System for Assessing the Effectiveness of Temporary Blinding Devices

M. Terekhova, S. Rudikov, A. Shumski, A. Shkadarevich

*Scientific and Technical Center LEMT of the BelOMO,
Makayonok str., 23/1, Minsk 220114, Belarus*

*Received 02.02.2020
Accepted for publication 12.05.2020*

Abstract

The development of non-lethal weapons and, in particular, temporary blinding devices is associated with problem of choosing boundaries of effectiveness. The aim of present work is determination of criteria for estimation of the effects of visual jamming devices action on the naked eye.

The present-day scoring system used for effectiveness estimation of laser temporary blinding devices is based on maximum permissible exposure and/or accessible emission level defined for each hazard class in accordance with operating standard.

In the present work we carried out analysis and modeling of the cases of application of temporary blinding laser devices. The proposed scoring system was founded on international standard IEC 60825-1-2014 as well as Manual on Laser Emitters and Flight Safety. The modeling of bright light action on observer eye was rested on CIE General Disability Glare Equation and provided quantitative description of jamming effectiveness. The main parameters used in this model and dictated by ambient light level and human eye characteristics, were veiling luminance and angle of distinguishing objects under it.

In terms of exposition level and perception effects we determined six zones – unallowed, hazard, temporary blinding, discomfort, alerting, completely safe. Proposed system combined with modeling provides with visual demonstration of perceived light source and allows to describe human physiological sensation and to establish the fact of jamming at different distances. This system was the basis of the development of temporary blinding device for revelation of safe but effective spatial boundaries of action.

Keywords: dazzle, temporary blindning, hazard class, veiling luminance.

DOI: 10.21122/2220-9506-2020-11-2-105-113

Адрес для переписки:
М.С. Терехова
Научно-технический центр «ЛЭМТ» БелОМО,
ул. Макаёнка, 23/1, г. Минск 220114, Беларусь
e-mail: terekhova.m.s@yandex.by

Address for correspondence:
M. Terekhova
Scientific and Technical Center LEMT of the BelOMO,
Makayonok str., 23/1, Minsk 220114, Belarus
e-mail: terekhova.m.s@yandex.by

Для цитирования:
M. Terekhova, S. Rudikov, A. Shumski, A. Shkadarevich.
System for Assessing the Effectiveness of Temporary Blinding Devices.
Приборы и методы измерений.
2020. – Т. 11, № 2. – С. 105–113.
DOI: 10.21122/2220-9506-2020-11-2-105-113

For citation:
M. Terekhova, S. Rudikov, A. Shumski, A. Shkadarevich.
System for Assessing the Effectiveness of Temporary Blinding Devices.
Devices and Methods of Measurements.
2020, vol. 11, no. 2, pp. 105–113.
DOI: 10.21122/2220-9506-2020-11-2-105-113

Devices and Methods of Measurements
2020, vol. 11, no. 2, pp. 105–113
M. Terekhova et al.

Система оценки эффективности устройств временного ослепления

М.С. Терехова, С.И. Рудиков, А.П. Шумский, А.П. Шкадаревич

Научно-технический центр «ЛЭМТ» БелОМО,
ул. Макаёнка, 23/1, г. Минск 220114, Беларусь

Поступила 02.02.2020
Принята к печати 12.05.2020

Разработка оружия нелетального действия, в частности устройств временного ослепления, сопряжена с проблемой выбора эффективных границ действия. Целью данной работы являлось установление критериев оценки действия устройств постановки зрительных помех невооружённому глазу.

Для определения эффективности действия представленных на рынке лазерных устройств временного ослепления обычно используется система оценки, основанная на предельно допустимом уровне излучения и/или предельной интенсивности излучения для выбранного класса опасности в соответствии с действующим стандартом.

В данной работе проведён анализ и моделирование ситуаций применения устройств временного ослепления на основе лазеров. Предложена система оценки, основанная как на международном стандарте IEC 60825-1-2014, так и на руководстве по лазерным излучателям в аспекте безопасности полётов. Моделирование воздействия яркого излучения на глаз наблюдателя базировалось на основном уравнении слепящей блесткости (*CIE General Disability Glare Equation*) и обеспечивало количественную оценку эффективности постановки помех. В качестве основных параметров в модели использовались величины яркости засветки и угол различения объектов под ней, которые определялись параметрами человеческого глаза и внешней среды.

