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AIR DISINFECTION BY UV GERMICIDAL RADIATION

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ABSTRACT

Since 2005, in our country, the use of UV germicidal radiation for disinfection of the indoor air environment is regulated by the guidance of R3.5.1904–64 (as the recommendations). This radiation is dangerous for humans: skin and especially the eyes are affected. It is necessary to use closed irradiators (recirculators) with germicidal lamps, and not open ones, the radiation of which covers the entire volume of the room in order to avoid exposure of people during disinfection of indoor air. This requires taking people from the premises and observing all relevant safety measures.

Unfortunately, in practice, there may occur, accidentally or out of ignorance of the rules for open irradiators operating by personnel, violations of safety rules leading to grave consequences. To eliminate such violations, it is necessary to increase the level of knowledge of staff, but there is no special educational and technical literature. This article attempts to fill this gap.

Keywords: UV germicidal radiation, spectrum of activity, germicidal effectiveness, productivity of a germicidal irradiator, surface or volume emitter, volumetric dose

FOREWORD

The first studies on the use of UV radiation (UVR) for the destruction of pathogens are the hundred years old. The study of this phenomenon belongs to science – Photobiology.

In solving the problems of applying this technology these days, three important stages can be noted:

- Development, mastering of production and manufacture of UV tube low pressure mercury lamps (LPML) with a power of 15 W and 30 W, with a bulb made of uviole glass blocking ozone-forming radiation; this work was directed by the chief engineer of the Moscow Electric Lamp Plant R.A. Nilender, an outstanding organizer of the lamp industry of the USSR. The first irradiators with these lamps were open and they could be used only in the absence of people in the room;
- Proposed by a doctor Y.E. Neystadtom irradiator with closed design, which could be used in the presence of people – the so-called recirculator [1];
- Development, mastering of production and manufacture of a new type of UV tubular ozoneless LPMLs with a capacity of up to 1000 W and above, with a quartz glass bulb and using not liquid mercury, but a solid solution of mercury in another metal – amalgam; this work was led by the Director General of NPO “LIT” S.V. Kostyuchenko [2, 3].

At present, a scientific and technical line has been formed in Russia on UV technology for air disinfection. At the same time, industrial production was organized and a wide range of germicidal lamps and irradiators has appeared. In 2012, a fundamental work of a high scientific level was published [4], edited by F.V. Karmazinova, S.V. Kostyuchenko, N.N. Kudryavtseva, S.V. Khramenkova. It should be noted the great contribution of domestic scientists to the theory and practice of using UVR for air disinfection: first of all, G.M. Franka, N.F. Galanina, N.M. Danzig, J.E. Neystadt, V.I. Vashkova, A.L. Koshkina, D.N. Lazareva, V.F. Sokolova, M.V. Sokolova, M.G. Shandalu, T.I. Noskov, G.S. Sarycheva, D.A. Shklover, R.A. Nilendera and others. The lack of appropriate technical literature

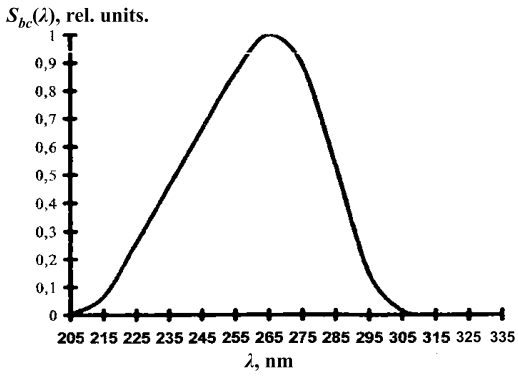

Fig. 1. Relative spectral germicidal efficacy curve $S_{bc}(\lambda)$

hinders the practical application of UV disinfection of indoor air.

When writing the article, the author used previously published materials, some of which were written in collaboration with M.G. Chandaloy and V.G. Yuzbashev [5,6].

The author hopes that this article, prepared for specialists, will improve mutual understanding in solving the practical problems of workers and manufacturers of germicidal lamps and irradiators, designers of germicidal plants, sanitary doctors who carry out epidemiological surveillance and medical students.

1. INTRODUCTION

The epidemiological well-being of the air environment, as the most important component to protecting the health of the country's population, is the socio-economic task of our state. The condition and environmental conditions of a person's living environment are essential for his normal life, especially in enclosed spaces of limited volume, the air environment of which contains pathogens. One of the ways of spreading infectious diseases is aero-genic (or airborne), which refers to the main way of transmitting the spread of diseases such as flu, tuberculosis, diphtheria, etc. This is due to the fact that the airborne droplet bacterial aerosol is constantly suspended in air volume due to air movement, which increases the likelihood of infection of people and unpacked food.

1.1. UV Radiation and its Germicidal Effect

For the prevention of diseases and the improvement of the living environment, various methods and means are used, and in particular, the use of UVR, which has a germicidal effect. The high efficiency of this method is ensured by its following features:

– A wide range of coverage of pathogenic micro-flora in air and water, as well as on surfaces;

– The absence of the need to use additional chemicals;

– Lack of smell and the formation of toxic secondary products;

– A relatively short treatment time for premises to achieve the required level of disinfection, within 1 h;

– Low costs for installation of equipment in the premises and ease of operation.

