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Microwave Evaluation of Electromagnetic Compatibility of Dielectric Remedial and Therapeutic Materials with Human Body

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Abstract: Inherent attribute of the materials using in medicine and biology is microwave range electromagnetic radiation (EMR). The methods of the identification and determination of the compatibility of indicated materials are considered in the paper. The man-made and natural sources of the microwave radiation are described. Examples of the microwave signals using in practical medicine technologies are given. The parameters of microwave signals that can be used to identify biomedical materials are determined. The features of the studied positive and negative electromagnetic radiation streams and possibilities for their use for therapy and identification of biomaterials are described. The results of experimental investigation of the EMR of dental materials are presented. Electromagnetic properties of the dental materials and natural teeth tissues were compared. The recommendations for possible use of the biomaterials electromagnetic identification methods are given. The features of the materials for the physiotherapy were studied experimentally. It was stated that physiotherapeutic materials in determined regimen of the therapy, beside the thermal action, form microwaves streams that could be positive or negative. The level of the microwave component and corresponding physiotherapeutic procedure effectiveness may be regulated by the combination of the physiotherapeutic materials.

Keywords: Biomaterial, Electromagnetic Radiation, Compatibility, Identification

1. Introduction

Technogenic electromagnetic loading of the environment is constantly increasing nowadays. New radiating devices and systems are being put into operation, operating frequency ranges are expanding, mobile communication zones and power generating devices are increasing.

The microwave range includes decimeter, centimeter and millimeter waves of frequency from 300 MHz to 300 GHz.

The introduction of new 3G, 4G, and even 5G mobile systems involves the use of a range of high and ultrahigh frequencies from 3 GHz and can reach tens of GHz, which greatly increases the electromagnetic background of the environment.

It should be noted that the ultrahigh frequency range (3-30 GHz) has a significant effect on the biological structures of the human body and is therefore used in physiotherapy. The range of mm waves with frequencies of 30…300 GHz is used to a lesser extent. The main types of mm range therapy are microwave resonance therapy, information-wave therapy, mm-therapy [1, 2]. The peculiarity of microwave range therapy is the use of equipment of low intensity monochromatic signals at level ($10^{-10}…10^{-12}$) W and 1 ($10^{-18}…10^{-20}$) W/Hz for noise signals devices [1, 3]. Such levels of power are comparable or not much larger than the own radiation of the human body, whose integral power is within $10^{-13}… 10^{-14}$ W. The reaction of the organism to such a level of low intensity signals is confirmed by laboratory tests to improve the parameters of the immune system of patients [1, 2].

At the same time, beside the man-made sources of electromagnetic radiation (EMR), there are natural sources that also contribute to the electromagnetic background of the environment and affect the human body. Such sources include heated, for example, under the influence of solar radiation, dielectric bodies and liquids - the surrounding soil, sand, various minerals and stones, vegetation, water surface, etc. [3, 4]. The dielectric materials also include internal bones of the human body, liquid fractions of blood and plasma, as well as orthopedic and dental implants, among them created by technologies of bioengineering and nanomedicine also.

At the last time combined implants, which have metal core (scaffold) and dielectric external cover, with use of nanomaterials, too, for medical use. Implants of such type under the temperature action form own electromagnetic irradiation and create long-term influence on the surrounding biological structures, it's necessary to consider this affect [5]. We should receive prognosed result if we should consider this effect.

Therefore, the study of the interaction of low-intensity microwave fields and radiation with the human body, including materials for biomedical applications is an urgent task for specialists of different fields - biologists, physicians, physicists, developers of radio engineering devices and apparature industry.

2. Main Body

It is known that under the influence of temperature a thermal radiation of heated physical bodies arises. Heat noises are related to the atomic structure of matter and the discrete nature of electric current. The power spectrum of thermal noise is sufficiently long, and its upper bound lies in the frequency range $10^{13}...10^{14}$ Hz, fully covering the mm-range of waves.

