150–S160. [CrossRef] [PubMed]
104. Bailey, E.S.; Choi, J.Y.; Zemke, J.; Yondon, M.; Gray, G.C. Molecular surveillance of respiratory viruses with bioaerosol sampling in an airport. *Trop. Dis. Travel Med. Vaccines.* **2018**, *4*, 11. [CrossRef] [PubMed]
105. Schlosser, O. Bioaerosols and health: Current knowledge and gaps in the field of waste management. *Detritus* **2019**. [CrossRef]
106. Noss, I.; Wouters, I.M.; Bezemer, G.; Metwali, N.; Sander, I.; Raulf-Heimsoth, M.; Heederik, D.J.; Thorne, P.S.; Doekes, G. β-(1, 3)-Glucan exposure assessment by passive airborne dust sampling and new sensitive immunoassays. *Appl. Environ. Microbiol.* **2010**, *76*, 1158–1167. [CrossRef] [PubMed]
107. Raulf, M.; Buters, J.; Chapman, M.; Cecchi, L.; De Blay, F.; Doekes, G.; Eduard, W.; Heederik, D.; Jeebhay, M.F.; Kespohl, S.; et al. Monitoring of occupational and environmental aeroallergens–EAACI Position Paper: Concerted action of the EAACI IG Occupational Allergy and Aerobiology & Air Pollution. *Allergy* **2014**, *69*, 1280–1299. [PubMed]
108. Poole, J.A.; Dooley, G.P.; Saito, R.; Burrell, A.M.; Bailey, K.L.; Romberger, D.J.; Mehaffy, J.; Reynolds, S.J. Muramic acid, endotoxin, 3-hydroxy fatty acids, and ergosterol content explain monocyte and epithelial cell inflammatory responses to agricultural dusts. *J. Toxicol. Environ. Health Part A* **2010**, *73*, 684–700. [CrossRef] [PubMed]
109. Viegas, S.; Viegas, C.; Oppliger, A. Occupational exposure to mycotoxins: Current knowledge and prospects. *Annals Work Expo. Health* **2018**, *62*, 923–941. [CrossRef]
110. Duquenne, P. On the identification of culturable microorganisms for the assessment of biodiversity in bioaerosols. *Annals Work Expo. Health* **2018**, *62*, 139–146. [CrossRef] [PubMed]
111. Mbareche, H.; Veillette, M.; Bonifait, L.; Dubuis, M.E.; Benard, Y.; Marchand, G.; Bilodeau, G.J.; Duchaine, C. A next generation sequencing approach with a suitable bioinformatics workflow to study fungal diversity in bioaerosols released from two different types of composting plants. *Sci. Total Environ.* **2017**, *601*, 1306–1314. [CrossRef] [PubMed]
112. Degois, J.; Clerc, F.; Simon, X.; Bontemps, C.; Leblond, P.; Duquenne, P. First metagenomic survey of the microbial diversity in bioaerosols emitted in waste sorting plants. *Ann. Work Expo. Health* **2017**, *61*, 1076–1086. [CrossRef]
113. White, J.K.; Nielsen, J.L.; Madsen, A.M. Microbial species and biodiversity in settling dust within and between pig farms. *Environ. Res.* **2019**, *171*, 558–567. [CrossRef]
114. SUVA (Schweizerische Unfallversicherungsanstalt). *Valeurs limites D'exposition aux Postes de Travail 2015*, 2015 ed.; (Référence 1903.f; http://www.suva.ch); SUVA: Luzern, Switzerland, 2015.
115. Arbeit und Soziales im Gemeinsamen Ministerialblatt, TRBA (Technische Regel für Biologische Arbeitsstoffe) 214—Abfallbehandlungsanlagen. *Jt. Minist. Gaz.* **2013**, *49*, 978–989.
116. Lavoie, J.; Cloutier, Y.; Lara, J.; Marchand, G. *Guide sur la Protection Respiratoire Contre les Bioaérosols—Recommandations sur le Choix et L'utilisation, Rapport Etudes et Recherches RG-497*; Institut de Recherche Robert-Sauvé en Santé et en Sécurité du Travail (IRSST): Montréal, QC, Canada, 2007; pp. 1–30.
117. Crook, B.H.S.L. *Difficulty of Assessing Biological Risks in the Workplace*; An Agency of the Health and Safety Excutive: Bruxelles, Belgium, 2007; p. 19.

118. Dasaklis, T.K.; Pappis, C.P.; Rachaniotis, N.P. Epidemics control and logistics operations: A review. *Int. J. Prod. Econ.* **2012**, *139*, 393–410. [CrossRef]
119. Fauci, A.S.; Morens, D.M. The Perpetual Challenge of Infectious Diseases. *N. Engl. J. Med.* **2012**, *366*, 454–461. [CrossRef] [PubMed]
120. Woo, G. Quantitative Terrorism Risk Assessment. *J. Risk Financ.* **2002**, *4*, 7–14. [CrossRef]
121. Roberts, K.; Horgan, J. Risk Assessment and the Terrorist. In Perspectives on Terrorism, Winston-Salem, NC, USA. *Terror. Res. Initiat.* **2010**, *2*, 3–9.
122. Ghosh, B.; Lal, H.; Srivastava, A. Review of bioaerosols in indoor environment with special reference to sampling, analysis and control mechanisms. *Environ. Int.* **2015**, *85*, 254–272. [CrossRef] [PubMed]
123. Xu, Z.; Wu, Y.; Shen, F.; Chen, Q.; Tan, M.; Yao, M. Bioaerosol Science, Technology, and Engineering: Past, Present, and Future. *Aerosol Sci. Technol.* **2011**, *45*, 1337–1349. [CrossRef]
124. Carducci, A.; Donzelli, G.; Cioni, L.; Verani, M. Quantitative Microbial Risk Assessment in Occupational Settings Applied to the Airborne Human Adenovirus Infection. *Int. J. Environ. Res. Public Health* **2016**, *13*, 733. [CrossRef]
125. Paccha, B.; Jones, R.M.; Gibbs, S.; Kane, M.J.; Torremorell, M.; Neira-Ramirez, V.; Rabinowitz, P.M. Modeling risk of occupational zoonotic influenza infection in swine workers. *J. Occup. Environ. Hyg.* **2016**, *13*, 577–587. [CrossRef] [PubMed]
126. Rose, J.B.; Gurian, P.L.; Haas, C.N.; Weir, M.H.; Eisenberg, J. *Theory and Practice of Quantitative Microbial Risk Assessment: An Introduction*; Center for Advancing Microbial Risk Assessment (CAMRA): East Lansing, MI, USA, 2013.