Theoretical basis of comfortable, tolerable and destructive effects of sounds and noise

Evgeny L Ovchinnikov
Department of Medical and Biological Physics,
Problem Laboratory of Hearing & Equilibrium,
Samara State Medical University, Samara, Russia
E-mail: E.L.Ovchinnikov@ya.ru

Vladislav V Ivanov
Faculty of Information Technology,
Samara Engineering College, Samara, Russia
E-mail: vv.ivanov@live.ru

Abstract. The methodology of theoretical base of sound dosimetry is offered. The physiological approach to a problem is considered, is constructed bio- and psychophysical model of sound effects on human hearing, and values of comfortable, tolerable and destructive sound pressure and establishment its maximal levels.

1. Introduction
Sounds are recognized adverse by the signs creating a complex of physical factors, negatively influencing not only on technical constructions, but also on human health.

Sound effects is integrally, but is estimated by specific organ – the hearing’s organ. Degree of danger of noise is characterized by "risk of damage" structures of an ear and regulated by experimentally well-founded maximum permissible levels (MPL) of sound pressure and maximum permissible dose of effect (Table 1, [1]).

| Excess of actual noise level over limiting (in dB) | Expected reaction               |
|--------------------------------------------------|---------------------------------|
| 0                                                | Reactions not observed          |
| 5                                                | Separate complaints             |
| 10                                               | Numerous complaints             |
| 15                                               | Threat of public intervention   |
| 20                                               | Resolute of public actions      |

Graphical analysis of experimental values MPL (Fig. 1.a [2]), established in some countries as the national standard to limit the effect of noise on humans (eg, Russia), shows their obvious
incorrectness. Mathematically, it is shown in absence of monotony of change, an elaborate spectral landscape and a freakish relief of its surface (Fig. 1,b, c).

These facts demand theoretical development and scientific substantiation of principles of sound dosimetry.

2. Methodology of the theoretical bases of sound dosimetry

Sound dosimetry is included into many areas of a science, technics and technology: physiology of hearing and otorhinolaryngology, human hygiene and ecology of the noise enterprises, sound dosimetry and metrology of sound parameters. The question essence consists in proving a method of definition of a susceptibility of acoustic receptors to external sound stimulus and its quantitative estimation. The bottom line is to support the method for determining the sensitivity of receptors hearings on the external sound stimulus and its quantification.

This condition appears, because in practice direct measurement is spent only for three sound parameters, namely:
1) exposure time – by stop-clock or usual hours;
2) sound frequencies – by Helmholtz-resonators or electronic means;
3) sound pressure – by manometers of various types and measuring microphones;
4) levels of sound pressure – by measurement of sound pressure levels.

Options (1) and (2) are measured by standard methods. Measurement of parameters (3) and (4) is carried out in environment while transformation of sound energy (of a sound pressure) to electric potential occurs in a ear analyzer.

Solving the problem of sound dosimetry studies to consider the complex, including:
1) definition of units of sound radiations doses;
2) identifying the physiological mechanisms of perception of acoustic receptors of sound pressure from external sources;
3) development of biophysical mechanisms of transformation of sound energy by ear receptors;
4) development of psychophysical mechanisms of perception of sound by ear receptors;
5) quantitative calculation of maximum permissible doses of sound effects, maximum allowable sound pressure, maximum permissible sound pressure levels and health standards of human exposure.

The general solution to the problem of sound dosimetry can be expressed that:
1) to determine the values of the MPC has raised doubts about the graphical analysis of experimental data;
2) to prove the theoretically criteria of energy parameters of a sound on a hearing system;
3) to establish the critical dose of sound, which should not cause destructive changes in the structure of the hearing analyzer.

**Figure 1.** Quantitative calculation of loudness levels (a, on: [2]), their spectral landscape (b) and a surface relief (c) as a card of levels of a surface
If to consider the first problem it is possible to notice that it has trivial, but the decision not proved theoretically, – for this purpose is required simple decrease obviously overestimated MPL, as is executed, for example, in sanitary rules and norms. Other two directions consist in the analysis of physiological, bio- and psychophysical effects of sound energy on hearing system and its receptors. For this purpose, is the law of Weber – Fechner. This is a mathematical expression of quantitative evaluation of psycho-physical stimulation as a correlate of the perception of the external sound pressure.

