Second International Conference on Radiation and Dosimetry in Various Fields of Research

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EXPERIMENTAL ELECTROMAGNET FOR IN VIVO EXPOSURE OF SMALL ANIMALS TO ELF ELECTROMAGNETIC FIELDS

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Abstract. The ubiquitous presence of electromagnetic (EM) fields in living environment motivates investigation of their influence on biological systems. Existing research data shows a high degree of inconsistency, covers very limited regions of electromagnetic spectrum and in many cases lacks detailed and accurate description of the electromagnetic fields necessary for the replication of experiments. Exposure systems, designed specifically for biomedical research, offer the solution to the above problems. We present experimental electromagnet for in vivo small animal research. It covers both static magnetic field and extra-low-frequency (ELF) electromagnetic field range, offering higher EM field intensities than those produced by most other systems.

Key words: electromagnetic (EM) fields, static magnetic field (SMF), biological effects, exposure system, in vivo, small animal research

1. INTRODUCTION

Exposure systems, such as the ones described in [1]–[6], are specialized devices aimed at producing, controlling and monitoring electromagnetic fields for biomedical research. It is a prerequisite for an experiment to be well-designed and for the consistent interpretation of results that the desired fields are accurately adjusted and precisely known. Systems for the in vitro research, mostly due to the smaller volume involved, but also because of the relatively static experimental conditions, can be realized with greater precision. Also, most of the systems are intended for a narrow range of EM fields, often for a single frequency and lower field levels. With the notable increase of the variety of small commercial devices being produced and rapid extension of the utilized frequency ranges to the previously unused parts of the electromagnetic spectrum, it becomes increasingly important to systematically investigate the biomedical effects of various EM fields.

We have so far investigated the effects on mice of the two types of static magnetic fields (SMF): inhomogeneous, vertically declining SMF, whose mean magnetic flux density equals 1 mT and its mean gradient equals 0.02 T/m [7], and homogeneous SMF whose magnetic flux density is 128 mT [8]. Results show influence of both considered field types to the circulatory system in mice [9]–[11]. In continuation of our previous work we are interested in further analysis of SMFs of intensity 100 mT and more. Additionally, we plan to extend our research to other EM fields, starting with the extra-low frequency (ELF) range already shown to produce certain biological effects.

In order to employ it in our experiments as well as evaluate the prototype of a product that could be made commercially available, we are currently constructing the exposure system to cover both SMFs and the ELF field range. The most straightforward solution to obtain the required relatively strong field intensities is to use the solenoidal fields, either by placement of experimental animals within a solenoid or by usage of combined solenoidal fields with or without the ferromagnetic core. For the device functioning in the direct-current (DC) regime, DC current generator is to be used. Alternating-current (AC) current source will enable the production of sinusoidal electromagnetic fields. The device will be tested for as wide part of the ELF range, as possible to achieve. Frequency range of 0 Hz to 100 Hz is chosen as an initial requirement.

2. EXPERIMENTAL ELECTROMAGNET REQUIREMENTS AND INITIAL COIL DESIGN

Design requirements for an experimental EM field exposure system can be divided in several subgroups. Among the most important factors are the ones dictated by the user community, including compliance with the usual conditions and practices of a biomedical experiment as well as the ease of utilization. Therefore, experimental electromagnet is devised as a flexible device providing EM fields of different magnitudes, gradients, directions and frequencies. The constituent parts of this device belong to one of the five subgroups: copper wire coils, ferromagnetic (iron) cores, direct
and alternating current generators, calibration and measurement equipment and accessory equipment. Accessory equipment has to be specific and very carefully designed in order to enable flexible and modular use of the device. For example, biomedical experiment regulations and the recommendations for the result interpretation allow comparisons of different parameter influences only if all the data is acquired simultaneously as a result of a single experiment. Two copper wire coils are required if the effects of different static magnetic field directions, such as the same or opposite orientation with respect to the Earth’s geomagnetic field, are to be compared. Otherwise, the accessory equipment has to ensure position and power supply adjustment for the two coils, in order to combine their EM fields for increased strength and homogeneity. For the higher EM field magnitudes, ferromagnetic cores have to be used as well. Calibration and measurement equipment includes the ambient EM field measurement panel as well as the equipment for monitoring other physical quantities, such as ambient temperature and temperature inside the experimental volume.

![Fig. 1 Copper coils of the experimental electromagnet for in vivo exposure to ELF EM fields. To obtain the required relatively strong field intensities above 100 mT, coil size must enable placement of one or several cages inside the solenoid.](image)

### 2.1. Minimal Size Requirements

For the *in vivo* experiments involving small animals such as mice, care has to be taken of usual routines and rules for their accommodation and treatment. A layer of sawdust is used for padding the cages for mice as this would resemble their natural habitat; animals are fed and watered in the cages. It is most convenient to enable placement of the whole cages occupied by animals within the experimental volume, without disturbing the animals. Not only that it facilitates organization of chronic and sub-chronic experiments; such practice is equally important for the short-term acute exposures to avoid stress as a factor interfering with the actual investigations.

Standard small cages or standard large cages are typically used. Width and length of the small standard cage are 165 mm and 260 mm, respectively, and its height equals 150 mm. Large standard cage is 260 mm wide, 420 mm long, and its height equals 185 mm. This imposes the inner copper coil diameter larger than 500 mm in order to enable its vertical placement as shown in part (b) of Fig. 1. Therefore, the coil stand will support its placement as in Fig. 1(a), in order to study the influence of horizontally directed fields that penetrate animal’s body in all different directions as an animal moves inside the cage, or as shown in Fig. 1 (b) to provide vertical field direction. The cage centered inside the coil results in the higher uniformity of the applied field distribution, whereas to study gradient fields the cage positioning toward the edges or just outside the coil would be appropriate. For the vertical placement of the coil, it can accommodate more than one cage including the combination of large and small cages.

For the preliminary analysis of power requirements and EM field levels that could be produced, we investigate the case where the coil length equals its inner diameter, \( l = 2R' = 500 \text{ mm} \). To keep coil price and weight reasonable, its thickness is initially chosen equal to \( R'' - R' = 150 \text{ mm} \). Coil cross-section is shown in part (a) of Fig. 2.

### 2.2. Limiting Magnetomotive Force

From the user point of view, the need for any specialized power installations can be complicated, expensive and time consuming. Therefore, one of the main requirements for the designed device is to utilize the regular power network. Having in mind maximal wire current density not requiring water-cooling of \( J_m = 3 \text{ A/mm}^2 \), as well as total maximum current of \( I_m = 25 \text{ A} \), we determine the optimal wire diameter of \( d = 3 \text{ mm} \). This choice is illustrated by the data presented in Table 1. Wire diameter \( d \) corresponds to the wire cross-section \( S_w \) and the number of coils in the given coil cross-section \( N \).

\[
N = \frac{S_{\text{coil}}}{S_w} = \frac{l(R'' - R')}{S_w}. \tag{1}
\]

The total length of the wire used, \( l_w \), and its resistivity, \( R \), with the copper conductivity \( \sigma_{\text{Cu}} = 58 \text{ MS/m} \), can be assessed as
\[ l_w = \frac{2\pi}{2} \frac{R^* + R''}{N}, \quad R = \frac{1}{\sigma_{Cu} S_w} \cdot \quad (2) \]

Table 1 Magnetomotive force \( NI \) and coil resistivity \( R \)

<table>
<thead>
<tr>
<th>( d ) (mm)</th>
<th>( S_w ) (mm(^2))</th>
<th>( J ) (A/mm(^2))</th>
<th>( I ) (A)</th>
<th>( N )</th>
<th>( R ) (( \Omega ))</th>
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<tr>
<td>1</td>
<td>0.785</td>
<td>3.00</td>
<td>2.36</td>
<td>95493</td>
<td>4280.7</td>
</tr>
<tr>
<td>2</td>
<td>3.141</td>
<td>3.00</td>
<td>9.42</td>
<td>23873</td>
<td>267.5</td>
</tr>
<tr>
<td>3</td>
<td>7.068</td>
<td>3.00</td>
<td>21.21</td>
<td>10610</td>
<td>52.8</td>
</tr>
<tr>
<td>4</td>
<td>12.566</td>
<td>1.99</td>
<td>25.00</td>
<td>5968</td>
<td>16.7</td>
</tr>
<tr>
<td>5</td>
<td>19.635</td>
<td>1.27</td>
<td>25.00</td>
<td>3820</td>
<td>6.8</td>
</tr>
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Critical parameter here is the active power that should not exceed 5.5 kW in the monophase regime, under the condition of inductivity compensation for an AC current operation. If the regular power network is to be used, it will be necessary to decrease the current density, resulting in the maximal produced magnetic flux density of 150 mT. This is in agreement with the desired initial design requirements. The following analysis is given for several values of the current density and illustrates field levels that could be produced by the considered coil.

Fig. 2 Copper coil and the produced magnetic flux density.
(a) Coil cross-section and the coordinate system used.
(b) Calculated three-dimensional magnetic flux density inside and surrounding the coil.

3. MEAN ELECTROMAGNETIC FIELD PARAMETERS

The described copper coil is modeled using the commercially available Mermaid finite element suite for magnetostatics. Calculated magnetic flux density distribution inside and surrounding the coil, whose cross-section is shown in Fig. 2 (a), is presented in part (b) of Fig. 2. As seen from the figure, nonuniformity of the magnetic flux density distribution is less than 8% in the central part of a solenoid, for \( r<125 \) mm and \( z \in [18, 32] \) mm. Further modeling and optimization of this initial model is due, to additionally improve the field homogeneity in the central part of the device. For the experimenter, it is the mean magnetic flux density over the experimental volume (or the mean maximal magnetic flux density in the experimental volume for the time-varying ELF EM fields) that is of interest. Where applicable, mean \( z \)-axis gradient of the field, defined as \( G_z(z) = -\text{grad}_z B_z(z) \), is another necessary parameter for the field description. Height of the experimental volume most often coincides with the average size of the animal, whereas exposed horizontal range coincides with the size of the cage bottom.

In the case of unavailability of CAE modeling tools such as Mermaid, magnetic flux density and its \( z \)-axis gradient can be approximately assessed using the analytical expressions for the magnetic flux density along the axis of a thick solenoid, \( B_z(z) \).

Fig. 3 Magnetic field produced with different coil currents.
(a) Magnetic flux density at the solenoid axis. (b) The \( z \)-axis gradient of the magnetic flux density along the axis.
Integration, from $z = 0$ to $z = l$, of the magnetic flux density on the axis of many constituent circular loops yields an expression for the magnetic flux density along the axis of a thin solenoid:

$$B_z(z) = \frac{\mu_0 NI}{2l} (\cos \alpha_1 - \cos \alpha_2). \quad (3)$$

Angles $\alpha_1$ and $\alpha_2$ are denoted in Fig. 2 (a) for the inner layer of copper wire (primed) as well as the outermost layer (double primed). Free space permeability equals $\mu_0 = 4\pi \times 10^{-7}$. Further integration, from $r = R'$ to $r = R''$, of the $z$-axis field components due to layers of wire of thickness $dr$, magnetomotive force in each layer being equal to $NIdr / (R'' - R')$, results in magnetic flux density of a thick solenoid,

$$B_z(z) = \frac{\mu_0 NI}{2l(R'' - R')} \left( \tan \left( \frac{\pi}{2} \cdot \frac{4\alpha_1^2}{2} \right) - \tan \left( \frac{\pi}{2} \cdot \frac{4\alpha_2^2}{2} \right) \right). \quad (4)$$

Equation (4) has been used to calculate magnetic fields and their gradients for different coil current densities, given in Fig. 3 as an illustration of the electromagnet capabilities. For the vertical coil placement and usual experimental volume height of 35 mm, nonuniformity of the magnetic flux density with height is less than 0.1% and its gradient nonuniformity less than 0.2%. Using the curves such as ones given in Fig. 3, an appropriate combination of field strength and field gradient for exposure of animals can be chosen. Coils will be further optimized for higher field homogeneity in their central regions as well as stronger field gradients toward ends and outside the coils.

4. CONCLUSIONS

Novel exposure system for biomedical research, experimental electromagnet for both static magnetic field research and extra-low frequency EM field range, is described. Design guidelines and requirements for such system are defined and explained. These requirements mostly stem from the usual experimental routines and recommendations. Special care has to be taken to ensure flexibility and modularity of the device utilization. Initial electromagnet coil design has been carried on, showing that the desired field strength of 150 mT could be easily achieved using the regular power network available everywhere. Further design to improve field homogeneity and provide stronger field gradients is under way.

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NEUTRON DETECTOR FOR THE “GAMMA-400” SPACE OBSERVATORY

V.V. Kadilin, G.L. Dedenko, A.A. Kaplun, A.A. Taraskin, E.M. Tyurin, V.I. Muhin
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Abstract. This paper talks about the neutron detector which is designed as an additional instrument for separation between electromagnetic and nuclear cascades in «GAMMA-400» orbital gamma-observatory. It is a necessary procedure to eliminate a proton background during space measurements. The detector operates in counting mode. It contains two layers of ZnS(Tl)+6LiF scintillator and, in particular, the (n, α) reaction on lithium is used to capture neutrons.

Key words: neutron detectors, positional sensitive detectors, space experiments, gamma-ray telescopes, gamma-ray astronomy

1. INTRODUCTION

Neutron detectors may be applied to gamma astronomy and find their place in gamma-ray space telescopes designed for dark matter search, observations of various astrophysical objects and other purposes where reducing impact of cosmic background is critical. In practice, the first successful attempt to use neutron detector for such tasks was demonstrated in PAMELA experiment launched on 15 June 2006 [1][2].

While proceeding through a calorimeter gamma rays produce electrons and positrons, which (when a primordial photon energy is sufficiently high) may have significant energy and may in turn produce lots of subatomic particles including neutrons. At the same time there is a significant background of charged particles in space mainly composed of protons. A background proton passing through the calorimeter may be mistaken for an electron and added to the statistic of useful events. Thus it is important to apply various methods of proton rejection to deal with background radiation.

This article describes some principles and methods of operation and design of a neutron detector for the "GAMMA-400" space observatory. This observatory is designed for investigation of the Galactic gamma-ray energy spectra in a very high energy range (100 MeV — 3 TeV [3]) and in particular for dark matter search, studying mechanisms of generation, acceleration, propagation and interaction of cosmic rays in Galactic and intergalactic spaces, studying the nature and features of variable gamma-ray activity of various astrophysical objects etc [4].

2. APPLICATION OF A NEUTRON DETECTOR IN REJECTION TECHNIQUES

Though high-energy protons and electrons behavior in solid medium is quite similar, cascades, which they produce, could be effectively analyzed and used to obtain comprehensive information of a primordial particle. In "Gamma-400" space telescope it is to be carried out by cross cascade progression analysis in strip and spectrometric detectors of the calorimeter, longitudinal cascade progression analysis in all detectors, by the energy released to detectors of the telescope and by neutron detection.

![Fig. 1 Cascade progression for electron (400 GeV, left) and proton (1000 GeV, right) inside the "Gamma-400" space telescope. Neutron detector is shown below in the form of a rectangular plate.](image1)

![Fig. 2 “Gamma-400” design scheme used in modeling the characteristics of the neutron detector. CT – converter-tracker, C1, C2, C3, C4 – scintillator detectors. CC1, CC2 - calorimeters, ND - neutron detector.](image2)
To identify a primary particle "Gamma-400" neutron detector uses number of neutrons in the shower produced by this particle. From the simulation (table 1) conducted for the "Gamma-400" computational model it is clear that number of neutrons for a proton and electron of relevant energies (corresponding to the same energy release in the calorimeter) differs by more than an order of magnitude. A comparison between neutron spectra of proton and electron shower is shown in figure 3.

In all the calculations electrons and protons characterized by the same energy release in the "Gamma-400" calorimeter are compared (e.g. 400 GeV electron and 1000 GeV proton).

Time distribution of cascade particles also may be used to identify a primordial particle. Figure 4 shows time distributions of charged particle produced by a proton and an electron (including alpha-particles occurring due to (n, α) reaction on lithium in the scintillator). Fitting by a power function shows a significant difference between fitting coefficients for a proton and electron cascades. Thus the time method could be effectively used in addition to the quantitative one.

Simulations also show a spatial distribution of events in the neutron detector. Spatial distributions for proton and electron cascades were fitted by a normal distribution (figure 5). As it can be seen the fitting parameters differs but they are quite similar to be a reliable method of proton rejection. Nevertheless they could be used in addition to the time and quantitative methods of particle identification.

Table 1 Number of neutrons detected by the “Gamma-400” neutron detector as function of type and energy of an initial particle.

<table>
<thead>
<tr>
<th>Proton/electron energy (GeV)</th>
<th>25/10</th>
<th>250/100</th>
<th>1000/400</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of detected neutrons (for 10 initial particles)</td>
<td>2912/56</td>
<td>9185/620</td>
<td>39530/2720</td>
</tr>
<tr>
<td>Factor of e/p separation</td>
<td>52.0</td>
<td>14.8</td>
<td>14.5</td>
</tr>
</tbody>
</table>
3. DETECTOR DESIGN

The neutron detector for "Gamma-400" has a size of 1000x1000 mm$^2$ and is 85 mm thick. Detector consists of two layers of scintillator each of which is made of 100x1000 mm$^2$ isolated strips. Each strip has a ZnS(Tl)+$^6$LiF thin scintillator layers, thus neutron capture occurs on a lithium-6 nuclei with production of an alpha-particles (1).

$$^6\text{Li} + _0^1\text{n} \rightarrow _2^4\text{He} + _1^3\text{H} + 4.8\text{MeV} \quad (1)$$

Scintillation light is gathered by organic glass optical layers (fibers) and is detected by photomultipliers connected to the small ends of a strip. Upper and lower 1000x1000 mm$^2$ scintillator layers have strips perpendicularly oriented relative to each other, thus it is possible to obtain coordinates of an event, taking place in the neutron detector.

Given the purpose of the neutron detector to detect neutrons from a charged particle cascade, it is important to separate events produced by neutrons and those produced from charged particles of a shower (protons, electrons, mesons, etc.) In the neutron detector detecting layers alternate with layers of an organic moderator, which, aside from increasing neutron detection efficiency [5], allows separation between neutrons and other particles of a cascade by simple setting a time threshold for event detection.

Figure 6 shows that 100 ns interval between a reference time signal and event detection will eliminate most of undesirable events preserving neutron-produced alpha particles.

4. DETECTOR PROTOTYPE

Before neutron detector could be a part of the "Gamma-400" equipment it is necessary to design, construct and test a working prototype which in this case consists of two independent detection units placed one under another to simulate the full two-layered detector during a prototype testing. A size of each of the units is equal to half of the final detector strip, i.e. is about 100x500 mm$^2$. Each of the units has one thin layer of ZnS(Tl)+$^6$LiF scintillator. To investigate different methods of light collection one unit is equipped with StensL SiPM and the other one has common PMT (Hamamatsu). Appearance and design of the units is shown in figure 7.

5. CONCLUSION

Simulations conducted using GEANT libraries show, that including a fast and positional sensitive neutron detector in orbital gamma-observatories could be an effective instrument for a proton background rejection in various space experiments.

Acknowledgement: This paper is a part of research done within “Gamma-400” collaboration. We would like to thank other project participants and, apart from them, PhD Thant Zin, who took a significant part in the GEANT simulations.

REFERENCES

ALPHA AND ICP-MS SPECTROMETRY APPLICATION IN ANALYZING VARIETY OF MATRICES AND ACTIVITY CONCENTRATIONS

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Abstract. Determining the activity of alpha-emitting radionuclides is important task in the field of radiation protection and radioecology because of long physical and biological half-lives of some of them and their high radiotoxicity. A variety of analytical methods exists in order to separate and detect alpha radioactive isotopes: α-spectrometry, mass spectrometry (ICP-MS, AMS, RIMS, SIMS) gamma -and XRF spectrometry, etc. In the present paper the results from alpha spectrometry measurements of the thin sources prepared after radiochemical separation of environmental and Low-level radioactive waste samples (LL RAW) are discussed in relation to the different factors contributing to the quality and uncertainty of the activity results. In radiochemical separation schemes ion-exchange resins, high selective chromatographic materials (TRU, TEVA and UTEVA (Eichrom Technologies) and other purification techniques were combined. In about only 2 % of the cases the quality of the final source was considered not useful to quantify the activity concentration. A method for determination of uranium content and impurities in (NH4)3UO2(CO3)3 (AUC) and U3O8, produced after 36 hours of heating at 750°C is described. The quadrupole ICP-MS is applied to measure uranium isotopes and trace metals after dissolution, dilution and filtration of AUC. Alpha-spectrometry of the co-precipitated thin source is performed in parallel. The results from alpha-spectrometry analyses of 239U, 235U and 234U is compared to the calculated ICP-MS uranium isotopes mass concentration.

Key words (bold): alpha-spectrometry, ICP-MS, RAW, uranium isotopes, TRE

1. INTRODUCTION

There are many radionuclides naturally occurring in the environment which undergo alpha decay. In addition because of human nuclear activity, including nuclear weapon testing, operation of nuclear power plants (NPPs), nuclear fuel reprocessing plant, etc the inventory of alpha emitting radionuclides is increasing. The need for analyses to characterize the activity concentration and to categorize the materials is also increasing. The experience in the use of alpha spectrometry to analyze uranium isotopes and transuranic elements in variety of radioactive materials is the main topic of this work. Alpha isotopes of interest in the radioactive waste (RAW) are 235U, 238U, 239U, 238U; 239Pu, 240Pu, 241Pu; 242Am and 244Cm and 244Cm [1]. High resolution alpha spectrometry is performed after sample pretreatment and complete separation of the target radionuclides from the matrix, achieved by anion and cation exchange or by extraction chromatography separation, for example with TEVA, UTEVA EC, TRU resin etc. [2,3]. Because of the long and complex radiochemical procedures usually the method of isotopic dilution is applied and known activity of tracer radionuclide is added before the sample processing. The thin sources for alpha spectrometry in our practice are prepared by (a) micro co-precipitation with Nd as fluorides, (b) electro deposition or (c) drop deposition for efficiency calibration for specific geometries. The development of complex radiochemical separation of Uranium, Plutonium, Americium and Curium isotopes from alkaline low level liquid and solid radioactive waste collected in NPP “Kozloduy” is described in details in [4, 5, 6].

The procedure developed for Uranium isotopes determination in RAW material was successfully applied to Ammonium uranyl carbonate and U3O8 materials from former uranium mining. The results of uranium determination by alpha spectrometry and ICP-MS are compared and discussed.

2. EXPERIMENTAL

2.2. Alpha spectrometry

Alpha spectrometry was performed by ORTEC Octete Alpha Spectrometry System equipped with 8 chambers and ion implanted type ULTRA-SATM detectors with 300 mm2 active area. The energy resolution (FWHM) for 241Am 5.486 MeV is 20 keV for 4cm sources to detector distance for all detectors.

For energy efficiency and calibration three certified calibration source are used: mixed radionuclides containing 238U, 235U, 239Pu and 241Am isotopes, traceable to NIST and 239Pu, 241Am, 244Cm,
traceable to PTB mixed nuclides source, suitable for energy and efficiency calibration. Amersham 241Am source is used for efficiency calibration of electrodeposited sources.

For the efficiency calibration of the geometry of micro precipitated on 0.1 μm filers, drop deposited sources were prepared. Four types of sources were made: (1) a tracer of a known activity is directly dropped in micro portions onto the stainless disks, (2) dropped over the filter, (3) by co-precipitation of standard solutions with NdF₃ and by electrodeposition (4).

In standard spectrum with well separated peaks of analyte/s and tracer as in the case of ²³⁸U and ²³⁴U from the ²³²U tracer, Fig. 1. the activity is calculated by Eq. (1).

\[ A_T = c_T m_T \left( \frac{R_{GA} - R_{AT}}{R_{GT} - R_{BT}} - q \right) \frac{P_{al}}{P_{al}} \]  

where \( c_T, m_T \) are mass and specific activity of tracer solution; \( R_{GA} \) and \( R_{GT} \) are gross counting rate in analyte (A) and tracer(T) peaks, \( P_{GT} \) is sum of alpha emission probabilities for tracer and \( P_{GA} \) for analyte region of interest, \( R_{BT} \) and \( R_{BT} \) are blank or background counting rate. The counting rates are assumed to be live-time corrected. Additional correction factors are taken into account: the decay of the analyte in the time interval from the end of sampling to the beginning of the measurement; the decay of the analyte and the tracer during the counting interval; the decay of the tracer radionuclide in the time interval from its calibration date to the beginning of the measurement [7].

\[ b_{corrected} = b - \frac{ac}{b + ad} / c \]  

The correction in Eq.2 is important in all Americium spectrum of co-precipitated sources from RAW sludge samples with high ²⁴¹Am activities. In some cases of high ²³⁹Pu activity in RAW and wide peaks (FWHM~100 keV) this correction is applied. The increase in overall uncertainty is observed in this case.

The source to detector distance usually is kept close, typically at about 1cm (Geom.1). The resolution increases with the distance and for distance of 4cm (Geom.5) the FWHM of ²⁴¹Am peak decrease from 90 to 80 keV and that of ²⁴⁴Cm from ~80 to 60 keV. Better resolution allow to see the main lines in ²³³U peak (4.722MeV, 28.42% and 4.774, 71.37%) and ²³²U peak (5.263, 31.55%; 5.320, 68.15%) (Fig.1).

The increase in energy resolution with distance causes decrease in efficiency, so to achieve the same counting statistics the time of measurements is 3 times for Geom.5 compare to Geom.1.

In the case of Americium spectra in micro precipitated sources tail correction is required. The approach is to sum the counts in ROIs of A, B, C and D (Fig.2.) as a, b, c and d. The width of each ROI and the difference between the two neighboring peaks are the same.

\[ \text{Fig. 1. Uranium in sludge sample, detector 4, geom. 5.} \]

The activity of the added tracer might be higher than analyte (Fig.3) or lower (Fig.4).
For example, $^{236}\text{Pu}$ in the sample in Fig. 4 is significantly lower than the activity of the analytes $^{239+240}\text{Pu}$ and $^{238}\text{Pu}$. In fact, its peak is not easily noticeable if the spectrum is shown in linear scale. Switching to logarithmic scale the $^{236}\text{Pu}$ peak is easy to see as the most right peak in Fig. 4.

2.2. Development of ICP-MS technique and its application for uranium determination in AUC and $\text{U}_3\text{O}_8$ material

Ammonium uranyl carbonate (AUC) is a very important raw material and is one of the many forms called “yellowcake”. In Bulgaria there was significant amount of AUC, produced before the closing of uranium mining industry almost 30 years ago, so it is very important to provide fast, economic and reliable analysis of content of uranium and the impurities in it.

The presented method uses a simple procedure of acid dissolution of the AUC, with filtration and dilution for ICP-MS measurement. Because of great amount of the uranium, for determination of thorium impurities, there was a solvent extraction stage with the use of extraction chromatography resin for the removal of uranium.

The production and analysis of $\text{U}_3\text{O}_8$ is more complex and difficult. $\text{U}_3\text{O}_8$ is obtained after 36 hours of heating at a temperature of 750°C in melting pot, inserted in muffle furnace. After heating, the product is dissolved in strong acid and after that diluted with ultra-pure water for ICP-MS measurement. And again for the determination of thorium, the uranium in the sample was removed with solvent extraction.

A comparison was made between the specific activity in kBq/kg (Bq/g) of $^{238}\text{U}$, calculated by using the mass-activity connection, and those measured by alpha-spectrometry. The theoretical mass-activity connection was confirmed by measuring of standard raw material from the natural uranium with known specific activity.

There are references in the literature reporting use of ICP-MS for the determination of U in environmental materials [2, 8] and waters [9, 10, 11], but there was no public information about determination of uranium in AUC and $\text{U}_3\text{O}_8$.

Our Inductively coupled plasma mass spectrometry measurements were made using a VARIAN 820-MS ICP-MS spectrometer, equipped with a Varian Scott-type spray chamber and cross-flow nebulizer. Sample solutions were aspirated into the argon plasma via a peristaltic pump and the data was acquired using a DELL computer with Varian quantitative software.

A multi-element stock CPAchem® standard solution is used to calibrate of instrument and for the preparation of a set of external standards for ICP-MS. UTEVA™ extraction chromatographic resin of Bio-Rad Laboratories® is used for solvent extraction.

Strong ultra-pure HNO$_3$ 69% (v/v) Romil (Cambridge, UK) is used for the dissolution of the samples and for the preparation of aliquots for ICP-MS measurement. High purity gas argon (C-45) of 99.995% purity was supplied by SIAD Bulgaria.

Dissolution procedure for AUC is as follows: A small amount of AUC - 100mg, was transferred in a glass beaker with magnetic stirrer and diluted with 8ml of concentrated HNO$_3$. The solution was filtered trough filter with a 0.45µm pore diameter. 100µl from the filtrate was transferred in a 1000ml volumetric flask and diluted with 18.2 MΩ ultrapure water. After first dilution, there was after-dilution with ultrapure water with a dilution factor 1000.

3. Results and Discussion

Decay counting represents the classical highly successful approach for $\alpha$-decay detection. The determination of alpha emitting radionuclides by mass spectrometry is very attractive, especially for radionuclides with low specific activity as natural uranium and thorium isotopes. Still, the alpha spectrometry is the preferable method, if not the only one suitable for $^{239}\text{Pu}$, $^{241}\text{Am}$ and $^{244}\text{Cm}$ and $^{244}\text{Cm}$ analyses [2, 8, 12].

The concentration of $^{238}\text{U}$, measured with ICP-MS compared to the alpha spectrometry measurements is shown in Fig. 4.

![Fig. 4 $^{238}\text{U}$ concentration in AUC (a) and $\text{U}_3\text{O}_8$ (b): by columns ICP-MS results are shown; points with 1 sigma uncertainty presents $\alpha$-spectrometry results.](image-url)
production of U$_3$O$_8$ are from 41.27% to 46.82%, leading to corresponding increase in mass and activity concentrations, well observed comparing Fig.4a to Fig.4b. There were significant amounts of impurities of Ba, Ca, Fe, Mg, Mn and Zn into the samples of AUC and U$_3$O$_8$.

The $^{235}$U/$^{238}$U activity ratio measured by the two techniques is very close in every particular sample, but displays variation from 2 to almost 5% from one particular sample to the other, Fig.5.

The $^{235}$U/$^{238}$U activity ratio is considered very uniform with value of 0.046 if not DU influence is expected. But some wider variations are observed in waters from Italy and some Balkan regions [13].

The results from the analyses usually are reported with 1 sigma combined uncertainty from counting statistics of the tracer and analyte, the uncertainty of weighting and the tracer activity. In the case of incomplete chemical separation there is an increase in uncertainty because of peak overlapping of α-emitters of different element like Pu contamination in U eluates, observed in few Low-level RAW samples. The uncertainty increases with 5-10% when a tail correction is made (see Fig.2). The uncertainty of the chemical yield determination based on the tracer activity in a series of samples is estimated to be 20.5% for $^{241}$Am, 25.8% for $^{234,238}$U isotopes and 31.5% for $^{238,239,240}$Pu isotopes. In general the highest increase of uncertainty, up to 50 percent, in some of the analyzed RAW material is due to the low tracer activity added, because of the initially unknown activity of specific radionuclides.

In the environmental samples the main source of uncertainty is coming from counting statistics of the low activity concentration.

4. CONCLUSIONS

The alpha spectrometry of the sources, processed by adequate radiochemical separation procedure, proved to be a reliable measurement technique for natural (U) and TRE radionuclides. It was confirmed that uranium isotopes mass concentration by ICP-MS and activity concentrations by alpha-spectrometry produce comparable and reproducible results. The difference is in the range of 5% for $^{238}$U which is below the total uncertainty of all stages of the analytical procedure. It shows the possibility of ICP-MS for fast and reproducible measurements of long-lived alpha emitting radionuclides ($T_{1/2}$~ 1.07 years).

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MULTIVARIATE ANALYSIS OF CLIMATE VARIABLES, TELECONNECTION INDICES AND ACTIVITIES OF LEAD-210 AND BERYLLIUM-7 IN SURFACE AIR IN BELGRADE, SERBIA

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Abstract. Activities of lead-210 and beryllium-7 have been monitored at the Vinča Institute of Nuclear Sciences in Belgrade, Serbia. The monthly mean activities in composite aerosol samples were determined on HPGe detectors by standard gamma spectrometry. The meteorological data, consisting of the temperature, atmospheric pressure, relative humidity, sunshine hours and cloud cover data were obtained from the European Climate Assessment & Dataset and the Republic Hydrometeorological Service of Serbia. Five teleconnection indices of large scale atmospheric circulation: North Atlantic Oscillation, East Atlantic Pattern, East Atlantic/West Russia Pattern, Scandinavia Pattern, and Polar/Eurasia Pattern were obtained from the data archive of the United States National Oceanic and Atmospheric Administration’s Climate Prediction Center. The first lead-210 and beryllium-7 activities measured at the Vinča Institute date back to 1985 and 1991, respectively, and their relation with the climate variables and teleconnection indices is investigated using multivariate methods of analysis.

The most appropriate multivariate method of analysis of these sets of measurements is selected from a wide spectrum of multivariate methods developed for data analysis in high-energy physics and implemented in the Toolkit for Multivariate Analysis software package. The evaluation ranking results based on the best signal efficiency and purity, show that the Boosted Decision Trees (BDT) multivariate method is the most suitable for the variable analysis. Further multivariate analysis results give insight into the dependence of lead-210 and beryllium-7 concentrations upon the climate variables and atmospheric circulation (via the teleconnection indices) during the time of measurements. The BDT method singles out the Scandinavia Pattern index as the variable with the highest importance for both radionuclides. Amongst the climate variables, temperature shows the strongest influence on the radionuclide concentrations, while relative humidity is the lowest ranking variable. Moreover, the multivariate regression methods give a good approximation of lead-210 and beryllium-7 concentrations for all the sets of climate variables and teleconnection indices.

Key words: lead-210, Be-7, air, climate variables, teleconnection indices, multivariate methods

1. INTRODUCTION

Environmental radioactivity monitoring in Belgrade, Serbia, includes continuous control of radioactivity of aerosols at meteorological station in Vinča Institute of Nuclear Sciences. The continuous control is done by measurements of radioactivity of lead-210 and beryllium-7. These two naturally occurring radionuclides have different sources: 220Pb (half-life 22.3 years) in air results from 222Rn decay, ground resuspension, and anthropogenic activities (mainly coal combustion), while 7Be (half-life 53.28 days) is produced in the upper troposphere and lower stratosphere, and then transported into lower altitudes. However, washout is the major removal process from the atmosphere for both radionuclides, which is a likely reason for the radionuclides medium, but significant correlation in surface air [1]. The extent of influence of local climate variables on the activities of these radionuclides has been studied before [e.g., 1, 2], while the impact of large scale atmospheric transport is not as well documented [3].

The goal of this analysis is therefore to look more thoroughly into possible relations between the 220Pb and 7Be activities in surface air and available meteorological data and large scale atmospheric transport patterns (quantified by teleconnection indices). Multivariate methods which have been developed and used in high-energy physics were chosen for our analysis. Numerous multivariate methods and algorithms for classification and regression can be found in the analysis framework ROOT [4] and, more precisely, in the Toolkit for...
Multivariate analysis (TMVA) [5]. These multivariate methods were used to test all available classifiers and regression methods implemented, in order to find a most appropriate method for the analysis of the $^{210}$Pb and $^7$Be dependence on the climate variables and teleconnection indices.

2. EXPERIMENTAL DATA

The monthly mean activities of lead-210 and beryllium-7 in composite aerosol samples are determined using HPGe detectors by standard gamma spectrometry. The measurements of activities of lead-210 started in 1985 and of beryllium-7 in 1991.[8]

The meteorological data, consisting of temperature, atmospheric pressure, relative humidity, sunshine hours and cloud cover data were obtained from European Climate Assessment & Dataset (ECA&D) [6] and the Republic Hydrometeorological Service of Serbia.

Five teleconnection indices of large scale atmospheric circulation: North Atlantic Oscillation, East Atlantic Pattern, East Atlantic/West Russia Pattern, Scandinavia Pattern, and Polar/Eurasia Pattern were obtained from the data archive of the United States National Oceanic and Atmospheric Administration’s Climate Prediction Center (http://www.cpc.ncep.noaa.gov/data/teledoc/telecontents.shtml) visited on 18 October 2013).

3. CALCULATIONS

The first step in the analysis was to calculate and rank the correlation coefficients between all the given variables and the $^{210}$Pb and $^7$Be activities (Table 1). Apart from the useful information on the connection between the variables and measured activities, the first stage calculations also help in setting up and testing the framework for running the various multivariate methods contained in the TMVA.

In the next step, the multivariate methods were used and compared in order to find the one best suited for classification (division) of the $^{210}$Pb and $^7$Be activities into two sets of data: acceptable concentrations and increased concentrations in air samples. Preferably, the result of this method comparison is a single method which, given the input climate variables and atmospheric indices, provides an output close to the observed variations in the $^{210}$Pb and $^7$Be concentrations.

In order to use the multivariate classification, a set of input events (consisting of $^{210}$Pb or $^7$Be concentration value along with meteorological variables and teleconnection indices values measured/taken simultaneously) was first split into events that correspond to the signal (i.e., events that include $^{210}$Pb or $^7$Be concentrations that are considered increased) and to the background (events that include $^{210}$Pb or $^7$Be concentration that is declared acceptable). For the purpose of this preliminary analysis, the splitting of the input events was performed at 1.1 mBq/m$^3$ and 5 mBq/m$^3$ for $^{210}$Pb and $^7$Be, respectively. These limits were used for the majority of the analyses. They were selected because the splitting ensured maximum employment of multivariate comparison methods. Moreover, these particular values reflected the fact that the number of background events is greater that the number of signal events. The method of multivariate regression, however, does not require preliminary splitting of input events, and is therefore more general.

4. MULTIVARIATE METHODS

The Multivariate methods in Toolkit for Multivariate Analysis (TMVA) belong to the family of “supervised learning” algorithms. They make use of training events, for which the desired output is known, to determine the mapping function that either describes a decision boundary (classification) or an approximation of the underlying functional behavior defining the target value (regression). The two most important Multivariate methods for our purposes are “Boosted Decision Trees” (BDT) and “Artificial Neural Networks” (ANN).

4.1. Boosted Decision Trees

In BDT, the selection is based on a majority vote on the result of several decision trees. Decision tree consists of successive decision nodes which are used to categorize the events in a sample as either signal or background. Typically, BDT is constructed of a forest of such decision trees. However, the advantage of the straightforward interpretation of the decision tree is lost. Detailed information on BDT can be found in the TMVA manual [5].

4.2. Artificial Neural Networks

ANN is any simulated collection of interconnected neurons, with each neuron producing a certain response at a given set of input signals [7]. ANNs in TMVA belong to the class of Multilayer Perceptrons (MLP), which are feed-forward neural networks.

5. RESULTS

A relation between the radionuclides’ activities and the input variables was first investigated through correlation coefficients given in table 1. The coefficients showed a stronger correlation of the $^7$Be activity with the climate variables (mean, minimum and maximum temperature and sunshine hours). Lead-210, on the other hand did not show correlation with any of the input variables.

The best method for MVA classification was BDT followed by MLP. Table 2 shows variable importance ranking of the top 4 variables. The method independent variable importance shows which of the input variables used contributes the most to classification of the radionuclides’ activities to normal and increased ones.
Table 1 Correlation coefficients in % for the input variables and the \(^{210}\text{Pb}\) and \(^{7}\text{Be}\) activities

<table>
<thead>
<tr>
<th>Variable</th>
<th>(\text{Pb-210})</th>
<th>(\text{Be-7})</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean temperature</td>
<td>-8</td>
<td>46</td>
</tr>
<tr>
<td>Minimum temperature</td>
<td>-9</td>
<td>45</td>
</tr>
<tr>
<td>Maximum temperature</td>
<td>-7</td>
<td>46</td>
</tr>
<tr>
<td>Pressure at sea level</td>
<td>11</td>
<td>-14</td>
</tr>
<tr>
<td>Humidity</td>
<td>5</td>
<td>-24</td>
</tr>
<tr>
<td>Precipitation</td>
<td>-5</td>
<td>-2</td>
</tr>
<tr>
<td>Sunshine hours</td>
<td>-5</td>
<td>30</td>
</tr>
<tr>
<td>Cloud cover</td>
<td>-7</td>
<td>-19</td>
</tr>
<tr>
<td>North Atlantic Oscillation</td>
<td>6</td>
<td>-3</td>
</tr>
<tr>
<td>East Atlantic Pattern</td>
<td>-1</td>
<td>9</td>
</tr>
<tr>
<td>West Pacific Pattern</td>
<td>-2</td>
<td>-1</td>
</tr>
<tr>
<td>East Pacific / North Pacific Pattern</td>
<td>17</td>
<td>8</td>
</tr>
<tr>
<td>Pacific/North American Pattern</td>
<td>-4</td>
<td>-6</td>
</tr>
<tr>
<td>East Atlantic/West Russia Pattern</td>
<td>8</td>
<td>14</td>
</tr>
<tr>
<td>Scandinavia Pattern</td>
<td>10</td>
<td>-3</td>
</tr>
<tr>
<td>Polar/Eurasia Pattern</td>
<td>14</td>
<td>/</td>
</tr>
</tbody>
</table>

Table 2 BDT variable importance ranking of 4 most important variables

<table>
<thead>
<tr>
<th>(^{210}\text{Pb})</th>
<th>(^{7}\text{Be})</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scandinavia Pattern</td>
<td>Scandinavia Pattern</td>
</tr>
<tr>
<td>East Pacific / North Pacific Pattern</td>
<td>West Pacific Pattern</td>
</tr>
<tr>
<td>Polar/Eurasia Pattern</td>
<td>North Atlantic Oscillation</td>
</tr>
<tr>
<td>West Pacific Pattern</td>
<td>East Atlantic Pattern</td>
</tr>
</tbody>
</table>

5.1. Regression MVA methods

Regression represents an approximation of the underlying functional behavior which defines the target value (\(^{210}\text{Pb}\) and \(^{7}\text{Be}\) activities) in dependence on the input climate variables and atmospheric indices. Prior to commencing an investigation into the best MVA methods, we want to make method independent ranking of input variables (Table 3) by correlation with the measured concentration values of \(^{210}\text{Pb}\) and \(^{7}\text{Be}\). It can be concluded from the table which of the input variables are likely to be most important for the MVA regression. Similar to the correlation coefficients table for classification methods (Table 1), the method independent table shows that for regression most important variables are the temperature, sunshine hours (and humidity) for the \(^{7}\text{Be}\) concentration evaluations. For \(^{210}\text{Pb}\) the most important variables were the two teleconnection indices and pressure at sea level.

In further analysis, an attempt was made to find the best regression method that gives output values (evaluated \(^{210}\text{Pb}\) and \(^{7}\text{Be}\) activities) as close as possible to the measured concentrations. The best multivariate regression method was found to be BDT, and the second one MLP, i.e. the same methods singled out in the case of multivariate classifiers. Figure 1 presents the comparison of frequency distributions of \(^{210}\text{Pb}\) for measured and MLP evaluated values.

It is worth mentioning that when using the “supervised learning” MVA methods, caution in selecting resulting methods is required. This primarily means that the selected method ought to be proven good. To do that, good test algorithms are needed. Unfortunately, not all MVA regression methods have a sound test of a training process. The test process shows whether the evaluated values of concentrations are far from measured. The MLP (Figure 2) and DBT methods have good tests of the learning process, which is not the case for all MVA methods. Also, we need to mention that, if some MVA method gave distributions of evaluated \(^{210}\text{Pb}\) or \(^{7}\text{Be}\) concentrations with many apparent discrete values, we did not consider it as an appropriate method for our analysis, since we expect the more continual distributions to be closer to reality.

Table 3 Variable importance ranking, independent of the method for MVA regression

<table>
<thead>
<tr>
<th>(^{210}\text{Pb})</th>
<th>(^{7}\text{Be})</th>
</tr>
</thead>
<tbody>
<tr>
<td>Polar/Eurasia Pattern</td>
<td>Mean temperature</td>
</tr>
<tr>
<td>East Pacific / North Pacific Pattern</td>
<td>Maximum temperature</td>
</tr>
<tr>
<td>Pressure at sea level</td>
<td>Minimum temperature</td>
</tr>
<tr>
<td>Scandinavia Pattern</td>
<td>Sunshine hours</td>
</tr>
<tr>
<td>North Atlantic Oscillation</td>
<td>Humidity</td>
</tr>
<tr>
<td>Cloud cover</td>
<td>Pressure at sea level</td>
</tr>
<tr>
<td>East Atlantic/West Russia Pattern</td>
<td>East Atlantic Pattern</td>
</tr>
<tr>
<td>Maximum temperature</td>
<td>East Pacific / North Pacific Pattern</td>
</tr>
<tr>
<td>Precipitation</td>
<td>Pacific/North American Pattern</td>
</tr>
<tr>
<td>Sunshine hours</td>
<td>North Atlantic Oscillation</td>
</tr>
<tr>
<td>Humidity</td>
<td>Scandinavia Pattern</td>
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<tr>
<td>Pacific/North American Pattern</td>
<td>Precipitation</td>
</tr>
<tr>
<td>West Pacific Pattern</td>
<td>West Pacific Pattern</td>
</tr>
<tr>
<td>East Atlantic Pattern</td>
<td>Polar/Eurasia Pattern</td>
</tr>
</tbody>
</table>

Additionally, several MVA methods, like Function Discriminant Analysis (FDA) (Fig. 3) had negative regression coefficient for distribution of differences of the evaluated and measured values of \(^{201}\text{Pb}\) concentrations vs \(^{201}\text{Pb}\) concentrations. This negative regression coefficient was corrected, thus making several more MVA methods useful for our analysis. As a result, methods which could successfully be used for regression were the following MVA methods: Artificial Neural Networks, Boosted Decision Trees, Function Discriminant Analysis, Linear Discriminant, Multidimensional k-Nearest Neighbour Method, and Multidimensional k-Nearest Neighbour Method.
Probability Density Estimator Range-Search. All these methods gave distributions of the evaluated values similar to MLP, which encouraged us to use all the results from the MVA analysis. Since MVA methods are mathematically very diverse, getting the same results points out that they properly describe the connection between the experimental values and the meteorological variables and teleconnection indices.

![Fig. 1 Distribution of the MLP evaluated values and measured 210Pb activities.](image1)

Fig. 1 Distribution of the MLP evaluated values and measured 210Pb activities.

![Fig. 2 Testing of MLP method. The evaluated values of 210Pb concentrations were close enough to the measured values, and during a training process the difference between the evaluated and measured value was getting smaller.](image2)

Fig. 2 Testing of MLP method. The evaluated values of 210Pb concentrations were close enough to the measured values, and during a training process the difference between the evaluated and measured value was getting smaller.

![Fig. 3 Correction of evaluations for the FDA method.](image3)

Fig. 3 Correction of evaluations for the FDA method.

6. Conclusion

The first tests of using the MVA methods in finding the relation between the 210Pb and 7Be activities in air, and the meteorological variables and teleconnection indices, were shown to be very promising. The MVA classification and regression methods can distinguish between inter-correlations of input variables and correlation of input variables and 210Pb and 7Be activities, and also to point out to the, MVA method specific, variables which contribute the most to efficient classification and evaluation of the measured 210Pb and 7Be activities. Successful MVA mapping of functional behavior of the 210Pb and 7Be activities is the most important result of this work. Having the MVA mapped functional behavior will help us with further research of activities of these isotopes in air samples.

Acknowledgement:

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REFERENCES

HYPERSPECTRAL REMOTE SENSING APPLICATIONS FOR ENVIRONMENTAL PROTECTION

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3 Institute of Plant physiology and Genetics, Bulgarian Academy of Sciences

Abstract: Hyperspectral remote sensing techniques based on reflectance and fluorescence measurements were used for monitoring and assessment the effects of adverse environmental conditions on plant ecosystems and the opportunities for making decisions before the occurrence of injuries. The hyperspectral reflectance and fluorescence data were obtained in the visible and near infrared ranges (400-1100 nm) using a portable fiber-optics spectrometer. Statistical analyses (Student’s t-criterion and cluster analysis) were applied to assess the differences between the spectral data of healthy and injured (stressed) plants. Spectral analyses were performed in four most informative for the reflected radiation of investigated plant species (Paulownia tree) regions: green, red, red edge and near infrared. The fluorescence spectra were analyzed at five characteristic wavelengths located at the maxima of the emitted radiation and at the forefronts and rear slopes. First derivative analysis was performed to assess the red edge position of reflectance spectra. Strong relationship was found between the results from the two applied remote sensing techniques.

Key words: hyperspectral remote sensing, leaf reflectance, chlorophyll fluorescence, paulownia tree

1. INTRODUCTION

The remote sensing technologies have advanced significantly in last decade and have improved the capability to gather information about Earth’s resources and environment. Remote sensing from ground, air, or space-based platforms is capable of providing detailed spectral, spatial and temporal information on terrestrial ecosystems [1]. The fundamental feature of remote sensing is the detection of the energy emitted or reflected by various objects whether being in the form of acoustical energy (sound) or electromagnetic energy in the ultraviolet (UV), visible (VIS), infrared (IR), and microwave (MW) ranges [2]. The latest developments in spectroscopic instruments, hyperspectral sensors with high spectral resolution along with a high signal to noise ratio, are now able to generate exceptionally high-quality digital hyperspectral information far beyond the capabilities of multispectral remote sensing data [3]. Hyperspectral sensors are providing high spectral resolution across a wide range of the electromagnetic spectrum, allowing for identification of the surface composition of the imaged target (vegetation, soils, rocks, etc.). Hyperspectral remote sensing (HRS) techniques have many applications in Earth observation. Hydrology, disaster management, land-use and land-cover, weather forecasting, atmospheric study, geology, ecology, agriculture, and national security are only a few of the applications for HRS technology today [4].

HRS offers unique opportunities in the environmental monitoring. The measurements and representations of earth surface characteristics support the information requirements for effective environmental management and decision making. Recent remote sensing systems due to regular, synoptic, hyperspectral and multitemporal coverage of an area provide accurate database on spectral behavior of the objects, in particular vegetation and its growing environment.

In this study, the physical principles and some applications of two hyperspectral remote sensing techniques, leaf spectral reflectance and chlorophyll fluorescence, are discussed with a view to the responses of the plant ecosystems to adverse changes of the environment.

2. PRINCIPLES OF REMOTE SENSING

The science of remote sensing involves the use of ground, air, and space-based sensors to measure the reflection and emission of electromagnetic radiation (EMR) from all terrestrial materials (solid, liquid and gas) principally in the UV, VIS, IR, and MW ranges [2]. Sun radiation, when incident upon the earth’s surface, is reflected by the surface, transmitted into the surface or absorbed and emitted by the surface. When EMR interacted a number of changes were acquired in magnitude, direction, wavelength, polarization and phase [5]. These changes are detected by the remote sensor and enable to obtain useful information about the object of interest. The remotely sensed data contain both spatial information (size, shape and orientation) and spectral information (tone, color and spectral signature) [6]. Spectral behavior of the vegetation depends on its nature and interactions with solar
radiation and other climate factors, also by the content of chemical nutrients and water [7].

HRS is an advanced tool that provides high spatial/spectral resolution data from a distance, with the aim of providing near-laboratory-quality radiance and subsequent related information for each picture element (pixel) from a distance [5]. This information enables the identification of targets based on the spectral behavior of the material in question. HRS sensors acquire many hundreds of contiguous spectral bands across the spectrum from 350 nm to 2500 nm. This approach was found to be very useful in many terrestrial, atmospheric and marine applications.

2.1. Spectral reflectance

Each terrestrial material has its own unique distribution of reflected, emitted and absorbed radiation. These spectral characteristics can be used to distinguish one object from another or to obtain information about shape, size and other properties. The amount of radiation from an object (radiance) is influenced by the properties of the object (structural, chemical, and physical) and the radiation hitting the object (irradiance), as well as angle of incidence, intensity, and wavelength of radiant energy [7]. With hyperspectral analysis, which is based on scanning hundreds of closely spaced and very narrow spectral bands across the spectrum from 350 nm to 2500 nm, it is possible to create continuous spectral response curves, which may be used to identify many objects positively.

![Fig. 1 Typical reflectance spectra of water, soil, and vegetation](Image)

Thus, the objects can be differentiated by their spectral reflectance signatures, the measured reflected EMR at varying wavelengths in VIS (400-700 nm), NIR (700-1200 nm), and sort wave infrared (SWIR, 1200-2500 nm) spectral ranges. But the sensing system is necessary to have sufficient spectral resolution to distinguish its spectrum from those of other materials. The spectral reflectance (SR) function described by the dependence of the ratios of the intensity of reflected light to the illuminated light on wavelength, of three main classes of natural objects (water, soil, and green vegetation), is shown in Fig. 1, [8]. Areas 1 to 7 are the spectral bands of LANDSAT 7.

Green vegetation species all have unique spectral features, mainly because of the chlorophyll and carotenoid, and other pigments and water content. Green plant leaves typically display very low reflectance and transmittance in VIS regions of the spectrum (400-700 nm) due to strong absorption by photosynthetic and accessory plant pigments [9], Fig. 1. By contrast, reflectance and transmittance are both usually high in the NIR region (700-1300 nm) because there is very little absorption by subcellular particles or pigments and also because there is considerable scattering at mesophyll cell wall interfaces [10]. Changes in the absorption of incident light allow the identification of plant health and stress.

2.2. Chlorophyll fluorescence

Chlorophyll fluorescence (ChF) allows for studying the different functional levels of photosynthesis indirectly (e.g. process at pigment level, primary light reaction, electron transport reaction, slow regulatory process), and can be used to study components of the photosynthetic apparatus and their reactions to changes in the environment [11]. Chlorophyll (Ch) is the primary pigment of the plants that absorbs light energy from the sun for photosynthesis. Fluorescence occurs when chlorophyll absorbs a specific wavelength of light and subsequently emits light at another wavelength. Light energy that is absorbed by chlorophyll in a leaf can undergo three fates, Fig. 2 [12]. It can be used to drive photosynthesis (photochemistry), it can be dissipated as heat or it can be re-emitted as light at longer wavelength, i.e. chlorophyll fluorescence. These three processes occur in competition. Since the sum of rate constants is constant, any increase in the efficiency of one process will result in a decrease in the yield of the other two. Therefore, determining the yield of chlorophyll fluorescence will give information about changes in the efficiency of photochemistry and heat dissipation.

![Fig. 2 Possible fates of excited chlorophyll](Image)

Spectral reflectance and chlorophyll fluorescence are functions of tissue optical properties and biological status of the plants, and the illumination conditions. In this respect, SR and ChF have proved their potential by detecting stress-related changes in the pattern of light emission from plant leaves.

2.3. Spectral measurements

Hyperspectral reflectance data were collected in VIS and NIR ranges (400-1100 nm) by means of a portable fiber-optics spectrometer (USB2000, Ocean Optics). In the range investigated (450-850 nm) the main part of the reflected from leaves radiation is concentrated. Data were obtained at 1170 spectral bands with a step of 0.3 nm and a spectral resolution of 1.5 nm. The spectral reflectance characteristics (SRC) were obtained as a ratio of the intensity of leaf reflected light to the light reflected from a diffuse reflectance standard for each wavelength in the range. As a source of light, a halogen lamp providing...
homogeneous illumination of measured leaf surfaces was used [13].

Chlorophyll fluorescence data were measured under laboratory conditions using the same portable fiber-optics spectrometer. Hyperspectral data were analyzed in spectral range (600–900 nm) in 910 spectral bands with a step of 0.3 nm where the main part of the emitted from the plant leaves fluorescence radiation is concentrated. As a source of actinic light, a visible-light LED with maximum output at 470 nm was used. The tested leaves were dark adapted before the measurements for ten minutes.

2.4. Data analysis

Student’s t-criterion, cluster analysis, and first derivative analyses were applied for determination of the statistically significance of differences between the sets of the values of reflectance spectra of healthy (control) and subjected to adverse environmental conditions plants and the position of the inflection points of SRC in the red edge region. The spectral reflectance analysis was performed in four most informative for investigated plants spectral ranges: green (520–580 nm, maximal reflectivity of green vegetation), red (640–680 nm, maximal chlorophyll absorption), red edge (690–730 nm, maximal slope of the reflectance spectra) and the NIR (750–780 nm). The statistical significance of the differences between SR of control and treated plants was examined in ten wavelengths (λ1 = 475.22 nm, λ2 = 489.37 nm, λ3 = 524.29 nm, λ4 = 539.65 nm, λ5 = 552.82 nm, λ6 = 667.33 nm, λ7 = 703.56 nm, λ8 = 719.31 nm, λ9 = 724.31 nm, and λ10 = 758.39 nm) chosen to be disposed uniformly over these ranges [13]. The fluorescence spectra were analyzed in five characteristic spectral bands, chosen at specific wavelengths: middle of the forefront edge, first maximum, middle between first and second maximum, second maximum, middle of the rear slope.

3. RESULTS AND DISCUSSION

Hyperspectral remote sensing techniques, leaf reflectance and chlorophyll fluorescence, were applied for investigation of the responses of deciduous tree species *Paulownia tomentosa* to some natural stress factors such as acid rain and enhanced UV-B radiation, the growth regulator MEIA (beta-monomethyl ester of itaconic acid), and the combinations of MEIA+acid rain and MEIA+UV-B radiation. Paulownia is ideal tree species for a forestation and improvement and restoration of contaminated and poor soils. Our investigations have been conducted with three months old *Paulownia* seedlings grown as soil cultures in a growth chamber under controlled conditions. Some of the plants were healthy (control). The averaged (over 25 pixels) SRC of control and treated plants are shown in Fig. 3. SRC of the plants subjected to acid rain differ most significantly against the control in the VIS range. The leaves sprayed with MEIA looked visually like healthy leaves and their SRC are close to the control SRC. The SRC of groups of plants under combined treatments are more close to the control SRC than the cases of single treatment.

The results after applying the Student’s t-criterion on the sets of spectral data are given in Table 1. For group MEIA significant differences (sd) are in VIS because of stimulating growth action. UV-B radiation was applied at low intensity and sd are less than in case of acid rain. For group MEIA+acid rain the number of sd decreased against acid rain treatment.

First derivative analyses were performed to assess the red edge position of averaged SRC of treated plants against the control. Fig. 4. shows the maximum of SRC derivatives for control leaves and for two groups, acid rain and MEIA+acid rain. Shifts to lower wavelengths, by about 4 nm and 0.5 nm, respectively, are observed which is indicator for the degree of plant injury.
Table 1. p-values of the Student’s t-criterion for sets of reflectance data of paulownia leaves

<table>
<thead>
<tr>
<th>Pairs compared</th>
<th>Control mean</th>
<th>MEIA+UV-B mean</th>
<th>Acid rain mean</th>
<th>UV-B mean</th>
<th>MEIA mean</th>
<th>MEIA+acid rain mean</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>p mean</td>
<td>p mean</td>
<td>p mean</td>
<td>p mean</td>
<td>p mean</td>
<td>p mean</td>
</tr>
<tr>
<td>( \lambda_1 / \lambda_{ac} )</td>
<td>5.23</td>
<td>***</td>
<td>6.88</td>
<td>***</td>
<td>6.43</td>
<td>***</td>
</tr>
<tr>
<td>( \lambda_2 / \lambda_{ac} )</td>
<td>5.34</td>
<td>***</td>
<td>7.04</td>
<td>***</td>
<td>6.67</td>
<td>ns</td>
</tr>
<tr>
<td>( \lambda_3 / \lambda_{ac} )</td>
<td>13.31</td>
<td>***</td>
<td>16.92</td>
<td>***</td>
<td>16.91</td>
<td>ns</td>
</tr>
<tr>
<td>( \lambda_4 / \lambda_{ac} )</td>
<td>17.02</td>
<td>***</td>
<td>21.05</td>
<td>**</td>
<td>20.72</td>
<td>*</td>
</tr>
<tr>
<td>( \lambda_5 / \lambda_{ac} )</td>
<td>17.71</td>
<td>***</td>
<td>21.93</td>
<td>**</td>
<td>21.51</td>
<td>*</td>
</tr>
<tr>
<td>( \lambda_6 / \lambda_{ac} )</td>
<td>5.49</td>
<td>***</td>
<td>7.28</td>
<td>***</td>
<td>7.76</td>
<td>***</td>
</tr>
<tr>
<td>( \lambda_7 / \lambda_{ac} )</td>
<td>19.95</td>
<td>**</td>
<td>24.66</td>
<td>**</td>
<td>24.15</td>
<td>ns</td>
</tr>
<tr>
<td>( \lambda_8 / \lambda_{ac} )</td>
<td>34.47</td>
<td>**</td>
<td>39.75</td>
<td>ns</td>
<td>36.08</td>
<td>*</td>
</tr>
<tr>
<td>( \lambda_9 / \lambda_{ac} )</td>
<td>37.06</td>
<td>**</td>
<td>43.17</td>
<td>ns</td>
<td>38.58</td>
<td>*</td>
</tr>
<tr>
<td>( \lambda_{10} / \lambda_{ac} )</td>
<td>44.16</td>
<td>*</td>
<td>49.72</td>
<td>ns</td>
<td>44.13</td>
<td>ns</td>
</tr>
</tbody>
</table>

ns – no significance (p>0.05); * - p<0.05; ** - p<0.01;*** - p<0.001

Tree cluster analysis was applied to the reflectance data in the spectral range 530-580 nm, Fig.5. Two completely separate clusters were received. The first one includes the spectral data of control and UV-B groups and the second – data of the rest treatments.

The averaged fluorescence spectra of control and treated Paulownia leaves are shown in Fig.6. Most significant are differences between SRC of control and treated with acid rain leaves. For combined treatments differences decreased because of regenerating action of growth regulator MEIA.

![Fluorescence spectrum](image)

Fig.6 Averaged fluorescence spectra of paulownia leaves: control and treated with acid rain, UV-B radiation, MEIA and their combinations

The Student’s t-criterion was applied to fluorescence data in above mentioned five characteristic wavelengths. The sd were obtained in first three wavelengths, most significant (p<0.001) in the case of acid rain treatment. A shift of the first maximums against the control was also observed.

4. CONCLUSIONS

The strong relationship between the results from the spectral reflectance and chlorophyll fluorescence applied to the case study demonstrates the potential of these two remote sensing techniques for monitoring and preservation of the Earth’s ecosystems, in particular, for early diagnosis and efficient and objective assessment of the influences of the environmental changes to spectral responses of plant species for making timely management decisions.

REFERENCES

CALCULATION OF THE CROSS SECTIONS ON COPPER-64 AND LUTECIUM-177 TARGETS THERAPEUTIC RADIONUCLIDES BY USING THE TALYS AND EMPIRE CODES

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Abstract: The cross sections of \((n,\gamma)\) reactions on \(^{64}\text{Cu}\) and \(^{177}\text{Lu}\) targets by using the exciton model of pre-equilibrium reaction mechanism have been compared with the experimental data. In our calculations, some free parameters input of the optical model potentials level density and the squared matrix element \(M^2\) have been adjusted for good agreement with the experimental data.

Key words: calculation of the cross sections, Empire and Talys codes, Therapeutic radionuclides

1. INTRODUCTION

Copper-64 and Lutecium-177 can be technically reproduced by several different reactions with the most common methods using either a reactor or an accelerator. Copper-64 was originally produced by means of the \(^{60}\text{Cu}(n, \gamma)^{64}\text{Cu}\) reaction and it is one of the most important emerging therapeutic radionuclides that can be adopted to undertake a combination of radiotherapy and positron emission tomography (PET) [1]. Another method involves the use of a charged particle induced reaction, instead of the \((n,\gamma)\) process, \(^{64}\text{Ni}(p, n)^{64}\text{Cu}\) [2] is successfully applied. Lutecium-177 has found a variety of applications in biomedical fields. It is partly produced via the indirect route and partly via the direct \((n,\gamma)\) reaction, the resulting specific radioactivity in the latter case being appreciably lower. In this work, theoretical nuclear model calculations have been carried out by using Empire 3.2 [3] programs and also the Talys-1.6 [4] code for reactions and the calculated results were compared with experimental cross sections by using EXFOR database [5].

2. THEORETICAL CALCULATIONS

The excitations functions of \((n,\gamma)\) reactions on \(^{64}\text{Cu}\) and \(^{177}\text{Lu}\) targets nuclei are investigated from 1 KeV to 9 MeV by using equilibrium and pre-equilibrium reaction mechanisms. The Empire 3.2 code [3] and Talys-1.6 [4] programs describe the same single nucleon radiative mechanism formula for the \(\gamma\) emission. In the framework of compound nucleus model, the \(\gamma\) strength function for a \(\gamma\) ray emission of multipole type \(XL\) is defined as the average reduced partial radiation width \(E_{\gamma}^{-2(2L+1)} \langle \Gamma_{XL}(E_{\gamma}) \rangle\) divided by the average level spacing \(D_{\gamma}\) [6]. For \(E_1\) radiation, the generalized Lorentzian form of Kopecky and Uhl [7] can be written as:

\[
f_{E_1}(E_\gamma, T) = K_{E_1} \left( \frac{E_{\gamma} \tilde{\Gamma}_{E_1}(E_{\gamma})}{(E_{\gamma}^2 - E_{E_1}^2)^2 + E_{E_1}^2 \tilde{\Gamma}_{E_1}(E_{\gamma})^2} + 0.7\Gamma_{E_1} 4\pi^2 T^2 \right)
\]

\[
\times \sigma_{E_1} \Gamma_{E_1}
\]

where the energy-dependent damping width \(\tilde{\Gamma}(E_{\gamma})\) is given by

\[
\tilde{\Gamma}_{E_1}(E_{\gamma}) = \tilde{\Gamma}_{E_1} \frac{E_{\gamma}^2 + 4\pi^2 T^2}{E_{E_1}^2}
\]

and \(T\) is the nuclear temperature given by [8]

\[
T = \sqrt{\frac{E_n^2 + S_n^2 - \Delta - E_n}{a(S_n)}
\]

where \(S_n\) is the neutron separation energy, \(E_n\) the incident neutron energy, \(\Delta\) the pairing correction and \(a\) the level density parameter at \(S_n\). In the framework of pre-equilibrium model, the exciton model is used in both codes of Empire 3.2 [3] and Talys-1.6 [4]. Empire [3] permits the calculation of pre-equilibrium emission in photonuclear reactions using the exciton model module PCROSS. The pre-equilibrium spectra can be calculated as:
The calculated excitation functions for $^{64}$Cu($n,\gamma$)$^{65}$Cu and $^{176}$Lu($n,\gamma$)$^{177}$Lu using Empire 3.2 [3] and TALYS 1.6 [4] codes are shown in Fig. 1 and Fig. 2 and compared with the experimental cross sections using the available experimental data [20-25]. The calculations with TALYS code agree well with the experimental data for neutrons. Also, the calculated excitation functions for $^{64}$Ni($p, n$)$^{64}$Cu reaction shown in Fig. 3 agree well with the experimental data [26-27-28-29] for protons and the maximum cross-sections of the excitation functions are obtained with TALYS code.
4. Conclusion

The results with the Empire and Talys codes show the similar behavior with the experimental data and the optimum energy for production of therapeutic radionuclides is 0.01 MeV for $^{60}$Cu(n,γ)$^{61}$Cu and $^{176}$Lu(n,γ)$^{177}$Lu reactions and 5-11 MeV range for $^{64}$Ni(p,n)$^{64}$Cu reaction.

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TITLE OF PAPER ADVANCED TECHNOLOGY FOR NEUTRON REGISTRATION TO REPLACE WIDELY USED HELIUM DETECTORS IN PARTICULAR WITH SCINTILLATORS DETECTORS

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Abstract. The aim of proposed topic is to present analysis of task to replace widely used detectors on base of helium-3 to modern technology of neutron registration. The task of replacement is the consequence of two facts: 1) current shortage of helium-3 for the requests for planned activities in the near future; 2) wide current use of detectors on helium-3 in the working system and so needs to support facilities on security and safety as for example portal neutron detectors systems.

Scintillation detectors are proposed as substitutions for helium detectors as far they may provide large sensitive area and high resolution. But it is necessary to find out optimal detector, what has simultaneously high sensitivity to neutrons, low sensitivity to gamma, high output of photons and high transparency and to find out optimal method of readout. Taking into account the described tasks the following scintillators technology based on Li and B reactions are considered:

1) Glasses 6Li:Ce3+
2) 6LiI:Euv2+
3) 6LiF/ZnS:Ag+
4) 6Li6Gd(Bo3)3:Ce
5) Cs2LiYCl6(Ce) (CLYC )
6) Boron laded plastics.

Key words: neutrons and gamma registration, scintillators, computer modeling, Helium-3 tubes.

1. INTRODUCTION

Technology of neutron registration is widely used in research activities, for example in experimental physics, as well in applied tasks: in energy industry (for monitoring of nuclear power plant fluxes) and for neutron activation analysis, neutron-neutron borehole logging, neutron captured therapy etc. Today the widely applicable technology for neutron registration is the use of detectors on base of helium-3. Increasing needs for helium-3 in short future will exceed the isotope production. The solution of the problem of helium-3 shortage is in search of alternative technologies for use in radiation portal monitors and other large area neutron detectors.

2. PROSPECTIVE TECHNOLOGIES FOR HELIUM_3 TUBE SUBSTITUTION

There are the following technologies for neutron registration: gas filling tube, scintillator, semiconductors and tracks. For replacement of helium tunes all types of detectors are applicable, but with dramatically different level of success. In framework of the current article the scintillator detectors are considered, with more or less available or planned to be available technologies. The list of chosen scintillators is in the Table 1.

3. NUCLEAR REACTIONS TO BE USED FOR NEUTRON REGISTRATION

To register neutrons in the discussed scintillators the following reaction are used:

\[ n + ^{6}\text{Li} \rightarrow ^{4}\text{He} + ^{3}\text{H} + 4.79 \text{ MeV} \]
\[ n + ^{10}\text{B} \rightarrow 7\text{Li}^* + ^{4}\text{He} \]
\[ \rightarrow ^{7}\text{Li} + ^{4}\text{He} + 2.31 \text{ MeV} + \gamma \ (0.48 \text{ MeV}) \ (93.7\%) \]
\[ \rightarrow ^{7}\text{Li} + ^{4}\text{He} + 2.79 \text{ MeV} \ (6.3\%) \]
\[ n + ^{153}\text{Gd} \rightarrow ^{156}\text{Gd}^* \rightarrow \gamma \text{gamma-ray spectrum} + \text{conversion electron spectrum}(0.039-0.199 \text{ MeV}) \]
\[ n + ^{157}\text{Gd} \rightarrow ^{159}\text{Gd}^* \rightarrow \gamma \text{gamma-ray spectrum} + \text{conversion electron spectrum}(0.029-0.182 \text{ MeV}) \]
4. Properties of chosen scintillators

To estimate applicability of scintillators on first stage it is necessary to analyze their properties. From this point of view the common physical properties are considered [1]. The organic and non-organic scintillators were investigated. The general physical scintillation’s properties are collected from the papers in Table 1.

The properties, substantial for alternative helium-3 tube substitution in radiation portal monitors should be considered separately.

If consider the possibility to use of scintillators in the frame of radiation portal monitors, firstly it is necessary to compare properties of scintillators and helium-3 tubes for the tasks, which are facing neutron detectors in radiation portal monitor. This is the task of neutrons radiation registration from small (on mass and activity) sources and keeping the ability to register neutrons in presence of high-fluxes of gamma. In the paper [2] the technical requirements for neutron detection efficiency and gamma detection efficiency are determined.

There are the following requirements:

1) Absolute neutron detection efficiency

\[ \varepsilon_{abs, n} = \frac{\text{number of pulses recorded}}{\text{number of neutron emitted from source}} \]  

(1)

Absolute efficiency is measured for source equal to 2 ng \(^{252}\text{Cf}\), located from 2 m form detector. Charged particles, emitted by source are shielded by 0,5 sm layer of lead. The detector is located in the moderator layer with thickness 2,5 sm.