It should be emphasized that the use of UVR as a physical factor affecting microorganisms can give a disinfection of the environment to a very high degree – up to 99.9 %. In addition, the processing of indoor air using UVR is the final link in the list of sanitary and hygienic measures provided for by regulatory documents of the Federal Service for Supervision of Consumer Protection and Human Well-being.

The germicidal effect of UVR on microorganisms in the spectral range of (205–315) nm

The degree of exposure to microorganisms is determined by the function of the relative spectral germicidal efficacy $S_{bc}(\lambda)$. Its maximum occurs at a wavelength of 265 nm, corresponding to the maximum sensitivity of microorganisms (their nucleic acids), as shown in Fig. 1 and Table 1[1]. This function is also called the relative germicidal spectrum of UVR, i.e. microorganisms are *selective receivers of radiation,* and applying energy quantities to them is impractical. From the Table 1 it can be seen that $S_{bc}(\lambda)$ in the mercury line of 254 nm is 85 % of $S_{bc}(\lambda)$ in the line of 265 nm. Taking into account the indicated selectivity of microorganisms, germicidal radiometers are used to measure the germicidal flux, whose spectral sensitivity is corrected for $S_{bc}(\lambda)$. Such germicidal radiometers exist, for example, the TKA-PKM UV radiometer (models 12 and 13), the TKA-VD UV spectroradiometer, etc. These radiometers measure germicidal irradiation (W/m^2) from solid or linear UV radiation spectrum sources. The main germicidal value is the

[1] It is important to note that germicidal UVR is dangerous for humans. It is fraught with burns on the body and eye damage. Therefore, in rooms in the presence of people, it is permissible to use only closed irradiators with germicidal lamps.

Table 1. Relative Spectral Germicidal Efficacy Function S_{bc} (λ)
[S_{bc} (λ) max = 1 at λ = 265 nm]

λ, nm	S_{bc} (λ)	λ, nm	S_{bc} (λ)
205	0,000	265	1
210	0.009	270	0.98
215	0,066	275	0,900
220	0.160	280	0.760
225	0.260	285	0.540
230	0.360	290	0.330
235	0.460	295	0.150
240	0.560	300	0,030
245	0.660	305	0.006
250	0, 765	310	0.001
254	0.850	315	0,000

Table 2. Germicidal Quantities and Units of Measurement of UV Radiation in the Spectral Range (205–315) nm

Value	Designation and formula	Definition	Unit of measurement
Radiation energy	W_{bc}	Energy carried by radiation	J
Radiation flux (radiation power)	$\Phi_{bc} = W_{bc}/t$	The ratio of radiation energy to the time t	W
Spectral density of the radiation flux	$\Phi_{bc}(\lambda)$	The ratio of the radiation flux in an infinitely narrow range of wavelengths to this interval	W/nm
Intensity of rdiation	I_{bc}	Spatial flux density	W/sr
Irradiation	$E_{bc} = \Phi_{bc}/S$	The ratio of the radiation flux to the irradiated surface area	W/m^2
Surface dose	$H_s = W_{bc}/S$	he ratio of radiation energy to the area of the irradiated surface	J/m^2
Volumetric dose	$H_v = W_{bc}/V$	The ratio of radiation energy to the volume of the irradiated part of space	J/m^3

germicidal flux F_{bc}. With this in mind, a system of germicidal quantities and units of measure has been created, which is used in the UV technology for air disinfection (Table 2). Considering the process of killing bacteria on the surface with germicidal irradiation E_s (W/m^3) and, accordingly, the necessary radiation dose H_s (J/m^2), we can conclude that the estimations of the effective dose of volumetric exposure to air space H_v (J/m^3) cannot be produced by the formulas according to which H_s are calculated.

It was established that the type of S_{bc} (λ) curves for different types of pathogenic microorganisms is almost the same.

Bacteria (in the vegetative form) and viruses are more sensitive to UV radiation. Spores of bacteria and protozoa are less sensitive. The most resistant are mushrooms and moulds.

The absorption of radiation by a microorganism is an intra-molecular discrete physical process of interaction between radiation quanta, molecules and atoms according to the Einstein-Stark quantum equivalence law. As follows from this law, each absorbed quantum is capable of activating only one molecule or atom, i.e. a single shock absorption process occurs. Upon absorption of a quantum of radiation, in the case of a coincidence of the frequency of oscillations of a quantum with the frequency of oscillations of electrons in a macromolecule, resonant absorption occurs with the maximum transfer of quantum energy. This leads to damage to important

Table 3. The Dependence of Germicidal Efficacy and Volumetric Dose on the Cleanliness Class

Room cleanliness class	J_{bc}, %	H_v, J/m^3
Extra Clean (A)	99.9	385
Clean (B)	99	257
Conditionally clean (B)	95	167
Dirty (g)	90	129

structures of the microorganism. Ultimately, microorganisms in the air volume become inactivated and lose their ability to reproduce. The maximum radiation effect occurs at λ = 265 nm, which corresponds to the maximum spectral sensitivity of the nucleic acids of microorganisms. Moreover, the quanta of the germicidal UVR are not sufficiently energetic for ionization of oxygen molecules, i.e. when a neutral molecule absorbs oxygen of one quantum, the molecule does not decay into a negative electron and a positive ion, and, therefore, ozone is not formed in the air. In this regard, germicidal UVR is classified as non-ionizing radiation.