По уровню экспозиции и проявляемому эффекту было выделено шесть зон – запрещённая, опасная, временного ослепления, дискомфортная, оповещения, полностью безопасная. В совокупности с моделированием данная система позволяет описать физиологические ощущения человека, дать наглядное изображение воспринимаемого источника света и установить факт постановки помех на различных расстояниях. Эта система была положена в основу разработки устройства временного ослепления для выявления безопасных и эффективных пространственных границ действия.

Ключевые слова: даззлер, временное ослепление, класс опасности, яркость засветки.

DOI: 10.21122/2220-9506-2020-11-2-105-113

Адрес для переписки:
М.С. Терехова
Научно-технический центр «ЛЭМТ» БелОМО,
ул. Макаёнка, 23/1, г. Минск 220114, Беларусь
e-mail: terekhova.m.s@yandex.by

Address for correspondence:
M. Terekhova
Scientific and Technical Center LEMT of the BelOMO,
Makayonok str., 23/1, Minsk 220114, Belarus
e-mail: terekhova.m.s@yandex.by

Для цитирования:
M. Terekhova, S. Rudikov, A. Shumski, A. Shkadarevich.
System for Assessing the Effectiveness of Temporary Blinding Devices.
Приборы и методы измерений.
2020. – Т. 11, № 2. – С. 105–113.
DOI: 10.21122/2220-9506-2020-11-2-105-113

For citation:
M. Terekhova, S. Rudikov, A. Shumski, A. Shkadarevich.
System for Assessing the Effectiveness of Temporary Blinding Devices.
Devices and Methods of Measurements.
2020, vol. 11, no. 2, pp. 105–113.
DOI: 10.21122/2220-9506-2020-11-2-105-113

Introduction

Nowadays there is a growing interest in non-lethal weapons as a method of conducting humane combat. Non-lethal weapons (NLW) are a type of weapon designed for personnel temporarily disable, in the offensive or in the defensive, as well as to disrupt the operation of the enemy's weapons, military equipment and infrastructure while minimizing lethality, significant materiel destruction and environmental pollution [1]. One of the NLW development trends is creation of weapons based on temporary blinding of the enemy troops. Both coherent (laser) and incoherent radiation can be used as a light source. The advantage of using laser radiation (LR) is a longer range, high accuracy and lower required radiation power.

Vision is an irreplaceable sensory receptor and there are no prostheses or rehabilitation measures that can replace the lost sensory organ. Therefore, the magnitude of fear of losing sight for a sighted person (be it conscious or unconscious fear) [2, 3] and the concealed nature of the threat lead to a serious destabilization of the enemy's actions.

The NLW under discussion are in operational service with many countries. Examples of systems that cause temporary blindness are the products of E. Meyers Advanced Photonics (GLARE MOUNT and its modifications), Laser Energetics (Dazer Laser in various versions), Thales Group (GLOW), etc. Their method of application usually involves preliminary detection, alerting the enemy, and then inducing interference by directing a beam of light into the eyes.

In the Republic of Belarus a device causing temporary blindness has also been created. The project design developed by STC LEMT of the BelOMO is a mobile complex for monitoring the terrain, buildings and structures ("ISKRA"). It can be operated in three channels with wavelengths $\lambda = 525$ nm, 640 nm, 808 nm. The specified output power for each channel is approximately 3 W. The radiation divergence for the green radiation channel constitutes 6×3 mrad, for the red radiation channel – 6×2 mrad, for the IR – 5.8×5.2 mrad.

This system is intended for use during military operations and has a universal action. The operation of channels with wavelengths of $\lambda = 525$ nm and $\lambda = 640$ nm provides for temporary blinding of the enemy, i.e. disabling of the personnel through disorientation, and issuance of warnings over a wide range of distances. The channel operating at a wavelength of $\lambda = 808$ nm is designed to jam the enemy night vision devices and TV cameras.

The device itself is mounted on a pan and tilt platform and allows for regulating the impact effectiveness by pre-aiming at the target, determining the distance to it with the help of the rangefinder and for automatically adjusting the radiation power.

The technical characteristics of the temporary blinding devices/dazzlers are specified in Table 1.