2) Intrinsic gamma detection efficiency

\[ \varepsilon_{int, \gamma} = \frac{\text{number of pulses recorded}}{\text{number of photons striking the detector}} \]  

(2)

Intrinsic gamma detection efficiency is measured under condition of the same geometry, that for neutrons, but in presence of \(^{60}\text{Co}\) source. Exposure rate should be 10 mR/hour at the detector

The proposed requirements were investigated in the several papers. For example, in article [3] the required characteristics were measured and results for helium-3 tubes were presented in conditions of sources and detectors geometry. In the paper [4] characteristics of helium-3 tubes were simulated by software MCNP in the similar geometrical conditions. The results after modeling and experiments are the following \(\varepsilon_{abs, n} \geq 1.2 \times 10^{-3}\) (or 2-5 cps/ng of \(^{252}\text{Cf}\) in the specified test configuration), \(\varepsilon_{int, \gamma} \leq 10^{-5}\)


The numerical experiments were implemented. The conditions of experiments repeated conditions and modeling for helium tubes in the above mentioned papers (fig.1). The irradiation was done by point isotropic souce of \(^{252}\text{Cf}\) with corresponding fission neutron’s spectra. Scintillator (detector) from the front and back side are surrounded by polyethylene. The geometrical shape and dimensions of scintillators were chosen as cylinders as they available on the market recently (to be validated experimentally on the following stage of investigation). To compare the characteristics of different materials, the scintillators dimensions were the same for all types: diameter-100mm, height- 25mm.

For simulating efficiency on gamma irradiation the model of irradiation from the point isotopic source of \(^{60}\text{Co}\) was carried out. The same geometry (as for \(^{252}\text{Cf}\) on fig. 1.) was used

The modeling was done by software GEANT4. Number of particles emitted by source in every experiment was \(10^7\). Number of registered pulses were calculated taking into account reactions resulting charge particles and calculating energy deposition by produced particles. The threshold for cutting in framework of neutrons producing pulses accounting and calculation was 50 MeV.

6. Modeling results and characteristics comparison

The modeling results are shown in the table 2. For calculation of intrinsic efficiency the geometric factor was taken into account, the similar approach was used in paper [5]. The number of photons striking the detectors were collected in special tail, so interaction of gamma with materials of shielding (including polyethylene) were taken into account. To reach the above mentioned efficiency’s characteristics (for helium-3 tubes) the corresponding dimensions of scintillators should be used. At the first stage the similar dimensions were used to have possibility to compare simulated efficiencies for every material. It is understandable than the absolute efficiency will be reached with extended dimensions. Comparisons among absolute efficiencies are possible only among the scintillators itself. Data on efficiencies of helium-3 tubes were used for validation of GEANT4 application. The efficiency \(\varepsilon_{abs, n}\) for neutrons, absolute and intrinsic efficiency \(\varepsilon_{int, \gamma}\) for gamma.
7. CONCLUSION

As is seen from the Table 2 there is no one absolute leader – the best appropriate scintillator- material to meet the proposed criteria Crystal $^{6}\text{LiGd}(^{10}\text{BO}_3)_3$:Ce has the highest efficiency to neutrons with boron loaded plastics and Li-glasses on the second place. However $^{6}\text{LiGd}(^{10}\text{BO}_3)_3$:Ce has excessive high intrinsic efficiency to gamma, and further methods to separate signals registration gamma from neutron should be used. For $^{6}\text{LiGd}(^{10}\text{BO}_3)_3$:Ce it is not completely clear understanding of industrial making with required properties also.

Future plan of investigation is consist in conduction of optimization of geometrical parameters and isotope’s composition, and then validation experiments with simulated and selected models.

References


<table>
<thead>
<tr>
<th>Scintillator</th>
<th>Density (g/cm³)</th>
<th>Number of ⁶Li atoms/cm³</th>
<th>ρZ eff</th>
<th>Scintillation Efficiency</th>
<th>Emission Photon Wavelength (nm)</th>
<th>Light Yield Photon/MeV Neutrons</th>
<th>Light Yield Photon/MeV Photons</th>
<th>α/β Ratio</th>
<th>Lifetime, τ (ns)</th>
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<tbody>
<tr>
<td>$^{6}$Li glass (Ce)</td>
<td>2.5</td>
<td>$1.75 \times 10^{22}$</td>
<td>0.45%</td>
<td>395</td>
<td>7 000</td>
<td>4 000</td>
<td>0.3</td>
<td>75</td>
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<td>LiI(Eu)</td>
<td>4.1</td>
<td>$1.83 \times 10^{22}$</td>
<td>2.8%</td>
<td>470</td>
<td>51 000</td>
<td>12 000</td>
<td>0.87</td>
<td>1400</td>
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<tr>
<td>$^{6}$LiF/ZnS(Ag⁺)</td>
<td>2.6</td>
<td>$1.18 \times 10^{22}$</td>
<td>9.2%</td>
<td>450</td>
<td>160 000</td>
<td>75 000</td>
<td>0.44</td>
<td>1000</td>
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<tr>
<td>$^{8}$LiGd(¹⁰BO₃)₃:Ce</td>
<td>3.5</td>
<td>$3.3 \times 10^{22}$</td>
<td>25</td>
<td>385,415</td>
<td>40 000</td>
<td>25 000</td>
<td>0.32</td>
<td>200/800</td>
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<tr>
<td>Cs₂LiYCl₆:0.1:Ce</td>
<td>3.6</td>
<td>3.2</td>
<td>0.44</td>
<td>1000</td>
<td></td>
<td></td>
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<tr>
<td>Boron loaded plastic</td>
<td>1.023</td>
<td>$2.83 \times 10^{20}$ For $^{10}$B</td>
<td>425</td>
<td></td>
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<tr>
<th>Scintillator</th>
<th>$^6$Li Enrichment</th>
<th>Absolute Efficiency for Neutron Registration $\varepsilon_{\text{abs,n}}$</th>
<th>Absolute Efficiency for Gamma Registration $\varepsilon_{\text{abs,\gamma}}$</th>
<th>Intrinsic Efficiency for Gamma Registration $\varepsilon_{\text{int,\gamma}}$</th>
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<td>Li glass (Ce)</td>
<td>natural</td>
<td>1.675±0.012</td>
<td>1.502±0.013</td>
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<td></td>
<td>95%</td>
<td>1.837±0.008</td>
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<td>LiI(Eu)</td>
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<td>6LiF/ZnS(Ag⁺)</td>
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<td>1.644±0.008</td>
<td>1.553±0.020</td>
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<td>$^8$LiGd(¹⁰BO₃)₃:Ce</td>
<td>Natural B</td>
<td>2.321±0.013</td>
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<td>Enriched with $^{10}$B</td>
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<td>2.020±0.010</td>
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<tr>
<td>Cs₂LiYCl₆:0.1:Ce</td>
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<td>1.246±0.007</td>
<td>1.913±0.014</td>
<td>0.043</td>
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<tr>
<td></td>
<td>95%</td>
<td>1.416±0.008</td>
<td>1.913±0.014</td>
<td>0.043</td>
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<td>Boron loaded plastic</td>
<td>2.5% $^{10}$B</td>
<td>1.826±0.011</td>
<td>0.846±0.011</td>
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</table>
INFLUENCE OF SOME RISK FACTORS ON CHEST X-RAY FINDINGS IN PATIENTS WITH INITIAL PNEUMOCONIOSES

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Abstract. The aim of the study is to analyze the influences of different risk factors for appearance of p small round opacities as well as s, t and u irregular opacities on chest radiography in cases of borderline and initial forms of silicosis, and mixed pneumoconiosis, caused by quartz containing dust.

Materials and methods. A nested case control study of the p small round opacities and s, t, u irregular opacities (on chest x-ray, accounted according to ILO’80) found in patients with pneumoconiosis (silicosis, mixed pneumoconiosis) was done. The subject of the study were 480 miners in brown, black, anthracite coal mining, and lead - zinc mining, as well as 120 workers exposed to mixed quartz containing dust during the period since 1985 y. up to 2003 years. The group of unexposed individuals was composed by 121 persons. The average age of the exposed workers and the unexposed individuals were respectively 42.6 and 42.3 years. The average duration of the workers’ dust exposure was varied between 10.95 and 16.52 years. An anamnesis, pulmonary examination, posterior – anterior chest radiography (read by ILO’80), and spirometry were done. A statistical analysis by SPSS software was performed. Non-parametric analysis (Pearson Chi-Square Test, Fisher’s Exact Test etc.), Mean, Std. Deviation, χ², and Significance (P) were calculated.

Results and Conclusions: A significant trend of appearance of p 0/1, p1/0, p1/1 small round opacities on chest radiography in workers with initial pneumoconiosis with 11 years dust exposure, was detected. The average quartz exposure duration, related to appearance of initial p0/1 small round opacities was 12.42 years. A statistical correlation between s, t irregular opacities (ILO’80) and dust exposure duration were found (Pearson’s R = 0.458, P < 0.0001). The synergistic effects of tobacco smoking, alcohol consumption, and dust exposure duration play an important role for the appearance of s, t, u irregular opacities, and p small round opacities found on chest radiographies in dust exposed individuals.

Conclusions: The occupational dust exposure duration, tobacco smoking, and alcohol intake play an important role on appearance of pneumoconiosis, and they must be taken into account during preventive medical screening.

Key words: chest x-ray, pneumoconiosis, ILO’80, s, t, u, p opacities, dust, alcohol, smoking.

INTRODUCTION.

The x-ray shadows on lung radiography in patients with different forms of pneumoconiosis are influenced by many exogenous factors as tobacco smoking, alcohol abuse, occupational dust exposure, complications with infectious diseases, as well as rheumatoid arthritis etc (1 - 7). The aim of the study is to analyze the influences of different risk factors for the appearance of p small round opacities, as well as s, t and u irregular opacities on lung radiography in cases of borderline and initial forms of silicosis, and mixed pneumoconiosis, caused by dust containing quartz.

MATERIALS AND METHODS.

Nestled case control study of p small round opacities and s, t, u irregular opacities (on chest x-ray, accounted according to ILO’80 - 4) which are found in patients with pneumoconiosis (silicosis, mixed pneumoconiosis) was done. The subject of the study were 480 miners in brown, black, anthracite coal mining, lead - zinc mining, as well as 120 workers exposed to mixed dust containing quartz during the period till 1985 year up to 2003 year. The group of unexposed individuals was composed by 121 persons. The average age of exposed and unexposed workers was respectively 42.6 and 42.3 years. The average exposure duration of the workers varied between 10.95 and 16.52 years. A statistical analysis by SPSS software was performed.

RESULTS.

The distribution of the p small round opacities depending on duration of occupational exposure to dust in the group of exposed workers, and amongst the persons, unexposed to dust, was illustrated with fig. 1. There were not found p small round opacities on pulmonary radiography in 111(27.0%) unexposed persons and in 139(34.6%) workers, exposed to dust containing quartz during 10 years, as well as in 152 (37.8%) workers exposed to dust during 11 and more years period. It was established increasing number
and share of dust exposed workers with p opacities on lung x-ray (by ILO’80), related to increasing of exposure duration to occupational dust (Fig. 1). In 106 (46.9%) workers, exposed to quartz, were identified p small round opacities after 10 years exposure, as well as in 116(51.3%) workers - after 11 and more years exposure (Chi Square = 64.585; P<0.0001).

![Fig. 1 Distribution of p small round opacities related to occupational exposure to dust containing quartz in workers and in unexposed individuals](image)

The appearance of po/1, pt/o and pt/1 small round opacities was influenced by average exposure duration to occupational dust (mean) - Fig. 2. The appearance of initial pneumoconiotic p 0/1 small round opacities was related with 12.42 years duration of occupational exposure to dust containing quartz - See Fig. 2.

![Fig. 2 Influence of mean duration of occupational dust exposure upon p 0/1, p1/o and p1/1 small round opacities in exposed workers](image)

P small round opacities were detected amongst 43(19.0%) workers, who were non smokers, as well as in 185(81.0%) workers smokers (P<0.01). It was found statistically significant increasing of the number of po/1, and pt/1 small round opacities in the group of tobacco smokers, exposed to dust containing quartz in work environment air. (P<0.05).

P small round opacities were detected amongst 27(11.9%) workers, who were exposed to quartz, and who were not used alcohol, but 199(88.1%) were workers who have used alcohol (100ml hard alcohol per 24 h) - P<0.001. The share of po/1 and pt/o x-ray opacities in the group of workers who abused with alcohol was increased. Conversely, the x-ray share of po/1 up to pt/1 opacities were decreased amongst workers who were not consumed alcohol (P<0.001). It was detected a significant increase of p small round opacities amongst dust exposed workers who abused with alcohol, in comparison with the decrease of the share of p opacities in workers who didn’t consumed alcohol (P<0.001).

The influence of exposure duration to dust upon s, t and u small irregular opacities is illustrated with Fig. 3. The share of the low grade profusion of s, t and u irregular opacities after 10 years duration of dust exposure is higher amongst exposed workers in comparison to the share of the same x-ray impairments in individuals who weren’t exposed to dust. There was a significant progression of 2/1 to 3/3+ s, t, and u irregular opacities with increase of duration of exposure to dust up to 11 and more years (P < 0.0001).

![Fig. 3 Distribution of pneumoconiotic s, t and u small round opacities and duration of exposure to dust containing quartz in unexposed individuals](image)

We did not find s, t and u irregular opacities in 65(67.75%) unexposed workers, but in 49(9.2%) of them were found s and t opacities. S and t irregular opacities were detected in 226(42.6%) workers, occupationally exposed to dust up to 10 years period. The share of irregular opacities was increased in 256(48.2%) workers with rise of dust exposure duration to 11 and more years. Statistical significant correlation between s and t irregular opacities and dust exposure duration (Pearson’s R = 0.458;P<0.0001) was detected. It was detected dose/effect relationship between expanding of the interstitial pulmonary fibrosis and dust exposure duration. The number and the share of s, t and u irregular opacities with different x-ray profusion predominated amongst workers exposed to occupational dust in the work environment air. With increasing of the occupational exposure to dust containing quartz up to 11 and more years the number and the share of 2/1 up to 3/3+ s, t, and u opacities were increased up to 49(42.2%) - P < 0.05.

The number and share of the u 0/0 up to ½ irregular opacities was with trend to increase in intensity with increase of exposure duration to occupational dust, containing quartz up to 10 y. (156 persons = 41.1%) and more than 11 years (178 persons = 46.6%). U opacities were significantly more intensive in exposed individuals, than in unexposed group. u 2/1 to 3/3+ irregular opacities were detected rarely in exposed individuals, but there was trend of increment, and it might be related to the extension of duration of dust
exposure, respectively to 10 years - in 17(29.8%) persons, and 11 and more years – in 25(43.9%) individuals (P < 0.01). U irregular opacities might be manifestation of other events in the lung, including lung inflammation.

The distribution of s and t irregular opacities and their relationship to tobacco smoking amongst workers exposed to dust was analyzed. It was established increase of number and share of tobacco smokers with presence of s and t small irregular opacities – 40.4p.(76.1%), in comparison to non smokers - 127p. (23.9%) – Pearson’s R = 0.128; P < 0.01. The influence of alcohol abuse on the s and t irregular opacities from lung parenchyma in dust exposed workers was analyzed. S and t irregular opacities were found amongst 100(20.0%) persons, who were not consumed alcohol and in 425(80.0%) individuals who were abused with alcohol (hard drinks). Distinctly were predominated s and t irregular opacities amongst workers who abuse with alcohol (Pearson’s R=0.331; P < 0.001).

DISCUSSION

The detected pulmonary radiographic findings in dust exposed individuals were influenced by different exogenous factors (dust, smoking, alcohol abuse etc). The relationship between pulmonary x-ray impairments and different risk factors gave us information for some mechanisms in the pathogenesis of the pneumoconiosis, which influence upon the radio morphologic substrate. Initial p=1/1, p=0/1 и p=1/1 pneumoconiosis might arise after average 12.4 years occupational quartz exposure. We found a trend for appearance of p small round opacities after increasing of the average quartz exposure up to 11 and more years. The dust concentration and exposure duration are the main parameters of dust depot in the lungs in dust exposed workers. The basic radiographic pneumoconiotic finds (p=0/1, p=1/0 и p=1/1) were influenced by dust exposure duration, and they were interpreted as dose/effect relationships. The smoking influences the initial p small round opacities, and supports the development of pulmonary fibrosis in workers exposed to quartz containing dust. There was a trend of significant potentiating influence of tobacco smoking on appearance of initial p small round opacities on chest radiography. P small round opacities (p=0/1, p=1/0, p=1/1) were predominated on pulmonary radiography in alcohol abusers with occupational exposure to quartz containing dust. A significant trend for influence of alcohol on the appearance and progression of borderline p=0/1 and p=1/0, and initial p=1/1 opacities was detected. S and t irregular opacities appear in workers with occupational exposure to quartz or asbestos containing dust. S and t irregular opacities are X-ray signs of interstitial pulmonary fibrosis in dust exposed individuals. S and t irregular opacities, combined with borderline p=0/1 and p=1/0 small round opacities were assumed as manifestation of minimal interstitial fibrosis or initial silicosis. A dose/effect relationship between appearance of s and t irregular opacities and duration of occupational exposure to dust was detected. Tobacco smoking and alcohol abuse play important potentiating role for appearance of s and t irregular opacities in patients exposed to occupational dust (2, 6, 7).

CONCLUSIONS

1. We found dose/effect relationship between the average duration of occupational exposure to dust containing quartz and the appearance (after 12.42 years), and the progression of the initial p silicotic opacities amongst underground miners.

2. The appearance and progression of s and t irregular opacities are based on similar dose/effect relationship. 3. The duration of occupational exposure to dust, tobacco smoking, and alcohol intake play an important role on appearance and progression of pneumoconiosis, and they must bear in mind during preventive medical screening.

REFERENCES:


A COMPARATIVE TREATMENT PLANNING STUDY OF INTENSITY MODULATED RADIOTHERAPY AND 3-D CONFORMAL RADIOTHERAPY FOR HEAD & NECK CANCER

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2 Department of Physics, Çukurova University, Adana, Turkey

Abstract

The purpose of this study was to investigate the main differences and the advantages of Intensity Modulated Radiation Therapy (IMRT) in comparison to 3D Conformal Radiotherapy (3DCRT) for head & neck (h&n) patients. In this work, treatment plans of 20 h&n patients treated between 01.01.2011 - 01.01.2012 in Radiation Oncology Department at Çukurova University were prepared for both two treatment techniques and compared statistically. Target volumes described by radiation oncologists were classified according to the taken doses and the defined area planning target volume (PTV) as PTV1, PTV2 and PTV3. Dose values of minimum, maximum and V95% of the target volumes were determined as percentage for each specific definition and the dose values of organ at risk (OAR) were determined as Gray (Gy). Each result for these two techniques was compared in Eclipse Treatment Planning System (TPS) and the results were discussed according to the p values with using Student’s t-test.

Additionally, factor of Compatibility Index (Conformity Index, CI) was used to determine the extent which high dose region was compatible with PTV. Radiotherapy compatibility index is a very useful method to quantitatively determine the quality of radiotherapy treatment plans and to show the relationship between isodose distributions and the target volume.

Key words: h&n cancer, 3DCRT, IMRT, TPS.

1. INTRODUCTION

Early studies show that radiation therapy is of great importance to treat h&n cancer beside chemotherapy and surgery. Especially, h&n cancers generates 10% of whole body cancers and responsible for 4% of cancer deaths [1, 2]. Significant evolutions in the treatment efficacy of head and neck tumours have occurred with the development of IMRT [3, 4]. To obtain homogeneous dose distribution with high doses to PTVs and low damage to OARs are difficult due to the concave target volume being adjacent to radiosensitive organs at risk. Studies comparing 3DCRT with IMRT have demonstrated that dose distributions for several tumour sites have improved by IMRT. However, 3DCRT is still useful technique for some specific volumes in h&n region [5].

3DCRT treatment planning improves the accuracy of planning, providing both better coverage of tumor volumes and reduced doses of healthy tissues. As a more advanced form, a high dose of radiation to a localized tumour from multiple angles is given by IMRT planning. A large number of beams cover the target while minimizing the dose to the surrounding normal tissue. When side effects are reduced, the chance of eradicating the tumour is increased.

3DCRT treatment planning is a manual, repetitive and forward process with choosing fields and beam modifiers and modifications are made after the calculation of dose distributions. Contrarily, IMRT treatment planning is an inverse process with specifying the required dose distribution over the target and surrounding structures and an optimization algorithm calculates a fluence map for each field to provide the specification [6].

2. MATERIALS AND METHODS

In this study, Varian 600 C (Clinac DBX) linear accelerator (monoenergetic, 6 MV) with 120 multileaf collimator (MLC) and eclipse 8.6 TPS (Varian Medical Systems, Palo Alto, CA) were used in Çukurova University Radiation Oncology department. 3DCRT and IMRT plans were calculated with Analytical Anisotropic Algorithm (AAA) and IMRT plans were delivered using the sliding window technique.

20 h&n patients’ plans, 10 patients were treated using 3DCRT technique and 10 patients were treated using IMRT technique in the clinic before, were used for comparison. Both 3DCRT and IMRT plans were done for 20 patients to compare advantages and disadvantages over the targets and OARs as a part of the treatment planning study. Patients were chosen...
according to defined volume as 5 nasopharynx, 5 larynx, 5 oral cavity and 5 other regions (2 parotids, 1 hypopharynx, 1 nasal cavity and 1 oropharynx).

Patients were immobilized in the supine position with a 5-point thermoplastic mask. Treatment planning CT scans were obtained with 3-5 mm slice thickness.

PTV_{min}, PTV_{max} and D_{95\%} (dose received 95\% of the target volume) dose values of target volume, maximum and average dose values of OARs were compared for both techniques. Boost volumes were considered with lower dose target volume region and dose distributions were evaluated for all PTVs.

2.1. Dose assessment and planning techniques

In this study, more than one PTV was defined respectively as, PTV 1: Low dose region, low risk lymph nodes, PTV 2: High dose region 1, high risk lymph nodes, PTV 3: High dose region 2, primary tumour and the area around. Patients were classified as Table 1. To protect OARs and take into account the build-up region, corresponding PTVs were generated by adding 3-5 mm asymmetric margins to CTVs.

<table>
<thead>
<tr>
<th>PTV</th>
<th>PTV classifications of the patients</th>
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<tbody>
<tr>
<td>PTV1</td>
<td>18 patients 46 Gy 1 patient 48Gy 1 patient 50Gy 46 – 50 Gy</td>
</tr>
<tr>
<td>PTV2</td>
<td>10 patients 50Gy 3 patients 60Gy 1 patient 63Gy 56 – 63 Gy</td>
</tr>
<tr>
<td>PTV3</td>
<td>6 patients 66Gy 5 patients 68Gy 1 patient 70Gy 66 – 70 Gy</td>
</tr>
</tbody>
</table>

5 field 3DCRT (70\(^\circ\)-150\(^\circ\)-180\(^\circ\)-210\(^\circ\)-290\(^\circ\)) and 9 field IMRT (0\(^\circ\)-40\(^\circ\)-80\(^\circ\)-120\(^\circ\)-160\(^\circ\)-200\(^\circ\)-240\(^\circ\)-280\(^\circ\)-320\(^\circ\)) plans were applied for 20 patients (see Fig. 1). For 3DCRT plans, 15\(^\circ\) and 345\(^\circ\) couch angle was used for left and right AP obliques. 90\(^\circ\) collimator angle was used for PA field to protect medulla. Beam weights calculated as; 84\% AP obliques, 12\% PA obliques and 4\% PA.

5 field 3DCRT planning technique was used for PTV1 volume for the patients except two parotid patients. AP and PA fields were used for both parotid patients to avoid from any dose to oral cavity.

In IMRT, it is suggested to use five to nine directions depending on the tumour and patient geometry to obtain the almost optimal dose distribution without the need for direction optimization [7]. Thus Ferreira et al. were tested beam configurations using five, seven or nine equidistant photon beams of 6MV for all patients [8]. Cozzi et al. used five isocentric photon fields arranged with two laterally opposed fields, two posterior-oblique fields shielding the spinal cord, gantry angles at 210\(^\circ\) and 150\(^\circ\), and one posterior field with a similar partial coverage of the target above the spinal cord projection in 3DCRT technique for five h\&n patient plans. In IMRT, they prepared five and nine equally spaced fields with gantry angles at 36\(^\circ\), 108\(^\circ\), 180\(^\circ\), 252\(^\circ\), 324\(^\circ\) and 20\(^\circ\), 60\(^\circ\), 100\(^\circ\), 140\(^\circ\), 180\(^\circ\), 220\(^\circ\), 260\(^\circ\), 300\(^\circ\), 340\(^\circ\)[9].

2.2. Evaluation methods

Comparisons were made by the evaluation of Dose Volume Histogram (DVH) and dose distributions on the planning system. DVHs were used to analyze the doses of OARs and target volumes (PTV, GTV). Patients were evaluated due to their PTV classifications as respectively; PTV1-2 (nasopharynx3, oral cavity1-2-4-5, larynx2-4, and parotid2), PTV1-3 (nasopharynx4, larynx5, oral cavity3, parotid1, hypopharynx and nasal cavity) and PTV1-2-3 (nasopharynx1-2-5, larynx1-3 and oropharynx).

Emami et al. presented a comprehensive set of dose tolerance limits for normal tissue organs to therapeutic radiation [10]. Using dose limits for the OARs for h\&n radiotherapy (RT), surrounding tissues were defined for each group cases. Dose limitations for both target volume and OAR are shown in Table 2.

Table 2 Dose limitations of h\&n patients [10-12]

<table>
<thead>
<tr>
<th>OARs</th>
<th>D_{max} \leq 54 Gy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brain</td>
<td></td>
</tr>
<tr>
<td>Steam</td>
<td></td>
</tr>
<tr>
<td>MS</td>
<td>D_{max} \leq 45 Gy</td>
</tr>
<tr>
<td>Optic Nerve</td>
<td>D_{max} \leq 55 Gy</td>
</tr>
<tr>
<td>Lens</td>
<td>D_{max} \leq 6 Gy</td>
</tr>
<tr>
<td>Eye</td>
<td>D_{max} \leq 50 Gy</td>
</tr>
<tr>
<td>Parotid</td>
<td>D_{max} \leq 26 Gy</td>
</tr>
<tr>
<td>Larynx</td>
<td>D_{max} \leq 30 Gy</td>
</tr>
<tr>
<td>Oral Cavity</td>
<td>D_{max} \leq 45 Gy</td>
</tr>
<tr>
<td>Thyroid</td>
<td>D_{max} \leq 45 Gy</td>
</tr>
<tr>
<td>Brain</td>
<td>D_{max} \leq 50 Gy</td>
</tr>
</tbody>
</table>

Target Volumes

<table>
<thead>
<tr>
<th>GTV</th>
<th>100 %GTV \geq 98% Defined Dose</th>
</tr>
</thead>
<tbody>
<tr>
<td>PTV</td>
<td>100% PTV \geq 95% Defined Dose</td>
</tr>
</tbody>
</table>

CI values were calculated as a yield of two parameters. One of them is PTV volume where target volume’s dose reaches 95\% of defined value and the other parameter is normal tissue volume shown below.

\[
CI = \frac{V_{PTV,95\%}}{V_{PTV}} \times \frac{V_{PTV,95\%}}{V_{T}}
\]

CI has values between 0 and 1. If this value is unitary (equal to 1), it shows that 95\% of isodose has a certain concordance with PTV [13].
Statistical importance of the difference between dose parameters of two planning techniques is stated using two-tailed Student’s t-test. If p value which is a test factor of the difference between two parameters is lower than 0.05, it means that parameters are totally different from each other. If the value is bigger than 0.05, it can be said that these two parameters are very similar. That’s why, it is expected that p value is lower than 0.05 for the values which IMRT technique is ascendant comparing with 3DCRT.

3. RESULTS

3.1. Dose distributions and DVHs

3DCRT and IMRT plans of 20 h&n patients were evaluated to see the differences according to dose distributions for surrounding structures. Especially, the most attention was given to medulla spinalis (ms) and parotid glands. A tolerance of the medulla most often limits the dose to 45–50 Gy and it is suggested not to exceed 45 Gy as a maximum dose [11].

Fig. 2 Dose distributions at 45 Gy to show protection of ms with IMRT (left) and 3DCRT (right)

It is clear that IMRT shows better protection in contrast with 3DCRT as seen in Fig. 2. Also, IMRT plans provided better PTV coverage for all defined targets.

The most important complication occurred during the treatment due to the less parotid protection is xerostomia. That’s why, it is important to known the doses of parotid glands. Protection of parotid glands was shown by comparing isodose (see Fig. 3).

Fig. 3 Dose distributions at 45 Gy to show protection of parotid glands with IMRT (left) and 3DCRT (right)

OAR dose values were below the suggested dose limits with IMRT. The most important difference was usually seen at parotid glands. One of DVH comparison is shown in Fig. 4 for an oral cavity patient.

Fig. 4 DVHs of an oral cavity patient showing PTV, ms and parotid gland for IMRT (□) and 3DCRT (Δ)

3.2. Target coverage

Defined target volumes of the patients were compared for both techniques according to their PTV classifications. Results were evaluated separately among three PTV groups and results were used to calculate p value for each group. According to the comparison for the patients of PTV1-2 group, main differences were found as PTVV95% (0.002) and Dmax (0.049). For the patients of PTV1-3 group, PTVV95% (0.018) and for the patients of PTV1-2-3 group, PTVV95% (0.004) and Dmax (0.001).

Nasopharynx1-2-3-4-5, hypopharynx, oropharynx and nasal cavity patients were also evaluated according to the coverage of their GTV’s. “p” values of dose minimum, maximum and v95% are 0.001 for each.

3.3. OARs

In this study for nasopharynx patients, OARs were defined as brain steam, ms, lenses, optic nerves, brain, eyes, parotid glands, larynx, thyroid, oral cavity. “p” values of parotids and larynx were very close to 0, brain, lenses and optic nerves were 0.03, oral cavity and thyroid were 0.01.

For oral cavity patients; ms, brain, brain steam, parotids, larynx and thyroid. “p” values of parotids was 0.01.

For larynx patients; ms, brain, brain steam, oral cavity, thyroid and parotids. “p” value of parotids was 0.04.

For parotid patients; ms, brain, brain steam, oral cavity, opposite parotid. “p” value of larynx was 0.04.

For hypopharynx and oropharynx patients ms, brain, brain steam, oral cavity, thyroid, parotids. “p” value of brain steam is close to 0.

3.4. Conformity Index

CI values calculated by Eq.1 were used to see the concordance between isodose and PTV. The result shows the relation for 20 h&n patients in Table 3. IMRT shows better conformity than 3DCRT.

The conformity of the prescription isodose to PTV is relatively low in h&n area according to other regions due to concave shapes of target volumes and the vicinity of the high number of critical organs close to target.
For the target volumes, the main differences were seen in $D_{\text{max}}$ and V95% dose values of PTV and $D_{\text{max}}$, $D_{\text{min}}$, and V95% dose values of GTV. "p" values of target volumes were found as $p<0.05$ for all patients.

In treatment, nine-field IMRT is superior to five-field 3DCRT concerning tumour coverage and conformity. Several studies have shown the importance of IMRT comparing with 3DCRT [7-9]. However, the major gain with IMRT is the reduction in dose to OARs and non-specific normal tissues.

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THE ROLE OF FORENSIC RADIOLOGY IN THE PROCESS OF FORENSIC EXPERTISE AND INVESTIGATION

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Abstract. Forensic Radiology is a science which takes an important place among the medical and forensic sciences. Based on this fact, the focus of this paper is to show where and how forensic radiology helps in solving, processing and analysis of the cases.

The materials used for the analysis were the autopsy cases at the Institute of Forensic Medicine and Criminology in Skopje where the X-ray investigations were carried out with Shimadzu’s mobile X-ray equipment in order to determine the mechanism of injury in car accidents, fall from heights, distinguish missiles and other foreign objects in firearm injuries, verify the identity of unidentified persons by comparing the ante-mortem with post-mortem facts, as well as identification of living individuals by ossification of the bones.

The X-ray investigation significantly improved and simplified the analysis of mechanism of death, because it allows the analysis to be repeated even after the forensic autopsy is finalized and provides permanent evidence in further court proceedings.

Key words: forensic radiology, x-ray, expertise, investigation

INTRODUCTION

Forensic radiology has an important place among the forensic and medical sciences. It plays a significant role in determining the mechanism of injury in traffic accidents, falls from height, determination of presence of missiles and other foreign objects in injuries caused by firearms, determination of the age of unidentified persons and identification of living individuals by assessing the degree of the bones ossification on X-ray.

Forensic radiology was used for the first time in the UK, few weeks after the discovery of the X-rays by Wilhelm Roentgen in 1895.

MATERIALS AND METHOD

For the purpose of this paper, we used X-rayed autopsied cases from our Institute and examined living individuals in order to determine the age of the unidentified ones. We processed deaths from traffic accidents, falls from height, detection of missiles and other foreign objects in injuries, establishing identity, determining the age of living individuals by X-rays on the hands, thus assessing the degree of bones ossification. This paper presents seven cases, out of which six deaths and one alive.

PRESENTATION OF THE CASE


The recently deceased pedestrian, died immediately on the scene of the accident due to the sustained injuries. X-ray was performed on the pelvis, chest, head, upper legs, lower legs, upper arms and forearms, followed by autopsy.

Fig. 1 pelvic fracture; Fig. 2 ribs fracture; Fig. 3 head fracture; Fig. 4 femoral fracture; Fig. 5 upper arm fracture
Case 2 - Fall from a height with SP 15882/23-14. The received information described that the recently deceased jumped from the eighth floor of a construction site and died at the scene of the accident due to the sustained injuries. X-rays of the chest, pelvis, knees and knees was done, followed by an autopsy.

Case 3 - Perforating gunshot injury with SP 15890/31-14. The received information describe that the recently deceased was killed in a shootout. X-rays of the head was performed, followed by an autopsy.

Case 4 - Other foreign objects, case with SP 15827/312-13. During the crime scene investigation, information has been received that a construction worker fell in a space envisaged for an elevator, in a construction building with several levels of scaffolding and died immediately on the scene of the accident. In the right facial area, we detected presence of knife blade. Head X-ray was performed, followed by an autopsy.

Case 5 - Determining the age of unidentified persons and alive. A.S. Female. A little girl has been brought from the Centre for Social Care, previously found at the bus station and left without identity documents. She only knew her name and the fact that she has been left by her mother. X-ray of the right palm has been performed to determine her age.

Case 6 - Determining the age of skeleton remains with SP 15883/24-14. Information have been received that bones have been excavated near a monastery, in the surrounding of the city of Tetovo, Republic of Macedonia. X-ray of the undamaged upper arm bone has been performed.
Case 7 - Injuries by blunt hard force, with SP 15601/86-13. Information are received that the recently deceased died on the scene of the accident due to head injury. Data from the investigative organs indicate that the trauma has been caused by blunt force (brick and adze). The body of the recently deceased was X-rayed, followed by an autopsy.

RESULT AND DISCUSSION

Case 1 – Pelvic X-ray (picture 1) shows double bilateral pelvic ring fracture, localised on the pubic rami. Chest X-ray (picture 2) shows fractured right scapula (shoulder blade) and serial bilateral fracture of the ribs. Head X-ray (picture 3), shows depressed fracture in the left temporal area, linear fractures of the other head bones, the jaw and the facial bones. The right upper leg X-ray (picture 4) shows femoral neck fracture (fractura coli femoris), multi-fragmental, inter-condylar fracture in the distal diaphysial area, with dislocated fragments and luxation of the condyles. We have also found reduction of the joint space. X-rays of the right upper arm and forearm (picture 5) detect fracture at the level of the upper diaphysis, around the surgical neck of the humerus (upper arm bone), with dislocation and rotation of the head of the upper arm bone. Fractures in the lower third of the diaphysis of the upper arm bone can be also detected, apparent multi-fragmental, inter-condylar fracture, with visible luxation, dislocation and rotation of the medial and lateral condyle. The X-ray of the distal part of the ulna in the area of the proximal end of the olecranon shows multi-fragmental, complete fracture with dislocation. There is also a visible dislocation of the elbow.

After the analysis of the detected fractures and the autopsy findings, we can conclude that the pedestrian was hit by a high vehicle (van). The primary contact was in the right rear area of the body, as indicated by the fracture of the right scapular bone, shoulder area and right thigh bone. We also note multiple trauma.

Case 2 - On the chest X-ray (picture 6), we note bilateral fracture of the ribs in two lines, with dislocation of fragments on the left side. From the pelvic X-ray (picture 7) we can conclude multi-fragmental fracture, fracture of the second lumbar vertebra, bilateral fracture of the two inferior pubic rami and bilateral fracture of the sacroiliac joint. Knee and lower leg X-ray (picture 8) shows multi-fragmental fracture with dislocation of fragments in the area of the middle and the upper diaphysis of the tibia.

After the analysis of the bone fractures and from the autopsy findings, we can conclude that during the fall, the deceased first contact with the base was with his left foot, than followed by the buttocks and the back.

Case 3 – In this radiological analysis (picture 9), at the height of the left temporal area in the head, we note a presence of a metal fragment, which best suits the description of a missile shell being shot in the head. At the level of the right upper temporal edge and the lower edge of the parietal bone, we can detect metal fragment corresponding to a shape of a missile. Between the shell of the left side and the missile on the right side, there are smaller metal fragments, which clearly point the precise direction of the channel created by the missile’s movement.

From the X-rays reading and the autopsy findings, we can conclude that the deceased had a perforating gunshot injury on the head, moving in direction from the left to the right and slightly up.

Case 4 – With the X-ray examination of the head (picture 10), shows metal foreign object, shape corresponding to a blade of a knife, which goes under
the soft tissues of the right side of the face and does not damage the facial bones or enters the skull (cranium).

The findings of the autopsy and X-ray readings lead us to a conclusion that the knife is not connected with the cause of death. Data obtained from the investigative bodies clarified that the employee had a knife in his right upper pocket, which means that during his fall the blade accidentally stabbed in the facial area.

Case 5 - From the right hand X-ray (picture 11), we can ascertain the presence of the following ossification cores:
- Os Capitatum and Os Hamatum - 3-5 months of age; Os Triquetrum - 1-4 years of age, usually 3 years old; Distal epiphysis of Os Radius - 2 years old; Epiphyses of metacarpal bones and phalanges - 2-4 years old; Ossis metacarpalia - 5 years old

Data obtained from hands X-rays of A.S., tell us that there are ossification cores at the three of the meta-carpal bones, the distal epiphysis of the radius and meta-carpal bones. The latter suggests that the age of the child at the time of the forensic analysis has been between 4.5 to 5 years.

Case 6 - From the X-ray of the upper arm bone (picture 12) it is concluded that the medullar channel is completely lost in spongious substance. This finding indicates older age, that the excavated bones belong to a person over 70 years old.

Case 7 - The reading of the skull X-ray (pictures 13, 14, 15) confirms the presence of depressing, multi-fragmental fracture with dislocation of fragments in the right temporal-occipital area and fragmented bone fractures of the middle and posterior cranium on the right side of the head. From the autopsy and the X-ray readings, we can conclude trauma by blunt force, which operated in multiple areas and directions on the right side of the head.

From the above presented cases, we can conclude that the forensic radiology has important role in determining the type of the force, the means by which the injuries are inflicted and the direction of the force. With the X-ray analysis, depending on the case requirements, the forensic examiner can continue the analysis even after the autopsy is completed. Hence, this provides specific indicator for the condition, which can be further used as reliable evidence in the subsequent case analysis.

CONCLUSION

The radiological investigation in the forensic medicine is of a great importance, as a method that helps the forensic examiner analyse the injuries. With the X-rays investigation of the bone fractures and the autopsy findings, we can promptly and effectively respond about the mechanism of injury. Moreover, the X-ray investigation helps in the detection of missiles, missiles fragments and other foreign objects in the body of the deceased and thus helps in determining the direction of the missiles channels and contributes to a faster completion of the autopsy and case solving. With regard to the X-ray investigation used in determination of the age by analysis of the ossification cores of the hand bones of children, as well as analysis of the medullar channel in adults, we can say that the X-ray investigation is indispensable.

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Abstract
In this article, we would like to present our work at CVREZ on (i) our objectives in utilizing Gamma Irradiation facility, (ii) technical description of the facility (iii) special features and equipment’s that will be installed (iii) methodology for specific experimental test set-up that will enable to perform the experimental studies at high/extreme temperatures, cryogenic temperature’s and in inert environment, (iv) summarize modern material characterization tools available at CVREZ and (v) finally report about experiments intended to perform in the facility and its usefulness to society.

Key words: Gamma irradiation facility, new experimental apparatus, material testing, elevated andcryogenic temperatures

1. INTRODUCTION

The commercial usage of Gamma irradiation facilities started in early 1950’s. Till date, the users, demand and network of gamma irradiation facility centers are growing rapidly to support industries as well as in research. A trend in the exponential growth in usage and fields of application of these facilities can be found elsewhere [1]. A trend in the statistics of cobalt source usage until 2003 is represented graphically in Figure 1. The specific reason for its growth is that the ionizing radiation can amend the physical, chemical and biological properties of the materials that are irradiated. Irradiation of materials by gamma source is a simplified technology and the depth of penetration is deeper. At present, its beneficial applications are in the fields of biological, chemical, solid state physics, medical, food sterilization and materials modification (polymerization, crosslinking) etc. [2-8]. With its increasing demand in usage and gained technological experiences, versatile applications are being developed and there is tremendous variation in design of each irradiation facilities that are being built now-a-days.

2. CURRENT STATUS OF THE GAMMA IRRADIATION FACILITY AT RESEARCH CENTER ŘEŽ (CENTRUM VÝZKUMU ŘEŽ, CVREZ)

Cobalt -Co60 irradiation facility at Research Center Řež in Czech Republic was installed in the year 1960’s by joint collaboration of Nuclear Research Institute (NRI) and Institute for Research, Production and Usage of Radioisotopes (ÚVVVR in Czech). Until the year 2002, this facility was dedicated to perform the research activities related to physics, electronics and chemical analysis.
CVREZ it makes possible to perform pre and post-irradiation examinations of the materials to study their response to gamma irradiation and to identify the key alterations/developments.

3. Investigating for SUSTAINABLE MATERIALS

The refurbishment of the current multi-purpose type gamma irradiation facility has the following prominent objectives. Firstly it is the reliable approach to qualify and quantify lifespan of materials that are subjected to ionizing radiation used in Nuclear Power Plants (NNP’s). For instance, rubber composite seals are used in the electrical equipment’s of NPP’s, where they may be exposed to high-energy radiation and heat. Under the above mentioned conditions, depending on their level, can lead to the degradation of the seals and therefore shorten their lifespan [9] [10]. Secondly, there is great research interest to study the radiation effects in metallic materials susceptible to ionization damage. For example, there is a renewed research interest to understand its impact on radiation-induced embrittlement of ferritic steels used as structural material in NNP’s because gamma rays can induce atomic displacements in metals [11]. Furthermore the facility also provides feasibility to perform hardness testing of electronic-component, materials properties testing, examinations of various physical and chemical processes, to simulate electron-rich environments for space environments, to study gamma irradiation effects on solar technology components, etc. Above illustrated scientific research topics brings our attention to design and develop new experimental apparatus for the gamma irradiation facility to characterize materials. They include:

- Propylene rubber seals, metal-polymeric composites and metallic components etc.
- Light emitting diodes, pin-type photo-detectors and optical fibers.

4. DESCRIPTION OF THE INSTRUMENTATION

4.1 A brief description of the Gamma Irradiation Facility at CVREZ

Irradiation facility at CVREZ is a self-contained compact dry type irradiator with Cobalt –60 as source. It was designed and constructed for the purpose of the execute carrying out research activities. It can also be used for the applications that involve small doses and relatively small throughputs. The irradiator’s schematic design is shown in Fig. 2, with the following characteristics listed in Table 1.

Table 1 Characteristics of CVREZ gamma irradiation facility

<table>
<thead>
<tr>
<th>No.</th>
<th>Characteristics</th>
<th>Source</th>
<th>Source Capacity</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Cobalt-60 capacity</td>
<td>200 TBq</td>
<td>Cylindrical</td>
</tr>
<tr>
<td>2.</td>
<td>Source geometry type</td>
<td></td>
<td>Capsule</td>
</tr>
<tr>
<td>3.</td>
<td>Shield walls material</td>
<td></td>
<td>Concrete</td>
</tr>
<tr>
<td>4.</td>
<td>Shield doors material</td>
<td></td>
<td>Lead</td>
</tr>
<tr>
<td>5.</td>
<td>Source hoist mechanism operation type</td>
<td>Manual, Rack and Pinion type</td>
<td></td>
</tr>
</tbody>
</table>

Foremost advantage of the self-contained compact type irradiator is due to its simple design, ease in installation and operation. The irradiation facility has chamber as shown in Fig. 2 built with concrete, with a wall thickness of app. 1.45 m. Chamber is divided into two parts bottom part (shielded storage room) and the upper part (irradiation room). Bottom part is to place the source in dry conditions. Source can be moved from the loading position (bottom part) to the irradiation position (irradiation room) with the help of Rack and Pinion source hoist mechanism that is operated manually from outside the chamber. From Figure 3 of the irradiation chamber, one could see the provision for the maintenance purpose or for source replacement that is sealed with several lead blocks of required thickness (as per calculations). Chamber has tunnel to feed the test samples and lead shielding block inside to cover the inner surface of tunnel, when the source is in the irradiation room. Chamber tunnel and pulleys of the source hoist drive mechanism are depicted in Fig.3. The uniqueness of the design remains on rotating the source hoist mechanism that is assembled with the lead shielding block to close the tunnel. When the source is in the bottom part of chamber i.e. shielded storage room, the tunnel shielding lead block is away from its closing position and makes provision to feed samples into the irradiation room. On the other hand when the source is moved to the upper part i.e. into the irradiation room with the help of hoist mechanism, the tunnel shielding lead block completely shields the tunnel. The outer surface of tunnel is closed by a manually operated rectangular lead block as shown in Fig.4. This attenuates the radiation originating from the source and maintains radiation level at the location of work to natural background. Prominent work at present in CVREZ involves replacement of Cobalt-60 source with activity of 200 TBq and upgrade some of the technical features but still keeping the originality of the facility.

4.2 Objective and Description of experimental Apparatus for Gamma Irradiation Facility

Objective: We present here, 3 most important topics out of our research interests that drawn our attention to design and develop new experimental apparatus for the gamma irradiation facility to characterize materials. They include:

1. Electrical system unit in a nuclear power plants consists of several components. For instance some of them are light emitting diodes, pin-type photo-detectors and optical fibers, Ethylene propylene rubber seals, metal-polymeric composites and metallic components etc. Under normal
environmental conditions these materials possess good mechanical properties/chemical stability. The qualifications of these materials for usage in the NPPs under radiation environments and at high (elevated) temperatures are desired for their better performance.

Fig. 2: 3D schematic design of the compact type Irradiation Facility at CVREZ.

Fig. 3: Chamber tunnel for feeding experimental set-up.

2. Space research occupies a vital role in the current developments. Solar cells are being extensively used in satellites as auxiliary power sources. Also, they comprise of many electronic components like HCMOS devices, transistors- SiGe HBTs, Si-JFETs, rad-hard MOSFETs, and GaAs MESFETs etc. requiring operation at cryogenic temperatures. These components are particularly sensitive to electromagnetic radiation such as x-rays and gamma-rays (γ-rays).

3. Polymers and Polymer composites are significantly used now-a-days in almost all applications. For example, polymer-carbon fiber composite has tremendous usage. Ionizing radiation at different temperatures has been found as an effective approach to enhance the structure as well as properties of polymers and their composites.

**Description of the Experimental apparatus:** The specific design of the experimental apparatus depends on the type of irradiation facility. In this current situation, the simplicity of CVREZ gamma irradiation facility with feeding tunnel, shown in Fig. 2-4 makes feasible to develop experimental apparatus. In Fig. 5, the preliminary design of experimental apparatus has been illustrated. It consists of basically 2 parts i.e. Part A: Test chamber and Part B: Head. The other parts of the experimental apparatus consists of programmable temperature controller unit for heating elements, cryogenic tank for liquid helium/nitrogen, low/high vacuum pumps, solenoid valve to control cryogenic liquid flow into test chamber and telescopic dosimeter.

The head part of the experimental apparatus has a provision for mounting the test specimen. It has also vacuum hosing, heating elements, cryogenic liquid hosing, pressure sensor and thermocouples. The cryogenic tank and the vacuum pumps will be connected to the respective hosing and are present out-side of gamma irradiation facility. Only the experimental apparatus will be passed into the tunnel of gamma facility, as shown in Fig. 6. By passing the head into the test chamber and locking them by clamps one could create the vacuum inside the test chamber i.e. Part A to the desired level. It is also possible to allow the inert gas into test chamber and pump-out to create a clean atmosphere in the test chamber. Instead of inert gas, it is also possible to direct the cryogenic liquid into the test chamber instead of inert gas. This set-up will help to perform experiments at cryogenic temperature under gamma radiation. On the other hand, after the vacuum creation step, avoiding the cryogenic liquid flow step, the specimen temperature could be raised to desired level (20°C - 400°C) by heating elements.

In the heating experiments mode, since the heating elements will be coupled with the programmable temperature controller unit, test temperature could be maintained stable throughout the test period. In cryogenic mode experiments, solenoid valve will control flow of the liquid helium/nitrogen into test chamber. Solenoid valve is
connected to the programmable temperature controller unit. When the temperature in the test chamber drops down, it detected by thermocouples and information is sent to programmable control unit that lets the solenoid valve to open allowing flow of liquid helium/nitrogen and vice-versa. Detailed arrangement of experimental apparatus with different units is shown schematically in the Fig. 7.

5. CONCLUSION

Preliminary design of the experimental apparatus of gamma irradiation facility has been described. There is further scope to enhance some of the technical aspects and optimize the design. The experimental apparatus that will be developed in-house should provide flexibility to execute the intended pilot scale studies. At CVREZ, it is planned to have the gamma facility with new source and experimental apparatus in full working conditions by 2015.

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REFERENCES

SUMMARY OF THE METHODS USED TO LOWER THE ANXIETY PARAMETER - STRESS INDEX (T) - ACCORDING TO THE MEASUREMENTS MADE WITH THE GDV CAMERA

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Abstract. In this article, we have tried to systematize the experiments made with the GDV (Gas Discharge Visualization) Camera and the afferent special software, focusing mainly on the Anxiety parameter – referred to as Stress Index (T) as it was defined by Dr. Konstantin Korotkov, the inventor of this method. The GDV method is a non-invasive method of extraction of information from the properties of the biological energy field through a non-linear mathematical analysis of the fractal images obtained by photographing the discharge of the 10 fingers in a high frequency field, followed by the processing of the images with the aid of some special software.

By studying the stress index we are able to estimate the type of interaction between man and environment. The anxiety or stress parameter (T) is based on the hypothesis that the difference between the mental and physical field represents the level of anxiety. This hypothesis has been confirmed by psychological tests (POMS – Profile of Mood States). The decrease of this parameter was done through different methods: Art of Living Programme, dance therapy, music, sounds created by specially tuned crystal bowls, states changed by consciousness, the ingestion of colloidal solutions etc. These methods are presented in a number of dissertations from Holos University in the USA (Gibson, Cowan), Romania (Mohirta, Manolea), as well as the experiments conducted by the above-mentioned authors.

Key words: GDV, Stress Index, Electro-Colloidal Silver (ECS), Bio-Energy Field

1. INTRODUCTION. STRESS

The methods used to reduce stress, e.g. Qi gong [1], meditation [2], hypnosis [3], sounds created by the crystal bowl [4], even music therapy [5] have a guaranteed efficiency, but at the same time they also have some disadvantages, i.e. they require a lot of training and assistance from a qualified person, e.g. a psychologist, they have to be performed in an adequate environment, e.g. practice – meditation room etc. Any type of psycho-emotional tension can cause these activations that can be perceived as states of stress. We consider that any type of method of reducing stress that has been applied by a person and has had results, no matter if it is simple or complex is considered to be beneficial.

1.1. Briefly about stress

Firstly, it is important to mention that stress is not necessarily a bad thing, i.e. it is the natural/normal reaction of the organism, when it is subjected to a sudden aggression [1]; when the level of stress is low, it plays an important role in increasing the capacity of adaptation to a potential danger. Stress activates the neuro-vegetative, endocrine and tissue factors, which produce symptoms located in different parts of the body, depending on each person.

The excess of stress is manifested through, excessive eating, alcohol consumption, smoking, drug abuse, sleep deprivation, lack of patience, reckless driving, irascibility, apathy or depression etc. The German physicians W. von Holst and W. Kühni remarked, in their “Koloidale silber als medizin” [6], the fact that silver, especially in its colloidal form, is more and more often nicknamed “natural antibiotic”, but this fact only refers to a small part of its action spectrum, and it does not explain, for example, its action upon viruses, its capacity to accelerate the closing of wounds [7,8] or to ameliorate pain [9,10], or its anti-depressive effect.

2. THE AIMED OBJECTIVES ARE:

- to determine, with the aid of the GDV camera, whether ECS produces measurable effects upon the parameters of the human body, notably upon the Stress Index, and to make the statistical analysis of the obtained results.

- to compare the evolution of the Stress Index after the ingestion of ECS with the results obtained through other methods, measured with the GDV camera, and presented and statistically validated in different PhD theses [2,3,4,5].
3. ABOUT ELECTRO-COLLOIDAL SILVER SOLUTION (ECS)

The electro-colloidal silver solution (ECS) used in the experiments is a liquid mineral food supplement with concentrations of 25 ppm. It has a slightly bitter taste and it is made up of only two elements, i.e. distilled and structured water and silver particles of nanometric dimensions with high purity: 99.99%.

4. GDV CAMERA METHOD

The device and method named GDV were developed by a team coordinated by Professor Ph. D. Konstantin Korotkov in Russia in 1995. Currently it is used by hundreds of researchers and physicians in over 60 countries (www.korotkov.org, www.ktispb.ru). After almost 20 years of use of the “GDV” term, another term has started being used: that of Electro-photonic Capture (EPC), as it is considered to define this procedure more accurately. The GDV/EPC method is a remarkable extension of the Kirlian effect, of the images of the photonic emissions resulted from the stimulation in electromagnetic field, followed by computed processing with dedicated software using the nonlinear fractal analysis [1].

By making measurements of the ten fingers and using complex software, a distribution image of the human energy field is created. The principle relies on the connection of the different areas of the fingers to different organs and systems of the body through energy meridians described by Asian medicine [11]. This idea was first put forward by Dr. Voll in Germany. Later it was developed by Dr. Mandel in Germany and then it was clinically verified and corrected by a team coordinated by Dr. Korotkov in Russia.

GDV is certified as a medical device in Russia and Europe. The FDA certification procedure for this device in the USA is in course.

PhD Nancy Rizzo Roberts has conducted an interesting study, in which she compared the results obtained by the GDV Camera after an acupressure treatment with those obtained after a placebo treatment. The results were statistically analyzed and they confirmed that the GDV method can detect the changes produced by acupressure in the human body.

The advantages of using the GDV/EPC technique are numerous [12, 13]. Among them we remind the non-invasive, simple, safe and sterile technique. It simply records the pictures of the fingers.

4.1. Value intervals of Stress Index (T) established by the prof. K. Korotkov

The usual values of T range between 0.30 and 0.73 [1]. Thus, 0-2 = low level of stress – a calm and harmonic state (this can be caused by a weakened energetic functional level of the organism, a person under the influence of sedatives etc.) which can also be seen in chi-quong masters or experienced meditators.

2-4 = normal level
4-6 = high level, which influences a person’s state
6-8 = high level, which affects both the psychological and physical state
8-10 = exhaustion, major issues

The quantitative estimation of the level of stress and anxiety is important in determining the subject’s general condition. By introducing the filter we can make the difference between the psycho-physiological field and the physical field. The higher the level of stress experienced by a person, the bigger the difference between the two images. The filter disables the influence of all the processes that are directly connected to the surface of the skin – the first being the sweat. “We can assume that the filter distinguishes between the activity of the sympathetic and parasympathetic nervous system. To analyze the psycho-physiological field it is necessary to take the GDV-grams without the filter” [1, pg 34]. Comparing represents the tolerance to stress and a capacity to resist the psychological load.

5. SUMMARIES OF PAPERS RELATED TO THE DECREASE OF STRESS INDEX (T)

We will next present the short summaries of some research papers that treat of different ways of reducing stress, which used the GDV camera and ended by turning into PhD theses. We would like to mention that there are yet certain limitations given by the fact that the works cover the period 2002 - 2013 and the GDV camera software has been constantly improved, with the limitations given by the fact that the research that the article refers to was conducted between 2002 and 2013. The measurements were made with different versions of software, owing to the fact that during that period the GDV camera software was constantly improved.

Susanne Gibson’s PhD Thesis

In her PhD thesis in 2002, PhD Suzanne Gibson presented some studies [2] conducted with the help of 49 subjects, which showed that music (15 minutes only) and Focused Meditation reduce the level of stress. The measurements were taken with the GDV Camera, they were then confirmed through The Profile of Mood State (POMS) technique and finally were validated through the statistical analysis. The POMS consists of 65 adjectives describing mood rated on occurrence “within the past week” for the pre-test and “at this moment” for the post-test.

In the research conducted on 82 people, PhD Marianne Cowan [4] reduces “the music/the vibration” transferred to the body to only one musical note – the C note – produced by the Cristal bowl tuning and through the statistical analysis she shows that this note only influences the 5th Chakra.

Mohirta’s PhD Thesis: By means of an experiment that used 30 subjects – all students – using a GDV camera, Dr. Mohirta statistically demonstrated the fact that [5], under the influence of music therapy, the difference between the density of the luminosity of the physical body and that of the emotional one (stress level) decreases. The subjects displayed a decrease of stress index from an average of 3.85 to 2.72. The difference reached the threshold of statistical significance (F(30) = 4.59, p = 0.001). The correlation analysis of the two distributions showed that there is a statistically significant positive correlation between the two distributions (r = 0.6, N = 30, p = 0.001). The consistence was done on the R2 = 0.36 radius, which indicates great consistence.

Manolea’s PhD Thesis

Manolea’s PhD Thesis [3] starts from the premise that psychic activity exerts some major influence upon
the autonomous nervous system and the emotional states ("feelings"), irrespective of their biological, psychic, social or cultural motivation, may modify the body's physiological parameters in a sometimes spectacular manner. When assessing the stress level, Mr. Manolea used the Cohen-Williamson questionnaire, which lays stress on the individual's reaction to the stressful context.

Mr. Manolea has proved that, under the influence of the consciousness-modified states produced under hypnosis, the parameter whose modification proved to be statistically significant was the activation coefficient, which a measure of the psycho-emotional stress Korotkov [1].

6. EXPERIMENTAL RESEARCH

32 subjects aged between 22 and 74 participated in the experiment. There were 21 female and 11 male subjects. Age grouping was as follows: 5 subjects were aged between 20 and 30, 14 subjects were aged between 30 and 40, 10 subjects were aged between 40 and 50, 1 subject was aged between 50 and 60 and 2 were older than 60. The subjects were explained the working protocol that comprised 4 series of GDV camera measurements and they signed the participation agreement.

The research took place on the 28th and 29th of August 2012, during the first part of the day, thus complying with the requirements of the protocol established by Dr. Korotkov [1] chapter 5, after his research sessions.

Prior to this experiment, a pilot study was conducted (3 subjects/7 measurements/8 hours) that allowed establishing the number of and optimal time intervals between the measurements, i.e.: t₀; procedure: ingestion 10 ml ECS, t₁ – immediately after the procedure (2-5 minutes); t₂ / 30 minutes after the procedure, and t₃ – 90 minutes after the procedure.

The device used: GDV Compact Camera and the afferent software (GDV Aura, GDV Diagram, GDV Chakras etc.), produced by Kirlionics Technologies International Ltd. In this case, the GDV camera was used to find/highlight the impact of the ingestion of a small amount of ECS upon the human energy-informational field.

The premise we are starting from is that the modifications first occur/are reflected in the energy-informational field, long before the physiological manifestation.

Hypotheses: Following the ingestion of ECS, the difference between the density of the luminosity of the physical body and the emotional one (the stress level) decreases, and the restructuring of the energy-informational field takes place. Cumulative chart of the measurement results of the Stress Index in the 32 subjects for the 4 measurements:

Table 1. T-values interval of the 32 subjects measured at 4 different times (T₀ before procedure)

<table>
<thead>
<tr>
<th>T₀</th>
<th>T₁</th>
<th>T₂</th>
<th>T₃</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-2 = 6</td>
<td>0-2 = 8</td>
<td>0-2 = 13</td>
<td>0-2 = 6</td>
</tr>
<tr>
<td>2-4 = 15</td>
<td>2-4 = 16</td>
<td>2-4 = 11</td>
<td>2-4 = 19</td>
</tr>
</tbody>
</table>

One may notice from the chart above that, as compared to the initial time, which is the control measurement, we find NO value in the 6-8 interval at the t₃ time, the number of subjects with a stress index in the 4-6 interval has dropped from 9 to 7, the number of subjects with a stress index in the 2-4 interval has increased from 15 to 19, and the values in the 0-2 interval have remained unchanged (after they were higher at the intermediary times.

Even though the results seem obvious, a statistical analysis was made, which validated the initial hypothesis, i.e. the ingestion of ECS leads to the decrease of the stress index.

7. STATISTICAL METHOD

The statistical analysis of the data collected based on this experimental model is made using the t test (test/retest) for pair samples with repeated measurements. An experimental Plan will be used (with a single independent variable) on correlated dependant groups. The independent variable is the triggering of certain changes in the entire energy-informational field of the human body after the ingestion of a controlled amount of ECS, quantified through the modification of the parameters GDV camera measured parameters.

Test – Stress index T

Table 2. Deviation coefficients of the T-averages

<table>
<thead>
<tr>
<th>Statistical descriptors</th>
<th>Average Number of subjects</th>
<th>Standard deviation</th>
<th>Average standard deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>T Stress Index</td>
<td>3.24 32 1.59 0.28</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RT₁ Stress Index</td>
<td>3.06 32 1.45 0.25</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RT₂ Stress Index</td>
<td>2.71 32 1.55 0.27</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RT₃ Stress Index</td>
<td>2.96 32 1.31 0.23</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The variation coefficients of the 4 series, i.e. 1.59, 1.45, 1.55 and 1.31, indicate a very good homogeneity and the 3.24, 3.06, 2.71 and 2.96 averages are representative for the series.
Table 3. Correlation coefficients (r) and significance threshold (p)

<table>
<thead>
<tr>
<th>Stress Index</th>
<th>Number of subjects</th>
<th>Coefficient (r)</th>
<th>Significance threshold (p)</th>
</tr>
</thead>
<tbody>
<tr>
<td>T_RT1</td>
<td>32</td>
<td>.45</td>
<td>.010</td>
</tr>
<tr>
<td>T_RT2</td>
<td>32</td>
<td>.40</td>
<td>.020</td>
</tr>
<tr>
<td>T_RT3</td>
<td>32</td>
<td>.45</td>
<td>.009</td>
</tr>
</tbody>
</table>

7.1. Statistical conclusions:

Time M1: the stress index presented a decrease from an average of 3.24 to 3.06: the correlation of the two data distributions is average, \( r = 0.45 \) and strongly statistically significant, \( p = 0.010 \).

Time M2: the stress index presented a significant decrease from an average of 3.24 to 2.71: the correlation of the two data distributions is average, \( r = 0.40 \) and strongly statistically significant, \( p = 0.020 \).

Time M3: the stress index presented a significant decrease from an average of 3.24 to 2.87: the correlation of the two data distributions is average, \( r = 0.37 \) and of average statistical significance, \( p = 0.034 \).

These data indicate the fact that the ingestion of ECS bears effect upon the values of the T stress index averages.

The determining coefficients: \( R_2 = 0.20 \), \( R_2 = 0.16 \) and, \( R_2 = 0.13 \), indicate an average effect, in the sense that the existence of a significant difference between the two times may be attributed to the independent variable, i.e. the ingestion of ECS.

8. Final Conclusions

1. All the 32 subjects reacted to the procedure.

2. ECS has a very quick, almost instantaneous action.

3. The Stress Index had a special evolution, as there was a significant decrease, from an average of 3.23 at the control measurement, to 2.96 – 90 minutes after the ingestion, going through intermediary values. At the end of the technique, most of the values fall under the normal interval 2-4, whereas values exceeding 6 no longer exist [1]. We believe this is an exceptional result that confirms the empirical observations about the comforting effect of ECS that Dr. W. Kühhni and W. von Holst [6] put forward.

3. Parameters measured without a filter have a faster evolution than those measured with a filter, which may indicate that the sympathetic nervous system is the first to react.

4. If compared to music therapy (Mohirta) and the consciousness-modified states, the ECS ingestion has a weaker effect, its maximum efficacy being noticeable 90 minutes after the ingestion. After that, the effect starts to diminish. The advantage of this method lies in its simplicity and rapid effect.

Certainly, additional measurements and compared analyses will be necessary to highlight the resemblances and differences from other manners of anxiety reduction (music therapy, dance therapy, color therapy etc.)

8. General directions for the continuance and completion of the research

- During the experiment, the idea of a new experiment emerged that would allow determining the action of ECS based on how it this solution comes into contact with the body (moistening of the epithelial surface, keeping it in the mouth without ingesting, ingestion), thus to determine the difference between the effects of these processes.

- Measurements with different concentrations of ECS for the purpose of determining a threshold level or value.

- We could notice that, at the measurement made at the T3 time, 2 hours after the ingestion, the stress index average increased as compared to the value measured at T2 (30 minutes before), which indicated the decrease of the effect in time. Certainly, an experiment would be useful that would allow determining the maximum efficacy point on the efficacy/time curve. Moreover, we believe it would be useful to have an efficacy/ECS concentration graph.

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EMPLOYMENT OF BAYESIAN AND MONTE CARLO METHODS
FOR BIOLOGICAL DOSE ASSESSMENT FOLLOWING ACCIDENTAL OVEREXPOSURES
OF PEOPLE TO NUCLEAR REACTOR RADIATION

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Abstract. A nuclear reactor radiation is composed mainly by fission neutrons and gamma radiation. Because of markedly different biological effectiveness of these two types of radiation, it is important to be able to estimate separately the neutron and gamma components of the total dose that a person received in a case of a nuclear reactor accident. The objective of this paper is to present procedures based on the Bayesian statistics and the Monte Carlo simulation, which can be used to calculate the separate neutron and gamma doses in biological dosimetry by dicentric chromosome aberration analysis. The both probabilistic methods have the potential to be an attractive alternative to the iterative method currently used for dose estimation in situations where the neutron to gamma dose ratio is uncertain.

Key words: Bayesian statistics, biological dosimetry, Monte Carlo, neutron-gamma radiation, radiation cytogenetics

1. INTRODUCTION

In a case of an accidental external exposure to nuclear reactor radiation, the dose that a person received should be estimated as soon as possible. This greatly helps physicians to provide medical aid for an accident victim who received a high total dose and to reassure that who has not received any significant exposure.

In the case where physical dosimetry cannot be used or does not provide sufficient information, biological dosimetry is a valuable tool to determine the radiation dose to the human body [1]. Of the biological methods adopted for radiation dosimetry purposes, the analysis of dicentric chromosome aberrations in peripheral blood lymphocytes is the most documented and validated method to estimate recent external exposure and dose [1, 2, 3]. Biological evaluation of the dose is carried out by referring the observed dicentric frequency to a dose - response calibration curve obtained from carefully controlled in vitro studies performed in the same laboratory where dose estimation occurs. Since peripheral blood lymphocytes are circulating cells, the dicentric frequency reflects the average total - body dose, independent of specific regions of the body that was exposed.

Occupational accidents or overexposures of persons to nuclear reactor radiation are rare events but more complex in evaluation, because the total dose received is not only from a fission neutrons but also from gamma radiation [4]. These two types of radiation have a markedly different relative biological effectiveness [1]. So, there is a need to evaluate the total dose as well as the separate neutron and gamma doses.

If the ratio of neutron to gamma doses is available from personal physical dosimeters or from accident reconstruction calculations, the evaluation of the neutron and gamma doses may be made by iterative method [1, 2]. This method allows to discriminate the dicentrics to neutron and gamma components of the exposure, under the assumption that both types of radiation are additive in the production of chromosome aberrations, and that their distribution among the cells scored is Poissonian [1]. Estimation of the neutron and gamma doses is performed with the use of laboratory calibration curves for 60Co gamma radiation and fission neutrons. Unfortunately, in the case where a physical estimate of the ratio of neutron to gamma doses is not precisely known, the use of the above method is not possible [5].

The objective of this paper is to present two probabilistic methods for dose calculations in situations where the ratio estimate is uncertain. These are a Bayesian method and a Monte Carlo simulation. The key elements of these methods which can be used in radiation biological dosimetry by the dicentric assay are indicated as well. Presented results of Bayesian, Monte Carlo and iterative estimates of neutron and gamma ray doses provide an illustration of the issue discussed.
2. METHODOLOGY

2.1. Calculations of posterior distributions for neutron and gamma doses

For dicentrics a good dose - response relationship exists [1, 2]. It is linear for neutrons:

\[ Y_n = Y_0 + \alpha D_n \]  

and linear - quadratic for gamma rays:

\[ Y_g = Y_0 + \beta D_g + \lambda D_g^2 \]  

The Bayesian statistics, as different approach to inferences in comparison to classical (frequencies) regards probability as a measure of the personal state of incomplete knowledge about the value of an unknown parameter. This state is a result of information obtained from the observed sample data as well as the additional information which is available to an investigator prior to the data. Therefore, it allows to describe probability to any uncertain event taking these two sources information into account.

The sample data are expressed formally by the likelihood function (LF). The additional information that is available prior to the data is expressed as a probability distribution, known specifically as the prior distribution (PD). The use of prior information in addition to the sample data is fundamental to the Bayesian statistics which allows transformation of prior distributions into posterior distributions through the Equation 3:

\[ \text{Posterior} \propto \text{LF} \cdot \text{PD} \]  

Such posterior distribution expresses what is known about an unknown event or parameter based on both the sample data and prior information.