3. Defining units of measure of sound radiation doses

Effect of sound and noise at the sites evaluated the dose D as an integrated consideration of the size of the acoustic energy over a certain period of time. At the current average sound pressure $p_A(t)$, Pa; the dose in experiment D in time T is defined by a ratio

$$D = \int_0^T p_A^2(t) \, dt,$$

with the unit $[D] = 1 \text{ Pa}^2 \cdot \text{h}$.

Equivalent (in energy) sound pressure level $L_A$, dB, is thus calculated by the formula

$$L_A = 20 \cdot \log \left( \frac{\int_0^T p_A(t) \, dt}{p_o} \right),$$

where $p_o = 2 \times 10^{-5}$ Pa – the minimum sound pressure (an hearing threshold), perceived by spiral body of the person on standard frequency $f_c = 1$ kHz with probability $1/2$.

Permissible dose of noise $D_m$ in practice determined by the formula

$$D_m = p_{A_m}^2 \cdot T_p,$$

where $p_{A_m}$, Pa, – the value of sound pressure, corresponding to admissible sound level $L_A$; $T_p$, h, – duration of the working day (shift). At $p_{A_m} = 0.356$ Pa (that corresponds to an admissible pressure level $L_{A_m} = 85$ dB) and $T_p = 8$ h an admissible dose of sound effects $D_m = p_{A_m}^2 \cdot T_p = 1 \text{ Pa}^2 \cdot \text{h}$.

The physical meaning of this size $D_m = 1 \text{ Pa}^2 \cdot \text{h}$ is that it determines the exposure dose of sound energy average sound pressure $p_A = 0.356$ Pa and the duration of action equal to a shift in 8 h. In the physics the unit of measure of a dose of any kind of radiation is defined by specific energy – energy $W$ having on a mass unit $m$ of object,

$$D_e = \frac{W}{m},$$

with a unit $[D] = 1 \text{ J/kg}$. (In the radiating physics the unit of this size is called the Gray, Gy). Here we note that in accordance with the International Commission on Radiological Protection natural background radiation for the year is the radiation dose to 0.002 Gy). For the same ratio should be established, and the dose of radiation of sound, and

$$D_e = \frac{1}{m_o} \int dW = \frac{1}{m_o} \int \Phi \, dt,$$

where $\Phi$ – the flow of energy a sound wave, when, in fact, its capacity. As, by definition, $\Phi = I S$, where $I$ – sound intensity, and $S$ – the area of its influence, $D_e = \frac{1}{m_o} \int I S \, dt$.

Increasing and dividing the right side of this equation in an element of length d$\ell$, traversed by the wave in time dt, we obtain $D_e = \frac{1}{m_o} \int I S \frac{d\ell}{dt} \, dt$. In this equality $S \, d\ell = dV$ – an element of volume.
of a body which the sound wave influences, \( \frac{df}{dt} = v \) – the speed of its spread. Performing the change of variables, we obtain
\[
D_e = \frac{1}{m} \int \frac{1}{V} dV, \quad \text{and at fixed (constant) sound intensity } I \text{ it is had}
\]
\[
D_e = \frac{1}{m} \cdot \frac{V}{v} = \frac{1}{\rho v} = \frac{1}{z},
\]
where \( \rho = \frac{m}{V} \), kg m\(^{-3}\), – environment density in which the sound wave is observed, \( z = \rho v \), N \cdot s m\(^{-3}\), – its wave (acoustic) resistance. Applying the relation \( I = \frac{p_e^2}{z} \), linking the wave intensity \( I \), with its effective pressure \( p_e \), we have
\[
D_e = \frac{p_e^2}{z}. \tag{5}
\]
Comparing (3) and (5), we can write the obvious equation
\[
D_e = kD_m, \quad \text{where } k \text{ – a compliance factor between dose } D_m, \text{ Pa}^2 \text{h}, \text{ determined experimentally and theoretical dose } D_e, \frac{J}{kg}.
\]