Table 1

Dazzler characteristics

Name	Manufacturer	Power, W	Declared distance of temporary blinding	Divergence, mrad
Medusa	Passive Force LLC	5.00	Not specified. Probably ≈ 2 km	5.0
Sealase II	Passive Force LLC	5.00	Not specified. Probably ≈ 2 km	2.0
Hydra	Passive Force LLC	1.00	Not specified. Probably ≈ 0.5 km	Adjustable
Photonic Disruptor	Wicked Lasers	0.10	Not specified. Probably ≈ 0.5 km	Adjustable, 1.5–7.5
Laser Dazer Guardian	Laser Energetics	0.20	25–300 m (depends on divergence)	for 300 m – 3.3
GLARE LA-9/P	B.E. Meyers Advanced Photonics	0.25	500 m	Not specified. Probably ≈ 5.0
ISKRA	STC "LEMT" BelOMO	3.00	50–2500 m	6.0×3.0

Prior to using temporarily blinding weapons, it is necessary to determine and register the emitter characteristics within the safety limits. The aim of this work is to establish the criteria for estimation of the effects of visual jamming devices action on the naked eye.

Temporary blinding devices / dazzlers efficiency criteria

Estimation of the effectiveness of temporary blinding devices is based on comparing the laser radiation characteristics with the limit values given in the standards. The main parameters used for comparison are the laser power density, or the power per pupil. At the same time, the standards assign the values of the maximum permissible exposure (MPE) levels of laser radiation, to which an object can be exposed without adverse consequences, and the accessible emission level (AEL) for each laser class[1]. Comparing the parameters of the selected LR with the specified values allows to determine the effect of the LR on the eye.

Considering that the human perception is governed by the Weber-Fechner law, the described method is inaccurate, since it does not allow describing the physiological effect and the human response in case of significant decrease in the laser power density.

There are two types distinguished in the phenomenon of glare: discomfort glare and disability glare [4]. Discomfort glare is annoying and painful sensation caused by the light from a bright glare source. Nowadays, there are scales that allow to assess the discomfort glare, i.e. the subjective sensations of a human when exposed to bright light: the British Glare Index, the Discomfort Glare Index, the Unified Glare Rating), etc. [5]. However, they are applicable for sources whose solid angle for the observer is not less than 10^{-5} Sr (small sources) [6]. If the laser beam at the output aperture has dimensions of the order of 1×1 mm, then the solid angle at which the source is visible from the observer's position is much less than 10^{-5} Sr and tends to zero. At the same time the power density in the beam is large and can result in injuries. In view of this, there arises a need to discriminate additional power density boundary values that define certain conditional zones of LR impact and allow us to characterize the LR action at different distances and power outputs.

From henceforth, we will assume a continuous exposure mode, i. e. the one in which the pulse duration is equal to or greater than the duration of the wink reflex of 0.25 s [7].

We suggest to discriminate six zones with hazard scores assigned to them. The upper limit of the maximum allowable laser power density is determined based on the parameters which are characteristic of hazard class 3B, since observation of the radiation of this class is dangerous to vision. According to IEC 60825-1-2014, the AEL for class 3B laser falling on an aperture of 7 mm and corresponding to the diameter of the pupil adapted to night vision, of wavelengths λ = 400–700 nm, with a radiation pulse duration of 0.25 s constitutes 0.5 W (13 kW/m^2). Hence, when the power density increases above the specified value, irreversible effects occur. A zone where the power density exceeds 13 kW/m^2 is "forbidden" ("Unallowed") and has hazard score 6.

Since the laser class parameters are based on the MPE, which determines the LR level to which people can be exposed without negative effects, the next boundary is the laser power density of 25 W/m^2. Irradiation of the eyes within the five-point hazard score zone (power density from 25 to $13 \cdot 10^3$ W/m^2) will lead to temporary blinding, while the probability of causing physical damage is quite high.

Two subzones should be discriminated within the "danger" zone: from 25 to 130 W/m^2 and from 130 to $13 \cdot 10^3$ W/m^2. An additional boundary is related to the characteristics of hazard class 3R (with the above-specified parameters, the AEL is $5 \cdot 10^{-3}$ W–130 W/m^2). The division into sub-zones is necessary in order to focus on the growing risk of damage with an increase in power density (i.e., 130 to $13 \cdot 10^3$ W/m^2), which should be kept in mind when setting the operating modes of equipment aimed at temporary eye-blinding.