This approach to the calculation of radiation doses in biological dosimetry by dicentric assay was pioneered by Groer, Brame and Pereira [6, 7]. Their works build a mathematical base of this concept for the calculation of the total doses as well as the separate neutron and gamma doses. Their results were adopted to derive the posterior distributions for the neutron and gamma doses. However, numerical values of the fitted parameters of the neutron and gamma dose - response calibration curves were used instead of the calibration data used to their estimation, so the presented calculations of posterior distributions are less mathematically complicated. A detailed description of those calculations gave Fornalski [8]. In brief, in the situation where the number of dicentrics was observed in a sample of \( w \) lymphocytes after exposure to any dose of mixed neutron + gamma radiation dependence, the Equation 3 can be rewritten as follows [8]:

\[ P(D_x) = \int_0^1 L(D_x \mid \theta) p(\theta) d\theta \]  

where \( P(Dx) \) is the posterior distribution for the neutron (x=n) or the gamma (x=g) dose, \( L(Dx \mid \theta) \) is the likelihood function and \( p(\theta) \) is the prior distribution of parameter \( \theta \). This parameter corresponds to the contribution of gamma dose to the total dose, that can vary from 0 to 1, and appears from dependence [7]:

\[ \theta = \frac{D_g}{D_g + D_n} = \frac{1}{\rho + 1} \]  

where \( \rho \) is the ratio of neutron to gamma dose. Generally the prior distribution of \( \theta \) can be approximated by Gaussian distribution for \( \theta \) with standard deviation of \( \alpha_\theta \). However, if the information about \( \theta \) is completely not available or impossible to assess, the prior \( p(\theta) = const \equiv 1 \) need to be used. Likelihood function represents a classical statistics that has the Poisson distribution form [7]. It express what is known about the expected number of dicentrics induced by neutrons as well as gamma rays. Based on the assumption that the number of \( u \) dicentrics observed in irradiated sample of \( w \) lymphocytes is distributed in Poissonian way where the mean is a combination of Equation 1 and 2 for mixed radiation field, the likelihood functions for both doses can be given by:

\[ L(D_x \mid \theta) = \frac{(w \cdot y_f)^u}{u!} \cdot e^{-w y_f} \]  

where \( x = \{g, n\} \) and for gamma radiation in mixed field \( y_f \) is given by Equation 7:

\[ y_f = Y_0 + \alpha \frac{1 - \theta}{\theta} D_n + \beta D_g + \gamma D_g^2 \]  

For neutrons in mixed field Equation 7 can be rewritten as:

\[ y_f = Y_0 + \alpha D_n + \beta \frac{\theta}{1 - \theta} D_n + \gamma \left( \frac{\theta}{1 - \theta} D_n \right)^2 \]  

A value of the neutron or gamma dose can be found from the maximum of the posterior distribution curve (Equation 4), which is equivalent to the first derivate equation:

\[ \frac{dP(D_x)}{dD_x} = 0 \]  

In practice all calculations in the presented method need numerical solutions, because analytical ones can be too complicated in some cases.

2.2. Calculation by Monte Carlo simulation

The presented Bayesian approach can be successfully replaced by a computational Monte Carlo (MC) simulation method, see Fig. 1. MC method also allows to use distribution functions describing all uncertain parameters and calculates both gamma and neutron doses. More than that, thanks to MC method one can simulate the distribution of damages in modelled group of cells. The detailed algorithm of MC method is not described here. It can be found in [8].
3. RESULTS AND DISCUSSION

The selected example concerns a situation where 33 dicentrics were observed in 1000 lymphocytes after in vitro irradiation of the whole blood sample at the horizontal channel of the nuclear research reactor MARIA in the National Centre for Nuclear Research (Otwock-Świerk, Poland). The radiation field was composed mostly by gamma radiation and thermalized neutrons. The absorbed dose to the blood sample was 0.5 Gy. The neutron contribution to the absorbed dose was 8%, so that the neutron and gamma doses were 0.04 Gy and 0.46 Gy, respectively. In order to determine the total dose and the dose contribution from neutrons, twin detector method and recombination method based on analysis of the shape of the saturation curves were used [4].

In this example the parameter $\theta$ is precisely known from careful dosimetric measurements. Its value is 0.92 and corresponds to the 92% contribution of gamma dose to the total dose. As may be seen in Fig.2, the prior $p(\theta)$ has the Gaussian distribution form. The result posterior distributions for the neutron and gamma doses are shown in Fig. 3 and Fig. 4. Table 1 show values of doses derived from the observed dicentric frequency by the iterative, Bayesian and Monte Carlo methods. All values are in good agreement. This fact makes the Bayesian and Monte Carlo methods an attractive alternative to the iterative method currently used for dose estimation after exposure to the mixed radiation.

Additionally, two virtual examples were analysed. In the first the parameter $\theta$ was assumed to be not precisely measured, whereas in the second $\theta$ was completely unavailable. The results show that an uncertain contribution of gamma dose to the total dose leads to greater uncertainty in the estimates of neutron and gamma doses derived from the observed dicentric frequency.

Biological and physical estimates of the neutron and gamma doses perfectly agreed, indicating that established at Central Laboratory for Radiological Protection (CLOR) methodology for biological dose assessment in a case of accidental exposure to nuclear reactor radiation works well.

Table 1. A comparison of Bayesian, Monte Carlo and iterative dose estimates for the known and unknown contribution of gamma dose to the total dose ($\theta$).

<table>
<thead>
<tr>
<th>Prior: Gauss distribution</th>
<th>Iterative</th>
<th>Bayesian</th>
<th>Monte Carlo</th>
</tr>
</thead>
<tbody>
<tr>
<td>for $\theta = 0.92$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dn [Gy]</td>
<td>0.041 ± 0.014</td>
<td>0.045 ± 0.011</td>
<td>0.039 ± 0.015</td>
</tr>
<tr>
<td>Dg [Gy]</td>
<td>0.466 ± 0.124</td>
<td>0.470 ± 0.080</td>
<td>0.481 ± 0.079</td>
</tr>
<tr>
<td>for $\theta = 0.80$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dn [Gy]</td>
<td>0.069 ± 0.018</td>
<td>0.070 ± 0.012</td>
<td>0.070 ± 0.013</td>
</tr>
<tr>
<td>Dg [Gy]</td>
<td>0.276 ± 0.080</td>
<td>0.279 ± 0.053</td>
<td>0.288 ± 0.087</td>
</tr>
<tr>
<td>Prior: const=1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\theta$ not known</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dn [Gy]</td>
<td>- ± 0.087</td>
<td>0.087 ± 0.017</td>
<td>0.093 ± 0.005</td>
</tr>
<tr>
<td>Dg [Gy]</td>
<td>- ± 0.098</td>
<td>0.098 ± 0.147</td>
<td>0.093 ± 0.039</td>
</tr>
</tbody>
</table>

* the exact value of $\theta$ for iterative method was assumed to be equal the given Gaussian mean
**Acknowledgement:** Authors wish to thank Professor P. G. Groer and Doctor R. S. Brame for detailed explanation of their method and the Doctors A. M. Gryziński and P. Tulik for careful dosimetric measurements.

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Abstract. Activities of beryllium-7 and lead-210 are monitored in ground level air in Belgrade, Serbia. The measuring sites are located at the Institute of Nuclear Sciences Vinča. The activities are determined on HPGe detectors by standard gamma spectrometry. Five teleconnection indices of large scale atmospheric circulation: North Atlantic Oscillation, East Atlantic Pattern, East Atlantic/West Russia Pattern, Scandinavia Pattern, and Polar/Eurasia Pattern are obtained from the data archive of the United States National Oceanic and Atmospheric Administration's Climate Prediction Center. The collected time series consist of monthly values and span more than two decades: beryllium-7 since 1991, lead-210 since 1985, and the teleconnection indices since 1950, thus offering data arrays of sufficient lengths for wavelet spectral analysis. A relation between the radionuclides’ activities and the indices is first investigated using Pearson’s correlation coefficients. The computed coefficients do not indicate a linear relationship between the variables. However, the wavelet spectral analysis shows a number of common characteristic frequencies in the data arrays. The annual cycle of all the variables is clearly evident. A common time period of two to three years is also found, as well as a higher frequency variability corresponding to five to six months.

Key words: beryllium-7, lead-210, air, teleconnection indices, wavelet analysis

1. INTRODUCTION

Beryllium-7 and lead-210 are naturally occurring radionuclides that can be used as tracers of air mass history. These isotopes have different origins: 7Be (half-life 53.22 days) is produced in the upper troposphere and lower stratosphere, while the main source of 210Pb (half-life 22.23 years) is its radioactive parent radon-222 that emanates from the soil.

The behaviour of 7Be and 210Pb after their formation is similar: they promptly get attached to aerosols, whose mean residence time in the atmosphere is longer than 30 days [1], and their ensuing transport is governed by atmospheric circulation. Furthermore, mechanisms of their removal from the atmosphere are the same, with wet deposition being most significant [2]. Concentrations of 7Be and 210Pb and their relation to local climate variables have been extensively studied [2, 3].

Due to their different origin, the concentrations of 7Be and 210Pb vary with height in the atmosphere. Air masses coming from the upper troposphere and lower stratosphere contain higher concentrations of 7Be than surface air masses. Beryllium-7 can thus be used as a stratospheric tracer, and has been investigated as an indicator of exchange processes between the stratosphere and troposphere [4, 5]. On the other hand, surface air masses are richer in 210Pb than air masses from higher altitudes. Moreover, the 210Pb concentration is higher in continental air masses than in air masses originating over a body of water [6].

The behaviour of 7Be and 210Pb in surface air is influenced by large-scale atmospheric transport [4, 7], which is quantified by teleconnection indices.

The North Atlantic Oscillation (NAO) index is one of the most commonly used teleconnection indices to describe a large-scale circulation pattern over the North Atlantic Ocean and surrounding land masses [8]. The North Atlantic Oscillation can be described as a pressure dipole with one centre associated with the Icelandic low and the other with the Azores high pressure centre. Two oscillation phases, distinguished by the NAO index, induce differences in the position and strength of the North Atlantic jet stream and storm track in midlatitudes [9]. The changes in large-scale circulation patterns further reflect on local weather conditions especially over eastern North America and across Europe, including Serbia [10].

The Polar/Eurasia pattern (POL) is another teleconnection that has an impact on weather in Europe [11]. The POL index quantifies tri-pole anomalies centred over the Northern Hemisphere polar region, and Europe and north-eastern China [8].
In Belgrade, Serbia, at the Vinča Institute of Nuclear Sciences, continual measurements of the $^7$Be and $^{210}$Pb activities in surface air started in 1991 and 1985, respectively. The monthly mean activities of $^7$Be and $^{210}$Pb in composite aerosol samples were determined on HPGe detectors by standard gamma spectrometry. The activities of $^7$Be and $^{210}$Pb were determined by using the gamma energies of 477.6 keV and 46.5 keV, respectively. A detailed description of the measurement procedure is given in [3].

The monthly values of five teleconnection indices of large scale atmospheric circulation: North Atlantic Oscillation, East Atlantic Pattern, East Atlantic/West Russia Pattern, Scandinavia Pattern, and Polar/Eurasia Pattern were obtained from the data archive of the United States National Oceanic and Atmospheric Administration’s Climate Prediction Center (http://www.cpc.ncep.noaa.gov/data/teledoc/telecontents.shtml visited on 18 October 2013). A description of the procedure used to identify the Northern Hemisphere teleconnection patterns and indices is given in [8]. The monthly values of teleconnection indices since 1950 were available.

An investigation of a relation between the time series was conducted in two steps. First, Pearson’s linear correlation coefficients were used to quantify a degree of linear correlation between the variables. Second, wavelet transform analysis was performed to investigate similar periodicities in the time series which could imply a causal relationship between the radionuclides’ activities and teleconnection patterns, even if that relationship is not linear in its nature.

Wavelet transform (WT) is a useful tool in investigation of time series that contain nonstationarities on a number of different frequencies [12]. Transforming a signal $s(t)$ with a set of wavelet functions $\psi_{a,b}(t)$ gives a set of coefficients (wavelet amplitudes):

$$W(a,b) = \int \psi_{a,b} \cdot s(t) \cdot dt$$  \hspace{1cm} (1)

Using WT, a global wavelet power spectrum (which corresponds to Fourier power spectrum) can be obtained by integrating wavelet amplitudes over time parameter $b$:

$$E_p(a) = \int W(a,b) \cdot db$$  \hspace{1cm} (2)

A set of Morlet wavelets (with $\omega_0=4$) was used to calculate WT and then the wavelet scale $a$ was recalculated into a corresponding Fourier period $T$. In contrast to Fourier spectra, wavelet spectra are smooth and can therefore be used to estimate characteristic times (periods) in the data sets containing the radionuclides’ activities and teleconnection indices.

The calculated spectra represent variations of the analysed signals on different time scales, and show increased values for the events occurring at a characteristic time scale. To detect those characteristic scales, a standard peak analysis was performed by searching the maximum and saddle (for hidden peaks) points in the global wavelet power spectra of the radionuclides’ activities and teleconnection indices.

Pearson’s linear correlation coefficients were first calculated by pairing the data points from the activities and teleconnection indices for each given month. The computed coefficients did not indicate a linear relationship between the variables. Next, a time lag of 1 to 12 months was introduced in the calculations, thus allowing a possible shift in the correlation. For example, a linear correlation with a time lag of 1 month would imply that changes in one variable took about a month to reflect on the changes in the second variable. However, the obtained coefficients again indicated that there was no linear correlation between the variables.

To further investigate a relation between the teleconnection patterns and the activities, wavelet transform was used to calculate characteristic periods in each of the data sets separately. Characteristic periods correspond to a time coordinate of the local maxima in the power spectrum. For example, the power spectra for $^7$Be, $^{210}$Pb, North Atlantic Oscillation and Polar/Eurasia indices are given in Fig. 1.

The characteristic frequencies were then examined to find similarities in different data sets. The aim of this analysis, however, was only to suggest a possible direction in which to search for a potential causality between the radionuclides’ activities and atmospheric circulation.

Short characteristic periods of 2-3 and 5-6 months were found in all of the data sets. These seasonal and biannual periodicities are well known in the behaviour of $^7$Be and $^{210}$Pb [2, 3, 13].

The time periods of 11-13 months, corresponding to an annual cycle, were also found. A longer time period of 30-36 months was evident in the isotopes’ activities, as well as in the NAO and POL time series (Fig. 1). For example, a 36-month period found in the NAO series agrees well with the period of 2-4 years noted by [14].

Our results further showed a somewhat shorter time period of 20-30 months in the $^7$Be concentrations. This period was also found in the analysis of [7] and was attributed to quasi-biennial oscillation.

The North Atlantic Oscillation is considered a dominant teleconnection in the Northern Hemisphere, but its specific frequencies did not match the $^7$Be and $^{210}$Pb frequencies as well as the POL pattern (Fig. 1). An explanation may lie in the fact that one of the three poles of the POL is centred over central Europe, and the pressure anomalies associated with it can have a rather direct influence on weather in Serbia. Over Europe, a positive phase of POL is accompanied by an anticyclonic pressure field, which is often characterised by dry weather condition, air subsidence and temperatures higher than the average. Since the $^7$Be and $^{210}$Pb activities show correlation with this type of weather condition [3], it could be expected that they are also correlated with POL. This type of correlation between the NAO index and the radionuclides’ activities is less evident because the NAO poles are positioned westward of Serbia. Still, a frequency of stratospheric intrusions over the Apennines was related to the NAO phases [4] implying an indirect, but possibly localised, influence of NAO on the $^7$Be concentration.
The availability of the aerosol samples (a composite monthly sample) limited the shortest time periods that could be captured in our analysis to an order of a month, not allowing examination of higher frequencies such as 19 and 36 days that were found in a wavelet analysis of daily $^{7}$Be concentrations by [15].

At the other end of the time scale, the longest time periods, of about 40 months, were limited by the length of the time series. Thus, the 11-year solar cycle whose signature on the $^{7}$Be concentration has been found [2, 16], could not be observed in our analysis.

4. CONCLUSIONS

A relation between the $^{7}$Be and $^{210}$Pb activities measured in Belgrade, Serbia, on one hand, and five teleconnection indices representative of large-scale atmospheric circulation, on the other hand, was investigated. Linear correlation between the variables was not found. Similar periodicities in the activities and the teleconnection indices were calculated in the wavelet transform analysis. Apart from the seasonal, biannual and annual behaviour, an oscillation of 30-36 months was also found. Further, the characteristic time periods of the Polar/Eurasia pattern seemed to match the periods of the radionuclides' activities better than the other investigated indices.

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SENSITIVITY ANALYSIS OF HEALTH RISK
TO PROBABILITY DISTRIBUTIONS FOR THE EXPOSURE PARAMETERS

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Abstract. Purpose of this paper was to estimate cancer mortality risk related to direct soil ingestion exposure to radionuclide 238U using Monte Carlo simulations. This method enables adequate description of assessed risk that should include estimated probability density function with statement about related measurement uncertainty. Ten soil samples were taken from the alluvial horizon of the Djetina River. Gamma spectroscopic measurement was performed for determination of the radionuclide 238U activity concentration in soil samples. Four hypothetical exposure cases were considered with different combinations of input parameter distributions. Also, it was made attempt to extract influence of the specific distributions for input quantities on the assessed risk using parameter sensitivity analysis techniques.

Key words: health risk, Monte Carlo simulation, radionuclides, internal exposure, sensitivity analysis

1. INTRODUCTION

Monte Carlo method is important tool in environmental and health risk assessment which enables overcoming high level of conservatism related to point risk estimate. Monte Carlo method propagates probability density functions (PDF) for the input quantities through the model in order to obtain probability density function for the output quantity. PDFs of the input quantities are sampled for the n times, so there are n realizations of the final risk.

This method gives adequate description of assessed risk that should include estimated probability density function with statement about related measurement uncertainty. This statement provides information about the range and likelihood of risks to receptors from exposures to contaminants in the environment, as the output from the Monte Carlo quantitative uncertainty analysis [1, 2, 3, 4, 5].

Besides uncertainty analysis that quantifies uncertainty of the final risk, it is important to conduct sensitivity analysis as a part of risk assessment. Sensitivity analysis determines influence of the variability and uncertainty of the input quantities on the overall output variability. Also, high sensitivity can be observed if there is correlation between output and input parameter. For models that consist of large number of input quantities, sensitivity analysis will identify parameters that should be described with point values or with probability functions regarding their influence on the final risk [4].

1.1. Parameter sensitivity analysis

A large number of sensitivity analysis techniques are used in health and environmental risk assessment [1, 5]. According to the methodology, three groups of sensitivity analysis techniques can be mentioned: i) those that operate on one input parameter at a time while others are kept constant; ii) those that operate on generated input matrix and output vector; iii) those that require segmenting input probability density functions based on some critical value of the output vector (e.g. The Smirnov test and the Cramer-von Mises Test) [5].

Differential analysis is one of the most frequently used techniques from the first group (i) along with other techniques like factorial analysis and determination of the sensitivity index or importance factors [3, 5]. Differential analysis is based on approximation of the model using Taylor series where dependent variable Y is a function of independent variables \( Y = \left( X_1, ..., X_n \right) \). Variance in Y is a measure of uncertainty in model output and variance in \( X_i \) weighted by the first order partial of Y with respect to \( X_i \) is a measure of output sensitivity to \( X_i \). ANOVA test provides reliable results of sensitivity analysis for complex nonlinear models with thresholds and saturation points [6, 7].

Sensitivity analysis techniques from the second group (ii) are based on random sampling methods. Scatter plots give visual representation of the input/output correlation and they are often used as a screening method [5, 7]. Pearson’s product moment correlation coefficient \( r \) represents quantitative estimate of linear correlation between input and output values [5, 6]. Regression techniques are based
on the regression equation that uses the most sensitive input parameters to approximate model output and requires calculation of regression coefficients, standard errors of the regression coefficients and level of significance of the regression coefficients [3, 5, 7].

In this paper, cancer mortality risks were calculated related to direct soil ingestion exposure to 238U using Monte Carlo simulations. A primary objective of the sensitivity analysis is to determine which variables the most strongly influence the risk estimate. Apart from the common procedures for uncertainty estimation due to overall uncertainties of input variables (Monte Carlo procedure [8] and GUM framework [9]), it was made attempt to extract influence of the specific distributions on the risk uncertainty estimation.

2. METHODS

Ten soil samples were taken from the alluvial horizon of the Djetina River at the depth of (15-20) cm with sample weight of 5 kg. Gamma spectroscopic measurement was performed for determination of the radionuclide 238U activity concentration in soil samples. Gamma spectrometry was performed with high purity, low energy, germanium semiconductor detector (HPGe), manufactured by ORTEC, with accompanying electronic equipment and ORTEC software for spectra evaluation. The relative efficiency of HPGe detector was 28% with energy resolution of 2 keV in measurements at the 1.33 MeV reference transition of 60Co. Detectable energy range was up to 2 MeV. The expanded measurement uncertainty of radionuclide activity concentration was 15% (k=2).

According to determined radionuclide activity concentrations in soil samples, lifetime cancer mortality risk per capita were calculated [10]. Lifetime cancer mortality risk was calculated using risk coefficients that represent average risk per unit activity intake to members of a population [10]: exposed throughout life to a constant concentration of radionuclide in soil or acutely exposed to the radionuclide in soil. Considered exposure pathway was direct ingestion of soil.

Lifetime cancer mortality risk per capita from exposure via direct ingestion pathway was calculated using equation:

\[ \text{Risk} = R_c \times A \times IR_i \times EF_i \times ET_i \]

where \( R_c \) represents risk conversion factor (risk/Bq), \( A \) is activity concentration of radionuclide in soil (Bq/kg), \( IR_i \) is ingestion rate (mg/day), \( EF_i \) is exposure frequency (day/year) and \( ET_i \) is exposure time (year).

Probability density functions were assigned to the model input quantities in order to perform risk assessment, uncertainty analysis and sensitivity analysis using Monte Carlo method.

Four hypothetical exposure cases were considered with different combinations of input parameter distributions. In each case, same probability density distributions were assigned to the input quantities like activity concentration, cancer mortality risk coefficient and exposure frequency. Two probability density distributions were assigned to the quantities considering daily soil ingestion rate and exposure duration. In order to perform sensitivity analysis for the model, following techniques were used: graphical representation of output sensitivity based on overlapping probability density functions of input/output and regression analysis

3. RESULTS AND DISCUSSION

Four hypothetical exposure cases were presented in Table 1, where appropriate probability density function was assigned to every input quantity. Results of assessed risks for these exposure cases with range of uncertainty for probability of 95% are presented in Table 2. Lower and upper bounds of uncertainty range (95%) are asymmetrically distributed relative to mean which makes use of standard uncertainty estimation techniques (according to GUM) inappropriate for this model.

Figure 1 shows graphical representation of parameter sensitivity analysis for case I exposure scenario, where normalized probability density function of output quantity (assessed risk) is overlapped with normalized probability density function of input quantity. It can be seen that assessed risk is the most sensitive for risk conversion factor \( R_c \). Figure 2 presents five diagrams of relationships between each input quantity and risk as a results of regression analysis for case I exposure scenario. Figure 3 shows cumulative distribution functions for risk based on simulations of four cases of exposure. The 95th percentile risk for these four exposure cases may range from approximately \((0.11 \pm 0.19) \times 10^{-6}\).

### Table 1. Probability density functions of input quantities for four hypothetical exposure cases

<table>
<thead>
<tr>
<th>Case</th>
<th>PDF A</th>
<th>PDF IRi</th>
<th>PDF Rc</th>
<th>PDF EFi</th>
<th>PDF ETi</th>
</tr>
</thead>
<tbody>
<tr>
<td>Case I</td>
<td>Uniform (34.8; 45.2)</td>
<td>Log-Normal (4: 0.4)</td>
<td>Log-Normal (-20.3; 0.95)</td>
<td>Triangular (250, 300, 350)</td>
<td>Triangular (0, 20, 40)</td>
</tr>
<tr>
<td>Case II</td>
<td>Uniform (34.8; 45.2)</td>
<td>Triangular (50, 100, 150)</td>
<td>Log-Normal (-20.3; 0.95)</td>
<td>Triangular (250, 300, 350)</td>
<td>Triangular (0, 20, 40)</td>
</tr>
<tr>
<td>Case III</td>
<td>Uniform (34.8; 45.2)</td>
<td>Log-Normal (4: 0.4)</td>
<td>Log-Normal (-20.3; 0.95)</td>
<td>Triangular (250, 300, 350)</td>
<td>Uniform (0, 40)</td>
</tr>
<tr>
<td>Case IV</td>
<td>Uniform (34.8; 45.2)</td>
<td>Triangular (50, 100, 150)</td>
<td>Log-Normal (-20.3; 0.95)</td>
<td>Triangular (250, 300, 350)</td>
<td>Uniform (0, 40)</td>
</tr>
</tbody>
</table>

Uniform distribution is characterized with minimum and maximum values, Log-Normal distribution with two parameters, and triangular distribution with lower and upper limit and mode.
Fig 1. Parameter sensitivity analysis: set of diagrams with parallel representation of overlapping PDFs for risk and input quantities

Fig 2. Parameter sensitivity analysis: regression analysis
### Table 2. Assessed risks for four exposure cases with range of uncertainty for probability of 95 %

<table>
<thead>
<tr>
<th></th>
<th>Mean cancer mortality risk $\times 10^6$</th>
<th>Range of uncertainty (95 %) $\times 10^6$</th>
<th>Standard deviation $\times 10^6$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Case I</td>
<td>0.045</td>
<td>0.0028 – 0.19</td>
<td>0.052</td>
</tr>
<tr>
<td>Case II</td>
<td>0.054</td>
<td>0.0038 – 0.22</td>
<td>0.058</td>
</tr>
<tr>
<td>Case III</td>
<td>0.045</td>
<td>0.00087 – 0.21</td>
<td>0.058</td>
</tr>
<tr>
<td>Case IV</td>
<td>0.054</td>
<td>0.0011 – 0.24</td>
<td>0.065</td>
</tr>
</tbody>
</table>

$Q_{2.5}$ and $Q_{97.5}$ are 2.5th percentile and 97.5th percentile.

### Table 3. Determined regression coefficients for input quantities

<table>
<thead>
<tr>
<th></th>
<th>$\beta_0$</th>
<th>$\beta_{RC}$</th>
<th>$\beta_A$</th>
<th>$\beta_{RS}$</th>
<th>$\beta_{EF}$</th>
<th>$\beta_{ED}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Case I</td>
<td>-0.00098</td>
<td>0.73</td>
<td>0.041</td>
<td>0.30</td>
<td>0.055</td>
<td>0.34</td>
</tr>
<tr>
<td>Case II</td>
<td>-0.0017</td>
<td>0.81</td>
<td>0.055</td>
<td>0.19</td>
<td>0.075</td>
<td>0.37</td>
</tr>
<tr>
<td>Case III</td>
<td>-0.012</td>
<td>0.67</td>
<td>0.058</td>
<td>0.24</td>
<td>0.059</td>
<td>0.46</td>
</tr>
<tr>
<td>Case IV</td>
<td>0.015</td>
<td>0.75</td>
<td>0.068</td>
<td>0.19</td>
<td>0.069</td>
<td>0.50</td>
</tr>
</tbody>
</table>

Fig 3. Cumulative distribution functions for risk based on four cases of exposure

Regression coefficients $\beta_i$ from the multi-dimensional regression analysis can be seen in Table 3. The form of regression equation is:

$$\text{Risk} = \beta_0 + \beta_{RC} \cdot R_c + \beta_A \cdot A + \beta_{RS} \cdot R_s + \beta_{EF} \cdot E_f + \beta_{ED} \cdot E_d$$

Coefficients $\beta_i$ give quantitative estimation of sensitivities on particular input quantities. The output quantity, Risk, is the most sensitive on $R_c$, and the least sensitive on $A$. It is evident that coefficients $\beta_i$ closely follow graphical sensitivity representation given in Picture 1.

### 4. Conclusion

Monte Carlo method is frequently used technique in environmental and health risk assessment because method provides adequate description of assessed risk that includes estimated probability density function with statement about related measurement uncertainty. According to their compliance with Monte Carlo method, two techniques for parameter sensitivity analysis were presented in this paper: graphical representation of output sensitivity based on overlapping probability density functions of input/output and regression analysis. Both techniques showed compliance with model for lifetime cancer mortality risk due to $^{238}$U direct ingestion. Also, the results of two tests were in correspondence.

### Acknowledgement

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### References

IMPORTANCE OF ULTRASOUND ELASTOGRAPHY PRIOR TO TESTICULAR SURGERY: CLINICAL EVIDENCE

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Abstract. In the last few years it has been developed more and more an ultrasound software called Ultrasound Elastography, which is an important step in the revolutionary technological ability of ultrasound to become a method that in addition to "see" lesions, "recognizes" them for what they are. The elastography is a validated method in the characterization of thyroid nodules, lesions of the prostate, breast lesions, the muscle and tendon injuries, and a small part is being developed in the study of the pathology of the liver, in particular chronic liver diseases. The technological foundation on which it is based is the ability of the tissues to deform and undergo the compression of the probe, exerted through the skin, in a different way according to its anatomical and histological composition. The elastosonographic study is a comparative study of the density of the lesions investigated in comparison with the surrounding tissue of the body that you are looking at. Typically, for example, benign lesions tend not to present histological upheavals compared to "normal surrounding tissue" thus reserving very similar deformability; on the contrary, a malignant lesion tends to present histological alterations of the composition compared to normal parenchyma that infiltrates, making it often more rigid and less deformable. We used this technique of investigation to assess the nature of a testicular lesion in a patient affected by Carney Complex Syndrome.

Key words: Ultrasound Elastography, Carney Complex Syndrome, Testicular Lesion

1.Introduction
The Elastography is a diagnostic mode of recent introduction, based on ultrasound, which allows the tissue characterization [1]. Unlike ultrasonography, which analyzes the acoustic properties of the tissues, or the variations in density of the medium in exam, the Elastography evaluate the mechanical properties of tissues, namely the ability to undergo deformation by the action of external forces and to return subsequently to the original form [2, 3]. The application of elastography in the medical field starts from two basic assumptions: first that there are significant differences in the mechanical properties of various tissue components, and the second that many diseases lead to changes in tissue elasticity, in particular the acute and chronic inflammation, malignant tumors and aging processes generally modify the elastic properties of tissues [3]. The Elastography is a validated method for the characterization of thyroid nodules [1, 4, 5], of prostate lesions [1, 6], lesions of the breast [1, 6, 7, 8, 9], muscle and tendon injuries [1] and a small part is being developed in the study of liver disease, in particular chronic liver disease [6]. The technology foundation on which it is based is the ability of the tissues to deform and undergo the compression of the probe, exerted through the skin, in a different way depending on its composition anatomo-histological [1]. The elastosonographic study is a study of the comparison of the density of lesions investigated in comparison with the surrounding tissue of the organ that you are looking at [1]. A cystic lesion, due to its liquid nature, has a higher compressibility than the surrounding tissue and, deformed by the compression exerted by the probe through the skin, tends to present a typical tri stratification due to the contrast in density between the front and rear walls and the cavity liquid that compose it[1, 6]. On the other hand, a solid lesion will tend to present different compressibility or equal than normal tissue (thyroid or breast, prostate, etc.) depending on its nature and composition histology. Typically, for example, benign lesions tend not to present upheavals histological compared to "normal surrounding tissue" thus reserving a deformation very similar, on the contrary, a malignant lesion tends to have histological alterations in the composition compared to normal parenchyma that is infiltrated, making it often more rigid and less deformable [3]. With intelligent software, these comparisons compressibility / deformability between healthy and pathological tissues can be scanned in color differences [1, 10].

In this study, we present a case of a patient, a man of 63 years old affected by Carney Complex Syndrome [11], who presented a testicular lesion which has been examined with elastosonographic technique [12, 13, 14].

2.Materials and Methods
The method is able to characterize in "real-time" the nodular lesions tissue through an algorithm, CAM, (Combined Autocorrelation Method), which allows to obtain an elastogram, a color image, in which each color gradient is related to a degree of elasticity of the tissue [15]. In our clinical practice the instrument used is an ultrasound Hitachi, EUB 8500 Logos (Hitachi Medical System, Tokyo, Japan) equipped with linear probe LS5 which uses frequencies between 6 to 14 MHz. In Figure 1 the scale of colors of the represented tissues is shown. The scale of colors obviously depends from the programmed characteristics of the instruments used, so it could change from instrument to instrument.
The case report was a 63 year old man underwent excision of left atrial myxoma, (in Fig. 2 and 3 schematic representation of atrial myxoma) at the age of 61, and to reoperation for recurrence after 19 months from the first. In Figure 4 a transesophageal echocardiography image of the myxoma of the case report is shown.

In 1981 at the age of 34 years it was performed on him a total parotidectomy for "Malignant melanotic schwannoma". The association of atrial myxoma and Schwannoma were suggestive for the possible presence of a rare genetic syndrome : the "Carney Complex", a syndrome with multiple clinical manifestations, represented in Figure 5, described for the first time in 1985 by J. A. Carney, then furtherly described in its genetic, molecular and clinical aspects by Stratakis in 2001 [16].

The hypothesis was confirmed by a positive for the mutation of the PRKAR1A gene on the long arm of chromosome 17 (17q22-24), which is typical of the disease. During the follow-up period in this disease the testicular ultrasound study had detected a small intraparenchymal mass of about 5mm, with calcified rib on the left. The lesion was not palpable on physical examination.

3. Results
Elastosonography has allowed us to characterize the nodule, highlighting the nature of rigid, non-deformable (calcific), and it was therefore possible to assume a conservative treatment.

The extemporaneous study of the removed pathological lesion confirmed the benign nature of the nodule in question, characterized as an 'hyperplastic area of Leydig cell'.

It was therefore adopted a conservative surgery approach with saving the testicle. In the next Figures 6, 7 and 8 the elastosonographic and B-Mode images, resulting from the examination on the left testicle of our patient.

In particular the Figure 6 and 7 show the examination made on September and October 2009. Then the Figure 8 shows the elastosonographic detection made on November 2010 during the conservative intervention ultrasound guided.
4. Conclusions

Considering the limitations of clinical assessment, ultrasound has so far been considered the gold standard for evaluating scrotal abnormalities and in the detection of testicular masses, but does not provide a histological diagnosis [14]. The ultrasonography alone is insufficient to define the nature of these injuries and it is in this context that the elastography can provide valuable support to their diagnostic definition, and allows a surgical approach less demolitive. Elastosonography, for its immediacy and ease of execution, could provide an additional aid in the decisions to be taken when undertaking an indication of which other tests to perform, especially in small lesions, the most difficult. Elastography has many benefits as exam. For example: Elastography is the first method for ultrasonic tissue characterization; it’s easy to perform, fast, accurate and reproducible; allows real-time qualitative assessment of tissue elasticity; it also allows a semiquantitative evaluation index of tissue deformation; increases sensitivity, specificity and negative predictive value of ultrasound examinations in the diagnosis of breast cancer; increase the degree of diagnostic confidence for the operator; the importance of altered elastic avoids the use of a diagnostic procedure or controls seriated; reduces the anxiety of uncertain diagnosis for patients that require controls seriated; lowers costs for any further diagnostic.

As for the risks there are no known harmful effects to the human organism correlated with diagnostic ultrasound. This work aims to be an incentive to use the Ultrasound Elastography prior to any testicular surgery to avoid, as much as possible and in the cases where it is effectively possible, radical surgery, seen and shown that, in this context, the only ultrasound exam can not provide enough clinical informations.

According to the guidelines of EAU (European Association of Urologists), a testicular mass detected by Ultrasound indicates the necessity of orchiectomy. Pre-surgery biopsy and organ-spare surgery can be attempted in special cases: in synchronous bilateral testicular tumours, metachronous contralateral tumours, or in a tumour in a solitary testis with normal pre-operative testosterone levels [17, 18]. The orchiectomy indication is also present in cancer classified as “Stage I”, that is those without limphonodal positivity [19]. This makes it necessary for science to try to define new diagnostic methods with a conservative intent, thus to avoid the orchiectomy in patients affected by benign tumor, with the psicological and social consequences that such kind of surgery would bring.

In such contest elastography is a valid help for the urologist and the radiologist to define the nature of such nodule and in this case to amplify the therapeutic spectrum. Not only, but, because the elastography exam is an ultrasonographic technique, it has the positive aspects of being fast, not expensive and not implicating ionizing radiations on germinative organs like testicles. Even if it doesn’t substitute the diagnostic accuracy of the biopsy, it lets us see new criteria to ultrasonography and elastographic classification. All of this has to be added to the already present and detailed histologic classification; so we can re-evaluate in a conservative sense the main aspects of the diagnostic classificatory approach to testicular cancer.

References


IS IT POSSIBLE THAT GET CLOSER TO GOLDEN RATIO MEANS TO BE MORE HEALTHY?

A STUDY OF PROPORTIONS OF THE HUMAN BODY 
THROUGH MAGNETIC RESONANCE IMAGING

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Abstract. Magnetic Resonance, through the use of imaging (Magnetic Resonance Imaging – MRI), is a widespread method in clinical practice, due to its high resolution of contrast, in the absence of ionizing radiation. The purpose of this study was to investigate on the possible relation between the Golden Ratio and health. To do this, for this study, we made measurements on singulars MRI of 10 subjects (5 M, 5 F, aged 31-65y) and furthermore we made comparisons on 3 other subjects (3 M, aged 56-67y), evaluated at the beginning and at the end of a training period with a patented device for postural correction. An high-field MR apparatus has been used (AVANTO 1,5T). The results showed some interesting relations between the Golden Ratio and the presence or absence of pain or the probability to reach a healthy or unhealthy situation for the human body. These results, although in limited series, suggest that the Golden Ratio could be related to health. Since the Golden Ratio has been studied from centuries, but never in small portions of the human body seen through MRI, as a pilot study, these findings do not want to impose any theory, but could open a chance to new studies in this way to analyze many possibilities.

Key words: Nuclear Magnetic Resonance, Golden Ratio

1.Introduction

NMR is an investigation technique based on measurement of the precession of the spin of protons of hydrogen nuclei, or other nuclei with magnetic moment, when they are subjected to a magnetic field. In medicine, MRI provides different information than conventional radiological images. In fact, in NMR technique, the signal of intensity is due to the atomic characteristics of the examined element; while the radiographic density in X-Ray exams is mainly due to characteristics of resistance of the target organ, which depends on properties of electron orbitals of the atoms affected by X-rays. MRI allows to investigate only the morphological stuctures, or in some cases to monitorate the functionality of the internal organs (Functional MRI). The main fields of use of MRI are Diagnostic and Research, mainly in Neurosciences. Due to its sensibility in appreciating also little anatomic particulars of the internal structures, it seemed useful to try to find what kind of relation could be between human body proportions and the Golden Ratio. The Golden Ratio in mathematics and the arts is a geometric proportion based on a specific ratio. Given a segment (AC), you get a golden section when the shorter part of the segment (BC) is to the longest (AB) as the longest (AB) is to the entire segment (AC). The Golden Ratio, defined as $\phi$, is about equal to 1.618 and also seems to be the standard for perfection, grace and harmony. From centuries, $\phi$ has been studied in many fields, from pure mathematics to psychology, from art to architecture, and even in botany, music and literature. The interesting fact is that in all the fields where $\phi$ has been studied, it has been found some interesting relations between $\phi$ and the most perfect harmony in those fields. For example, many architectural works of different history periods have golden ratio proportions; or also many musical instruments have golden ratio proportions so to produce perfect sounds; and again, in psychology, in the nineteenth century began the first psychological studies designed to certify on scientific basis the claim of aesthetics superiority of the golden section, especially the test focused on aesthetic preference for the golden rectangle, that between all the geometric derivatives of the divine proportion seems to be the one which has inherited most of its halo "charm". The golden section has always been considered a relationship with great harmony, capable of giving to the figures inherently beauty, and among all its geometric applications, the golden rectangle is undoubtedly the polygon that has inherited the most fame. Rightly or wrongly, it was felt that since ancient
times it has been used in the construction of important buildings to give them a special harmony, and these beliefs in centuries have given perplexity among scholars, and sometimes even long controversies. An interesting fact, from a medical point of view, is that $\phi$ is present also in human body proportions, and in recent years some medical studies have tried to confirm the relation between $\phi$ and several physiological function of the human body. In this pilot study, we try to suppose a relation between $\phi$ and health, considering health as the absence of painful situations, caused by anatomical alterations of the body. To do this we made measurements on singulars MRI of 10 subjects (5 M, 5 F, aged 31-65y) and furthermore we made comparisons on 3 other subjects (3 M, aged 56-67y), evaluated at the beginning and at the end of a training period with a patented device for postural correction. This study aims to be an hypothesis that $\phi$ should not be considered only from a “beauty” point of view, but also from a medical point of view, where the reaching of the $\phi$ proportions could be the reaching of the healthier situations.

2. Materials and Methods
We made cervical, thoracic and lumbar vertebra measurements (mm) on singulars MRI of 10 subjects (5 M, 5 F, aged 31-65y) and furthermore we made comparisons on 3 other subjects (3 M, aged 56-67y), evaluated at the beginning and at the end of a training period with a patented device for postural correction (Fig.1).

The execution of the task is outlined in Figures 2a and 2b: starting from a seated position (2a) each of the participants were required to extend the arms (2b), keeping elbows at shoulder height, to lift a weight through the cables of the equipment. Regardless of gender, age, level of training, the weight was lifted within a range between 6 and 8 kilograms. The Motory Task was of 2 + 2 minutes of performance duration with a recovery interval of 2 minutes. The 3 subjects, trained with Angel’s Wings, performed the motory task daily (morning and evening) for 30 days. Starting from the concept of the golden rectangle (Fig.3) we made simple measurements on the planes coronal, sagittal and axial of all the MRI of all the subjects examined in this study.

\[
\frac{1}{\phi} = \phi - 1
\]

Fig.1: The machinery, named Angel’s Wings, designed and built by Eng. Luca Valerio Messa, is patented and protected in many legal ways, and its aim is the distension of the cervical-dorsal spine, with contemporary rehabilitation of the shoulder joint position in its natural seat, rather than rotated forward.

The 3 subjects trained with Angel’s Wings, were asked to perform a Motory Task with this apparatus (Fig.2).

The main measurements were performed on the vertebral column of every single subject. In Figure 4 it is represented a schematic lateral view of a vertebral column.

Fig.3: Golden Rectangle

An high-field MR apparatus has been used (Avanto 1,5 T; A.G. SIEMENS, Erlangen, Germany), using spin echo sequences and turbo spin echo T1-weighted and T2-weighted, oriented in the planes coronal, sagittal and axial. The measurements were performed with the software built into the MR system (Syngo 8.4 version, A.G. SIEMENS, Erlangen, Germany).

3. Results
The main measurements were performed on the vertebral column of every single subject. In Figure 4 it is represented a schematic lateral view of a vertebral column.

Fig.4: Vertebral column

The Figures 5 and 6 show two sagittal MRI results of the same subject, a male of 35 years old, where it has been measured a cervical vertebra and a thoracic vertebra (Fig.5), and a thoracic vertebra and a lumbar vertebra (Fig.6), considering all the vertebrae as rectangles.
To have immediate comparison in the measurements that follow, we will equal \( \phi \) to the results obtained from the same measurements. Considering the measurements in Fig. 5, we have the \( \phi \) ratio = 1.212 (19,0271 : 15,6918 mm) for the cervical vertebra, and \( \phi \) = 1.512 (29,1234 : 19,2531 mm) for the thoracic vertebra. In Fig. 6 we have the \( \phi \) ratio = 1.445 (31,7735 : 21,9882 mm) for the thoracic vertebra, and \( \phi \) = 1.240 (33,2023 : 26,7595 mm) for the lumbar vertebra.

Again, the Figures 7 and 8 show two sagittal MRI results of another subject, a female of 65 years old. So, in the Figure 7 we have the \( \phi \) ratio = 1.137 (14,1623 : 12,4511 mm) for the cervical vertebra, and \( \phi \) = 1.496 (24,6784 : 16,4945 mm) for the thoracic vertebra. In the Fig. 8 we have the \( \phi \) ratio = 1.509 (26,4442 : 17,5232 mm) for the thoracic vertebra, \( \phi \) = 1.181 (28,5859 : 24,2041 mm) and \( \phi \) = 1.075 (28,3873 : 26,3906 mm) for the two lumbar vertebrae.

Then, in the next Figures 9 and 10, there are the sagittal MRI results of one of the subjects who has been trained with Angel’s Wings.
For this subject, a male of 64 years old, the measurements were made exactly where the Angel’s Wings acts. So, in Fig. 9 we have the ratio $\varphi = 1.433 \ (177.55 : 123.84 \text{ mm})$, while in Fig. 10 we have the ratio $\varphi = 1.617 \ (183.13 : 113.23 \text{ mm})$. Finally, in Figures 11 and 12 some measurements made on the axial plane of a singular vertebra of another subject, male 60 years old, are shown. In particular, in Fig. 11, we have some potential ratios like $(70.76 : 43.35) \varphi = 1.632$, or $\varphi = 1.418 [(28.69 + 15.62) : 31.24]$ or again $\varphi = 1.633 [(31.24 + 15.62) : 28.69]$. Then, in Fig. 12, we have the ratio $\varphi = 1.615 \ (53.55 : 33.15)$. All of the ratios, calculated from the measurements made on these MR images, suggest that the Golden Ratio proportions are potentially related in some ways also to very small proportions of the human body.

4. Conclusions

Statistically, the cervical and the lumbar vertebrae are the most affected by hernia. This pilot study suggests that the thoracic vertebrae are the most "proportioned", the nearest to $\varphi$. Furthermore, on subjects who made a training period, the proportions of the area of the body on which the used device acts, changed, going to be really closer to $\varphi$ at the end of the training period than at the beginning. All the 3 subjects, at the end of the training period, stated, in subjective evaluation, to feel less pain, probably caused by their altered posture, than the beginning. This results could suggest that the more the proportions of the body are near to $\varphi$, the less is the probability to develop painful situations, so the more the body is healthy. However this results are limited, and so, we don’t want to impose any theory, but just to make to consider that if by chance the suggested hypothesis were true, so $\varphi$ could be a “key way” of approach in many medical fields, and also, it could be possible to try to find a relation between $\varphi$ and every function, mechanical or physiological, or proportion of the human body.

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A NATIONAL INTERCOMPARISON PROGRAM FOR PERFORMANCE APPROVAL TESTS OF INDIVIDUAL DOSIMETRY SERVICE PROVIDERS IN IRAN

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Abstract Performance testing as part of approval procedures is carried out to demonstrate that the essential performance specifications are routinely maintained.
There are four service providers in Iran which use different luminescence techniques (e.g. TLD and RPL) with various kinds of dosimeter materials/reader instruments in the personal dosimetry services.
A national performance approval tests program has been performed on the dosimeters of the service providers in energy range of soft x-ray, 660 keV and 1.25 MeV, at the doses values around the recoding, investigation and annual dose limits, and different angle of incidents (e.g. 0, 20, 40 and 60 degree).
The results of this testing satisfies the overall accuracy criteria with 95% confidence levels specified by the ICRP, except that of RPL technique in low energy x-ray which overestimates the dose out of the acceptable accuracy band defined as the ICRP trumpet curves.

Key words: TLD, RPL, Dosimetry, Intercomparison, Individual, Performance, Tests

1. INTRODUCTION

There are different kinds of passive dosimetry methods that service providers may use them for the personal dosimetry. Among the methods, the luminescence techniques inclusive of thermally stimulated luminescence (TLD), radio-photoluminescence (RPL) and optically stimulated luminescence (OSL) are the most general accurate methods in this regard [1].

There are many factors such as energy and angular dependency which may increase the uncertainty of measurements by luminescence dosimeter in personal dosimetry [2].

Based upon the ICRP criteria for personal dosimetry, the overall accuracy in measurements should be satisfied at different dose limits. These evaluations are being done via a performance test program as a part of approval procedures by a competent authority to demonstrate that the essential performance specifications are routinely maintained [3].

There are four private service providers in Iran that use the luminescence techniques in their personal dosimetry services. They cover approximately five thousand workers in various industries who deal with radiation.

In this research first the procedure has been explained, and then according to the type of dosimeters, the results of a national intercomparison program on the dosimeters have been presented and discussed in detailed.

2. MATERIALS AND METHODS

The types of dosimeters which have been participated in the program are shown in Fig.1. These are inclusive of TLD-100 and GR-200 dosimeters which have been placed in HARSHAW, RADOS and PTW badges. As well one of the service providers uses RPL dosimeters of model UIF-01 in their services. The combination of dosimeter-badges which are used by the service providers are presented in table 1.

The selected energies for the performance test have been x-ray beams of 120 keV, γ-ray beams of 660 keV and 1.25 MeV provided by Secondary Standard Dosimetry Laboratory (SSDL) of Iran. All the dosimeters have been exposed in different angle of incident by value of 0, 20, 40 and 60 degree.

The ICRP trumpet curves have been calculated with the assumption that the recoding level to be 0.1 mSv by value for a bimonthly/quarterly periodic dosimetry time. Then:
\[ R_{UL} = \begin{cases} 1 & \text{for } H_f < H_0 \\ \frac{1}{1 + \frac{2H_0}{H_0 + H_1}} & \text{for } H_f \geq H_0 \end{cases} \]

\[ R_{UL} = 1.5 \times \left( 1 + \frac{H_0}{2H_0 + H_1} \right) \]

where, \( R_{UL} \) and \( R_{UH} \) are the low and high level curves respectively, \( H_0 \) is the recoding level value, and \( H_1 \) is the true doses.

which have

\[ \text{(i)} \]

which have comparison table 1).

Table 1: The dosimeter-badges which are used by the service providers.

<table>
<thead>
<tr>
<th>Label of Service Provider</th>
<th>Type of dosimeter</th>
<th>Type of badge</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>LiF: Mg, Ti</td>
<td>Home-made</td>
</tr>
<tr>
<td>B</td>
<td>LiF: Mg, Cu, P</td>
<td>PTW</td>
</tr>
<tr>
<td>C</td>
<td>(1) LiF, Mg, Ti</td>
<td>RADOS</td>
</tr>
<tr>
<td></td>
<td>(2) LiF: Mg, Cu, P</td>
<td>HARSHAW</td>
</tr>
<tr>
<td>D</td>
<td>RPL</td>
<td>UIF-01</td>
</tr>
</tbody>
</table>

Based upon the recoding, investigation and annual dose limits, the true dose arounds the limits have been selected as 0.7, 2.4 and 25 mSv.

A response curve should be constructed for each type of radiation by calculating and plotting the average angular response for each energy \( \varepsilon \):

\[ \bar{R}_{\varepsilon} = 0.25(R_{\varepsilon,0} + R_{\varepsilon,20} + R_{\varepsilon,40} + R_{\varepsilon,60}) \]  

where \( R_{\varepsilon,\alpha} \) is the response at energy \( \varepsilon \) and incident angle \( \alpha \), and

Fig. 2 \( \bar{R}_{\varepsilon} \) values for the various dosimeters of the service providers in the national performance test program, (a) LiF: Mg, Ti in Home-made badge, (b) LiF: Mg, Cu, P in PTW badge, (c) LiF: Mg, Ti in RADOS badge, (d) LiF: Mg, Cu, P in Harshaw badge (d) RPL in UIF-01 badge.
\[ R_{L,t} = \frac{(H_{L,t})_m}{(H_{L,t})_c}, \]

where \((H_{L,t})_m\) is the measured dose and \((H_{L,t})_c\) is the conventional true value.

3. RESULTS AND DISCUSSION

Fig. 2 shows the trumpet curves along with \( R_{L,t} \) values for the various dosimeters in the national performance test program.

As it can be seen, the values for TLD-Based individual dosimeters have been placed inside of the trumpet curves. However, the TLD dosimeters which have LiF:Mg, Cu, P dosimeters underestimate the dose in x-ray energy range, while LiF: Mg, Ti overestimate it regardless of the type/shape of badges. The results are compatible with the energy response of the bare dosimeters which have been reported by other investigators [4,5].

As well, the results of RPL dosimeter show that its response in higher energy range is placed inside the trumpet curve, while it may overestimates the dose outside of the curves in x-ray low energy range. That is, the dosimeter is more appropriate in high energy gamma radiation fields.

4. CONCLUSION

A national performance test program has been carried out for the personal dosimeters of four private service providers in Iran which use different luminescence techniques. According to the obtained results, it can be concluded that the overall accuracy criteria with 95% confidence levels specified by the ICRP are satisfied. Since the RPL dosimeter in low energy x-ray overestimates the dose out of the acceptable accuracy band defined as the trumpet curves, it is recommended that it being used in the high energy gamma radiation areas.

REFERENCES

OCCUPATIONAL EXPOSURE FROM A PORTABLE DENTAL X-RAY UNIT

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Abstract A new hand-held battery operated x-ray system was introduced to dentists less than ten years ago. Such systems are generally used in emergency situations (e.g., in natural disasters), for disabled/aged patients, and in patient rooms. In this research, the operator exposures due to using of a Genoray dental portable x-ray system have been investigated. For this aim, the doses of some sensitive organs of operator have been measured using implanted TLD in a Rando-phantom during different situations of exposure by the system. The maximum total dose was measured in closed hands/arms situation of the operator when maxillary teeth of patient are exposed. Considering the geometry of this imaging system as well as annual organ dose limits, the main limitation in number of its using is determined by the results of hand dose.

Keywords: Portable Dental x-ray, TLD, RANDO phantom, Dose Equivalent

1. INTRODUCTION

There are different kinds of imaging systems which are used for dental radiography. Based upon the international guidelines on radiation protection, a distance of 2 m from the x-ray tube should be kept by the operators [1]. The portable dental x-ray systems have potential for use in forensic density, humanitarian missions, nursing homes, and disabled patients. Since the operators have to hold the unit during the exposure, the related occupational exposure risk may be increased via using such systems. It has been conducted little studies on radiation risk by the system and most of them have been done by the manufacturers [2-4]. Recently, an investigation on radiation exposure with NOMAD™ portable x-ray system has shown that the risk is no greater than with national standard radiographic units (USA) to the patient or operator-, and the measured doses are well below the recommended levels [4].

In this research, based upon the ICRP criteria [5], the occupational radiological quantities as well as critical organ doses of the operator in neck/head area are investigated when a portable dental radiography system is used under different exposure positions.

2. MATERIALS AND METHODS

A portable dental x-ray model of GENORAY PORT X II has been selected for investigations [6] (see Fig. 1). The exposures have been performed at high voltage of 60 kV with 2 mA current and a total duration time of 2 s per shot.

Fig. 1 A typical Genoray Dental Portable x-ray system

A RANDO phantom has been used to simulate the operator body, and a 30 cm diameter polyethylene sphere placed on a cubic Plexiglass (30 × 30 × 15 cm³) has been used to simulate the scattering rays of the upper part of a patient body. The experiment was done while exposing -the maxillary and mandibular teeth of patient (Fig. 2) in 2 cases, with and without using protective means (lead apron and thyroid shield).

In all exposures it is assumed that the operator’s hands/arms are in as closed as possible position so that the Genoray system was placed near the operator’s chest. In this experiment between 40-90 shots were performed, in order to increase the accuracy of measurements.

The organ doses in RANDO phantom have been measured by at least 3 TLD dosimeters in each organ,
type GR-200 pellets, which were implanted in the phantom before the exposures [7].

The exposed TLDs were annealed and measured by a Harshaw TLD reader system, and the mean organ equivalent doses calculated using the equation 1:

$$H_T = \frac{\sum TL_i \cdot ECC_i \cdot CF \cdot RL_i \cdot \left(\frac{\mu_{en}}{\rho}\right)_{wave}}{100 \cdot n}$$  \hspace{1cm} (1)

Where TL is the TLD pellet reading value, ECC is its element correction coefficient of each pellets, CF is calibration factor, n is the number of implanted pellets at each organ, RL is the reference light values of TLD reader and $\mu_{en}/\rho$ is the mass energy absorption coefficient at effective energy of 60 kV of X-ray tube. As well, the operational quantity of $H_T(10)$ has been measured to calculate the whole body dose of the operator.

3. RESULTS AND DISCUSSIONS

The results of organ doses and whole body dose of operator in various exposure conditions are shown in Table 1. The measured values from table 1 show that the scattering radiation from the patient has the most contribution in organ dose of the operator by such a system.

The ICRP-60 recommends an annual dose limit of 20 mSv due to occupational exposure of whole body, 500 mSv for hand dose and 150 mSv for eye lenses. The maximum total dose was measured 95 $\mu$Sv per shot in closed hand/arm situation of the operator when maxillary teeth of patient are exposed. As well the eye-lens and finger doses have been measured 0.111 and 1.410 mSv per shot respectively. Thus considering both the annual limits and the dose values in table 1, the main restriction in using of the system can be calculated by hand dose. The dose values in table 1 also show that the use of shields (lead apron or thyroid shield) may decrease the values significantly.

Table 1 The measured values of organ doses (in $\mu$Sv per shot) in two different kind of examinations (The dose values are the mean values of TLDs in each organ with the related standard deviations).

<table>
<thead>
<tr>
<th>Organ dose &amp; exposed area of patient</th>
<th>Type of shield</th>
<th>Without lead shield</th>
<th>With lead shield (apron /thyroid shields)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Whole body [H$_T$(10)]</td>
<td>maxillary teeth</td>
<td>95±14</td>
<td>153.6×10^{-3}±20×10^{-3}</td>
</tr>
<tr>
<td></td>
<td>mandibular teeth</td>
<td>28±9</td>
<td>86.2×10^{-3}±14×10^{-3}</td>
</tr>
<tr>
<td>Fingers</td>
<td>maxillary teeth</td>
<td>1410 ± 200</td>
<td></td>
</tr>
<tr>
<td></td>
<td>mandibular teeth</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Eye Lenses</td>
<td>maxillary teeth</td>
<td>111 ± 6.2</td>
<td></td>
</tr>
<tr>
<td></td>
<td>mandibular teeth</td>
<td>19 ± 2</td>
<td></td>
</tr>
<tr>
<td>Thyroid gland</td>
<td>maxillary teeth</td>
<td>53±3</td>
<td>256×10^{-3}±35×10^{-3}</td>
</tr>
<tr>
<td></td>
<td>mandibular teeth</td>
<td>10±0.6</td>
<td>121×10^{-3}±20×10^{-3}</td>
</tr>
<tr>
<td>Salivary gland</td>
<td>maxillary teeth</td>
<td>49±7.3</td>
<td></td>
</tr>
<tr>
<td></td>
<td>mandibular teeth</td>
<td>6±1.5</td>
<td></td>
</tr>
<tr>
<td>Parathyroid gland</td>
<td>maxillary teeth</td>
<td>8±1.1</td>
<td>Negligible</td>
</tr>
<tr>
<td></td>
<td>mandibular teeth</td>
<td>2±0.2</td>
<td>Negligible</td>
</tr>
<tr>
<td>Cheekbone</td>
<td>maxillary teeth</td>
<td>5±1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>mandibular teeth</td>
<td>1±0.3</td>
<td></td>
</tr>
<tr>
<td>Gonads</td>
<td>maxillary teeth</td>
<td>2.7±2</td>
<td>Negligible</td>
</tr>
<tr>
<td></td>
<td>mandibular teeth</td>
<td>2±1</td>
<td>Negligible</td>
</tr>
</tbody>
</table>

4. CONCLUSION

Considering sensitive organ and total effective dose, it can be concluded that the portable dental X-ray system in general could be a safe device for the operators. The limitation in use of the system is derived by the averaged time duration of exposures and annual dose limit of the hands. The total effective dose as well as organ doses in neck area may be decreased using the proper protection means such as lead apron or thyroid shields.

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EFFICIENCY OF $^{14}$C DETECTION BY LIQUID SCINTILLATORS USING TRIPLE TO DOUBLE COINCIDENCE RATIO AND QUENCH PARAMETER EXTERNAL

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Abstract. The aim of this study is to determine the $^{14}$C efficiency by liquid scintillation counting using Quench Parameter External (QPE) and Triple to Double Coincidence Ratio (TDCR), and to compare the results. The equipment used was the HIDEX model 300-SL Liquid Scintillation Counter, composed of three photomultipliers coupled with coincidence pulses, discrimination level and MikroWin 2000 software. For the determination of the quench curve and efficiency for the two methods, 15 quench cocktail standards with different quenching agents were used. The quench parameter of cocktail standard varied from 410 to 813. The efficiency varied from 0.493 to 0.964 cps dps$^{-1}$ for QPE and from 0.408 to 0.968 cps dps$^{-1}$ for TDCR. Different efficiencies, above 10%, were obtained using the two methods in the range of 410 to 513 quench parameter, above this range the efficiencies were similar. The verification of the efficiencies was performed by measuring standard solutions.

Key words: TDCR, QPE, liquid scintillation counting, $^{14}$C

Introduction: The liquid scintillation counting (LSC) is a technique in which the sample is mixed to the liquid scintillator, forming a scintillation solution, capable of converting the kinetic energy of nuclear emissions into light photons [1]. The interaction of the emissions occurs in the liquid solution, producing excitement with emission of photons of ultraviolet radiation. Quench is a reduction in system efficiency, as a result of energy loss in the liquid scintillation solution. Because of quench, the energy spectrum detected from the radionuclide appears to be shifted toward a lower energy. The three major types of quench are photon, chemical and optical [2]. The counting efficiency is determined by the relative quenching of the sample, by using an external source for the determination of quench parameter [3]. Quench Parameter External (QPE) is the most common method for determination of efficiency in LSC, used with external standard generating the parameter of indication of quench. Triple to Double Coincidence Ratio (TDCR) is a primary measurement method based on calculation of the efficiency from the measured ratio of double and triple coincidence counting rates [4]. TDCR does not require radioactive source and quenching curve, therefore it is an absolute measurement [5]. The quenching factor is critical for the determination of $^{14}$C. The $^{14}$C is a pure beta emitter, with 49.5 keV average energy and half-life of 5,730 years [6], produced naturally in the atmosphere and during atmospheric nuclear tests [7]. The $^{14}$C is also used as an important tool in research, in the field of pharmaceutical, biology, agriculture, pollution control and archeology [8]; different matrices can generate different quenches. This paper aims to compare the efficiencies for $^{14}$C determination in water by LSC using QPE and TDCR.

Materials and Methods: The efficiency for $^{14}$C was measured with a LSC, HIDEX model 300-SL, composed by three photomultipliers coupled with coincidence pulses, discrimination level and MikroWin 2000 software. The counts were determined using two different Quenched Standards Sets, $^{14}$C UG Quenched Standard Set (UG) (activity: 125,200 ± 1.3% dpm) and $^{14}$C XR Quenched Standard Set (XR) (activity: 125,200 ± 1.3% dpm), and two reference standards without quench (Unquenched) (activities: 128,600± 1.3% and 99,100± 1.3% dpm). All the standards sets were provided by PerkinElmer with vials made of glass and a volume of 15 ml. For QPE methodology, an external source of $^{152}$Eu was used for producing a quench parameter. The counting efficiency was obtained by the equation (1).

\[
Ef_{\text{QPE}} = \frac{\text{counts} - Bg}{\text{Activity}}
\]  

(1)

where: \(Ef_{\text{QPE}}\): counting efficiency (cps dps$^{-1}$),
\(\text{Activity}\): source activity (Bq),
\(\text{counts}\): source counts (cps),
\(Bg\): background radiation (cps).
For the TDCR methodology, the calculation took into account the differences between the counting ratios on the photomultipliers, based on the efficiency from the measured ratio of double and triple coincidence counting rates, by the expression (2) [9].

\[
TDCR = \frac{\int_{0}^{E_0} S(E)(1-e^{-n})^3 dE}{\int_{0}^{E_0} S(E)(3(1-e^{-n})^3 - 2(1-e^{-n})^3) dE}
\]

where: \(TDCR\): counting efficiency,
\((1-e^{-n})^3\): triple coincidences,
\((3(1-e^{-n})^3 - 2(1-e^{-n})^3)\): all coincidences.

The counting time was 20 minutes for each Quenched Standard Set. The Quenched Standards Sets were analyzed in triplicate. The background radiation was determined by using the same scintillating vial provided by PerkinElmer, the count rate obtained was 0.91 cps.

**Results and Discussion:** For the two methodologies, fifteen \(^{14}\)C quench cocktail standards with different quenching agents, with activity of 2087 Bq for UG, 2167 Bq for XR and Unquenched with activities 2143 Bq and 1651 Bq, were used. The efficiency results of QPE and TDCR are presented in Table 1.

<table>
<thead>
<tr>
<th>Quench parameter</th>
<th>QPE Efficiency (cps dps(^{-1}))</th>
<th>TDCR Efficiency (cps dps(^{-1}))</th>
<th>QPE/TDCR</th>
</tr>
</thead>
<tbody>
<tr>
<td>410</td>
<td>0.493 ± 0.003</td>
<td>0.408 ± 0.001</td>
<td>1.21</td>
</tr>
<tr>
<td>431</td>
<td>0.587 ± 0.001</td>
<td>0.492 ± 0.002</td>
<td>1.19</td>
</tr>
<tr>
<td>470</td>
<td>0.677 ± 0.001</td>
<td>0.587 ± 0.001</td>
<td>1.15</td>
</tr>
<tr>
<td>513</td>
<td>0.766 ± 0.001</td>
<td>0.694 ± 0.001</td>
<td>1.10</td>
</tr>
<tr>
<td>580</td>
<td>0.845 ± 0.001</td>
<td>0.802 ± 0.001</td>
<td>1.05</td>
</tr>
<tr>
<td>598</td>
<td>0.876 ± 0.001</td>
<td>0.844 ± 0.001</td>
<td>1.04</td>
</tr>
<tr>
<td>662</td>
<td>0.912 ± 0.001</td>
<td>0.898 ± 0.001</td>
<td>1.02</td>
</tr>
<tr>
<td>688</td>
<td>0.926 ± 0.001</td>
<td>0.918 ± 0.001</td>
<td>1.01</td>
</tr>
<tr>
<td>703</td>
<td>0.939 ± 0.002</td>
<td>0.935 ± 0.001</td>
<td>1.00</td>
</tr>
<tr>
<td>710</td>
<td>0.936 ± 0.001</td>
<td>0.932 ± 0.001</td>
<td>1.00</td>
</tr>
<tr>
<td>727</td>
<td>0.946 ± 0.001</td>
<td>0.946 ± 0.001</td>
<td>1.00</td>
</tr>
</tbody>
</table>

Figure 1 presents the efficiency curve with of indication of quench parameter for \(^{14}\)C using QPE method obtained in the present study. The curve was adjusted with polynomial equation and a correlation coefficient of 0.9989 was obtained.

![Efficiency curve](image1)

**Fig. 1 Quenching curve obtained for \(^{14}\)C**

Figure 2 presents the relationship between the TDCR efficiency and the QPE efficiency, for \(^{14}\)C standards with different quenching agents, calculated in the present study.

![Relationship between TDCR and QPE](image2)

**Fig. 2 Relationship between the TDCR efficiency and the QPE efficiency for \(^{14}\)C**

The verification of the TDCR and QPE efficiencies was performed by measuring two standards solutions provided by PerkinElmer, for quench parameter range from 807 to 491. Each standard solution was analyzed in triplicate. The results are presented in Table 2.
Table 2 Relative Error and Relative Standard Deviation of $^{14}$C determination by using QPE and TDCR efficiencies

<table>
<thead>
<tr>
<th>Quench parameter</th>
<th>Relative Error % (QPE)</th>
<th>Relative Error % (TDCR)</th>
<th>Relative Standard Deviation (QPE)</th>
<th>Relative Standard Deviation (TDCR)</th>
</tr>
</thead>
<tbody>
<tr>
<td>807</td>
<td>0.15</td>
<td>0.31</td>
<td>2.15</td>
<td>0.07</td>
</tr>
<tr>
<td>759</td>
<td>0.29</td>
<td>0.02</td>
<td>2.19</td>
<td>0.06</td>
</tr>
<tr>
<td>731</td>
<td>0.22</td>
<td>0.27</td>
<td>2.19</td>
<td>0.09</td>
</tr>
<tr>
<td>653</td>
<td>0.27</td>
<td>1.54</td>
<td>2.14</td>
<td>0.03</td>
</tr>
<tr>
<td>628</td>
<td>1.05</td>
<td>2.94</td>
<td>2.20</td>
<td>0.12</td>
</tr>
<tr>
<td>537</td>
<td>1.90</td>
<td>7.39</td>
<td>2.13</td>
<td>0.06</td>
</tr>
<tr>
<td>491</td>
<td>3.31</td>
<td>11.5</td>
<td>2.11</td>
<td>0.07</td>
</tr>
</tbody>
</table>

The QPE and TDCR methods gave results with a good precision and accuracy in the range from 537 to 807 for the quench parameter. The QPE and TDCR methods gave worse results with the increment of the quench parameter. The QPE method was more appropriate in the quench parameter 491.

Conclusions: The TDCR method requires equipment with three photomultipliers, whereas the QPE method requires equipment with only two photomultipliers, but needs different quenching standards of the element to be analyzed.

The TDCR method is in general faster and simpler, and does not require radioactive standard and quench parameter curve, since it is an absolute measurement.

The QPE and TDCR methods gave results with a good precision and accuracy in the range from 537 to 807 for the quench parameter.

The relative error obtained for the efficiency using the TDCR method in the quench parameter 491 was higher than 10%. Above this value, the efficiencies were similar for the two methods. The QPE method in the quench parameter 491 was more appropriate.

REFERENCES


COMPARISON OF $^{210}$Pb DETERMINATION IN ENVIRONMENTAL SAMPLES
BY LIQUID SCINTILLATION COUNTING AND GAS FLOW PROPORTIONAL COUNTING

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$^1$ Instituto de Pesquisas Energéticas e Nucleares (IPEN / CNEN - SP)
$^2$ Universidade Nove de Julho

Abstract. In this paper, two analytical techniques for Pb determination in environmental samples, Liquid Scintillation Counting and Gas Flow Proportional Counting, are reviewed; with emphasis on radionuclide separation and purification, source preparation and measurement techniques. The accuracy, precision and minimum detectable activity of the two techniques is presented.

Key words: Liquid Scintillation Counting, Gas Flow Proportional Counting, $^{210}$Pb

Introduction: Pb-210 is part of the U-238 natural series, formed by the decay of the gas Rn-222, with a half-live of 22.3 years and emission of beta particles with 16.5 keV (80.2%) and 63.0 keV (19.8%). The diffusion of Rn-222 from the soils and rocks introduces the Pb-210 in to the atmosphere and its subsequent fallout provides an input of this radionuclide to surface soil and sediments. Therefore Pb-210 has been widely used for dating lake sediment cores, for estimating soil erosion rates and for atmospheric research. Pb-210 is also important in terms of radiation protection.

This radionuclide can be determined by many techniques, such as Liquid Scintillation Counting (LSC), Gas Flow Proportional Counting (GFPC), Gamma spectrometry and alpha spectrometry. The LSC is a technique in which the sample is mixed to the liquid scintillation, forming a scintillation solution, capable of converting the kinetic energy of nuclear emissions into light photons. The interactions of the emissions occur in the liquid solution, producing excitation with emission of photons of ultraviolet radiation. The GFPC consists of an anode, Mylar window and a gas flow P-10 (mixture of argon and methane). Alpha and beta particles penetrate the window and ionize the gas, resulting in further ionizations. These ionizations are accumulated at the anode to produce electrical pulses, and alpha and beta measurement are separated based on rise time and pulse height discrimination. This paper reviews the two techniques in terms of accuracy, precision and minimum detectable activity (MDA) for Pb-210 determination in environmental samples; aiming to implement the LSC as a new methodology in our laboratory.

Materials and Methods: The verification of the two methodologies studied was performed using reference materials IAEA-326 – Radionuclides in Soil, IAEA-385 Irish Sea Sediment and participating in Proficiency Tests (PT) organized by Instituto de Radioproteção e Dosimetria (IRD/CNEN).

The determination of Pb-210 by LSC measurement was performed using a 1220 Quantulus™ Ultra Low Level Liquid Scintillation Spectrometer. The standard reference materials were dissolved in a microwave digestor using an EPA 3052 method and mixed with Pb$^{2+}$ carrier solution (30 mg mL$^{-1}$) and were percolated through a glass column filled with 3 g of Sr-Spec resin from EICHRON, pre-conditioned in HCl 2M. In this condition, the Pb-210 and Bi-210 are retained. A volume of 80 mL of HCl 2M was used to elute the interfering element Bi-210. In the next step, Pb-210 was eluted with HCl 6M. The solution was dried and the residue dissolved in a hot solution of 20 mL HNO$_3$ and 0.4g of oxalic acid was added. The pH was adjusted with NH$_4$OH and the Pb-210 was precipitated as a Pb oxalate and filtered in a Whatman 40 filter. The chemical yield was determined gravimetrically. The filter was transferred to a vial with 15 mL of scintillation solution Hisafe III and immediately measured using a Quantulus. The chemical yield achieved varied from 42 to 75 %, and the counting efficiency for the Pb-210 was 91%. The blank was determined by measuring deionized water and using the model proposed by Currie. The MDA achieved was 6 mBq per sample for a counting time of 24,000 s.

