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Research article

INFECTION OF PERSONNEL WORKING IN CLINICAL AND DIAGNOSTIC LABORATORIES: QUALITATIVE ANALYSIS AND RISK ASSESSMENT

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Personnel who work in laboratories and directly deal with detecting and examining pathogenic biological agents (PBA) in human biomaterials have to face high risks of becoming infected. At present, working conditions at workplaces of personnel in such laboratories are to be analyzed and checked thoroughly with subsequent implementation of relevant correction measures.

We performed qualitative analysis of infection risks in clinical and diagnostic laboratories using a reason tree and event tree analysis and determined a risk probability range for an ending event considering combined effects produced by preconditions.

We revealed basic reasons why personnel in medical laboratories became infected when working with PBA. The events were considered at three levels and four directions in their development. We performed mathematical calculation of possible event combinations and determined the whole probability range for occurrence of the events. Quantitative risk analysis showed that a probability of a person becoming infected remained within $0.9 \cdot 10^{-4}$–$0.9 \cdot 10^{-3}$ range even in case of the most unfavorable outcome. The study provides a well-substantiated conclusion about peculiarities of work tasks accomplished in laboratories; we established that laboratory personnel who were involved in determining drug resistance of microbacteria had the highest risks of infection. The most hazardous scenarios of emergencies were identified; they made the highest contribution to the analyzed risk. We established that a probability of personnel becoming infected that starts with the value being $1.3 \cdot 10^{-6}$ occurs when immune prevention is neglected and a disease is revealed too late.

It is advisable to analyze ways how emergencies develop in medical laboratories since this helps to make necessary amendments in the system and influence factors of its functioning. This analysis procedure gives an opportunity to select the most relevant measures for protection and prevention of emergencies involving PBA leakage out of all the available ones. These measures can reduce risks of infection for personnel down to their acceptable levels.

Keywords: *occupational risk, working conditions, laboratory personnel, infection, pathogenic biological agents, hazard analysis, risk assessment.*

Over the whole history of occupational risk assessment, risks caused by exposure to physical and chemical factors have been those studied most frequently. Chemical factor has always been given special attention within hygienic assessment of risks at workplaces [1]. Undoubtedly, this is due to its prevalence in the overall structure of occupational incidence among all occupational groups over the whole period of research in the sphere [2]. In our country, a term "occupational risk" was first introduced by N.F. Izmerov and E.I. Denisov in 1959; however, biological factors first attracted any attention when occupational pathologies were assessed only in the early 1990ties. Still, this factor is largely neglected. It is rather typical to underestimate its effects on working conditions for many occupational groups or specific occupations. Special assessment of working conditions (SAWC) gives preference exactly to physical factors. We cannot consider this situation well grounded since this means that a mechanistic approach prevails in hygienic assessment of factors existing in the working environment.

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Appendix 9 to the Order by the RF Ministry of Labor and Social Security No. 33n dated January 24, 2014 stipulates that, regardless of concentrations of pathogenic microorganisms, working conditions that involve dealing with them should be assigned into the relevant hazard category without any measurements[1]. Biological factor is determined by a contact with infectious agents. According to the rules of strict biological safety, microorganisms are not determined in workplace air [3]. At the same time, the Order No. 29n dated January 28, 2021[2] fixes the following list of biological factors: producing fungi, protein and vitamin concentrates (PVC), nutrient yeast, mixed fodders, enzymatic drugs, biological stimulators, allergens used in diagnostics and treatment, blood components and preparations, immunobiological drugs, infected materials and materials suspected to be infected with microorganisms from 3–4 pathogenicity groups (hazard) or helminthes [4]. The same applies to biological materials that are already infected or suspected to be infected with, among other things, microorganisms from 1–2 pathogenicity groups (hazard), hepatitis viruses and HIV, biological toxins (animal, fish or plant poisons), animal and plant dust including that with bacterial contamination. At present, the list is added with COVID-19 viral cultures and isolates.

All the aforementioned components are predominantly dealt with in laboratories where personnel is directly involved into examining and establishing occurrence of pathogenic biological agents (PBA) in human biomaterials.

Occupational activities in any laboratory include multiple sections with different work tasks on handling infected materials. These activities involve large volumes of manual labor, intensive use of specialized laboratory equipment as well as technical devices for control over ambient air, disinfection equipment etc. Given that, a risk rate of infection in a laboratory depends on both relevance of applied infection control measures and on awareness about the issue among laboratory personnel. Studies with their focus on assessing risks for personnel associated with an environment in closed spaces were accomplished and described by N.V. Eremina [5]. New guidelines on biological safety in laboratory conditions were issued in 2020 due to occurrence of the new coronavirus (2019-nCoV). According to them, each laboratory can perform local (within a specific organization) risk assessment to make sure that its personnel have all competences necessary to perform laboratory tests in safe conditions and to check that relevant risk control measures are available to them [6].

Some authors took efforts to perform retrospective analysis of reasons for emergencies with PBA; methods for analyzing risks of emergencies when working with pathogenic biological agents were examined in the dissertations by the V.N. Khramov and E.A. Stakovskii [7]. However, these methods most fre-

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[1] Ob utverzhdenii Metodiki provedeniya spetsial'noi otsenki uslovii truda, Klassifikatora vrednykh i (ili) opasnykh proizvodstvennykh faktorov, formy otcheta o provedenii spetsial'noi otsenki uslovii truda i instruktsii po ee zapolneniyu (s izmeneniyami na 27 aprelya 2020 goda): prikaz Ministerstva truda i sotsial'noi zashchity RF № 33n ot 24.01.2014 [On Approval of Procedure for conducting a special assessment of working conditions, Classifier of adverse and (or) hazardous production factors, reporting form on a specific assessment of working conditions and instructions how to fill it in: The Order issued by the RF Ministry for labor and Social Protection on January 24, 2014 No. 33n (last amended on April 27, 2020)]. *KODEKS: electronic fund for legal and reference documentation*. Available at: https://docs.cntd.ru/document/499072756 (November 12, 2021) (in Russian).