The maximum of the heated bodies radiation is at the infrared range. In the microwave range, the distribution of the radiation power density of any object (body) is determined by the law of Rayleigh-Jeans:

$$G(f,T)=\beta\frac{2\pi\cdot f^2}{c^2}kT \tag{1}$$

where G – spectral density of the radiation power (SDRP) at frequency f ; β – coefficient of radiating ability (grayness) of the body; c – the rate of EMR propagation in a vacuum; k –Boltzmann constant; T – thermodynamic temperature of the body.

SDRP is measured in W/Hz. To get the integral power value (W) the band of the analysis Δf is introduced in the formula (1), which for high sensitive radiometric system was used in the experimental studies, is Δf =10^8 Hz.

Coefficient of radiating ability depends on the surface (configuration) of the body and its composition and for a absolutely black body (ABB) is equal to one. For a particular research object (material), it can be determined by the formula:

$$\beta=\frac{G_1}{G_2} \tag{2}$$

where G_1 – the density of the material irradiation power, and G_2 – the density of the absolutely black body on the same frequency.

Spectral density of the power of the natural background in the range of mm waves is about 10^{-19} W/m^2·Hz, and spectrum of the natural solar irradiation is determined by the bandwidth of absorption of molecular oxygen at wavelengths 5 and 2,5mm and water vapor at 1.71 mm, 0,9 mm and 0,77 mm [1, 3].

To measure such small powers, a high-sensitivity microwave devices are required. The issues of increasing the sensitivity of such equipment are considered by the authors. [6]. In the National Technical University of Ukraine "Igor Sikorsky Kyiv Politechnical Institute" the «Scientific and educational laboratory of microwave radiometry and UHF measurements» was established. On the basis of this Laboratory the measuring radiometric system (MRS) was developed on the range of the operating frequencies 37…53 GHz, which has the following technical features, which are confirmed by the metrological certification of the State Standard of Ukraine [1, 3]:

1. range of measured integrated power, $0,3\cdot10^{-13}…3\cdot10^{-6}$ W;
2. threshold of sensitivity, no more $3\cdot10^{-14}$ W;
3. analyzed frequencies band, no more than, 100MHz.

With the developed radiometric system, measurements and studies of low-intensity electromagnetic fields and radiation of different objects, including biomedical materials were performed [9, 10].

2.1. Registration of the Positive and Negative EMR Streams at the Microwave Range

In the range of optical signals, the distribution of positive and negative (reverse) streams has been described by the author [7]. Using the developed radiometric system of the microwave range, the authors [3, 4] recorded similar streams in the microwave range.

Positive EMR stream in relation to the selected object of irradiation (material) with temperature T1 is formed if the temperature of the irradiating signal T2 is T1, and is negative, in the case of T2 < T1. In the first case, the EMR is absorbed by the object or the material, and in the second case, the EMR is directed from the object and is absorbed by an irradiating source with a low temperature of irradiation. The generator of the negative (reverse) streams on the Peltier elements was designed by the authors. Such a generator provides the formation of a noise signal over a wide range of frequencies, which is limited to the geometrical dimensions of the waveguide (critical waveguide frequency).

The spectral density of the power of the noise signal of the designed generator, at a possible temperature of the element of the Peltier, was in the range of $10^{-21}...10^{-22}$ W/Hz in the frequency range 37…78 Hz. At the expense of the reverse of the input current, the generator also provides the formation of positive flow signals. Appearance of the generator is presented in Figure 1, on the structural scheme of which the authors received a patent.

The generator was used for experimental studies of interaction of negatim streams with biological objects and different substances, so as medical studies of EMR influence on the human organism and for new treatment technologies.

As a contact type antenna, dielectric material is used to provide filtering of infrared radiation, isolation of the microwave component and high-level harmonization with the biological tissue. Serials of the experimental studies using the designed generator were carried out by the authors, in part, the reaction of the human body (palm) to the positive and negative EMR streams was assessed [3].