We will establish its size and physical meaning. The dose of sound effects, in fact, is the amount of energy and in accordance with the law of conservation and transformation of the total mechanical energy of sound radiation dose \( D \) at time \( T \), the dose effect of sound pressure \( p_e \) is subjected to the measurement of the external sound field:
\[
D_e = k \cdot \frac{p_e^2}{z} t, \quad \text{whence for time } t = 1 \text{ s}
\]
\[
k = \frac{1}{z} \cdot \frac{1}{(\rho v)^2} = \frac{m^6}{N^2 \cdot s^3}. \tag{6}
\]
So, \( k \) – a size, inversely to a square of wave resistance of environment, in which a sound wave during time \( t = 1 \) s is spread. Thus, the theoretical understanding of the dose of the sound effect is the specific energy of a sound wave is proportional to the effective pressure and duration of exposure of the object in the sound field.
\[
D_e = k \cdot \frac{p_e^2}{z} t = \frac{1}{(\rho v)^2} \cdot \frac{p_e^2}{z} t, \quad \frac{J}{kg}. \tag{7}
\]
Under the Russian standard maximum permissible dose of effects of a sound frequency \( f_c = 1 \) kHz at the 8-hour work shift \( T_p \) must not exceed \( D_m = 1 \) Pa\(^2\)h. This value is an exposure dose as it is defined in an external sound field (in air, for which density \( \rho = 1.2928 \) kg m\(^{-3}\), speed of distribution of a sound in which \( v = 330 \) m/s). Then for a shift duration \( T_p = 8 \) h at accepted in Russia scientific consensus effective pressure \( p_e = 0.356 \) Pa it is had exposure dose
\[
D_e = \frac{1}{(\rho v)^2} \cdot \frac{p_e^2}{z} \cdot T_p, \quad \text{where the duration of a sound effect is defined as } T_p, \text{ in s}.
\]

| L (dB) | p(L) (Pa) | D_e(L) (Pa\(^2\)h) |
|-------|----------|-----------------|
| 1     | 45       | 0.00356         | 0.0001 |
| 2     | 55       | 0.0112          | 0.001 |
| 3     | 65       | 0.0356          | 0.01  |
| 4     | 75       | 0.112           | 0.1   |
| 5     | 85       | 0.356           | 1     |
| 6     | 95       | 1.12            | 10    |

Table 2
Calculation of sound pressure \( p \) (L) and a sound dose \( D_e(L) \) on set level \( L \) (on: \([2]\))
A simple calculation shows (Table 2) that at the given effective pressure $p_e$, corresponding to level of intensity $L(p_e) = 85.0$ dB, the sound radiation exposure dose, as expected, makes $D_e = 1 \text{ Pa}^2\cdot\text{h}$, and the maximum permissible dose of sound pressure makes $D_m = 0.02 \frac{\text{J}}{\text{kg}}$, and $k = 5.5 \times 10^{-6} \frac{\text{m}^6}{\text{N}^2\cdot\text{s}}$. Thus the dose of sound radiation equal to $D_e = 0.002 \frac{\text{J}}{\text{kg}}$, is carried out on the sound pressure level $L = 75$ dB.

4. Physiological approach to an establishment of limit rates of sound pressure

Physiologic approach to establishing mechanisms to sense sound pressure from external sound sources of energy based on the rationale of the mission of acoustic receptors: inner and outer hair cells (IHC and OHC), which functional properties are determined by their structural organization.

The perception of height of one tone at any loudness level demands only displacement tectorial membrane concerning HC. Such monomodal interaction with an integumentary membrane possess inner HC of a spiral organ, located on a basilar plate are linearly and ordered – in single row (Fig. 1). Therefore inner HC is possible to consider as the structures responsible for perception of height of tones as psychophysical correlate of sounds frequency. Such assumption is admissible and for the reason that number IHC ($N_{IHC} \sim 3000$) coincides with quantity of the tones distinguished by the person at any loudness level.

For signals of one tone, but various loudness levels, is required more difficult and multimodal character of displacement of an tectorial membrane concerning HC. Such a variety differ interactions and, accordingly, vibrations of an tectorial membrane concerning outer HC as they are located on a basilar plate in three rows. Number OHC exceeds IHC approximately in six times, and density of their distribution twice more than IHC. The distribution OHC concerning IHC such is that can correspond to one inner hair cell not less than $13 \div 15$ (and more, [3]) cells of all three outer rows of a spiral organ, the raised which number will be defined by multiple perception on loudness levels of one tone.

Then is admissible to consider OHC – the structures, responsible for perception of tones loudness, and loudness level of tone to define number OHC involved in process of perception of acoustic energy which on co–ordinates are correlated with IHC, responsible for perception of frequency of a sound as sensations of height of tone (Fig. 1).

Such approach also is not unreasonable. Appreciable primary loss of perception of loudness is observed at level 50 dB. The pathology of these six OHC of the first row, raised by sounds small интенсивностей, probably, causes observable increase in a loudness threshold.

The further loss of loudness becomes significant at level 100 dB. This can be explained presence of OHC pathology of the first and second series of spiral organ, raised by the sounds both small, and average intensity. Thus, the presented assumptions are phenomenological proved, and the physiological and psychophysiological role of hair cell, both inner, and outer, is becoming clearer.