[2] Ob utverzhdenii Poryadka provedeniya obyazatel'nykh predvaritel'nykh i periodicheskikh meditsinskikh osmotrov rabotnikov, predusmotrennykh chast'yu chetvertoi stat'i 213 Trudovogo kodeksa Rossiiskoi Federatsii, perechnya meditsinskikh protivopokazanii k osushchestvleniyu rabot s vrednymi i (ili) opasnymi proizvodstvennymi faktorami, a takzhe rabotam, pri vypolnenii kotorykh provodyatsya obyazatel'nye predvaritel'nye i periodicheskie meditsinskie osmotry: prikaz Minzdrava Rossii ot 28.01.2021 № 29n [On Approval of the Procedure for mandatory preliminary and periodical medical examinations of workers stipulated by the part 4 of the clause 213 in the RF Labor Code, a list of medical contraindications to accomplishing works tasks under exposure to harmful and (or) hazardous occupational factors, as well as work tasks which require mandatory preliminary and periodical medical examinations: the Order by the RF Public Healthcare Ministry dated January 28, 2021 No. 29n]. *KonsultantPlus*. Available at: http://www.consultant.ru/document/cons_doc_LAW_375353/ (November 12, 2021) (in Russian).

quently rely on using analytics or conventional statistical analysis techniques, which makes their use a bit "subjective".

Our research goal was to assess risks of infection and biological hazards for personnel employed at clinical and diagnostic laboratories of a public healthcare organization.

Research objects and techniques. Our research object was a clinical and diagnostic laboratory of a public medical organization. Working conditions in the selected laboratory conformed to the existing legislation. We selected formal analysis techniques to be used in our study. They provide the highest "objectivity" since they are performed at the qualitative level; at the same time, facts are separated from stereotypical opinions, and only scientifically grounded judgments are considered [8]. Quantification was performed manually with using all possible variants how events would develop and all probabilities that personnel would become infected.

Fault tree and event tree methods give an opportunity to consider functional interrelations between various elements in a system as logical schemes that allow for interdependence between faults of elements or element groups [9]. Generally, both fault trees and event tress are just a visual illustrating the simplest probabilistic models. However, they are of special interests for experts involved in exploiting, maintaining and supervising technical objects. When such a scheme is available to them, these experts can not only find the most critical event among all possible ones but also assess an expected associated risk if a relevant event tree is added with necessary statistical data. These operations do not require any substantial knowledge on probability theory [10].

Research results. We analyzed infection of personnel employed in laboratories of public healthcare organizations and involved in dealing with PBA, established reasons for infection and created a tree-like scheme, which is shown in Figure 1.

When creating this reason tree, we distributed events as per different levels. They are places from left to right in the scheme, from the zero level to the fifth one; this does not

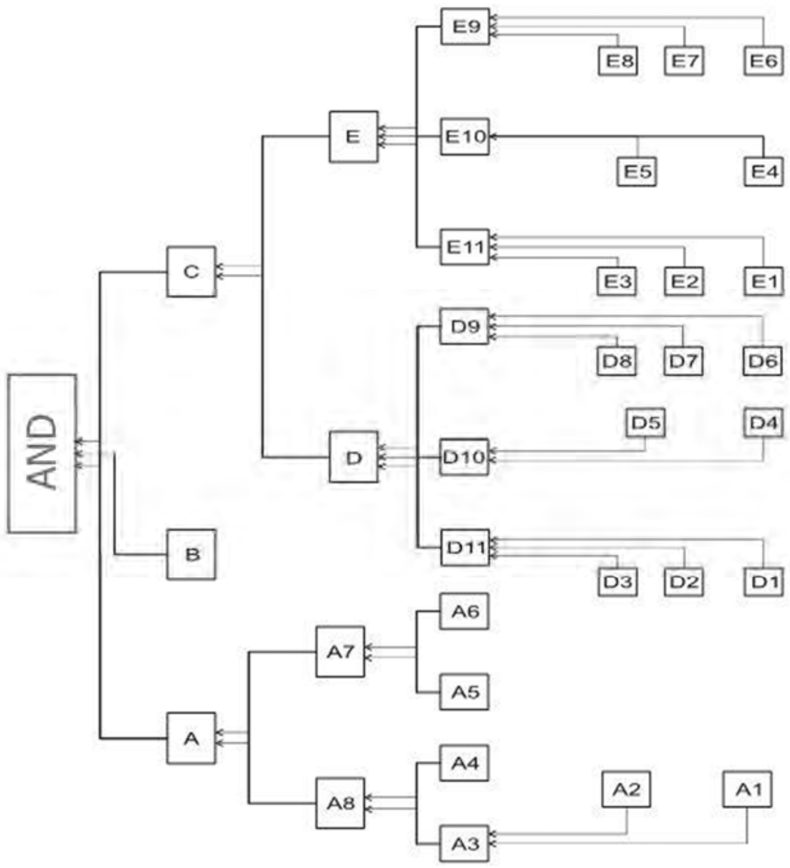

Figure 1. Tree analysis. A reason tree for infection of laboratory personnel

contradict to the logic of creating and reading it. The main (end) event is located at the zero level, followed by events belonging to the first level (some events among them might be initial ones), then the second level and up to the fourth one according to the suggested scheme [11].