The next boundaries are set in accordance with the Manual on Laser Emitters and Flight Safety (ICAO (Doc 9815-AN/447, 2003)). In accordance with this document [8], in the immediate vicinity of the airfield three flight zones are distinguished in accordance to AEL (sensitive (1 W/m^2), critical ($5 \cdot 10^{-2}$ W/m^2), free (from laser radiation) ($5 \cdot 10^{-4}$ W/m^2)). Therefore, a zone where the power density varies from 1 to 25 W/m^2 is a four-point zone of "temporary blinding". At this power density, the effects of short-term blindness or afterimages may begin to occur, but without permanent damage to the eye caused.

[1] IEC 60825-1:2014

The LR power density range from $5\cdot10^{-2}$ to $1\ \mathrm{W/m^2}$ is a three-point "discomfort" zone, where glaring effects may occur, but the phenomenon of flashblinding will not be achieved. At the same time, any negative effects on the eyes are also completely excluded.

In the two-point "alert" zone, the LR power density (from $5\cdot10^{-4}$ to $5\cdot10^{-2}\ \mathrm{W/m^2}$) is not sufficient to cause glare, but it is large enough to warn/ illuminate the target.

If the power density is less than $5\cdot10^{-4}\ \mathrm{W/m^2}$, the zone is "completely safe" and has hazard score one.

Analysis of the known characteristics of some of the above-mentioned devices allows us to make a theoretical calculation (Formula 1) of the radiation power density at different distances from the emitter (Figure 1):

$$E = \frac{P}{\pi \cdot \mathrm{tg}\frac{\varphi_1}{2} \cdot \mathrm{tg}\frac{\varphi_2}{2} \cdot L^2}, \tag{1}$$

where E is the radiation power density, $\mathrm{W/m^2}$; L is the distance from the emitter, m; P is the LR power, W; φ_1, φ_2 are the LR divergence angles along both axes.

With $L = 0$, all outputted radiation falls on the object, while the power density is maximal and depends on the beam diameter (r) at the output of the emitter. Accordingly, formula (1) is applicable for distances $L > \frac{r}{\mathrm{tg}\frac{\varphi}{2}}$, where $\varphi = \max[\varphi_1, \varphi_2]$.

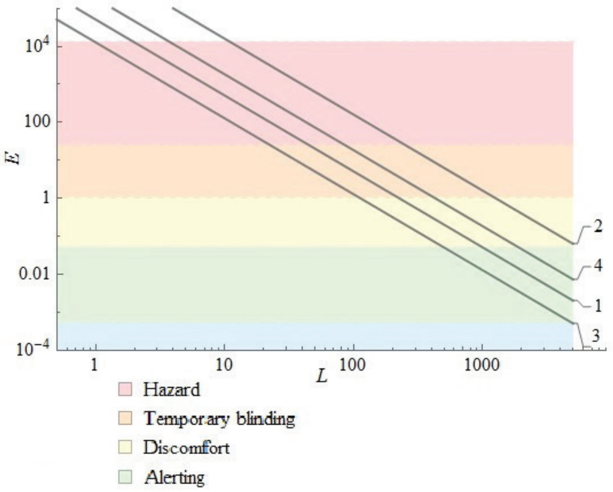

Figure 1 – Dependence of the radiation power density (E, $\mathrm{W/m^2}$) on the distance to the source (L, m) for different devices: 1 – Hydra; 2 – Sealase II; 3 – GLARE LA-9/P; 4 – ISKRA system

Knowing the initial parameters of the systems, a theoretical calculation has been made (Table 2) of the distances (Formula 2) at which certain effects from each device are manifested:

$$L = \left(\frac{P}{E \cdot \pi \cdot \mathrm{tg}\frac{\varphi_1}{2} \cdot \mathrm{tg}\frac{\varphi_2}{2}} \right)^{1/2}. \tag{2}$$

Table 2

Effective zones of temporary blinding devices/dazzlers depending on the distance to the source