**Figure 2.** The analysis of microphotos (a – on : [4], b – on: [5] c – on: [6])
The carried out analysis of the structural organization of hearing organ assumes that:
1) for a perception of sounds as a hearing must:
   a) for a perception of the height of an one tone, mel, – excitation of one inner hair cells (IHC) for the corresponding distribution [7] (Fig. 2, allocated to the sector with the fat line);
   b) for perception of one tone of various loudness levels $E$, in decaphon (various levels of sound pressure or sound intensity $L$, in B), – excitation of several outer hair cell (OHC) by number $n$, on unit exceeding value of loudness level or sound pressure level $(n = L+1 = E + 1$: at level $E = L = 0$ is raised $n = 1$ OHC, at level $E = L = 1$ is raised $n = 2$ OHC, etc.), on corresponding distribution [7, 8] (Fig. 2, any selected sector);
2) for stationary and full functional operation of hearing organ (without adaptation) at any frequency must:
   a) obligatory conformity of the instruction about full soundproofing in the sound field of the highest sound pressure (the highest intensity) with $L \geq 11$ B at excitation $n \geq 12$ OHC, leading to an acoustical contusion (devocalization), partial and full deafness [4],
   b) observance of the instruction for protection of the hearing organ perceiving sound stimulus of short duration and high sound pressure (high intensity), in $5 < L \leq 11$ B and excitation $6 < n \leq 12$ OHC,
   c) the tolerant relation to stimulus of small sound pressure (small intensity) with levels $L \leq 5$ B at excitation $n \leq 6$ OHC, not leading to adaptation of acoustical perception for a long time.

Thus, the physiological approach to an establishment of principles of dosimetry of a sound shows that fact that such level of sound pressure (of a sound intensity) which would involve in perception of a sound to 6 outer HC is necessary for steady and full–functional work of hearing organ. Excitation $n > 6$ OHC can cause problems in its work.

5. Development of biophysical bases of sound dosimetry
Axiomatic that a research complex should include four main groups of the documents, establishing:
1) parameters of sound effects in the premises to which the person spends at $\frac{2}{3}$ of life;
2) parameters of sound effects in the working environment that a person spends on $\frac{1}{3}$ of life;
3) methods of measurement of parameters of sound effects;
4) standards of safety of living and working.

For the biophysical decision of a problem we will use the law of Weber – Fechner proved only for named standard frequency $f_c = 1$ kHz. Under the law of Weber – Fechner a sound pressure level $L$ at this frequency made for man, is perceived as

$$ L = 2 \log \frac{p}{p_0}, \quad B, $$

where $p_0 = 2 \times 10^{-5}$ Pa – the minimum sound pressure (hearing threshold), are perceived by an ear of the average person on standard frequency with probability $\frac{1}{2}$. Then, for sound pressure level $L$, we pressure

$$ p(L) = p_0 \cdot 10^{\frac{L}{2}}. $$

Let’s divide $p(L)$ into functional mobility OHC $Z - (n - 1)$ at level $L$, where $Z = N_o + N_i$ – total of all hair cells ($N_o = 15$ outer and $N_i = 1$ inner HC, Fig. 2). We reach to $\frac{p(L)}{Z - (n - 1)}$, getting sense of OHC susceptibility at corresponding level $L$ of sound pressure $p(L)$. Having further divided susceptibility OHC into total number of cells $Z$ and having increased to number $n$ OHC, responding on the enclosed pressure, we will receive value of that pressure $g(L, n)$ in an internal ear which can be identified with level $L$ for $n$ raised OHC

$$ g(L, n) = \frac{p(L)}{Z - (n - 1)} \cdot \frac{n}{Z}. $$
Figure 3. Calculation of sound pressure \( g(L) \) (a) and of sensitivity \( G(L) \) of hearing receptors

Graphical analysis (10) and calculation of pressure \( g(L, n) \) for \( n_c = 6 \) OHC, which corresponds to the level \( L_c = 5 \) B, they have created (with \( n = L + 1 \)), we get \( g(L_c, n_c) = 2.156 \times 10^{-4} \) Pa (Fig. 3.a). It can be assumed as a pressure reference point in physiology of acoustical researches. \( \Theta \)-plane \( \Theta = g(L_c, n_c) \approx 2.2 \times 10^{-4} \) Pa.