Let us enumerate all the initial events necessary to induce the analyzed infection. At the first level, there are events that directly lead to personnel becoming infected:

A is existing biological peculiarities (a biological burden on an object that significantly increases risks of infection);

B is human factor being present in a system;

C is microbacteria occurring in the air or on surfaces inside a laboratory.

The following blocks on the path A are: A8 is a burden crated by microbacteria; A7 is a person's health; A6 is concomitant diseases (diabetes mellitus); A5 is an overall decline in immunity; A4 is the primary resistance and persistence of microbacteria; A3 is multiple drug resistance; A2 is a disrupted treatment scheme; A1 is lack of proper funding.

We can see two categories of preconditions with the same significance on the path C:

E is violation of sanitary rules and standards: E11 means US-radiation has been performed improperly; E10, rules and standards for disinfection have been violated; E9, technical failure of equipment; E8, a decrease in bactericide flow due to voltage changes; E7, equipment has been removed from service too early due to defects; E6, equipment has not been replaced when necessary, its service life has been exceeded (a natural fall in a bactericide flow); E5, improper disinfection; E4, improper concentration of a disinfectant; E3, failure to switch on a lamp; E2, radiation has been performed for a shorter period than required; E1, improper exploitation (just after cleaning);

D is an emergency associated with microbacteria emission: D11 is improper working procedures; D10, an error (lacking experience, nervous overstrain); D9, an expert has lost attentiveness; D8, a decrease in concentration and attention; D7, improper waking and sleeping regime; D6, attention has been moved to another object (a distraction); D5, a new procedure; D4, a young expert; D3, lack of competence needed to apply a new methodology; D2, negligence; D1, lack of knowledge.

The analysis traces an interrelation between preconditions and an end event. Infection can occur already at a moment when a person contacts a bacterium, that is, at the BC combination. The block A elevates this risk and sometimes is the most critical determinant in this event. We cannot possibly single out one certain precondition when trying to determine which exact precondition leads to the main event most rapidly.

This tree has a peculiarity, which is that all the reasons at the level going from left to right can be considered equal. This is because each of the existing reasons can equivalently lead to an event of the higher level. For example, the events D9, D10, D11 can equally be minimal preconditions for the event D to occur. They, in their own turn, result from other equal preconditions. They are mostly represented by the human factor and cannot be neglected by definition. Another peculiarity is that we do not consider any reasons for experts to be within this system. This fact is a priori associated with the reality where most actions aimed at examining a biomaterial in microbiological and bacteriological laboratories have to be performed by people, either manually or by using relevant technical devices and equipment. Therefore, we can totally neglect a probability of their presence in this system.

The probability of the main event P(I) occurs due to a combination of an expert being in a zone with elevated risks and a certain amount of microbacteria (b) that is present on a given surface or environment. This surface can be clothing and the environment is, for example, ambient air inside a room or a box. Another case (a) is organisms having a certain biological peculiarity. Creation of various scenarios as per emergency types logically converts to a technology for hazard quantification [12].

a) $P(I) = P(A) \cdot P(B) \cdot P(C)$

b) $P(I) = P(B) \cdot P(C)$

Each probability of previous events can be given as per the same scheme, for example, regarding a biological burden:

$P1(A) = P(A8) \cdot P(A7)$;

$P2(A) = P(A8) + P(A7) – P(A8) \cdot P(A7)$.

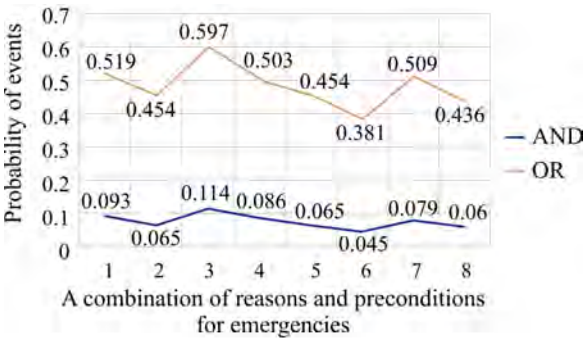

Figure 2. The results produced by calculating probabilities of events as per the paths E and D in the scheme

Since the events A1, A2, A4, A5, A6, D3, D2, D1, D5, D4, D8, D7, D6, E1, E2, E3, E4, E5, E6, E7, E8 are statistically dependent on each other, that is, occurrence of one can result in occurrence of another, then A1 = A2 = A4 = ……….. = E7 = E8. We can calculate their value out of the total probability of these events by dividing 1 by a number of basic events: 1 / 21 = 0.0476.

First, we had to find the probabilities A7 and A8 by considering all possible combinations of the events. The event A7 can occur due to two variants: “AND”, “OR”, consequently:

$P_1(A7) = P(A5) \cdot P(A6) = 0.0476 \cdot 0.0476 =$
$= 0.0226;$

$P_2(A7) = P(A5) + P(A6) – P(A5) \cdot P(A6) =$
$= 0.0476 + 0.0476 – 0.0476 \cdot 0.0476 = 0.0929.$

Similarly, we found all the probabilities that the event A8 would occur considering all combinations of events in the variants “AND” and “OR”. Quantitative analysis revealed that the total probability of the event A varied within 0.0015–0.216 depending on a single precondition or their combinations.