E, W/m²		More than $13\cdot10^3$	$13\cdot10^3$–25	25–1	1–$5\cdot10^{-2}$	$5\cdot10^{-2}$–$5\cdot10^{-4}$	Less than $5\cdot10^{-4}$
	Score points	●●●●●●	●●●●●	●●●●	●●●	●●	●
	Zone name	Unallowed	Hazard	Temporary blinding	Discomfort	Alerting	Completely safe
		Effective range, m					
Name	Medusa	Less than 4	Up to 101	Up to 505	Up to 2300	Up to 23000	Over 23000
	Sealase II	Less than 11	Up to 252	Up to 1000	Up to 5600	Up to 56000	Over 56000
	Hydra	Less than 2	Up to 45	Up to 226	Up to 1000	Up to 10000	Over 10000
	Photonic Disruptor	Less than 2	Up to 48	Up to 238	Up to 1000	Up to 10600	Over 17000
	Laser Dazer Guardian	Less than 1	Up to 31	Up to 153	Up to 684	Up to 7000	Over 7000
	GLARE LA-9/P	Less than 1	Up to 23	Up to 113	Up to 505	Up to 5000	Over 5000
	ISKRA	Less than 4	Up to 86	Up to 430	Up to 2000	Up to 20000	Over 20000

Comparison of the data (Table 2) with the established zone boundaries allows to assess the effect of temporary blinding systems. If operation of the devices is analyzed based only on the laser classification, their effectiveness is extremely low. However, the use of the proposed system of six zones allows us to fully characterize the action of the systems at different distances. Thus, all the devices discussed provide the necessary effect at the stated distance.

Modeling of laser radiation effects on eyes

One of the manifestations of blinding is disability glare, which is understood to mean a decrease in visibility caused by irradiation by a bright light source. In this case, subjective sensations are not taken into account [4]. As a result, the apparent brightness of the object that a person is looking at decreases on the retina exposed to the bright counter-flash, and it becomes impossible to distinguish the object. The use of the blinding glare parameters together with the zones of permissible power densities correlated with physiological effects allows us to fully assess and substantiate the effect of temporary blinding devices on the human eye.

The characteristic of the disability glare is the brightness of the veiling luminance, which is described by the *CIE General Disability Glare Equation* [9]:

$$g(\theta)=\frac{L_{veil}}{E_{glare}}=\frac{10}{\theta^3}+\left(\frac{5}{\theta^2}+\frac{0.1\cdot p}{\theta}\right)\cdot\left(1+\left(\frac{A}{62.5}\right)^4\right)+0.0025\cdot p, \quad (3)$$

where E_{glare} is irradiance from the source of flash, lx; L_{veil} is brightness of the veiling luminance, Cd/m^2; θ is the angle between the visual direction and the direction of the source beam (0,1º < θ < 100º) (Figure 2), degrees; p is the iris pigmentation coefficient (equal to 1.2 for very light-colored eyes, θ – for very dark eyes); A is the age of the observer.

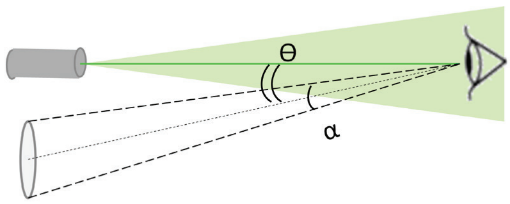

Figure 2 – Schematic representation of the laser radiation effect on the viewer's eye: α is the visible angular size of the target; θ is the angle between the visual direction and the direction of the laser beam

The luminous efficiency (visibility curve) allows to assess the effect of a certain radiation wavelength. Taking into account the calibration coefficients, the final formula showing the variation of the veiling luminance brightness depending on the radiation power density on the eye, has the following form [10]:

$$L_{veil}=g(\theta)\cdot 0.9239\cdot L_b^{0.6795}\cdot C\cdot V_\lambda\cdot E, \quad (4)$$

where L_b – background ‘ambient’ luminance (bright day, twilight, night), cd/m^2; V_λ – eye’s photopic efficiency at the wavelength, λ; E – radiation power density, W/m^2; C = 683 Lm/W is the multiplicative constant.

In practice, disability glare can be estimated using the concept of maximum dazzle exposure (MDE) [11], which shows the value of the laser field illuminance, above which the object located behind the field cannot be detected. The calculation takes into account the angular size of the target that a person is looking at, the age and the degree of pigmentation of the person's eyes, the brightness of the background and the target contrast:

$$\mathrm{MDE}=\frac{\left(\frac{L_b\cdot C_{orig}}{\Omega\cdot AF}-L_b\right)}{g(\theta)\cdot 0.9239\cdot L_b^{0.6795}\cdot C\cdot V_\lambda}, \quad (5)$$

where MDE is the maximum dazzle exposure, W/m^2; C_{orig} is the target contrast in the absence of a laser field (nondimensional value, the ratio of the object brightness to the field brightness); Ω is the calibration factor including the target angular size α and total luminance; AF is the age factor.