Further, in the case of germicidal irradiation of the air, while maintaining a constant dose level of H_v and a short exposure time, an increase in the volume density of the germicidal radiation flux (W/m^3) is required due to the need to increase the number of quanta, which increases the likelihood of a successful collision of a quantum of germicidal radiation with atoms of macromolecules. A decrease in bulk radiation density reduces the likelihood of a successful collision; to compensate for this, it is necessary to increase the exposure time, while maintaining H_v, i.e. quantum equivalence is respected. It was experimentally established that the process of death of microorganisms in the air during their germicidal irradiation is characterized by an exponential relationship between the number of surviving microorganisms N_{sur} at their initial number N_o and H_v:

$$N_{sur} = N_0 \cdot \exp(-\sigma_v H_v), \qquad (1)$$

where σ_v is the constant characterizing the photosensitivity value of a given type of microorganism under volume exposure. To control the germicidal efficacy J_{bc}, the *Staphyloccous Aureus* microorganism was adopted in our country, the σ_v value of which is equal to 0.0179 m^3 /J (Appendix 1).

J_{bc} is the indicator of the level of reduction of microbial contamination of the air environment as a result of UV radiation, expressed as the ratio of the number of dead microorganisms N_d to N_o (in relative units or in percentage). From the equality $N_d = N_o - N_{sur}$ and expression (1) it follows that:

$$J_{bc} = (N_d / N_0) \cdot 100 = [(1 - \exp(-\sigma_v H_v)] \cdot 100, \%$$

$$H_v = -\ln(1 - J_{bc} \cdot 10^{-2}) / \sigma_v, \text{ J/m}^3. \qquad (2)$$

The recommended modes of exposure to air in dependence on the room class cleanliness are shown in the Table. 3

An increase in relative humidity and dustiness in the room reduces J_{bc}. With an increase in relative humidity from (45–65) % to (80–90) %, J_{bc} decreases by (30–40) %, because drops of water settle on dust particles, which have a screening effect on radiation. It was established that the sensitivity of microorganisms to UVR in moist air is (20–50) times lower than in dry air.

It should be noted that if the UVR contains spectral lines at λ shorter than 200 nm, then ozone[2] is formed in the air of the room, extremely poisonous gas (more toxic than carbon monoxide). According to toxic properties, it belongs to the first hazard class. In the Table 4, the effects caused by the presence of ozone in the indoor air are shown.

2. SOURCES OF GERMICIDAL UV RADIATION

The main sources of germicidal UVR are mercury tube lamps, of which LP mercury lamps are most effective. This is due to the fact that more than 60 %

[2] Ozone is an allotropic modification of oxygen and consists of three of its atoms. At low temperatures, the decomposition of ozone occurs slowly, with increasing temperature it accelerates; at room temperature, the decomposition takes several minutes, and at 100° C it is less than a second. The decay rate of ozone also depends on the relative humidity of the air, at 50 % ozone decays twice as slow as at 80 %.

of the radiation energy of these lamps falls on the resonance line 254 nm, lying in the range of maximum germicidal action, which explains their high germicidal efficacy $\eta_{bc,}$ defined as $\eta_{bc} = (\Phi_{bq} / P_l) \times$ ×100, %, where P_l is the lamp power, and equal about (30–40) %.

According to the main structural features, LP mercury lamps are divided into two groups – lamps with an uviol lamp bulb and bulb made of quartz glass doped with titanium oxide. These bulbs exclude the output of the 185 nm ozone-forming line in the emission spectrum. On this basis, they received the name of the ozone-less. In uviol bulb lamps, mercury is in a liquid state, and in quartz lamps it is replaced by an amalgam. When the lamp is operating, the amalgam heats up and mercury vapours are released into the discharge. On this basis, such lamps are called amalgam. The vapour pressure of mercury over a solid amalgam is orders of magnitude lower than over liquid mercury, therefore, when the bulbs of such lamps are destroyed, mercury vapour in quantities significantly lower than the MPC can enter the air, and there is no need for room demercurization. Amalgam lamps are mechanically stronger than uviol lamps. The latter have a small unit power in the range of (8–75) W, and amalgam ones have a large one, about (100–1000) W. In most uviol lamps, the electrical characteristics at the same power are identical to those of ordinary FLs, so they are operated with similar switching circuits (currently, in most cases, electronic ballasts with a power factor (cos φ) equal to one are used). The useful lifetime decline when Φ_{bc} to 20 % of the initial amounts of amalgam lamps for 12000 h, and for uviol lamp bulb about 8000 h. There are several key parameters describing the technical and operational characteristics of different radiation sources. These include: relative or absolute emission spectra; integral values of germicidal flux or radiation power in a certain spectral range; radiation intensity distribution curves in the longitudinal and transverse planes; power, current and voltage on the lamp; mains voltage; useful life; environmental safety – availability in the radiation spectrum of ozone-forming lines and the possibility of release of toxic substances into the environment during the destruction of a lamp bulb.