We also determined P(E), or a probability that sanitary rules and standards would be violated; the probability of the event E may vary from 0.213 to 0.375 depending on a combination of factors. Similarly, we calculated probabilities as per the preconditions from the group D and established that the events preceding an error could also overlap, for example, due to improper waking and sleeping regime and any other event that would provoke an expert to abruptly get distracted from manipulations being performed at the moment. It seemed logical to calculate this probability as well [13]: $P_2 (D9) = P (D8) + P (D7) \cdot P (D6) – P (D8) \cdot P (D7) \cdot P (D6) = 0.049$.

To determine the whole range of probabilities that a certain event would occur, we calculated all possible combinations of events. The results are provided in the Figure 2.

Figure 3 shows an “event tree” in a situation when an analyzed biomaterial with PBA has been splashed. The scenario approach with an emergency involving PBA splashing makes it possible to determine [14]:

- four analyzed outcomes: no infection, recovery, disease, fatal outcome;
- five bifurcation stages, that is, stages where separation or qualitative restructuring takes place; in our case, a division into 2–3 paths (outcomes);
- a logical-probabilistic chain that includes [15]:

a) an initiator – an emergency involving splashing and formation of liquid droplet aerosol (the frequency of this initial event is equal to 1);

b) the influencing factor of the 1st order – dispersity of an aerosol;

c) the influencing factor of the 2nd order – a probability to become infected;

d) the influencing factor of the 3rd order – a period before an emergency was detected;

e) the influencing factor of the 4th order – effective measures to eliminate the emergency, taken or not taken;

f) the factor of the 5th order – an outcome (there can be three possible ones: recovery, disease, fatality).

Particles with PBA can occur in air inside a laboratory due to procedures involving aerosol formation. Coarsely dispersed aerosol (liquid droplet diameter is > 5 μm) disperses within one meter away from its source. Typically, such aerosols rapidly deposit from air on skin, clothing and work surfaces in a room. After liquid droplets in an aerosol dry out, finest particles (droplet nuclei) occur and their diameter varies from one to five μm. Each such particle can contain from one to several viable microbacteria. They can remain

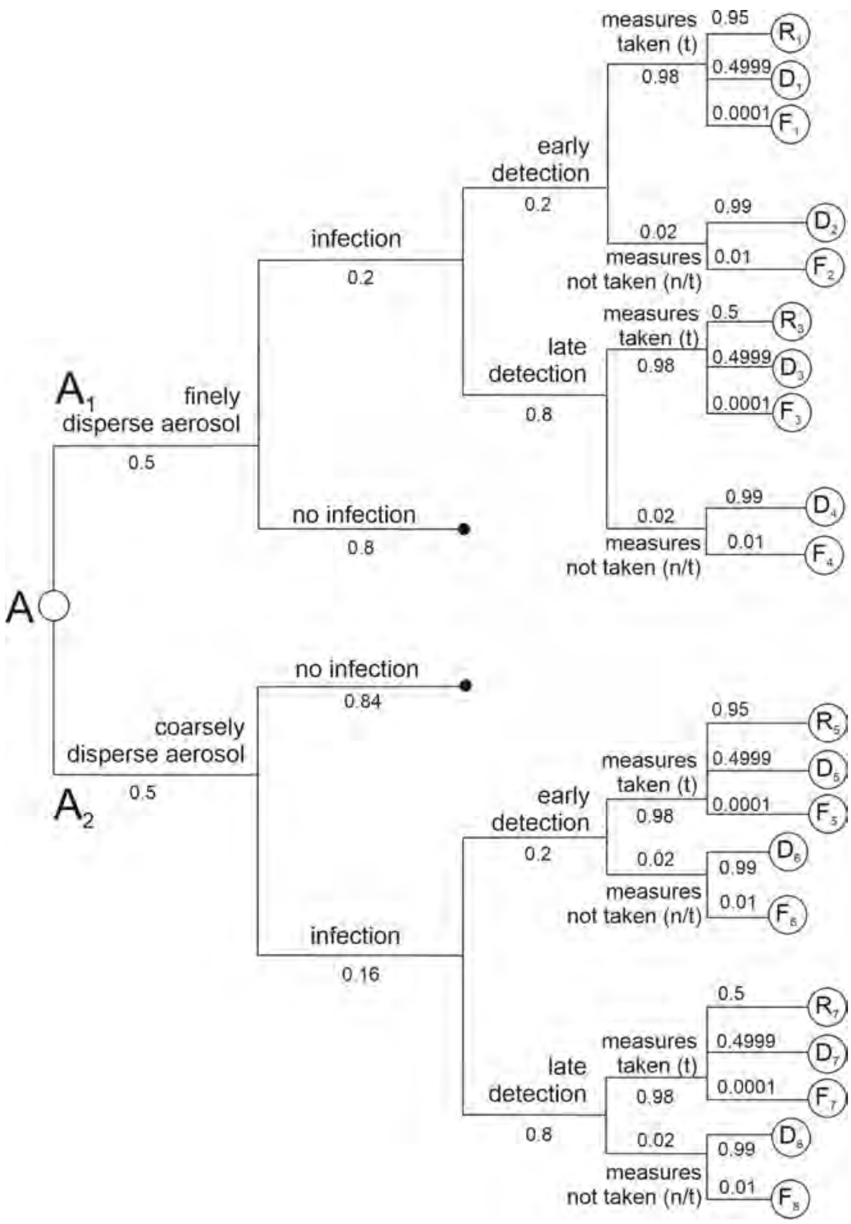

Figure 3. A tree analysis. The event tree when an analyzed biomaterial with PBA has been splashed

viable for a long period, enter the lung alveoli when inhaled, and, consequently, can induce an infection[3].