The Pb-210 determination by GFPC measurement was performed using a low background gas flow proportional detector (10-channel Low-Level Planchet Counter LB 770 Berthold). The dissolved samples containing the standard reference materials were mixed with Pb$^{2+}$ carrier (20 mg mL$^{-1}$). Pb-210 concentration was determined by radiochemical procedure that consists of an initial precipitation of Pb
with 3M H$_2$SO$_4$, dissolution of the precipitate with nitrilo-tri-acetic acid at basic pH, and precipitation of $^{210}$PbCrO$_4$ with 30% sodium chromate. The Pb-210 concentration was determined through its decay product, Bi-210 by measuring the gross beta activity of the $^{210}$PbCrO$_4$ precipitate. The chemical yields were determined by gravimetric analysis, the results obtained varied from 80% to 93%. The blank was determined by using deionized water, the MDA achieved was 4 mBq per sample for a counting time of 7,200 s.

All the analysis was carried out in triplicate.

Results and Discussion: The results obtained for the concentration of Pb-210 by LSC and GFPC and the corresponding precision and accuracy are presented in Table 1 and Table 2, respectively.

Table 1 Concentration of Pb-210 in Bq kg$^{-1}$ by LSC and GFPC

<table>
<thead>
<tr>
<th>Reference materials</th>
<th>Reference value</th>
<th>LSC mean value</th>
<th>GFPC mean value</th>
</tr>
</thead>
<tbody>
<tr>
<td>PT/IRD August/11</td>
<td>1.43±0.29</td>
<td>1.40±0.1</td>
<td>1.56±0.08</td>
</tr>
<tr>
<td>PT/IRD December/11</td>
<td>2.80±0.6</td>
<td>2.71±0.05</td>
<td>2.50±0.08</td>
</tr>
<tr>
<td>PT/IRD April/11</td>
<td>0.50±0.10</td>
<td>0.46±0.05</td>
<td>0.45±0.03</td>
</tr>
<tr>
<td>IAEA - 326</td>
<td>53.3</td>
<td>56.1±3.8</td>
<td>56.8±3.2</td>
</tr>
<tr>
<td>IAEA - 385</td>
<td>32.9</td>
<td>33.6±3.5</td>
<td>34.7±2.5</td>
</tr>
</tbody>
</table>

Table 2 Precision and accuracy for the determination of Pb-210 by LSC and GFPC

<table>
<thead>
<tr>
<th>Reference Materials</th>
<th>Relative Error % (LSC)</th>
<th>Relative Standard Deviation (LSC)</th>
<th>Relative Error % (GFPC)</th>
<th>Relative Standard Deviation (GFPC)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PT/IRD August/11</td>
<td>2.1</td>
<td>7.1</td>
<td>9.1</td>
<td>5.1</td>
</tr>
<tr>
<td>PT/IRD December/11</td>
<td>3.2</td>
<td>1.8</td>
<td>10.7</td>
<td>3.2</td>
</tr>
<tr>
<td>PT/IRD April/11</td>
<td>8.0</td>
<td>10.9</td>
<td>10.0</td>
<td>6.7</td>
</tr>
<tr>
<td>IAEA - 326</td>
<td>5.3</td>
<td>6.8</td>
<td>6.6</td>
<td>5.6</td>
</tr>
<tr>
<td>IAEA - 385</td>
<td>2.1</td>
<td>10.4</td>
<td>5.4</td>
<td>7.2</td>
</tr>
</tbody>
</table>

The relative error and relative standard deviation obtained are below 10%, giving evidence of the performance of the two techniques in terms of accuracy and precision.

The results obtained for the chemical yield for the methodology GFPC was better than LSC. The two techniques presented similar sensibility, with MDAs of the same order of magnitude. However, for the LSC technique a counting time 3 times higher was necessary to achieve the same sensibility.

Comparing the two techniques in terms of selectivity, LSC separate and concentrate the radionuclides of interest by using a specific resin (Sr-Spec); the GFPC technique use an extensive radiochemical procedure for the separation and concentration of Pb-210, which includes a series of precipitations and re-precipitations. Therefore, this technique is more expensive, more time consuming and use many chemical reagents, which final disposal is an environmental concern.

Another advantage of the LSC technique is that the spectra obtained allows discriminating the Pb-210 peak from other possible interfering beta emitter’s. The figure 1 shows a typical spectrum of Pb-210 obtained by the LSC Quantulus equipment, with the region of interest adjusted manually.

Figure 1 Spectrum of Pb-210 using LSC

Conclusion: This study was carried out to compare the two methodologies seeking the implementation in our laboratory. The results obtained showed that the precision and accuracy of the two methodologies are equally suitable for the determination of Pb-210 in soil, sediment and water samples. The LSC requires a counting time 3 times higher than GFPC to achieve the same sensibility.

References

SYSTEM FOR DATA ACQUISITION AND CONTROL OF ANKLE FOOT ORTHOSIS

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1Institute of Mechanics and Biomechanics, Bulgarian Academy of Sciences, Sofia 1113, Bulgaria

Abstract. In the cases of neurological disorders (cerebral palsy, insult, spinal cord injury), muscular-skeletal disorders (traumas, age changes) and pathologies of the ankle-foot complex can result in abnormal gaits and commonly treated with orthoses to partially compensate functional loss. For increasing stability and mobility of the ankle different type of orthoses are used. These technical assisting devices are served for improvement of the gait and reduced the high-energy cost as well as preserved of the dynamic walking balance.

Particular interest to biomechanics and orthotics is the analysis of human motion. With the development of sensors technologies and gait data analyzing techniques are investigates kinematics, kinetics and dynamics of lower limbs, improves the locomotion and makes a comparison in normal and clinical conditions. The different types of motion sensors and systems are used for various gait analysis applications.

There is a need for a system that can provide a wireless connection in real-time and reliable result to measure ankle foot movements. In this article is present a system based on Brushless Direct Current (BLDC) motor attached to Ankle Foot Orthosis (AFO) with wireless communication XBee for data acquisition and control in complex movements of more than one joint. Considering the advantages of BLDC motor (better speed versus torque characteristics, high dynamic response, high efficiency, long operating life, noiseless operation, higher speed ranges) we choose it as the best option for data acquisition system and control in orthotics.

The method use high precision quadrant encoder in addition to Hall sensors built in the BLDC motor to increase precision of measurement of angles and creates corrective moments if necessary. In same time the system allows measurement and data acquisition for ankle joint movement and then transfers collected data by wireless connectivity to the analyzing software. We designed a controller board meets the block diagram requirement with possibility to connect wireless module directly via built in RS-485 interface. As a result of the work are shown software and hardware realizations. Brushless motor application is useful in highly compact spaces with small motors. The proposed method estimation can improve measurement accuracy and commutation smoothness.

Key words: ankle foot orthosis, human gait, BLDC motor, data acquisition system

1. INTRODUCTION

Biomechanical deficits of the lower extremities and their related pathologies affect joint mobility and muscle activity. Ankle-foot orthoses (AFOs) can be used for increasing stability and assisting ankle foot motions. These technical devices are served for improvement the gait and recognition of gait phase’s, reduced the high-energy cost as well as preserved of the dynamic walking balance.

To control the orthosis, it is necessary to identify the gait cycle and its phases. A gait cycle [1] can be divided into two phases: a stance and a swing. Stance phase beginning with initial heel strike (HS) and ending with toe-off (TO). Swing phase beginning with toe-off and ending with second heel strike (foot is in the air). For one gait cycle there are first double support - from heel strike of right leg (HSr) to toe-off of left leg (TOl), single support – from toe-off of left leg (TOl) to heel strike of left leg (HSi), second double support – from heel strike of left leg (HSi) to toe-off of right leg (Tor), and swing phase – from toe-off of right leg (TOr) to heel strike of right leg (HSr).

The movements in ankle foot complex are plantarflexion, dorsiflexion, inversion and eversion (see Fig.1). The plantarflexion is the movement which increases the approximate 90 degree angle between the front part of the foot and the shin. The movement in the opposite direction is dorsiflexion, where the dorsal part (top) of the foot is moved in a manner towards the tibia. The inversion is combination from adduction (movement of the foot towards the center line of the body) and supination (external rotation). The eversion is combination from abduction (movement of the foot away from the center line of the body) and pronation (internal rotation).

Fig.1 Direction movements in ankle foot complex
The key muscles for the ankle joint movement are plantar flexors and dorsiflexors [2]. Weakness in the dorsiflexor and plantar flexor muscle groups is a cause of impaired gait [3].

In the gait analysis, a gyroscope is usually combined with an accelerometer to construct a complete initial sensing system. By detecting the linear motion from the Coriolis effort and performing an integration of the gyroscopic signal, the angular rate [4-6] can be obtained.

Recently Brushless Direct Current (BLDC) motors have gained tremendous popularity. They have better speed versus torque characteristics, high dynamic response, high efficiency, long operating life, noiseless operation, higher speed ranges, rugged construction and so on. Also, torque delivered to the motor size is higher, making it useful in applications where space and weight are critical factors.

2. METHODS

In this paper is presented a hybrid system for data acquisition and control of ankle foot orthosis (AFO). It consist of BLDC controller (RS-485) attached to AFO, digital 6 DOF (three-axis accelerometer and three-axis gyro sensor), DSP micro-processor (dsPIC33FJ32MC204), serial EEPROM 25LC640A and ZigBee wireless module (see Fig.2).

Brushless DC motor requires precise absolute position feedback in order to be properly electronically commutated.

The accelerometer is inertial sensor that measures acceleration along its sensitive axis. A gyroscope is an angular velocity sensor and determines position of foot in the sagittal plane.

A method use high precision quadrant encoder in addition to Hall sensors [7] built in the BLDC motor to increase precision of measurement of angles and creates corrective moments if necessary. Encoders are sensors that generate digital signals in response to movement. Optical encoders are devices that convert a mechanical position into a representative electrical signal by means of a patterned disk or scale, a light source and photo-sensitive element.

The system allows data acquisition of human gait and transfers collected data by wireless connectivity to the analyzing software. Proposed network architecture allows connecting of multiple controllers in a system which provides capability for analysis and control of complex movements of more than one joint.

Fig. 2 AFO with BLDC motor and block diagram

The block diagram describes how the BLDC motor controller is driven and how optical incremental encoder [8] read using a dsPIC30F2010. The actual speed value is determined via this encoder which ensures high precision of speed measurement especially in low speed ranges.

The six MC PWM outputs (PWM1L to PWM3H) are connected to three MOSFET driver pairs (IR2101S), which in turn are connected to six MOSFETs. These MOSFETs are connected in a three-phase bridge format to the three BLDC motor windings. In the current implementation, the maximum MOSFET voltage is 70 Volts, and the maximum MOSFET current is 6 Amps. The motor is a 24V BLDC motor so the DC+ to DC- bus voltage is 24V. A regulated 5V is provided to drive the dsPIC33FJXXMXX. The three Hall effect sensor inputs are connected to input pins that have Change Notification circuits associated with them (CN). These inputs are enabled along with their interrupt. If a change occurs on any of these three pins, an interrupt is generated. To provide some current feedback to the motor, a low value resistor (50 milliohms) is placed between the DC- bus voltage and ground or Vss. The voltage generated by this resistor is amplified by an external op amp (MCP6002) and fed to an ADC input. Optical encoder is connected to dedicated inputs of QUADRATURE ENCODER INTERFACE (QEI) MODULE. The QEI module provides the interface to incremental encoders for obtaining mechanical position data.

The operational features of the QEI include:
- Three input channels for two phase signals and index pulse
- 16-bit up/down position counter
- Count direction status
- Position Measurement (x2 and x4) mode
- Precision of measurement – 0.09°
- Programmable digital noise filters on inputs
- Alternate 16-bit Timer/Counter mode
- Quadrature Encoder Interface interrupts

Integrated USART module provides necessary capabilities to build communication interface for motor control, parametrization and data acquisition. Wireless communication is realized by Xbee 24 module which is engineered to meet IEEE 802.15.4 standards and supports the unique needs of low-cost, low-power wireless sensor networks. The modules require minimal power and provide reliable delivery of data between devices.

MEMS Gyro Accelerometer combines a 3-axis gyroscope, 3-axis accelerometer. The device features three 16-bit analog-to-digital converts (ADCs) for digitalizing the gyroscope outputs and 16-bit ADCs for digitalizing accelerometer outputs. For precision tracking of both fast and slow motions, the parts feature a user-programmable gyroscope full scale range of ±250, ±500, ±1000, and ± 2000°/sec (dps) and a user-programmable accelerometer full scale range of ±2g, ±4g, ±8g, and ±16g.

Communication with all registers of the device is performed using either I²C at 400 kHz or SPI at 1

84
MHz (the case in this study). For applications requiring faster communications, the sensor and interrupt registers may be read using SPI at 20 MHz. Additional features include an embedded temperature sensor and on-chip oscillator with ±1% variation over the operating temperature range.

In the Fig. 3 is given a designed controller board. The controller meets the block diagram requirement with possibility to connect wireless module directly via built in RS-485 interface.

![Fig.3 Brushless controller with RS-485 interface](image)

3. RESULTS AND DISCUSSION

Particular interest to biomechanics and orthotics is the analysis of human motion. With the development of sensors technologies and gait data analyzing techniques is investigates kinematics, kinetics and dynamics of lower limbs, improves the locomotion and makes a comparison in normal and clinical conditions. There is a need for a system that can provide a wireless connection in real-time and reliable result to measure ankle foot movements.

By introduced hybrid system we obtain data for movement of lower limb, its orientation, joint angles, velocities and accelerations. The collected data is transfers to analyzing software by wireless connectivity.

The registered data from 20 number records of gait cycle for time interval 10 seconds are shown below.

In the Fig.4 are shown graphic values from an accelerometer measured along x, y, z axes.

![Fig.4 Measured values from accelerometer along x, y, z axes](image)

The data from gyro sensor determined orientation of foot in the sagittal plane are given in the Fig.5.

![Fig.5 Measured values from gyro sensor in sagittal plane](image)

In Table 1 and Table 2 are presented numerical values obtained from movements of lower legs with AFO via accelerometer and gyro sensor.

<table>
<thead>
<tr>
<th>Table 1 Table values from accelerometer x, y, z</th>
</tr>
</thead>
<tbody>
<tr>
<td>accelerometer x (m/s²)</td>
</tr>
<tr>
<td>-2.8826</td>
</tr>
<tr>
<td>-3.5601</td>
</tr>
<tr>
<td>-3.1412</td>
</tr>
<tr>
<td>-12.4594</td>
</tr>
<tr>
<td>-9.2512</td>
</tr>
<tr>
<td>-3.1029</td>
</tr>
<tr>
<td>-5.1811</td>
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<tr>
<td>-4.3096</td>
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<td>-3.3992</td>
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<td>-8.102</td>
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<tr>
<td>-2.4036</td>
</tr>
<tr>
<td>-3.1412</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Table 2 Table values from gyro sensor</th>
</tr>
</thead>
<tbody>
<tr>
<td>orientation x (°)</td>
</tr>
<tr>
<td>54.83</td>
</tr>
<tr>
<td>52.65</td>
</tr>
<tr>
<td>46.35</td>
</tr>
<tr>
<td>44.22</td>
</tr>
<tr>
<td>269.4</td>
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<td>26.74</td>
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<tr>
<td>311.74</td>
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<td>253.74</td>
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<tr>
<td>236.12</td>
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<tr>
<td>239.29</td>
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<td>220.99</td>
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<td>256.21</td>
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<td>248.4</td>
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<td>208.4</td>
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<td>46.68</td>
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<tr>
<td>210.24</td>
</tr>
<tr>
<td>216.63</td>
</tr>
<tr>
<td>210.84</td>
</tr>
<tr>
<td>211.11</td>
</tr>
</tbody>
</table>
The high precision of measurements of angles and corrective moments are provided by incremental encoder (see Fig. 6) and Hall sensors built into motor and excellent BLDC motor characteristics (high dynamic response, high efficiency, higher speed ranges and etc.). Therefore those type motors are appropriate for control of AFO.

![Real time graph of the incremental encoder](image)

The combination of BLDC motor and MEMS Gyro Accelerometer may provide a reliable assessment for measurement process.

The hybrid system gives many possibilities for monitoring, data processing and analyzing of human movements with ankle-foot orthoses (AFOs) in real time.

The proposed method can be useful for different goals in clinical practice, such as comparing normal movements with pathological movements, planning and evaluating treatment protocols, and evaluating design of orthosis and prosthesis.

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**REFERENCES**

THE RADIOLOGICAL HAZARD DUE TO NATURALLY OCCURRING RADIONUCLIDES IN SOIL AROUND THERMOELECTRIC POWER PLANT

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Abstract: Primordial radionuclides, 238U, 232Th and 40K in soil samples collected in the vicinity of the largest thermoelectric power plant in Serbia were analyzed gamma-ray spectrometrically. Mean values of radionuclide activity concentrations were 50.7 Bq kg⁻¹ for 238U, 48.7 Bq kg⁻¹ for 232Th and 560 Bq kg⁻¹ for 40K. Based on measured activity concentration the radiological hazard due to naturally occurring radionuclides in soil was assessed. Estimated absorbed gamma dose rates were geographically mapped. The annual effective dose outdoor due to analysed radionuclides ranged from 51.4 to 114.2 μSv. The distribution pattern of natural radionuclides in the environment surrounding thermoelectric power plant and their enrichment in soil at some sampling sites were attributed mainly to windblown ash from open ash dumps. The obtained results indicated that the operation of thermoelectric power plant has no significant negative impact on the surrounding environment with regard to the content of natural radionuclides. However, much effort should be made regarding ash storage in order to minimize the windblown of ash to surrounding environment.

Key words: primordial radionuclides, gamma dose rates, soil pollution, geostatistical analysis.

1. INTRODUCTION

Radiation risk from natural radioactivity enhanced by human activity exists in many branches of the non-nuclear industry. Millions of tons of coal are burnt every year in thermoelectric power plants (TEPPs) worldwide, producing naturally occurring radioactive material waste, generated at each step of the process. Knowledge of natural radionuclide distribution in soils is important for assessing radiation exposure to the population and is useful to set standards and national guidelines in accordance with international recommendations. During coal combustion, organic compounds are converted into gases, while inorganic elements, which include the naturally occurring radionuclides, are concentrated in the ash. Populations living in the vicinity of TEPPs are exposed to enhanced levels of natural radionuclides and the main pathways are inhalation, external irradiation and ingestion following deposition on the ground. According to UNSCEAR (2010) the world average activity concentrations for 238U, 232Th and 40K in soils are 33, 45 and 412 Bq kg⁻¹ respectively [1].

Based on measured activity concentrations of radionuclides (238U, 232Th, 40K) in soil samples in the vicinity of the largest TEPP in Serbia, the dose rate and hazard index of gamma-ray radiation for the population living in the investigated area were estimated. Ordinary kriging revealed the spatial distribution of total absorbed gamma dose rates (D) arising from members of terrestrial radionuclides.

2. MATERIALS AND METHODS

2.1. Study area and sampling

The thermoelectric power plant complex 'Nikola Tesla' consisting of two blocks (A, B) are situated in western Serbia in the municipality of Obrenovac (N 44°03' E 20°01'), on the right bank of the River Sava, 42 km upstream from Belgrade, the Serbian capital city. There are around 75000 people living in the municipality of Obrenovac. The ash deposits area located in the immediate vicinity of TEPP blocks. All by-products of combustion lead to changes in the environment and ash carried by wind can cause damage to the surrounding environment.

Samples of undisturbed soils that had not been treated with fertilizers were taken during 2011 from 72 locations applying the 'systematic random sampling' procedure [2]. Samples were taken up to
of 20 cm and the locations were recorded using an eTrex Vista Garmin handheld Global Positioning System (GPS) with a precision of ±10 m.

2.2. Radioactivity measurements

For gamma spectrometry measurements air dried, crushed and sieved samples were weighed and placed in Marinelli beakers and hermetically sealed for at least 4 weeks to ensure that radioactive equilibrium was reached between 226Ra, 222Rn and their short-lived daughters. The activity concentration (Bq kg⁻¹) of naturally occurring radionuclides was determined using a p-type high germanium detector (ORTEC-AMATEC). The detector is enclosed in a low background well-type shielded chamber consisting from the outside inwards of 100 mm low level lead, 2 mm copper, 1 mm cadmium and 4 mm Perspex. The detector is mounted on a cryostat that dips into a 50 l Dewar filled with liquid nitrogen and is connected to 8192-channel pulse height analyzers. The resolution and relative efficiency of the detector for 1332 keV γ-rays and efficiency calibration of the detector, a mixed calibration source (MBSS 2 type from the Czech Metrological Institute) and standard reference materials from the IAEA were used for quality assurance and quality control (RGU-1 and RGTh-1). The activity concentration of 238U was determined by measuring the gamma-ray lines of 228Ac at 63.3, 92.35 and 92.78 keV. The activity concentration of 232Th was evaluated from gamma-ray lines of 228Ac at 338.4, 911.1 and 968.9 keV. Gamma-ray spectra were analysed using Gamma Vision 32 MCA emulation software [3].

2.3. Estimation of dose rate and hazard index of γ-ray radiation

The total absorbed dose rate in air is a relevant quality when considering radiation risk to humans and other biota. It is calculated using conversion factors (obtained by the Monte Carlo method) to transform the measured activity concentrations $A_U$, $A_{Th}$, and $A_K$ (Bq kg⁻¹) of U, Th and K into absorbed dose rate ($D$) (nGy h⁻¹) (Eq. 1) at 1 m above the ground [4]:

$$D = 0.462A_U + 0.604A_{Th} + 0.042A_K$$

(1)

The annual effective dose ($H$) (μSv) (Eq. 2) in natural environmental radioactivity situations, can be calculated multiplying the estimated absorbed dose rate by factors, where 0.7 Sv Gy⁻¹ represents the quotient of absorbed dose rate in air to annual effective dose received by adults, 0.2 is the outdoor occupancy factor and 8760 is the number of hours in one year.

$$H = D \times 0.7 \times 0.2 \times 8760$$

(2)

The external hazard index ($Hex$) provides a useful guideline for regulating the safety standards on radiation protection for the population. This index (Eq. 3), as defined by Beretka and Mathew (1985) [5], must be less than unity in order to keep the radiation hazard insignificant. The external hazard index is obtained from the radium equivalent activity of 370 Bq kg⁻¹ and corresponds to a dose limit of 1.0 mSv for the general population.

$$Hex = \frac{A_U}{370} + \frac{A_{Th}}{259} + \frac{A_K}{4810}$$

(3)

Excess lifetime cancer risk outdoors ($ELCR_{outdoor}$) was calculated according to the following equation:

$$ELCR_{outdoor} = H \times LS \times PC$$

(4)

where: $LS$ - lifespan (average 70 years) and $PC$ – the nominal probability coefficient for detriment-adjusted cancer risk of 0.055 Sv⁻¹ for the public [6]. This risk represents the number of extra cancers expected in a given number of people exposed to a carcinogen at a given dose.

2.4. Geostatistical analysis

Geostatistical data were modelled using ArcGIS mapping software [9] by the Geostatistical Analyst extension. The kriging method was chosen because it has advantages over other interpolation techniques. Among kriging procedures, the ordinary kriging method is most commonly used for environmental situations.

3. RESULTS AND DISCUSSION

The external dose rate and hazard index of γ-ray radiation were estimated using results for activity concentrations of 238U, 232Th and 40K. The activity concentrations of primordial radionuclides in soil samples varied from 21 to 82 Bq kg⁻¹ for 238U, from 15 to 61 Bq kg⁻¹ for 232Th and from 275 to 751 Bq kg⁻¹ for 40K. Descriptive statistics for total absorbed dose rate, annual effective dose rate, external hazard index and excess lifetime cancer risk outdoors for all 72 sampling locations are presented in Table 1.

<table>
<thead>
<tr>
<th>Descriptive statistics</th>
<th>$D$</th>
<th>$H$</th>
<th>$Hex$</th>
<th>$ELCR_{outdoor} 	imes 10^4$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>76.3</td>
<td>93.6</td>
<td>0.4</td>
<td>3.6</td>
</tr>
<tr>
<td>Range</td>
<td>51.1</td>
<td>62.7</td>
<td>0.3</td>
<td>2.4</td>
</tr>
<tr>
<td>Sd. deviation</td>
<td>11.2</td>
<td>13.7</td>
<td>0.06</td>
<td>0.5</td>
</tr>
<tr>
<td>Minimum</td>
<td>41.9</td>
<td>51.4</td>
<td>0.24</td>
<td>2.0</td>
</tr>
<tr>
<td>Maximum</td>
<td>93.1</td>
<td>114.2</td>
<td>0.54</td>
<td>4.4</td>
</tr>
</tbody>
</table>

Table 1. Descriptive statistics of estimated $D$ (nGy h⁻¹), $H$ (μSv), $Hex$, and $ELCR$ around TEPP ‘Nikola Tesla’ based on results of activity concentration of primordial radionuclides in analysed soil samples.

The spatial distribution of total absorbed gamma dose rates arising from members of terrestrial radionuclides from the uranium and thorium decay chains and by 40K in the soils around the TEPP is presented in Fig. 1. The map of distribution revealed areas with the highest dose rate, which coincides with the dominant wind direction.
Fig. 1 The spatial distribution of total absorrbed
gamma d
dose rates arisiing from mem
mbers of terresstrial
radionucllides from the uranium an
nd thorium d
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area.
Total gamma dose rates varied between 41.9 and
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circumstaances the tottal dose rate
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radionucllides is 60 nG
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While beaaring
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78.8 [9] and
66.8 nGyy h-1 [10]. When comparing these
t
findingss one
should haave in mind that the study of Bikit et all. [9]
comprised 50 samp
ples from Vojvodina,
V
w
while
Dragović et al. [10] ex
xamined a total of 140 sam
mples
from 21 regions in Serbia and Montenegro.
The
M
regions in
nvestigated in
n these studies differ in resspect
to age, ggenesis, minerral content and petrochem
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he total absorrbed
gamma d
dose rates around
a
TEPP
Ps worldwide are
presented
d in Table 2.

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y h-1)
C
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76.3
3
S
Serbia [this sttudy]
75.2
2
C
China [11]
86.6
6
C
China [12]
53.9
9
T
Turkey [13]
89.2
2
H
Hungary [14]
58.0
0
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Spain [15]
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0
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Greece [16]
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Table 2. Gamm
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dose ra
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samples around TE
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To esttimate the ann
nual effective dose using E
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utdoor occupaancy
factor frrom the absorbed dose in air mustt be
considereed. In this stu
udy estimated
d annual effecctive
dose valu
ues ranged fro
om 51.4 to 114
4.2 μSv. Estim
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values weere about 10 times
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han the maxim
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permissib
ble dose of 1 mSv
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for mem
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effective dose, estimated on
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radiation sou
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i 70 μSv [4]..
The mean va
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almost one orrder of magnit
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insignificant. Descriptive sstatistics for Hex calculated
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according to Eq. 3 are prresented in Table
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maximum value was 0.54,, which indiccates that soill
from the stud
dy area is of no significan
nt radiologicall
threat to the population.
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The mean excess lifetim
me cancer risk for all samplee
-4, whic
locations is 3.6×10
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ch is less than the world
average of 2.9
9×10-3 [4]. Th
his implies that the chancee
of developing cancer, due tto work at the
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by people livin
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comparison with
w
data repported by Jan
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and Dragović (2010) [8] foor the territory
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Serbia, the me
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ELCR found here
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Based on estimated dosse rate and ha
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γ-ray radiatio
concluded th
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surrounding.
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The resullts obtained here can be
valuable datab
base for futurre estimations of the impactt
of radioactive
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onstruction off
the planned new block off the thermoe
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Acknowledg
A
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SYNERGY OF CHEMICAL AND ISOTOPIC SIGNATURES DATA FOR ENVIRONMENTAL FATE STUDIES

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Abstract (bold). Short abstract (Style Abstract: 8 pt, italic, pt, justified, 0.75 pt left and right indentation).

Environmental fate study conducted for case of uranium contamination of the environment have been described and discussed in the paper as an example of combined application of radiochemical separation methods, spectrometric analytical techniques and elemental speciation procedures to obtain the most complete set of data for investigation of their correlations. As a result, isotopic and chemical composition, ratios of activities concentrations and indication of probable physicochemical forms and bonding with different substrates were obtained. Radiochemical ion-exchange separation procedures followed by alpha spectrometry analysis have shown the isotopic ratios of $^{238}$U, $^{234}$U and $^{235}$U activity concentrations characteristic for depleted uranium. The isotopic signature of contaminant was determined on the basis of activity ratios $^{235}$U/$^{238}$U and $^{234}$U/$^{238}$U. These isotopic ratios differ for natural and depleted uranium and their values in the soil samples or their components are corresponding to the amount of depleted uranium in total uranium content of the sample. In the fractions obtained after the soil samples underwent a series of successive solid/liquid chemical extractions simulating environmental conditions, depleted uranium contribution to the total uranium contents was calculated and analyzed together with data on chemical composition of fractions. Correlations derived from isotopic and stable elements concentrations determined in extraction phases after multistep sequential extraction indicated potential substrates and bonding potential. Although contamination was not widespread, on the basis of obtained data, environmental fate of contaminant in terms of geochemical fractionation and mobility may be indicated.

Key words (bold): environmental fate, sequential extractions, alpha-spectrometry, isotopic signature, depleted uranium

1. INTRODUCTION

The isotopic signature may be obtained by application of radiometric spectrometric methods able to distinguish decay energies characteristic for different radioactive isotopes of the same chemical element. On the other hand, chemical signatures data are related to bonding capacity and oxidation states of elements in various surroundings and environmental conditions and may be determined by application of sequential extraction procedures followed by standard analytical techniques and further investigated by statistical analysis such as PCA. These two applied approaches in synergy have led to correlations of radion isotopes of interest and their potential substrates in real conditions for the time elapsed from the moment of contamination. On the basis of obtained data, environmental fate of contaminant in terms of geochemical fractionation and mobility may be indicated.

Subject of the study was soil contamination by depleted uranium. The origin of the environmental contamination were military actions and material was spread over the certain territory. A sample of the source material (projectile) was subjected to dissolution and radiochemical procedure of uranium separation and alpha spectrometry measurements and analysis. The isotopic signature of contaminant was determined on the basis of isotopic activity ratios $^{235}$U/$^{238}$U and $^{234}$U/$^{238}$U. These isotopic ratios differ for natural and depleted uranium and their values in the soil samples or their components are corresponding to the amount of depleted uranium in total uranium content. In the fractions obtained after the soil samples underwent a series of successive solid/liquid chemical extractions simulating environmental conditions, depleted uranium contribution to the total uranium contents was calculated and analyzed together with data on chemical composition of fractions. By
The application of principal component analysis, significant correlations of radioactive and stable elements in separated phases were derived.

2. MATERIALS AND METHODS

Projectile material and surface soil samples were analyzed by alpha-spectrometry method involving ion-exchange radiochemical uranium separation procedure, thin-layer radioactive sources preparation by Talvities electro-deposition and alpha spectrometry analysis. Measurements are performed in vacuum controlled Canberra 2004 chamber with PIPS detector (300 mm area) with counting efficiency 16% at 25 mm distance, multichannel energy scale 9.1 keV/ch and energy resolution 24 keV for 241Am line.

Stable elements were analyzed by standard atomic absorption spectroscopy, flame and graphite techniques (Perkin Elmer AA600, AA200) using mixed standard solutions for calibration to simulate matrix composition.

Soil composition was determined by ED-XRF using the 240Cd and 241Am excitation sources and geo-microscopic analysis.

Table 1. Five-step sequential extraction schema

<table>
<thead>
<tr>
<th>Fraction</th>
<th>Extraction reagent</th>
<th>T, °C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ion-exchangable</td>
<td>1.0 M NH₄Ac, pH7</td>
<td>20</td>
</tr>
<tr>
<td>Carbonates</td>
<td>0.6 M HCl/0.1 M NH₄OH u 0.01 M HCl, pH4</td>
<td>20</td>
</tr>
<tr>
<td>Fe/Mn oxides</td>
<td>0.2 M (COOH)₃</td>
<td>85/20</td>
</tr>
<tr>
<td>Organic</td>
<td>30% H₂O₂ u 0.01 M HNO₃, pH 2</td>
<td>20</td>
</tr>
<tr>
<td>Acidic/residual</td>
<td>6 M HCl</td>
<td>85</td>
</tr>
</tbody>
</table>

Soil samples for analysis were collected from the surface (0-15 cm depth) of the contaminated areas and “as appeared in the environment” subjected to a multiple sequential extractions in the laboratory. The extractive reagents, targeted to a specific physical/chemical association such as: water soluble, ion-exchangeable, carbonates, iron/manganese oxides, organic and acid soluble were applied in several steps. (Table 1.)

The sample/reagent ratio was 1:45. Contact time for solid/liquid phases was 2-9 hours with continuous stirring. The specific rules for work with radioactive material were followed.

3. Results and discussion

Results of total uranium content (in %) in 5 fractions obtained after sequential extraction of three soil samples of different origin and different contamination levels are presented in Table 2. It illustrates that soil (sample 1 and sample 2) with almost the same total uranium content but different geochemical composition may have very different behavior in the environment. Sample 1 is taken from uncultivated soil surface, exposed to weathering and the most of uranium is present in the fifth phase fraction, presumably bonded for silicates in soil matrix. Sample 2 is the forest soil with significant content of uranium in the forth phase fraction, that is characteristic for bonding with organic matter, probably humic acids complexes, but also in the first phases fractions due to the weak ion-exchange bonding.

Table 2. Uranium content in the sequential extraction phases of soil samples

<table>
<thead>
<tr>
<th>Uranium</th>
<th>Sample 1</th>
<th>Sample 2</th>
<th>Sample 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>c (mg/kg)</td>
<td>1.62</td>
<td>1.63</td>
<td>2260</td>
</tr>
<tr>
<td>Phase 1 (%)</td>
<td>4.9</td>
<td>19</td>
<td>40</td>
</tr>
<tr>
<td>Phase 2 (%)</td>
<td>1.4</td>
<td>20.8</td>
<td>24.8</td>
</tr>
<tr>
<td>Phase 3 (%)</td>
<td>21</td>
<td>41</td>
<td>7.6</td>
</tr>
<tr>
<td>Phase 4 (%)</td>
<td>7.4</td>
<td>16</td>
<td>2.1</td>
</tr>
<tr>
<td>Phase 5 (%)</td>
<td>65</td>
<td>2.3</td>
<td>25</td>
</tr>
</tbody>
</table>

The results presented for sample 1 and sample 3 also indicate that contamination level has the important role in environmental fate. Although with same geochemical origin, these samples differ in uranium proportion in two first phases obviously due to the unselective bonding of uranium in the highly contaminated sample 3. Uranium appearance in the first phases of sequential extraction indicate high mobility of contamination for this type of soil.

Depleted uranium portion in the total uranium content in soil samples was determined based on expression:

\[ n(\%) = \frac{P_{235U} \times (1 - n)}{P_{238U} \times (1 - n) + P_{238U}} \times 100 \]  

\[ P_{238U} \times (1 - n) + P_{238U} \]  

Where \( n(\%) \) – mass portion of depleted uranium in total uranium in sample, \( P_{235U} \) – mass portion of natural uranium in total uranium in sample, \( P_{238U} \) – average value of the mass portion of isotope in uncontaminated sample, \( P_{238U} \) - average value of the mass portion of isotope in depleted uranium. Relations for specific activities of isotopes 235U and 238U are:

\[ A_{235U} = 2.312 \times 10^5 \times m_{235U} \]  

\[ A_{238U} = 12.4 \times m_{238U} \]

Where \( A_{235U} \) and \( m_{235U} \) are specific activity of isotope and its mass. In practice since the activity ratios are obtained, more useful relation would be:

\[ R_m = \frac{2.312 \times 10^5 \times A_{235U}}{12.4} \]

Where \( R_m \) – activity isotopic ratio and \( R_m \) – mass isotopic ratio.
Isotopic activity ratio $^{234}$U/$^{238}$U distribution presented in Figure 1, is a measure of depleted uranium presence in each of the five sequential extraction phases of investigated surface soil samples (Series 1-Series 4). The ratio values less than one are indication that samples are contaminated with depleted uranium. Depleted uranium substrates are hydrated oxides of iron and manganese as for most of the metals but also the carbonates that may be expected since there is analogy with calcium (II). Desorption coefficients calculated from uranium distribution in sequential extraction phases are in the range 0.03-21.7 µg/ml.

![Fig. 1 Activity ratio $^{234}$U/$^{238}$U distribution in five sequential extraction phases for surface soil samples (Series 1-Series 4)](image)

In general, proportion of depleted uranium in different extraction phases depend on the geochemical and geomorphologic characteristics of soil as well as its composition and contamination level indicating geochemical fractionation and strength of bonding in available substrates in the investigated area and finally the mobility of depleted uranium and its environmental fate.

**Acknowledgement:** The paper is a part of the research done within the project III40009, financed by Ministry of Education, Science and Technological Development of Republic of Serbia.

**REFERENCES**

RADIATION EXPOSURE IN DWELLINGS MADE OF SIPOREX BLOCKS PERFORMED BY THE RESRAD-BUILD CODE

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Abstract. The paper presents results of using the RESRAD-BUILD code to assess the radiation exposure in dwellings built of siporex blocks. Depending on the established modes of ventilation, the annual dose in rooms have been estimated. Realistic scenario was created to predict annual equivalent dose between old person, housewife, student and employed tenant who live in the same apartment spending different periods of time in it.

Key words: radiation exposure, siporex, RESRAD-BUILD code

1. INTRODUCTION

Radon (222Rn) and its progeny are present in all dwellings, because radium is present in building materials as well as in the soil. It is important to understand the generation and migration process of radon from building materials, which contributes to 55% of total radiation dose received by the population from the environment (UNSCEAR, 2000) [1]. A research dealing with the radiation exposure produced by radon decay products in homes has shown that the cause of increased radiation may as well be the construction material of the building. When estimating an average annual radiation exposure one should also take into account life at home, because the level of radiation can be higher within homes than without, bearing in mind that walls themselves can contain and emit radionuclides. Depending on the type of the construction material and ventilation efficiency [2,3], radiation indoors can be many times higher than outdoors, and as such it represents a serious health hazard. The average annual dose in Europe from radon and its progeny is estimated to be 1,6 mSv.

This paper presents the possibilities of using RESRAD-BUILD programme [4-6] for the purpose of assessing radiation exposure as a serious health hazard in homes built of siporex blocks and concrete material. We have only analysed the impact of natural radionuclides in the construction material, depending on the established ventilation mode. Since the main source of radon and its progeny is soil, this simulation should consider only apartments on higher floors in modern residential building.

Depending on the established mode of ventilation, the annual equivalent doses for assumed living scenario have been calculated.

2. A MODEL OF A HOME AND BASIC DATA NECESSARY FOR THE ASSESSMENT

The RESRAD-BUILD is one of the programmes belonging to the RESRAD codes family which has recently been developed in Argonne National Laboratory, USA [2]. The programme is used to estimate radiation exposure of the persons who work or live in enclosed spaces, especially in facilities contaminated with radioactive material. For the purposes of this paper we have run a simulation of an exposure to natural radionuclides from the construction materials (siporex and plain concrete) which have been used to construct modern residential building. Depending on a ventilation mode, we have simulated overall annual exposure to radionuclides in rooms.

2.1. Building materials and dwelling model

This paper presents a simplified model of a home of 42 m² whose walls are built of siporex blocks. Dwelling is made of siporex blocks where
walls are 0.25 m thick and 0.6 g/cm³ dense, while floors, ceilings and pillars are made of a 2.3 g/cm³ dense concrete. The assumption is that the home consists of four rooms: bedroom, livingroom, vestibule, and bathroom, which surface areas are 12 m², 16 m², 8 m², 6 m², respectively. The height of the ceiling in the dwelling is 2.5 m. Volume of the bedroom is 30 m³, living room - 40 m³, vestibule - 20 m³, and bathroom - 15 m³. In the center of each room there is a recipient (tenant) who spends some required time in it.

The specific activity of radionuclides in siporex blocks is: $^{226}Ra = 9.4 \text{ Bq/kg}$, $^{232}Th = 5.4 \text{ Bq/kg}$, $^{235}U = 121 \text{ Bq/kg}$ and $^{40}K = 0.70 \text{ Bq/kg}$ [7], while the specific activity of radionuclides in concrete is: $^{226}Ra = 40 \text{ Bq/kg}$, $^{232}Th = 30 \text{ Bq/kg}$, $^{40}K = 400 \text{ Bq/kg}$ [8].

2.2. Ventilation

An air exchange model on the premises is presented in Figure 1, and the values of air exchange rate $R_{ij}$ (indices i, j mark the rooms), in Table 1. Since the airflow is not constant, six modes of ventilation have been considered in order to observe the dependence between a dose of radiation and that of ventilation, the assumption being that the vestibule and bathroom have less intensive air exchange with the environment and the adjacent rooms. The zero mode of ventilation suits the utter absence of air exchange between the rooms and the environment, while the mode 5 marks the most intensive ventilation. Each ventilation rate is in equilibrium which means that there is no pressure difference between rooms.

For all the parameters which are not fully known in the model (the volume of inhaled air per time unit, the speed of deposition, etc.) the programme used the default values.

<table>
<thead>
<tr>
<th>Mode</th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>$R_{10}$</td>
<td>0</td>
<td>0.36</td>
<td>0.85</td>
<td>1.32</td>
<td>1.66</td>
<td>2.07</td>
</tr>
<tr>
<td>$R_{12}$</td>
<td>0</td>
<td>0.40</td>
<td>0.90</td>
<td>1.30</td>
<td>1.70</td>
<td>2.10</td>
</tr>
<tr>
<td>$R_{12}$</td>
<td>0</td>
<td>0.10</td>
<td>0.30</td>
<td>0.40</td>
<td>0.50</td>
<td>0.60</td>
</tr>
<tr>
<td>$R_{21}$</td>
<td>0.12</td>
<td>0.33</td>
<td>0.38</td>
<td>0.53</td>
<td>0.64</td>
<td></td>
</tr>
<tr>
<td>$R_{21}$</td>
<td>0.50</td>
<td>1.00</td>
<td>1.50</td>
<td>2.00</td>
<td>2.50</td>
<td></td>
</tr>
<tr>
<td>$R_{10}$</td>
<td>0.52</td>
<td>1.03</td>
<td>1.48</td>
<td>2.03</td>
<td>2.54</td>
<td></td>
</tr>
<tr>
<td>$R_{12}$</td>
<td>0.08</td>
<td>0.20</td>
<td>0.30</td>
<td>0.40</td>
<td>0.50</td>
<td></td>
</tr>
<tr>
<td>$R_{32}$</td>
<td>0.06</td>
<td>0.22</td>
<td>0.31</td>
<td>0.41</td>
<td>0.49</td>
<td></td>
</tr>
<tr>
<td>$R_{32}$</td>
<td>0.50</td>
<td>1.00</td>
<td>1.40</td>
<td>1.80</td>
<td>2.40</td>
<td></td>
</tr>
<tr>
<td>$R_{42}$</td>
<td>0.52</td>
<td>1.02</td>
<td>1.41</td>
<td>1.81</td>
<td>2.39</td>
<td></td>
</tr>
<tr>
<td>$R_{42}$</td>
<td>0.01</td>
<td>0.02</td>
<td>0.05</td>
<td>0.10</td>
<td>0.15</td>
<td></td>
</tr>
<tr>
<td>$R_{42}$</td>
<td>0.05</td>
<td>0.07</td>
<td>0.03</td>
<td>0.14</td>
<td>0.18</td>
<td></td>
</tr>
<tr>
<td>$R_{42}$</td>
<td>0.10</td>
<td>0.25</td>
<td>0.40</td>
<td>0.60</td>
<td>0.80</td>
<td></td>
</tr>
<tr>
<td>$R_{42}$</td>
<td>0.06</td>
<td>0.20</td>
<td>0.42</td>
<td>0.56</td>
<td>0.77</td>
<td></td>
</tr>
</tbody>
</table>

3. THE RESULTS OF THE ASSESSMENT

For each room the results are obtained by changing air ventilation mode, wherein for each changing of ventilation mode three different times spent by tenants in specific room were also varied (Table 2).

<table>
<thead>
<tr>
<th>Rooms</th>
<th>Living room</th>
<th>Vestibule</th>
<th>Bedroom</th>
<th>Bathroom</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>0.5</td>
<td>8</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>1</td>
<td>10</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>2</td>
<td>12</td>
<td>3</td>
<td></td>
</tr>
</tbody>
</table>

3.1. The annual equivalent dose as a function of the ventilation mode

In Figures 2-5 we present the calculated results for annual equivalent dose of a recipient in each room in dependence on ventilation mode and assumed time spent in them.
3.2. Assessment of the radiation dose over rooms

The annual radiation dose is calculated for the two residence time in rooms (2 h and 10 h) and for the maximum ventilation or no ventilation mode (Table 3).

By comparing the values of equivalent doses, we can conclude that at maximum ventilation and 2 hours residence time the tenant residing in the vestibule receives the lowest dose of radiation (0.04 mSv), while the tenant who spends the same time in the bathroom will receive the highest dose (0.13 mSv). In the absence of ventilation, the highest dose will also receive a tenant who is in the bathroom, a slight lower dose tenant who is in the hallway, then the tenants residing in the living room.

From the results for 10 hours residence time we can see that the annual radiation doses in the living room and bedroom are very similar for both modes of ventilation.

Table 3. Annual radiation dose (in mSv) for tenants which spends 2 hours or 10 hours in different rooms

<table>
<thead>
<tr>
<th>Room</th>
<th>Living room</th>
<th>Vestibule</th>
<th>Bedroom</th>
<th>Bathroom</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time 2 h</td>
<td>Mode 0</td>
<td>0.26</td>
<td>0.31</td>
<td>/</td>
</tr>
<tr>
<td>Time 2 h</td>
<td>Mode 5</td>
<td>0.10</td>
<td>0.04</td>
<td>/</td>
</tr>
<tr>
<td>Time 10 h</td>
<td>Mode 0</td>
<td>0.92</td>
<td>/</td>
<td>0.97</td>
</tr>
<tr>
<td>Time 10 h</td>
<td>Mode 5</td>
<td>0.51</td>
<td>/</td>
<td>0.58</td>
</tr>
</tbody>
</table>

3.3. Assessment of equivalent annual dose based on four possible scenarios

In Table 4 we have presented the four scenarios for different types of tenants, assuming that each of them spends an appropriate period of time in every room of the apartment and a part of the day outside of home. On this basis, the maximum and minimum annual doses received by the tenants are calculated that correspond to the maximum and minimum air exchange rates.
Table 4. Potential scenario for different tenants in apartment

<table>
<thead>
<tr>
<th>Tenant</th>
<th>Old person</th>
<th>Student</th>
<th>Housewife</th>
<th>Employed person</th>
</tr>
</thead>
<tbody>
<tr>
<td>Living room</td>
<td>10 h</td>
<td>2 h</td>
<td>10 h</td>
<td>2 h</td>
</tr>
<tr>
<td>Vestibule</td>
<td>1 h</td>
<td>1 h</td>
<td>2 h</td>
<td>1 h</td>
</tr>
<tr>
<td>Bathroom</td>
<td>1 h</td>
<td>2 h</td>
<td>3 h</td>
<td>2 h</td>
</tr>
<tr>
<td>Bedroom</td>
<td>0 h</td>
<td>9 h</td>
<td>1 h</td>
<td>11 h</td>
</tr>
<tr>
<td>Period outside</td>
<td>12 h</td>
<td>10 h</td>
<td>8 h</td>
<td>8 h</td>
</tr>
<tr>
<td>Dose</td>
<td>Min</td>
<td>1.34</td>
<td>0.82</td>
<td>2.43</td>
</tr>
<tr>
<td></td>
<td>Max</td>
<td>2.52</td>
<td>1.76</td>
<td>1.23</td>
</tr>
</tbody>
</table>

Table 4 shows that the highest dose will be received by an old person who spends all the time in the apartment, followed by a housewife who spends only one hour outside the apartment. The difference between the dose received by a student and the dose received by an employed person is about 0.1 mSv. The lowest annual equivalent dose in both modes of ventilation will receive an employed person, in agreement with the biggest number of hours spent outside home.

4. CONCLUSION

The total annual dose received by a tenant from siporex blocks, as well as concrete floors, ceilings and pillars, is in the acceptable limits even at zero ventilation. The highest annual dose of about 1.2 mSv was calculated for the bedroom and living room at the residence time of 10 and 12 hours, respectively, and the zero-mode ventilation. The results have pointed out the necessity of a regular ventilation of residential premises by means of air exchange with the environment in order to reduce the annual equivalent dose, as much as a threat to to the health of the tenants.

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RELATION BETWEEN DAILY GAMMA-RAY BACKGROUND AND RADON VARIABILITY IN THE UNDERGROUND LOW-LEVEL LABORATORY IN BELGRADE


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Abstract. The most important background source in low-level gamma-ray spectrometry is radon which additionally causes background variability. Intensive daily radon variation at the same time with daily variation of gamma-ray background was already measured in our ground level laboratory. The new simultaneously measurements of radon concentration and gamma-ray background performed in the underground laboratory and correlation between them in a wide range of radon concentration was analyzed.

Key words: gamma-ray background, radon variability, underground laboratory

1. INTRODUCTION

Correlation between diurnal variation of radon concentration and intensities of postradon background lines measured simultaneously in a surface laboratory was already analyzed, [1]. Daily variation of postradon gamma-ray lines intensity is important as a source of systematic error in low-level NORM-sample measuring, containing Ra-226. Background measurement in the underground laboratory, as well radon monitoring, [1], did not show obvious neither radon progenies nor radon daily periodicity but the new measurements inside the underground laboratory were done.

Description of laboratories, measuring techniques and used detectors is shown in detail in [1,2].

Radon concentration is known to vary considerably, depending on many parameters, but one of the most important is ventilation rate. For indoor spaces is known that depending of ventilation rate, equilibrium factor between radon concentration and its progenies is expecting to vary from 0.3 to 0.7. The UL is equipped with ventilation system which provide a low value of radon concentration due to, among other factors, constant exchange rate of fresh air thus radon monitoring should be preferably performed together with atmospheric parameters.

2. PRELIMINARY MEASUREMENTS

In order to prepare a new setup of „radon vs. postradon“ measurement inside the UL, the results from several different radon measurements proved useful.

Radon measurement using track detectors at several positions within the UL was done, during ventilation was switched on. Preliminary results show significant inhomogeneity in spatial distribution of radon concentration after 6 months of track detectors exposition. For this long time period a single value of radon concentration obtained by each track detector can not see diurnal radon variability inside the UL (air volume of 135 m³).

For the last six years, radon concentration inside the UL was measured several times during transition ventilation regime. From the low averaged value (about 10 Bq m⁻³) with ventilation on mode, radon concentration rised lineary after ventilation was switched off up to saturated value. Rising time lasted for several days (3 to 4) while mean saturated value of radon concentartion varied from 300 Bq m⁻³ up to 900 Bq m⁻³, which strongly depends on ambiental parameters and eventually on season. Obviously, diffusion rate of radon from 4π surrounding soil and concrete must be measured precisely. For radon progenies spatial distribution is very important deposition rate of radon progenies on the walls of lead shielding as well on the detector itself. Relationship between deposition and attachment rates in Jacobi room model, [3], can be tested in order to explain spatial radon progenies distribution in the UL.

Additional preliminary result obtained using radon monitor (RM) positioned in front of one fresh-air inlet inside the UL, for ten days. The measured values of radon concentration have been often below detection level of the instrument, detecting a zero value, which confirms that radon-free air enters to the lab.

Finally, radon was simultaneously measured using a Rad7 detector for inside and RM for outside positions of lead shielding of the germanium detector (VGe). That measurements were conducted in ventilation „on“
regime, as well when ventilation was switched off. After a month of measurement there was no difference in radon concentration measured between two radon detectors, figure 1. The sampling time of both detectors was set to 12 hours during ventilation on mode in order to minimize statistical errors, and only 2 hours after ventilation was switched off.

The RM, model SN1029, is used by readings on every thirty minutes, which was the same time chosen for sampling intensities of postradon lines in time series of germanium detectors. Correlation between radon concentration and postradon line intensities during ventilation on and off regimes was analyzed. One cycle of two consecutive ventilation regimes, on then off, presented on figure 3. Here are presented just two most intensive ones at 352 keV from Pb-214 and at 609 keV from Bi-214.

On the figure 3, radon concentration values are shifted up for 400 to emphasize similarity of variations, especially between radon and radon progenies measured by VGe. Due to smaller detection efficiency of smaller MGe detector, one can expect better correlation between the VGe and the RM, additionally because of spatial radon distribution and separated positions of germanium detectors. The other postradon lines which have smaller intensities do not show obvious variation even in rising part of radon, during a tree days after ventilation was switched off.

When the ventilation was switched on, both radon concentartion and postradon line intensites had almost constant values. For the chosen sampling time of 30 minutes, detection sensitivity of the RM is too low to register non zero values, when the ventilation is on and the mean value of radon concentration is only about 10 Bqm⁻¹.

When the ventilation was in “on” regime there was no significant variation in radon and postradon measured values. From the figure 2 is obvious that postradon values follows each other, more for the same germanium detectors, and less comparing to radon data. When radon concentration achieved saturation in “off” regime, expected daily variation of both values can not be proved using even sophisticated Lomb-Scargle periodogram analysis, [2], because of a short measuring period. A poor statistics is reason, too, why any time lag effect between 609 keV (from Bi-214) and 352 keV (from Pb-214) did not registered.

Pearson correlation coefficient (Pcc) determined for every combination of variables in rising part of ventilation “off” regime, table 1.
Slightly smaller correlation coefficient for radon and MGe lines combination compared to that between radon and VGe lines can be caused by difference in radon concentration on the two different positions of germanium detectors. On the contrary, there is a strong correlation for the same postradon line detected by both Ge detectors. Similarly, the Pcc value for 352 vs. 609 combination of the MGe detector is slightly smaller than that of the VGe detector, which can be caused by the same reason mentioned above. Obviously, there is a need for further investigations for getting better explanation with better statistics.

In another ventilation “on/off” cycle after short period in ventilation “off” regime, radon concentration drops down immediately when ventilation was switched on. Then, the surfaces of both germanium detectors was cleaned thoroughly by alcohol, but in a new cycle the differences in postradon line intensities did not detected. As the both germanium detectors were in lead shielding before, for a long time period, we can conclude indirectly that attachment rates of aerosol particles on detector surfaces, measured via postradon progenies, have small values.

4. Conclusions

Correlation between daily gamma-ray background and radon variability was tested in the underground low-level laboratory in Belgrade using two unshielded germanium detectors and single radon monitor.

Pearson correlation coefficients are determined for every combination of variables in rising part of ventilation “off” regime. Daily variations in radon and postradon lines did not registered in ventilation “on” regime, as well as in saturated radon atmosphere during ventilation “off” regime. Hence, there is a need for further investigations for getting better statistics to explain radon behavior inside the underground laboratory.

The majority of commercial available active radon detectors have sensitivity threshold of radon detection about 10 Bqm⁻³. Radon atmosphere inside the underground laboratory with long-term low radon concentration seems to be suitable place for some kind of radon chamber.

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REFERENCES

MEASUREMENTS OF WAVEGUIDES PARAMETERS

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Abstract
Behavior of a transmission circuit device with two ports, in different conditions of frequency and load is explored by measuring voltage and current. Since measurement of the voltage and current at high frequencies is very difficult, instead of measuring them directly, we measured their main parameters. At frequencies above 1 GHz, geometrical dimensions of the transmission line become comparable with the wavelength in which they work and this intensifies the changes in the behavior of the circuits. The measurements are performed using the stationary wave mode in waveguides. In this case the waveguide was left open-ended, as we inserted reflective metal sheet in contact with the line. In this paper, for each frequency, we defined two consecutive positions where minima are detected.

Key words: waveguide, measurement, network, circuit behavior

1. INTRODUCTION

The measurement of voltage and current at high and very high frequencies, in a transmission line is very difficult. Instead of measuring them directly, we measured their main parameters. The main parameters in the case of waveguide are: wave resistance, remission in the waveguide line, the phase constant, power of vibrations, wavelength, and phase velocity in waveguides, frequency and wavelength $\lambda_v$.

Electronic circuits, which work at high frequencies, introduce some changes in their behavior compared to circuits that work at lower frequencies. At higher frequencies the wavelength becomes comparable to the physical dimensions of the circuit elements.

2. MODES OF TRANSMISSION

A waveguide is a hollow tube of metal with right-angled or circular cross section. In this case we will work with right-angled waveguides. So, mathematical analysis is based on right-angled waveguide, the wave equation of which is [5]:

$$\nabla^2 \varphi + K \varphi = 0 \quad (1.1)$$

where $\varphi(x, y, z)$ is a wave scalar function and $K$ is the wave number, defined as $K^2 = \omega \varepsilon \mu \varepsilon$ for a perfect dielectric.

The equation (1.1) can be written in the right-angled coordinate system as follows:

$$\frac{\partial^2 \varphi}{\partial x^2} + \frac{\partial^2 \varphi}{\partial y^2} + \frac{\partial^2 \varphi}{\partial z^2} + K^2 \varphi = 0 \quad (1.2)$$

In the right-angled coordinate system it is accepted that $z$ is the direction of the wave propagation (see Fig.1).

Fig. 1. Rectangular waveguide in the rectangular coordinate system
Our goal is to obtain a final solution in the form of:

\[ g(x, y), f(z) \]  

(1.3)

where \( f \) is a function of \( z \) only, while \( g \) is a function of \( x \) and \( y \) (of the coordinates of waveguides section).

Three types of the wave propagation are of particular interest for us \([2, 5]\):

TEM (transverse electric and magnetic mode) - In this type, both electric and magnetic fields are perpendicular to the direction of propagation. In the direction of propagation there is no field component. TEM modes are not used in waveguides.

TE (transverse electric mode) or H-mode - In this type, there is only the magnetic field in the direction of propagation (the electric field is absent). All field components can be derived from the axial component of the electric field \( E_z \).

TM (transverse magnetic mode) or E-mode - In this type, only the electric field exists in the direction of propagation (the magnetic field is absent). All field components can be derived from the axial component of the magnetic field \( H_z \).

Both TE and TM represent modes of propagation in an empty waveguide.

We will continue with mathematical efforts to determine the field components for TE modes. Thus, to simplify the solutions, the interior part of the waveguide is accepted as a perfect conductor (its conductivity being \( \sigma = \infty \)) and filled with perfect dielectric (\( \sigma = 0 \)). TEM Modes \([2, 5]\)

3. THE WAVELENGTH IN A RECTANGULAR WAVEGUIDE

Assume \( \lambda_v \) is the wavelength in the waveguide. Starting from

\[ \beta = \sqrt{K^2 - K_c^2}, \quad K = \frac{2\pi}{\lambda} \quad \text{and} \quad K_c = \frac{2\pi}{\lambda_c} \]

we find:

\[ \left( \frac{2\pi}{\lambda_c} \right)^2 = \left( \frac{2\pi}{\lambda} \right)^2 - \left( \frac{2\pi}{\lambda} \right)^2 \]

(1.4)

\[ \lambda_v = \frac{\lambda}{\sqrt{1 - \left( \frac{\lambda}{\lambda_c} \right)^2}} \]

(1.5)

where \( \lambda \) is the wavelength in free space. From equation (1.5) it appears that propagation of waves in waveguides are characterized by \( \lambda_v > \lambda \). This shows that the wavelength in waveguides, \( \lambda_v \), is longer than the wavelength \( \lambda \) in free space.

4. MEASURING THE FREQUENCY AND WAVELENGTH IN FREE SPACE AND IN WAVEGUIDES

The main purpose of this paper is to measure wavelengths in waveguide and in free space. Measurements are performed using the microwave system of transmitting and receiving type Ed 3000 with waveguide WR-90 for the range 8.2-12.4 GHz (X-band) with size 22.86x10.16 mm building block scheme.

4.1. The procedure of measuring the frequency

The following steps show the actions performed:

- First there was the continual voltage implemented to Gunn oscillator with value \( V_{DC} = 8-8.5 \) V. This value provided sufficient power for measurements and the oscillator is not overcharged.
- Than we applied right-angled modulating oscillation with frequency \( f = 1 \) kHz and 2 Vpp value to the PIN diode modulator. The oscillation was detected on the sliding lines.
- We performed the measurement of SWR at low frequency 1 kHz, because this frequency simplifies and increases the accuracy of measurement of the SWR. The SWR reading was arranged in the middle of the scale, using variable attenuators with value of 10 dB, and interfering somewhat on the voltage.
- Next, we intervened on the frequency of the modulating oscillation (right-angled oscillation), to get the maximum value of the SWR indicator.
- We tuned up the frequency meter until we received a significant decrease in SWR indicator. Frequencies, in which the measurements were performed, are displayed in the Table 1.
- After the measurement of each frequency we un-tuned the frequency meter, in order not to prevent other measurements, because his action has greater absorption in the resonance frequency \([1]\).

4.2. Measuring the wavelength in the waveguide

This measurement was performed using the stationary wave mode in waveguides. In this case the waveguide was left open-ended. Inside it we placed the reflective metal sheet in contact with the line, covering it. In this case the waveguide was used in the regime of stationary waves. This change of the standing wave was detected from the sliding line, with which is associated the SWR indicator. In this case, for each frequency, we defined two consecutive positions where minima are detected.
The distance between two sets of minima represents one half of the wavelength in the waveguide. The measured values are presented in Table 1. The distance between the two sets of maxima also represents one half of the wavelength in the waveguide, but in this case the detection is performed with big error, because the changes are not steep.

4.3. Measuring wavelength in free space

Measuring wavelength in free space was performed by placing the reflective sheet in a short distance from the open end of the waveguide. The distance was chosen no more than the wavelength, so that the reflected wave is comparable to the downward wave, which greatly facilitates the definition of a node voltage (minimum value) and bellies of the voltage (maximum value). We located the sliding line at a position near the beginning of the scale (10-15 mm) and by displacing the reflective metal sheet we found the first minimum (voltage node). In the next step we increased the distance of the reflective sheet until the next minimum was reached. The distance between them, determine the half wavelength in free space. Measured values are also shown in Table 1.

Table 1 Measured values

<table>
<thead>
<tr>
<th>Frequency (GHz)</th>
<th>8.65</th>
<th>8.74</th>
<th>9.375</th>
<th>9.58</th>
<th>9.85</th>
</tr>
</thead>
<tbody>
<tr>
<td>Measured Value</td>
<td>37</td>
<td>36</td>
<td>35</td>
<td>32</td>
<td>31</td>
</tr>
<tr>
<td>( \lambda )</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Measured Value</td>
<td>51</td>
<td>50</td>
<td>46</td>
<td>43</td>
<td>41</td>
</tr>
<tr>
<td>( \lambda_\nu )</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Calculated Value</td>
<td>34.6</td>
<td>34.3</td>
<td>32.0</td>
<td>31.3</td>
<td>30.4</td>
</tr>
<tr>
<td>( \lambda )</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Calculated Value</td>
<td>48.8</td>
<td>48.4</td>
<td>45.1</td>
<td>40.2</td>
<td>37.1</td>
</tr>
<tr>
<td>( \lambda_\nu )</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Calculations were carried out using the equation (1.4), which we can rewrite as follows:

\[
\left( \frac{1}{\lambda_\nu} \right)^2 = \left( \frac{1}{\lambda} \right)^2 - \left( \frac{1}{\lambda_c} \right)^2
\]

(1.6)

Calculated values of critical wavelength (cut-off) for different pairs of values are taken into account in calculating the wavelength in waveguides (see Table 1).

5. Calculation of the cutoff frequency, attenuation and the phase and group propagation

Calculating the frequency of cutting and specific attenuation dB/m was performed.

These calculations were made for three frequencies and the results obtained are presented in Table 2.

Table 2 Calculated values

<table>
<thead>
<tr>
<th>Frequency (GHz)</th>
<th>8.580</th>
<th>9.850</th>
<th>10.312</th>
</tr>
</thead>
<tbody>
<tr>
<td>( f_c ) (GHz)</td>
<td>6.557</td>
<td>6.557</td>
<td>6.557</td>
</tr>
<tr>
<td>Attenuation (dB/m)</td>
<td>0.1292</td>
<td>0.1103</td>
<td>0.1069</td>
</tr>
<tr>
<td>( \nu_g ) (x10^8m/s)</td>
<td>1.9348</td>
<td>2.2387</td>
<td>2.3168</td>
</tr>
<tr>
<td>( \nu_\varphi ) (x10^8m/s)</td>
<td>4.6515</td>
<td>4.0202</td>
<td>3.8847</td>
</tr>
</tbody>
</table>

Wavelength is characterized by the group velocity, \( \nu_\varphi \), and the phase velocity, \( \nu_g \), which are functions that vary widely depending on the ratio of the used frequency versus frequency of cutting. The relationship between them is:

\[
\nu_g = c \sqrt{1 - \left( \frac{f_c}{f} \right)^2} = \frac{c^2}{\nu_\varphi}
\]

(1.7)

6. Conclusions

1. Measurements were performed and practically verified the relation \( \lambda_\nu > \lambda_c \).
2. Analysis of the results of wavelengths measurements and calculations showed that the measurements in the high band frequencies, where microwave system works, introduce big error. To reduce the error we performed some other measurements for several other wavelengths: \((2n +1)(2n +3)\), where \(n\) is an integer. In all cases it was showed that \(n = 9\). From the measurements, the wavelength was determined with a difference of 2%.
3. It was observed that when the waveguide was covered by reflective sheets, node points (minima) were practically that of a lossless line (\( V_{\min} \approx 0 \)), since the line length is less than 1 m (see Table 2).
4. Many other measurements, which can be a presentation of full and detailed features and characteristics of the microwave system, can be performed with small changes in the measurement scheme.
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CHARACTERIZATION AND VERIFICATION OF A LATCHUP PROTECTION SWITCH IN RADIATION ENVIRONMENT

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Abstract. The paper presents a single event latchup protection technique based on use of redundant circuits (and power domains) and custom switches for power-domain control. The protection switches of different types and sizes have been characterized by irradiation tests and measurements.

Key words: Single event latchup, fault-tolerance, protection switch, ASIC design

1. INTRODUCTION

The integrated circuits and systems require protection against a single event latchup (SEL) effect typical for operation in radiation environments [1], [2]. The logic affected by the latchup should be disconnected from the main supply line for a period of time in order to stop the extremely high current through the NPNP structure of a CMOS integrated circuit (Figure 1).

![Fig. 1 The parasitic NPNP structure](image)

Regarding latchup effects (SEL – single event latchup), all the known techniques for latchup mitigation are classified in three main groups.

First group uses the current sensors at the board level to detect the excessive current induced by the latchup. The power supply of the affected device is switched-off and, after a pre-specified (long enough) period of time, re-established again. This approach suffers from a serious drawback: the circuit state is destroyed and cannot be recovered. In addition, the board protection circuits must be designed with special care and the following requirements have to be met:

- Proper decoupling of ICs,
- Clamping of outputs with diodes when driving inductive loads,
- Clamping of inputs with diodes if the input signal exceeds the power supply voltage,
- Use of star grounds in high-current applications.

Second latchup effect mitigation approach [3] is based on introduction of an epitaxial-buried layer process and reduction of the well resistivity. However, this modification incurs additional costs and may impact circuit performance (the breakdown voltage, for example).

Third latchup effect mitigation approach [4] uses guard rings (additional N-type and P-type regions) that break the parasitic bipolar transistor structure. This solution is very efficient but can result in excessive circuit area and, therefore, price.

In order to have an automated design flow for the fault-tolerant circuits, it is essential to design the specific components which are not present in standard or radiation hardened design kits.

2. PROPOSED SOLUTION

A combination of the redundant circuits and SEL protection switches (SPS) has recently been proposed as a promising solution for suppressing the latchup in CMOS integrated circuits [5], [6]. The SPS must quickly react and simply disconnect the harmed part of the circuit. A simplified SPS schematic is presented in Figure 2.

The protection switches are placed exactly under the power-stripes/cell-rows crossover points instead of the filler (empty) cells. The power-stripes and power-rows are mutually connected by the SPS cells only. The SPS cell has an output that is, in fact, a controlled power-supply line for one of the redundant circuits. This requirement is based on the concept of having separate power-supply domains for the two redundant circuits. The SPS cells placed on the supply lines of a double modular redundant design are shown in Figure 3. When the latchup occurs on VDD1, Sensor 1 detects much higher current then usual and, at the same time the drain voltage of the S11 switch decreases to the ground level. Therefore, the S11 switch is off and the S12 switch is on. In this period, until the S11 switch is off, the controlled logic is disconnected from the VDD1.
power supply line. The latchup sensor is a fast MOS transistor able to react quickly in case of the latchup occurrence.

![Fig. 2 SEL protection switch schematic](image_url1)

The redundant circuits are connected to separate power supply lines. As shown in Figure 3, the SPS cells work in such a way that the SPS cell connected to one power domain (VDD1) always controls the other power domain (VDD2). This scheme provides the SPS cell self-protected from the latchup. The SPS control logic needs to have a continuous and independent power supply in order to control the power-supply lines of the logic suffering the latchup conditions.

3. TEST STRUCTURES

During the development process of SPS cell, in order to provide the accurate verification, it was important to define an appropriate test environment. Block diagram of test environment is shown in Figure 4. The test environment of SPS cell consists of the three main parts:

a) Latchup generator,
b) Control block,
c) Digital block supplied by the SPS cell.

Latchup generator is a simple switch controlled by voltage (VCSW), also known as reed relay. This approach, used for latchup generator, also provides a simple hardware realization which is required for measurements. Main tasks of control block are: communication with PC, setting the input control signals for the SPS cell under test, SPS outputs observation and setting the input signal for digital circuit, which is protected by SPS cell.

Timing measurements are done in order to characterize and use the SPS cell in an automated design flow. The measurements are carried out using a latchup generator. It is important to note that in case of permanent short circuit on the VDD1 output pin, the SPS cell will automatically be in the protection mode. It is also possible to control the activity of the SPS cell by the Poff pin.

Maximal current tests are based on the longer shortcut time and measurements when the output transistor of the protection switch is destroyed. The burn-off test (the shortcut between the drain of driving transistor and the ground) of the T5 transistor has been performed to prove its resistivity to the high latchup current.

In order to prove the functionality of the SPS cell, three groups of test circuits are implemented in standard IHP 250 nm process [7]. The first group of circuits is used to test the functionality of the SPS cell and measure its timing parameters in the moment of latchup occurrence. It is important to note that only first group of test circuits is used for radiation tests. The rest of circuits are used for characterization only: burn-off time measurements of the output transistor (T5) in the latchup (short-circuit) mode and functional analysis of the SPS cell integrated in a small redundant digital circuit.

A test chip named LUT-03 (Figure 5) is designed and fabricated as a test field of the nine different structures.
Measurement equipment necessary for the characterization of mentioned test circuits comprises a stimulus generator and a data acquisition system. The stimulus generator is a circuit based on Microcontroller, Thyristor, and connections for stimulus and measured data. The Microchip® PIC16F177A microcontroller is used to control the emulated short-circuit. In the same time, the microcontroller sends from the other terminal a triggering signal to the oscilloscope to synchronize the data recording. The microcontroller can also be connected to a personal computer and support extra timers and external memory for data storage. A basic block diagram of the measurement equipment and test set-up is presented in Figure 6.

Data acquisition part consists of an oscilloscope (OSCI), personal computer (PC), microcontroller (µC), voltmeters, and ammeters. Oscilloscope should have minimum two channels and an external triggering option. All cables and connections between equipment and test board are coaxial based due to maximal measurement accuracy. PC is connected to the test board through RS232 communication protocol. As µC is used as a stimulus generator, there is possibility to use an extended option, based on the data processing and proportional A/D conversion. Therefore, the measured data processing can be done in µC and transferred to PC or memory device.