Since at the set distance the viewer's eye is exposed (Figure 2) to a well-defined power density (Formula 1) it is possible to determine the maximum angle θ at which an object with angular size α will not be distinguished by equating this value to the MDE (Formula 5). Therefore, the simulated zone model can be supplemented with the values of the object distinguishing angle.

The results of the MDE calculation (Formula 5) for the ISKRA system for the established zones are presented in Table 3. The following initial input parameters of the system were used: radiation wavelength – 525 nm, human age – 30 years, eye pigmentation – 0.5 (brown), target contrast – 0.8, external luminance – 10000 cd/m^2 (bright day), target size – 5 m. The calculation does not consider the dark adaptation of the eyes, because at close distances (unallowed and hazard zones), the entire field of view is filled with the light from the source, which makes it impossible to distinguish the object. At long distances (temporary blinding zone, discomfort zone, alerting zone, completely safe zone), the angular size of the target is small, and with its low contrast can not be distinguished in low external lighting conditions, even at low radiation power density.

It should be emphasized that the calculation of the maximum object distinguishing angles does not take into account the sensations of the subject. Literature data [12] suggest that, despite the possibility of detecting an object under the field of veiling luminance, observation of radiation is discomforting and affects the subject's activity (in particular, the shooting accuracy and rate decreases).

Table 3

Operating range of ISKRA, angle of object detection (θ) under veiling luminance and effects in dependence on distance from light source (*L*) and angular size of a target (*α*) in case of light adaptation of eyes

E, W/m^2	Zone name	Score points	L, m	α, degrees	θ, degrees	Effect
More than $13 \cdot 10^3$	Unallowed	●●●●●●	Less than 4	Over 51.33	All field dazzled	Blinding
From – to $13 \cdot 10^3$–25	Hazard	●●●●●	Up to 86	Up to 3.32	At least 5.83	Temporary flash blinding, potential injuries
From–to 25–1	Temporary blinding	●●●●	Up to 430	Up to 0.72	At least 1.73	Temporary blinding, afterimages, without injury
From – to 1–$5 \cdot 10^{-2}$	Discomfort	●●●	Up to 2000	Up to 0.15	At least 0.84	Temporary blinding effects, afterimages of short duration
From – to $5 \cdot 10^{-2}$–$5 \cdot 10^{-4}$	Alerting	●●	Up to 20000	Up to 0.02	At least 1.22	Illumination, blinking
Less than $5 \cdot 10^{-4}$	Completely safe	●	Over 20000	Less than 0.02	Less than 1.22	Illumination

Based on the recalculation mechanism proposed in [11], the disability glare was visualized for the three channels of the ISKRA system under conditions of the daytime adaptation of the eye. The resulting distribution was superimposed on the photograph of the selected horizontal field of view for better visual clarity (Table 4). The image is a model of a light spot on the retina of the eye and serves as an additional way to visualize the boundaries of the zones presented above.

From Table 4 it is evident that the green channel has a greater effect on the human visual organ, which is explained by the structure of the eye's receptor cells and is numerically fixed in the spectral sensitivity curve of the eye.

Figure 3 schematically shows the value of the object distinguishing angle when exposed to radiation with a power density of 1 W/m^2. Diverting the eye by this angle is necessary, but not sufficient to distinguish the target, because the person will experience discomfort, causing impairment of responses.