Equation (11) can be simplified to one variable communication \( n = L + 1 \), so that (Fig. 3,b)

\[
g(L) = \frac{p(L) - L + 1}{Z}.
\]

where for \( L_c = 5 \) B it is had \( g(L_c) = 2.156 \times 10^{-4} \) Pa. It is such a pressure, which, as noted, does not destroy of receptors for a long time (possibly all human life). This can be considered as a base for creating maximum influencing the acoustic receptors of the inner ear without affecting their normal functioning for a long time, dose (reference dose of acoustic metrology). For any level \( L \), the sound effect dose can be established formula \( D(L) = g(L) \cdot T \), for \( L_c = 5 \) B and time \( T = 360 \) years, on which work ear [8] is calculated, we have \( D(L_c) = 0.147 \) Pa².h.

The dose of sound effects, in fact, is energy size and in accordance with the law of conservation and transformation of the total mechanical energy dose of sound effects in inner ear \( D(L) \) during \( T \) is a dose effect of sound pressure \( G(L) \), exposed to calculation in an external sound field for the duration of work shift \( T_p \), ie \( D(L) = G(L)^2 \cdot T_p \), where

\[
G(L) = \frac{D(L)}{T} = g(L) \cdot \sqrt{\frac{T}{T_p}}.
\]

For \( L_c = 5 \) B we have pressure \( G(L_c) = 0.135 \) Pa. This pressure subjected to measurement in space surrounding the person, also is threshold, or maximum permissible, at calculation for a duration \( T_p = 8 \) h, \( p_{II} = G(L_c) \), and \( p_{II} = 0.135 \) Pa (pressure point reference in acoustic metrology).

6. Psychophysical basis of sound dosimetry

The psychophysical substantiation of the concept consists in estimating loudness level of the sound signal which is not causing destructive changes in hearing organ. For the standard frequency \( f_c = 1 \) kHz it is reached by means of the law of Weber – Fechner (1) who for established \( p_{II} = 0.135 \) Pa gives value \( L_{II} = 7.7 \) B (or 77 dB).

This sound pressure level (for standard frequency) is the maximum (reference point of sound pressure level in biophysics of a hearing).

The offered concept allows, having transformed (8), receive dependence for definition of an person exposure in a sound field with a maximum permissible dose of sound effects \( D_{II} = D(L_c) = 0.147 \) Pa².h.

\[
\tau(L) = \frac{D_{II}}{p(L)^2}.
\]
Figure 4. Results of calculation: a – for comfortable levels of sound effects $L < 80$ dB; b – for tolerable levels $80 < L < 110$ dB; c – for destructive levels $L > 110$ dB.

Using the same relation can be solved and the inverse problem of determining the sound pressure is supported by a person in a sound field with a maximum permissible dose $D_{\Pi}$ depending on the duration of impact $\tau$ (Fig. 4)

$$p(\tau) = \sqrt{\frac{D_{\Pi}}{\tau}}.$$ (14)

Application of the law of Weber - Fechner and ratio (8) gives the decision of a psychophysical problem of definition of pressure level $L(\tau)$ as function of an person exposure $\tau$ in a sound field with the set maximum permissible dose of sound effects $D_{\Pi}$

$$L(\tau) = 2 \log \frac{p(\tau)}{p_o}.$$ (15)

On Fig. 5 are ratio (14) and (15) given in 3D-presentation as function of two variable -the maximum dose $D_{\Pi}$ and exposure $\tau$, in form

$$(\tau, D_{\Pi}) = \sqrt{\frac{D_{\Pi}}{\tau}},$$ (16)

$$L(\tau, D_{\Pi}) = 2 \log \frac{p(\tau, D_{\Pi})}{p_o}.$$ (17)

On Fig. 5,a except a surface of pressure $p(\tau, D_{\Pi})$ is presented additional $\Omega$-plane: $\Omega = p_{\Pi}$ which separates tolerable pressure ($p(\tau, D_{\Pi}) \leq p_{\Pi}$) from exceeding threshold (with $p(\tau, D_{\Pi}) > p_{\Pi}$), on Fig. 5,b – $\Gamma$-plane: $\Gamma = L_{\Pi}$ which separates tolerant admissible levels of pressure (with $L(\tau, D_{\Pi}) \leq L_{\Pi}$) from exceeding surface (with $L(\tau, D_{\Pi}) > L_{\Pi}$), and on Fig. 5,c – defines the nature of the change of maximum permissible doses $D_{\Pi}$ as function of two variables – $L$ and $\tau$, in the form
Figure 5. Calculation: a – of sound pressure \( p(\tau, D_{II}) \), b – of sound pressure levels \( L(\tau, D_{II}) \), c – of maximum permissible doses \( D_{II}(\tau, L) \), d – of exposure \( \tau(D_{II}, L) \)

\[
D_{II}(\tau, L) = \left( p_o \cdot 10^{\frac{L}{10}} \right)^2 \cdot \tau. \quad (18)
\]

In addition is here shown the \( \theta \)-plane: \( \theta = D_{II} \), – limiting from below admissible sound pressure levels \( L \) and exposure \( \tau \).