4. SPS CELL CHARACTERIZATION

Timing measurements are done in order to characterize the SPS as a standard power switch cell for usage in the automated design flow. In Figure 7 is presented waveform diagram of the mentioned signals and required timings. The strobe signal, in Figure 7, presents the latchup activation signal. The Table 1 shows the simulated and measured signal timings. The timing measurements are done on the 50% voltage level of the signal transitions.

Before we discuss simulated and measured SPS timings, it is important to note that measurements are done with standard equipment. Measured values are normalized by correction factors for each pad on the test circuit due parasitic capacitances in cables and connections.

<table>
<thead>
<tr>
<th>Simulated</th>
<th>POFT</th>
<th>LRT</th>
<th>PONT</th>
<th>PDT</th>
<th>MAT</th>
</tr>
</thead>
</table>

It is important also to note that in case of permanent short circuit on the Vdd1 output pin, SPS will automatically be in the protection mode. It is also possible to control activity of the SPS by the Pst pin.

The measured power consumption, of SPS itself, is about 500 µW in normal conditions and it goes up to 1.25 mW when stimulated latchup occurs. A simulated value of the SPS power consumption is 75 pW in normal conditions and 1.16 mW in the latchup mode. This power consumption difference, between two mentioned modes, is due to the pull-down resistor shown in Figure 2.

5. RADIATION MEASUREMENTS

The irradiation tests of SPS cells were performed at the Radiation Effects Facility at the Cyclotron Institute located in the campus of Texas A&M University in College Station, Texas (USA) at different temperatures and ion energies up to 74.8 MeVcm/kg [8].

TAMU-REF is equipped with a K500 superconducting cyclotron and an ECR ion source allowing a diverse range of particle beams and energies. These beams provide a wide range of LET values with energies high enough to obtain deep penetration in DUTs.

Beams can be delivered with a high degree of uniformity over a 4.6 x 4.6 cm cross sectional area for measurements inside the vacuum chamber and up to maximum of 2.54 cm diameter circular cross sectional area for the in-air station. Uniformity is achieved by means of magnetic defocusing.

In addition, a degrader foils system makes it possible to set the desired beam LET value at a particular depth inside the target without changing the beam or rotating the target. The beam energy is reduced by means of metal foils having a suitable thickness and orientation with respect to the incident beam. Each foil can be inserted, withdrawn, and rotated remotely through use of computer controls.

TAMU-REF facility consists of two main areas:

1. The irradiation bunker where the beam line is found in two possible testing setups:
   • Vacuum station, including a 30° diameter vacuum chamber.
   • In-air station, in case no vacuum conditions are required.

2. A control/data room, located directly above the bunker, to allow the users to deploy their control SW/HW.

The irradiation test setup is shown in Figure 8. It is easy to note that DUTs (device under test) are mounted
on the mother board, which contains signal generators required for proper function of the DUT during irradiation. It is important to note that the board is placed on the frame adaptor, which is mounted on the positioning system which can provide different angles and mobile cross-section. Selected TAMU heavy ion cocktail is listed in Table 2.

The environment conditions used during test are selected through temperature, humidity and ionizing environment. The SEU/SET tests were performed at room temperature. Temperature during irradiation was set at 25 °C. Temperature was not changed more than 3 degrees during irradiation. SEL test at worst case conditions was performed at 65 °C. It was not changed more than 3 degrees during irradiation. Humidity was monitored during the tests without detected changes. The SPS cell operated correctly during the irradiation tests.

6. CONCLUSION

The SPS cells have been characterized by measurements and have been proven as a good hardware infrastructure for the proposed latchup protection technique. The irradiation measurements have been conducted for the standard heavy ion cocktail which emulates the irradiation in space. The results have proven the correct design and successful implementation of the SPS cell that provides a good base for the fault-tolerant circuit design.

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ERGOMETRIC ANALYSIS BY CORRELATIVE METHODS OF THE THERMAL RADIATION EMISSION DEVELOPED WITHIN HAND FOLLOWING A CONTROLLED EFFORT

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Abstract. The hand-arm assembly represents the anatomical structure required to develop multiple activities involving effort, precision, stamina and performance of repetitive or random motions etc. and also the determination of an ergonomic comfort condition. The actions developed on prolonged durations requiring effort, repetitive and random motions and accurate displacement of some various weight objects represent a source of local temperature growth at tissues level. This thermal radiation gradient analyzed in a correlative manner with respect to the physiological mechanisms developed within tissues and also considering initial anthropometrical data allows the evaluation by means of ANOVA method of the induced and/or developed fatigue degree, of the ergonomic coefficients related to static and dynamic posture and last but not least allows the evaluation of the operating limits of the hand-arm assembly. Also we considered the combined action of the thermal radiation emission occurred following the development of a controlled effort with the electromagnetic radiations manifested in a specialized medical ward. The subjects’ sample taking part in this experiment was determined by taking into account several initial criteria of anthropometrical type, age, effort degree, motion type and were followed during a certain time period corresponding to the induced effort activity in order to find the thermal radiation emission gradient by thermo-vision methods and then the interactions with the environment loaded by electromagnetic radiation in the specialized medical offices. The surveillance, determination and correlative analysis procedures are part of the final chapter of the paper, where we highlight the aspects regarding the development of the thermal radiation emission effects in the hand-arm assembly, following the induction of a certain controlled effort condition and the interactions with the environment are evaluated.

Key words: thermo-vision, finger-hand-arm assembly, effort, correlation, ergonomics.

1. INTRODUCTION

From anatomical and morpho-functional point of view, the assembly consisting of fingers-hand-arm represents for the human subject the most complex used structure in both strength actions and high accuracy actions. For these reasons, actions like motions coordination in fingers-hand-arm assembly, force concentration on certain segments as well as obtaining a prolonged comfort status during a motion activity represents the main purpose in ergometric analyses and the results are used in accomplishing new steps in improving the technical systems controlled by this assembly. In case that motion actions of this assembly take place within environments where the physical parameters are maintained at constant levels, a change in the physiological parameters of the human subjects can be emphasized only due to the characteristics of the developed actions or to the type of surgical or sportive interventions in this structure. [1, 2, 3] Thus, in the paper [5] “skin temperature (Tsk) disorders have been proposed as sign of impaired innervation in several conditions, but the influence of different factors on the infrared thermography (IRT) findings remains unclear. The relations between the Tsk (temperature of sick human subjects) and δT (side-to-side temperature difference) values, and influence of age, gender, anthropometric characteristics and pain intensity on those values were analyzed in non-specific neck pain (NP) patients using mixed model analysis”.

In another research [6] dedicated to cases developed by the effects “of work related mechanical stress on the peripheral temperature of the hand”, it is shown that “episodes of constriction of small arteries and/or arterioles of hands and feet, with sequential changes in color of the skin, pallor, cyanosis and usually following exposure to cold represent a condition known as Raynaud’s phenomenon”. This frequent medical problem was firstly described by Maurice Raynaud, a French physician who in 1862 stated that it is related to a large number of conditions such as neurological and/or vascular diseases that can affect the extremities”. Also in order to be able to assess and test cold stress we define an index expressing the difference of the temperature gradient (ΔTfw) between fingers and the metacarpal surface of the hand. This index can be computed starting from two of the infrared captured images, processed by help of specific image processing methods. [4] On the other hand, the analyses performed on various forms of stress [6] that may act at hand and fingers level reveal the fact that mechanical stress (squeeze, grasp or press) induce temperature changes in tissues and
muscular structure of the assembly fingers-hand-arm (FHA) by the mechanisms adjusted by the bloodstream. Extension and prolonged exposure of FHA to the effects of mechanical stress may lead to the occurrence of a static syndrome in hand and arm (HAS), with a more striking manifestation of discomfort in fingers and then pains or tensions in arm (repetitive arm pain injuries - RAPI). This RAPI type manifestation is generated by a "range of conditions due to repetitive occupational tasks and/or wrong posture affecting muscles, tendons and nerves in the upper extremities and upper back provoking chronic pain and discomfort in affected subjects". [6] The hand-arm assembly (HAA) at rest assumes a characteristic posture, easy to visualize when the hand hangs freely at the side of the human body. The joint at rest takes a middle position which according to the extended axis of the forearm is slightly bent towards the trunk with approximately 35°. It is a fact that this is the position with the highest grasp force. The middle position for radial/ulna flexion is such manner because it allows the centre of the meta-carpal-phalangean joint of the third finger to be in the extended sagittal plane of the joint. From biomechanical point of view, the fingers, hand and arm perform a very extended range of combined motions, of great interest in the working activities being the grasping motions (repetitive and/or with great strength). These grasp motions are classified according to several criteria and from their analysis we find that the most important is the grasp motion required in many working activities, leading to various issues related to discomfort, pains, tensions or even injuries.

2. METHODOLOGY AND EXPERIMENTAL SETUP

In order to analyze the thermal radiation developed in hand, following a controlled effort, grasp type we developed a flexible methodology of assessment by means of which we aim at highlighting the temperature distribution at fingers-hand level and also its evolution along various durations and intensities of induces effort. Thus, the analysis system consists of the FLIR type thermo-vision camera, devices and instruments (gonio-meters, dynamometer, pinch-meter etc.) for anthropometric measurements of the fingers-hand-arm assembly (FHA), computerized system for data processing as thermo-sensitive images (fig.1).

The target group used for the procedure consists of 10 subjects with ages between 21-23, without any motor malfunctions of the fingers-hand-arm assembly and examined in the same environmental conditions (environmental temperature, atmospheric pressure, humidity, luminosity), respectively in the same physiological conditions (fatigue or relaxation degree).

The used methodology allows obtaining, as a follow of image processing, of data regarding the thermal gradient developed in the right assembly (all subjects were right-handed) after a controlled effort developed along 7 minutes respectively during 14 minutes. During the induced controlled effort, by help of a dynamometer with analogical display, the FHA assembly was set on a support in order to allow the action upon the dynamometer without any obstacle (fig.2). Thus, this induced effort was mainly induced on the fingers-hand structure and less on the arm, in order to be able to capture later the thermal image in the grasp process, namely on fingers and hand.

As an example we selected 4 subjects of the target group (fig.3) with very different anthropometric characteristics of the entire human body and of the FHA assembly, to whom the evolution of the anatomic and physiologic force were recorded and also the frequency of grasp-squeeze actions along 7 minutes, respectively 14 minutes, before (1) and after (2) performing the controlled effort.

Table no.1 – before and after 7 minutes

<table>
<thead>
<tr>
<th></th>
<th>Fa</th>
<th>Ff</th>
<th>No/min</th>
<th>Fa</th>
<th>Ff</th>
<th>No/min</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1 M</td>
<td>52</td>
<td>20</td>
<td>457</td>
<td>46</td>
<td>18</td>
<td>65</td>
</tr>
<tr>
<td>S2 M</td>
<td>38</td>
<td>18</td>
<td>400</td>
<td>32</td>
<td>10</td>
<td>57</td>
</tr>
<tr>
<td>S3 F</td>
<td>27</td>
<td>10</td>
<td>258</td>
<td>25</td>
<td>8</td>
<td>37</td>
</tr>
<tr>
<td>S4 F</td>
<td>38</td>
<td>14</td>
<td>350</td>
<td>38</td>
<td>12</td>
<td>50</td>
</tr>
</tbody>
</table>

Table no.2 – before and after 14 minutes

<table>
<thead>
<tr>
<th></th>
<th>Fa</th>
<th>Ff</th>
<th>No/min</th>
<th>Fa</th>
<th>Ff</th>
<th>No/min</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1 M</td>
<td>50</td>
<td>22</td>
<td>823</td>
<td>40</td>
<td>18</td>
<td>59</td>
</tr>
<tr>
<td>S2 M</td>
<td>38</td>
<td>20</td>
<td>840</td>
<td>32</td>
<td>18</td>
<td>60</td>
</tr>
<tr>
<td>S3 F</td>
<td>28</td>
<td>12</td>
<td>712</td>
<td>25</td>
<td>10</td>
<td>51</td>
</tr>
<tr>
<td>S4 F</td>
<td>37</td>
<td>15</td>
<td>825</td>
<td>36</td>
<td>15</td>
<td>59</td>
</tr>
</tbody>
</table>

Note: Fa=anatomic force; Ff=physiologic force; No=number of squeezing during the experiment; No/min=frequency of grasp-squeeze actions;

Dynamometric measurements performed on the selected sample (4 subjects) before and after the established time are presented in table no.1 and no.2.

Both testing options were developed in different days but respecting the initially imposed environmental conditions (environmental temperature 21°C, normal atmospheric pressure, humidity 80%, ambient lighting 500-750 lx) in order to avoid inducing
a fatigue state and the lack of concentration upon the subjects. [7] Also we aimed at maintaining the same level of electromagnetic radiations coming from the computerized equipment from the laboratory. Initially the physiological parameters of the subjects were measured (body temperature during 10 minutes, blood pressure and pulse) and the thermo-graphic images of the fingers-hand assembly were recorded, while leaned on a support without thermal radiation and of gray color (fig.2). With the data obtained at the initial evaluations of this sample we establish the next structure for data acquisition, valid for all the subjects. Thus the investigation structure includes following modules: a) Recording the thermo-graphic image of the FH assembly before inducing the effort, b) Developing the action of inducing the effort in this assembly (7 or 14 minutes), c) Immediate capture at the end of the period of a new thermo-graphic image of the same area, d) Relaxation of FHA assembly for the subjects for 45 minutes, e) Resuming the procedure of effort inducing and capturing the thermo-graphic image for other 2 times.

By applying this way the investigation structure on the subjects’ sample we found that the mechanical stress acting upon the FH assembly becomes stabilized in time, as the subjects’ sample develop a better understanding level and participation in procedures progress.

3. RESULTS OF EXPERIMENTS
Following the recordings performed on the subjects’ sample, we obtain some information presented in the next figures: the thermographic images and those processed in 3D in order to highlight the temperature gradient, before and after inducing the controlled effort for 7 minutes, respectively before and after 14 minutes (fig.4a-h) in case of the subject S1M and of subject S3F (having the most developed anthropometric and biomechanical characteristics). [9]

![Fig.4. 3D and thermographic image of S1M and S3F before effort (a and c); after inducing the 7 minutes effort (b and f), S1M and S3F before effort (c and g); after inducing the 14 minutes effort (d and h)](image)

The range of the temperature scales measured on the surface of FH assembly was established to be the same for all categories of recordings so that their transfer into false colors highlights the surfaces corresponding to this interval. By applying the ANOVA analysis upon the values of the anatomical and physiological forces developed by the subjects during testing we obtained the following values according to the formulas below (1):

$$F = \frac{DF_2 \cdot SSB}{DF_1 \cdot SSW} = \frac{DF_2 \cdot SST}{DF_1 \cdot SSW} - 1$$

where $DF_1$ and $DF_2$ = degrees of freedom of the value groups, respectively SST= Total Sum of Squares; SSW=Sum of Squares Within; SSB=Sum of Squares Between; $x_i$values from the analysis groups (anatomic and physiologic forces, before and after inducing effort) correlated with maximum temperature values.

Value of F coefficient determined by ANOVA for inducing a 7 minutes effort is 13.23, while for exposing subjects to an effort of 14 minutes it becomes 13.35 which indicates a good correlation between the recordings performed according to the two procedures related to time.

![Fig.5 Maximum temperature variation developed at FH assembly level after 7 min (a) and after 14 min (b)](image)

![Fig.6 Correlation of maximum temperature variation developed at FH assembly level with the number of grasp actions/min during 7 minutes (a) and 14 minutes (b)](image)

Analyzing the thermal gradient for every type of recording and correlating these values to the anatomic and physiologic forces we are able to highlight important aspects related to the degree of comfort evolution in the FH assembly. Thus, during the methodology unfolding, we observed the development of a direct relation between the decrease of the physiologic effort after performing the induced effort and the change in temperature at the FH assembly.
level, which indicates a certain variation of the fatigue degree or local discomfort (fig.6). Correlative analysis developed by this procedure defines the degree of comfort in effort (DCE) by a direct relation between the squeeze/grasp cycles and the maximum temperature developed in the FH assembly.

Thus, calculating the DCE for the target group we found the following values (table no.3).

Table no.3

<table>
<thead>
<tr>
<th>S1</th>
<th>S2</th>
<th>S3</th>
<th>S4</th>
<th>S5</th>
<th>S6</th>
<th>S7</th>
<th>S8</th>
<th>S9</th>
<th>S10</th>
</tr>
</thead>
<tbody>
<tr>
<td>M</td>
<td>M</td>
<td>F</td>
<td>F</td>
<td>M</td>
<td>M</td>
<td>F</td>
<td>M</td>
<td>M</td>
<td>M</td>
</tr>
<tr>
<td>N</td>
<td>65</td>
<td>57</td>
<td>37</td>
<td>50</td>
<td>68</td>
<td>62</td>
<td>45</td>
<td>35</td>
<td>69</td>
</tr>
<tr>
<td>N</td>
<td>59</td>
<td>60</td>
<td>51</td>
<td>59</td>
<td>60</td>
<td>58</td>
<td>54</td>
<td>49</td>
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</tr>
<tr>
<td>T</td>
<td>40</td>
<td>35</td>
<td>35</td>
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<td>35</td>
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<td>T</td>
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<td>40</td>
<td>35</td>
<td>35</td>
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<td>45</td>
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<tr>
<td>DCE</td>
<td>1.101</td>
<td>0.950</td>
<td>0.725</td>
<td>0.968</td>
<td>0.001</td>
<td>0.0620</td>
<td>0.0720</td>
<td>0.614</td>
<td>0.99</td>
</tr>
</tbody>
</table>

Note: M=male; F=female; S1-S10=target group; Nf and Nm=frequency of squeeze/grasp cycles for 7 minutes, respectively 14 minutes; Tm7 and Tm14=maximum temperature developed in the assembly FH for 7 minutes, respectively for 14 minutes.

4. CONCLUSIONS

The applied procedure indicates thus, by DCE, the degree of fatigue exposure in relation to the displayed values. For example, the subjects with a DCE coefficient lower than 1 are the most exposed to the fatigue level, faster and more intense for the subjects with a coefficient higher than 1. In case of a DCE equal to 1, then these subjects are able to develop an activity at the low limit of the comfort state, which they can easily control and also are able to efficiently dose the effort along the entire exposure period.

Fig.7 Variation of degree of comfort in effort (DCE)

We were also able to observe from the performed analyses that the subjects develop initially a higher effort involving a local growth of temperature for the FH assembly that is later adjusted by physiological mechanisms in the tegumentary area until they reach comfort level. But if the anthropometric dimensions as well as lack of training in such actions are substantially decreased then these characteristics may lead to lower temperatures at the final of the action as initially, in the FH assembly. This situation became obvious at the female subjects especially but also for the male ones, for which the lack of training and certain anthropometric dimensions influenced this manifestation.

As a follow, DCE is a measure of the fatigue degree occurrence level which contributes to the change of the required degree of comfort during an action with a certain type of effort, simple or complex motion. The maximum final temperature measured by thermo-vision, being correlated with the effort level and motion type, represents a main quantity in establishing DCE, which makes of the thermo-vision method an easy to use, flexible and fast method in several activity areas [10, 11].

The procedure can be extended on investigations performed on the entire surface of the human body, in environmental conditions meant to induce a temperature variation at both upper/lower limbs and at head or eyes level.

By these investigations we are able to establish a general degree of comfort (GDC) with the two components – static/relaxation (GDC-S/R) and respectively dynamic/effort (GDC-D/E) in order to simultaneously evaluate a target group performing different actions. [12]

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ANALYSIS OF VISUAL PARAMETERS VARIANCE UNDER THE INCIDENCE OF RADIATION PRODUCED BY COMPUTER MONITORS AND MEDICAL DEVICES UPON THE OPERATORS WORKING IN SPECIALIZED SURGERIES

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Abstract. The performances of the human visual system are strongly affected by some parameters reaching the human factor as luminous radiation. The amount of perceived and processed information by human visual system is estimated at approximately 98% of the entire information amount received by the human factor. This fact requires the maximum protection of the human visual system according to various luminous radiation levels originated from the medical equipment monitors or computers or other type of electromagnetic radiation from the specialized medical wards.

By means of this research we try to create a fast and flexible mechanism of the influence degree for the performances of the human visual system of a subjects’ sample by the optical radiations originated from the medical equipment and computer monitors from a medical ward.

The modular construction of the analysis methodology allows obtaining some complex and complementary evaluations, also allows the accomplishment of analyses correlated to the anthropometric parameters of the subjects’ sample, to the environmental parameters and last but not least to the analyzed devices parameters.

In the final part of this research a methodology and evaluation procedure is structured in order to assess the influence of the radiations originated from the specific equipment on a subjects’ sample and by specific ANOVA type methods the variance coefficients of the visual parameters are established in order to accomplish the optimization of use for these equipment and the human factor protection.

Key words: visual system, display radiation, chromatic vision, visual acuity.

1. INTRODUCTION

Human visual system represents for the human body “the entrance” of the greatest range of information that the “central system”, the brain is processing in real time, stores them, interprets them and reacts to them by its specific mechanisms.

Optical radiation consisting of ultraviolet (UV), visible (DV) and infrared (IR) radiation specters creates the category of electromagnetic radiation able to interact with the visual system both in positive and negative ways.

Light radiation in the visible domain (DV) represents for the visual system an excitatory mechanism, which induces at the posterior pole level (retina, optic nerve, visual cortex) a set of neuronal signals considered as data originated from external “information sources”. These data create thus a “map” of information that are to be processed, stored or/and used in the process of subject’s adjustment to the environment.

Radiation in ultraviolet domain (UV), being not perceived by the retina, represents for the visual system a source of negative reactions that may degenerate even in damage or destruction of retinal structure.

Radiation in infrared domain (IR) is also a type of radiation that goes unperceived by the retina but in its turn is able to irreversible affect the optical structures and environments of the eyeball. IR (wavelength 760 nm - 1600 nm) is commonly referred to as heat, emitted from any warm object and this is why the protection of the visual system is supported and amplified by the reflex of general protection of the human body. [1]

As shown in a report of American Association of Physicists in Medicine of the American Institute of Physics, published in 1995 [2], the authors define a series of parameters and measure units used in detection of the presence and quantity of radiations in specialized surgeries. Thus, it is mentioned that “radiation is measured in radiation units: roentgen, rad, and rem. The roentgen (R) is a measure of exposure the amount of ionization in air produced by radiation at a location. The rad (rad) is the radiation absorbed dose and refers to the amount of energy absorbed by any material from the radiation. The rem (rem) determines the radiobiological equivalent and refers to the biological effect of the absorbed radiation on living things.

From a practical, radiation safety concern, these radiation terms are frequently used interchangeably despite their different scientific definitions”. [2]

But because in these locations the radiations amounts are of milliroentgen (mR), millirad (mrad) or millirem (mrem) order, it is more important to measure another aspect that occurs and develops...
during the activity, namely the exposure of the human subjects to the so called absorbed dose or/and equivalent dose, quantities that are measured in International System in: coulomb per kilogram (C/kg), gray (Gy), and Sievert (Sv), respectively. [3]

These aspects, as well as the incidence of some deficiencies that amplify or are just initiated in the subjects’ organism working in these locations, represent situations that should be analyzed from all points of view, especially for assuring the human subjects’ protection, particularly their visual function.

A very wide range of researches are performed, at different levels and the exposure limits of the human body are established and then checked, especially the cumulated effects along a whole year (table no.1). [3]

Table no.1. Radiations dosage limits [3]

<table>
<thead>
<tr>
<th>Dosimetry type</th>
<th>Regulatory limit</th>
<th>Level 1</th>
<th>Level 2</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>[mrem/yr]</td>
<td>(month)</td>
<td>(accumulated)</td>
</tr>
<tr>
<td>Whole body</td>
<td>5,000</td>
<td>100</td>
<td>1,000</td>
</tr>
<tr>
<td>Lens of the eye</td>
<td>15,000</td>
<td>300</td>
<td>3,000</td>
</tr>
<tr>
<td>Skin and/or extremity</td>
<td>50,000</td>
<td>1,000</td>
<td>10,000</td>
</tr>
</tbody>
</table>

Another important aspect in the human subjects’ protection process, for those working in specialized surgeries is represented by the visual system protection against laser radiations, first by using special glasses.

As shown in the guide published by Health and Safety Executive England [4] other series of practical measures can be taken in order to diminish the effect of laser radiation upon the human subjects who handle, use or repair these systems.

At any rate, visual function by its main characteristics (visual acuity, chromatic sight and visual field) must be periodically controlled, protected and corrected when necessary for persons working in specialized surgeries. [5]

2. METHODOLOGY AND EXPERIMENTAL SETUP

In order to establish a screening type methodology for evaluation and control for persons working in aggressive (from radiations point of view) environments for the visual system, we designed by this research a flexible and adjustable structure for action. [6]

This methodology involves for the first part a primary evaluation of the visual function of the subjects, of their visual needs for comfort and protection, by the specific structure of an anamnesis procedure.

In the second part, a sequence of tests and measurements are established, according to the screening kit of the visual system (SKVS) in order to accomplish a correlated evaluation of the main characteristics of the subjects’ visual system.

Thus we built a set of anamnesis questionnaires on three issues categories: in the first part, the general aspects of the visual function and of the environment surrounding the target group are analyzed, in the second part primary evaluations of visual acuity (VA), chromatic vision (CV) and visual field (VF) are performed and in the third, these measurements are correlated with the working conditions and the optical radiations level by which the target group can activate. (fig.1).

The used experimental structure consists of a system for visual acuity evaluation, for chromatic vision and visual field, before and after controlled exposure to optical radiation originated form displays of specialized surgeries while data processing can be done on a computerized system.

As mentioned in fig.1, the three parameters of the visual system are analyzed before controlled exposure to optical radiation of the target group consisting of 30 human subjects, average age 28+/−0,3 years, with an equal number of male and female subjects, in a good state of comfort and normal physiologic parameters (fig.2 and fig.3).
Fig. 4. Measuring the initial visual field

These initial measurements are continued with the evaluation of chromatic vision by using Ishihara tests in the same environmental conditions as for the entire investigation. Another important parameter of the evaluation is the initial testing of the visual field in order to highlight the normal or the scotoma areas that limit a correct perception. (fig. 4).

Following the initial evaluation of the target group we established the simulation conditions of the effect of some optical radiations originated from the displays located in the surgery. Thus, we measured the general, local and combined lighting on the entire period of the experiment, obtaining 545 lx for general lighting, 750 lx for local and respectively 600 lx for combined lighting, in order to avoid variations that might influence the measurements.

The subjects were exposed 3 times successively for 25 minutes each (with a break of 10 minutes), representing 23.33 % of the normal activity time, to an intensity of optical radiation originated from a display with 1000 lx illumination and a continuous image (in an environment with 545 lx environmental lighting).

After this cumulated exposure (of 105 min.), the subjects were tested for VA, CV and VF characteristics in the same environmental conditions as the initial ones.

3. RESULTS AND CONCLUSIONS

Following the performed tests, the results are analyzed from the point of view of the display radiation impact upon the capacity of re-adapting to the environment and maintaining chromatic perceptions. In this respect we present the example of a 3 subjects’ sample, who were in the category VA=normal, CV=normal and VF=normal after the initial check of the visual system.

After the controlled exposure of the visual system according to the methodology (fig. 1) the three characteristics of the subjects were evaluated, observing significant differences, especially concerning the capacity of maintaining chromatic vision normal, this being a very important parameter in developing activities in various professions.

Thus, the Farnsworth-Munsell test, in a normal option is presented like in fig. 5, where the concentric circles of the graph indicate the error points 2, 5, 10, 15 and 20. The more it goes farther from the centre, the higher will the error in placing different colors. The perfect graph will be a circle on level 2 (total points: 0). Minor errors (inside circle 5) are generally acceptable, color detection might be affected by the hardware (monitor, software graphics etc.). The big unbalances towards one sector or another are indicators of diminished performances of chromatic vision for the respective colors in the evaluated subjects.

If initially the subjects’ sample presented some values comparable to the analyzed visual system parameters (VS) (table no. 2), after the exposure these values are substantially changed and showed a decreased sensitivity in both perceiving stimuli at visual level and correctness of the chromatic vision test.

Table no.2 Initial values of the VS parameters for the 3 subjects of the sample

<table>
<thead>
<tr>
<th></th>
<th>VA</th>
<th>CV [pct]</th>
<th>VF</th>
<th>Observation</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1M</td>
<td>0.9</td>
<td>10</td>
<td>normal</td>
<td>VS normal</td>
</tr>
<tr>
<td>S2M</td>
<td>1.0</td>
<td>6</td>
<td>normal</td>
<td>VS normal</td>
</tr>
<tr>
<td>S3F</td>
<td>1.0</td>
<td>4</td>
<td>normal</td>
<td>VS normal</td>
</tr>
</tbody>
</table>

These changes in VS parameters were recorded after the testing period and are presented in table no. 3.
showing in all three cases a faulty visual system, which reveals the fact that prolonged exposure to intense optical radiation affects the main parameters of the visual system.

Table no.3 Values of recorded parameters after exposure

<table>
<thead>
<tr>
<th></th>
<th>VA</th>
<th>CV [pct]</th>
<th>VF</th>
<th>Observations</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1M</td>
<td>0.7</td>
<td>216</td>
<td>abnormal</td>
<td>VS faulty</td>
</tr>
<tr>
<td>S2M</td>
<td>0.9</td>
<td>64</td>
<td>abnormal</td>
<td>VS faulty</td>
</tr>
<tr>
<td>S3F</td>
<td>0.8</td>
<td>72</td>
<td>abnormal</td>
<td>VS faulty</td>
</tr>
</tbody>
</table>

We also are able to observe that the female subject from the chosen sample, though she has a substantial decreased VA, the changes in chromatic vision are important but can be compensated by experience and knowledge.

Weber also are able to observe that the female subject from the chosen sample, though she has a substantial decreased VA, the changes in chromatic vision are important but can be compensated by experience and knowledge.

We also are able to observe that the female subject from the chosen sample, though she has a substantial decreased VA, the changes in chromatic vision are important but can be compensated by experience and knowledge.

From the global analysis of the experimental results we may conclude that:

- Impairment of the visual system, just after the experiment by diminishing the main visual parameters (VA, CV and VF) represents a physiological manifestation of the adjusting process to the initial values by a rebalancing mechanism of the photo-chemical reactions at retinal level;
- Variation of visual acuity between the initial phase and the final one is correlated in 93% proportion for the entire evaluated target group;
- Variation of chromatic vision between the initial and the final phase is defined by a correlation coefficient of 85.33% and also for the visual acuity in 76.4% proportion.

This way, by help of the evaluation kit (consisting of the visual acuity measuring system, computerized chromatic tests and visual field evaluation system) and by the analysis manner based upon the ANOVA procedure we are able to rapidly determine the effects of optical radiations from the displays of the specialized surgery equipments and the required measures can be taken in order to eliminate the negative effects and establish operational comfort conditions. [7,8]

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THE POSSIBILITY OF USING NUCLEAR TRACK MEMBRANE FOR OPHTHALMOLOGY

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² Institute of Physics and Technology, National Research Tomsk Polytechnic University, Tomsk

Abstract: This work researches the possibility of using nuclear track membrane for ophthalmology in epithelial-endothelial corneal dystrophy treatment. Experiments were conducted using a track membrane “TOMTREK” based on PET with pores diameters (0.2-0.8)µm and (5*10⁶-2*10⁹) pores/cm² density. The pores were formed by irradiating the polymer PET 40 Ar +8 ions with energy 41.5 MeV. After irradiation, the membrane was chemically treated in the alkaline solution. Imparting hydrophilicity membrane was the next step.

Contact angle of the wettability the surface track membrane was measured just after the chemical treatment in NaOH and after 10 hours in air.

The surface had been processed by the plasma self-sustained volume discharge to give the surface the hydrophilic properties of the membrane.

The maximum voltage on plasma discharge was 20-22 kV. The energy density in the discharge was 6*10⁻⁴ J/cm² per pulse/ Pulse repetition rate was 10⁵ s⁻¹. Samples of 6×6 cm were attached in a special rotating device. Thus, the effects were both surfaces of the membrane. After surface treatment, TM samples were placed in plastic bags. After a night contact angle of wetting was measured with these samples.

Disks treating by the plasma were cut. The disk’s diameter was 10-11 cm. The edges of the disks were incised and processed with hot temperature in order to obtain the model of an appropriate shape.

It was a shape of a truncated sphere with a certain radius of curvature.

Then, the membrane was sterilized and implanted into the anterior chamber of the pig’s eye. Thus, we trained the methods of barrier keratoplasty using a nuclear track membrane.

Key words: track membrane, implantation, cornea, keratoplasty, permeability

1. Introduction

One of the leading causes of blindness and visual problems is corneal diseases. There are more 500,000 blind and patient with visually problems on the territory of the Russian Federation. 18 percent of patients are people with corneal disease [1].

Endothelial – epithelial corneal dystrophy is a progressive disease of the cornea with decompensating of endothelial layer. Leading role in the pathogenesis of conditions corneal dystrophy plays poor barrier function of the corneal endothelium layer. It leads to impregnation of intraocular fluid into stroma of cornea. Then transparency of the cornea is disrupted.

Corneal dystrophy is a chronic and difficult to treat disease.

Treatments of corneal dystrophy can be divided into conservative and surgical treatments. Conservative treatment are aimed at the removal of corneal edema and increased corneal trophism ( subconjunctival injections of vitamins, a course of laser stimulation and others) . These methods are ineffective. This type of treatment is not able to restore the damaged barrier function of the corneal endothelium [2,3].

There are the surgical treatments such as not- transplantation and transplantation.

Transplantation treatments includes various modifications of keratoplasty. It is a penetrating keratoplasty, lamellar keratoplasty, amniotic transplantation and others. Surgical methods are more effective as pathogenesis methods. One of these methods is barrier keratoplasty [2,4,5].

The problem of corneal treatment is actual. Disease outcomes after treatment are not satisfactory.
2. Experimental set-up

The main objective in creating a semipermeable membrane is the searching for biocompatible materials which due to its structure could have the necessary conditions. The using of biological membranes based on the type of polymer has greatest interest. Thus, it was suggested to use the PET membrane.

Technique of producing porous track structures is based on irradiated different polymers by high-energy heavy ions [6,7,10,11]. These ions induce latent narrow tracks through the entire thickness of the polymeric material. Latent tracks are defective area with a diameter of 5-12 nm. Subsequent selective etching can remove these defective areas and receive the porous material with nano pores density from $10^6$ cm$^{-2}$ to $10^9$ cm$^{-2}$.

Oriented polymer films are irradiated by Ar ion beam with a maximum energy of 41 MeV in a specially designed vacuum chamber with a tape transport mechanism. Accelerated beam of argon ions was extracted from the chamber with an electrostatic deflector. Argon ion beam was directed into the channel, in which there were a uniform system for scanning the ion beam and the camera exposure film. The original scheme with electrostatic scanning beam in the horizontal direction was designed and used to scan the beam in the horizontal direction.

A beam of argon admitted to the vacuum chamber, where the irradiation of the film was done after passing through the scanning system. Energy of the accelerated ions was measured before irradiation of the film with high accuracy using the method of recording backscattered ions (POP). It allowed to identify the acceleration ions by mass and to determine the energy of the incident ions. The intensity distribution of the beam on the film was controlled by measuring the current on the lamellae arranged in the film over its entire width. Ions passing through the film created an area of high density ionization. It was the track of the ion. Selective etching of the alkaline material in the region of track allowed to get a porous film in the original system with cylindrical holes with a typical symmetric structure. The film was irradiated with UV light for an additional sensitization before etching. The etching was carried out in an aqueous solution of NaOH 1,5 N concentration at temperatures in the range 72-82°C.

Characteristics of initial membranes and membranes modified in the plasma were determined by a number of complementary techniques [8,9]. The density and pore sizes were controlled with the electron microscope Hitachi TM - 1000 and composed a pore diameter (0,2-0,8) um density (5 x $10^6$ -2 x $10^9$) pores / cm$^2$.

Contact angle of the wettability was performed by sedentary drops with a horizontal microscope on the appropriate method. Contact angle of the wettability the surface track membrane was measured just after the chemical treatment in NaOH and after 10 hours in air.

The surface had been processed by the plasma self-sustained volume discharge to give the surface the hydrophilic properties of the membrane.

The maximum voltage on plasma discharge was 20-22 kV. The energy density in the discharge was $6 \times 10^{-4}$ J/cm$^2$ per pulse/ Pulse repetition rate was $10^3$ s$^{-1}$. Samples of 6 x 6 cm were attached in a special rotating device. Thus, the effects were both surfaces of the membrane. After surface treatment, track membrane (TM) samples were placed in plastic bags. After a night contact angle of wetting was measured with these samples.

Experimental studies on the use of PET TM as a corneal bio implant were conducted on the base clinic of Siberian State University, Department of Ophthalmology.

3. Results and Discussion

The main objective of our research was to create an optimal bio implant corresponding the physical, chemical and biological requirements. We have some difficulties in solving this problem, such as surface hydrophilicity, an optimal surgical method of barrier keratoplasty with the track membrane.
Table 1 The results of measurement of the angle $\Theta$ wettability TM without further processing. The measurements were performed at room temperature.

<table>
<thead>
<tr>
<th>Pore density in TM Por/sm²</th>
<th>$\Theta$ after etching in NaOH</th>
<th>$\Theta$ After 10 hours, (Atmosphere)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$1.2 \times 10^6$</td>
<td>77.2</td>
<td>78.2</td>
</tr>
<tr>
<td>$7.25 \times 10^8$</td>
<td>76.1</td>
<td>76.9</td>
</tr>
</tbody>
</table>

The results of wetting angle were obtained after surface processing with plasma self-discharge volume. Wetting contact angle decreased to about 40.0 on average.

Table 2 The results of measurement of the angle $\Theta$ wettability TM after the plasma treatment. The measurements were performed at room temperature.

<table>
<thead>
<tr>
<th>Pore density in TM Por/sm²</th>
<th>$\Theta$ Side a) before plasma treatment</th>
<th>$\Theta$ Side b) before plasma treatment</th>
<th>$\Theta$ Side a) after plasma treatment</th>
<th>$\Theta$ Side b) after plasma treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td>$1.2 \times 10^6$</td>
<td>78.2</td>
<td>77.6</td>
<td>42.8</td>
<td>41.6</td>
</tr>
<tr>
<td>$7.25 \times 10^8$</td>
<td>76.9</td>
<td>77.1</td>
<td>40.0</td>
<td>40.1</td>
</tr>
</tbody>
</table>

TM samples were placed in plastic bags after surface treatment. Measurements were made on the same $\Theta$ samples the next day. Wetting angle $\Theta$ did not change in comparison with previous results. We got a stable hydrophilic membrane surface.

Disks treating by the plasma were cut. The disk's diameter was 10-11 cm. The edges of the disks were incised and processed with hot temperature in order to obtain the model of an appropriate shape.

It was a shape of a truncated sphere with a certain radius of curvature.

Method of barrier keratoplasty was done in the two ways in the eyes of a pig. According to the first method, the cornea was readjusted inside by needle-spatula in paracentesis port. Then sterile air was given by the cannula. Insertion forceps was introduced through paracentesis port. Insertion forceps hitched membrane and implanted it in the layers of the cornea. In the layers of the corneal the membrane was readjusted by the needle-spatula.

With the second method, the membrane was implanted into the anterior chamber. The membrane was readjusted and needled with a continuous suture.

In conclusion it is necessary to say that we had the very first experiments on track membrane implantation in the anterior wall of the eye. When the membrane thickness 10 mkm, we encountered the same problem as unfolding membrane layers of the cornea. As a result of studies, the inventors have found that
the thickness of the membrane should be about 5-7 microns, and porosity of the membrane not exceeding $10^6$ por/sm$^2$. Membrane must also be resistant hydrophilicity surface. The sample should be a certain shape. Studies have shown the possibility and promise of this trend.

5. **Acknowledgement**

The authors would like to thank to the laboratory number 16 of National Research Tomsk Polytechnic University in connection with the experiments.

6. **REFERENCE**

Abstract. This study presents the survey results of the $^{226}$Ra activity concentrations in well and spring waters from 170 sampling sites in Serbia which are not under monitoring programme in Serbia. The purpose of use of the majority of the analyzed waters by small rural communities is not under surveillance. The mean activity concentrations of $^{226}$Ra were found to be 0.36 Bq L$^{-1}$ and 0.57 Bq L$^{-1}$ in well and spring waters, respectively. In more than 90% of the analyzed waters the $^{226}$Ra activity concentrations were below 1 Bq L$^{-1}$. The high $^{226}$Ra activity concentrations were associated mainly with granitic and metamorphic rocks with occurrences of uranium mineralisations. The activity concentrations of this radionuclide were found to be highest in crystalline rocks-and carbon dioxide rich-aquifers (up to 17 Bq L$^{-1}$). The study indicates the need of further investigation which should include other radionuclides in water, chemical composition of water, geochemical conditions of the environment, discharge rates, transport and other phenomena which could influence radium migration and accumulation in groundwater.

Key words: radium, groundwater, well, spring, geological structure.

1. Introduction

Water quality is an important parameter of environmental studies. The measurement of radioactivity in water allows the determination of population exposure to radiation by the habitual consumption of water.

High radiotoxicity of $^{226}$Ra in water requires particular attention for human health. Because of the long half life of $^{226}$Ra ($T_{1/2} = 1622$ y), it is accumulated by the human body for a long time. When radium is absorbed into the body, its metabolic behaviour is similar to that of calcium and appreciable fraction is deposited in the bone, the remaining fraction being distributed almost uniformly in the soft tissues. When people are exposed to very high levels of radium for a long time, it may result in cancer of the bone and the nasal cavity in human beings (1).

Groundwater is extracted from sediments, some of which are derived from uranium, thorium or potassium-40 (2). The isotope $^{226}$Ra is often found in natural environment as a component of minerals forming groundwater reservoir rocks in lithosphere (3).

There is very limited public information available about the levels of radioactivity in Serbian groundwater. This study presents the results of a survey of $^{226}$Ra activity concentrations in well and spring waters in Serbia and their relationship with geological formations.

2. Materials and methods

The water samples were collected from 117 wells and 53 springs in the three years in the territory of Serbia. All the samples were collected in 40 L volume polypropylene bottles and then acidified with concentrated nitric acid to pH 2 to break down the organic materials and to prevent loss of ions in the sample following binding to the container or precipitation.

The samples were pre-concentrated by evaporation to a volume of 1 L and afterwards sealed into Marinelli beakers for about 4 weeks to ensure that a state of secular equilibrium is reached between $^{226}$Ra and daughters ($^{214}$Bi and $^{214}$Pb).

The measurements were performed using a low-background HPGe gamma-ray spectrometer ORTEC- AMETEK (35% relative efficiency and 1.65 keV FWHM for $^{57}$Co at 1.33MeV, 8192 channels). Samples were measured for 280000 s. The gamma ray lines of 351.9 keV ($^{214}$Pb) and 609.3 keV ($^{214}$Bi) were used to
determine the activity concentration of $^{226}$Ra. Gamma Vision 32 software was used to process the spectra obtained\(^4\).

3. RESULTS AND DISCUSSION

Descriptive statistics for $^{226}$Ra activity concentrations in well and spring water is summarized in Table 1.

Table 1 Descriptive statistics of the $^{226}$Ra activity concentration in Serbia groundwater

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Wells</th>
<th>Springs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geometric mean $^{226}$Ra (Bq L$^{-1}$)</td>
<td>0.36</td>
<td>0.57</td>
</tr>
<tr>
<td>Geometric standard deviation</td>
<td>1.79</td>
<td>3.72</td>
</tr>
<tr>
<td>Minimum $^{226}$Ra (Bq L$^{-1}$)</td>
<td>0.12</td>
<td>0.18</td>
</tr>
<tr>
<td>Maximum $^{226}$Ra (Bq L$^{-1}$)</td>
<td>14.8</td>
<td>17.0</td>
</tr>
<tr>
<td>Range $^{226}$Ra (Bq L$^{-1}$)</td>
<td>14.7</td>
<td>16.8</td>
</tr>
</tbody>
</table>

The distribution of $^{226}$Ra activity concentrations in water samples from wells and springs analyzed in this study is presented in Fig. 1. About 96% of well water samples have $^{226}$Ra activity concentrations below 1 Bq L$^{-1}$, which is the guidance level for $^{226}$Ra in drinking water recommended by World Health Organization (5). In Serbia, according to the current regulations (6), the recommended limit for $^{226}$Ra in drinking water is below 0.49 Bq L$^{-1}$.

The frequency distributions of $^{226}$Ra activity concentrations in wells and springs waters in Serbia analyzed in this study are presented in Fig. 2. The mean $^{226}$Ra activity concentration in wells of 0.36 Bq L$^{-1}$ obtained in this study is similar to that of 0.26 Bq L$^{-1}$ reported for well waters in Sweden\(^6\) and 0.11 reported for Finland\(^7\). The $^{226}$Ra activity concentrations were found to be below 1 Bq L$^{-1}$ in more than 80% of analyzed spring water samples. The mean activity concentration of $^{226}$Ra in springs (0.57 Bq L$^{-1}$) was similar to those of 0.62 and 0.46 Bq L$^{-1}$, reported for spring waters in Hungary\(^8\).

The mean activity concentration of $^{226}$Ra in springs (0.57 Bq L$^{-1}$) was similar to those of 0.62 and 0.46 Bq L$^{-1}$, reported for spring waters in Hungary\(^8\).

A wide range of $^{226}$Ra activity concentration in groundwater has been reported (Table 2). The differences in activity concentrations are related to uranium content in underlying soils and bedrocks and also differences in chemical composition of water between countries. The activities were generally found to be higher in the granitic rock aquifers than those in the metamorphic or sedimentary rock aquifers\(^16\).

Table 2 Comparison of the activity concentrations of $^{226}$Ra in well and spring water in Serbia with reported European well and spring water

<table>
<thead>
<tr>
<th>Country</th>
<th>$^{226}$Ra (Bq L$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 1 Distribution of the $^{226}$Ra activity concentration in well and spring waters in Serbia

Figure 2 Frequency distribution of $^{226}$Ra activity concentrations in well (A) and spring (B) waters in Serbia
The results obtained in this study provide a baseline to identify regions with elevated radium activity concentrations in groundwater. It is essential to carry out more extensive research of the occurrence of radium in the groundwater of these regions. These investigations in conjunction with the identified exposure pathways are highly needed in order to assess radiation exposure of population.

**Conclusion**

The results of a survey of radium activity concentrations in well and spring waters from 170 sampling sites in Serbia and their relation to geological formations are presented. The $^{226}$Ra activity concentrations were found to be in range 0.12-14.8 Bq L$^{-1}$ in well waters and 0.18-17.0 Bq L$^{-1}$ in spring waters.

The highest $^{226}$Ra activity concentrations were associated mainly with granitic and metamorphic rocks with occurrences of uranium mineralisations. These are the preliminary results of the research. Further investigations which should include other radionuclides in water, chemical composition of water, geochemical conditions of the environment, discharge rates, transport and other phenomena which could influence radium migration and accumulation in groundwater is needed. Determination of natural and artificial radionuclides in drinking water has importance because it allows the assessment of population exposure to radiation by the consumption of the water.

**Acknowledgement:** This work was supported by the Ministry of Education, Science and Technological Development of the Republic of Serbia (Project No. III 43009).

**References**


<table>
<thead>
<tr>
<th>Wells</th>
<th>Activity Concentrations (Bq L$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sweden</td>
<td>0.12-4.9</td>
</tr>
<tr>
<td>Finland</td>
<td>0.01-49.0</td>
</tr>
<tr>
<td>Serbia (present study)</td>
<td>0.12-14.8 (mean 0.36)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Springs</th>
<th>Activity Concentrations (Bq L$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hungary</td>
<td>0.32-1.1</td>
</tr>
<tr>
<td>Austria</td>
<td>0.04-4.9</td>
</tr>
<tr>
<td>Croatia</td>
<td>0.09-6.2</td>
</tr>
<tr>
<td>France</td>
<td>0.6-2.3 (mean 1.1)</td>
</tr>
<tr>
<td>Romania</td>
<td>0.06-1.8</td>
</tr>
<tr>
<td>Serbia</td>
<td>0.09-2.28 (mean 0.29)</td>
</tr>
<tr>
<td>Slovenia</td>
<td>0.008-0.043 (mean 0.023)</td>
</tr>
<tr>
<td>Spain</td>
<td>0.004-3.7</td>
</tr>
<tr>
<td>Serbia (present study)</td>
<td>0.18-17.0 (mean 0.57)</td>
</tr>
</tbody>
</table>
A CONTRIBUTION OF THE COMPTON SCATTERED RADIATION FROM Mn-54 TO DOUBLE GAMMA COINCIDENCES SPECTRA AT THE 32-DETECTOR SYSTEM

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Abstract. The Compton scattering of the 835 keV gamma rays from ⁵⁴Mn decay has been considered, i.e., its contribution to double coincidences spectra at the 32-detector Crystal Ball spectrometer ARGUS – Institute of Physics, Academy of Sciences of Belarus. Disc shaped leaden collimators were mounted on each detector – to reduce the effect, and averaged over all detector-duplet combinations able to register the Compton scattered radiation in double coincidences spectra – the geometry defined by the angle 37.38° showed minimum counting rate, whilst the detector pairs at the ~180° – maximum one. The effect suppression ranged from 25 to 264 times (geometries – 116.57° and 41.81°, respectively).

Key words: 835 keV, Compton scattering, double coincidences

1. INTRODUCTION

Multidetector systems working in the coincidence modes of counting often need measures for the Compton scattering effect suppression. This is because the photon scattering from detector to detector gives the main contribution to background double coincidences. For example, in registering annihilation photons from the positronium ³⁷γ-decay, background is mostly related to the scattering of one (of two) γ-rays from two-photon decay (511 keV) and its registration by the other detector [1].

In order to reduce a contribution of the Compton scattering to the spectrum (i.e., its region) of interest, anticoincidence modes and ACS systems were often used [e.g. 2-4].

The Compton scattered radiation and its contribution to double gamma coincidences spectra at the 32-detector system ARGUS – located in the Laboratory for Nuclear Spectroscopy at the Institute of Physics in Minsk (National Academy of Sciences of Belarus), had been comprehensively investigated, including gamma rays with energies 166 keV, 392 keV, 835 keV and 1115 keV, which follow decays of ¹³⁹Ce, ¹¹³Sn, ⁵⁴Mn and ⁶⁵Zn, respectively. A dependence on gamma ray energy and measuring geometry was also considered, together with considering photo- and total registration efficiency (individual detectors and whole spectrometer) and suppression after introducing lead collimator on each detector.

2. 4π⁶γ-COINCIDENCE SPECTROMETER ARGUS

The ARGUS spectrometer (shown in Fig. 1) contains 12 steel penta- and 20 hexahedral pyramids, with 32 NaI(Tl) detectors (crystals: 15 cm x 10 cm). A detection chamber is relatively large (radius ~0.22 m) and measuring geometry is very close to 4π (0.9-4π sr [7]).

Its modular pulse-processing electronics is made to CAMAC standard.

A block diagram of the ARGUS spectrometer is shown in Fig. 2, where D₁-D₃₂ are NaI(Tl) detectors, F₁-F₃₂ – time discriminators by the leading edge, JV₁-JV₃₂ – delay univibrators, MSK – majority coincidence circuit, ADC – 32 8-bit analog-to-digital converters, H – 32-bit hodoscope, RO – splitter-univibrator, Cₐ – counter of events, GI – clock-pulse generator, Cₐ – live-time counter, KK – CAMAC crate controller, S₁ – strobe pulses for the ADC (650 ns), S₂ – strobe pulses for the hodoscope (50 ns), S₃ – signal following the
input strobe pulse from the MSK, $S_4$ – dead-time signal, $S_5$ – clock pulses.

Fig. 1 Spectrometer ARGUS

Signals from the preamplifiers are fed into ADC and the time discriminator (F) – for the time and amplitude analyses. The pulses from discriminators enter the majority coincidence circuit (MSK) operating by pulse overlapping and permitting selection of coincidence range from 1 to 5. The MSK gate signal initiates recording numbers of detectors registering the coincidence, and the amplitude analysis of the detectors signals (by the hodoscope H, and ADCs – 256 channels each, respectively). A detected coincidence is recorded in the form of detector numbers participating in the event, and photon energies.

The programs for processing various spectrometric data are KOLIB, ASKSUM, ARGUS, etc. [1].

Pairs of the ARGUS detectors registering double coincidences are presented in Table 1. A total number of such detector-duplet combinations, is 496.

To reduce Compton scattering, disc shaped leaden collimators were mounted on each detector (thickness – 30 mm, diameter – 150 mm) – shown in Fig 3. These collimators reduced background, particularly in spectra of coincidences.

Fig. 2 A block diagram of the spectrometer ARGUS

Fig. 3 Spectrometer ARGUS with collimators

The background counting rate (spectra acquired over 2000 s in the energy range from 200 to 1500 keV) in the mode of double coincidences in the system without collimators was 38.6 cps, while in the system with collimators – 19.4 cps (Fig. 4 – a and b, respectively).

Photoefficiencies ($\epsilon_{\text{photo}}$) and total registration efficiencies ($\epsilon_{\text{tot}}$) of the whole ARGUS spectrometer, before and after introducing the collimators, are given in Table 2 (index 1 is related to the spectrometer without the collimator system, and index 2 – to the spectrometer with mounted collimators).

Photoefficiencies for individual detectors are shown in Fig. 5, as total registration efficiencies – in Fig. 6.

These photoefficiencies ranged from 0.005897 to 0.012385 (sum 0.323149), with an average 0.010098 – without, and from 0.002193 to 0.003798 (sum

Table 1 ARGUS detector pairs registering double coincidences

<table>
<thead>
<tr>
<th>Angle [°]</th>
<th>Number of detector pairs ($n$)</th>
<th>Between (penta- and hexahedral)</th>
</tr>
</thead>
<tbody>
<tr>
<td>179.99</td>
<td>6</td>
<td>5 and 5</td>
</tr>
<tr>
<td>142.62</td>
<td>10</td>
<td>6 and 5</td>
</tr>
<tr>
<td>138.19</td>
<td>30</td>
<td>6 and 5</td>
</tr>
<tr>
<td>116.57</td>
<td>30</td>
<td>5 and 5</td>
</tr>
<tr>
<td>109.47</td>
<td>60</td>
<td>6 and 6</td>
</tr>
<tr>
<td>100.81</td>
<td>60</td>
<td>6 and 5</td>
</tr>
<tr>
<td>79.19</td>
<td>60</td>
<td>6 and 5</td>
</tr>
<tr>
<td>70.53</td>
<td>60</td>
<td>6 and 6</td>
</tr>
<tr>
<td>63.43</td>
<td>30</td>
<td>5 and 5</td>
</tr>
<tr>
<td>41.81</td>
<td>30</td>
<td>6 and 6</td>
</tr>
<tr>
<td>37.38</td>
<td>60</td>
<td>6 and 5</td>
</tr>
</tbody>
</table>
0.108376), with an average 0.003387 – with collimators.

At the same time, total registration efficiencies ranged from 0.013121 to 0.025325 (sum 0.653832), with an average 0.020432 – without, and from 0.003838 to 0.007239 (sum 0.1868), with an average 0.005838 – with collimators.

On the other hand, for the 662 keV photons (\(^{137}\)Cs), for example, photoefficiency of the whole spectrometer after introducing collimators was reduced around 3.2, whilst total registration efficiency – around 3.8 times. For individual detectors, \(\varepsilon_{\text{photo}}\) ranged from 0.007062 to 0.014471 (sum 0.383553, average: 0.011986), as \(\varepsilon_{\text{photo}}\) from 0.001959 to 0.0044 (sum: 0.123658, average: 0.003864) [8]. Moreover, \(\varepsilon_{\text{tot}}\) ranged from 0.013847 to 0.026053 (sum: 0.677527, average: 0.021173), and \(\varepsilon_{\text{tot}}\) from 0.002965 to 0.006833 (sum: 0.17914, average: 0.005598) [8].

### Table 2 Photo- and total registration efficiency of the spectrometer ARGUS – obtained from sum spectra

<table>
<thead>
<tr>
<th>Photon, keV</th>
<th>(\varepsilon_{\text{photo1}})</th>
<th>(\varepsilon_{\text{photo2}})</th>
<th>(\varepsilon_{\text{tot1}})</th>
<th>(\varepsilon_{\text{tot2}})</th>
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<td>835</td>
<td>0.32</td>
<td>0.11</td>
<td>0.65</td>
<td>0.19</td>
</tr>
</tbody>
</table>

3. Double coincidences caused by the Compton scattered 835 keV photons

Double coincidences at the ARGUS spectrometer initiated by the Compton scattered 835 keV photons, in dependence on detectors arrangement, are given in Table 3 (\(N\) – number of registered double coincidences, \(n\) – number of detector-duplet combinations at the pointed angle, \(b\) – corresponding background counting rate).

The scattered photons with sum energy corresponding to the energy of emitted photon, and background counting rate for given detectors geometry in energy region of interest, have been taken into consideration, i.e.,

\[E_1, E_2 = (50-1000) \text{ keV},\]
\[\Sigma \varepsilon_{\varepsilon(835\pm2\Delta E/E) \text{ keV}}\]

(from the spectra of \(^{54}\)Mn – 200.5 s and 600 s – before and after introducing the collimators, respectively).

Minimum, maximum, arithmetic mean and standard deviation of the counting rates were found to be 0.5413 (63.43°), 3.3007 (41.81°), 2.135, 0.886 cps, respectively (without collimators) and 0.0116 (37.38°), 0.0639 (179.99°), 0.003377, 0.0196 cps, respectively (with collimators).

The Compton scattering effect suppression in different measuring geometries showed the range from...
the lowest 25 to the highest 264 times (116.57° and 41.81°, respectively), i.e., for the geometries in order as given in Tables 1 and 2: 32, 33, 48, 25, 72, 49, 72, 162, 41, 264 and 239, respectively.

Table 3 The Compton scattered radiation at the ARGUS spectrometer in dependence on the detectors arrangement – double coincidences (ARGUS1 – without collimators, ARGUS 2 – with collimators)

<table>
<thead>
<tr>
<th>Angle [°]</th>
<th>N</th>
<th>( N/N )</th>
<th>( t/N )</th>
<th>( t/N/n )</th>
<th>( 1/N/n/t )</th>
</tr>
</thead>
<tbody>
<tr>
<td>179.99</td>
<td>6737</td>
<td>421.062</td>
<td>2.1000</td>
<td>2.0884</td>
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<td>142.62</td>
<td>22081</td>
<td>368.016</td>
<td>1.8354</td>
<td>1.8256</td>
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<tr>
<td>138.19</td>
<td>16650</td>
<td>555.000</td>
<td>2.7680</td>
<td>2.7564</td>
<td></td>
</tr>
<tr>
<td>116.57</td>
<td>6661</td>
<td>222.033</td>
<td>1.1073</td>
<td>1.1017</td>
<td></td>
</tr>
<tr>
<td>109.47</td>
<td>35242</td>
<td>587.366</td>
<td>2.9295</td>
<td>2.9167</td>
<td></td>
</tr>
<tr>
<td>100.81</td>
<td>20404</td>
<td>340.066</td>
<td>1.6960</td>
<td>1.6891</td>
<td></td>
</tr>
<tr>
<td>70.53</td>
<td>36294</td>
<td>604.900</td>
<td>3.0169</td>
<td>3.0057</td>
<td></td>
</tr>
<tr>
<td>63.43</td>
<td>3281</td>
<td>109.366</td>
<td>0.5454</td>
<td>0.5413</td>
<td></td>
</tr>
<tr>
<td>41.81</td>
<td>19948</td>
<td>664.933</td>
<td>3.3007</td>
<td></td>
<td></td>
</tr>
<tr>
<td>37.38</td>
<td>33664</td>
<td>561.066</td>
<td>2.7983</td>
<td>2.7823</td>
<td></td>
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</table>

An average suppression was found to be ~94 times, and three geometries showed significantly higher suppression (37.38°, 41.81° and 70.53°).

On the other hand, besides for the detector pairs at the 116.57°, for those at the 138.19° and 100.81°, a factor of suppression is found to be either on one third or on a half of an average.

4. CONCLUSIONS

After introducing the collimators in the ARGUS system, background counting rate was reduced by a factor of 2 in the mode of double coincidences, as well as registration efficiency of the spectrometer for the photon with energy of 835 keV \((^{54}\text{Mn})\) – 2.9 and 3.4 times (photo- and total registration efficiency, respectively).

Minimum counting rate of double coincidences caused by the Compton scattering of considered photons in the system without collimators was showed by the detector pairs at the angle of 63.43°, while maximum one – by pairs of detectors at the angle of 41.81°. Averaged over all such detector-duplet combinations, after introducing the collimators, the geometry defined by the angle 37.38° showed minimum counting rate. Maximum double coincidence counting rate was registered for the detectors pairs at the 179.99°, i.e., ~180°.

In regards to the Compton scattering effect suppression, in different measuring geometries, minimum one has been found for the double coincidences registered by the detectors at the angle 116.57°. On the other hand, maximum one was obtained for the geometry defined by the angle of 41.81°.

Acknowledgement: The paper is a part of the research done within the projects 01-683 (Ministry of Science of Montenegro) and F96-138 (Fundamental Research Foundation of the Belarusian Academy of Sciences).

REFERENCES

SPATIO-TEMPORAL VARIATIONS OF ANTHROPOGENIC RADIONUCLIDES IN THE SEAWATER OF EAST SEA/JAPAN SEA BEFORE FUKUSHIMA ACCIDENT

Seokwon. Choi , S.A. Yim, J.S. Chae
Korea Institute of Nuclear Safety

Abstract. The anthropogenic radionuclides, \(^{137}\)Cs, \(^{90}\)Sr, and \(^{239+240}\)Pu, were determined in the water column at 8 sites of the East Sea/Japan Sea and 1 site of the western North Pacific Ocean during the period 1994-2007 before Fukushima accident, investigated spatio-temporal variations of vertical structure.

The concentrations of \(^{137}\)Cs, and \(^{90}\)Sr in the upper 500m layer have decreased with time from 1994 to 2003. Those of \(^{137}\)Cs, and \(^{90}\)Sr in the bottom layer have a little increased since 1994. The layer-averaged concentrations (LAC) were calculated to investigate the differences in the vertical distribution of radionuclides between the East Sea/ Japan Sea and the western North Pacific Ocean. LAC of \(^{137}\)Cs, and \(^{90}\)Sr in the upper 500 m layer were almost the same level in the East Sea/ Japan Sea and the western North Pacific Ocean. Below the 750m, there are a large difference of value \(^{137}\)Cs, and \(^{90}\)Sr LAC between the East Sea/ Japan Sea and the western North Pacific Ocean. LAC of \(^{239+240}\)Pu at all layer in the East Sea/Japan Sea were higher than those in the western North Pacific Ocean. The anthropogenic radionuclides in surface water of the East Sea/ Japan Sea may be the result of vertical transport of water mass to deeper layers by the deep convection in wintertime.

Rate of LAC in the \(^{137}\)Cs, and \(^{90}\)Sr each layer were calculated to analyzed variation of vertical structure of those. The pattern in Rate of LAC in the \(^{137}\)Cs, and \(^{90}\)Sr are the same in the layers at the the East Sea/Japan Sea and the western North Pacific, but these of LAC in the \(^{137}\)Cs, and \(^{90}\)Sr differ from the layer at two areas.

The pairs with cross-correlation coefficients of \(^{137}\)Cs, \(^{90}\)Sr, and \(^{239+240}\)Pu concentrations in the East Sea/Japan Sea are greater than 0.87, 0.64, 0.52, between all pairs among 8 stations. The cross-correlation coefficients of \(^{137}\)Cs in upper 750 m are higher than 0.75, but the concentration variation of those in all anthropogenic radionuclides differ from that of bottom layer.

Key words: anthropogenic, radionuclides, East Sea, variations

1. INTRODUCTION

The East Sea/Japan Sea (hereafter, referred to as 'the East Sea') is a semi-enclosed basin separated by four straits with depths of less than 200m, which is connected to the Pacific Ocean through the Korea Strait in the south and the Tsugaru and Soya Straits in the northwestern. The exchange of seawater in the East Sea occurs mainly in the surface layer water. The East Sea Proper Water(ESPW) is below the surface layer, which is extremely homogeneous in salinity(34.04~34.10 PSU), in low temperature (0.2~0.5 °C) [1]. The upper part of the ESPW is formed in the chimney denoting the homogeneous water from the sea surface to about 400 m depth by surface cooling and subsequent vertical mixing in winter [2~3]. The ESPW sunken from the surface layer of chimney in winter spreads out under the Tsushima Warm Current area. The main source of the anthropogenic radionuclides in the East Sea is global fallout delivered from atmospheric nuclear test from 1961 to 1962 and the Chernobyl accident in 1986, and radioactive waste dumping by the Russian Federation. The anthropogenic radionuclides contained sea surface water spreads through transport processes of seawater. The long-lived anthropogenic radionuclides, such as \(^{137}\)Cs, \(^{90}\)Sr, \(^{239+240}\)Pu, are not only good indicators of the radioactivity pollution but also useful tracers in understanding the oceanographic features [4].

In this paper, through analysis of historic data of the anthropogenic radionuclides in the East Sea and NW Pacific Ocean from 1994 to 2007 years, we studied the spatio-temporal variations of vertical structure, the space scales of depth, and
vertically contained concentration for the anthropogenic radionuclides in the East Sea.

2. DATA AND METHODS OF ANALYSIS
The data set used in this work is the concentrations of anthropogenic radionuclide in the sea water for 14 years (1994~2007) at 8 stations around western side of Japan and eastern side of Korea, and 1 station (33.5°N, 140.3°E) at the NW Pacific Ocean (Fig. 1). The survey stations of anthropogenic radionuclide at the NW Pacific Ocean differ from each year, so that the coordinates of latitude and longitude at the NW Pacific Ocean are treated one station averaging the coordinates at the stations. The data set was published by Japan Coast Guard homepage (http://www1.kaiho.mlit.go.jp/KANKYO/OSEN/gaiyo/radioactivity.htm). At all stations, the seawater samples were collected at 0 m (surface), 200 m, 500 m, 750 m, 1000 m depths and 50 m above from the bottom. In addition, the deep seawater samples at the 2000 m in depth were collected at the station 3, 6, 7 and 8.

3. RESULTS AND DISCUSSION
3.1 Spatio-temporal variations
The temporal variations of the radionuclide (137Cs, 90Sr, 239+240Pu) concentrations in the East Sea are represented by the time series of averaged concentrations, that is, the average over 8 stations in each layer (Fig. 2). The mean concentrations of 137Cs in the surface water are between 1.76 and 3.65 Bq/m3. The concentration of 90Sr in the surface water ranged from 1.08 mBq/m3 in the 2007 year to 1.84 Bq/m3 in the 1994 year. The time series of concentrations within the upper 750 m have gradually decreased from 1994 to 2003, but those within the under 2000 m have a tendency to increase with time. 137Cs and 90Sr concentration in the Japanese coastal water decreased with time from 1994 to 2007 [4]. The annual march of the concentrations of 239+240Pu at all layers shows that 239+240Pu are nearly the same in the year-to-year fluctuations. The depth profiles of the radionuclide at 8 stations averaged over 14 years in the East Sea are shown Fig. 3. The depth profiles of 137Cs, 90Sr, and 239+240Pu were similar at all stations in the East Sea, respectively. 137Cs concentrations were ca. 2.2 Bq/m3 in upper seawater column (0~500 m), which were well mixed vertically. 137Cs concentration was drastically decreased between 500 m to 2000 m in depth, and its concentration in the seawater was quit constant below 0.2 Bq/m3 in the bottom layer. The concentration of 90Sr in the surface water ranged from 1.36 Bq/m3 in the station 8 to 1.54 Bq/m3 in the station 1. The depth distribution of 90Sr was similar to that seen
for $^{137}$Cs in the stations. The highest $^{90}$Sr concentration occurred in the surface or sub-surface layer and the lowest $^{90}$Sr concentration occurred in the bottom layer. Sharper $^{90}$Sr gradients extended down to depths of 2000 m below which concentrations were relatively uniform. The depth distribution of $^{239+240}$Pu was quite different from those of $^{137}$Cs and $^{90}$Sr. In the depth profile of $^{239+240}$Pu, lowest concentration of $^{239+240}$Pu occurred at the surface layer and a highest concentration occurred at the subsurface layer in 700 m or 1000 m, and then decrease by a small degree with depth. $^{239+240}$Pu concentrations ranged 0.003–0.009 Bq/m$^3$ at sea surface, 0.038–0.046 Bq/m$^3$ at the 750 m in depth and 0.0028–0.0031 Bq/m$^3$ at the bottom depth as shown in Fig. 3. The $^{137}$Cs, $^{90}$Sr, $^{239+240}$Pu concentrations measured in this study were similar to previous data [1], [4–6].

Fig. 1 Temporal variations of the radionuclide concentrations

Fig. 2. Depth profile of the radionuclide concentrations

Fig. 4 shows the e-folding depths associated with an exponential decrease of concentration of the observed radionuclides ($^{137}$Cs and $^{90}$Sr) at 7 depths. This figure shows that the e-folding depths in $^{137}$Cs concentration are between 980 and 1408 m, and those in $^{90}$Sr concentration are between 1111 and 1471 m.

Table 1 The similarity between distribution patterns of the concentration $^{137}$Cs, $^{90}$Sr for the 7 depths

<table>
<thead>
<tr>
<th></th>
<th>0m</th>
<th>200m</th>
<th>500m</th>
<th>750m</th>
<th>1000m</th>
<th>2000m</th>
<th>&lt;3000m</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{137}$Cs</td>
<td>1.00</td>
<td>0.92</td>
<td>0.90</td>
<td>0.89</td>
<td>0.76</td>
<td>0.18</td>
<td>0.00</td>
</tr>
<tr>
<td>$^{90}$Sr</td>
<td>1.00</td>
<td>0.68</td>
<td>0.61</td>
<td>0.47</td>
<td>0.27</td>
<td>0.08</td>
<td>-0.31</td>
</tr>
</tbody>
</table>

3.2 Vertical correlation

The e-folding depths in $^{137}$Cs and $^{90}$Sr concentrations deepened in 2007 year, and that deepened in 2007 years. We estimated the similarity between e-folding depth patterns in the $^{137}$Cs concentrations and $^{90}$Sr concentrations at the same time by employing the cross-correlation. The cross-correlation coefficient between the two time series is 0.90. It implies that the fluctuations in the depth profile of $^{137}$Cs concentrations up to 1000m are similar to that of $^{90}$Sr concentrations for each year.

Table 1 The similarity between distribution patterns of the concentration $^{137}$Cs, $^{90}$Sr for the 7 depths

<table>
<thead>
<tr>
<th></th>
<th>0m</th>
<th>200m</th>
<th>500m</th>
<th>750m</th>
<th>1000m</th>
<th>2000m</th>
<th>&lt;3000m</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{137}$Cs</td>
<td>1.00</td>
<td>0.89</td>
<td>0.86</td>
<td>0.75</td>
<td>0.65</td>
<td>0.47</td>
<td>0.18</td>
</tr>
<tr>
<td>$^{90}$Sr</td>
<td>1.00</td>
<td>0.92</td>
<td>0.91</td>
<td>0.65</td>
<td>0.44</td>
<td>0.04</td>
<td>-0.38</td>
</tr>
</tbody>
</table>

3.3 Layered-Averaged Concentrations

The contained concentration of anthropogenic radionuclides is useful parameters for assessing the accumulation of radionuclides in the sea. LAC was calculated to investigate the differences of the contained concentration in the vertical distribution of radionuclides between the East Sea and the NW Pacific Ocean. LAC of radionuclides in seawater samples at the East Sea and the NW Pacific Ocean is shown in Fig. 5. The

Fig. 4 The e-folding depth of $^{137}$Cs, $^{90}$Sr concentrations
highest LAC of $^{137}$Cs and $^{90}$Sr occurred in the surface layer, and the lowest that occurred in the bottom layer at the East and the NW Pacific Ocean. The LAC of $^{137}$Cs and $^{90}$Sr at the East Sea are higher than those at the NW Pacific Ocean under between 750 m to 1000 m in depth. The LAC of $^{137}$Cs in the East Sea was significantly higher than those in the NW Pacific Ocean between 1000 m to bottom. $^{137}$Cs and $^{90}$Sr at the East Sea will be transported to deeper layer by deep convection in winter time [6]. The LAC of $^{239+240}$Pu in all layer at the East Sea is higher than those at the NW Pacific Ocean (Fig. 5). The deep convection and surface mixing in winter play an important role to control the distribution and behavior of radionuclides in East Sea [1], [7].