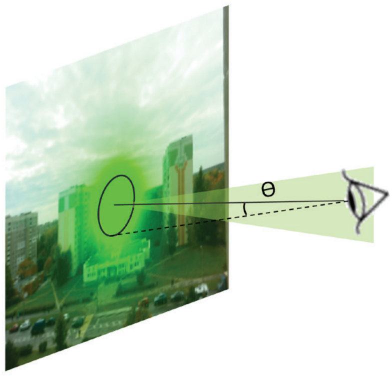

Figure 3 – Schematic representation of the object distinguishing angle (θ) under exposure to veiling luminance

Table 4

Simulated image of dazzle spot on eye retina exposed to irradiation with power density *E*

Zone name	E, W/m^2	Irradiation wavelength, nm	
		525	640
Unallowed	$13 \cdot 10^3$		
Hazard	25		
Temporary blinding	1		
Discomfort	$5 \cdot 10^{-2}$		
Alerting	$5 \cdot 10^{-4}$		

Based on the proposed pattern, one can assess the efficacy of the devices under various conditions. For example, the ISKRA system provides for induction of sensible visual interference at a distance of up to ≈ 2 km ("discomfort" zone), while temporary blinding is achieved at distances of up to ≈ 0.5 km. This provides for the effect of evasion of the bright light source (disorientation), due to a physiological reaction, as well as the effect of disruption of the human work activity due to the veiling luminance of part of the field of view and the inability to properly perform actions aimed at excluding the source of radiation. The efficiency of the λ = 525 nm channel is higher compared to the other channels, since the radiation wavelength is close to the maximum spectral sensitivity of the eye. The highest effectiveness of the device is achieved during the dark adaptation of the eye under low ambient luminance conditions.

Conclusion

As a result of the study, a system of power density zones has been established that allows us to characterize and to provide visual demonstration of the perception of the irradiated human during operation of temporary blinding devices at different distances (unallowed, hazard, temporary blinding, discomforting, alerting, completely safe zones).

In the case of development of the new device it has been proposed to use the angle of object detection, which depends on the parameters of the emitter, external space and the human, along with the zone system for numerical demonstration of device operation. Based on the described system, the parameters of the new device designed for suppressing the enemy's actions by means of laser radiation were estimated.

References

1. Hoffberger E. Non-lethal weapons: The Principle of proportionality in armed conflict and the right to health in law enforcement. *Zb Pravnog Fak Sveučilišta U Rijeci*, 2017, vol. 38, no. 2, pp. 831–853. **DOI:** 10.30925/zpfsr.38.2.6

2. Peters A. Blinding Laser Weapons: New Limits on the Technology of Warfare. *Loy LA Int'l & Comp LJ*, 1996, vol. 18, pp. 733–766.

3. Giridhar P., Dandona R., Prasad M.N., Kovai V., Dandona L. Fear of Blindness and Perceptions about Blind People. *The Andhra Pradesh Eye Disease Study*. *INDIAN J Ophthalmol*, 2002, vol. 50, no. 3, pp. 8.

4. Bullough J.D., Sweater-Hickcox K., Narendran N. A method for estimating discomfort glare from exterior lighting system. *Alliance Solid-State Illum Syst Technol*, 2011, vol. 9, pp. 1–7.

5. Clear R. Discomfort glare: What do we actually know? *Light Res Technol*, 2013, vol. 45, no. 2, pp. 141–158. **DOI:** 10.1177/1477153512444527

6. Tyukhova Y.I. Discomfort glare from small, high luminance light sources in outdoor nighttime environments. *Architectural Engineering − Dissertations and Student Research. Lincoln*, 2015, 295 p.

7. Denniston A., Murray P. Oxford Handbook of Ophthalmology. *OUP Oxford*, 2014, 1108 p.

8. IKAO [ICAO]. Available at: https://www.favt.ru/dejatelnost-mezhdunarodnaja-dejatelnostikao/?id=796 (accessed 17 September 2019).

9. Vos J.J. On the cause of disability glare and its dependence on glare angle, age and ocular pigmentation. *Clin Exp. Optom.*, 2003, vol. 86, no. 6, pp. 363–370. **DOI:** 10.1111/j.1444-0938.2003.tb03080.x

10. Williamson C.A. Simple computer visualization of laser eye dazzle. *J Laser Appl.*, 2016, vol. 28, no. 1, pp. 012003. **DOI:** 10.2351/1.4932620

11. Williamson C.A., McLin L.N. Nominal ocular dazzle distance (NODD). *Appl. Opt.*, 2015, vol. 54, no. 7, pp. 1564. **DOI:** 10.1364/AO.54.001564

12. Vandewal M., Eeckhout M., Budin D. Estimation of Laser Dazzle Effects on Shooting Performance. *Hum Factors Mech. Eng. Def. Saf.*, 2019, vol. 3, no. 1, p. 12. **DOI:** 10.1007/s41314-019-0028-2