When a finely dispersed aerosol occurs with its particles being less than 5 μm in diameter, particles deposit slower, they are retained in air for a longer period, and a risk of directly inhaling particles with PBA remains high. In bacteriological and microbiological laboratories, both coarsely and finely dispersed aerosols are likely to occur and a probability of their formation can be considered the same. This is due to peculiarities of various working processes in a laboratory. Thus, centrifuging and manipulations with PCR-devices involve higher risks that a finely dispersed aerosol with PBA particles would occur whereas using pipettes, pouring liquids from one vessel to another, stirring or any other non-automated manipulations with a biomaterial more often result in formation of a coarsely dispersed aerosol. Given

[3] Sistema infektsionnogo kontrolya v protivotuberkuleznykh uchrezhdeniyakh: rukovodstvo [The infection control system in anti-tuberculosis institutions: guide]. In: L.S. Fedorova ed. Moscow – Tver, Izd-vo "Triada" LLC, 2013, 192 p. (in Russian).

that, we took a probability of each aerosol out of these two types as equal to 0.5.

The A1 path. In case there is an emergency with a finely dispersed aerosol, a negative outcome of most such emergencies is assumed to be prevented by individual and collective protection systems (from gloves and a facemask to an ultraviolet bactericide device). Multiple statistical studies have proven that such an outcome when an emergency is detected in due time and all the safety precautions are taken properly occurs in not more than 80 % of actual cases [16]. The remaining 20 % of cases involve primary infection of an expert; therefore, we assume that a probability of infection is 0.1 (80 % from 0.5) and a probability of its absence is 0.4 accordingly.

Such a fact as a person becoming infected with microbacteria is assessed in a peculiar way. This peculiarity is that primary infection is often latent for a long period; this does not allow detecting it in a short time and results produced by diagnostic examinations might not be objective. Hence, a probability that infection is established early will be significantly lower at the 3rd bifurcation stage than a probability of it being established rather late, 0.02 against 0.08.

The next stage involved considering whether effective measures were taken or not and treatment methods that were applied would produce positive effects practically in any situation in future. Hence:

– measures are taken (effective) in 98 % – 0.0196;

– measures are not taken (human factor, not effective, a treatment scheme is improper) in 2 % – 0.0004.

Measures that have been taken directly after infection was established produce a positive effect in treatment and lead to:

– recovery with its probability being 0.95 – 0.01862;

– disease (0.0499) – 0.00097804;

– fatal outcome (0.0001) – 0.00000196.

In case relevant measures have not been taken, we can assume only 2 ultimate outcomes, disease (0.00038) and fatal outcome (0.00002).

Similarly, if we consider a scenario when infection with a biological agent was established late, we get the following figures. Recovery is achieved due to proper immune prevention and express treatment (0.0392) whereas a developed disease (0.0384) will require additional treatment procedures and more time. We cannot exclude a fatal outcome completely with its probability being 0.000784. In case of refusal from treatment or selecting improper treatment, we cannot speak about early recovery just as in the first case. Disease development is equal to 0.00158 and a probability of a fatal outcome is equal to 0.000016. The quantification results as per outcomes of probable events are provided in the Table.

We checked the validity as follows. All the end probabilities of outcomes resulting from the bifurcation stages as per the path related to formation of a finely dispersed aerosol should be equal to 0.5: $P(A_1) = (0.01862 + 0.00097804 + 0.00000196 + 0.000396 + 0.000004 + 0.0392 + 0.03919216 + 0.00000784 + 0.001584 + 0.000016) + 0.4 = 0.1 + 0.4 = 0.5$.

Depending on a situation, a probability of a fatal outcome $P\ (F_{fda})$ can have the following values 0.00000196, 0.00002, 0.00000784, 0.000016. The most unfavorable scenario occurs when infection has been established too late and effective prevention activities and treatment procedures have been neglected. Its value is 0.00002.

Similarly, we determined probabilities as per the A2 path when a coarsely dispersed aerosol occurred.

Validity as per this path was checked as well.

$$P(A_2) = (0.014896 + 0.000782432 + 0.000001568 + 0.0003168 + 0.0000032 + 0.03136 + 0.0311353728 + 0.000006272 + 0.0012672 + 0.0000128) + 0.42 = = 0.8 + 0.42 = 0.5.$$

The probability of a fatal outcome varies within 0.000001568–0.000016 on this path. When assessing biological factors, it is most difficult to make any assessments as per the disease path since we have to consider all the peculiarities of biological factors, how contagious a specific bacterium is, multiple drug resistance and in future it is also necessary to consider a risk that closed relatives or friends of an infected person may become infected as well.