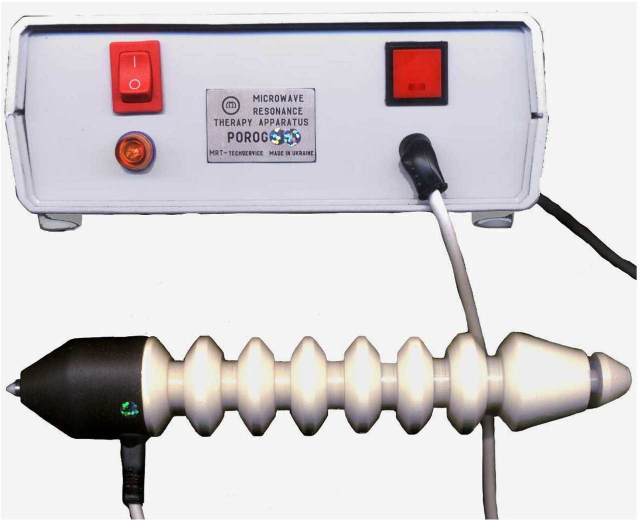

Figure 1. *Appearance of the generator of negative streams.*

The results of the palm absorption ability measurement of the absorption coefficient K_p from the radiation level G_1, are shown in the Figure 2.

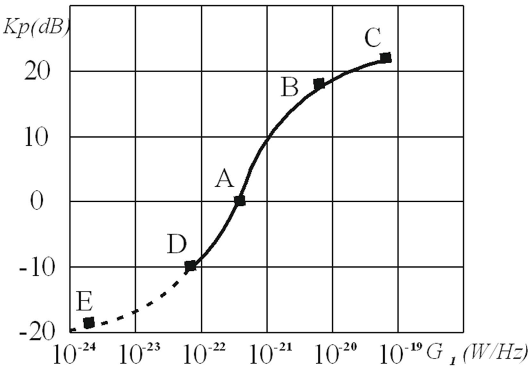

Figure 2. *Distribution of the human palm absorbance ability in contact with the positive and negative EMR streams.*

Increasing the power of the irradiating signal in relation to the level of own radiation within the limits of $10^{-21} < G_1 < 10^{-19}$ at resonant frequencies, leads to the complete absorption of the signal (area AB in the Figure 2).

Further increasing of the irradiating power $G_1 > \cdot 10^{-20}$ W/Hz leads to the reflection of the signal (area BC in the Figure 2), which is characterization of the effect of the saturation of this field of the skin. The absorption is distributed in the same way in the case of irradiating by EMR negative streams at the area AD. Distribution within the DE curve is predictive due to the difficulties of negative high-intensity streams forming; it may be refined experimentally with time.

Note that the steepness of the growth of the reflected power exceeds the steepness of the irradiation power increasing; this results in saturation with distortion of the characteristics in the BC area. Based on the experimental data [3] and the distribution shown in Figure 2, we can conclude that the dynamic range of absorption capacity of a bioobject at the levels that exceed the level of own radiation, is 15…20 dB. Therefore, even such small levels of microwave radiation can cause a positive or negative effect on the human body, as evidenced by experimental studies.

Experimental testing of the influence of positive and negative streams of low-intensity electromagnetic fields, was carried out in the laboratory of the R. E. Kavetsky Institute of Radiology and Oncology (National Academy of Sciences of Ukraine, Kyiv). Experimental animals (30 mice), divided onto three groups, were grafted with 1 million of the tumorous cells in the saline solution (0,2 ml per animal). Than animals of the first group (n=10) were irradiated with positive streams, animals of the second group (n=10) – with negative streams, and the third group (n=10) was control. In laboratory conditions, the inhibition (by 27,4%) of the development of sarcomas C-37 was noted in experimental animals when exposed to irradiation by negative streams, positive streams accelerated (by 13,5%) tumor growth. The technology of research and the results of these experiments, are described in detail by the patent [8].

2.2. Microwave Electromagnetic Identification of the Dental Materials

Experimental studies of the irradiative abilities and identification of the dental materials were conducted by the authors [9-11]. In fact, this procedure is equivalent to the electromagnetic compatibility of dental materials with natural tissues of tooth evaluation. The significant difference in radiating abilities of materials and natural tissues may lead to the appearance of non-comfort condition. When such different material is in contact with soft tissues, pain syndromes and even local inflammation may appear, due to the difference between the permanent positive or negative streams of the EMR.

The following dental materials were examined [12].

Material based on the resorcin–formalin mixture “Foredent” (SPOFA, Slovakia) was the Sample №1. Its positive property - high antimicrobial properties, but a number of shortcomings - cytotoxic, not sufficiently adhesive, stains tooth hard tissues and even surrounding soft tissues - have led in many countries to its rejection of practical use.