The e-folding depths in $^{137}$Cs and $^{90}$Sr in the East Sea are between 1000 m and 1470 m from 1994 to 2007 years. The fluctuations in the depth profile of $^{137}$Cs concentrations up to 1000 m are similar to those of $^{90}$Sr concentrations for each year. The similarity between $^{137}$Cs and $^{90}$Sr for each pair among 5 depths except for 2000 m and bottom is highly correlated.

LAC of $^{137}$Cs and $^{90}$Sr up to the forth layer (750 m~1000 m in depth) were almost the same in the East Sea and the NW Pacific Ocean. LAC of $^{239+240}$Pu in the East Sea at all layers was higher than those in the NW Pacific Ocean. The rate of LAC of $^{137}$Cs and $^{90}$Sr are almost the same each layers in the East Sea and the NW Pacific Ocean, respectively (Fig. 6). But the value of these differs from the layer at two areas. The rate of LAC of $^{137}$Cs and $^{90}$Sr upper 3 layers at the East Sea was ca. 4% lower than that at the NW Pacific Ocean. But the rate of LAC of $^{137}$Cs and $^{90}$Sr lower 3 layer at the East Sea was ca. 4% lower than that at the NW Pacific Ocean.

### 4. Conclusion

We studied the spatio-temporal variations of vertical structure, the space scales of depth, and vertically contained concentration for the anthropogenic radionuclides in the East Sea by means of analysis the data of the anthropogenic radionuclides in the East Sea and NW Pacific Ocean from 1994 to 2007 years. The concentrations of $^{137}$Cs in the East Sea were higher concentrate in surface and decreased as it deepens, and quite constant below 0.5 Bq/m$^3$ in the bottom water. The depth profile of $^{90}$Sr concentration in the East Sea was similar to that seen for $^{137}$Cs. The concentration of $^{239+240}$Pu in the surface water was very low and gradually increased inward to a mid-depth at most ca. 750 m, and then decreased by a small degree with depth.

The depth profile of $^{90}$Sr concentration in the East Sea was similar to that seen for $^{137}$Cs. The concentration of $^{239+240}$Pu in the surface water was very low and gradually increased inward to a mid-depth at most ca. 750 m, and then decreased by a small degree with depth.

### References

Abstract. A radioecological research on the South Adriatic Sea (Coast of Montenegro) marine environment has been performed recently, and included the three Liza species occurring there (Liza aurata Risso, 1810, Liza ramada Risso, 1826, and Liza saliens Risso, 1810). In the present study - two whole individuals, seven muscles, two gastrointestinal systems of each species (collected at the locality Solila, Tivat, Boka Kotorska Bay), are considered for 212Pb and 214Pb activity – ranged from $<0.86$ (L. saliens muscle) to $21.8$ Bq/kg (L. aurata muscle) – 212Pb, as well as from $<0.69$ (L. saliens whole individual) to $29.7$ Bq/kg (L. aurata muscle) – 214Pb. The concentration factors – from seawater and bottom to whole individuals, muscles and gastrointestinal systems of the Liza species, are also reported.

Key words: Liza, South Adriatic, Pb-212,214, concentration factors

1. INTRODUCTION

The report about mullets (fam. Mugilidae) in the Mediterranean and North Eastern Atlantic was given by Trewavas and Ingham [1], and one about the Mediterranean mullets – by Tortonese [2].

The mullet species occurring in the South Adriatic Sea – Coast of Montenegro (Mugil cephalus Linnaeus, 1758, Chelon labrosus Risso, 1826, Oedalechilus labrosus Cuvier, 1829, Liza aurata Risso, 1810, Liza ramada Risso, 1826 and Liza saliens Risso, 1810) were previously investigated through – phenetic relationships on visceral and dermal skeleton [3], phylogenetic relationships inferred from continuous osteological characters [4], but some of them also radioecologically – for example, $^{239}$Th in M. cephalus [5], concentration factors for $^{226}$Ra in M. cephalus [6], $^{137}$Cs and $^{226}$Ra in C. labrosus [7]. In a few samples of L. aurata (whole individuals and muscles) $^{226}$Ra activity concentration was measured previously, using multidetector system with geometry of radiation registration close to $4\pi$ [8], as well as natural $^{40}$K and man-made $^{137}$Cs [9]. An exposure analysis for 4 L. ramada individuals has been also performed [10].

To complete ecological picture of the South Adriatic Sea (Coast of Montenegro) environment, in the Center for Ecotoxicological Research in Podgorica comprehensive research has been carried out recently, resulting with data related to the mullet species, as well. Namely, among six Euro-Mediterranean mullet species occurring in the South Adriatic, three are from the genera Liza (L. aurata, L. ramada, and L. saliens), and they were considered for elements (including heavy metals) content and radioactive isotopes activity. This is because metals (released into ecosystems by various processes), as important pollutants, can be toxic to aquatic species, and because radioactivity (radiation) can cause different effects on non-human biota (in dependence on dose rates). A consideration of both of them is important in environmental risk assessment.

Therefore, together with considering elements (As, Zn, Ni, Pb, Cd, Cu, etc.) content in the three Liza species – sampled in the Boka Kotorska Bay (Tivat, Solila), Montenegro, eleven individuals of each – were considered for radioactivity due to natural radionuclides (from $^{238}$U/$^{226}$Ra and $^{232}$Th series – $^{214}$Bi, $^{214}$Pb, and $^{228}$Ac, $^{210}$Pb, respectively; $^{40}$K and cosmogenic $^{137}$Be), as well as man-made $^{137}$Cs. Obtained data can be used to evaluate bioaccumulation of the radioisotopes in the Liza species, as well as the total dose rate (internal and external exposure).

Although the other radionuclides have been also measured, this paper presents activity concentrations of $^{212}$Pb (from the $^{232}$Th series) and $^{214}$Pb (from the $^{226}$Ra series) in two whole individuals, seven muscles, two gastrointestinal systems (of L. aurata, L. ramada, and L. saliens), together with radionuclide concentration factors from seawater and bottom sample.

Both isotopes are gamma emitters, and their activity could be determined using standard gamma spectrometry procedures.
2. MATERIAL AND METHODS

Eleven specimens of each of the *Liza* species were collected in 2013 – by a trawl net (the locality Solila, Tivat, Boka Kotorska Bay, Montenegro). The *L. aurata*, *L. ramada* and *L. saliens* individuals were determined by the taxonomic characters [11].

Their total lengths were from 23.1 to 36 cm (*L. aurata*), 28.6 to 37.4 cm (*L. ramada*), and 26.8 to 33.9 cm (*L. saliens*); whilst fresh masses: 120-227 g (*L. aurata*), 136.6-338 g (*L. ramada*), and 140-247 g (*L. saliens*).

All the samples (whole individuals, muscles, gastrointestinal systems) were freshly ground, weighed and placed in the 50 mL, 200 mL cylindrical beakers or 0.5 L Marinelli beaker, and distilled water was added to a few samples.

Seawater (20 L) and bottom sample (sand, with some mud and mussels) were also sampled at the same locality (Solila, Tivat), and water was evaporated (to 1 L) and placed in 1 L Marinelli beaker, while bottom sample was dried, weighed (in mass of 672 g) and placed in 0.5 L Marinelli beaker.

The HPGe spectrometers ORTEC GEM-40190 and GEM-30185-S, with efficiency of 40 and 30 %, respectively, calibrated using the Czech Metrological Institute standards with mixtures of gamma emitting isotopes (50 mL, 200 mL, 0.5 L and 1 L), are used to perform the 212Pb and 214Pb activity measurements in fish, seawater and bottom sample. Live measuring times were different, for example – from 85 170 to 143 948 s (whole individuals), from 58 334 to 169 471 s (muscles), and from 66 666 to 158 127 s (gastrointestinal systems).

As abovementioned, 212Pb originates from the 232Th series, decays via β--decay to 212Bi (half-life 10.64 h), followed by emission of many gamma rays, but the most intense is 238.6 keV (43.3 %) [12], and it is used in the present study. The most intense 351.9 keV (37.6 %) gamma ray following β--decay of 214Pb to 214Bi [12], is used to detect this radionuclide from the 226Ra series. The peak (created by the mentioned gamma rays) analyses were carried out by the Gamma Vision 32 software.

Activity concentrations of 212Pb and 214Pb in fish, seawater and bottom sample are used to estimate concentration factors:

seawater to fish,

\[ CF_1 = \frac{Bq/kg}{Bq/L} \]

(1)

bottom to fish,

\[ CF_2 = \frac{Bq/kg}{Bq/kg - dried bottom sample} \]

(2)

3. RESULTS AND DISCUSSION

The 212Pb and 214Pb activity concentrations in the *Liza* species, seawater and bottom sample are given in Table 1. In a number of samples, activities were below minimum detectable activity (MDA), calculated using the 3MDA method [13] (in some of them, it was on the MDA level). Therefore, taking into account sample mass, minimum detectable activity concentration was estimated and presented in Table 1.

### Table 1 Activity concentrations of 212Pb and 214Pb

<table>
<thead>
<tr>
<th>Sample</th>
<th>Pb-212, Bq/kg</th>
<th>Pb-214, Bq/kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seawater (in Bq/L)</td>
<td>0.036±0.003</td>
<td>0.015±0.001</td>
</tr>
<tr>
<td>Bottom</td>
<td>3.74±0.17</td>
<td>1.14±0.14</td>
</tr>
<tr>
<td><strong>L. aurata</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Whole individual</td>
<td>1.51±0.26</td>
<td>&lt;0.8</td>
</tr>
<tr>
<td>Whole individual</td>
<td>1.25±0.3</td>
<td>&lt;1</td>
</tr>
<tr>
<td>Muscle</td>
<td>&lt;1.1</td>
<td>29.7±1.2</td>
</tr>
<tr>
<td>Muscle</td>
<td>21.8±1.2</td>
<td>9.2±0.8</td>
</tr>
<tr>
<td>Muscle</td>
<td>19.6±1.1</td>
<td>18.1±1.1</td>
</tr>
<tr>
<td>Muscle</td>
<td>2.78±0.37</td>
<td>&lt;1.2</td>
</tr>
<tr>
<td>Muscle</td>
<td>1.9±0.5</td>
<td>&lt;2.2</td>
</tr>
<tr>
<td>Muscle</td>
<td>2.23±0.5</td>
<td>4.46±0.33</td>
</tr>
<tr>
<td>Muscle</td>
<td>&lt;1.4</td>
<td>&lt;1.9</td>
</tr>
<tr>
<td>Gastrointes. system</td>
<td>4.6±0.7</td>
<td>2.48±0.46</td>
</tr>
<tr>
<td>Gastrointes. system</td>
<td>7.15±0.84</td>
<td>19.4±1.2</td>
</tr>
<tr>
<td><strong>L. ramada</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Whole individual</td>
<td>1.39±0.32</td>
<td>6.55±0.38</td>
</tr>
<tr>
<td>Whole individual</td>
<td>6.15±0.47</td>
<td>11.1±0.6</td>
</tr>
<tr>
<td>Muscle</td>
<td>2.53±0.41</td>
<td>6.32±0.47</td>
</tr>
<tr>
<td>Muscle</td>
<td>1.55±0.33</td>
<td>6.15±0.4</td>
</tr>
<tr>
<td>Muscle</td>
<td>1.75±0.56</td>
<td>17.7±0.9</td>
</tr>
<tr>
<td>Muscle</td>
<td>1.48±0.32</td>
<td>6.46±0.42</td>
</tr>
<tr>
<td>Muscle</td>
<td>1.7±0.6</td>
<td>1.5±0.2</td>
</tr>
<tr>
<td>Muscle</td>
<td>2.64±0.5</td>
<td>15.8±0.9</td>
</tr>
<tr>
<td>Muscle</td>
<td>1.6±0.4</td>
<td>11.7±0.6</td>
</tr>
<tr>
<td>Gastrointes. system</td>
<td>9.5±0.53</td>
<td>13.6±0.7</td>
</tr>
<tr>
<td>Gastrointes. system</td>
<td>8.34±0.7</td>
<td>20.7±1.1</td>
</tr>
<tr>
<td><strong>L. saliens</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Whole individual</td>
<td>3.92±0.46</td>
<td>4.36±0.27</td>
</tr>
<tr>
<td>Whole individual</td>
<td>1.64±0.21</td>
<td>&lt;0.7</td>
</tr>
<tr>
<td>Muscle</td>
<td>11.1±0.6</td>
<td>&lt;1.4</td>
</tr>
<tr>
<td>Muscle</td>
<td>&lt;1.1</td>
<td>1.55±0.14</td>
</tr>
<tr>
<td>Muscle</td>
<td>9.7±0.62</td>
<td>1.53±0.17</td>
</tr>
<tr>
<td>Muscle</td>
<td>1.27±0.25</td>
<td>2.29±0.16</td>
</tr>
<tr>
<td>Muscle</td>
<td>4.11±0.41</td>
<td>&lt;1.2</td>
</tr>
<tr>
<td>Muscle</td>
<td>&lt;0.9</td>
<td>&lt;1.2</td>
</tr>
<tr>
<td>Muscle</td>
<td>&lt;1.2</td>
<td>8.47±0.56</td>
</tr>
<tr>
<td>Gastrointes. system</td>
<td>9.64±0.6</td>
<td>10.3±0.6</td>
</tr>
<tr>
<td>Gastrointes. system</td>
<td>10.1±0.6</td>
<td>17.0±0.8</td>
</tr>
</tbody>
</table>
In regard to whole individuals, $^{212}\text{Pb}$ ($^{232}\text{Th}$ progeny), detected in all whole fish, has similar activities in the $L. \text{aurata}$ individuals, whilst in the case of $L. \text{saliens}$ and $L. \text{ramada}$ it varied up to 6.15 Bq/kg.

In $M. \text{cephalus}$, level of thorium was found to be from 0.63 to 1.67 Bq/kg [5], while in fish from lakes near the city of Elliot Lake, Ontario – Canada, $^{232}\text{Th}$ activity in all body tissues was found to be below 20 Bq/kg [14]. At the same time, $^{214}\text{Pb}$ ($^{226}\text{Ra}$ progeny) level was found to be low in $L. \text{aurata}$, while in the case of $L. \text{ramada}$, it goes to 11 Bq/kg.

Previous consideration of $^{226}\text{Ra}$ activity in $L. \text{aurata}$ showed the range from 0.58 to 1.97 Bq/kg [8], which is comparable with here presented ($^{214}\text{Pb}$). In $M. \text{cephalus}$ it was from 0.89 to 3.09 Bq/kg [6], as in $C. \text{labrosus}$ – from 0.4 to 2 Bq/kg [7]. On the other hand, activities in the $Liza$ species are generally found to be slightly higher than those reported, for example, for whole benthic fish [15], or sprat from the Baltic Sea [16].

In regard to muscles, $^{212}\text{Pb}$ activity was below MDA in one $L. \text{aurata}$ muscle, only. It ranged up to 21.8 Bq/kg in $L. \text{aurata}$, 11.1 Bq/kg in $L. \text{saliens}$, and generally found to be lower in $L. \text{ramada}$ (maximum 2.6 Bq/kg). In previously analyzed (four) $M. \text{cephalus}$ muscles an average $^{232}\text{Th}$ activity was found to be 1.25 Bq/kg, and ranged to 1.57 Bq/kg [5].

$\text{Pb-214}$ was found to be 29.7 Bq/kg in one $L. \text{aurata}$ muscle, which is the highest detected $^{214}\text{Pb}$ activity. In $L. \text{ramada}$ and $L. \text{saliens}$ muscles, it ranges from 1.5 to 17.7; and from <1.21 to 8.47 Bq/kg, respectively. Comparing these results, for example, with $^{226}\text{Ra}$ activity detected in muscle of herring from Quirke Lake in Canada – 1.4 Bq/kg [17], and four $C. \text{labrosus}$ [7] and $M. \text{cephalus}$ muscles [6], ranged from 0.88 to 1.95, and from 1.7 to 3.08 Bq/kg respectively, the $Liza$ species seem to show higher radium activities, although there are detected activities on the levels of those in the other two mullet species. This means that a variation of radium activity concentrations in the mullets could be relatively high.

The $Liza$ gastrointestinal systems showed the $^{212}\text{Pb}$ activity concentrations up to 10.1 Bq/kg; in $L. \text{aurata}$ somewhat lower than in $L. \text{ramada}$ and $L. \text{saliens}$. As can be seen from Table 1, $^{214}\text{Pb}$ activity concentrations ranged from 2.5 to 21 Bq/kg, which is higher than, for example, radium activity in gastrointestinal systems of $C. \text{labrosus}$ [7] and $M. \text{cephalus}$ [6].

The concentration factors ($CF_1$ and $CF_2$) are calculated using data from Table 1 and Eq. (1) and (2), respectively.

The $CF_1$ for two whole individuals of $L. \text{aurata}$ are found to be 42 and 35, respectively – for $^{212}\text{Pb}$, <51 and <65, respectively – for $^{214}\text{Pb}$; $L. \text{ramada}$ – 39 and 171, respectively – for $^{212}\text{Pb}$, 437 and 740, respectively – for $^{214}\text{Pb}$; $L. \text{saliens}$ – 109 and 45, respectively – for $^{212}\text{Pb}$, 291 and <46, respectively – for $^{214}\text{Pb}$. The $CF_2$ for two whole individuals of $L. \text{aurata}$ – 0.4 and 0.33, respectively – for $^{212}\text{Pb}$, <0.67 and <0.86, respectively – for $^{214}\text{Pb}$; $L. \text{ramada}$ – 0.37 and 1.64, respectively – for $^{212}\text{Pb}$, 5.74 and 9.74, respectively – for $^{214}\text{Pb}$; $L. \text{saliens}$ – 1.05 and 0.44, respectively – for $^{212}\text{Pb}$, 3.82 and <0.6, respectively – for $^{214}\text{Pb}$.

The concentration factors for two gastrointestinal systems of $L. \text{aurata}$ are found to be $CF_1$ – 128 and 199, respectively – for $^{212}\text{Pb}$, 165 and 1293, respectively – for $^{214}\text{Pb}$; $CF_2$ – 1.23 and 1.91, respectively – for $^{212}\text{Pb}$, 2.17 and 17.02, respectively – for $^{214}\text{Pb}$;

$L. \text{ramada}$:

$CF_1$ – 264 and 232, respectively – for $^{212}\text{Pb}$, 907 and 1380, respectively – for $^{214}\text{Pb}$;

$CF_2$ – 2.54 and 2.23, respectively – for $^{212}\text{Pb}$, 11.9 and 18.1, respectively – for $^{214}\text{Pb}$;

$L. \text{saliens}$:

$CF_1$ – 267 and 280, respectively – for $^{212}\text{Pb}$, 687 and 1133, respectively – for $^{214}\text{Pb}$;

$CF_2$ – 2.58 and 2.7, respectively – for $^{212}\text{Pb}$, 9.03 and 14.9, respectively – for $^{214}\text{Pb}$.

The concentration factors for the muscles of $L. \text{aurata}$, $L. \text{ramada}$ and $L. \text{saliens}$ are shown in Tables 2 and 3 ($CF_1$ and $CF_2$, respectively).

<table>
<thead>
<tr>
<th>Sample</th>
<th>$CF_1$ ($^{212}\text{Pb}$)</th>
<th>$CF_1$ ($^{214}\text{Pb}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$L. \text{aurata}$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Muscle</td>
<td>&lt;30.5</td>
<td>1980</td>
</tr>
<tr>
<td>Muscle</td>
<td>605</td>
<td>613</td>
</tr>
<tr>
<td>Muscle</td>
<td>378</td>
<td>1209</td>
</tr>
<tr>
<td>Muscle</td>
<td>77.2</td>
<td>&lt;82</td>
</tr>
<tr>
<td>Muscle</td>
<td>52.8</td>
<td>&lt;144</td>
</tr>
<tr>
<td>Muscle</td>
<td>61.9</td>
<td>297</td>
</tr>
<tr>
<td>Muscle</td>
<td>&lt;39.2</td>
<td>&lt;127</td>
</tr>
<tr>
<td>$L. \text{ramada}$</td>
<td></td>
<td></td>
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<tr>
<td>Muscle</td>
<td>70.3</td>
<td>421</td>
</tr>
<tr>
<td>Muscle</td>
<td>43</td>
<td>410</td>
</tr>
<tr>
<td>Muscle</td>
<td>48.6</td>
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</tr>
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<td>Muscle</td>
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</tr>
<tr>
<td>Muscle</td>
<td>73.3</td>
<td>1053</td>
</tr>
<tr>
<td>Muscle</td>
<td>44.4</td>
<td>780</td>
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<tr>
<td>$L. \text{saliens}$</td>
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<td></td>
</tr>
<tr>
<td>Muscle</td>
<td>308</td>
<td>&lt;96</td>
</tr>
<tr>
<td>Muscle</td>
<td>&lt;31.4</td>
<td>103</td>
</tr>
<tr>
<td>Muscle</td>
<td>269</td>
<td>102</td>
</tr>
<tr>
<td>Muscle</td>
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<td>Muscle</td>
<td>114</td>
<td>&lt;79.3</td>
</tr>
<tr>
<td>Muscle</td>
<td>&lt;23.9</td>
<td>&lt;80.7</td>
</tr>
<tr>
<td>Muscle</td>
<td>&lt;34.2</td>
<td>565</td>
</tr>
</tbody>
</table>

In $L. \text{aurata}$, they showed the range from <30.5 to 605 ($CF_1$ – $^{212}\text{Pb}$), from <82 to 1980 ($CF_1$ – $^{214}\text{Pb}$), from <0.29 to 5.83 ($CF_2$ – $^{212}\text{Pb}$), from <1.08 to 26 ($CF_2$ – $^{214}\text{Pb}$);

$L. \text{ramada}$:

from 41.1 to 73.3 ($CF_1$ – $^{212}\text{Pb}$), from 100 to 1180 ($CF_1$ – $^{214}\text{Pb}$), from 0.39 to 0.7 ($CF_2$ – $^{212}\text{Pb}$), from 1.31 to 15.5 ($CF_2$ – $^{214}\text{Pb}$);

$L. \text{saliens}$:
from <23.9 to 308 \((CF_1 - 212\text{Pb})\), from <79.3 to 565, \((CF_2 - 214\text{Pb})\), from <0.23 to 2.97 \((CF_2 - 212\text{Pb})\), from <1.04 to 7.43 \((CF_2 - 214\text{Pb})\).

### Table 3 The muscle concentration factor \(CF_2\)

<table>
<thead>
<tr>
<th>Sample</th>
<th>(CF_2\ (212\text{Pb}))</th>
<th>(CF_2\ (214\text{Pb}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>L. aurata</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Muscle</td>
<td>&lt;0.29</td>
<td>26</td>
</tr>
<tr>
<td>Muscle</td>
<td>&lt;0.74</td>
<td>8.07</td>
</tr>
<tr>
<td>Muscle</td>
<td>3.64</td>
<td>15.9</td>
</tr>
<tr>
<td>Muscle</td>
<td>0.51</td>
<td>&lt;1.08</td>
</tr>
<tr>
<td>Muscle</td>
<td>0.51</td>
<td>&lt;1.89</td>
</tr>
<tr>
<td>Muscle</td>
<td>0.6</td>
<td>3.91</td>
</tr>
<tr>
<td>Muscle</td>
<td>&lt;0.38</td>
<td>&lt;1.06</td>
</tr>
<tr>
<td>L. ramada</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Muscle</td>
<td>0.68</td>
<td>5.54</td>
</tr>
<tr>
<td>Muscle</td>
<td>0.41</td>
<td>5.39</td>
</tr>
<tr>
<td>Muscle</td>
<td>0.48</td>
<td>15.5</td>
</tr>
<tr>
<td>Muscle</td>
<td>0.39</td>
<td>5.67</td>
</tr>
<tr>
<td>Muscle</td>
<td>0.45</td>
<td>1.31</td>
</tr>
<tr>
<td>Muscle</td>
<td>0.7</td>
<td>13.8</td>
</tr>
<tr>
<td>Muscle</td>
<td>0.43</td>
<td>10.3</td>
</tr>
<tr>
<td>L. saliens</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Muscle</td>
<td>2.97</td>
<td>&lt;1.26</td>
</tr>
<tr>
<td>Muscle</td>
<td>&lt;0.3</td>
<td>1.36</td>
</tr>
<tr>
<td>Muscle</td>
<td>2.59</td>
<td>1.34</td>
</tr>
<tr>
<td>Muscle</td>
<td>0.34</td>
<td>2.01</td>
</tr>
<tr>
<td>Muscle</td>
<td>1.1</td>
<td>&lt;1.04</td>
</tr>
<tr>
<td>Muscle</td>
<td>&lt;0.23</td>
<td>&lt;1.06</td>
</tr>
<tr>
<td>Muscle</td>
<td>&lt;0.33</td>
<td>7.43</td>
</tr>
</tbody>
</table>

### 4. Conclusions

The \(212\text{Pb}\) and \(214\text{Pb}\) concentration factors \(CF_1\) (from seawater to the \(Liza\) species) are found to be significantly higher than the \(CF_2\) (from bottom to the \(Liza\) species). In regard to fish muscles, concentration factors have been found to be the highest for \(L. aurata\), which also showed the ranges of both \(CF_1\) and \(CF_2\) – wider than ones of \(L. ramada\) and \(L. saliens\). These findings, as well as relatively high activity concentrations of \(212\text{Pb}\) and \(214\text{Pb}\) found in the \(Liza\) species, clearly indicate that a further research is needed. It should also include an analysis of the total dose rate (internal and external exposure due to natural and anthropogenic radionuclides) – to evaluate whether effects could be expected, on individual, population or ecosystem level.

**Acknowledgement:** The research was supported by the Ministry of Science of Montenegro (01-683/2013).

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7. I. Antovic, N. M. Antovic, "Determination of concentration factors for \(Cs-137\) and \(Ra-226\) in the mullet species \(Chelon labrosus\) (Mugilidae) from the South Adriatic Sea", J. Environ. Radioact., 102, pp. 713-717, 2011.
ULTRA HIGH PRECISION MEASUREMENT OF THE HALF-LIFE OF 20Ne


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The aim of the experiment was to measure the half-life of 20Ne with high precision of 0.01% and to estimate the influence of the environment on the beta decay. The experiment was conducted in the Grand Accelerateur National d’Ions Lourds – GANIL, Caen, France. The radioactive beam of 20Ne was implanted in two targets made of two different materials: lead as a metallic environment and Cd as a dielectric environment. The targets have been installed on the same moving arm, allowing us to change the target swiftly after every implantation – measurement cycle. Through repeating procedure of implantation and measuring cycles, the influence of systematic uncertainties on the comparative measurement of the half-life of 20Ne in two different environments was significantly reduced. Special attention has been paid to reduce the influence of systematic uncertainties on the absolute measurement of the 20Ne half-life (dead-time, gain shift, threshold change, beam intensity, triggering rate). Herein the preliminary results will be presented.

Key words: beta decay, half-life measurement, electron screening, 20Ne

1. INTRODUCTION

Electron cloud that surrounds a nucleus acts as a screening potential. The screening potential can reduce or increase the penetrability of charged projectile (depending on its charge polarity) in the interaction channel when he goes through Coulomb barrier of the nucleus. When some radioactive nucleus is implanted in some kind of target (metal or isolator) quasi-free electrons of a target material could induce a screening effect on a embedded radioactive nuclei, influencing on their decay probability. Electrons in metals are degenerated and they must be treated as fermions, so screening effect can be described with Thomas-Fermi screening model. Very recent precise half-life measurements have a precision comparable to, or smaller than, the theoretically expected influence of the Thomas-Fermi screening energy. The most precise measurement of a half-life ever made resulted in a relative precision of 0.012% [1]. In this case for example, the screening energy of Al implanted in Pb would be 470 eV, which leads to a 0.065% change of the half-life of 26Al (compared to the value measured in vacuum). The "simple" Thomas-Fermi model predicts a non-negligible correction. In the case of 20Ne, the most precise measurements are of 0.03-0.04% and the expected influence of the Thomas-Fermi screening (in metallic host) on the 20Ne half-life would be 0.07%. High precision measurements are conducted in order to investigate and determine the half-lives of superallowed Fermi β decay transitions between two 0+ spin states with
isospin \( T=1 \). An estimation of the corresponding \( J^P \) values can be used to obtain a value of \( V_{ud} \) the up-down element of the Cabibbo-Kobayashi-Maskawa quark-mixing matrix and provides an important probe of the standard model [2]. Aside from the pure Fermi \( \beta \) decay, the measure lifetime and electron asymmetry in neutron decay can be used to evaluate the contribution of right-handed currents to the weak interaction and to obtain a value of \( V_{ud} \). A very convenient alternative to neutron decay is the decay of \( ^{20}\text{Ne} \).

2. Equipment and procedures

Experiment e658s was performed in GANIL (Grand Accélérateur National d’Îons Lourds), Caen, France. The \( ^{20}\text{Ne} \) radioactive beam was produced with SPIRAL1 facility with beam intensity higher than \( 10^6 \) pps (possibly up to \( 10^7 \) pps), which is the most intensity radioactive beam on SPIRAL1 facility. In order to provide a 100\% pure beam the stripper foil is introduced after CIME cyclotron and pure beam with 10+ charge state was separated in the beam line. The \( ^{20}\text{Ne} \) beam of 10+ charge state cannot have contaminants with silicon number lower than 10, such as \( ^{18}\text{F} \) and \( ^{16}\text{O} \). The purity was confirmed by detection with silicon detector with and without degrader introduced into the beam line. Two types of targets were used in experiment:
- Lead target is used as metallic host.
- Cesium-Iodine target acts as insulating environment (with lead degrader in front of it and thin aluminum backing).

The lead degrader on CsI target is used to lower down the beam energy and to reduce the reaction probability with the Cs or I nuclei. The aluminum backing was used to prevent eventual diffusion of neon out of the target.

Two plastic scintillators in close geometry with the target (moving arm) are used as beta particle detectors and they were connected directly to a fast scaler counter. Each signal from the plastic, with a typical width of a few ns, is used to generate a gate of 20 ns which fed the scalers module. In estimation of real observed counts that came from detector were used next expression:

\[
N = \frac{N_n}{1 - \frac{N_m}{T}}
\]

where \( N_m \) are counts recorded during the time \( T \) and \( \tau \) is dead time. The dead time of the experimental set-up was measured after the experiment using the light generated by two impulse generators controlling two light emitting diodes. The light was conducted right in front of the plastic scintillators using optical fibers. The time distance between two light impulses was changed in steps of 0.1 ns. The dead time is estimated as the time distance between two light signals when two impulses become a single one. The estimated dead time was of 26.3 ns and it was used as fixed value for the correction of counting rate.

The nominal acquisition trigger rate was 100 Hz. Since the two measurement are made quasi-simultaneously, the relative change of the half-life could be measured with an ultra-high precision. Two plastic scintillators, each with
different thresholds, different electronics, different counters, different photomultiplier were used, which allows an additional comparison between two independent measurements. They are used to cross-check the measurement. In the process of sampling signals that measure real world physical conditions and converting the resulting samples into digital numeric values that can be manipulated with computer on this experiment were used two data acquisition systems:
- Narval DAS (Ganil/Caen)
- Faster DAS (LPC/Caen)

3. Results and discussion

Comparing the half-life measurements of $^{19}$Ne in lead and in cesium iodine, it is obvious that the neon was diffusing out of the cesium iodine. The estimated half-life of the neon in CsI target was $\sim 17.20$ s, while the estimated half-life in lead target is $\sim 17.25$ s. The only possible explanation for such difference is the escape of the neon from CsI target which effectively makes its estimation of its half-life shorter comparing it with half-life in the lead target. It is most probable that the neon was escaping through thin aluminum backing ($<1$ μm thickness) of CsI. During the experiment several parameters have been changing: applied bias on the photomultipliers (the gain of photomultipliers), the thresholds, the beam intensity and the gate widths. The influence of the applied bias and the thresholds on the half-life is negligible (see Table1). The applied HT on four photomultipliers was $\sim 700$ V. The bias was changed for -10 V, then for +10 V, while the threshold was changed from 100 mV to 110 mV.

Table 1: Half-life dependence on applied bias on photomultipliers and threshold.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Half-life [s]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bias, Threshold</td>
<td></td>
</tr>
<tr>
<td>nominal – 10 V, nominal</td>
<td>17.287±0.003</td>
</tr>
<tr>
<td>nominal + 10 V, nominal</td>
<td>17.289±0.003</td>
</tr>
<tr>
<td>nominal, nominal + 10 mV</td>
<td>17.289±0.002</td>
</tr>
</tbody>
</table>

However, the influence of the counting rate on the estimation of the half-life was not negligible. Most probably that the gain shift or the recovery time of the photomultipliers induced the reduction of the counting rate, when the counting rate was higher than 50000 cps (see Fig. 3). The consequence is that the fitted half-life with such high initial counting rate is much longer.

Preliminary estimation, using the fits of the half-life of $^{19}$Ne with initial count rate of $\sim 30000$ cps is $17.251 \pm 0.002$ s, which is in a quite good agreement with recently measured half-lives of $^{19}$Ne – $17.254 \pm 0.005$ s [3] and $17.262 \pm 0.007$ s [4].

Acknowledgement: We would like to express our gratitude to the GANIL crew for delivering the radioactive beams and for friendly collaboration. We acknowledge the support from French-Romanian Collaboration Agreement IN2P3-IFIN-HH Bucharest No. 03-33, the Region of Normandy, the support of European ENSAR project cycles (No. 262010), the support of NAVIN® VII-VI-417 and LEA IN2P3-ASCNuAG projects and Ministry of Education, Science and Technological Development of Serbia - the project 171018.

References

Abstract. The objective of this study was to investigate iodine interactions with hardened cement paste (HCP) under hyperalkaline conditions (pH<12) with/without reductant Na₂S₂O₅. For this purpose, series of Kᵦ experiments using ¹²⁷I as tracer were performed. The results of sorption experiments showed that after one day 45-56% of iodine, when in reduced form as iodide (I⁻), was immobilized in HCP. The results, obtained in the batch experiments without reductant, showed that the bulk amount of iodine was removed from solution after one day as well but sorption of iodine was slightly higher (79-85%). The Kᵦ values of iodine were obviously higher in the batch experiment without reductant, and they ranged from 172 mL/g in the batch II to 203 mL/g and 1095 mL/g in the batch I and batch III, respectively. The Kᵦ values of iodine in the experiment with reductant were 83 mL/g, 85 mL/g and 92 mL/g in the batch I, batch II and batch III, respectively. The obtained results allow supposing that chemical speciation of iodine has influence on the interaction of iodine with HCP under hyperalkaline conditions.

Key words: iodine, cementitious materials, Kᵦ.

INTRODUCTION

Solidification of low and intermediate level radioactive waste by cementitious materials is one of the most frequently applied techniques prior to near-surface or underground disposal [1-3]. Cement (concrete) is used to construct the engineered barriers of the repository as backfill material in vaults and tunnels. The most abundant cement mineral in hardened cement paste (HCP) are calcium silicate hydrates (C-S-H) [1,2], which are capable of immobilizing many radionuclides. The interaction of groundwater with hardened cement paste can bring about a chemical alteration therein, and further degradation of concrete [3, 4]. Degradation of hydrated cement involves dissolution and leaching related to processes, such as carbonation (dissolution of portlandite) and decalcification (ionic leaching from dissolution of portlandite and calcium-silicate-hydrate) [3]. These processes induce gradual changes in the composition of the pore water, from typical “young” cement leachate with a pH above 13 to leachate with a pH lower than 10 [5]. It has been shown that calcium silicate hydrates are a determining factor in the immobilization of di-, tri-, and hexavalent radionuclides in cementitious materials [1,2].

The behaviour of iodine in the geomedia is of particular importance because of its long half-life (¹²⁹I, T½ = 1.57 · 10⁷years), its radiotoxicity, and its chemistry. Since iodine is very much soluble, it migrates easily along water pathways if it enters the environment [6]. The knowledge of the extent of iodine interaction with engineered barriers is of vital importance in modelling the iodine release from irradiated nuclear reactor fuel elements stored in underground vaults.

The objective of this study was to investigate iodine interactions with cementitious materials under hyperalkaline conditions (pH<12) with/without reductant Na₂S₂O₅. For this purpose, a series of Kᵦ and sorption kinetics experiments, using ¹²⁷I, as tracers, were performed. The concentrations of iodine in solution were measured by ICP-MS. The distribution coefficient for ¹²⁷I in a cement-water system was determined.
1. MATERIALS AND METHODS

Solutions were made from reagent grade chemicals in deionized water prepared by the water purification system TKA LAB MICRO (conductivity 0.055 μS/cm; TOC < 10 ppb). Polyethylene centrifuge tubes used in the batch sorption experiments were washed, left overnight in a solution of 0.1 M HCl, and thoroughly rinsed with deionized water, prior to use. All experiments were carried out under ambient conditions. All batch experiments were performed in triplicate. The relative errors of the data were about 10%. Commercial Portland cement (CEM II/A – LL 42.5 W) was used for iodine sorption/desorption experiments.

Measurements of ${^{127}}I$ and the major cation concentrations were carried out with an inductively coupled plasma sector field mass spectrometer (ELEMENT2 Thermo Scientific, Germany). The redox potential (Eh) and pH of solutions were measured with the “WTW pH-meter pH 315i” with the combined glass/reference electrode calibrated against standard buffers pH4 and pH7 (HANNA pH standard buffer solutions, Sigma-Aldrich Chemie) with a measurement error of ±0.01. The particle sizes of cement were determined by SEM Helios NanoLab 650 (FEI, Netherlands). XRD analysis of Portland cement was performed by means with the X-ray diffractometer D8 Advance (Bruker AXS, Germany). Chemical composition of cement (Table 1) was determined with a fluorescent X-ray spectrometer with wave dispersion (WD-XRF) Axios mAX (Panalytical, Netherlands) supplied with software Omnian (PANlytical) for standard-less quantitative analysis.

Batch experiments were conducted to determine the distribution coefficient ($K_D$) for iodine in cement under alkaline conditions. All the experiments were carried out under ambient conditions at room temperature (22±3 °C). Both $K_D$ and sorption kinetic studies were performed in two series of experiments, with/ without reducing agent 5·10−3 mol/L Na2S2O4. Deionized water and cement pore water (CPW) were used as the working solutions. Sorption of iodine on hydrated hardened cement paste (HCP) was investigated using three slightly different approaches. In the first one ($K_D$ experiment, batch I), 25 mL of deionized water was added to 1g of powdered HCP, and the suspensions were mixed for 2 weeks with an end-over-end shaker. Then, iodine (I⁻) was added from a stock solution (KI, MERCK) to reach a concentration of 3.15·10−6 mol/L. The suspensions were thoroughly stirred, and the pH/Eh value was monitored, the vials were corked up, and allowed to stir for 7 days. After equilibration, the solutions were separated and concentration of iodine was measured by ICP-SFMS. In the second series of experiments (batch II), 1g of powdered HCP was mixed with 25 mL of CPW, 3.15·10−6 mol/L of iodide was added and the suspensions were stirred for 7 days. The third series of experiments (batch III) were performed in parallel with batch II but using deionized water. The set of duplicate experiments was performed with reductant Na2S2O4 (5·10−3 mol/L). All sorption kinetic experiments were carried out within 1, 2, 6, 14, 42 days according to the same scheme as mentioned above.

2. RESULTS

The main components of cement obtained with X-ray fluorescence were CaO (68.57%), SiO₂ (14.60%), Fe₂O₃ (4.54%), Al₂O₃ (3.28%), MgO (2.33%), K₂O (1.17%). The Ca/Si ratio was found 0.14 in cement. Non hydrated Portland cement contains calcium silicate oxide as dominant phase and the brownmillerite and calcium aluminum oxide as well. XRD analysis of hydrated Portland cement shows the presence of portlandite (Ca(OH)₂, 34.15%). Based on SEM analysis, particle sizes of cement were in the range of 3.058-87.88 μm.

The pH/Eh of the solution was monitored at the beginning of the experiment, and then at the end of the experiment. The pH ranged between 12.18 and 12.50 throughout the experiment in all batch systems; the initial Eh of the suspensions was -313 mV, during the first 24 hours it decreased to -328 mV and remained unchanged to the end of the experiment. The graphic image of the time dependence of sorption kinetics of iodine (I⁻) on HPC is shown in Fig.1.
Fig. 1 Time dependence of iodine (I-) sorption on HCP. a: pH 12.18-12.50, C(I-) = 3.15·10^{-6} mol/L, m/V = 0.04 g/mL; b: pH 12.18-12.50, C(I-) = 3.15·10^{-6} mol/L, m/V = 0.04 g/mL, 5·10^{-3} mol/L Na_{2}S_{2}O_{4}

The sorption of iodine (I-) on hydrated cement was mainly attained within one day (24 hours) in the batch experiments without reductant, while the steady value of sorption was achieved during 42 days (Fig. 1a). The results of the sorption of iodine in the presence of reductant indicate that the uptake process was not so fast, but equilibrium was achieved within 42 days as well (Fig. 1b). More detailed results of the sorption, based upon the calculations, are given in Table 1.

Table 1. Percentage of iodine sorption on hardened cement paste in the batch systems with/without reductant

<table>
<thead>
<tr>
<th>SORPTION TIME, DAYS</th>
<th>BATCH I</th>
<th>BATCH II</th>
<th>BATCH III</th>
<th>SORPTION, % (I-, WITHOUT REDUCTANT)</th>
<th>SORPTION, % (I- + 0.005 M Na_{2}S_{2}O_{4})</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>85</td>
<td>79</td>
<td>80</td>
<td>56</td>
<td>45</td>
</tr>
<tr>
<td>2</td>
<td>91</td>
<td>90</td>
<td>93</td>
<td>66</td>
<td>62</td>
</tr>
<tr>
<td>6</td>
<td>93</td>
<td>94</td>
<td>100</td>
<td>83</td>
<td>82</td>
</tr>
</tbody>
</table>

By comparing the results of both types of sorption experiments (with/without reductant, Table 1), the percentage of iodine sorption on HCP under the investigation conditions (pH 12.18-12.50) is slightly different. The results showed that after one day 45-56% of iodine, when in reduced form as iodide (I^-), was immobilized in cement. Hereinafter the amount of sorbed iodide decreased exponentially till it was completely removed from the solution within 42 days. The results, obtained in the batch experiments without reductant, showed that the bulk amount of iodine was removed from solution after one day as well, but percentage sorption of iodine was slightly higher (79-85%).

The experiments were conducted in order to obtain the K_D values of iodine species in the cement system under the given experimental conditions. The K_D values of iodine were obviously higher in the batch experiment without reductant, and they ranged from 172 mL/g in the batch II to 203 mL/g and 1095 mL/g in the batch I and batch III, respectively. The K_D values of iodine in the experiments with reductant were 83 mL/g, 85 mL/g and 92 mL/g in the batch I, batch II and batch III, respectively. The obtained results allow supposing that chemical speciation of iodine has influence on the interaction of iodine with cementitious materials under hyperalkaline conditions.

3. DISCUSSION

The mechanism of iodine uptake in hardened cement paste is sorption and/or incorporation according to Evans [7]. Fast incorporation of iodine into HCP suggests that the mechanism involves a surface sorption process rather than incorporation into the structure. The dominant species of iodine in cement systems is iodide (I^-), except under oxidizing conditions, where iodate (IO_3^-) may be the dominant species [8]. Our work shows that percentage sorption of iodine was higher (79-85%) in the batch experiments without reductant then in the presence of reductant (45-56%). This result suggests that under investigation conditions (oxygen access, pH > 12) iodide (I^-) can be oxidized to the higher valency state (e.g.
and this alteration influences the iodine behaviour in HCP. This result is in good agreement with published data which indicate that cement has much stronger affinity for \(\text{IO}_3^-\) than \(\Gamma^-\) because of more complex structure of the \(\text{IO}_3^-\) anion with the surrounding oxygen acting as bridges with the complex cement substrate. [6]. Differences in \(K_D\) values obtained in experiment with/without reductant suggest that cement has a less affinity to \(\Gamma^-\) than \(\text{IO}_3^-\). It is in agreement with literature data [7,8]. Based on the results of this work, one can conclude that chemical speciation of iodine has influence on the interaction of iodine with cementitious materials under hyperalkaline conditions.

CONCLUSIONS

The experimental results have demonstrated that the iodine uptake by hardened cement paste under hyperalkaline (pH>12) conditions is fast and achieves equilibrium within 42 days. Within the first day 45-56% of \(\Gamma^-\) removed from solution in the batch experiments with reductant \(\text{Na}_2\text{S}_2\text{O}_4\) (\(5\times10^{-3}\) mol/L). The results, obtained in the batch experiments without reductant, showed that 79-85% of iodine removed from solution after one day.

The \(K_D\) values in the batch experiments without reductant ranged from 172 mL/g in the batch II to 203 mL/g and 1095 mL/g in the batch I and batch III, respectively. The \(K_D\) values of iodine in the experiments with reductant were 83 mL/g, 85 mL/g and 92 mL/g in the batch I, batch II and batch III, respectively.

The study of iodine interaction with HCP under hyperalkaline conditions indicates that iodine sorption governed by surface sorption and it depends on the chemical speciation of iodine.

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REFERENCE

MONTE CARLO CALCULATIONS OF THE NEUTRON DOSE EQUIVALENT IN THE ICRU SLAB

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Abstract. Monte Carlo simulations are performed to evaluate the neutron dose equivalent for irradiation on the ICRU slab by Am-Be source. To simulate the neutron transport and neutron interaction with the atoms of the ICRU slab, the MCNP5/X code was used coupled to a home-made code to calculate the neutron dose equivalent. Previously developed home-made code, Neutron_CR-39.F90 written in the FORTRAN 90 programming language for irradiation CR-39 detector with neutrons, was rearranged for the ICRU slab. Comparison of results of MCNP and home-made codes for different distances the ICRU slab from neutron source was presented in this paper.

Key words: neutron, the ICRU slab, dose equivalent, Monte Carlo

1. INTRODUCTION

Since the time of the neutron discovery efforts have been made to understand the effects of neutron radiation on tissue and eventually, to use neutrons for cancer treatment [1]. Neutrons were chosen for cancer treatment since they offer a theoretical advantage over photons to fight radio-resistant tumors by the differential relative biological effect between normal and tumor tissues.

For all types of external radiation, the operational quantities for area monitoring are defined on the basis of a dose equivalent quantity. The ability to interpret the readings of dosimeters worn on the human trunk in terms of the protection quantities is of the greatest interest for monitoring external radiation exposure [2]. The simplified tissue-substitute phantoms often taken to be surrogates for the human torso are ICRU sphere (30cm diameter) and the 30 cm x 30 cm x 15 cm ICRU slab [3]. These phantoms adequately approximate the human body with regards to scattering and attenuation of radiation field.

In this paper, Monte Carlo simulations are performed to evaluate the neutron dose equivalent for irradiation on the ICRU slab by Am-Be source. To simulate the neutron transport and neutron interaction with the atoms of the ICRU slab the MCNP5/X code [4] was used as well as home-made code, Neutron_ICRU.F90, written in the Fortran 90 programming language. Previously developed code named Neutron_CR-39.F90 [5] used to calculate the neutron dose equivalent rate for a CR-39 detector was rearranged for the ICRU slab.

Comparison of results of MCNP and home-made codes for different distances the ICRU slab from neutron source was presented in this paper.

2. PROGRAM DESCRIPTION

Calculations were performed for phantoms which were irradiated using a cylindrical Am-Be neutron source. The phantoms used for the calculations were the ICRU slab phantom, consisting of 4-element ICRU tissue.

The position of the detector and the source with their dimensions are presented in Fig. 1. The center of the front-face of the ICRU slab is at the origin of coordinate system in the z=0 plane.

![Fig. 1 Geometry of the source and the ICRU slab. The ICRU slab dimensions are: height, h; width, w; thickness of the detector, t. Source dimensions are: diameter, Ds; height Hs. The distance between slab and source is d.](image-url)
FORTRAN simulation of neutron transport and interactions was performed using the Monte Carlo method. The user defines the input parameters before the program execution: energy of neutrons (monoenergetic or spectrum energy); the number of simulations; slab dimensions; source dimensions and the distance from the source to the slab. The neutron cross-section data library used in these calculations is based on the ENDF/B-VII.

It is taken that neutrons are emitted randomly from the source, neglecting the interaction within the source itself and in the air space between the source and the ICRU slab. The simulation starts with the homogenous sampling of the emission point of the neutron in the source at \((x_s, y_s, z_s)\), its initial energy \(E_0\). Initial direction of neutron in source determined with cosines \((p_{xs}, p_{ys}, p_{zs})\) was sampled isotropic according to well known formula given for example by Lux and Koblinger [6].

If the sampled direction did not cut the slab top surface, sampling was repeated. When the sampled neutron struck the slab surface at the point \((x_0, y_0, z_0=0)\), a further step was the sampling of these atoms, H, C, O or N which could be struck. The standard method of discrete event sampling was applied to “choose” an atom. The new coordinates of the interaction point within the detector, \((x_i, y_i, z_i)\), were calculated based on the known mean free path \(\lambda\) and new sampled direction \((p_{xs}, p_{ys}, p_{zs})\). The free path of the neutron, \(\lambda\), and the total macroscopic cross section were calculated according to well known formula [6]. The next step was sampling of the interaction type, detailed description is given in [5, 7, 8]. The neutron path was further simulated until the neutron was outside of the detector or the secondary particle had been created.

3. RESULTS

The neutrons from Am-Be source type span a wide energy spectrum in the range between 0.2 and 11 MeV with broad peaks at 3 and 5 MeV [9]. The simulations were performed for \(10^7\) neutron histories and dimensions of the ICRU slab \(w \times h \times t\) (30 cm x 30 cm x 15 cm). ICRU tissue-equivalent material has a density of 1 g/cm\(^3\) and a mass composition of 76.2\% oxygen, 11.1\% carbon, 10.1\% hydrogen and 2.6\% nitrogen. Dimensions of the source, diameter and height are: \(D_s=2.25\) cm and \(H_s=3.1\) cm.

Calculation of neutron fluence were carried out by Neutron_ICRU.F90 code considering different source to the ICRU slab distances and resent in Fig 2. The results obtained here were compared with data calculated by MCNP5/X code (Monte Carlo Neutron-Particle) [4]. Made the input file for the geometry shown in Figure 1. The neutron fluence tally of MCNP was employed (F4:n) for different distances between the source and ICRU slab. From the inspection of Fig. 2 there is an excellent agreement between neutron fluences calculated with home made code and MCNP, especially for larger distances.

Neutron fluence enables calculation of the dose equivalent according to the following equation:

\[ H = h_\phi \cdot \phi \]  

where \(h_\phi\) is the mean neutron fluence to dose equivalent conversion factor for the Am–Be source; \(h_\phi=391\) pSv·cm\(^2\) and \(\phi\) is the neutron fluence (cm\(^{-2}\)) [9, 10].

Using the MCNP5/X, for a different source to detector distances (neutron fluence), the neutron dose equivalent was calculated according to Eq. (1). The results were presented in Fig. 3.

4. CONCLUSION

Comparison of results of MCNP and home-made codes for different distances the ICRU slab from neutron source was presented in this paper. Agreement among results of MCNP and home made code suggest the potentiality of further development of Neutron_ICRU.F90 code and its using in fast neutron dosimetry.
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**REFERENCES**

REDUCTION OF AFLATOXIN B1 IN NATURALLY CONTAMINATED CORN SAMPLES
BY GAMMA IRRADIATION

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Mycotoxin aflatoxin B1 (AFB1) is a secondary metabolite of moulds from Aspergillus genera that can be found as food and feed contaminant around the world. Its toxicity is well established and numerous strategies have been developed in protecting animals and humans exposure to this mycotoxin. Gamma irradiation is a physical method that is commonly used for inactivation of moulds growth in foodstuffs and cultural heritage objects. However, effect of gamma irradiation on AFB1-reduction is not clear so far. The aim of this study was to investigate the effect of gamma irradiation on AFB1-reduction. Corn seeds samples (n=30) naturally contaminated with AFB1 at concentration range from 57 to 1210 μg/kg were irradiated at doses of 5 kGy and 10 kGy. The overall reduction of AFB1 level after 5 kGy irradiation dose was 76.5%, while at dose of 10 kGy it was 94.8%. These results indicate that gamma irradiation is effective method for reducing AFB1 level in commodities intended for animal and human consumption thus minimizing their exposure to this carcinogenic mycotoxin.

Key words: mycotoxins, aflatoxin B1-reduction, corn seeds, gamma irradiation

1. INTRODUCTION

Aflatoxin B1 (AFB1; Fig 1) is a mycotoxin, secondary metabolite of moulds from Aspergillus genera. Discovery of AFB1 in 1960s was connected with massive death of poultry in United Kingdom strongly alerting of AFB1 toxicity to animals and humans. Using experimental animals it was shown that AFB1 has hepatotoxic, teratogenic, immunosuppressive and carcinogenic properties (IPCS, 2001). Particularly in humans AFB1 causes hepatocellular carcinoma, and therefore International Agency for Research on Cancer (IARC) classified AFB1 in group 1, as carcinogenic to humans (IARC, 2002).

AFB1 can be found in different plant and animal derived substrates (seeds, dried fruits, cheese, dried meat), but seeds are considered the major vehicle of AFB1 in food chain. Contamination with AFB1 can occur in the field but also during storage period. It is connected with higher humidity and temperature that are favourable parameters for mould growth. In order to protect animal and human exposure to this toxic mycotoxin, countries around the world have limited the maximal permitted levels (MPLs) of AFB1 in different food and feed commodities. In European Union the MPLs of AFB1 in cereals and cereal-based products for food is set to 2.0 μg/kg (Commission Regulation 1881/2006 amended by 165/2010) while for feed it is 20 μg/kg (Commission Directive 2003/100/EC).

![Chemical structure of aflatoxin B1 (AFB1)](image)

Various strategies are used in preventing animal and human exposure to AFB1 as well as to other mycotoxins. The most important are the use of pesticide (fungicide) while crop is still in the field, and maintaining proper humidity and temperature during storage period of crop. Despite good agro-technical practice AFB1 can be still found in various commodities intended for animal and human consumption and even in very high concentration. In winter 2013, in Croatia and surrounding countries,
high level of aflatoxin M1 (AFM1) was detected in cow milk (AFM1 is AFB1 metabolite that can be found in milk). In our study on 633 corn seeds samples collected from the same region where AFM1 occurred in cow milk, high AFB1 contamination of up to 2072 µg/kg was found (Pleadin et al., 2014).

Gamma irradiation is a physical method that is used for decontamination and control of mould growth predominantly for pharmaceutical and food industry (WHO, 1997). In several studies gamma irradiation was tested for reduction of AFB1 level in various commodities, however, results are contradictory. For example, Azizi and Moussa (2002) completely reduced AFB1 level in fruit samples with dose of gamma irradiation as low as 3.5 kGy, while in study of Hooshmand and Klopenstein (1995) even 20 kGy was not high enough to reduce AFB1 level. Therefore, the aim of this study was to clarify effectiveness of gamma irradiation on reduction of AFB1 level on naturally AFB1-contaminated corn samples intended for animal feed (Commission Directive 2003/100/EC). After 57% methanol was supplemented and shaken vigorously head-over-head on a shaker for three minutes. The extract was filtrated (Whatman, black ribbon) and 1 ml of the obtained filtrate was diluted with an appropriate volume of deionized water.

AFB1 concentration was determined using the ELISA method by use of Ridascreen kits provided by R-Biopharm (Darmstadt, Germany). AFB1 analysis was performed according to the kit manufacturer’s instructions and with the aid of an auto-analyzer ChemWell 2910 (Awareness Technology, Inc, USA). The obtained AFB1 concentrations were calculated from a six-point calibration curve by taking the applied dilution factor into account and finally corrected for recovery. The procedure of determination was described earlier by Pleadin et al. (2014).

2. MATERIALS AND METHODS

2.1. Chemicals and reagents

Standard of AFB1 was purchased from Sigma (St. Louis, MO, USA). AFB1, stock (10 mg/l) and working (0.1 mg/l) solutions were prepared in methanol. For ELISA method kits provided by Ridascreen R-Biopharm (Darmstadt, Germany) were used. Each kit contains a micro-titer plate with 96 wells coated with antibodies against AFB1, aqueous AFB1 standard solutions (0, 1, 5, 10, 20, and 50 µg/l), peroxidase-conjugated AFB1 substrate/chromogen (urea peroxide), a stop-reactant (1 N-sulphuric acid), and a washing buffer (10 mM-phosphate buffer, pH=7.4). All other chemicals used for AFB1 extraction and analysis were of an analytical grade.

2.2. Samples

A total of 30 samples of corn seeds were collected during February to April 2013 from different fields situated in eastern part of Croatia and stored at 4 oC during February to April 2013 from different fields. The samples were kept in same conditions of temperature, air pressure and humidity.

2.3. Irradiation

Samples were irradiated with doses of 5 and 10 kGy using a panoramic 60Co source (activity about 870 TBq) of the Ruder Bošković Institute (Zagreb, Croatia). The dose rate was about 155 Gy/min. The accurate dose rate in the irradiating positions was established with the ethanol-chlorobenzene dosimetry system (Ražem et al., 1985) and calculated daily taking into account the radioactive decay of 60Co. All whole grain corn samples were irradiated at room temperature.

2.4. Samples preparation and AFB1 determination

To five grams of homogenized corn samples 25 ml of 70% methanol was supplemented and shaken vigorously head-over-head on a shaker for three minutes. The extract was filtrated (Whatman, black ribbon) and 1 ml of the obtained filtrate was diluted with an appropriate volume of deionized water.

AFB1 concentration was determined using the ELISA method by use of Ridascreen kits provided by R-Biopharm (Darmstadt, Germany). AFB1 analysis was performed according to the kit manufacturer’s instructions and with the aid of an auto-analyzer ChemWell 2910 (Awareness Technology, Inc, USA). The obtained AFB1 concentrations were calculated from a six-point calibration curve by taking the applied dilution factor into account and finally corrected for recovery. The procedure of determination was described earlier by Pleadin et al. (2014).

2.5. Validation of the ELISA

The limit of detection (LOD) and the limit of quantification (LOQ) were calculated from the mean value of ten corn control samples plus three- and ten-fold standard deviation, respectively. The recoveries were determined at four different levels (2, 5, 10 and 50 µg/kg; six replicates per concentration level per day) by virtue of spiking the control samples with the AFB1 standard working solution corresponded to the assessed content levels. As regards the determination of intermediate precision, the same steps were repeated on two additional occasions within a three-month period and by two independent analysts, but under the same analytical conditions.

2.6. Statistical analysis

Statistical data analysis was performed using Student’s t-test (SAS software, version 6.1, SAS Institute, USA) with statistical significance set at level of 95% (p <0.05).

3. RESULTS

The results of ELISA method validation presented in Pleadin et al. (2014) showed that applied method is capable for reliable and efficient determination of AFB1 in corn seeds samples. The results of this study are presented in Table 1. In 30 corn seeds samples from this study, AFB1 concentration was in the range from 57 to 1210 µg/kg that is above the MPL defined for feed (Commission Directive 2003/100/EC). After gamma irradiation with doses of 5 kGy and 10 kGy in all corn seeds samples significant reduction of AFB1 level was observed. This reduction was unaffected by previous concentration of AFB1 although better reduction was observed in samples with lower AFB1 level (AFB1 concentration less than 500 µg/kg). After irradiation at dose of 5 kGy the concentrations of AFB1 were in the range from 6.3 to 424.3 µg/kg. Significantly higher decrease of AFB1 level was obtained when dose of 10 kGy was applied. In corn seeds samples that were irradiated with 10 kGy dose the concentration range of...
AFB1 was from below detection limit to 173.8 µg/kg. These results point to dose-dependent effect of gamma irradiation on AFB1 level. Reduction of AFB1 concentration expressed as the percentage of AFB1 concentration was from 58.4 to 88.9% (overall reduction for 76.5%) when 5 kGy irradiation dose was applied, while dose of 10 kGy reduced AFB1 concentration from 85.6 to 100% (overall reduction for 94.8%) (Table 1).

Table 1 Concentration of AFB1 in corn seeds samples before and after gamma irradiation at doses of 5 and 10 kGy.

<table>
<thead>
<tr>
<th>c (AFB1) (µg/kg)</th>
<th>5 kGy</th>
<th>10 kGy</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>AFB1</td>
<td>Red. (%)</td>
</tr>
<tr>
<td>57</td>
<td>6.3</td>
<td>88.9</td>
</tr>
<tr>
<td>91</td>
<td>23.1</td>
<td>74.6</td>
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<tr>
<td>171</td>
<td>28.1</td>
<td>83.6</td>
</tr>
<tr>
<td>187</td>
<td>31.8</td>
<td>83</td>
</tr>
<tr>
<td>203</td>
<td>45.2</td>
<td>77.7</td>
</tr>
<tr>
<td>216</td>
<td>54.2</td>
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<td>798</td>
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<td>914</td>
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<td>61.9</td>
</tr>
<tr>
<td>1210</td>
<td>424.3</td>
<td>64.9</td>
</tr>
</tbody>
</table>

4. DISCUSSION

There are several studies that tested effectiveness of gamma irradiation on reduction of AFB1 level in naturally or artificially contaminated food or feed samples. In study of Jalili et al. (2012) samples of black and white pepper were spiked with known concentration of AFB1 (60 ng/g), and irradiated at doses of 5, 10, 20 and 30 kGy. In that study dose-dependent reduction of AFB1 level was observed. In black pepper dose of 5 kGy reduced AFB1 level only for around 4% (for 3.8±1.5%), while dose of 30 kGy reduced the level of AFB1 for 35% (35.2±4.1%). Similar results were observed on white pepper (5 kGy reduced for 6.5±4.1 % while 30 kGy reduced for 39.6±1.7 %). As expected, better reduction was observed when samples had higher moisture content. This result indicate that gamma irradiation is effective in reduction of AFB1 level only when is applied at high doses (over 30 kGy). Similarly, Hooshmand and Kloopenstein (1995) reported that irradiation doses of up to 20 kGy did not significantly affect the AFB1 level in wheat, corn or soybeans.

However, in several studies it has been shown that gamma irradiation effectively reduced AFB1 level at lower irradiation doses (under 10 kGy). In recent study of Iqbal et al. (2013) gamma irradiation at doses from 2 to 6 kGy was tested for reducing AFB1 level in ground and whole chilli samples collected in Pakistan. In that study slight reduction was observed with dose of 2 kGy (from AFB1 level of 250±10 to 212±1 µg/kg), and reduction for 95% (to AFB1 level of 1.8±0.1 µg/kg) was observed after irradiation dose of 6 kGy. There were no significant differences in AFB1-reduction between ground and whole chilies, although AFB1-reduction was slightly better in ground (from 92 to 98%) than in whole (from 86 to 97%) chilies. Aziz and Moussa (2002) in their study analyzed 100 fruit samples (strawberry, apricot, plum, peach, grapes, date palm, fig, apple, pear and mulberry) obtained from grocery stores in Egypt. Only samples of plum and date palm were contaminated with AFB1 (in the concentration range from 380 to 500 µg/kg), and after irradiation at dose of 3.5 kGy only in one sample detectible level of AFB1 was found (20 µg/kg) while in others AFB1 was not detected. The results of Iqbal et al. (2013) and Aziz and Moussa (2002) are in agreement with our observations showing that gamma irradiation at low doses (lower that 10 kGy) can reduce AFB1 level. In our study radiation dose of 5 kGy reduced AFB1 concentration for 76.5% (in the range from 58.4 to 88.9%), while radiation dose of 10 kGy reduced AFB1 concentration even better, for around 94.8% (in the range from 85.6 to 100%). Therefore, our observations support previous observations of other authors leading to conclusion that gamma irradiation can be effectively used in reduction of AFB1 level up to the recommended permitted limits.

From various food processes that may affect AFB1 level, the most promising are extrusion processing at very high temperatures. In study of Saalit and Phillips (2011) it is demonstrated that in peanut meal extrusion cooking reduced aflatoxins for 84%. Roasting is also effective method; roasting at 150 °C for 120 min reduced 95% of AFB1 in pistachio (Yazdanpanah et al., 2005). In experimental conditions a good reduction of AFB1 content (from 13-73%, depending on plant extract concentration) was achieved by plant extract of Thymus daenensis (Gorran et al., 2013). All mentioned methods have similar effects on AFB1 reduction. However, when comparing to gamma irradiation use of high temperature and pressure could affect nutritional values of food commodities.

Since contamination of crop with AFB1 is unavoidable and due to climatic changes (dry periods and higher temperatures) contamination with AFB1 could be expected to be world-wide. Therefore, various
strategies for reducing AFB1 level are needed and should be tested. In this study we showed that gamma irradiation can be successfully used as a method of choice for crop decontamination.

Acknowledgement: We are very grateful to Mr Igor Sajko and Mr Milan Blažević for their technical support during the irradiation of samples. Financial support of Ministry of Science, Education and Sport of Croatia is greatly acknowledged (grant no. 098-0982904-2954 "Physico-chemical effects of ionizing radiation in materials" and grant no. 058-0582184-0432 "Mycotoxins in food and feed in the territory of the Republic of Croatia").

REFERENCES


DETERMINATION OF INCREASED LEVELS OF AFLATOXINS IN FEEDSTUFFS AND RAW MILK IN REPUBLIC OF MACEDONIA APPLYING SCREENING AND CONFIRMATORY METHODS

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Abstract

The frequency of occurrence of AFM1 in commercially available milk and dairy products during the Western Balkan Countries outbreak in 2013, led to an increased concern about the establishment of measures to control Aflatoxin B1 contamination in feed, as well as Aflatoxin M1 in milk samples. In the light of these concerns, a comprehensive surveillance program for AFM1 in raw milk was established in Macedonia. The Aflatoxin M1 contamination in 105 samples (2.9%) was above the maximum allowed limit. The investigation of the feed sampled as follow-up revealed increased AFB1 presence with 13.4% noncompliance. The sampling season is likely highly influencing the AFM1 content in raw milk samples.

Key words (bold): aflatoxin B1, aflatoxin M1, feed, milk, contamination, seasonal variations

1. INTRODUCTION

Since the beginning of the 21st century there are a numerous reports and modeling simulations by competent expert bodies, United Nations Institutions and published articles showing that climate changes affect significantly the agricultural production, diminishing thereby food safety as well as treating public health [1]. Drought stresses reduces the crop plants resistance and extreme precipitations and heat waves increases the possibility of growth of plant pathogenic moulds, producing the toxic metabolites – mycotoxins, both prior to and post harvest [2]. Aflatoxins are highly toxic, mutagenic, teratogenic and carcinogenic fungal metabolites from Aspergillus found in foods and feeds. The attention to the presence of aflatoxins in feed is very important because of the possible contamination of the milk produced by animals fed with aflatoxin-contaminated feed. Aflatoxin M1 (AFM1), the hydroxylated metabolite of Aflatoxin B1 (AFB1), may be found in milk and milk products obtained from livestock that have ingested contaminated feed. Generally, it is deemed that approximately 1–6% AFB1 present in animal feed appears as AFM1 in milk, depending from animal to animal, season of milking and many other factors [3]. At the end of 2012 and beginning of 2013 the risk of mycotoxins was brought to public attention in Balkans and Central European countries following the European Commission Rapid Alert System for Food and Feed, where ten alerts for the presence of increased amounts of AFB1 in maize panel, have been reported [4]. Until 2013, the reported positive Aflatoxin M1 samples from the Balkans region were only sporadic, with a negligible MRL exceeding [5–7]. Recently a few published papers have stressed the regional aflatoxin problem, mainly arising from the long-lasting drought in 2012 [8–10].

This paper presents the preliminary results from the survey on the presence of AFB1 in feedstuffs and AFM1 in raw milk from Republic of Macedonia, conducted during the 2013.
2. MATERIALS AND METHODS

2.1. Sample collection

This paper presents some of the results from the survey on AFB1 in feedstuffs and AFM1 in raw milk from Republic of Macedonia, conducted during the 2013. In total 117 samples of feedstuffs and 3099 samples of raw milk were tested for the presence of AFB1 and AFM1, respectively. The samples were collected within the survey of the Food and veterinary agency of Republic of Macedonia.

2.2. Methods of testing

The milk samples were tested applying the immunochemical screening method (ELISA kit – TECNA, Trieste - Italy). The positive samples exceeding the maximum residue level (MRL) of 0.050 µg/kg were confirmed with high performance liquid chromatography (HPLC) with fluorescence detection (FD) on Alliance system consisted of a 2695 separation module and 240 fluorescence detector (Waters, Milford, MA, USA) [11]. Feed samples were tested for aflatoxin B1 applying the HPLC-FD method on Perkin Elmer Series 200 pump and LC 240 fluorescence detector (Norwalk, Connecticut, USA) [12]. Testing methods were validated and confirmed to be sensitive, selective, accurate and precise according to the requirements of Commission Regulation 401/2006/EC [13].

2.2. Statistical analysis

Statistical calculations for the between month and between season variations of AFM1 concentration were performed applying the IBM SPSS Statistics for Windows, version 2.2. (IBM Corp., Chicago, USA). To evaluate differences in the means between two series of samples t-test for independent samples has been applied. The differences between the values were considered significant at probability level (P) ≤ 0.05.

3. RESULTS AND DISCUSSION

3.1. Aflatoxin B1 testing

During the survey period, a total of 117 dairy cow feed samples were tested for AFB1 presence applying the validated HPLC-FD method. The results from detection of the aflatoxin B1 are presented at Figure 1. 29.9 % of the total feed samples were found containing AFB1 over the detection limit of the applied method. Among them, in 11 samples (9.4 %) the established MRL values have been exceeded [14].

Predominantly, the non-compliances have been revealed at complementary dairy cows feed samples (22.6 %) with obtained concentration range from 0.005 µg/kg up to 51.4 µg/kg. Regarding the maize panel samples, the AFB1 prevalence was 17.2 %, with four detected MRL exceeding. The concentration range was from 0.005 up to 75.0 µg/kg. Furthermore, the mean level of AFB1 in complementary feed samples was significantly higher (P<0.05) than that of maize panel samples. The AFB1 contamination in raw feed (silage) was negligible.

3.2. Aflatoxin M1 testing

For better comprehension of the AFM1 distribution during the whole year, the monthly occurrence and concentrations in the surveillance period from February 2013 until January 2014 are presented on Figure 2. After the initial incidence of 5.4 % and 2.9 % in February and March, respectively, slight decrease in the number of non-compliant samples was observed in the period from April to July, when the EU MRL exceeding [14] dropped to less than 2 %. The long lasting drought during the second half of 2013, and thus the lack of fresh feed caused significant increasing of the AFM1 concentrations during the period August-November. Therefore, the MRL has been exceeded in 3.7 %, 5.5 %, 6.7 % and 4.6 % of the tested samples for August, September, October and November, respectively. During this period, the AFM1 contamination levels were determined in the range from 6.6 to 408.4 ng/kg. The highest positive mean (34.8 ng/kg) and the highest level of AFM1 (408.4 ng/kg) were measured in October, with MRL exceeding in 6.7 % of the samples tested.
alert to milk producers before exceeding the maximum tolerable level. The significant decreasing of the positivity during December and January, 32.3 % and 26.9 %, was likely due to the stricter official controls, increased farmer awareness, and more intensive self controls in the dairy industry. Moreover, it is important to stress that in this period, the non-compliance was significantly reduced to less than 1 %.