Quantification as per outcomes

Conditions		A_1 path			A_2 path		
		Outcome	Notation	Value	Outcome	Notation	Value
Infection established early	Measures taken	Recovery	$P(R_1)$	0.01862	Recovery	$P(R_3)$	0.014896
		Disease	$P(D_1)$	0.00097804	Disease	$P(D_5)$	0.000782432
		Fatal outcome	$P(F_1)$	0.00000196	Fatal outcome	$P(F_5)$	0.000001568
	Measures not taken	Recovery	–	–	Recovery	–	–
		Disease	$P(D_2)$	0.000396	Disease	$P(D_6)$	0.0003168
		Fatal outcome	$P(F_2)$	0.000004	Fatal outcome	$P(F_6)$	0.0000032
Infection established late	Measures taken	Recovery	$P(R_2)$	0.0392	Recovery	$P(R_4)$	0.03136
		Disease	$P(D_3)$	0.03919216	Disease	$P(D_7)$	0.0311353728
		Fatal outcome	$P(F_3)$	0.00000784	Fatal outcome	$P(F_7)$	0.000006272
	Measures not taken	Recovery	–	–	Recovery	–	–
		Disease	$P(D_4)$	0.001584	Disease	$P(D_8)$	0.0012672
		Fatal outcome	$P(F_4)$	0.000016	Fatal outcome	$P(F_8)$	0.0000128

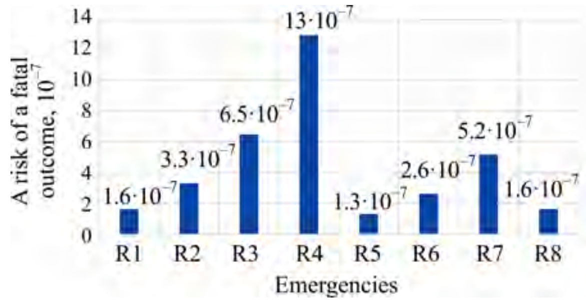

Figure 4. The results produced by calculating a risk of a fatal outcome for an expert depending on development of a situation involving splashing of a tested biomaterial with PBA

The most unfavorable scenario. A probability of emergencies during laboratory tests is equal to $8.3 \cdot 10^{-2}$ a year.

We calculated a risk (R) of a fatal outcome for an expert depending on how a situation developed. This risk was calculated by multiplying its probability by an annual probability of emergencies. Figure 4 provides the results.

The analysis revealed that the highest risk in a situation when immune prevention and treatment were neglected and infection was established late as well amounted to $1.3 \cdot 10^{-6}$ in case of an emergency involving occurrence of an aerosol.

Eventually, having calculated all the probabilities, we moved on to achieving the basic goal of creating the reason tree, which was to determine how probable the main event was. Having estimated all the combinations of preconditions, we determined a range for a probability / risk of an end event I. If we consider a combined implementation of single reasons as per the path A that is represented by biological peculiarities, then we can see that a probability of a person becoming infected, together with other reasons, will vary within $0.9 \cdot 10^{-4}$–$0.9 \cdot 10^{-3}$. This describes the most unfavorable outcome that can occur in a laboratory dealing with determining microbacteria drug resistance. Therefore, laboratory personnel who deal with examining bacterial drug resistance and multiple drug resistance are an occupational group with the highest risks of infection. If we consider a situation when only one biological factor works, a probability of such an event varies within a range from $2 \cdot 10^{-3}$–$7 \cdot 10^{-3}$ to $9 \cdot 10^{-2}$.

We determined all probable outcomes and united them in a logical sequence. This made it possible to detect potential emergency scenarios. By analyzing the event tree, we determined the most dangerous variants of how an emergency would develop; knots, which, in our opinion, would make the greatest contribution to a risk due to being very probable or due to potential damage caused by them.

Discussion. This methodology for assessing infection hazard for laboratory personnel relies on risk-based approaches meaning that absence of any hazard is provided by excluding impermissible risks. Permissible risks rates recommended by the WHO, for example, when it comes down to drinking water quality amount to 10^{-5}.

Risk assessment provides an insight into possible hazardous events, their reasons and outcomes, probability of their occurrence and making various relevant decisions. If we analyze concepts available in literature, we can conclude that ultimately a risk rate is determined by a possible damage even in cases when nothing indicates it directly [17]. Multiple risk analysis techniques are applied in world practice for emergencies, for example:

- ETA (Event Tree Analysis), which is a graphic method for representing mutually exclusive sequences of events that follow the initial one in accordance with functioning and not functioning of systems created to mitigate consequences of a hazardous event. This method can be applied to perform qualitative and / or quantitative assessment. A sequence of events can easily be depicted as an event tree; therefore, ETA makes it easy to establish what events aggravate or alleviate consequences bearing in mind additional systems, functions or barriers;
- "Bow tie" analysis is a schematic way to describe and analyze how a hazardous event develops, starting from its reasons and up to its consequences. This method combines examining reasons for an event by using a fault tree and analyzing consequences by using an event tree. However, the focus of bow tie analysis is on barriers between reasons and hazardous events and consequences. "Bow tie" diagrams can be built based on detected faults and event trees but they are more often created directly by performing a brainstorm. "Bow tie" analysis is used to examine risks by showing a range of possible reasons and consequences. This method should be applied in a situation when it is too difficult to perform full-scale analysis of a fault tree or when examination is mostly aimed at creating barriers or management techniques for each fault path. "Bow tie" analysis is often much simpler to understand than event tree analysis or fault tree analysis. Consequently, it can be quite useful for information exchange when more complicated analysis techniques are applied. Initial data for the method include information about reasons and consequences of hazardous events, risk, barriers and management techniques that can either prevent, mitigate or stimulate them;
- Bayesian analysis and Bayes net. Bayesian analysis is alleged to be created by Thomas Bayes. He suggested combining prior and posterior data to assess the complete probability. Events that reflect effects produced by "reasons" are called hypotheses in this case since they are probable events leading to this one. Unconditional probability that a hypothesis is valid is called prior (how probable a reason is in general); conditional probability, an occurred event considered, is called posterior (how probable a reason turned out to be considering data about an event)[4];
- Analytic network process (ANP) is a more general form of analytic hierarchy process (AHP), which considers dependence and feedbacks between elements. ANP has certain peculiarities including structurization of all the elements that describe a problem in a network, use of relative techniques to measure preferences by making pair comparisons (provides a universal way to solve an issue related to measuring criteria in different scales) and a possibility to consider and assess mutual influence exerted by criteria and selected alternatives (other methods do not provide this opportunity). Many issues in decision-making cannot be depicted as hierarchical structures due to existing dependences and interrelations between elements located at different levels in a hierarchy. Besides, there are tasks where not only significance of specific criteria influences priorities of alternatives but also significance of alternatives influences priorities of criteria [18];
- Decision tree represents a decision-making process graphically showing possible decisions, state of nature, probability of their occurrence, as well as costs (gains or losses) under different combinations of states of nature and possible decisions. Creating a decision tree based on tasking at a meaningful level requires differentiation between available decisions and probable accidental events that should be formulated as a whole group of events with known probabilities of their occurrence[5].