Glass-ionomer cement “Endion” (VOCO, Germany), which consists of fine fluoroalumosilicate glass and polycarboxylic acid, was the Sample №2. It chemically connects with dentine and ensure reliable tightness of the root canal, but under action of mechanical loads it wrecks. It’s difficult to remove it from the root canal if retreatment is necessary. This explain its unpopularity for the clinic applications.

Zinc oxide-eugenol material "Endomethazone" (Septodont, France) was the Sample №3. Due to eugenol it has an antiseptic effect, but the presence of a certain amount of free eugenol could cause an inflammatory tissue reaction. Steroid preparations, which are introduced in the material to reduce possible undesirable reactions, could cause general unexpected effects. More, it has enough strong odor and could affect polymerization of composites.

Polymeric cement “AH Plus” (Dentsply, USA) – epoxy-amine polymer, was the Sample №4. A very plastic material of uniform consistency, curing by polyaddition reaction after mixing two pastes, forms a thin film, but, unfortunately, gives a fairly large curing shrinkage. It has some cytotoxicity during the curing process, which can cause an inflammatory response, but the hardened material is tolerant to surrounding tissues, and reactive inflammation quickly passes.

Light-cured composite “Spectrum” (Dentsply, USA) (shade A3.5) was the Sample №5. It’s a light curing universal hybrid composite with an ultra-fine particles size for the restorations of the frontal teeth and molars. Barium glass and sintered silicon with an average particle size of 0.8 microns are used as fillers. It has excellent mechanical and aesthetic properties.

Self-curing composite “Compolux” (Septodont, France) based on Bis-GMA resin, was the Sample №6. It fills (63%) with a particles size of up to 20 microns. It’s quite mechanically stable and slightly aesthetic.

Glass–ionomer cement “Cavitan–plus” (SPOFA, Slovakia) was the Sample №7. It has remarkable property - to excrete fluorine, which is the basis of anti-caries action, in addition to the ability to form a chemical bond with hard tooth tissues. This cement is used for linings, temporary (long-term) and permanent fillings in permanent and decidual teeth.

A piece of the human tooth enamel was the Sample №8. Enamel is the hardest tissue of the human body. It consists of the 95-98% of the mineral substances, 1-2% of the water and 1-2% of the organic compounds (exact quantity may change depending on age and state of the enamel).

A piece of the human tooth dentine was the Sample №9. The biochemical composition of the dentine is characterized with higher amount, comparing with enamel, of the water and organic substances (till 30%). From the other physical properties, it’s more elastic (comparing with enamel).

A piece of spongy bone section was the Sample №10. Spongy bone is the tissue that surrounds teeth, ligamentous apparatus of the tooth is connected to the spongy bone. It must be enough hard to hold tooth in it position and enough elastic to redistribute chewing loading. Mineral substances of the spongy bone are in the range of the 67% (more than half of them are compounds of the calcium), and organic – about 33%, the most of them are collagenic fibers.

Patterns with a square of 0.5 mm^2 and a thickness of 1 mm, with the possibility of overlapping the cross section of a standard waveguide in the frequency range of 37…78 GHz, were prepared from these materials. In the course of the experiment, the radiation intensity of each material was checked at a temperature of 37°C, the level of which was recorded by a measuring unit NU-2 with a sensitivity of 10^{-14} W at a frequency of 52 GHz. According to our measurements, the integral radiation power of the considered range of dental materials was concentrated in the range (1,8…3,.1) 10^{-13} W / cm^2. Taking into account formulas (1, 2), the grayness coefficient (factor β) of the material was calculated. The results are presented in the nomogram (Figure 3).