In view of the indicatrix of radiation, tubular discharge lamps are divided into two types – with and without coating the bulb. On this basis, the former belong to surface emitters, and the latter to volume

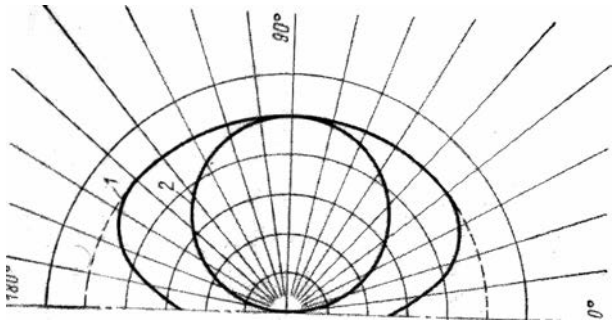

Fig. 2. Indicatrixes of radiation of discharge tube lamps in the longitudinal plane (surface emitter – fluorescent lamp, volume emitter – LP mercury tube lamp)

emitters. For surface emitters, the indicatrix of radiation in the longitudinal plane has a circle, and for bulk emitters – an ellipse (Fig. 2). (Indicators of some other discharge lamps are given in Appendix 2.)

The reason for the difference in the shapes of the radiation indicatrix between the two indicated types of lamps is that in the first type the discharge is not transparent to its own radiation, and in the second it is transparent (due to weak absorption of radiation in the discharge). Plasma is almost completely transparent to visible and UV radiation and the level of its radiation outwardly proportional to the volume occupied by the plasma. This does not depend on the type of discharge in the LP and HP mercury vapour, or in other gases [7, 8].

In this regard, I proposed and published [9] a method for measuring the radiation flux of germicidal mercury tube lamps LP that is an alternative, in particular, to the goniophotometric method [10], which is really unsuitable for routine laboratory measurements. The method is based on three working hypotheses, confirmed experimentally:

– The shape of the radiation indicatrix of tubular mercury lamps without coating the bulb in the longitudinal plane is fairly accurately described by an ellipse;

– The photometric body of such lamps is an ellipsoidal torus;

– The plasma of the electric discharge of LP germicidal lamps is transparent to visible and UV radiation.

3. UV GERMICIDAL IRRADIATORS

The UV germicidal irradiator is an autonomous electrical device containing germicidal lamps (uviol or amalgam), a reflector, ballasts, capacitors (for

Table 4. Effects Due to Ozone

The concentration of ozone, mg /m^3	Exposure time, h	Effect
0,03	8	Plant damage
0.2	1	Irritability, headache
0.3	8	Airway cramps, chest cough
2	2	Nausea, nosebleed, poisoning

Table 5. Some Materials Reflection Coefficients at Wavelength 254 nm

Material type	Reflection coefficient, p
Untreated aluminium	0.4–0.6
Aluminium (surface finish)	0.6–0.9
Duralumin	0.16
Stainless steel	0.25
Chrome plating	0.39
Black enamel	0.05

suppressing radio interference), an electronic meter that records the operating hours of the lamps, as well as auxiliary lamp mounts and fixtures for installing the device. The main objective of the germicidal irradiator is the disinfection of the indoor air from pathogenic microorganisms.

According to their design, the irradiators are divided into the following types: closed (recirculators) and open for to set at floor, wall and ceiling; for placement in rooms or in modules of supply and exhaust ventilation systems. In open irradiators, a direct germicidal flow of lamps, with or without a reflector, covers a wide area in space. In closed irradiators, the germicidal flow of lamps located in a small chamber does not have an outlet to the outside, and air is disinfected during its continuous pumping by means of a fan through the chamber and exit into the room volume. Modules with germicidal lamps located in the supply and exhaust ventilation systems can also be classified as closed irradiators.

On application is the disinfection of air in the absence of people.

According to the efficiency of using the germicidal flux of lamps, taken into account by the total coefficient $\boldsymbol{Z = K_\phi K_o}$, where $\boldsymbol{K_\phi}$ is the coefficient of use of the germicidal flux of lamps, taking into account their mutual shielding, the values of which for open, ceiling open and closed irradiators are approximately equal to 0.8, 0.6 and 0.4; $\boldsymbol{K_o}$ is the coefficient of multiple reflections of the germicidal flow from the inner surface of the reflector with a reflection coefficient ρ at λ = 254 nm, determined for open, ceiling open and closed irradiators as

$\boldsymbol{K_o}$ = 1, $\boldsymbol{K_o}$ =1 / (1–0.3 ρ) and $\boldsymbol{K_o}$ = 1 / (1–0.6 ρ), respectively.

The values of this ρ for some materials are shown in Table. 5.

The main parameter of the irradiator is its germicidal productivity $\mathrm{Pr_{bc}}$ (m^3/h), which characterizes the reduction of microbial contamination of the air medium to the given levels of J_{bc} or H_v for this type of microorganism.

The equations of the mathematical model Pr_{bc} are as follows:

$$\mathrm{Pr}_{bc} = N_l \Phi_{bc} K_\Phi K_0 \cdot 3600 / [-\ln(1 - J_{bc} \cdot 10^{-2})], \text{ or}$$

$$\mathrm{Pr}_{bc} = N_l \Phi_{bc} K_\Phi K_0 \cdot 3600 / H_v, \text{ m}^3\text{/h},$$

where N_l is the number of lamps in the irradiator; Φ_{bc} is the germicidal lamp flux, W.

It should be noted that these formulas are valid when the irradiator operates for a time t during which a given level of J_{bq} is achieved in a room of volume $V_p = \mathrm{Pr}_{bc} \cdot t$, m^3.