Having analyzed all the aforementioned methods, we selected decision tree since we consider this method to provide the best possible solutions to the research tasks set in the present study.

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[4] Crouhy M., Galai D., Mark R. The essentials of risk management. USA, McGraw Hill, 2014, 2nd ed., 672 p.
[5] Lantz B. Machine Learning with R. Birmingham–Mumbai, Packt Publishing, 2013, 396 p.

Methodologies of risk-based approaches that differ as per their specificity have been described in research works by contemporary scientists from many countries [19–22]. However, developing methodical support for the established risk factors and creating local regulatory and technical documentation for clinical and diagnostic laboratories requires further improvement.

Conclusion. Quantitative risk analysis has revealed that a probability of a person becoming infected is going to be within $0.9 \cdot 10^{-4}$–$0.9 \cdot 10^{-3}$ in case of the most unfavorable outcome. In case only one biological factor works, a probability of infection decreases.

Creating an event tree makes it possible to analyze an emergency involving PBA splashing in a laboratory and to establish the most unfavorable scenario of its development. Analysis of paths and development variants allows making changes in a system and influencing factors of its functioning. Therefore, developing recommendations on how to mitigate a risk is the last stage in logical-probabilistic approach to risk assessment and analysis. It is advisable to focus on developing safety measures aimed at preventing emergencies. A system of activities aimed at reducing a probability of an emergency involving PBA occurrence at a workplace includes the following: regular training in biologically safe work procedures; making overstrain and emotional loads of personnel as small as it is only possible; use of reliable equipment; tracing of defects; selecting proper protective equipment and biological safety boxes; keeping proper ventilation and disinfection; intelligent design of spaces where laboratory tests are accomplished; etc. It is advisable to select several safety measures and measures aimed at preventing emergencies involving PBA splashing out of all the suggested ones concentrating on those that require minimal costs and can still provide risk reduction down to its acceptable levels or those that can provide maximum risk reduction within laboratory spaces given the available means.

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References

1. Rakitskii V.N., Tarasova L.S., Artemova O.V., Ilnitskaya A.V., Fedorova S.G. The risk assessment for employees working under different technologies of application of pesticides. *Gigiena i sanitariya*, 2020, vol. 99, no. 12, pp. 1454–1459. DOI: 10.47470/0016-9900-2020-99-12-1454-1459 (in Russian).

2. Pega F., Norris S.L., Backes C., Bero L.A., Descatha A., Gagliardi D., Godderis L., Loney T. [et al.]. RoB-SPEO: A tool for assessing risk of bias in studies estimating the prevalence of exposure to occupational risk factors from the WHO/ILO Joint Estimates of the Work-related Burden of Disease and Injury. *Environ. Int.*, 2020, vol. 135, pp. 105039. DOI: 10.1016/j.envint.2019.105039

3. Burduniuc O.S., Hamza H.A. Biological risks and laboratory-acquired infections. *Nauchnye gorizonty*, 2020, vol. 38, no. 10, pp. 117–139 (in Russian).

4. Chernov A.N., Miftakhov N.R. Sovremennye trebovaniya pri rabote s patogennymi biologicheskimi agentami v veterinarnykh laboratoriyakh Rossiiskoi Federatsii [Modern requirements to working with pathogenic biological agents in veterinary laboratories of the Russian Federation]. *Aktual'nye voprosy sovershenstvovaniya tekhnologii proizvodstva i pererabotki produktsii sel'skogo khozyaistva*, 2019, no. 21, pp. 452–454 (in Russian).

5. Eremina N.V., Zhanataev A.K., Durnev A.D. Genotoxic biomarkers in employees of pathomorphological laboratories working with formaldehyde (systematic review). *Gigiena i sanitariya*, 2020, vol. 99, no. 8, pp. 792–802. DOI: 10.47470/0016-9900-2020-99-8-792-802 (in Russian).

6. Gritsenko M., Dudchik N.V., Gankin A.N., Prosviryakova I.A., Pshegroda A.E. Sovershenstvovanie metodicheskikh podkhodov k otsenke riska biologicheskikh faktorov vnutrennei sredy pomeshchenii [Improvement of methodological approaches to assessing the risk of biological factors of the internal environment of premises]. *Zdorov'e i okruzhayushchaya sreda: sbornik materialov respublikanskoi nauchno-prakticheskoi konferentsii s mezhdunarodnym uchastiem, posvyashchennoi 90-letiyu respublikanskogo unitarnogo predpriyatiya "Nauchno-prakticheskii tsentr gigieny"*. Minsk, 2017, pp. 14–16 (in Russian).