Fig. 5,d is given 3D-presentation of exposure \( \tau(D_{II}, L) \) as function of two variables – the maximum dose of sound effects \( D_{II} \) and sound pressure \( p(L) \)

\[
\tau(D_{II}, L) = \frac{D_{II}}{p(L)^{2/3}}. \quad (19)
\]

In addition, here represented by the \( \tau \)-plane: \( \tau = \tau_{II} \), – limiting from below an exposure \( \tau \leq T_p \).

7. Discussion of some results

As a result, we will finish by the analysis of examples of some concrete numerical calculations (Table 3). These results compare them with the existing standard significant differences in the direction to overestimate the standard of all sizes that characterize the sound effect on the frequency 1 kHz: maximum permissible doses (almost in 7 times – 1 Pa\(^2\)h under the standard against 0.147 Pa\(^2\)h under the theory), maximum permissible sound pressure (more than in 2.5 times – 0.356 Pa under the standard against 0.135 Pa under the theory), maximum permissible sound pressure levels of a sound field (almost on 10 dB – 85 dB under the standard against 77 dB under the theory).

But at the same time, we will specify that the comparison of these results to the recommended parameters of the sound effect on the this frequency by the World Health Organization [1], marks a slight increase in the MPL of the sound field by only 1.7 dB (compared to the recommended WHO 75 dB).

The action of many external factors, including high-intensity sounds, by the effect of tectorial membrane on the auditory receptors during the sound conduction in the inner ear, leading to their degradation and to destruction of the hearing organ (Fig. 6). Noise protection will preserve human health and improve quality of life on Earth.
Figure 6. The degradation of auditory receptors and destruction of the hearing organ. Photomicrographs of properly functioning hair cells – the inner (a) and outer (b), degrading the outer hair cells (c), almost destroyed the outer series (d) the outer hair cells (on: [5]).

Table 3
Calculation of sound parameters (on theory)

| Sound pressure | Sound pressure level | Number of raised OHC | Duration of stay in sound field | Notes |
|----------------|----------------------|----------------------|--------------------------------|-------|
| p, Pa          | L, dB                | n                    | τ,                             |       |
| p < 0.0063     | L < 50               | n ≤ 6                | Unlimited time                 | Comfortable conditions |
| 0.0063 < p < 0.1354 | 50 < L < 77         | 6 < n ≤ 8            | 8 h                            | Tolerant conditions |
| 0.1354 < p < 8.8322 | 77 < L < 113        | 9 < n ≤ 11           | 6.770 s                        | Tolerant conditions with protection |
| 8.8322 < p < 595.838 | 113 < L < 150      | 12 < n ≤ 15          | 1.488 ms                       | Destroying effect of a sound |
| 595.838 < p    | 150 < L              | 15 ≤ n               | 3.347 ns                       |       |

Thus, using the presented concept establishing physiological, bio- and psychophysical approaches to the mechanisms of the perception of sound energy (of sound pressure, sound intensity), the scientific bases of sound dosimetry are developed. They provide a theoretical basis for the establishment for standard frequency 1 kHz of maximum permissible doses of sound effects, maximum permissible sound pressure, maximum permissible sound pressure levels and limiting human exposure to the sound field.

References
[1] Hygienic criteria of a state of environment. 12. Noise. The world organization of public health services, Geneva, 1983
[2] GOST RF 12.1.036-1981. Noise. Admissible levels in inhabited and public buildings. Moscow: Gosstandart of Russia: Standards Publishing House, 2001
[3] Fernandez C. The innervation of the cochlea (guinea pig.). Laryngoscope, 1951, 61, 1152-1172
[4] Lim D.J. Fine morphology of the tectorial membranes: Its relationship to the organ of Corti. Arch. Otol., 1972, 96, 199-215.
[5] Pickles J.O. Neuroscience, 1992, 15, 254-258.
[6] Hallowell D., Silvermann S.R. Hearing and deafness, 3rd ed., 1970.
[7] Patent RF №2184485, A61B5/12, 2002.
[8] Patent RF №2248752, A61B5/12, 2005.