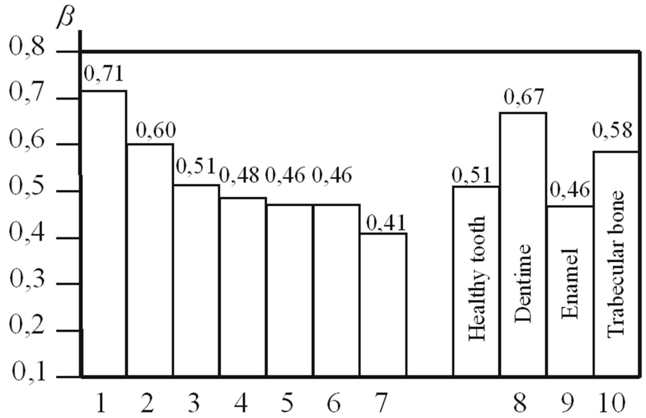

Figure 3. *The factor β of dental materials samples №№ 1…10.*

Samples №1, 2, 5 and 7 are used to fill the root canals of the teeth, therefore, the properties under study should be compared with the similar properties of dentin (№ 8) with which they come in contact. Samples of materials №3, 4, 6 are used to seal the tooth surface; therefore, their properties should be compared with the properties of tooth enamel (№9).

So, the identification of the grayness coefficient (factor β) deviates to 38,0% when compare pairs of materials №№ 7, 8, and 4, 3 in pair №№ 1 and 9, which used for root canals sealing, and from 0% in pair № №6 and 8 to 10,8% in pair №№ 3 and 8 – materials, that are used to restore tooth surfaces.

We think, that preference should be given to materials with the greatest coincidence of the grayness coefficient withnatural tooth tissues. The method of microwave electromagnetic identification (compatibility assessment) of dental materials is also promising for use in the development of new dental materials.

2.3. Investigation of the Radiation Ability of Materials for Physiotherapy

Experimental studies of the radiation ability of some materials for physiotherapy: mixtures of ozocerite; curative mud with admixtures of paraffin, pure paraffin, pure mud, wood, warm-blooded animal bone, so as human were carried out by the authors. As a result of measurements at the frequency $f = 45 ГГц$, the values of the integrated power and grayness coefficients of the irradiation samples were obtained, which are presented in Table 1.

Table 1. *EMR properties of the natural mixed materials.*

Studied sample	The value of power (W/cm^2)	Gray coefficient β
Ozokerite (pure)	1,8*10^{-13}	0,1
Themud (pure)	1,6*10^{-13}	0,08
Paraffin (pure)	1,05*10^{-14}	0,05
Paraffin+ mud (mix)	0,5*10^{-13}	0,02
Wood	6*10^{-13}	0,3
Salt	2,2*10^{-13}	0,11
Palm (t_r=31°C)	4*10^{-13}	0,21
Bone	6,8*10^{-13}	0,35

Ozocerite has a high heat capacity and low thermal conductivity with a possible temperature for use in thermal applications 40-50°C. It includes paraffin, ceresin, as well as in the composition of therapeutic mud - biologically active substances [13]. The radiations of a piece of wood (ash) and a fragment of bone were also examined for comparison. The measuring process of the radiation power values was carried out using a certified radiometric system with sensitivity, which allows us to speak with confidence about the accuracy and reliability of the results.

Table 1 shows that the radiation level of the areas of the palm of the person, even at a temperature (31°C), significantly lower than the temperature of the heated material (40°C), is greater in 2 times compared to pure wax and in 4 times in relation to the therapeutic mix of mud and paraffin.

Analysis of the results shows that along with warming ozocerite and mud applications (creation of positive streams) a microwave component creates "negative stream" in relation to the patient's body that can reduce pain syndromes with excess temperature.

Paraffin, which added to the ozocerite and mud in the preparation of therapeutic mixture to stabilize it, reduces the emissivity of the mixture in the microwave range, the value of which depends on the percentage of components

This ratio can adjust the "negative" stream, adding to the mixture a higher percentage of paraffin, and therefore the effectiveness of pain syndromes treatment increases. The same ability has salt and solutions based on it (salt applications, baths, etc.), in opposite to wood and bone that have a higher level of radiation than the human body and form towards it EMR positive streams.

The dynamics of change the material proper EMR when it cooled from the maximum heating temperature used during the procedure (50°C) to body temperature (controlled palm point) was also investigated. The graph showing the integrated power change is presented in Figure 4. The level of the human body emission for the temperature control points 31°C, 40°C and 50°C was calculated using the Nyquist formula

$$P = kT\Delta f \tag{3}$$

where $\Delta f = 10^8$ Hz - analysis band of highly sensitive radiometric system.