Constructive internal elements of a closed irradiator provide a certain resistance to air flow. The degree of hydraulic resistance is taken into account by the total coefficient of local resistance μ, the estimated value of which is in interval of 1.1–1.3. Moreover, the fan performance $\mathrm{Pr_{fan}} = \mu\ \mathrm{Pr_{bc}}$. Pho-

Table 6.1

Initial data	Values
Type of microorganism (SPM)	S aureus
Germicidal efficacy J_{bc}	99.9 %
Microorganism photosensitivity constant σ **v**	0.0179 m^3/J
Type of germicidal lamp	Amalgams
Germicidal lamp flux Φ_{bc}	50 W
Number of lamps N_l	1
The utilization rate of the germicidal lamp flux K_f	0.4
Reflector material	Polished aluminium
Reflectance ρ	0.7
Multiple reflection coefficient K_0 =1/(1–0.6 ρ)	1.72
Coefficient of local resistance to air flow from the fan μ	1,2

Table 6.2

Initial data	Values
Type of microorganism (SPM)	S aureus
Germicidal efficacy J_{bc}	99.9 %
Microorganism photosensitivity constant σ_v	0.0179 m^3/J
Type of germicidal lamp	Amalgams
Germicidal lamp flux Φ_{bc}	50 W
Number of lamps N_l	1
The utilization rate of the germicidal lamp flux K_f	0.6
Reflector material	Polished aluminium
Reflector reflectance ρ	0.7
Multiple reflection coefficient K_0 =1/(1–0.6 ρ)	1,265
Microorganism photosensitivity constant σ_v	0.0179 m 3 / J
Number of lamps N_l	1
The utilization rate of the germicidal lamp flux K_f	0.6

tographs of different types of irradiators are given in Appendix 3.

4. UV GERMICIDAL INSTALLATIONS

UV germicidal installation is a stationary group of indoor UV germicidal irradiators in the room or modules with germicidal lamps in the duct system of the supply and exhaust ventilation, which provide the specified level of the J_{bc} in the room. There are various methods for using irradiators in germicidal plants:

• ***Continuous disinfection of indoor air in the presence of people***

This mode is achieved using closed stationary irradiators (recirculators) or germicidal modules in the supply and exhaust ventilation systems. Such an irradiation regime is recommended to be used to ensure the effective disinfection of rooms with a large number of people, especially if they cannot be moved, for example, in wards with infectious patients, in schools, preschools, etc.

The number of irradiators in the room is determined by the project, according to the terms of technical task (TT). In TT are indicated: J_{bc}, V_p, air exchange rate K_p (h^{-1}), reliability factor K_r = 1.2. Then, the required germicidal performance of the recirculator in the room is determined: $Pr_{bc} = V_p K_p K_r$, with J_{bc} = 99.9 %, H_v = 385 J/m^3 and irradiation time t = 1 h.

For rooms of non-infectious profile, the operating time of the recirculators should be at least

Table 6.3

Initial data	Values
Type of microorganism (SPM)	S aureus
Germicidal efficacy J_{bc}	99.9 %
Microorganism photosensitivity constant σ_v	0.0179 m^3/J
Session exposure time t	0.25 h
Type of germicidal lamp	amalgams
Germicidal lamp stream Φ_{bc}	50 W
Number of lamps N_l	1
The utilization rate of the germicidal lamp flux K_f	0.8
Coefficient of multiple reflections K_0 =1/(1–0.6 ρ)	1

Table 6.4

Initial data	Values
The volume of the premises V_p	400 m^3
Germicidal efficacy J_{bc}	95 %
Air exchange rate K_p	2 h^{-1}
Reliability coefficient K_r	1,2

Table 6.5

Initial data	Values
The volume of the premises V_p	400 m^3
Germicidal efficacy J_{bc}	99.9 %
Session exposure time t	0.25 h
Reliability coefficient K_r	1,2

12 hours. For rooms with infectious patients, the working time of the recirculators should be around the clock. For offices with an infection profile, it is necessary to turn on the recirculator before starting to receive patients for a period of (15–20) minutes. Moreover, J_{bc} should be at least 99 %. For this, the recirculator operating mode is selected for various values of K_r and t <60 min, the doses are estimated by the formula (2).

• ***Intermittent exposure***

In this mode, the irradiation of the room is carried out during the working day with alternating sessions of irradiation at t = 15 min = 0.25 h and pauses between sessions of 3 h by the help of ceiling stationary open irradiators. During a 15-minute exposure session, people are removed from the room. During this time, it is necessary to provide a given level of J_{bc}.

The number of irradiators in the room is determined according to the data in the statement of work, which indicates: $V_{p,}$ J_{bc}, K_p and K_r = 1.2. Then, the required germicidal performance of the irradiator in the room, Pr_{bc}, is determined by the formula $Pr_{bc} = V_p K_p K_r$. From the existing nomenclature irradiator with the same Pr_{bc} or less, Pr_n, is selected but, however, with the predetermined value J_{bc}. Next, the number of indoor irradiators $N_{ir} = Pr_{bc} / Pr_{n.}$ At the same time, the number of irradiators, productivity and dose are proportional to K_p. It should be noted that with an increase in K_p, the costs of a germicidal installation are increasing.