Elevated AFM1 concentrations were detected in two reports for cow’s milk from Serbia [9], where concentrations ranged from 0.01 to 1.2 µg/kg and 0.01 to 1.44 µg/kg with 76 % positivity [10]. In the investigations conducted in Croatia during 2013, the determined concentration ranged from LOD up to 1135 ng/kg and 183.5 ng/kg, for raw and UHT milk, respectively [8]. These investigations were fully in line with the assumption that the whole region of Western Balkan countries, including Macedonia, was highly affected by the usage of contaminated feed with AFB1. The comparison among these countries is possible, apart from the different analytical procedures applied, due to the very similar climatic conditions, storage conditions, the sampling period and very likely same origin and similar AFB1 contamination of feed.

However, other studies mainly performed in Mediterranean or Asian countries, show enhanced occurrence of AFM1 in milk and dairy products, whereas in Sardinia the incidence was 31.5% [15], 16.6% in Italy [16], 100% in Iran [17], mainly attributed to the favorable climatic conditions for AFB1 production and the way of feed storage. According to the presented reports, the occurrence of Aflatoxin M1 is a global problem in regions affected by dry climate, or with seasons of long drought periods that favor the mould development. It can be concluded that the elevated Aflatoxin B1 levels in feed is a consequence of climatic and technical conditions.

Regarding the fact that dairy products are the most potent source of aflatoxins, countries with week system of feed control should increase the frequency of feed and milk samples, and should increase the level of breeder’s education about the harmful effects of aflatoxins to feedings.

### 3.3. Seasonal variations of AFM1 in raw milk

The sampling season is likely highly influencing the AFM1 content in raw milk samples. The present study revealed that 42 % of raw milk samples from the autumn-winter season exceeded as compared to only 1.8 % of spring-summer samples regarding the EU MRL value as showed in Table 1. The significant difference in the mean values has been confirmed by a suitable statistical test at confidence level P ≤0.05.

<table>
<thead>
<tr>
<th>Testing period</th>
<th>Tested (n)</th>
<th>Positive (n(%))</th>
<th>&gt;50.0 ng/kg (n(%)</th>
<th>Average ± SD ng/kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spring-summer</td>
<td>1271</td>
<td>474 (37.3)</td>
<td>26 (2.0)</td>
<td>10.14±16.5</td>
</tr>
<tr>
<td>Autumn-Winter</td>
<td>1828</td>
<td>1091 (59.7)</td>
<td>84 (4.6)</td>
<td>16.8±23.1</td>
</tr>
</tbody>
</table>

1. over LOD of the ELISA method
2. the number in parenthesis is incidence expressed in %

Some authors [21] suggest that the biggest risk with respect to mycotoxins from climate change will be found in developed countries with temperate climates (e.g. parts of Europe and the United States of America, etc.). The climate of these regions will become warmer reaching temperatures of 33 °C, close to the optimal for aflatoxin production. This may be the case with the crops, especially if recognised aflatoxin-susceptible plants (e.g. maize) are grown increasingly to exploit the new conditions.

### 4. CONCLUSION

The present study is reporting the results from the survey investigating the presence of AFM1 in raw milk samples collected from dairy production facilities in Macedonia, in the period February 2013 - January 2014, as well as Aflatoxin B1 presence in lactating cows feed. The contamination in 105 samples (2.9 %) was above the maximum allowed limit. The investigation of the feed sampled as follow-up revealed increased AFB1 presence with 13.4 % noncompliance. In summary, our results indicate that AFB1 in imported corn for dairy cattle is a major contributor to AFM1 content in raw milk. To ensure the safety of milk for human health it is extremely important to avoid providing feed contaminated with AFB1 to cows. Hence, regular monitoring of not only the AFM1 level in milk, but also the AFB1 level in feed, will be required to protect the public, especially infants and young children, against AFM1 toxicity. Future study could possibly focus on risk assessment of AFM1 in milk and dairy products.

**Acknowledgement:** The presented results in this paper are part of the survey conducted due 2013 in Republic of Macedonia. Faculty for veterinary medicine, Sts Cyril and Methodius University, Skopje is gratefully acknowledged for providing the financial support. Mrs. Liljana Ilievska-Trajkouska, Mrs. Daniela Zieksoska and Mrs. Snezana Dimitrovska from Faculty for veterinary medicine, Sts Cyril and Methodius University, Skopje are gratefully acknowledged for technical assistance.

**References**

APPLICATION OF EDXRF SPECTROMETRY FOR THE ANALYSIS OF ANCIENT CERAMICS

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Abstract. An analytical procedure developed for the analysis of ceramic samples using EDXRF spectrometry will be presented, together with some preliminary results from the analysis of Early Neolithic ceramic fragments excavated in different sites in Albania. Archaeological surveys and excavations have clearly shown that all the Albanian territory have been inhabited since prehistoric period. The excavations have shown that in some sites the humans have been living without interruption throughout the Neolithic period. The archaeological materials from these sites, mostly ceramics, constitute a unique case that could give information about the technological development of those societies from Early to Late Neolithic. Characteristic ceramic fragments from four sites of this type will be investigated by various analytical techniques aiming to evidence the similarities and differences between ceramics belonging to different Neolithic stages within one site and between different sites.

EDXRF spectrometry is widely used for studying ceramic samples because apart from being nondestructive, fast and low cost, the multielemental nature of the technique allows the application of different multivariate analysis.

The samples were measured in secondary target excitation EDXRF system, using Cu and Mo secondary targets for excitation of low- and medium-Z elements, respectively. The program Corex, which uses fundamental parameters and backscattered peaks from the measurements were used for the calculation of the concentrations. EDXRF spectrometry shows acceptable values of the detection limits for most of the determined elements. Precision and accuracy of the determinations were evaluated by the measurements of a series of standard reference materials. The results show good agreement between the recommended and calculated concentrations, i.e. no evidence of systematic error. Precision, expressed as relative standard deviation of the repeated measurements of SRM, shows values in the range 5 – 8 % for major elements, and values within 10 % for most of the minor elements.

Key words: Energy dispersive X-ray fluorescence analysis, Archaeological pottery, Early Neolithic

1. INTRODUCTION

Ceramic objects are the most abundant finds in archaeological excavations and provide a very informative evidence of the past. This is related with their wide spread use in ancient societies and with their resistance to natural weathering processes. Chemical “fingerprinting” and other technological investigations of the ceramic artefacts, when properly interpreted in associated contexts, has proven to be a powerful tool in solving archaeological tasks of different complexity. The application of sophisticated statistical and/or multivariate methods of analysis on large experimental datasets obtained by modern analytical techniques has proven to be a useful tool for supporting archaeologists’ hypotheses regarding the age and provenance of artefacts as well as technologies and trade routes used in their manufacture and distribution.

During the last years, the Institute of Applied Nuclear Physics of the University of Tirana and the Institute of Archaeology of the Center of Albanological Studies have initiated a cooperative study of the ceramic finds which aims the creation of a data base that apart from the archaeological characteristics of the ceramic finds will also include their respective analytical data. This will help for a better characterization and classification of the ceramic finds in the future.

In this context Energy dispersive X-ray fluorescence (EDXRF) spectrometry is being used for the elemental analysis of ceramic samples. EDXRF is a non-destructive technique, capable of quantifying a
wide range of chemical elements, within the concentration range from parts per million to percentages. EDXRF allows the relatively fast and cost effective analysis of the samples.

In this work, we will describe the analytical procedure used for the EDXRF analysis of ceramic samples and will present some data obtained from the analysis of a small group of ceramic samples belonging to two different early Neolithic sites in Albania.

The archaeological excavations of the Neolithic sites in Albania show that this area has been the centre of the confluence of different cultures with various levels of development, ideology and social organization [1].

Pottery manufacturing during early Neolithic in Albania is classified in two major groups: north culture represented by Koloshi site and south culture represented by Podgorie site. Early Neolithic period in southern Albanian territory is characterized by plain red shiny ceramics, sometimes painted in white over red background and also simple clay figurines which set up direct cultural report with early Neolithic in the area of Thessaloniki. Northern Albania’s representative culture is characterized by barbotine ceramics, ceramics painted in brown ink over red background, and also impreso ceramics which set up report with Rudnik’s culture in Kosovo and with all the other cultures in central Balkans [1].

2. EXPERIMENTAL

2.1. Sample preparation

We will consider here a small group of pottery sherds from the collection of the excavations at two early Neolithic sites in Albania that represent the two different cultural groups. The site named Blaz is situated in north while the site named Vashtri is situated in south east. Around 25 sherds were collected from each site and we were allowed to cut small pieces and use them for the analysis.

The samples were prepared in the form of thick pressed pellets. The sherds were first cleaned from depositions, dried overnight at 105 °C, grinded in a mixer/mill for 15 min and the fine powder (< 200 mesh) was converted in a pellet by pressing at 25 T [2].

2.2. Energy dispersive X-ray fluorescence (EDXRF) system

The samples were measured in secondary target excitation EDXRF system, using Cu and Mo secondary targets for excitation of low- and medium-Z elements, respectively.

The system consist of a Philips 1729 x-ray generator equipped with a Mo anode x-ray tube, a 30mm² Princeton Gamma Tech (PGT) Si(Li) detector, a Canberra Model 2024 Fast Spectroscopy Amplifier, a Canberra Model 8706 Fast ADC and a PC-based Canberra S-100 multichannel analyzer.

The low Z elements were excited in vacuum using the K radiation of Cu secondary target while the other elements were excited in air by Mo secondary target. The x-ray generator was operated at 20 kV for Cu target and at 35 kV for Mo target. The current, in both cases, was kept at 20 mA that allowed the dead time to be < 15%. The samples were measured for 1000-2000s.

The intensities of the analytical lines were calculated by fitting the spectra with the program AXIL [3].

The program COREX [4], which uses fundamental parameters and backscattered peaks from the measurements, was used for the calculation of the concentrations. This program uses mass absorption coefficients as fundamental parameters while excitation-detection efficiencies scattering coefficients for coherent and incoherent peaks are determined by the measurements of a set of standards prepared from pure compounds or elements. Around 60 pressed pellets prepared from pure compounds or elements were measured for the necessary calibrations.

In these conditions we could detect more that 20 elements in each ceramic sample.

3. RESULTS AND DISCUSSIONS

3.1. Analytical parameters

The values of the detection limit represent the concentration of an element with the intensity of the characteristic line equivalent to three standard deviations of the background at the energy of its characteristic line. The values of the background for each element were obtained by AXIL and the corresponding sensitivities are calculated by COREX. The calculated values of the detection limits vary from about 1% for Na to a few mg/kg for Sr and Zr.

The precision of the procedure was evaluated by repeated measurements of the Standard Reference Material GSS-1 (Chinese soil SRM) [5], which was frequently measured together with the samples. The data are summarized in table 1. It can be seen that the relative standard deviations for major elements are better than 5 %, while for minor elements it is generally within 15 %, except for some elements that suffer line interferences or have concentrations close to detection limit.

An assessment of accuracy was based on the analysis of around 25 international reference materials (Chinese soil and sediment SRM, Japanese rock SRM, and some IAEA soil SRM), which represent soil, sediment and rocks and resemble the composition of our ceramic samples [5]. The fact that these reference materials are well documented with recommended values of many elements allowed us to collect enough data for the elements Al, Si, K, Ca, Ti, Mn, Fe, Cu, Zn, Ga, As, Rb, Sr, Y, Zr and Pb.

On plotting ‘expected’ versus ‘analysed’ values most elements showed strong linear trends. Selected data are plotted in figure 1 for the following elements: Si and Fe, representing important major elements; Zn, representing a trace element with good excitation probability; Sr, representing a geochemically important element for which sensitivity is high.

These data are considered to demonstrate excellent linearity (R²>0,99). Further examination of these lines showed that beside the linearity, the lines have slopes very close to 1 and very small intercepts, approaching to the ideal one to one line of equivalence i.e. the
equivalence between ‘analyzed’ and ‘expected’ values. Generally the slopes differ from 1 by a value which is smaller that the precision of their determination while most of the times the intercepts are close to the detection limit values. These results show that a high degree of accuracy can be achieved during the analysis of geochemical samples.

Table 1 Reproducibility of the determinations

<table>
<thead>
<tr>
<th>Element</th>
<th>Certified Average</th>
<th>Calculated Average</th>
<th>St Dev</th>
<th>Rel St Dev (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Al (% )</td>
<td>7.124</td>
<td>7.200</td>
<td>0.25</td>
<td>3.5</td>
</tr>
<tr>
<td>Si (% )</td>
<td>27.804</td>
<td>27.65</td>
<td>0.62</td>
<td>2.3</td>
</tr>
<tr>
<td>K (%)</td>
<td>1.168</td>
<td>1.122</td>
<td>0.03</td>
<td>3.9</td>
</tr>
<tr>
<td>Ca (%)</td>
<td>0.459</td>
<td>0.439</td>
<td>0.01</td>
<td>2.2</td>
</tr>
<tr>
<td>Ti (%)</td>
<td>3.448</td>
<td>3.510</td>
<td>0.04</td>
<td>1.1</td>
</tr>
<tr>
<td>Fe (%)</td>
<td>81.7</td>
<td>97.6</td>
<td>25.7</td>
<td>26.3</td>
</tr>
<tr>
<td>Cr</td>
<td>19.9</td>
<td>1663.0</td>
<td>11.9</td>
<td>18.7</td>
</tr>
<tr>
<td>Mn</td>
<td>31.8</td>
<td>136.5</td>
<td>5.5</td>
<td>17.7</td>
</tr>
<tr>
<td>Ni</td>
<td>1671.9</td>
<td>1663.0</td>
<td>48.2</td>
<td>2.9</td>
</tr>
<tr>
<td>Cu</td>
<td>19.9</td>
<td>25.2</td>
<td>6.5</td>
<td>25.7</td>
</tr>
<tr>
<td>Zn</td>
<td>646.0</td>
<td>639.1</td>
<td>15.8</td>
<td>2.5</td>
</tr>
<tr>
<td>Ga</td>
<td>18.3</td>
<td>16.9</td>
<td>1.9</td>
<td>11.4</td>
</tr>
<tr>
<td>As</td>
<td>133.0</td>
<td>136.5</td>
<td>1.8</td>
<td>1.3</td>
</tr>
<tr>
<td>Rb</td>
<td>11.0</td>
<td>10.6</td>
<td>1.2</td>
<td>11.7</td>
</tr>
</tbody>
</table>

3.2. Results from ceramic samples

As was previously stated we have analyzed 23 ceramic sherds from the Neolithic site of Blaz and 31
sherds from the site of Vaštmi. In both sites the sherds belong to pottery with thick and thin walls. Most of the sherds show dark red and black colour with black layers in the middle and a few of them are painted on the surface.

Fig. 2 Photo of the sherds from the site Blaz

In each sample we have determined around 20 elements that include both the major and the minor elements. So we can characterize the clays used for the manufacture of the ceramics from the major elements, while some trace elements that concentrate in the clay fraction and whose concentrations vary largely among different geological formations, like barium, yttrium, scandium, manganese, iron, chromium, hafnium, zirconium, thorium, etc., can help us to observe the differences between the clays from different locations.

The analytical results indicate that the composition of samples from the different sites show observable differences as regards both the concentrations of major and minor elements that should reflect the differences of the clay composition at the different sites. In figures 3 and 4 are presented the tertiary plots respectively for some major and minor elements of the samples.

Fig. 3 Tertiary plot of some major elements

It is interesting to point out that while the samples from Vaštmi form a rather compact group in both plots (narrow concentrations range), the samples from Blaz are much more scattered. This can be an indication that the same clay sources around Vaštmi have been exploited for a long period while those of Blaz have changed through time or some of the ceramics are coming from other sites.

Although the analytical data collection should be considered at a preliminary stage there are some indications that can support the thesis of the exchange of the ceramic objects between the sites.

4. CONCLUSIONS

The analytical procedure based on EDXRF spectrometry is suitable for the analysis of ceramic samples. The analytical parameters obtained during the analysis of pressed powder pellets of soil and sediment samples were evaluated. The calculated detection limits show values from about 1% for Na to about 5 ppm for the elements from Rb to Zr. The precision for major elements is generally better than 5%. For most of the minor and trace analyzed elements the values of precision are within 10% and even at concentrations that approach the detection limits they are better than about 25%. The accuracy of the results was checked by measuring standard reference materials. Generally a good agreement between the measured and recommended values was observed.

The analytical results obtained for the studied ceramic sherds allow the characterization of clays used for their manufacture and permit their differentiation due to different clay sources.

The extension of the study by increasing the number of samples of early Neolithic from each site, including of samples from other periods of Neolithic from these sites and the inclusion of samples from other similar sites, together with investigations using other analytical techniques (microscopy, XRD, etc.) will help for a better interpretation of the results.

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RADIONUCLIDE RATIO IN TENORM STUDIES

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Abstract. This article considers anthropogenic uranium detection methods in soil based on the relationship between $^{238}\text{U}$ activity concentration and other natural radionuclide activity concentrations. A pronounced shift in the balance between $^{226}\text{Ra}$ and $^{238}\text{U}$ suggests that external causes modify the radionuclide activity concentrations in the decay chain. When reliable $^{235}\text{U}$ activity concentrations from anthropogenic uranium sources are confirmed, a significant difference in the $^{238}\text{U}/^{235}\text{U}$ ratio, i.e., 21.7 is observed. There are several soil samples with low-activity $^{235}\text{U}$. Moreover, analysis of the $^{238}\text{U}/^{226}\text{Th}$ and $^{238}\text{U}/^{40}\text{K}$ ratios confirms the estimated additional uranium content. The time required for the formation of anthropogenic soil contamination can be determined using the $^{137}\text{Cs}$ activity concentration.

Key words: Radionuclide, uranium isotopes, gamma-spectrometry, radionuclides ratio, soil contamination, retrospective analysis.

1. Introduction

Controlling radionuclide contents in the environment is an integral part of radiation safety systems at companies that handle uranium. Monitoring is required to maintain the operation of the radiation facility and separate technology systems within the framework of the optimal technological regulations, which guarantees the protection of human health against the radiation effects. The monitoring results can provide rapid detection of content changes and the signals, causes and extents of an emergency situation. Moreover, monitoring can predict further changes and possible effects on staff and the public. It is very important to identify the necessary measures to ensure radiation safety and normal radiation conditions. These problems are solved with a reasonable determination of excessive uranium levels in objects with long-term radionuclide accumulations (e.g., soil and sediment), which is typically a result of radiation facility activities.

Rocks provide a matrix for soil formation that is typical for the monitoring area. The radioactivity level of the soil depends on the natural radionuclide contents in the soil-forming rocks. Published studies have shown that natural radionuclide contents can vary greatly within the same petrochemical rock type. The maximum radioactivity was detected in soils formed from acid igneous rocks. However, the highest radionuclide concentration was observed in fine soils, particularly in clay particles. Furthermore, soil radioactivity levels depend on, for example, landscape, weather conditions, vertical and horizontal migration in soils and biological accumulation.

Natural radionuclide contents change during soil formation relative to the content in the original rocks. Moreover, the natural radionuclide distribution within the soil profile appears to be inhomogeneous. Changes are determined by radionuclide properties and physical and chemical soil properties. The physical and chemical properties are necessary because soil-forming processes involve different rocks with distinct natural radionuclide contents. In such circumstances, the natural uranium content in the soil cannot be determined by its content in the newly formed rock compositions.

The identification of soil contamination enriched or depleted in uranium requires analysis of the relationship between the $^{238}\text{U}$ and $^{235}\text{U}$ activity concentrations, which naturally must be 21.7. A pronounced changed in the ratio indicates the existence of anthropogenic effects. However, this approach is only suitable for samples with detectable $^{235}\text{U}$ in the soil. Soils with a natural uranium isotope activity ratio require other identification principles for anthropogenic contributions.

The identification of anthropogenic soil pollution by natural radionuclides can be achieved by analysing the radioactive equilibrium change between $^{238}\text{U}$ and $^{226}\text{Ra}$ in the $^{238}\text{U}$ chain. The justification of additional uranium content can be obtained from the joint analysis of the radionuclide ratios of $^{238}\text{U}$, $^{226}\text{Ra}$, $^{232}\text{Th}$ and $^{40}\text{K}$. Using data on the formation of soil contamination by artificial radionuclides from global fallout allows for a retrospective assessment of an anthropogenic uranium contamination formation study area. In the present work, we show the possibility of using a gamma spectrometer with a high-purity germanium detector (HPGe). This equipment permits the identification of anthropogenic pollution of natural radionuclides in the environment and the quantification of the $^{238}\text{U}$ anthropogenic component in soil samples.
2. MATERIALS AND METHODS

In this study, topsoil samples weighing 2.0 - 3.0 kg were obtained. The samples were regularly scattered near a uranium enrichment facility. In the laboratory, the soil samples were dried at room temperature. Dried samples were ground and sifted to obtain a homogeneous mass. To reduce the emanation of radon, some activated charcoal was added to each sample. The following radionuclides were determined in the 23 soil samples: $^{226}\text{Ra}$, $^{214}\text{Pb}$, $^{214}\text{Bi}$, $^{228}\text{Pb}$, $^{235}\text{U}$, $^{238}\text{U}$, $^{40}\text{K}$ and $^{137}\text{Cs}$. Measurements were performed on a gamma spectrometric installation RKG-1 (BSI) with the HPGe detector having a relative energy detection efficiency of 1.3% MeV (at least 40%)

Soil samples were measured using gamma spectrometry in Marinelli geometry for 5.5 to 6 hours.

Gamma spectrometry of soil samples identifies the radionuclide composition. However, the difficulty in processing gamma-ray spectrometry results is related to peaks from nearby gamma-ray lines from other radionuclides that inhibit the detection of the investigated radionuclide. Therefore, the identification of $^{235}\text{U}$ and $^{226}\text{Ra}$ in soils is complicated by the fact that both nuclides have 186-keV gamma lines. There are two main approaches to solve this problem and to calculate the $^{226}\text{Ra}$ activity. First, the $^{230}\text{Th}$, $^{223}\text{Ra}$, $^{228}\text{Ac}$ activities are calculated; the $^{235}\text{U}$ and $^{226}\text{Ra}$ activities are not determined. Then, the $^{226}\text{Ra}$ activity is determined using the decay products of radium, i.e., $^{214}\text{Bi}$ and $^{214}\text{Pb}$, which are in equilibrium with $^{226}\text{Ra}$.

By adding activated charcoal, the loss of $^{214}\text{Bi}$ and $^{214}\text{Pb}$ activity from inert $^{222}\text{Rn}$ gas emanation in the investigated soil samples is reduced. The total activity from the peak at 186.6 keV is subtracted from the $^{214}\text{Bi}$ and $^{214}\text{Pb}$ activities to determine the $^{235}\text{U}$ activity.

3. RESULTS AND DISCUSSION

In the 23 soil samples, $^{235}\text{U}$ activity was only found in three samples (i.e., U18, U20 and U23). The resulting $^{238}\text{U}/^{235}\text{U}$ activity ratios in these samples reach 1.7, 3.1 and 4.1, respectively. This finding indicates a high $^{235}\text{U}$ content, indicating anthropogenic uranium sources entering the soil.

An analysis of radionuclide activity concentration ratios for $^{238}\text{U}$ relative to $^{226}\text{Ra}$, $^{232}\text{Th}$, $^{40}\text{K}$ was performed to determine the contribution of anthropogenic uranium. The radionuclide ratios are presented in Table 1.

<table>
<thead>
<tr>
<th>Concentration ratios</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{238}\text{U}/^{226}\text{Ra}$</td>
<td>0.14 – 1.81</td>
</tr>
<tr>
<td>$^{238}\text{U}/^{232}\text{Th}$</td>
<td>1.6 – 6.1</td>
</tr>
<tr>
<td>$^{238}\text{U}/^{40}\text{K}$</td>
<td>0.11 – 0.62</td>
</tr>
</tbody>
</table>

Asymmetry and kurtosis were analysed to form a group of non-contaminated soil samples. Initially, asymmetry and kurtosis were determined for 23 radionuclide $^{238}\text{U}/^{226}\text{Ra}$ ratios ranked by increasing order. The first 17 radionuclide ratios were determined to be symmetrical; large asymmetry appeared when adding additional ratios to the distribution. This finding suggests that the 17 radionuclide ratios were formed without anthropogenic influences because the samples of radionuclide relationships did not change. The undisturbed radionuclide ratios were modelled along the line describing the radionuclide ratios in mineral and organic soil components (Fig. 1, 2, and 3).

- **Fig. 1**: The ratio between $^{238}\text{U}$ and $^{226}\text{Ra}$ activity concentrations. Row 1 – Activity concentrations in soil samples without anthropogenic contamination. Row 2 – Activity concentrations in soil samples with anthropogenic contamination.

- **Fig. 2**: The ratio between $^{238}\text{U}$ and $^{40}\text{K}$ activity concentrations. Row 1 – Activity concentrations in soil samples without anthropogenic contamination. Row 2 – Activity concentrations in soil samples with anthropogenic contamination.

- **Fig. 3**: The correlation ratio between $^{238}\text{U}$ and $^{232}\text{Th}$ activity concentrations. Row 1 – Activity concentrations in soil samples without anthropogenic contamination. Row 2 – Activity concentrations in soil samples with anthropogenic contamination.
We performed the analysis for $^{238}\text{U}/^{226}\text{Ra}$, $^{238}\text{U}/^{232}\text{Th}$ and $^{238}\text{U}/^{40}\text{K}$ to obtain radionuclide ratios that were not exposed to human effects. These ratios distinguished eight samples that clearly contained excess $^{238}\text{U}$. The contamination of two samples (i.e., U6 and U19) could not be determined because the activity concentrations in these samples were located within the error of the modelled line even though the samples contained excess $^{238}\text{U}$.

Using linear equation plots additional $^{238}\text{U}$ contents in the soil samples were determined, and the soils were classified as contaminated. The $^{238}\text{U}$ activity concentrations were calculated using the measured $^{226}\text{Ra}$, $^{232}\text{Th}$, $^{40}\text{K}$ activity concentrations in the contaminated samples. There was a difference between the calculated and measured $^{238}\text{U}$ activity concentrations, corresponding to an anthropogenic contribution in Table 2.

Table 2 Estimates of additional $^{238}\text{U}$ activity concentration in soil samples.

<table>
<thead>
<tr>
<th>Sample id</th>
<th>$^{238}\text{U}$ activity concentration*, Bq/kg</th>
<th>Anthropogenic contribution to $^{238}\text{U}$ in activity concentration in soil samples, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 U1 4</td>
<td>30</td>
<td>$^{226}\text{Ra}$ activity concentration, equatio n 1</td>
</tr>
<tr>
<td>1 U1 5</td>
<td>40</td>
<td>$^{232}\text{Th}$ activity concentration, equatio n 2</td>
</tr>
<tr>
<td>1 U1 7</td>
<td>59</td>
<td>$^{40}\text{K}$ activity concentration, equatio n 3</td>
</tr>
<tr>
<td>1 U1 8</td>
<td>48</td>
<td>Mean</td>
</tr>
<tr>
<td>1 U1 9</td>
<td>22</td>
<td></td>
</tr>
<tr>
<td>2 U20 63</td>
<td>65</td>
<td></td>
</tr>
<tr>
<td>2 U21 119</td>
<td>76</td>
<td></td>
</tr>
<tr>
<td>2 U22 57</td>
<td>67</td>
<td></td>
</tr>
<tr>
<td>2 U23 77</td>
<td>77</td>
<td></td>
</tr>
</tbody>
</table>

* - the measured value of $^{238}\text{U}$ activity concentration in contaminated soil samples.

The additional $^{238}\text{U}$ in the contaminated soil samples ranged from 27% to 78% of the measured value. The differences between the estimates of additional $^{238}\text{U}$ obtained using the correlation relationships did not exceed 15%.

Retrospective analysis of soil contamination by anthropogenic uranium was performed. The formation duration of anthropogenic contamination in the soil was assessed by measuring the $^{137}\text{Cs}$ activity concentration in the soil samples. The surface soil layer is exposed to contamination from atmospheric $^{137}\text{Cs}$ deposition. This radionuclide is formed from atmospheric nuclear explosions and accidents at radiation facilities. The $^{137}\text{Cs}$ half-life enhances its accumulation in the upper soil layer. If the period of undisturbed soil is long, larger amounts of caesium are deposited. The absence of $^{134}\text{Cs}$ in the soil samples indicates no influence of modern radiation accidents, such as at the nuclear power plant in Fukushima.

The $^{137}\text{Cs}$ specific activities ranged from 0.5 to 69.2 Bq/kg for all samples. According to these results, the samples were divided into two groups of radiocaesium contamination associated with the time of upper layer formation (Fig. 4).

Fig. 4 Radionuclide relationship between $^{238}\text{U}$ and $^{137}\text{Cs}$ activity concentrations in soil.
Row 1 – Activity concentrations in soil samples without anthropogenic contamination.
Row 2 – Activity concentrations in soil samples with anthropogenic contamination.

Several samples were included in group 1, being exposed to atmospheric fallouts of less than 25 years. Moreover, group 2 consisted of soil samples in which caesium accumulated for more than 25 years.

All samples with anthropogenic uranium were exposed to atmospheric deposition for at least 25 years; the “younger” soils were not contaminated by anthropogenic uranium. The estimated soil formation periods of $^{238}\text{U}$ suggest that the existing radiation facility technologies discharge low-intensity uranium isotopes into the atmosphere. That cannot be detected by gamma-spectrometric soil measurements during a period of less than 25 years.

4. CONCLUSIONS

Gamma-spectrometric analysis allows for the identification of radionuclide compositions, the determination of radionuclide ratios and the estimation of the anthropogenic contribution to uranium activity concentrations in soils. Seven soil samples (out of 23) with excess $^{238}\text{U}$ were found. With the established radionuclide activity dependencies, the anthropogenic $^{238}\text{U}$ contribution was determined. In the contaminated soil samples, excess $^{238}\text{U}$ was estimated to account for 27% to 78% of the measured value.

Gamma-spectrometric determination of $^{238}\text{U}$ and $^{226}\text{Ra}$ activity concentrations is complicated because both nuclides have their own gamma line at 186 keV. In practice, the $^{226}\text{Ra}$ activity is determined using the daughter products of the radium decay, i.e., preferably $^{214}\text{Bi}$ and $^{214}\text{Pb}$, which are in equilibrium with the
parent radium. However, the line at 186.6 keV is appropriate for $^{235}\text{U}$.

The approximate age of anthropogenic uranium contamination in the soil can be determined using the $^{137}\text{Cs}$ content. Prolonged uranium accumulation in the soil requires more than 25 years in areas affected by radiation hazard emissions into the atmosphere.

**Acknowledgement:** This research has been performed with the financial support of the Ural Branch of the Russian Academy of Sciences, project 12-II-1042-2.

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ROMANIAN PEDIATRIC EXPOSURE TO IONIZING RADIATION FROM DIAGNOSTIC MEDICAL PROCEDURES

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Abstract. Medical exposure to ionizing radiation is the main source of artificial exposure, especially for children. Taking into account that children have a higher sensitivity to the ionizing radiation and thus a higher risk of developing certain cancers in adulthood, it is necessary to monitor all the exposures with the purpose of estimating the radiation dose received by each child. According to the legally binding provisions, the recording system at the hospital level shall include at least the information concerning: patient data, data on individual exposure parameters used and data for patient dose assessment, as appropriate (DAP-meter values, skin absorbed dose, DLP/CTDI indication).

Based on data recorded in some state pediatric hospitals in Romania, estimations were made for the frequency of X-ray examinations and the mean dose received by patients for major conventional radiological and CT examinations performed during the years 2011-2013.

In this study, the available data for patient dose assessment were DAP (Dose area product) and DLP (Dose length product) indications. The conversion coefficients for relating values of DAP/DLP into effective doses are estimated by the NRPB Report 262.

The obtained data suggest the necessity to introduce, at the national level, the health cards with a special section for the registration of all medical exposures to ionizing radiation and the estimated dose received by each pediatric patient. Referring additional radiological examinations to the pediatric patient should be done by raising awareness of the higher risks for children, taking into account the dose already received and the use of other non-ionizing imaging techniques.

Key words: pediatric medical exposure, pediatric patient doses

1. INTRODUCTION

Medical exposure to ionizing radiation is the main source of artificial exposure, especially for children. Because of their longer life expectancy, the risk of late manifestations of detrimental radiation effects is greater for children than for adults. For this reason, all exposures to diagnostic X-rays need to be justified and optimized in terms of benefit and risk.

Taking into account that children have a higher sensitivity to the ionizing radiation and thus a higher risk of developing certain cancers in adulthood, it is necessary to monitor all exposures performed with the purpose of estimating the radiation dose received by each child.

National legal framework harmonized with the relevant Community provisions stipulate the obligation and responsibility of the public health network to provide radiological protection for medical exposure of patients to ionizing radiation.

In this respect, the Order of Health Ministry no. 1542/2006 [1] and Order of Health Ministry no. 1003/2008 [2] were promoted, which ensured a system concerning the registration, centralization and reporting of patient doses on medical exposures to ionizing radiation. They stipulate that all providers of radiology and medical imaging examinations have to record patient data (name, personal identification number, gender, height, weight) and the information relevant for dose assessment (examination type, projection, procedure code, focus-film distance, field size, kV, mAs, DAP, DLP).

In addition, the hospitals have to report quarterly the centralized data of medical exposures. The reporting forms of the centralized data have to contain the exam type, procedure code, total number per exam type and its distributions on age groups and gender groups. Dose information should be also available, in terms of DAP-meter values, ESD (Entrance surface dose) or DLP indication.

Ministry of Health through the National Institute of Public Health - Regional Centre for Public Health, centralizes the data of medical exposure to ionizing radiation reported by the
providers of radiology and medical imaging examinations, and elaborates an annual report.

Unfortunately, the legal provisions above are not respected by all providers of radiology and medical imaging examinations, the data regarding the dose received by the patients being incomplete and / or incorrectly registered and reported.

2. METHOD:

The actual study is based on the data received by the National Institute of Public Health - Regional Centre for Public Health, concerning the conventional radiological and CT procedures performed in three leading providers of radiology and medical imaging examinations, with pediatric profile, belonging to the state health system in Romania, during the years 2011-2013.

The available data for patient doses assessment are DAP values for conventional radiological procedures and DLP indications for CT procedures. Conversion coefficients used for relating measured values of DAP/DLP indications to effective doses are estimated by the NRPB R262 [3], NRPB R279 [4] and RP 154 [5].

The study involved a number of 92492 conventional radiological examinations (radiography and fluoroscopy) on pediatric patients, 58 % were males and 42 % females. In terms of frequency of examinations by age group: 70% of those aged between 5 and 15 years, 25 % were aged between 1 and 5 years and only 5 % are patients less than 1 year.

As regarding the CT scan, the study includes 3422 CT examinations on pediatric patients. In terms of gender, 55 % are male and 45 % female and this proportion is similar with that of conventional X-ray examinations. Compared to conventional radiological exams the small changes are in the frequency distribution by age: 60 % are those aged between 5 and 15 years, 31 % were aged between 1 and 5 years and only 9% of patients younger than 1 year.

3. RESULTS

The main results of the study are presented tables 1-2 and figures 1-2. The distributions of the conventional radiological examination and CT examination of pediatric patients are presented in Fig. 1 and Fig. 2, and the mean effective doses per procedure type are presented in Table 1 and Table 2.

<table>
<thead>
<tr>
<th>X-ray procedure type</th>
<th>Mean Effective Dose (mSv)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Head AP</td>
<td>0.033</td>
</tr>
<tr>
<td>Head LAT</td>
<td>0.020</td>
</tr>
<tr>
<td>Sinuses</td>
<td>0.032</td>
</tr>
<tr>
<td>Chest/Thorax AP</td>
<td>0.019</td>
</tr>
<tr>
<td>Chest/Thorax LAT</td>
<td>0.050</td>
</tr>
<tr>
<td>Arms &amp; Legs</td>
<td>0.004</td>
</tr>
<tr>
<td>Cervical Spine Ap+LAT</td>
<td>0.057</td>
</tr>
<tr>
<td>Thoracic Spine AP</td>
<td>0.066</td>
</tr>
<tr>
<td>Thoracic Spine LAT</td>
<td>0.068</td>
</tr>
<tr>
<td>Lumbar Spine AP</td>
<td>0.075</td>
</tr>
<tr>
<td>Lumbar Spine LAT</td>
<td>0.138</td>
</tr>
<tr>
<td>Thoracic-Lumbar Spine AP</td>
<td>0.042</td>
</tr>
<tr>
<td>Thoracic-Lumbar Spine LAT</td>
<td>0.073</td>
</tr>
<tr>
<td>Sacro-coccygeal Spine</td>
<td>0.171</td>
</tr>
<tr>
<td>Pelvis &amp; hip</td>
<td>0.104</td>
</tr>
<tr>
<td>Abdomen</td>
<td>0.103</td>
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<tr>
<td>Renal</td>
<td>0.167</td>
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<tr>
<td>Gastrointestinal - Esophagus</td>
<td>0.131</td>
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<tr>
<td>Gastrointestinal - Stomach</td>
<td>0.280</td>
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<tr>
<td>Colon</td>
<td>0.567</td>
</tr>
<tr>
<td>Urography</td>
<td>0.199</td>
</tr>
</tbody>
</table>

**Fluoroscopy**

<table>
<thead>
<tr>
<th>X-ray procedure type</th>
<th>Mean Effective Dose (mSv)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chest/Thorax</td>
<td>0.342</td>
</tr>
<tr>
<td>Ba meal</td>
<td>0.898</td>
</tr>
<tr>
<td>Ba enema</td>
<td>0.594</td>
</tr>
<tr>
<td>Cystography</td>
<td>0.510</td>
</tr>
</tbody>
</table>
4. DISCUSSIONS:

Concerning the CT examinations frequency, it is considered, based on the received data at the country level, that the data from these three important pediatric hospitals from Romania are representative for the whole country. It can be observed from this study that the number of CT examinations is much smaller than the conventional radiological examinations (only 3.6% of the total number of examinations). A very slight increase in the frequency of CT examinations in the last 12 to 13 years was observed, from 3.1% to 3.6%, compared with the surge from 0.1% in 1995 to 3.1% in 2000 [6].

Analyzing the frequency of the X-ray conventional examinations on pediatric patients, it can be seen that 52.3% from the total number of X-ray examinations are the exams of arms and legs, followed by the thorax (22.9%), pelvis (6.8%) and head (5.3%) examinations.

Regarding the frequency of the CT examinations, 50.4% represents the head examinations, followed by the arms and legs examinations (13.1%), thorax (7.6%), abdomen + pelvis (6.7%) and abdomen (6.1%) examinations.

Considering that the trunk includes the majority of radiosensitive organs and tissues, we have to remark that the number of CT examinations of the trunk (including all combinations of thorax, abdomen and pelvis) represent 29.3% from the total number of CT examination.

5. CONCLUSIONS

In case of pediatric patients, considering their longer life expectancy and that the risk of late manifestations of detrimental radiation effects is greater than for adults, it is very important to correctly register the data and to keep the records for a long time and in good conditions.

Therefore, the authors consider appropriate the implementation of the health cards at the national level, with a special section for the registration of all medical exposures to ionizing radiation and the estimated dose received by each pediatric patient.

Also, while referring pediatric patients to radiological examinations the awareness of the higher risks for children should be employed. The referral physician should take into account the dose received by the child earlier and to consider the use of other non-ionizing imaging techniques.

REFERENCES

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and reporting patient doses”, Official Gazette from Romania, Part I no. 1042/2006
2. "Order of the Health Ministry no. 1003/2008 for approving the use of registration forms and reporting data on medical exposures to ionizing radiation”, Official Gazette from Romania, Part I no. 393/2008
Abstract. The paper presents results of monitoring of Solar UV radiation covering period of eleven years and ozone layer thickness over the period of seven years. The measurements were made at the site located at the campus of the Novi Sad University (45.33° N, 19.85° E and 84 m a.s.l.). Daily maximums of UV radiation are compared with those obtained by numerical model NEOPLANTA. Even though we present single point measurements, due to relatively small horizontal variations in the ozone fields, obtained results and considerations are valid not only for Noel Sad region, but also for wider region of Province of Vojvodina.

Key words: Solar UV radiation, ozone layer thickness, monitoring

1. INTRODUCTION

Increasing public concern over declining ozone levels and the resultant UV radiation reaching the Earth has brought the world-wide ozone and the UV radiation networks and also a need to communicate daily information about UV radiation level to the public in a credible and understandable manner. This standard establishes a quantitative index for reporting the level of harmful ambient solar ultraviolet radiation reaching the surface of the Earth to the general public. The Global Solar UV Index quantifies the exposure of the skin to ultraviolet radiation. UV index (accordingly to World Meteorological Organization [1]) is defined as:

\[ UVI = \int_{250 \text{nm}}^{400 \text{nm}} E_G(\lambda) \cdot C(\lambda) d\lambda \]

where the above integral is expressed in W m\(^{-2}\). \(E_G(\lambda)\) is the global spectral irradiance and \(C(\lambda)\) is the action spectrum for erythema proposed by CIE and defined by [2].

2. MEASUREMENTS

The measuring equipment is placed at the campus of the University of Novi Sad. Geographical data are: 45.33° N, 19.85° E and 84 m a.s.l. and these data are used in data processing.

For Solar UV radiation monitoring, the Yankee Environmental Systems (YES) UVB-1 piranometer is used. This is broadband instrument [3] that are often used to build up national Solar UV radiation monitoring networks. The estimated error, combining uncertainty stated by manufacturer and error introduced by A/D conversion, is less than 7 %.

The relative spectral response [4] of the instrument is close to the erythemal action spectrum [2]. Due to such spectral response, in combination with the solar spectrum, the resulting measured quantity is very close to the value given by integral in Eq. (1). The instrument is connected to a computer for data acquisition via data logger. Measurements are done every 30 sec. The results are averaged over 10-min time interval and together with minimal and maximal data values, are recorded in the daily data base. At the same time, measured values are sent to the internet web page http://cmep.rs where are available for the public use. Measured values are presented numerically as well as graphically, by the means of diurnal course of UV index.

For the monitoring of ozone layer thickness Microtops II, Solar Light Co. [5] is used. The instrument is equipped with five accurately aligned optical collimators, capable of a full field view of 2.5°. Each channel is fitted with a narrow-band interference filter and photodiode suitable for the particular wavelength. Short wavelengths of UV radiation are much more readily absorbed by ozone than the longer wavelengths in the same UV bandwidth. This means that the amount of ozone between the observer and the Sun is proportional to the intensity ratio of two wavelengths of Solar UV radiation. This instrument uses that relationship to derive the total ozone column (ozone layer thickness in DU) from measurements of three wavelengths 305.0 nm, 312.5 nm and 320.5 nm. This principle is very similar to the traditional Dobson instrument. Two additional channels at 936 nm and 1020 nm are used for water column and aerosol optical thickness determinations. Measurements are possible only when Sun’s disc is clearly visible, and the best results are obtained with the Sun high in the sky. For
3. RESULTS AND DISCUSSION

3.1. Ozone layer thickness

In order to facilitate the presentation of obtained results and discussion, the measured values of ozone layer thickness are presented in Figure 1 for the measuring period of seven years. Instead of the date, horizontal axes presents day of the year (DY). Results of measurements obtained for different years are presented in different colors (see figure legend). In this figure the range of the values corresponding to the values of ozone holes is clearly marked. As a threshold 220 DU has been used [6].

The middle part of year (approximately between 70th and 260th DY) covers the period of the beginning of spring to the beginning of autumn. In that part of the year the Solar UV radiation that reaches the stratosphere is the most intense, so production of ozone is also intense. The ozone layer thickness measured for that time of the year, from year to year, is more than 300 DU. In the middle of the year (around 170th day) the average value is around 350 DU with the standard deviation of 30 DU. This fact shows that there have not been significant changes in ozone layer thickness in that period of year. On the other hand, one can notice considerable lower values during winter (220 - 365 DU) for years 2010 to 2013 comparing to the years 2007 - 2009. The average value for 335th day for the period 2010 - 2013 is around 185 DU, while for the period 2007 - 2009 is around 270 DU. Obviously there is considerable difference in the ozone thickness for those two periods.

3.2. UV radiation

Solar UV radiation has been monitored since 2003 regularly and daily recordings (for every 10 min interval) has been stored in the data base. Particular stored data (as maximal daily values, doses and other) can be retrieved by applying software developed for these purposes. In this paper maximal values of UV index (UVI) over the years will be presented and commented. The values of maximal daily values on DY are presented in Figure 2 for all the years when measurements has been done. Results for different years are presented in different colors of the points (see figure legend). The points of the low values in spring and summer period corresponds to cloudy days and these results were not taken into consideration. Observed period covers 11 years. As it can be seen from this figure, maximal results were obtained for the year period around the beginning of the summer (end of June and beginning of July). These values are around 9 UVI. In other parts of the year the value of UVI is lower and minimal values are reached during the end of autumn, winter and beginning of spring. This is in absolute agreement with the changes of ozone layer thickness over the year.

Significant changes in measured values cannot be noticed over the observed period of years. In order to quantify this statement, all measured values are presented in Figure 3 together with three curves. The yellow one represents Gaussian fit on all measured
data excluding the data for cloudy days. The green line represents the envelope of maximal measured values and red one (with square points) is obtained by applying NEOPLANTA model [8] for a particular day of year in 10 days step.

Gaussian fit gives the curve that is in well accordance with the maximal measured values. During the summers the standard deviation (for the maximum of the fitted curve) is 0.6–UVI or about 7 %. This is expected result since ozone layer thickness and other relevant factor has not been changed considerably over the observed period.

The better basis for commenting results of UV monitoring is the curve obtained using NEOPLANTA model. It has been shown that this model predicts the values of UVI for clear days that are in excellent agreement with the measurements [8]. The outputs of NEOPLANTA model, included in Figure 3, were obtained using the average values for ozone layer thickness for particular days as well as for other values that enters computer code (humidity, aerosols, optical thickness etc). Agreement between measured values and NEOPLANTA is perfect for the period of the middle of the year (yellow and red curves between 120 and 240 DU). The maximal difference for that period is 0.4 UVI. For the rest of the year agreement is still good but for winters NEOPLANTA predicts some higher values than measured. Possible reasons can be the lower ozone layer thickness values than taken into account in NEOPLANTA calculation, but also the error in UVI measurements that depend on the Sun’s zenith angle since it increases with the decrease of the Sun’s zenith angle. Generally, it cannot be concluded that ozone mini-holes detected during monitoring of ozone layer thickness considerably influence UVI.

Fig. 3 The measured daily maximal values of UV index over 11-years long time period (points). Green line is the envelope of maximal recorded values. Yellow line is Gaussian fit to measured data. Red points and line are obtained using numerical model NEOPLANTA [8].

4. CONCLUSION

The ozone layer thickness and intensity of Solar UV radiation for the region of Novi Sad, Province of Vojvodina, Serbia were considered. The analysis of obtained results of ozone layer thickness over 2007 - 2013 time period has shown that from 2010 now on the low content of ozone has appeared in October-January periods. Before 2010 this had not been detected. In these year periods detected values of ozone layer thickness were bellow 220 DU, the values that correspond to the appearance of ozone holes (mini-ozone holes in this case). The appearance of low ozone content coincides with the air mass flow in the atmosphere as well as with the satellite ozone observations. For the rest part of the years, significant changes in ozone layer thickness have not been detected.

Considering time period of 11 years, during which UV monitoring has been done, one can conclude that significant changes in the intensity have not been detected. This is in agreement with the observation of ozone layer thickness. This conclusion is also supported by fitting of Gaussian to the measured results which gives standard deviation of less 0.4 UVI for the summer periods. Comparison of measured values to outputs of NEOPLANTA model showed also good agreement.

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REFERENCES

PRELIMINARY EXAMINATION OF THE GROSS ALPHA AND GROSS BETA ACTIVITY IN VITAMINS

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Abstract
In this paper, preliminary examination of the gross alpha and gross beta activity in vitamins is presented. The gross alpha and gross beta activity in five vitamin samples collected in the local pharmacies was determined. Investigation was performed in only these five vitamins because they can be found in pure form. The instrumentation which was used for count the gross alpha and gross beta activities is α/β low level proportional counter. Preparation of the vitamin samples for the gross alpha and gross beta activity measurement was performed used MARLAP method. Vitamins which were covered by these preliminary measurements are: C (ascorbic acid) in bag and tablet, D (cholecalciferol), E (tocopherol) and B3 (niacin). The obtained results for the gross alpha activity were less than minimum detectable activity (MDA), while the gross beta activity ranged from <266 to 347 Bq kg⁻¹.

Key words: gross alpha and beta, vitamins

1. INTRODUCTION

Radioactivity of food is one of the main sources of exposure to humans. A large fraction of natural radiation exposure is due to ingestion of food containing natural radionuclides such as ⁴⁰K, ²²⁶Ra, ²¹⁰Po and ²¹⁰Pb [1]. Monitoring of any release of radioactivity material to the environment is very important to determine the amount of change. Hence, the determination of radionuclides in environmental samples is a crucial task in relation to the protection of human health. Therefore, there is a need to establish reference levels associated with alpha and beta activity concentrations from each food type. Naturally occurring radionuclides in environment are ²³⁸U, ²³⁵Th, ⁴⁰K and their decay products. Radon and two of its disintegration decay products, ²¹⁸Po and ²¹⁴Po, are sources of alpha radiation. Thoron, on the other hand, has two beta-decay products, ²¹⁴Pb and ²¹⁴Bi. Radionuclides from the ²³⁵Th and ²³⁹U series are responsible for the majority of the alpha and beta activity concentrations. For beta activity concentration, the largest contribution comes from ⁴⁰K [2]. For anthropogenic radioactivity, gross alpha may pertain to screening for transuranics in wastes, while gross beta pertains to screening for fission products from accidental reactor releases [3].

Vitamins are a large group of organic compounds that are minor, but essential, constituents of food required for normal growth, self-maintenance, and functioning of human and animal bodies [4].

Vitamin C (ascorbic acid) is a hydrosoluble, antioxidant vitamin. Vitamin C is known for its reductive properties, being easily oxidated to dehydroascorbic acid. It acts as a powerful antioxidant which fights against free–radical induced diseases. This vitamin can be found in many biological systems and food-stuffs, namely fresh vegetables and fruits. Rich sources include blackcurrant, citrus fruit, leafy vegetables, tomatoes, green and red peppers, etc. Ascorbic acid plays a great role in the metabolic process of human bodies. Ascorbic acid is frequently used as an antioxidant in food industry to prevent unwanted changes in color [5].

Vitamin D (a group of fat-soluble secosteroids) plays a central role in the maintenance of calcium and phosphorus homeostasis via specific actions on the intestine, bone and kidney. Although several vitamin D metabolites have been implicated in mediating these actions, it is clear that the most potent is ¹α, ₂₅-dihydroxyvitamin D₃ (1,₂₅(OH)₂D₃) [6,7]. The body can also synthesise vitamin D (specifically cholecalciferol) in the skin, from cholesterol, when sun exposure is adequate (hence, its nickname the “sunshine vitamin”). Interestingly, Vitamin D has been proposed to act as a neuroprotective factor in several neurologic disorders or conditions including Parkinson’s disease, multiple sclerosis, cognitive troubles and neurovascular disorders [8].

The term “Vitamin E” applies to a family of structurally related compounds, the tocopherols (group
of eight fat-soluble compounds). The major forms of Vitamin E (alpha, beta, delta or gamma) differ in the number and position of the methyl group substitution on the chromanol ring. \(\gamma\)-tocopherol can be found in corn oil, soybean oil, margarine and dressings. \(\alpha\)-tocopherol, the most biologically active form of vitamin E, can be found most abundantly in wheat germ oil, sunflower and sunflower oils. As a fat-soluble antioxidant, it stops the production of reactive oxygen species formed when fat undergoes oxidation. Vitamin E plays an essential role in maintaining the structure and function of the human nervous system [9].

Vitamin B\(_3\) (niacin) is a water-soluble vitamin and one of eight B vitamins. Historically, adequate dietary niacin is known to prevent the disease pellagra. Numerous reports indicate that niacin might help to prevent atherosclerosis, diabetes and hypercholesterolemia. Niacin is effective in assisting burn-wound recovery and in the prevention of cataracts and skin cancer [10]. All B vitamins help the body to convert food (carbohydrates) into fuel (glucose), which is used to produce energy. The main sources of vitamin B\(_3\) are: meat, eggs, milk, liver, fish, potato, green vegetable and yeast.

Among different kinds of supplements, vitamins are a reliable indicator of the general population intake of certain radionuclides, since vitamins are consumed by a large segment of the population and contains biologically significant radionuclides. Because of these considerations, the aim of this study has been to determine the gross alpha and gross beta activity in vitamins, as preliminary investigation.

2. EXPERIMENTAL

2.1. Sample preparation

Vitamin samples were purchased in the local pharmacies in the area of Belgrade during October 2013. All vitamin samples are produced in Serbia, except vitamin B\(_3\), which is produced in USA. The details of the investigated supplements are given in Table 1. Except vitamin C in the bag, other vitamin samples contained excipients, such as: corn starch, cellulose, magnesium stearate, lactose monohydrate, tafe, gelatin, dicalcium phosphate, stearic acid, etc.

Table 1 Characteristics of vitamin samples

<table>
<thead>
<tr>
<th>Sample of vitamin</th>
<th>Manufacturer</th>
<th>Content of vitamin (mg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>C (in tablet)</td>
<td>Eko Farm</td>
<td>500</td>
</tr>
<tr>
<td>C (powder in bag)</td>
<td>Ivančić &amp; Sons</td>
<td>1000</td>
</tr>
<tr>
<td>D (in capsule)</td>
<td>Ivančić &amp; Sons</td>
<td>0.01</td>
</tr>
<tr>
<td>E (in tablet)</td>
<td>Galenika</td>
<td>10</td>
</tr>
<tr>
<td>B(_3) (in tablet)</td>
<td>Now Foods</td>
<td>500</td>
</tr>
</tbody>
</table>

The preparation of the vitamin samples included weighing (about 130 mg) and placing into a stainless-steel planchet, after then vitamin samples were fixed with technically alcohol. The counting of the samples was conducted immediately after preparation. The preparation these samples for measurement of the gross alpha and gross beta activities was performed used MARLAP method [11].

2.2. Measurement of alpha and beta activity

The gross alpha and gross beta activity in vitamin samples was determined by \(\alpha/\beta\) low level proportional counter Thermo Eberline FHT 770 T. The counting time was 7200 s for gross alpha and beta activity.

Calibration was performed by using standard source of \(^{241}\text{Am}\) (EM 445, Prague) with an activity of 224 Bq on the day 1\(^{st}\) August 2011 for alpha activity and standard source of \(^{90}\text{Sr}\) (EM 145, Prague), with an activity of 189.4 Bq on the day 1\(^{st}\) August 2011 for beta activity. The counting gas was a mixture of 90 % argon and 10 % methane. The counting efficiencies for the system are 26 % for alpha and 35 % for beta. The background of each detector was determined by counting an empty planchet for 3600 s.

To assure that radiological monitoring are reasonably valid, quality assurance programs necessary. These programs are needed to identify deficiencies in the sampling and measurement processes. Quality of sampling and measurement and calculated uncertainty are very important for predicting the dose for population. In addition, validation monitoring aims to prove whether the results are acceptable. The accuracy and reproducibility of gas proportional counter were verified on a periodic basis-every week. Calibration is done every week with calibration standards and efficiency is checked. Total background count rate without a source is monitored to verify that the detector and shield have not been contaminated by radioactive materials. Alpha and beta efficiencies of gas proportional counter were checked with \(^{241}\text{Am}\) and \(^{90}\text{Sr}\) sources, respectively.

The gross alpha and gross beta activity was calculated using the following formula:

\[
A_{\text{eff}} = \frac{I}{m}
\]  

(1)

where \(A_{\text{eff}}\) is the activity of the sample (Bq kg\(^{-1}\)), \(m\) is the mass of the sample (kg), \(I\) is given by the formula:

\[
I = \frac{(N - B)}{E_f}
\]

(2)

where \(N\) is the count rate for the sample (s\(^{-1}\)), \(B\) is the background (s\(^{-1}\)) and \(E_f\) is the efficiency of the detectors for alpha and beta measurements.

Minimum detectable activity was calculated by the equation (3):

\[
MDA = \frac{LLD}{m}
\]

(3)

where \(LLD\) is the detection limit (s\(^{-1}\)).

3. RESULTS AND DISCUSSION

Table 2 shows the results for gross alpha and beta activity concentrations from all the analyzed samples. The gross alpha activity ranged from <127 to <312 Bq.
kg⁻¹, while the gross beta activity ranged from <266 to 347 Bq kg⁻¹.

Republic of Serbia has no regulations about recommended levels of radionuclides in vitamins. The question is whether vitamins should be considered as drugs or food. In current regulations [12], the limits of the radionuclide content in medicines are the same as the prescribed limits of contamination in drinking water. For medicines in solid state, limits of contamination are equal to prescribed limits of radionuclide content in drinking water, expressed in Bq kg⁻¹, where volume of 1 L of drinking water is replaced with mass of 1 kg. Radioactivity concentrations in drinking water for gross alpha and gross beta should be 0.5 and 1.0 Bq L⁻¹, respectively. However, as can be seen from Table 2, gross beta activity in vitamin C, regardless of the form of the vitamin used, bag or tablet, was 347 Bq kg⁻¹, which can’t possibly be compared to drinking water where gross beta activity should be 1 Bq L⁻¹. Also, there is no information available in literature in world about recommended levels of radionuclides in vitamins.

Results obtained in this paper presented preliminary studies of radioactivity in supplements. It can be concluded that the existing regulation can’t be applied to vitamins. It is impossible to directly compare gross alpha and beta activity in vitamins with activity in water, because adults drink 730 L of water a year, but they can’t eat 730 kg of vitamins. Based on the fact that in vitamin C gross beta activity is 347 Bq kg⁻¹, which is much higher than the 1 Bq kg⁻¹ (if we compare with drinking water), gamma spectrometric measurement should be applied to see which radionuclides contribute to gross beta activity.

Table 2 Gross alpha and beta activity in vitamins

<table>
<thead>
<tr>
<th>Sample of vitamin</th>
<th>Gross alpha activity (Bq kg⁻¹)</th>
<th>Gross beta activity (Bq kg⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>C (in tablet)</td>
<td>&lt;312</td>
<td>347 ± 75</td>
</tr>
<tr>
<td>C (in bag)</td>
<td>&lt;312</td>
<td>347 ± 75</td>
</tr>
<tr>
<td>D (in capsule)</td>
<td>&lt;271</td>
<td>377</td>
</tr>
<tr>
<td>E (in tablet)</td>
<td>&lt;213</td>
<td>295</td>
</tr>
<tr>
<td>B₃ (in tablet)</td>
<td>&lt;127</td>
<td>266</td>
</tr>
</tbody>
</table>

4. CONCLUSION

The determination of the gross alpha and beta activity used MARLAP method and measurement on α/β low level proportional counter described here proved to be useful and reliable to supply data on radioactivity in vitamins. Investigated vitamins were: C, D, E and B₃, as vitamins which are mostly used as supplements. Obtained values ranged from <127 to <312 Bq kg⁻¹ for the gross alpha activity and from <266 to 347 Bq kg⁻¹ for the gross beta activity. This study shows the preliminary examination of the gross alpha and gross beta activity in vitamins. There is no regulation for limit values for gross alpha and gross beta activity concentrations in vitamins for Serbia, thus the authors do not know the limit that can be hazardous to the population.

Acknowledgement: This paper is a part of the research done within the project III 43009. The authors would like to thank to the Ministry of Education, Science and Technological Development of the Republic of Serbia.

REFERENCES

DESIGNING AND FABRICATION OF AN IONTOPHORETIC TRANSDERMAL DRUG DELIVERY SYSTEM

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Abstract: Iontophoresis is a process used to deliver drugs through the skin into the body. To deliver the correct dosage of drug, the current flow through the skin must be actively controlled. This can be performed by means of an automated system. The transdermal drug delivery system that uses this technique is completely non-invasive. The main advantage of a transdermal drug delivery system is providing a controlled release of the drug without serious pain to the patient. In this work, a simple, low-cost and portable iontophoretic system based on skin modeling was designed and fabricated that allows the user to select the level and frequency of the current pulse (varies for each type of drug) and the polarity (depending on the drug). The system consists of a constant current driver circuit, the selection of current level unit, the polarity change unit and a microcontroller-based control. Performance of the system was evaluated by the skin model which was especially designed for iontophoresis system.

Key words (bold): iontophoresis, transdermal drug delivery, constant current driver.

1. INTRODUCTION

The application of electricity to the skin has found widespread diagnostic and therapeutic application in medicine. A common use is the enhancement of the transdermal flux of charged molecules through the skin, usually in the form of iontophoresis.

1.1. Iontophoresis

Iontophoresis may be defined as a phenomenon, which involves the use of electric potential to drive an ionic solute into the systemic circulation without any invasive procedures. Iontophoresis may be applied to a number of drugs to avoid using needles, lower dosage requirements, and provide constant therapy by continuous drug input. Iontophoresis is the method of using an electrical current to assist the infusion of a drug through the skin. The advantages to this approach are many. First, the medicine can be dosed at very high levels locally, rather than a lower dose distributed throughout the body. Second, there are far fewer side-effects associated with localized application of the medicine. Drugs suitable for iontophoretic application must carry a charge, have moderate molecular mass, partition well in both hydrophilic and lipophilic environments, and be relatively potent[1]. This technique has been classified as transdermal delivery system. The non-invasive nature of the method has led to the increase in the patient compliance. This has been attributed to the various disadvantages of the conventional delivery systems, viz. oral and parenteral delivery systems. Since the procedure allows the administration of the drug directly into the systemic circulation, various drugs with short shelf-life may also be tried as a formulation. The potential of this technique has been exploited by various researches for the transdermal delivery of many drugs with poor penetration properties (e.g. high molecular weight electrolytes such as proteins, peptides and oligonucleotides) which are normally difficult to administer except through parenteral route. Most of the drug molecules are ionic species which allows the administration of the drug using electric potential by facilitating its easy penetration through the skin into the systemic circulation[2].

1.2. Skin Modeling

It is well-known that mammalian skin possesses electrical properties. Over time scientists have learned to exploit these properties for iontophoretic delivery. For this study we need to learn about skin modeling. The typical arrangement for measuring the skin resistance with the dry electrode is a voltage source in series with a current sensing resistor, connected to the electrodes that are applied to the skin. The skin has been studied using this experimental setup, with electrodes of various sizes, materials and over a range of frequencies. A list of such studies are shown in table 1.

Previous Researches have found that skin impedance can be modeled by typical RC (resistor-capacitor) circuits, without the need of any inductive component[3] (see Fig. 1 and equations (1), (2)). We examined the drug delivery method through iontophoresis based on this skin impedance model. Of
course, It is essential to note that Skin impedance decreases during an iontophoresis treatment due to increased blood flow between the electrodes.

\[
I_E + I_R = C_m \frac{dU_m}{dt} + U_m G_t
\]

\[
C_m / G_t = -U_m \left( \frac{dU_m}{dt} \right)
\]

Table 1 experimental design of studies of the dry skin

<table>
<thead>
<tr>
<th>reference</th>
<th>Duration (s)</th>
<th>stimulus</th>
<th>Electrode area (mm²)</th>
<th>frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>[5]</td>
<td>20</td>
<td>Square, 24</td>
<td>56</td>
<td>0.2-500</td>
</tr>
<tr>
<td>[6]</td>
<td>9</td>
<td>250-600 v</td>
<td>0.018</td>
<td>DC</td>
</tr>
<tr>
<td>[7]</td>
<td>500</td>
<td>Sine, 200µA/cm²</td>
<td>100</td>
<td>0.01-100</td>
</tr>
<tr>
<td>[8]</td>
<td>40</td>
<td>Sine, 110 Vpp</td>
<td>100</td>
<td>0.01-5</td>
</tr>
<tr>
<td>[9]</td>
<td>40</td>
<td>15 v</td>
<td>0.15</td>
<td>DC</td>
</tr>
</tbody>
</table>

2. FABRICATION DESIGN

In this study, A constant current iontophoretic device was designed and fabricated. Block diagram of the iontophoresis device is shown in Fig. 2.

![Fig. 2. Block diagram of the iontophoresis device](image)

For driving the circuit, it is necessary to use a voltage booster. This part consists of a regulator (LM317), a capacitor, a diode and a potentiometer. This, provides the needed voltage for circuit. Using the potentiometer, the voltage is changeable.

The iontophoretic driver circuit should be able to deliver constant current for a particular experimental condition. LM 317 (variable voltage regulator, to be in making a constant current source) was used for maintaining constant current during an experiment. This constant current source was designed to drive a low level DC current for iontophoresis. This part of circuit provides a constant current based on the amount of voltage applied at the input to the circuit.

Higher current intensity is necessary in areas where skin and fat layers are thick. Because of using an alternating current to enhance drug delivery and iontophoretically drive drug into delivery site, the user can select current level using volume potentiometer. This unit permits user to select current level by a volume potentiometer. The current density should not exceed 0.5mA/cm² [10].

Because the desired drug is polarity sensitive, we used the transistor circuit for providing a regulated and periodically reversible electrical current into a type of skin electrical impedance model (the patient). So, we used the transistor circuit to change polarity for each drug. The magnitude, duty cycle and frequency of the positive and negative currents are substantially the same.

Pulses that drive transistor circuit, was controlled by a microcontroller (AVR atmega32, Atmel). Since the current waveform is controlled by the program, less electronic components are required to generate different frequency ranges of current and this reduces the overall device size. The iontophoretic device consists of a programmable microcontroller and controllable constant current output stage with a graphical LCD.

The microcontroller is programmed to produce pulses of frequency 0.5Hz – 1kHz, duty cycle of 50%, and output current magnitude is variable with potentiometer from 0.05-0.5mA, limited only by current source compliance.

Designed Circuit diagram in Altium Designer software can be seen in appendix.

3. SOFTWARE PROGRAMMING

To control the circuit, we used ATmega32 MCU. The microcontroller produces four frequency levels that is selective by user.

The microcontroller was programmed to set the output current to zero when the time exceeded a particular threshold.

The programs written in BASCOM-AVR, that is the original windows basic compiler for the AVR family.

The software and microprocessor easily allow passage of AC for periods of time up to 20 minutes or greater at any one polarity.

4. RESULTS

The waveforms of current output at four different frequency levels was observed. The result was acceptable. The accuracy of the device to deliver a constant current was evaluated. Two resistors with resistance of 1kΩ ± 1% and 100Ω ± 1% and a capacitor with the capacity of 100 µF were used to simulate the resistance of human skin and they formed an equivalent impedance. An ammeter was placed in series with the section of the circuit where a constant current was intended to pass in a no-load configuration. The ammeter was set to AC current
mode to measure milliampere current and the value of current was recorded after the reading stabilized at each amplitude in the range of 0.3 to 1 mA with the resolution of ± 0.001. The current level was changed by volume potentiometer. An example of the output pulse is shown in Fig. 3.

The constant current driver circuit was tested to determine its ability to deliver current to the skin, with a beautification mask, being sampled over the range of frequencies and amplitudes used in the measurement profile.

Fig 3. An example of the output pulse

5. CONCLUSIONS

The experimental derived results are consistent with the expected results. Based on the results, an optimized design was proposed. The results above show that the device is expected to operate effectively for drug delivery using iontophoresis. The simplicity of the device is evident since polarity and duration and frequency of the applied current can be adjusted by software and stored inside the microprocessor.

The electronics required for iontophoresis can be implemented using a small, low-cost microcontroller to drive a controlled current through the skin. The software-based control can be easily modified for additional features and for changes in the dose and duration without requiring hardware changes.

Suggestions for future works is developing transdermal absorption of a number of pharmaceuticals, particularly the macro-molecular drugs such as insulin and cationic drugs like propranolol HCl, because they have not been absorbed transdermally to any significant degree.

REFERENCES

Appendix:

Fig 4. Circuit diagram showing all the essential components. (a) part of voltage booster, (b) part of constant current source, (c) selection of current level unit, (d) polarity change unit, (e) Microcontroller - based control unit
Mathematical Modeling of Total Dose to a Hypothetical Resident in the Environment of Nuclear Facility by Contamination Through the Atmosphere

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Abstract. This paper presents an algorithm for the calculation of internal and external doses, which is an integral part of the mathematical model of atmospheric dispersion. Results of modeling were compared with values from an IAEA publication for a given scenario of radionuclide emission to the atmospheric boundary layer. Due to small differences in the results, compared to the IAEA recommended model, model presented in the paper can be used as a basis for this type of analysis.

In order to illustrate the application of this mathematical model (atmospheric dispersion + module for the calculation of radiation doses), using data of the hypothetical emission of radionuclides, ventilation parameters, then 3D topography and meteorological data, field of total annual dose received by a hypothetical resident in the vicinity of the reactor, during its routine operation over one-year period is presented.

Key words (bold): nuclear, air, dispersion, model, deposition, dose

INTRODUCTION

Exposure from the normal operation of a nuclear reactor to members of the public in its vicinity can occur from airborne releases. In analysis of doses from airborne releases through ventilation of a reactor, air pollution dispersion models play an important role. They could easily include large number of grid points so that outputs from the models are practically continual fields of air pollution.

MATHEMATICAL MODEL AND INPUT DATA

One such most frequently used model in the world is Gaussian straight line plume model [1]:

\[
C(x, y, z) = \frac{Q}{2\pi\sigma_y\sigma_z u} \exp \left( -\frac{1}{2} \frac{y^2}{\sigma_y^2} \right) \left[ \exp \left( -\frac{1}{2} \frac{(z - H)^2}{\sigma_z^2} \right) + \exp \left( -\frac{1}{2} \frac{(z + H)^2}{\sigma_z^2} \right) \right]
\]

Where:

\( C(x, y, z) \) (air pollution concentration at grid point (x, y, z))
\( Q \) source strength
\( H \) effective height of source emission
\( \sigma_y, \sigma_z \) diffusion coefficients in y and z directions
\( u \) average wind speed

To account for gravitational settling of heavy gases and aerosols we modified fixed height of emission H with the term:

\[
\left( H - \frac{v_s x}{u} \right)
\]

Where:

\( v_s \) terminal velocity
\( x \) downwind distance

Meteorological data are obtained by measurements at the automatic meteorological station, at least as an hourly meteorological data collected at a representative location of the source. On the basis of these data atmospheric stability and sigma parameter are obtained, as well as air pollution distribution on the basis of wind speed and wind direction.

During routine operation of the nuclear reactor, a part of radionuclide inventory is released via the ventilation stack. It is a conservative assumption that 1
% of the total activity inventory will be released in this way over one year. An upper estimate for the total activities and for the resulting release rates is contained in the Table 1.

In addition to the meteorological data (see Fig. 1) and emission of pollutants (Table 1), the physical characteristics of the sources are expected as input data for the mathematical model. With the 3D topography of the hilly terrain and with the physical and chemical characteristics of the emitted substances in the atmospheric boundary layer, minimum set of input data to run the model is completed.

![Fig. 1. Meteorology, annual wind rose, graphical presentation of wind speed and direction statistics](image)

Physical characteristics of the source that used in the model are its strength, physical height of the source, diameter at the top/exit of the source/chimney, gas temperature at the exit, exit vertical velocity of effluents, geographical coordinates and base of elevation of the source (see Fig. 2).