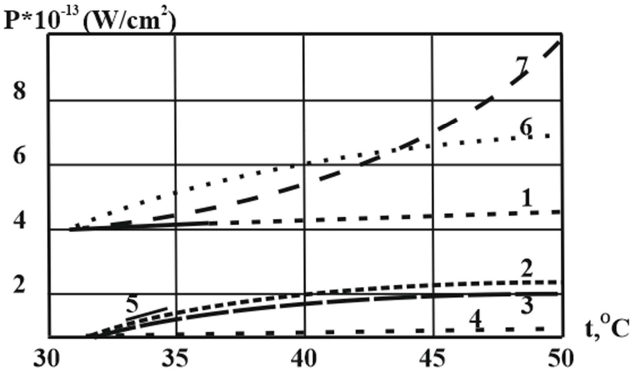

Figure 4. *The graph of the integrated power changes: 1 - human body; 2 - ozocerite mix; 3 - mud with added paraffine; 4 - paraffine; 5 - mud (pure); 6 - wood; 7- bone.*

For point 31°C the calculated value is 4.18 10^{-13} W/cm^2, which is different from the measured less than for 5 percent, which is suitable for microwave measurements and verifies measurements certainty well. The human body radiation levels were calculated for temperature 40°C and 50°C similarly.

From the studies of the EMR of medical materials using for physio procedures the following conclusions may be done:

1. effective use of natural materials in the thermal physiotherapy should be associated not only with the presence of infrared components, but, as studies have shown, with the presence of microwave component, which has a significant impact on treatment outcome;
2. microwave EMR of the studied therapeutic materials has negative stream in relation to the human body, which creates the effect of "selection" of energy at local inflammatory processes;
3. using a material with low radiating ability (paraffin) mixed with the main component (ozocerite or mud) can not only stabilize the therapeutic mix, but also adjust the power of the negative stream.

It should be noted also that human bones have higher levels of microwave radiation component, compared with soft tissues; they are like a kind of microwave generators that stimulate the cells of our body.

2.4. Comparative Experimental Studies of Some Physical Objects

For experimental research, a number of physical objects, including the mineral, were selected. The logic of choice was determined as follows: animal bone, as an analogue of human bone, salt as one of the most commonly used products, shell as a source of calcium, nephrite, which, according to previous studies, is characterized by high levels of radiation and ferroepoxide, a material widely used in microwave as an absorber - load (analogue of an absolutely black body for the microwave frequency range).

The research was carried out at the value of the ambient temperature and, accordingly, the temperature of the high-sensitivity radiometric measuring unit was 16°C. Under such conditions, the radiometric measuring system and objects of the study are in the thermodynamic equilibrium, the EMF system is not fixed, and the indicator is set on the zero.

Samples of minerals were small but of the same size (about 1 cm^2). They were placed in a micro-refrigerator (TEM), which consistently cooled them to temperatures -8°C, 0°C, 8°C, receiving a negative stream of radiation power relatively to the measuring system. Then, by switching the mode of operation of the TEM from cooling to the heating, the study of the radiation ability of materials in the temperature range (16…64)°C was conducted. The results of the measurement of the power stream are shown in Figure 5.

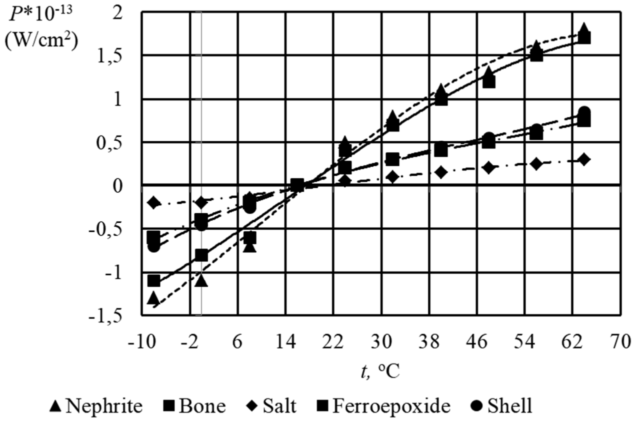

Figure 5. *Graph of the distribution of the EMR power stream of minerals from temperature.*

Figure 5 shows that the highest level of radiation has nephrite and bone, while the range of negative streams significantly expanding. Salt is characterized by the lowest level of radiation and if it enters a living organism in large quantities, it may affect the redistribution of EMR. The resulting dependencies can also be used to select material when thermal generators are constructing.