For a long time open irradiators were used to disinfect the indoor air environment. Their use in most cases complicates this procedure due to the need to periodically remove people from the premises. It should be noted that the presence of people in the room between the irradiation sessions leads to secondary contamination by the aero-genic microorganisms of the air in the room due to people carrying infections. This increases the level of nosocomial infections. In addition, between the irradiation sessions, the so-called photo-reactivation of dead microorganisms occurs under the influence of

Table 6.6

Initial data	Values
The volume of the premises V_p	400 m^3
Germicidal efficacy J_{bc}	99.9 %
Air exchange rate K_p	2 h^{-1}
Reliability coefficient K_r	1,2
Coefficient of local resistance to air flow from the fan μ	1,2

Table 6.7

t, min	K_p, h^{-1}	H_v, J/m^3	J_{bc},%	Pr_{bc}, m^3/h
60	1	385	99.9	54
15	1	96.25	81.73	54
20	1	128.3	89.4	54
30	1	192.5	96.8	54
20	2	256.6	99	108
60	2	385	99.9	108

visible light, i.e. restoration of their life. From this we can conclude that such an irradiation regime is ineffective for disinfecting rooms with a large number of people, especially if they cannot be moved. And this mode is not recommended.

In some cases of repeated-short-term exposure, for small rooms, you can use the single mobile open irradiators. The required germicidal performance of such an irradiator $Pr_{bc} = V_p K_r / t$, m^3 /h.

• ***Combined exposure mode***

This mode provides for the use of both open and closed irradiators in operating rooms, blood transfusion rooms and dressing rooms. The irradiators turn on simultaneously before preparing the room for 15 minutes. Then the open irradiators are turned off.

5. TYPICAL EXAMPLES OF CALCULATIONS

The first example: It is necessary to calculate Pr_{bc} of a closed feed and fan performance

The Table 6.1 contains the initial data for the calculation. According to them, Pr_{bc} and Pr_v are defined as

$Pr_{bc} = N_l \cdot \Phi_{bc} \cdot K_\Phi \cdot K_0 \cdot \sigma_v \cdot 3600 / [-\ln (1 - J_{bc} \cdot 10^{-2})] = 1 \cdot 50 \cdot 0.4 \cdot 1.72 \cdot 0.0179 \cdot 3600 / -\ln (1-99.9 \cdot 10^{-2}) = 321$ m^3 / h; $Pr_v = Pr_{bc} \cdot \mu = 321 \cdot 1.2 = 385$ m^3 /h.

The second example: It is necessary to calculate Pr_{bc} of a ceiling open illuminator.

The Table 6.2 contains the initial data for the calculation. According to them, Pr_{bc} is defined as $Pr_{bc} = N_l \cdot \Phi_{bc} \cdot K_\Phi \cdot K_0 \cdot \sigma_v \cdot 3600 / [-\ln (1 - J_{bc} \cdot 10^{-2})] = 1 \cdot 50 \cdot 0.6 \cdot 1.265 \cdot 0,0179 \cdot 3600 / [-\ln (1-99.9 \cdot 10^{-2})] = 351$ m^3 /h.

The third example: It is required to determine Pr_{bc} of a mobile open irradiator at $t = 0.25$ hours.

In the Table 6.3 are input data for the calculation. According to them, Pr_{bc} is calculated according to the previous formula: $1 \cdot 50 \cdot 0.8 \cdot 0.0179 \cdot 3600 / [-\ln (1-99.9 \cdot 10^{-2})] = 373$ m^3/h. The final value of Pr_{bc} for irradiation duration $t = 0.25$ h is $373 \cdot 0.25 = 93.25$ m^3/h.

The fourth example: It is necessary to ensure the disinfection of the air environment of the room with closed irradiators. According to the initial data given in the Table 6.4, the required germicidal performance of the irradiator Pr_{bc} with $J_{bc} = 95$ % is determined: $Pr_{bc} = V_p \cdot K_p \cdot K_r = 400 \cdot 2 \cdot 1.2 = 960$ m^3/h. There is no such irradiator on sale, but there is the DEZAR brand irradiator with a $Pr_v = 100$ m^3/h and $J_{bc} = 99.9$ %. A new operating mode of the selected irradiator is determined at $J_{bc} = 95$ % according to the formula $Pr_r = Pr_v \cdot [-\ln (1-0.999)] / [(-\ln (1-0.95))] = 100 \cdot 6.9/3 = 230$ m^3/h. Consequently, the number of indoor irradiators $N_{ir} = Pr_{bc} / Pr_r = 960/230 \approx 4$, and their location in the room determined by the design documentation.

The fifth example: It is required to ensure the disinfection of the air of the room with open ceiling irradiators. According to the initial data given in the Table 6.5, the required Pr_{bc} with $J_{bc} = 99.9$ % is determining for the irradiation time $t = 0.25$ h as $Pr_{bc} = V_p \cdot K_r / t = 400 \cdot 1.2 / 0.25 = 1920$ m^3/h with

J_{bc} = 99.9 %. There is no such irradiator on sale, but there is another one with Pr_v = 1500 m^3/h and J_{bc} = 99.9 %. A new operating mode of the selected irradiator is determined at t = 0.25 h: $Pr_r = Pr_v \cdot t$ =1500 · 0.25 = 375 m^3/h. Consequently, $N_l = Pr_{bc} / Pr_r$ = 1920/375 ≈ 5 and irradiators location in the room determined by the design documentation.