7. Malyukova T.A., Boiko A.V., Panin Yu.A., Bezsmertny V.E., Kutyrev V.V. Probability of biorisk occurrence attached to the performance of work with pathogenic biologic agents of the I-II

groups of hazard. *Epidemiologiya i infektsionnye bolezni*, 2016, vol. 21, no. 3, pp. 136–145. DOI: 10.18821/1560-9529-2016-21-3-136-145 (in Russian).

8. Chen S., Liu J., Xu Y. A logical reasoning based decision making method for handling qualitative knowledge. *International Journal of Approximate Reasoning*, 2021, vol. 129, pp. 49–63. DOI: 10.1016/j.ijar.2020.11.003

9. Zhulanov E.S., Ignatenko D.Yu., Sholokhov A.A. Sravnitel'nyi analiz metodov kachestvennoi i kolichestvennoi otsenki riskov [Comparative analysis of qualitative and quantitative risk assessment methods]. *Vestnik sovremennykh issledovanii*, 2018, no. 12.17 (27), pp. 139–142 (in Russian).

10. Sherbakov S.Yu., Fokin A.A., Zaborskikh A.A. Research of industrial environment hazards and injury risk factors. *Nauka i obrazovanie*, 2020, vol. 3, no. 2, pp. 58 (in Russian).

11. Balovtsev S.V., Skopintseva O.V., Kolikov K.S. Aerological risk management in designing, operation, closure and temporary shutdown of coal mines. *Gornyi informatsionno-analiticheskii byulleten' (nauchno-tekhnicheskii zhurnal),* 2020, no. 6, pp. 85–94. DOI: 10.25018/0236-1493-2020-6-0-85-94 (in Russian).

12. Lyapin M.N. K tekhnologiyam otsenki opasnosti pri rabote s patogennymi biologicheskimi agentami [On hazard assessment technologies when working with pathogenic biological agents]. *Infektsiya i immunitet*, 2017, no. S, pp. 1059 (in Russian).

13. Solopova V.A., D'yakova M.M. Analiz dinamiki kolichestva professional'nykh zabolevanii po biologicheskomu faktoru [Analysis of the number of occupational diseases as per the biological factor taken in dynamics]. *Actual problems of applied sciences*, 2018, no. 4, pp. 5–9 (in Russian).

14. Medyanik V.A., Salo A.V., Chernykh A.V. Improvement of methods for identification and analysis of hazards and industrial risk. *Vestnik Luganskogo natsional'nogo universiteta imeni Vladimira Dalya*, 2020, vol. 33, no. 3, pp. 133–137 (in Russian).

15. Bodienkov S.G., Tsevenova K.E., Timofeev S.S. Comprehensive assessment of professional risks to the health of healthcare workers. *XXI vek. Tekhnosfernaya bezopasnost'*, 2020, vol. 5, no. 3 (19), pp. 284–291. DOI: 10.21285/2500-1582-2020-3-284-291 (in Russian).

16. Sayfutdinov R.A., Kozlov A.A. Analysis of industrial injuries in the evaluation of professional risk. *Vestnik Ul'yanovskogo gosudarstvennogo tekhnicheskogo universiteta*, 2020, vol. 89, no. 1, pp. 60–69 (in Russian).

17. Tikhomirov N.P., Tikhomirova T.M. Risk-analiz v ekonomike [Risk analysis in economics]. Moscow, Ekonomika, 2010 (in Russian).

18. Seredenko N.N. Modelirovanie neopredelennosti v zadachakh prinyatiya reshenii s ispol'zovaniem metoda analiticheskikh setei [Modeling uncertainty in decision-making problems using the method of analytical networks]. *Aktual'nye problemy gumanitarnykh i estestvennykh nauk*, 2012, no. 3, pp. 88–97 (in Russian).

19. Babanov S.A., Budash D.S. Occupational lung diseases: statistical indicators, risk assessment and biological markers. *Meditsina neotlozhnykh sostoyanii*, 2018, vol. 88, no. 1, pp. 142–150. DOI: 10.22141/2224-0586.1.88.2018.124982 (in Russian).

20. Dubel E.V., Unguryanu T.N. Estimation of health risk factors perception by medical workers. *Ekologiya cheloveka*, 2015, vol. 22, no. 2, pp. 33–41. DOI: 10.33396/1728-0869-2015-2-33-41 (in Russian).

21. Fernandez R., Mitchell S., Ehrmantraut R., Meschke J.S., Simcox N.J., Wolz S.A., Parker S.H. Proactive Risk Assessment for Ebola-Infected Patients: A Systematic Approach to Identifying and Minimizing Risk to Healthcare Personnel. *Infect. Control Hosp. Epidemiol.*, 2016, vol. 37, no. 7, pp. 867–871. DOI: 10.1017/ice.2016.78

22. Howard-Anderson J., Adams C., Sherman A.C., Dube W.C., Smith T.C., Edupuganti N., Chea N., Magill S.S. [et al.]. Occupational risk factors for severe acute respiratory coronavirus virus 2 (SARS-CoV-2) infection among healthcare personnel: A cross-sectional analysis of subjects enrolled in the COVID-19 Prevention in Emory Healthcare Personnel (COPE) study. *Infect. Control Hosp. Epidemiol.*, 2022, vol. 43, no. 3, pp. 381–386. DOI: 10.1017/ice.2021.54

Burtseva T.I., Solopova V.A., Baitelova A.I., Rakhimova N.N. Infection of personnel working in clinical and diagnostic laboratories: qualitative analysis and risk assessment. Health Risk Analysis, 2022, no. 2, pp. 128–138. DOI: 10.21668/health.risk/2022.2.12.eng

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