The authors also measured and evaluated the radiation ability of specialized dielectric materials. The samples of the materials were heated to a temperature 38°C and at this temperature, the EMR of the heated materials were measured at the frequency of 53 GHz.

The scheme for the measurement of the proper radiation of dielectric materials included a thermostat with a heating element, a horn reception antenna and a high-sensitivity $(1 \cdot 10^{-14} W)$ *measuring system of modulation type [3]. After exposure at a set temperature for 30-40 minutes, measurements of the EMR power of the studied samples of ceramic materials were performed.*

The results of the measurement of the power of the EMR of heated samples showed that the greatest radiation had sital ceramics, its values were in the range (3.6-4.3) 10^{-13} *W. Zinc ceramics have lower values of radiation, its values are in the range (2.2 - 3.3)* 10^{-13} *W [14].*

Measurements of these materials were also carried out in defective places, in cracks and faults. Measurements of these materials were also carried out in defective places, in cracks and faults. The obtained results have shown that the value of the power EMR of materials on the practically does not depend on defects of small sizes on materials at a given frequency of measurements.

3. General Conclusions and Prospects of Use

In the course of radiometric studies of biomaterials, a number of features related to the human body and the properties of certain materials have been identified:

1. own radiation of the human body G lay at the range of $1*10^{-21} \ldots 1*10^{-22}$ W/Hz см^2;
2. the level of radiation of individual organism is constant value; it determined by the intensity of the metabolism of its cells and the temperature of the area of the skin. In fact, this level characterizes the "electromagnetic homeostasis" of a living organism, which is disturbed by illnesses, stress states, which can be used as a diagnostic signs;
3. the correlation coefficient between the radiation level and the temperature of this body area is within the range 0,85…0,87;
4. experimentally registered sensitivity of the human body to external EMR is $\sim 1 \cdot 10^{-20}$ W/Hz. Approximately the same level of radiation has an absinthe cigarette (moxa) used in Chinese acupuncture medicine;
5. the level of radiation of bone tissue (bones, teeth) is greater than that of soft tissues at the same temperature, and, in essence, the bones are natural microwave oscillators that irradiate the surrounding living cells of living tissues;
6. checking the interaction of various bone and dental implants, clothing items, accessoiries, and others. materials with the human body showed that the most compatible are physical bodies with radiation close to human radiation.

The proposed new method of microwave electromagnetic radiometric study and identification of biomaterials is promising, allows us to detect electromagnetic compatibility of materials with the human body and can be used in practical medicine in the design and application of dielectric implants of various sizes, even in nanomedicine.

The application of microwave diagnostics of solid and soft tissues and planned for incorporation biomaterials (implants) will open up new possibilities for increasing the efficiency of surgical and orthopedic treatment. It's important particularly in dentistry for dental rows defects restorations. Significant issue to make a decision on conducting these operations is evaluation of the general physical condition (at the level of the organism) and local status (at the level of tissues). Taking into account radiation levels, it will be possible to make appropriate correction with positive or negative electromagnetic radiation streams and thus create conditions for effective interventions. A similar correction, both local and general, can be carried out in case of detection of deviations from the normal course of postoperative regenerative processes in monitoring the levels of electromagnetic radiation, provided that there are devices of appropriate sensitivity. It will also be possible to increase the effectiveness of interventions by determining the compatibility of medicines used in these interventions, both local and general. Determination of the level of electromagnetic radiation will help to find the optimal type of physiotherapeutic treatment, therapeutic dose and the number of procedures.

The study of the irradiative abilities of the different materials and biological objects requires very special equipment. The main property of such equipment must be high sensitivity, because measured values are in the ‘pico’ range – about 10^{-12} – 10^{-14} W, that is difficult, but reachable technical task.

This promising method requires further research and technical solutions for practical application.

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