The sixth example: The germicidal performance of the module Pr_m in the supply and exhaust ventilation system in the room should be determined. The initial data are given in the Table 6.6. According to them, the fan performance is determined as $Pr_v = V_p \cdot K_r \cdot K_p$ = 400 · 2 · 1.2 = 960 m^3 /h, and then the required value of Pr_m according to the formula $Pr_m = Pr_v / \mu$= 960 /1.2 = 800 m^3 / h with germicidal efficacy of 99.9 % is determining.

The seventh example: It is required to determine Pr_{bc} of the recirculator in the office of the infectious profile for a working time of (15–20) minutes, before the start of patient reception. J_{bc} must be at least 99 %. Initial data: V_p = 45 m^3, K_p = 1 h^{-1}, K_r = 1.2. A recirculator with $Pr_{bc} = V_p \cdot K_r \cdot K_p \cdot t$ = 45 · 1 · 1.2 · 1 = 54 m^3/h and J_{bc} = 9.99 % during operation t = 1 h. Then a new operating mode of the recirculator is determined; it is calculated, for different values of K_p and t (60 min), according to the formulas $J_{bc} = [1 - \exp(-\sigma_v \cdot H_v)] \cdot 100$,%, where $H_v = 385 \cdot K_p \cdot t / 60$, J/m^3, and the calculation results are entered in the Table. 6.7.

6. OPERATION AND SAFETY

1. The implementation of germicidal plants should be carried out according to the agreed technical task and the project approved by the services of the Federal Service for Supervision of Consumer Rights Protection and Human Welfare

2. To carry out air disinfection in the presence of people, the required number of irradiators for each room is determined by calculation in accordance with applicable standards (SanPin 2.1.3.2630–10 requirement, clause 11.12).

3. UVR in the germicidal wavelength range is a danger to humans, especially to vision.

4. If it is necessary to find personnel in a room where operating open UV germicidal irradiators are installed or a germicidal flux of UV lamps is measured, face masks, glasses and gloves should be used.

5. Do not use ozonating UV lamps to disinfect the air in the room where people are located. Residual ozone decomposes at room temperature after (30–60) minutes. The appearance of the smell of ozone can serve as an indicator of danger to humans. If it is detected that the concentration of ozone in the room exceeds the permissible norm, the irradiator should be stopped and ozonizing lamps should be detected.

6. When the bulb of mercury lamps is destroyed, mercury vapours can enter the air in quantities significantly higher than the permissible norms, which in the case of uviol lamps requires demercurization of the room, and in the case of amalgam lamps, it needs to be ventilated.

7. The supply and disconnection of the power of open irradiators from the mains must be carried out using switches located outdoors at the front door, which are interlocked with a light panel above the door: “Do not enter! Dangerously! Ultraviolet disinfection is in progress. “

8. Germicidal lamps that have reached their useful life must be stored in a separate room until they are disposed of in accordance with current regulations.

9. It is necessary to periodically clean the reflecting surfaces of the irradiators and the lamp bulb from dust, since even a small layer of dust significantly reduces the value of the germicidal flow. Dust wiping and lamp replacement should be carried out monthly, strictly when the germicidal installation is disconnected from the network.

APPENDICES

Appendix 1: Tab. A.1.
Appendix 2: Fig. A.1 and Tab. A.2.
Appendix 3: Figs. A.2 – A.4.

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Table A.1.Photosensitivity constants for some species microorganisms during surface irradiation (σ_s, m^2 /J) and air volume(σ_v, m^3/J)

Bacteria	σ_s	σ_v	Fungal yeast	σ	σ_v
Bacillus anthracis	0.051	0.0195	*Baker's yeast*	0,060	–
Bacillus megatherium (veg)	0,084	0,034	*Brewer's yeast*	0,070	–
Bacillus megatherium (spores)	0.178	0,0743	Yeast-like mushrooms	0,038	–
Bacillus paratyphosus	0,072	0,0274	*Saccharomyces cerevisiae*	0,038	–
Bacillus subtilis (veg)	0,032	0.0123	*Saccharomyces ellipsoideus*	0,038	–
Bacillus subtilis (spores)	0.019	0.0073	*Saccharomyces sp.*	0,029	–
Campylobacter jejuni	0.209	0,0768	**Mold spores**		
Clostndium tetani	0.019	0.0073			
Corynebacterium diphtheriae	0,069	0,026			
Bacilli dysentery	0.105	0,040	*Aspergillus flavus*	0.003	–
Eberthella typhosa	0.108	0,041	*Aspergillus glaucus*	0.004	–
Escherichia coli	0,077	0,029	*Aspergillus niger*	0.0014	–
Klebsiella terrifani	0,089	0,034	*Mucor racemosus*	0.013	–
Micrococcus candidus	0,038	0.015	*Oospora lactis*	0,046	–
Phytomonas tumefaciens	0,023	0.0088	*Penicillium expansum*	0.018	–
Mycobacterium tuberculosis	0,038	0.015	*Penicillium roqueforti*	0.018	–
Micrococcus sphaeroides	0,053	0,020	**Viruses**		
Pseudomonas aeruginosa	0,042	0.014			
Pseudomonas fluorescens	0,065	0,025			
Proteus vulgaris	0,086	0,035	Hepatitis A	0,032	0.011
Salmonella enteritidis	0.058	0,022	Flu virus	0,064	0.024
Salmonella paratyphi	0,072	0,068	*MS-2 Coliphage*	0.012	0.0045
Salmonella typhimurium	0,029	0.011	Poliovirus	0,040	0.015
Sarcina lutea	0.012	0.0045	Rotavirus	0,028	0.0107
Seratia marcescens	0,095	0,037	**Protozoa**		
Shigella paradysenteriae	0.141	0.051			
Shigella sonnei	0,077	0,029			
Staphylococcus aureus	0.10	0.0179	Cryptosporidium parvum	0,092	0,035
Staphylococcus faecalis	0,053	0,020	Giardia lamblia	0.209	0,0768
Staphylococcus haemolyticus	0.106	0,042	**Seaweed**		
Streptococcus lactus	0,037	0.014			
Streptococcus viridans	0,043	0.115			
Vibrio Cholera (*V.comma)*	0,066	0,025	Chlorella vulgaris	0.019	–

Table A.2. High Intensity Amalgam Lamps

Lamp type	Lamp power, W	Germicidal flux, W	Arc length, mm	Full length mm
ALC100/32	100	23	320	470
ALC120/45	120	thirty	445	595
ALC170/70	170	fifty	695	845
ALC215/95	215	65	945	1095
ALC240/107	240	75	1070	1220

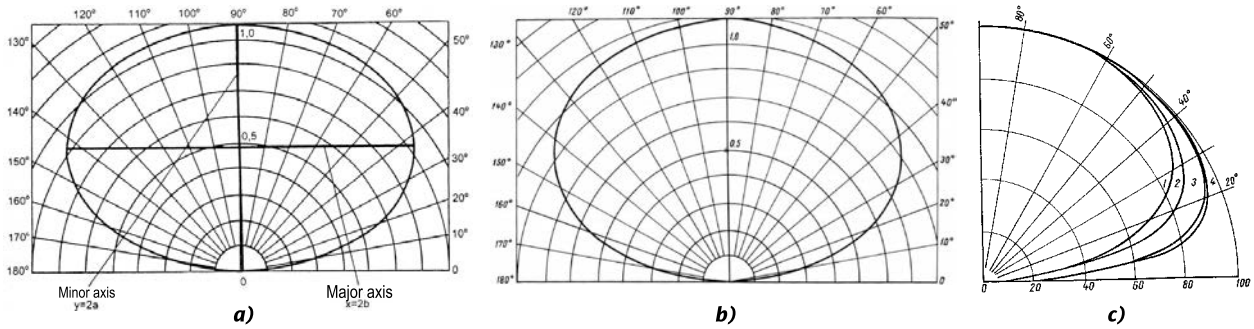

Fig. A.1. Radiation indicatrixes in the longitudinal plane of the discharge tube lamps – volume emitters:
a – mercury lamp HP type DRRT-400; *b* – xenon pulsed tube lamp ISPT 6000;
c – tubular xenon lamps: water-cooled – DKsTV 15000 (*1)* and DKsTV 6000 (*2)*;
air-cooled – DKst 5000 (*3)* and DKst 1000 (*4)*

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THE LIST OF REGULATORY DOCUMENTS

I. GOST R15013 “System for the development and putting products into production. Medical Products. “

Fig. A. 2. Appearance of industrial samples of germicidal closed irradiators (recirculators):
a) “ Stery box “ (*TissiMedica*, USA), productivity (20–50) m^3/h, 5 mercury lamps LP 25 W power each, 500×150×600 mm, 25 kg; *b)* “Dezar-5” (KRONT, RF), productivity 100 m^3/h, 5 mercury lamps LP 15 W power each, 890×150×145 mm, 7.2 kg; *c)* “AEROLIT-200” (NPO “LIT”, RF), productivity 200 m^3/h, 1 amalgam lamp 170 W power, 1100×285×150 mm, 15 kg

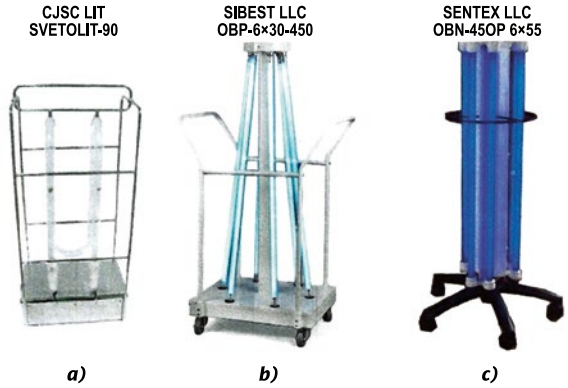

Fig. A.3. Appearance of industrial samples of germicidal open irradiators:
a) SVETOLIT-90 (NPO LIT, RF); *b)* OBP-6×30–450 (SibEST LLC, RF); *c)* OBN-450P 6×55 (LLC TsS SENTEH LLC, RF)

Fig. A.4. Module with germicidal lamps “MEGALIT-6” (NPO “LIT”, RF), which is built into the supply and exhaust ventilation system

II. SanPiN2.1.3.2630–10 “Sanitary and epidemic rules and regulations.”

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Manufacturers of Germicidal Lamps, Irradiators and UV Radiometers in Russia:

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– NPO LIT Moscow – Germicidal lamps and irradiators;

– CJSC KRONT, Moscow – Germicidal irradiators;

– NTP TKA LLC, St. Petersburg, VNIIOFI, Moscow – Radiometers.

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