![Fig. 2. Topography (3D) of the computational domain and location of the source](image)

**Table 1. Source strength (radionuclide inventory), publicly available data from Brookhaven National Laboratory U.S. [2]**

<table>
<thead>
<tr>
<th>Nuclide</th>
<th>Ci44</th>
<th>Co60</th>
<th>Fe59</th>
<th>Hg203</th>
<th>In224</th>
<th>I131</th>
<th>I133</th>
</tr>
</thead>
<tbody>
<tr>
<td>Emission</td>
<td>5.3e+16</td>
<td>6.9e+13</td>
<td>1.4e+15</td>
<td>2.2e+16</td>
<td>7.0e+15</td>
<td>1.2e+16</td>
<td>1.3e+17</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Nuclide</th>
<th>La140</th>
<th>Mo99</th>
<th>Na24</th>
<th>Nb22</th>
<th>Se46</th>
<th>Se75</th>
<th>Se91</th>
</tr>
</thead>
<tbody>
<tr>
<td>Emission</td>
<td>3.0e+17</td>
<td>5.7e+13</td>
<td>8.5e+16</td>
<td>1.8e+14</td>
<td>7.9e+12</td>
<td>7.5e+13</td>
<td>1.2e+17</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Nuclide</th>
<th>Tc99m</th>
<th>Ti44</th>
<th>Xe133</th>
<th>Xe135</th>
<th>Zn65</th>
<th>Zn69m</th>
</tr>
</thead>
<tbody>
<tr>
<td>Emission</td>
<td>2.2e+16</td>
<td>4.8e+13</td>
<td>3.8e+16</td>
<td>4.0e+17</td>
<td>7.2e+15</td>
<td>5.3e+14</td>
</tr>
</tbody>
</table>

Basic subroutines of the model are modules for the effective height of the source (Briggs plume rise concept) [3], module for ground deposition and module for estimation of dose.

The ground depositions of the radionuclides are calculated as follows:

\[
\dot{d}_i = (V_d + V_w) \cdot C_d \quad (3)
\]

where:

- \(\dot{d}_i\): total daily average deposition rate on the ground of a given radionuclide \(i\) from both dry and wet processes, including deposition either on to impervious surfaces or on to both vegetation and soil (Bq m\(^{-2}\) d\(^{-1}\));
- \(V_d\): dry deposition coefficient for a given radionuclide (md\(^{-1}\));
- \(V_w\): wet deposition coefficient for a given radionuclide (md\(^{-1}\)).

Annual radiation doses for a hypothetical resident are calculated as inhalation, dose of staying in radioactive cloud (dose of immersion) and a dose of radioactive material deposited on the ground in the form of dry and wet deposition. Total annual dose is calculated as sum of the doses listed above.

The doses from inhalation are calculated as the product of breathing rate, exposure time, dose inhalation coefficients and radionuclide concentration in the air, using an exposure time of an entire year (8760 h), an average breathing rate for adults of 0.95 m\(^3\)/h.

The doses from external irradiation from the activity deposited on the ground are calculated as the product of the ground surface concentration and the dose coefficients for surface deposits. External radiation dose received by the resident, which is immersed in a cloud of radionuclide/activities for observed annual periods, is proportional to the activity concentration in the air near ground, the exposure time and to the corresponding dose coefficients for radionuclide in the cloud.

**RESULTS**

Analysis of radionuclide dispersion through boundary layer of the atmosphere, for routine operation of reactor, for members of the public was done, following all the assumptions described in regarding the source term, meteorological condition, 3D terrain topography and physical and chemical
characteristics of the emitted substances in the atmospheric boundary layer.

Three step analysis were done:

1. The described mathematical model eq. (1) for estimating the dispersion of radionuclides through the atmosphere boundary layer in the vicinity of a nuclear facility, with a module for the evaluation of internal and external doses for the hypothetical adult resident, was tested in computational experiments with using the given input data from the publication of IAEA [4].

Table 2. The concentration of activities at 2m above the ground, per radionuclide

<table>
<thead>
<tr>
<th>Radionuclide</th>
<th>$^{137}$Cs</th>
<th>$^{90}$Sr</th>
<th>$^{60}$Co</th>
<th>$^{154}$Eu</th>
</tr>
</thead>
<tbody>
<tr>
<td>Modelled</td>
<td>4.8E-04</td>
<td>1.5E-06</td>
<td>3.0E-05</td>
<td>1.5E-05</td>
</tr>
<tr>
<td>IAEA document</td>
<td>4.8E-04</td>
<td>1.6E-06</td>
<td>3.2E-05</td>
<td>1.6E-05</td>
</tr>
</tbody>
</table>

Table 3. Dry deposition of radionuclide activity per year

<table>
<thead>
<tr>
<th>Radionuclide</th>
<th>$^{137}$Cs</th>
<th>$^{90}$Sr</th>
<th>$^{60}$Co</th>
<th>$^{154}$Eu</th>
</tr>
</thead>
<tbody>
<tr>
<td>Modelled</td>
<td>154.2</td>
<td>0.49</td>
<td>9.74</td>
<td>4.87</td>
</tr>
<tr>
<td>IAEA document</td>
<td>174</td>
<td>0.6</td>
<td>12</td>
<td>6</td>
</tr>
</tbody>
</table>

In the Tables 2. and 3. are presented results for ground surface concentrations in air and for the ground surface concentrations, for four radionuclides that were given in order to check the model. Very good agreement was found with the results of the preliminary analysis given in IAEA document [4].

2. Simulation of the airborne dispersion from the exhaust stack of the reactor facility to the environment in order to obtain values of the ground surface activity concentrations in the air and the ground surface concentrations, dry and wet deposition, for the radionuclides of interest (see Table 1).

Fields of average annual concentration of activities, gained by the presented emission of radionuclides, taking into account the characteristics of sources, weather conditions and soil characteristics, are shown graphically (see Fig.3). The maximum average annual activity concentration in the air at 2m above the ground was 3.9 Bq/m$^3$.

Dry deposition was calculated from the activity concentrations in air and deposition rate for the selected terrain and for the radionuclide emission inventory. Speed of dry deposition is taken from the literature, [4] and was based on the recommendations for the deposition rate of 1000 m$^{-1}$. Field of dry deposition corresponds to field of concentration of activities, both in shape and by zones with maximum values. Maximum annual value of dry deposition of activities for the selected annual period was 12 kBq/m$^2$ (see Fig. 4).

Wet deposition is calculated as washing with precipitation. The intensity of rainfall was measured by an automatic station for ten minutes. Field of annual activities of wet deposition is calculated from the distribution of activity concentrations with the height and intensity of rainfall. Maximum value of wet deposition was 140 Bq/m$^2$ (see Fig.5).

3. Modelling of the exposure for members of the public, total dose (inhalation + immersion + direct exposure from the ground deposits)

As mentioned above, total annual radiation dose, for a hypothetical resident in the vicinity of reactor in operation, is modeled as inhalation, dose of staying in radioactive cloud (dose of immersion) and a dose of radioactive material deposited on the ground in the
form of dry and wet deposition. Total annual dose is calculated as sum of the doses listed above.

Maximum value of the total annual dose to a hypothetical resident was $7.3 \times 10^{-6}$ Sv (see Fig. 6).

**CONCLUSION**

This study presents fields of activity concentration in air, deposition on soil and field of total annual dose to a hypothetical resident in the vicinity of nuclear reactor, contaminated by air. In the analysis is used computer code based on straight line Gaussian model for atmospheric dispersion, under conservative assumptions about the continuous operation of nuclear reactors and on the strength of the source based on the inventory of radionuclides that are for one year continuously emitted into boundary layer of the atmosphere.

By applying mathematical model maximum value of the total dose for a hypothetical population by air was $7.3 \times 10^{-6}$ Sv in the vicinity of nuclear reactor.

If in areas with a maximum total doses, doses are below the limit values of $10 \mu$Sv, then it could be concluded that a nuclear reactor, under stated conditions of its operation, could not influence the environment above the limit values in a selected one-year period.

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**REFERENCES**


CONTRAST VERSUS PATIENT DOSE IN MODERN DIAGNOSTIC RADIOLOGY

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Abstract. The paper considers and comments different aspects of the correlation between image contrast and patient dose in radiological investigations. The modern systems, with silicon detector and Computed Radiography assure a reduction of dose compared with the film system (1.7 - 2 times), without affecting the image quality. This may be explained by the analysis of all physical processes. The silicon system seems to be the best. The doses are measured usually, with a validated phantom. The dose reduction by digital systems with or without added filters must be compared. Measurements are ongoing in a pediatric hospital on a phantom. The filters attenuate low energies which are most absorbed in the body (more than 97%). The filters may affect the contrast, but the physician, based on his experience, may ahoose the adequate compromise. Even a small reduction of effective dose, will represent a huge reduction of the "collective dose" of millions of patients in the world, every year.

Key words: contrast, x-ray filtration, patient dose, optimization

1. INTRODUCTION

A good radiographic image, with a good contrast is necessary for an accurate diagnostic in radiology. In the same time, reducing the patient dose at an optimum is as well important; the international regulations imposed it [1, 2].

The reduction of doses is made usually by better filtration and in modern systems by using special silicon and NaI detectors [3]. Every filtration affects the image to a certain extent. So, the balance between patient dose and image quality is a basic problem in radiology [4].

The paper tries to analyze some aspects of this problem.

2. GOOD IMAGE VERSUS LOW DOSE

A good image means a great information so a big number of photons producing the image; but this means too a high dose. So, the contradiction between good image and low dose is very clear.

In modern systems, the silicon and NaI detectors absorb photons much more than the classic film, with its thin X-to-light converter. So, for a given number of absorbed photons for good image, the number of incident photons is smaller in modern systems. This explains the reduction of dose with approx. 20% in modern systems.

One may still think of additional reduction, using various voltages or/and filters.

3. CONTRAST

Good image means a good contrast. In Fig. 1, a simple definition of the contrast is given.

\[
\text{Contrast} = \frac{I_1 - I_2}{I_1}
\]

Fig. 1 The contrast definition

For a greater absorption in T₂, I₂ is smaller, the difference between I₁ and I₂ is greater, and the contrast is greater. Its maximum is 1.

The contrast in Fig. 1 is called subject contrast, which may be followed by detector contrast and image contrast. The detectors contrast differs from the subject contrast because I₁ and I₂ have different spectra, and efficiency of detectors varies with spectra.
Table 1. The attenuation of X-beam

<table>
<thead>
<tr>
<th>$E_x$ (keV)</th>
<th>$\mu$ (m$^{-1}$)</th>
<th>0.2$\mu$</th>
<th>$e^{-0.2\mu}$</th>
<th>Absorbed radiation (%)</th>
<th>0.3$\mu$</th>
<th>$e^{-0.3\mu}$</th>
<th>Absorbed radiation (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>40</td>
<td>25.8</td>
<td>5.16</td>
<td>0.0057</td>
<td>99.4</td>
<td>7.74</td>
<td>0.0004</td>
<td>99.96</td>
</tr>
<tr>
<td>50</td>
<td>22.1</td>
<td>4.42</td>
<td>0.0120</td>
<td>98.8</td>
<td>6.63</td>
<td>0.0013</td>
<td>99.87</td>
</tr>
<tr>
<td>60</td>
<td>20.3</td>
<td>4.06</td>
<td>0.0172</td>
<td>98.3</td>
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<td>0.0022</td>
<td>99.78</td>
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<td>80</td>
<td>18.2</td>
<td>3.64</td>
<td>0.0263</td>
<td>97.4</td>
<td>5.46</td>
<td>0.0042</td>
<td>99.58</td>
</tr>
<tr>
<td>100</td>
<td>17.1</td>
<td>3.42</td>
<td>0.0327</td>
<td>96.7</td>
<td>5.13</td>
<td>0.0059</td>
<td>99.41</td>
</tr>
<tr>
<td>125</td>
<td>15.9</td>
<td>3.18</td>
<td>0.0415</td>
<td>95.8</td>
<td>4.77</td>
<td>0.0084</td>
<td>99.16</td>
</tr>
</tbody>
</table>

As modern systems use a lot of electronics, one finds in literature the parameter “Contrast-to-Noise Ratio” (CNR). Some specialists used even the parameter “Visibility Index” (VI). Some refined definitions of contrast are not useful, they rather complicate things.

4. DOSE

One measures usually the “absorbed entrance dose” (ESD) with adequate calibrated TLD detectors and “the Kerma in air”, $K$, with a calibrated ionization chamber. They represent maximum values; the integrated dose in the body is smaller. More than that, one has to calculate the “effective dose”, $E$. The effective dose is not strictly a physical quantity. It is a bio-physical quantity because it contains the response of organs and tissues to ionizing radiation. To calculate the effective dose special programs are used. For instance PCXMC code software of STUK (Radiation and Nuclear Safety Authority in Finland) using Monte Carlo methods. All programs depend of the X-spectrum, which is hard to obtain, due to the huge intensity of the beam. ESD may be calculated if the output, $Q$, of the equipment is known, as (mGy/mAs), for given voltage and distance from focus [5]. The uncertainty of all methods seems to be satisfactory, about 10%.

5. THE ATTENUATION OF X-BEAM, IN THE BODY

In Table 1 the attenuation of different energies in a body "made from water", with a thickness of 20 cm and 30 cm is presented, where $\mu$ is the linear attenuation coefficient in the water. For a real body, with a density a little greater than 1, the figures in column 5 and 8 will be still greater.

A huge part of the beam is absorbed with a very little contribution to the diagnostic.

So a more filtration than usual is needed, to attenuate the inefficient low energies photons [6]. It will attenuate the other energies also, to the benefit of the patient.

Some papers prove that this will affect little the image, for the modern systems with silicon and NaI detectors. These sentences are not valid for arms, legs and children radiographies. The figures in the column 4 (and 7) of the Table 1 are much greater and the low energies are important for the image.

The patient dose may be reduced with the parameter (mAs) but this will not change the shape of the spectrum.

In all cases, the physician, based on his own experience, may choose the right compromise, between patient dose and image quality.

6. RESULTS FROM LITERATURE

There are many trials to reduce dose, without affecting much the image. The reduction is imposed by several international documents. Of course, there are cases in radiology when image is primordial.

A few typical results are presented in the following:

A part from most papers is dedicated only to chest (CXR), paper [5] contains a good statistics for lombo-spine (LS) radiographs. 200 clinics cases were studied. The radiographs with a good image were obtained with 1 mm Al filters. The methods of screen-film (SFR), computed (CR) and digital (DR) radiology were compared. The doses were computed using the parameters of the equipment. The doses for (CR) were higher than for (SFR) with 27% to 57%, for different cases. Those for (DR) were lower than for (SFR) with 16% to 60%. For chest, (SFR), (CR) and (DR) had doses of 0.07, 0.11 and 0.06 mGy. For (LS), doses were greater, up to 5.7 mGy. The bad situation of (CR), observed too in some previous papers, is due perhaps to some routine procedures, neglecting a possible low-dose. In some other papers, both (CR) and (DR) are considered to provide low doses. Lower than for up-to date (SFR).

Another paper [7] may be considered reference papers. Though published in 2003. It contains a statistics for 300 patients, investigated with (SFR), (CR), and (DR). Every patient was equipped with 24 calibrated TLD detectors, for entrance skin doses and estimation of the equivalent dose for 12 organs in tissue. The effective dose was determined with an anthropomorphic phantom, with 166 TLD detectors, which allowed too the study of contrast. The reduction of doses by modern systems was studied, without filtrations. The image quality was observed by 5 experienced radiologists. Doses to every organs tissue were represented suggestive in the paper [7], for (DR),
(CR) and (SFR), for Posteroanterior and Lateral condition. The mean values for entrance skin doses (in micro Gy) were: 67, 165 and 200 for (DR), (CR) and (SFR), for the first condition. The effective doses were, (in micro Sv) in same order, 10, 19 and 23. For lateral radiograph, doses were about 5 times greater. An extended paragraph of discussions ends the papers, permitting to note advantage of digital radiology.

The paper [8] tries to find optimum voltages and added filtration for chest radiographs with computed systems. Three chest regions were studied: lung, heart/spine and diaphragm. A validated phantom was used, with voltages from 60 kVp to 125 kVp and Cu filters from 0.1 to 0.3 mm.

The desired optimum is referred to high contrast-to-noise ratio (CNR), so the images quality. CNR was determined as a function of air-kerma at the (CR) plate and of effective dose. The curves have logarithmic aspects. Three blocks of plastic in the phantom imitated the lung, the heart and the diaphragm. A lot of curves are presented, Cu filters has an effect only for diaphragm. But, filters must be used to reduce the inefficient exposure of patients with low energies (see paragraph 5).

The CNR is defined [8] as:

\[
\text{CNR} = \frac{\bar{x}_{\text{wax}} - \bar{x}_{\text{bgd}}}{\sqrt{\left(\sigma^2_{\text{wax}} + \sigma^2_{\text{bgd}}\right)/2}}
\]  

Where “wax” means pixels in the region of interest and “bgd” means pixels in background. An aspect not underlined by authors, is the fact that, due to a small slope of CNR/air kerma and CNR/effective dose, one may accept a 25% reduction in CNR, to reduce dose with 50% using a low (mAs)! The aspect explains why additional filtration does not affect too much the image.

The interesting paper [9] presents a low-dose, whole-body X-ray scanner. It contains a rotating X-ray tube with 1 mm Al added filtration, mounted on a C-arm. On the other side of C-arm, a detector is placed made from a scintillator array. A fan-beam is emitted through a narrow collimator of 0.4 - 1 mm width!

This fact, which eliminates much of the Compton exposures of patients, combined with some distances focus – skin and voltages higher than usual, allowed for doses lower than conventional radiography. This surprising result is a great advantage for patients.

Entrance-skin doses were measured with an ionization chamber. Effective doses were obtained using PCXMC (version 2.0) Monte Carlo code. The good images were studied with a phantom, with special inserts. It is normal that low doses obtained with collimation, distances and high voltages do not affect the image quality. The authors studied the influence of added filters and found that 0.1 mm Cu at voltages above 110 kVp, reduced the doses with ~ 20%! High voltages and (mAs) are necessary for large persons with inherent higher doses. The 0.1 mm Cu filter is now in use in all equipments of the type used. Large persons need more filtration, see paragraph (5). Lateral radiographies need more filtrations.

Some more analyzed papers and references allowed several conclusions. For general aspects, see [10].

7. CONCLUSIONS

A good image necessitates usually a high dose and a low dose may affect the image. These contradictions are natural. The modern systems with computer and digital radiology reduce doses.

The absorption of X-beam in the body is huge.

It is strictly necessary that the low inefficient energies must be attenuated by filtration, but this is rarely case in practice. Large persons need high voltages; they suffer high doses.

There are cases where image is primordial. The physician, based on his experience, may choose a right compromise between image and dose.

The variation of contrast with an increased dose has generally a small positive slope. To reduce contrast with only 25% means a great reduction of doses with 50%.

Even a small reduction of patient dose means great reduction in the collective-dose of millions patients over world, every year!

REFERENCES

THE EFFECT OF THE HIGH-FREQUENCY ELECTROMAGNETIC FIELD ON THE BETA CELLS OF THE ENDOCRINE PANCREAS OF RATS

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Abstract. Taking into account the poor and contradictory data on the effects of high frequency electromagnetic field on both human and animal pancreas, especially its endocrine part, this paper aimed at testing the animal model for morphological features of the pancreas beta cells under the impact of high frequency electromagnetic field featuring 1.9 GHz, 4.79 V/m, 2.0 W/m² for a 30-day period. In our experimental environment, HF EMF caused the increase in the number, volume density, and nucleo-cytoplasmic ratio and the decrease in beta cell surface in comparison with the control animal group, all of which indicated the enhanced activity. The experimental animal group consisted of Wistar rats and the pancreas tissue of both control and radiated animals underwent a series of standard and immunohistochemical coloring as a preparation for the stereological analysis. Briefly summarizing results of the paper, we may infer that the experimental animals that were subjected to HF EMF suffered morphological and morphometric changes in beta cells. As the insulin, the hormone they excrete, decreases the glucose level, the results indicate a potential diabetogenic action of HF EMF with rats.

Key words: endocrine pancreas, beta cells, high-frequency electromagnetic fields, immunohistochemistry

1. INTRODUCTION

The pancreas is of utmost relevance for the organism and the high frequency electromagnetic field is a typical environmental feature that might be regarded as a potential health risk factor. It is necessary to run experiments so as to gain results that might help infer potential health consequences (Parkinson, 1984, Loweth and Morgan, 1998). Bearing in mind the complexity of pancreas, the goal of our research was to determine the effect of high frequency electromagnetic field (HF EMF) on the beta cells of the endocrine part of pancreas. We were prompted by the fact that bibliographical data indicated a possible connection between the EMF exposure and constant increase in the number of diabetic patients. The application of highly specific immunohistochemical techniques on endocrine pancreas enabled a precise functional cell identification. A combination of methods confirmed the existence of five major cell types: alpha, beta, D, PP, and EC cells in the endocrine part of pancreas (Bani-Sacchi and Bani, 1985). Beta cells make 60-70% of all compact islets cells whereas the diffuse islets contain only 20% of these. Being the largest part of insulocit in cytoplasm, beta cells contain many secretory granules the size of 200 nm in which there is the crystallized insulin. The position of beta cells and the polarity of the insulin granules within the cell confirm the endocrine nature of their activity (Orci et al., 1987; Weir et al., 1990, Yamaguchi, 2001). Being exposed to HF EMF, biological tissues are under the impact of magnetic flux and electric fields, which might induce new electromagnetic fields (Adey and Pettis, 1997). Mechanisms of HF EMF activity on biological systems suggest that the fields transfer energy to proteins of the cell membrane modifying the cell membrane and protein receptors (Ravnborg et al., 1990). Furthermore, there is a proven perturbation of balance between the free radicals production and anti-oxidative protection by electromagnetic field (Parkinson, 1984; Ravnborg et al., 1990; Preece et al, 2000). As a stress factor (Ciesler et al., 1995), the HF EMF affects beta cells by inducing synthesis and insulin granule release. The increased insulin synthesis causes beta cells to form sincicium, i.e. the cell membrane fades (Grünewald et al., 2000). The World Health Organization declared the maximum norms of intensity and frequency of HF EMF within the human environment. Thus, 10 GHz is the maximum frequency, 45 V/m is the maximum intensity, and SAR is 5 W/m². These are indeed high values and there still has not been a worldwide agreement on them (Møhå et al., 2003; Matthes, 2005; Halsei and Henric, 2010).

Once we completed our experiment with poorer values of 1.9 GHz, 4.79 V/m and 2.0 W/m², the pancreas of both control and radiated animal groups were submitted to standard biochemical, immunohistochemical, cytological, histological, and stereological methods, which were applied in order to analyze the beta cell changes. The analysis of beta cells indicated that these cells were activated under
the impact of HF EMF, which might be considered as an adaptive, anti-diabetogenic response, i.e. the diabetogenic effect of insulin.

2. EXPERIMENTAL PROCEDURE

The testing of the effect of HF EMF on the endocrine pancreas was performed on Wistar white male laboratory rats, which had been exposed to the HF EMF starting with 60th up to 90th post-natal days and bred at the Banjaluka Faculty of Sciences vivarium. At the beginning of the testing, the two-month old animals were divided into two experimental groups – the radiated group consisted of 21 animals exposed to HF EMF and the control group consisted of 20 animals that were not exposed to any kind of HF field. During the experiment, 5 animals were placed per cage. Both experimental groups were subjected to the controlled day-night light rhythm (14 hours of daylight and 10 hours of dark), the air temperature being 20±3°C. They were fed by the standard pelleted lab food (Subotica Institute of Animal Health), and the water was consumed when necessary. The animals selected for the HF EMF treatment were exposed for 2 hours a day, 5 days a week. The control group were kept in a similar environment but were completely isolated from any kind of artificial HF EMF. The research was performed with the approval of the Ethics committee for the experimental animals of the Faculty of Sciences, University of Banjaluka. The apparatus that provided HF EMF was the Republic of Srpska mobile phone network basic station at the top of the Banjaluka Telecom building. The station generated for its own purpose the HF EMF in accordance with the “ZASTITA” Ltd. Banjaluka company (Report number 066/09, report date June 8, 2009, report time 10:05, air temperature at the moment of HF EMF intensity was 20°C. The measurement equipment was HF 6080 Rev2 No. 01099, HyperLOG 6080, manufactured by ARONIA Germany; the instrument frequency and measurement range was 1MHz – 7MHz, -90dBm – 10dBm, antenna 680 MHz – 6 GHz, manufactured in 2005. Once the thirty-day exposure was completed, in the early morning on 31st day the animals were decapitated under the diethyl ether narcosis. The decapitated animals covered 12 from the control group and 15 from the radiated group, and the pancreases were submerged in the pufferized Bouin solution. The paraffine moulds were then cut by using Reichert slide microtome and the histological sections of 4 μm. The histological content of both control and exposed animals beta cells was studied by the light microscope using different cross section coloring methods such as hematoxylin eosine, Malori Azan, Mason, and Victoria blue 8GX-floxin light green. The cross sections were also colored using immunohistochemical methods typical of beta cells of endocrine pancreas. DAKO LSAB+/HRP technique was used for the presentation and localization of certain endocrine cells of the islet (DAKO LSAB+ kit in which streptavidin was marked by peroxidase). In accordance with our starting point, the morphometric and stereological analysis of the number, volume density, nucleocytoplasmatic ratio, and beta cell surface were performed between the control group and the exposed animals. The photographs of beta cells were devised by using Leica 8000D microscope with MEGA VIEW camera and the software system for the digital transfer and photo analysis. All the figures were then displayed as mean values ± standard error, along with the standard deviation and the variation coefficient. The reliability of differences between pancreas, cells, and cell elements between the control and radiated groups was analyzed by using statistical tests such as ANOVA, MANOVA, SSPS 2007 and Excel 2007. The existence and level of differences in mean values of the monitored stereological parameters between the two groups were analyzed via the F-test and t-test.

3. RESULTS

The stereological analysis of the endocrine pancreas beta cell density illustrated the increase of volume density mean value with the animals exposed to HF EMF in comparison with the control group (Fig.1). The exposed animals displayed the increase of the beta cell number (Fig. 2, 5) per 43% (p<0.05), which was statistically relevant. The results of stereological analysis of the endocrine beta cell surface illustrated the decrease of this parameter with the animals exposed to HF EMF in comparison with the control group and this decrease was statistically relevant as well (Fig. 3, 6). The decrease was most evident with beta cell surface mean values per 42,96 μm² and the decrease of surface mean values was statistically relevant (p<0.05). The value of nucleo-cytoplasmic ratio (Fig. 4, 5) increased with beta cells and it was statistically relevant – almost 8% with the animals exposed to HF EMF in comparison with the control group.

![Fig. 1 – Volume density of beta cells control group and animals exposed to HF EMF](image-url)
Fig. 2 – Number of beta cells in Langerhans islets control group animals and animals exposed to HF EMF

Fig. 3 – Surface beta cells of beta cells control group animals and animals exposed to HF EMF

Fig. 4 – Nucleo-cytoplasmic ratio of beta cells control group animals and animals exposed to HF EMF

Fig. 5 – Review numbers of beta cells in Langerhans islets control group animals (a) and animals exposed to HF EMF (b), DAKO LSAB+/HRP immunohistochemical technique, x100

Fig. 6 – Review surface beta cells of beta cells control group animals (a) and animals exposed to HF EMF (b), DAKO LSAB+/HRP immunohistochemical technique, x100
4. DISCUSSION

Our experiment established the increase in beta cell volume density with the animals exposed to HF EMF in comparison with the control group. Furthermore, the experimental environment indicated the growth of beta cells (34.6 cells per a pancreas cross section with the exposed animals and 19.8 cells per a pancreas cross section with the control group), which was statistically relevant. Simultaneously, the beta cell surface decreased with the exposed animals in comparison with the control group and the decrease was also statistically relevant. At the same time, beta cell surface decreased per 42.96 in comparison with other Langerhans islet cells. This decrease was accompanied by the significant increase of nucleo-cytoplasmic ratio in beta cells that increased from 0.30 (the control group) to 0.33 (the HF EMF exposed animals).

Furthermore, it was shown that beta cells may result from the transformation of acinus and centroacinus cells, epithel cells of small canals, from the existing stem cells localized in the epithel of small outlet canals (Bonner-Weir et al., 1993), or from the transformation of alpha cells. Nonetheless, nowadays, the belief is that beta cells of adult rats are multiplied via the self-duplication of the existing beta cells (Orci and Unger, 1975). As our experiment helped infer, the increased number of beta cells followed by the decrease of the surface upon the HF EMF exposure indicates a fast proliferation, which prevented the cells from reaching the optimum size.

Such results are in compliance with the earlier data on the heterogeneity of Langerhans islet beta cells (Orci and Unger, 1975). The previous research proved there were subpopulations among the beta cells that differ by the glucose sensitivity. Centrally-located cells are more sensitive to lower glucose concentration than the peripheral ones. In our experiment, we noticed the stronger light in the central beta cells with the Langerhans islet of animals exposed to HF EMF in comparison with the control group. One such result might indicate either the disturbance of insulin secretion or its fast synthesis due to which the insulin granules are piled within the cells. According to some researches, HF EMF causes the intensive secretion of insulin from beta cells, which might be the case with our experiment as well.

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REFERENCES


EXPERIMENTAL DATA PROCESSING FOR BIOEFFECTS OF ELECTROMAGNETIC RADIATION IN DIFFERENT FREQUENCY INTERVALS

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Abstract. According to laws of thermodynamics of irreversible processes, efficiency of conversion of electromagnetic radiation energy into other kinds of energy submits to various laws for various frequencies. In the field of short-wave radiation (the Wien region) efficiency follows the Weber-Fechner law, and in the field of long-wave radiation (the Rayleigh-Jeans region), efficiency obeys the Devyatkov law. According to a paradigm of exact measurement and the Devyatkov law in the Rayleigh-Jeans region experimenters did not observe statistically significant alteration.

Keywords: nonthermal effects of MM radiation, thermodynamic theory, endergonic and exergonic processes, paradigm of accuracy of measurements

Introduction
Electromagnetic radiation is the most powerful source of influence on living organisms. It has provided life occurrence on the Earth and supports its existence. The whole region of electromagnetic radiation is 22 order of frequency. Experimenters divide the whole region of electromagnetic radiation into 7 parts according to the used equipment for generation and detecting of electromagnetic radiation. Theoretical physicists divide the whole region of electromagnetic radiation into two parts (the Wein region and the Rayleigh-Jeans region) [1].

Thermodynamic laws
Laws to which efficiency $\eta$ of isothermal conversion of energy of electromagnetic radiation into other kinds of energy submits, have been formulated in second half of 20-th century by thermodynamics of irreversible processes [2 – 6] and schematically represented in Fig.1 [7] for dependence on power.

They are essentially various. In the Wien region (visible light, ultraviolet, x-rays and $\gamma$- radiation) efficiency $\eta$ has a slow increase under the logarithmic law, and in the Rayleigh-Jeans region (radiofrequencies and extra low frequency) $\eta$ increases very fast from zero to unit and the subsequent plateau, where dependence is absent (the Devyatkov law). Such dependence on power (step) has been found out by experimenters for the first time in 1973. On Jan. 17-18, 1973, there was a scientific session of the Division of General Physics and Astronomy of the USSR Academy of Science in Moscow. At this session, Academician N.D. Devyatkov reported for the first time frequency-dependent nonthermal biological effects in the frequency range from 39 GHz to 60 GHz [8]. These effects were observed at the different levels of living matter organization (molecules, cells, organ, and organism). Results were arrived by different experimentalists in laboratories of different institutes under direction of Acad. Devyatkov.

It was found for the biological objects studied:
- the existence of irradiation effects which depend strongly on frequency, sometimes in a resonant manner,
- the existence of a threshold intensity necessary for induction of such effects, and that over an intensity range of several orders of magnitude above the threshold, the induced effects do not vary with intensity (step).

Reproducibility of outcomes
Quickly it has been found, that researchers in this discipline have had great difficulty in replicating results obtained by others. And what is more, the same scientists can observed the effect or can not.
The strangest history was with colicin induction by \textit{E. coli}. For the first time this effect has been reported by Smolyanskaya and Vilenskaya in 1973 [9]. This effect has been confirmed by M.L. Swicord, T.W. Athey, F.L. Buchta and B.A. Krop at the 19th General Assembly of URSI in Helsinki in 1978 [10]. However, in 1979, at the Bioelectromagnetics Symposium in Seattle Athey T.W. (Bureau of radiological health, USA) reported: “We devoted about a year to the colicin induction experiment. In the pilot study using a temporary experimental system, we seemed to be getting some positive results; but after refining our experimental system we never again saw any increased colicin induction” [11]. In contrast to Athey, at the Seattle Symposium Motzkin S.M. (Polytechnic Institute of New York) reported results in support of the Smolyanskaya and Vilenskaya original observation. She said: “Preliminary observation that W3110Col E1 \textit{E. coli} can be induced to produce colicin by CW irradiation at 37ºC for 1hr, at 5.8 mm and a power density of 0.5 mW/cm²” [12].

The Bioelectromagnetics Symposium in Seattle on June 22. 1979 [15] was the most serious discussion of this problem. At this symposium L.M. Partlow (University of Utah, USA) has said: “Such sharply disparate findings serve to alert us to the fact that either we are not adequately controlling all known variables or that there exist other relevant factors which have not yet been identified. The control and identification of such variables is our greatest challenge and most important future goal. Unless this is accomplished we must expect the results of future experiments to be similarly clouded by lack of replicability”.

In 1978 W. Grundler [14, 15] studied the growth behavior of yeast cultures under coherent microwave irradiation. The temperature of the suspension (32º C) was continuously monitored. Similar to a yeast experiment described by Devyatkov, frequencies were chosen in a range near 42 GHz. When the cultures were irradiated by CW microwave fields of a few mW/cm² the growth rate either stayed constant or was considerably enhanced or reduced depending on the frequencies varying by no more than a few megahertz in the 42 GHz range.

In 1979 Webb published a paper [16], where the induction of lambda prophages in \textit{E. coli} under irradiation by millimetre microwaves was chosen as the test object. The effect was distinctly frequency-dependent and has dependence on power density at frequency 70.4 GHz. The effect was observed at 35ºC after 24 h incubation.

The American researchers could not reproduce experiments [8, 14, 15, 16]. It was not surprise, that after such numerous negative results the American experimentalists were sure that nonthermal frequency-dependent bioeffects are not in reality and finished researches in this discipline.

In 1991 in Moscow there was the International symposium “Millimeter waves of nonthermal intensity in medicine”. Motzkin S. (USA) has represented the abstract with the title “Low power continuous wave millimetre irradiation fails to produce biological effects in lipid vesicles, mammalian muscle cells and \textit{E. coli}” [17].

The paradigm of the precision measurement

The paradigm of the precision measurement is the statement that an exact result is the one averaged over a great numbers of the measurements. The probability theory, the error theory and the determination of the average are the basis of this paradigm. Fig. 2 shows an averaging process on the big number of samples and explains occurrence of statistically significant result in the Wien region. The physical sense of averaging is very simple. Averaging gives possibility to consider entropy generation rate in each sample. It is very important and useful because entropy generation rate cannot be directly measured in experiment.

![Fig. 2. Averaging in the conditions of linear increasing of entropy generation rate (the Wien region)](image)

Microbiology studies the ensembles of microorganisms, and a large numbers of microorganisms in ensemble is the condition of the true result. This is a paradigm of the precision of the microbiological measurement. But today there is the realm of biology, where this paradigm became a drag on progress. Such are the radiofrequency bioeffects. The study of radiofrequency bioeffects has begun four decades ago, but the progress is not sufficient. The experimentalists study usually the time-dependences only.

What thermodynamics predicts for the Rayleigh-Jeans region?

Dependence of a thermodynamic limit of efficiency \(\eta\) for conversion of electromagnetic radiation energy into the Helmholtz free energy in the Rayleigh-Jeans region is presented in Fig. 3 as solid line. It looks like a step. Such sharp dependence has been met in physics before only at experimental research of superconductivity and superfluidity.
As experimenters can have interest only to a real efficiency we will start a consideration of irreversibility of processes. The dashed lines 1, 2 and 3 show, how the limiting efficiency is changed influenced by irreversibility of processes. The linear entropy generation rate increases from curve 1 to curve 3. Entropy generation rate shifts a line along an axis of logarithm of spectral density $E_\nu$ of absorbed power into side higher absorption, and when the entropy generation rate is more, shift will be especially essential. Influence of the entropy generation rate, which submit to superlinear dependence on energy absorption, does not differ from that for the Wine region. But now we have interest to linear increasing of entropy generation rate only.

In the Rayleigh-Jeans region, dependence has two sites: very fast increase from zero to unit and the subsequent plateau. Dependence on absorption on a plateau is absent, therefore this site is not interesting to experimental researches. The site of fast increasing is interesting.

The Fig. 3 shows, how results for 3 various samples can look like on this site. What will give averaging of results in this case? Everything, including zero result. The zero result is most probable on ensemble with the big number of objects. An averaging has not sense in conditions of a sharp transition from exergonic processes (under an energy axis) to endergonic processes (over an energy axis). It has allowed to raise the question about crisis of a paradigm of exact measurement already in the last century [18]. In paper [19] it is convincingly shown on the big experimental material: averaging leads to loss of effects. The authoress thought, that she has proved absence of an influence effect of MM radiation.

**Conclusion**

Partlow L.M. was right, suspecting existence of the new not-considered parametre. Such parametre is the entropy generation rate. In all processes with weak dependence on parametre, its presence is compensated by an averaging technique. For the systems submitting to the Deyyatkov law, application of averaging has not sense and leads the experimenter to the false conclusion about absence of effect.

**References**

CALCULATION OF THE DOSE CONVERSION COEFFICIENTS FOR THE VOXELIZED MATHEMATICAL MODEL OF THE EYE LENS

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Objective of this work was to calculate te conversion coefficients from fluence to personal dose equivalent \( 
Hp(3) \) for neutron radiation and voxelized mathematical model of eye lens using Monte Carlo MCNP5/X code. For the purpose of dose calculation a voxelized mathematical model of the eye lens was developed and calculations of personal dose equivalent in terms of \( \text{Hp}(3) \) delivered by neutrons of various energies was performed. Dose calculation was also performed for anthropomorphic phantoms and results were compared with those obtained using voxelized phantoms.

Key words: eye lens, neutron beam, MCNP5/X, conversion coefficients

1. INTRODUCTION

Many recent studies have demonstrated that the lens of the eye is much more sensitive to radiation, indicated that radiation risk has been significantly underestimated in many practical situations at the workplace [1-3]. It has been shown that threshold for cataract development lens might be much lower than it was previously taught [2-3]. Consequently, the International Commission on Radiological protection (ICRP) proposed a reduction of dose limit for eye lens from 150 mSv to 20 mSv per year [4]. This 7.5 fold reduction of a dose limit has attracted great attention and eye lens dosimetry has become a very intensive research area [5-7], including development of new dosimeters, calibration procedures and eye lens monitoring arrangements in various fields of application of ionizing radiation. This ICRP recommendations has also increased interest in the calculation of conversion coefficients from fluence to personal dose equivalent \( \text{Hp}(3) \) for neutrons, which have not been available before [8]. Operational quantities for area and individual monitoring of external exposures have been defined by International Commission on Radiological Units and measurements (ICRU). The \( \text{Hp}(3) \) is recommended as operational quantity for eye lens monitoring [9]. It is the dose equivalent in ICRU (soft) tissue at an appropriate depth at 3 mm, below a specified point on the human body. Recently, activities carried out under the ORAMED (optimisation of radiation protection for medical staff) calculation of the conversion factors from air kerma to \( \text{Hp}(3) \) for photons, giving rise to operational quantities to monitor of the eye lens dose which could be applied not only for low-energy electrons and photons but also for all other types of radiation [6, 8, 9].

2. MATERIALS AND METHODS

Dosimetric approach based on Monte Carlo modelling and calculations using the MCNP5/X code was used in this work. MCNP5/X was also used to simulate the neutron transport from the source to the area of interest. MCNP allows the treatment the complex track transports of neutrons, photons and electrons in different geometrical models in 3-D space environment, allowing modular choice surface of interest. To calculate \( \text{Hp}(3) \) a slab phantom was used and irradiated for various incident angles and neutron energies. The irradiation geometry was simulated using parallel expanded and aligned field of monoenergetic neutrons in vacuum, large enough to irradiate the entire phantom. This model (slab) consisted of ICRU tissue, including 4-elements composition (10.1% H, 11.1% C, 2.6% N and 76.2% O with mass density 1.0 g.cm⁻³). The scoring volumes in the slab was modeled as follows: a cylinder of radius \( r=5 \) cm and thickness (height) of \( l=0.04 \) mm was used to model the eye lens. Eye lens was not modeled with the radius of 5 cm. Scoring volume was taken as 5 cm in radius which encompasses space between two eyes. Such approach was recommended by ORAMED project [10]. The cylinder was positioned at the centre of the front face of the slab phantom of dimensions \( 30 \times 30 \times 15 \) cm³ at a depth of \( d=3 \) mm. The axis of the cylinder was normal to the front face of the phantom. For the purpose of dose calculation, the region of interest was the cylinder was voxelized (figure 1). Dose was also
calculated for nonvoxelized geometry represented by slab phantom (figure 2) and results were compared subsequently.

![Fig. 1 Voxelized slab phantom](image1)

![Fig. 2 Nonvoxelized slab phantom](image2)

Using the advantage of libraries in MCNP5/X code, in this calculations to obtain the final results the tally cards for neutrons importance: F4:n and F6:n and for photons importance: F6:p were used. Totally 10⁷ simulations were run to obtain small relative calculation uncertainty that is not greater than few percents. Calculation of conversion coefficient from neutron fluence to Hp(3) was performed using tally kerma and suitable energy dependant quality factor for neutron radiation [11-22].

2.1 Results and discussion

Hp(3) was calculated at the depth of 3 mm below the surface of slab phantom. Conversion coefficients are provided for various neutron energies, incident angles and two mathematical models of the eye lens. For precise comparison and dose calculations for two types of slab phantom (voxelized and nonvoxelized), simulations were performed using MCNP5/X code for 21 different neutron energies from 0.016 eV up to 15 MeV using parallel expanded and aligned field for three different incident angles (θ=0°,30°,60°) of neutron beam irradiation. The first sets of data for voxelized slab phantoms are given in Table 1. and the second sets of data are given in Table 2. It can be seen that data for voxelized and nonvoxelized slab phantom approximation are in good agreement for all sets of energies and angles, indicating that there is no significant difference in eye dose of either of those phantoms is used.

Many authors have used various calculation tools to produce coefficients to convert radiometric quantities to suitable operational dosimetric quantities, including Hp(3)[23-25]. The air kerma to Hp(3) conversion coefficients for photon radiation of various energies, incident angles and phantom designs were calculated [11, 23-27]. The conversion factor were also calculated to convert electron fluence to Hp(3) and Hp(0.67) using a model of the lens an different geometries [24,28]. Thus, the conversion coefficient for photon and electron radiation have been calculated for a wide range of monoenergetic and polyenergetic beam and simplified and sophisticated models of the eye; however, to our knowledge there are only few papers dealing with conversion coefficients for neutron radiation [8]. Guadarrini et al (2013) to provided conversion coefficients suitable application in eye lens neutron dosimetry procedures in the energy range from thermal to 15 MeV in order to validate the kerma approximation for the calculation of the energy deposition. The results revealed that assessments of eye lens dose in terms of Hp(3) in the range of energies starting from 600 keV to 12 MeV might lead to an underestimate of the absorbed dose to the lens of the eye, which stress the importance of further investigations in this area.

Although there is a large probability that whole body dose limit would be reach prior eye lens dose limit [25] recent reduction of dose limit for the eye lens requires additional monitoring to verify compliance with dose limit wherever neutron radiation is used at the workplace or for dosimetry in the case of potential accident [8,29]. Eye dosimetry is only considered for radiation protection because of cataract induction which is classified as tissue reaction with a typical threshold. Nevertheless, recent data on the of this threshold are not consistent and disagree about one order of magnitude of this threshold [30]. There are even claims that cataract could be considered as a stochastic effect, whish also highlights the need for eye dosimetry.

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Table 2. Fluence to Hp(3) conversion coefficients calculated for neutron energies in the range of 1.00E-09 to 15 MeV and three incident angles for nonvoxelised geometry

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2.2 Conclusion

The results of this paper outlined a new sets of conversion coefficients for neutron radiation. For the purpose of dose calculation a voxelized mathematical model of the eye lens was developed and calculations of personal dose equivalent in terms of Hp(3) delivered by neutrons of various energies was performed. Owing the recent reduction of eye lens dose limit from 150 mSv to 20 mSv and fact that neutron radiation is predominant contributor to the total dose [28], a further investigation in to improve the accuracy of the ey dosimetry for neutron radiation is needed.

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DOSIMETRY OF ELECTRON BEAM EXTRACTED FROM BETATRON BY POLYMER FILMS GAFCHROMIC EBT 3

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Abstract. In this work we present the results of measurements of the depth distributions of absorbed dose, and an assessment of flatness and symmetry of the electron beam, which is generated by a new betatron for medical applications in the energy range of 2 - and 3 MeV in a tissue - equivalent phantom.

Key words: intraoperative radiotherapy (IORT), betatron, polymer films Gafchromic EBT3.

1. INTRODUCTION

Intraoperative radiotherapy (IORT) is a treatment modality for a locally advanced tumor of the abdomen, pelvis and breast, which involves the use of large single dose of radiation delivered to the tumor or bed of tumor and areas of potential regional spread during the surgical operation [1]. This treatment modality is mostly based on the electron beams with MeV energies. One chooses the electron beam for such a treatment because of particular dose distribution in the tissue-equivalent environment; namely, a depth dose distribution has a plateau that starts directly at the surface of irradiated volume and a rather steep slope that depends on the electron energy.

Nowadays, most of the clinics worldwide which carry on the IORT procedure use the electron sources based on the compact linear accelerators such as NOVAC-7 [http://www.newrt.com]. This mobile accelerator has a possibility to generate electron beams with discrete energies 4, 6, 8, and 10 MeV [2].

However, in Russia historically several clinics have been using the sources based on betatrons that were manufactured at Tomsk Polytechnic University. For example, Research Institute for Oncology (Tomsk, Russia) successfully uses a betatron with the fixed energy 6 MeV for the IORT procedure.

These days we are developing a new generation of betatrons for the IORT and skin cancer treatment in order to change old generation machines developed and manufactured at the end of 80-s. The main advantages of the new generation betatrons are the possibility to change the beam energy in a wide range with small steps (e.g. 1-3.5 MeV with spacing 0.1 MeV), low energy spread of the beam and the relatively low cost of a device (typically $ 200 000).

In this report we present the absolute distributions of the absorbed dose of electron beam generated by a prototype of the next-generation betatron for medical applications. The main goal was to demonstrate that the prototype is able to generate electron beams with desired energy that varies from 1 to 3.5 MeV at 100 keV step. The measurements were performed for the beam energy range 2-3 MeV at 500 keV step in a tissue-equivalent phantom with zero air gap.

2. MATERIALS AND METHODS

2.1 Betatron

Betatron is a cyclic accelerator, in which electrons travel through a vacuum chamber along a circular path. The beam is accelerated by an eddy current generated by a pulsed magnetic flux. The electron energy increases with each turn while traveling along a circular path at a small value of approx. 20 eV. The beam with a typical duration of 3 microseconds is injected by the thermoionic gun that is situated inside the vacuum chamber. The typical acceleration time is about 1 millisecond. The prototype developed operates at the frequency 400 Hz while old generation betatrons operated at the frequencies 50 Hz.

In order to extract the beam an additional short pulsed magnetic field is generated kicking the beam from the equilibrium orbit to the orbit of extraction. The fact that the beam is accelerated with a low gradient for a rather long time allows to generate the beam with any desirable energy up to maximal design energy. One can choose electron energy by a delay of the extraction pulse. The prototype designed allows to generate beams with the energies from 1 MeV up to 3.5 MeV at 100 keV steps. However, the steps in between can be even smaller if needed.

2.2 Film dosimetry of electron beams

For the commissioning of accelerators before operation in a clinic it is necessary to carry out a set of clinical dosimetric procedures, for example, to
measure the dose at a reference point or to determine the dose distribution in a reference phantom [3, 4]. These procedures may be performed by means of ion chambers (gold standard) or radiochromic films. EBT 3 films can be used the relative and absolutely dosimetry after procedures of film calibration in standard conditions [5, 6].

The latest model of the polymer Gafchromic dosimetric films known as EBT3 consists of a single active layer of nominal thickness 28 microns coated active ingredients, marking layer, stabilizers and other additional substances. Due to these materials the film is almost energy independent according to the manufacturer. The active layer is disposed between two layers of transparent polystyrene with a thickness approx. equal to 100 microns [7]. Thus, the film of the 3-rd generation is symmetrical, in a contrast to the previous generation films EBT2. We used the films of batch #A04041202 with the full thickness of 0.23 mm, which may vary from batch to batch. The film is suitable for the dose range (0.01 - 40) Gy according the manufacturer.

In this study were performed the measurements of depth doses, cross section profiles of beams, symmetry and flatness beams for energy range from 2 to 3 MeV.

2.3 Calibration of film and its using

In order to check the EBT-3 film sensitivity to electron radiation and electron energy dependence the films were calibrated. The calibration details can be found in Ref. [8]. Fig. 2 shows the obtained dependences of relative optical density of both red and green channel of the film on absorbed dose generated by 2 MeV and 10 MeV electron beams. The absorbed dose was measured by electron ionization chambers according to Protocol [9, 10].

In Fig. 1 one can see that the calibration dependences at 2 MeV (betatron electron beam) and 10 MeV (linac therapeutic accelerator Elekta Axesse) coincide rather well that allows to use one calibration dependence for this energy range. The absolute dosimetry was carried out using both electron ionization chamber (PTW 23343 Freiburg Marcus) and polymer films Gafchromic EBT3 [5-7].

2.4. Beam flatness and symmetry

Symmetry and flatness of an electron beam depend on the design and adjustment of the flattening system and the apparatus used for beam collimation. The electron beam passes through the vacuum window of the accelerator guide, the intervening air. Because scattered electrons are of lower energy, the flatness of the beams may change significantly with depth [3, 4].

For the determination of symmetry and flatness of radiation fields, we used depths of dose maximums. One of the most frequently used dosimetry systems for determining these parameters is a film. Using film, both flatness and symmetry can be evaluated for an electron field in a relatively short time [3, 4, 5-7, 9, 10].

3. EXPERIMENTAL RESULTS

For the measurement of dose distribution of electron beams, the films were placed at the plane perpendicular to the phantom surface and parallel to the central axis beams of betatron (see Fig. 2). During the experiment the electron beam with different energies was extracted to the air through 0.1 mm thick aluminum window. Just after the vacuum window (1) the slab tissue-equivalent phantom (2) (RW3 Slap Phantom T29672) with a film dosimeter (3) was situated, air gap was equal to 10 mm.

Fig. 2 The scheme the irradiation of films on the betatron

Fig. 3 and Fig. 4 show the results of depth distributions of absorbed doses from the betatron beams with energy 2 MeV and 3 MeV.
Fig. 4 The depth distribution of absorbed dose on the betatron beam 3 MeV

For data acquisition of flatness and symmetry betatron beams (2 mm for 2 MeV and 1 mm for 3 MeV), the film was irradiated at depth of maximum dose in a solid phantom, positioned perpendicular to the beam axis. Fig. 5 and Fig. 6 shows the transverse distribution of the absorbed dose for 2 MeV beam and 3 MeV beam, respectively. The curves were obtained at depths equal to 2 mm for 2 MeV beam and 1 mm for 3 MeV beam.

4. DISCUSSION

The distribution of the absorbed dose of 2 MeV electron beam betatron has the plateau region in a depth range of 0.1 mm to 2.6 mm, and then a sharp dose pad to a depth of 4.2 mm, i.e. shape of the depth dose distribution corresponds to the standard form of the depth dose distribution for the electron beam. The maximum dose is located at the depth of 2 mm. Thus, we can say with great certainty that from the output window goes betatron electron beam with a sufficiently small contamination from bremsstrahlung.

Unfortunately this is not true of the electron beam betatron with energy 3 MeV. In the depth dose distribution no plateau region was detected and shape of the curve does not match the correct representation of the dose distribution in depth tissue equivalent material for the electron beam. Position of the maximum dose is not exactly verified. Therefore, it cannot be accurately argued that the output we have a pure beam of electrons (bremsstrahlung without a large share), or that correct output beam itself. The possible reason could be not correct operation of the beam extraction system that will be completely changed in the future development of the accelerator.

Flatness and symmetry of electron beams for 2 MeV and 3 MeV exceed 5%, which is not within the normal range.

5. CONCLUSION

Due to the polymer films Gafchomnic EBT3, it were obtained the depth distribution of absorbed dose, flatness and symmetry of electron beam with high spatial resolution.

By the results of investigation, the depth distribution of dose for betatron electron beam with energy 2 MeV more adequately than for a beam with an energy of 3 MeV. It means that the system of beam extraction should be modified for reliable operation of the accelerator.

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REFERENCES


INFLUENCE OF VARIOUS FACTORS ON THE DOSE OF PERSONNEL DURING DIAGNOSTIC PROCEDURES IN CARDIOLOGY

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Abstract. The aim of this work was the determination of staff exposure during coronary diagnostic procedure and the investigation of the effect of some factors (working method, fluoroscopy time, physical characteristics of cardiologist) on the doses to personnel. The measured doses in this work were compared to the doses measured by the National Dosimetry Service. The doses were measured with LiF:Mg,Cu,P thermoluminescence and phosphate glass radiophotoluminescence dosimetry systems (GD-352M) under and over the apron on the chest, on the left eye (eyebrow), left shoulder out of the apron, and left wrist of 3 cardiology doctors. Each doctor carried out 5 diagnostic coronary angiography procedures. The annual effective doses \( E_{\text{eff}} \) calculated from the measured values as well as the equivalent doses to the eyes, were in all cases below the required dose limit (20 mSv/year). Significant differences of the effective doses were found among the three doctors in this study (15.5 mSv, 10.4 mSv, 8.7 mSv), as well as in the earlier results of the National Dosimetry Service (9.2 mSv, 4.6 mSv, 1.3 mSv). It was found that a single dosimeter under the apron performed by the National Service underestimates the \( E_{\text{eff}} \) as compared to the double dosimetry carried out in this study. The doses depend on many factors in coronary angiography, such as fluoroscopy time, complexity and number of examinations, experience of the doctor, feature of the doctor (height) and patient himself.

Key words: coronaryography, radiation protection, scattered radiation, RPL dosimetry

1. INTRODUCTION

A coronary catheterization using ionizing radiation is minimally invasive procedure to access the coronary circulation and blood filled chambers of heart using a catheter. In diagnostic radiology the technological developments offer the possibility to see cardiac function and the state of coronary and great vessels. The volume of diagnostic and therapeutic procedure in cardiology is increasing constantly. In 2002 in US almost 4 million cardiac catheterisations were carried out\(^{(1)}\) while in 2008 in Switzerland nearly 34000 coronary angiographies and more than 18000 coronary dilatations were done\(^{(2)}\). They are associated to 65% of the collective dose related to interventional radiology and 8% to that related to all medical X-rays. Coronary catheterization causes one of the highest potential exposures of the staff (cardiologists and nurses).

The Working Group on Interventional Cardiology of the Information System on Occupation in Medicine, Industry and Research and the International Atomic Energy Agency carried out a large scale survey in cardiology catheterization\(^{(3)}\). 76% of individual interventional cardiologists stated that they always used dosimeter and 45% applied double dosimetry. In the same survey 60% of regulatory bodies stated that the number and position of dosimeters are specified in their country; 40% prescribe one dosimeter most above the apron while 20% prescribe two dosimeters.

The new IAEA Basic Safety Standard\(^{(4)}\) recommends limit of 100mSv/5 years effective dose for the whole body and 20 mSv/year equivalent dose for eyes for professionals.

The aim of this work was the determination of staff exposure during coronary angiography procedures and the investigation of the effect of some factors (working method, fluoroscopy time, physical characteristics of cardiologist) on the doses to personnel. The measured doses were compared to the doses measured by the National Dosimetry Service (NDS).

2. MATERIAL AND METHODS

The doses were measured only during coronary angiography procedures. If therapy was required the dosimeters were taken off. After each procedure the dosimeters were changed. Advant X LCV X-ray unit produced in USA was used.

Tree cardiologists and six nurses (Table 1) were involved in the study. The doses were measured under and over the apron on the chest, on the left eye (eyebrow), left shoulder out of the apron, and left wrist of the cardiologists and under the apron on the chest of the nurses. Each doctor carried out 5 diagnostic coronary angiography procedures while nurses changed after 2-3 treatments in the cardiac catheter room.
For radiation protection of the personnel 0.5 mm thick lead aprons, thyroid collar, ceiling suspended screen and protection curtains between the table and the floor were applied.

Table 1. Doctors and nurses involved in the investigation

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<td>6 nurses changed after 2-3 treatments in the cardiac catheter room</td>
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The dose measurements were carried out with the polystyrene- TL (LiF: Mg, Cu, P-MCPN) and radiophotoluminescence-RPL (CD-352M) dosimetry systems. The doses were expressed in H_{10}. The readers as well as the evaluation parameters (preirradiation annealing, preheat and readout) are the same as described in the literature[5].

3. RESULTS AND DISCUSSION

The results of dose measurement with RPL dosimeters on various body parts on the doctors are shown in Table 2. The doses of nurses measured under the apron varied from 0 to 0.034 mSv. No systematic difference between the TL and RPL dosimetry systems was found. Doses were measured on the upper part of the body. The reason is that the staff doses are caused mainly by the scattered radiation. It is known that the relative position of the X-ray tube and image amplifier[6] influences which part of the body will get higher exposure. In this study the X-ray tube was above the patient while the image amplifier was under the table. Therefore doses were measured on the upper part of the body where higher doses were expected.

The doses were different even for a single operator and same position of dosemeter. The reason is different complexity of examination and different fluoroscopy time. From Table 2 it can be seen that M.L. and K.A. had higher doses than K.G. It can be explained that M.L. is of lower height, the upper part of his body is closer to the x-ray tube and scattered radiation. K.A. had some very complicated cases during this study. However, the calculated dose rate from the doses measured above the apron and the fluoroscopy times (H_{10}/fluoroscopy time), i.e. the dose value which is independent of fluoroscopy time (Figure 1) indicate also that M.G. and K.A. has higher doses than K.G.

The annual effective doses measured by NDS showed that M.L. carried out 22% more examination in 2012, however the dose received was 2 times higher than for K.G (Figure 2). These doses were measured by single dosemeter under the apron.

Table 2. Doses measured with RPL dosimeters during coronary angiography procedures.

<table>
<thead>
<tr>
<th>Doctors</th>
<th>H_{10} (mSv)</th>
</tr>
</thead>
<tbody>
<tr>
<td>M.L.</td>
<td>0.006</td>
</tr>
<tr>
<td>K.G.</td>
<td>0.013</td>
</tr>
<tr>
<td>K.A.</td>
<td>0.012</td>
</tr>
<tr>
<td>M.L.</td>
<td>0.004</td>
</tr>
<tr>
<td>K.G.</td>
<td>0.019</td>
</tr>
<tr>
<td>K.A.</td>
<td>0.010</td>
</tr>
</tbody>
</table>

Figure 1. Doses above the apron independently on fluoroscopy time.

In interventional cardiology double dosimetry is proposed[2] to increase the accuracy of the determination of the effective dose. Various algorithms can be applied[8] for calculation of the effective dose from the measured dose value. In our study the effective doses were calculated from double dosimetry according to the Swiss ordinance with thyroid shield. The effective dose values for 2012 measured by single and double dosimetry are compared in Figure 3 taking into account the number of examinations in this year. Significant differences of the effective doses were found among the three doctors in this recent study (15.5 mSv, 10.4 mSv, 8.7 mSv), as well as in the earlier results of the NDS (9.2 mSv, 4.6 mSv, 1.3 mSv), i.e. one
doctor with a long experience received higher doses than the other two. From these results it can be also seen that a single dosimeter under the apron performed by the NDS underestimates the $E_{eff}$ as compared to the double dosimetry carried out in this study.

The annual effective doses $E_{eff}$, calculated from the measured values in this study were in all cases below the dose limit (20 mSv/year) as required in the new IAEA Basic Safety Standard(4).

Similar situation was found with the equivalent doses on the left eye, i.e. M.L. had higher doses than the others however the annual doses (calculated from the number of examines and the mean equivalent dose on the eye measured in this study) were below the dose limit (20 mSv/year)$^{1}$ especially taking into account that NDS measured the dose in diagnostic and therapy treatment while in this study only diagnostic treatment was investigated.

4. CONCLUSION

In coronary angiography procedures different effective doses were found between doctors according to the national survey (single dosimetry under apron) as well as the recent study (double dosimetry). The doses depend on many factors, such as fluoroscopy time, complexity and number of examinations, experience of the doctor, feature of the doctor (height) and patient himself. Therefore measurements with good statistics have to be carried out.

TL and RPL dosimeters are adequate for dose measurements in coronaryography, no systematic difference between the TL and RPL dosimetry systems was found.

Acknowledgement: The authors are grateful for the Cardiology team in the Haemodinamical Laboratory in Cardiology Department, Budapest for participating in measurements and to Chiyoda Technol Corporation for support with RPL dosimeters.

References

ANALYSIS OF NEUTRON RESPONSE OF BEO-OSL PERSONEL DOSIMETERS

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Abstract. In this study, fast and thermal neutron response of the BeO OSL dosimeter, developed by Hemholtz Zentrum Muechen (HZM), are investigated. Am-Be neutron source and thermalized neutrons are used as a fast and thermal neutron source to determine neutron energy response of the BeO crystal.

Key words: Monte Carlo, Beryllium Oxide, Optically Stimulated Luminescence, OSL- Dosimeter

1. INTRODUCTION

In recent years, use of optically stimulated luminescent (OSL) dosimeters in personal monitoring service increases as a consequence of achievements in OSL technology. BeO is one of the most common OSL dosimeter crystals. When literature is examined, generally fast neutron response of the BeO crystal was investigated. The fast neutron response of the BeO ceramic was reported by Satoru Ohtani using thermally stimulated exoelectron emission (TSEE) method [1]. Satoru showed that the BeO ceramic has linear response when exposed to fast neutron spectrum. In another paper, the fast neutron response of the ceramic BeO Thermalox 995 was studied by R.B. Gammag et al. using TSEE method [2]. Gammag demonstrated that fast neutron (0.1-16 MeV) response of the ceramic BeO, which covered by teflon and polyethylene, is better than gamma response. Gammag used partial mice body as phantom in order to include neutron capture effects, which produced from hydrogen.

The personal dosimetry system”iBeOx” which uses optically stimulated luminescence (OSL) of beryllium oxide (BeO) has been developed by HZM. The X-ray and gamma-ray tests of BeO OSL system were conducted according to ISO-IEC 62387-1 by HZM [3]. In another paper, Jahn et.al, predicated dose linearity and energy response of the BeO OSL dosimeters for X-ray gammas and betas [4].

Many countries (Germany, Austria, Belgium, Turkey etc) have started using BeO OSL personal dosimeter for different purposes. Some radiation areas, for instance, radioisotope production centers, contain many type of radiation sources. However, there is limited information about neutron response of BeO OSL personal dosimeter in the literature especially for mix radiation sources. Therefore, to determine neutron response capability of the BeO OSL personal dosimeter in fast and thermal neutron fields are studied in this work.

2. MATERIALS

2.1. BeO OSL Dosimeter

The BeO OSL personal dosimeters are irradiated at thermal and fast neutron irradiation systems. Detector elements of the OSL dosimeter are sintered ceramics of BeO. The dimension of the detector elements is 4.7 x 4.7 mm in square with 0.5 mm thickness. The detector elements (BeO) density is given as 2.85 g/cm³ and the effective atomic number is 7.14 [4]. The dosimeter is covered using low Z plastic as shown in Fig. 1.

Fig. 1 BeO OSL Dosimeter
The cover includes filter materials, which are arranged symmetrical. The filter dimensions are chosen in a way that the detector is completely covered. 2.4 mm PTFE (Teflon) and 0.5 mm thick plastic window are used as filter material for \( H_{2}(10) \) and \( H_{2}(0.07) \) elements, respectively.

### 2.2. Irradiation Systems

#### 2.2.1 Thermal Neutron Irradiation

The OSL personal dosimetre based on BeO crystal are irradiated at thermal neutron irradiation system (TNIS) in SANAEM (fig. 2).

![Fig. 2 Thermal Neutron Irradiation System (TNIS)](image)

The TNIS has three Am-Be neutron sources with each activity 16 Ci. The Am-Be neutron source provide \( 2.2 \times 10^{7} \text{n/sec-Ci} \) source strength [5]. Each neutron source is cylindrical with 1.6 cm radius, 3 cm height and located at \( k_{1} \), \( k_{2} \) and \( k_{3} \) holes, as shown in figure 2. The OSL personal dosimeters were exposed to radiation at \( b_{1} \), \( b_{2} \), \( b_{3} \) as a function of time. The TNIS region-wise material properties are given in Table 1.

<table>
<thead>
<tr>
<th>Region Number</th>
<th>Material Type</th>
<th>Material Density(g/cm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Paraffin</td>
<td>1.03</td>
</tr>
<tr>
<td>2</td>
<td>Cadmium</td>
<td>8.65</td>
</tr>
<tr>
<td>3</td>
<td>Boric Acid</td>
<td>1.42</td>
</tr>
<tr>
<td>4</td>
<td>Lead</td>
<td>11.3</td>
</tr>
</tbody>
</table>

#### 2.2.2. Fast Neutron Irradiation

The OSL personal dosimetre based on BeO crystal are irradiated at fast neutron irradiation system (FNIS) in SANAEM (fig. 3).

![Fig. 3 Fast Neutron Irradiation System (FNIS)](image)

The FNIS has Am-Be neutron source with activity of 20 Ci. The neutron source is cylinder with 1.6 cm radius, 3 cm height and demonstrated as number 3 in fig. 3. The OSL personal dosimeters were exposed to radiation as a function of time. FNIS region-wise material properties are given in Table 2.

<table>
<thead>
<tr>
<th>Region Number</th>
<th>Material Type</th>
<th>Material Density(g/cm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Background(Soil)</td>
<td>1.03</td>
</tr>
<tr>
<td>2</td>
<td>Concrete</td>
<td>2.35</td>
</tr>
<tr>
<td>3</td>
<td>Am-Be Source</td>
<td>---</td>
</tr>
<tr>
<td>4</td>
<td>Lead</td>
<td>11.3</td>
</tr>
<tr>
<td>5</td>
<td>OSL dosimeter</td>
<td>---</td>
</tr>
</tbody>
</table>

#### 2.2.3. OSL System

The irradiated OSL dosimeters were read using iBeOx dosimeter system at RAKDOR personal dosimetry laboratory. The iBeOx OSL dosimeters were simulated by Continous Wave (CW) stimulation method with blue light [6]. The used iBeOx reader system has been accredited per ISO-IEC 17025 according to ISO-IEC 62387-1 and has a EURADOS certificates.

#### 2.3. Monte Carlo Simulation

The thermal and fast neutron irradiation system which are shown in figure 2 and 3, were modeled in Monte Carlo (MC) code MCNP5 [7]. The MC simulations were performed in neutron and photon mode to reveal contribution of gammas generated by means of neutron capture as well as neutrons. In the MC simulations, absorbed dose (energy/unit mass) was estimated in BeO crystal using MCNP5 F6 tally which is used to determine absorbed energy. The contribution of neutrons and photons to absorbed dose were calculated neutron and photon tally separately.

MC simulations were carried out using a computer system that contains 24 parallel processing cores. The core speciation is given as 12\* Intel(R) Xeon(R) CPU E3110 @ 3.00GHz. In the MC simulations, the number of particle is selected in such a way that relative errors of the tallies remain under 1%. The MC simulation process time.
depends on number of particle history. In this study, mean MC simulation time to attain 1% relative error was roughly 360 minutes. In MC simulations ENDF/B-VI material library is used

### 3. Calculations and Results

Absorbed dose rate in BeO crystal are estimated using MCNP5 F6 tally. The F6 tally gives results in unit MeV/g. To reveal only thermal neutron response of the BeO, the 59 keV gammas which is produced by Am-241, the 4.438 MeV gammas which is emitted by excited Carbon [8] and gammas which are generated by neutron capture, are tallied separately. The F6 tally results, which obtained using MCNP5 code, are modified in order to determine absorbed dose rate. The modified equation given as,

$$Dose\ Rate = \frac{(MeV) \cdot Joule}{gr \cdot kg \cdot sec} \cdot mGy / sec$$

(1)

Calculated factors for absorbed dose for TNIS are given below. The dose coefficients, given in equations 2-5 depend on source strength and type of radiation.

The 59 keV gamma

$$Gamma\ Dose\ Rate = F6_{\text{total}} \times 693.6 \ mGy / sec$$

(2)

The 4.438 MeV gamma

$$Gamma\ Dose\ Rate = F6_{\text{total}} \times 10.05 \ mGy / sec$$

(3)

The neutron capture

$$Gamma\ Dose\ Rate = F6_{\text{total}} \times 16.09 \ mGy / sec$$

(4)

Thermal neutrons

$$Neutron\ Dose\ Rate = F6_{\text{total}} \times 16.09 \ mGy / sec$$

(5)

Absorbed dose results which were obtained using MCNP5 code are given in Table 3 as a function of irradiation time and type of radiation. The experimental results for total absorbed dose were compared with total absorbed dose obtained from MC simulations. In the mix radiation area the neutron dose couldn’t be distinguished separately when BeO OSL personal dosimeter is used. The BeO OSL dosimeter studied in this work has only one crystal for equivalent dose. Increasing number of crystal and using appropriate filters could allow measure neutron and gamma dose separately.

Table 3. The absorbed dose for NTIS

<table>
<thead>
<tr>
<th>Irradiation Time (sec)</th>
<th>Meas. BeO (mGy)</th>
<th>Gamma MC (mGy)</th>
<th>Neutron MC (mGy)</th>
<th>Total MC (mGy)</th>
</tr>
</thead>
<tbody>
<tr>
<td>36</td>
<td>0.11</td>
<td>0.096</td>
<td>0.008</td>
<td>0.104</td>
</tr>
<tr>
<td>180</td>
<td>0.56</td>
<td>0.481</td>
<td>0.04</td>
<td>0.521</td>
</tr>
<tr>
<td>360</td>
<td>0.99</td>
<td>0.96</td>
<td>0.08</td>
<td>1.04</td>
</tr>
<tr>
<td>1800</td>
<td>4.95</td>
<td>4.81</td>
<td>0.402</td>
<td>5.21</td>
</tr>
<tr>
<td>3600</td>
<td>9.54</td>
<td>9.62</td>
<td>0.803</td>
<td>10.4</td>
</tr>
<tr>
<td>7200</td>
<td>20.47</td>
<td>19.25</td>
<td>1.607</td>
<td>20.86</td>
</tr>
</tbody>
</table>

*Relative error %10 for experimental data, %1 for MC data

To determine fast neutron absorbed dose due to irradiation at FNIS is calculated using eq. 6 as a function of irradiation time. The contribution of gammas is calculated using 7-9 equations.

$$Neutron\ Dose\ Rate = F6_{\text{total}} \times 7.04 \ mGy / sec$$

(6)

The neutron capture

$$Gamma\ Dose\ Rate = F6_{\text{total}} \times 7.04 \ mGy / sec$$

(7)

The Prompt 59 keV gamma

$$Gamma\ Dose\ Rate = F6_{\text{total}} \times 251.5 \ mGy / sec$$

(8)

The 4.438 MeV gamma

$$Gamma\ Dose\ Rate = F6_{\text{total}} \times 4.18 \ mGy / sec$$

(9)

The results of MC simulation and experimental measurements are given in Table 4. With the purpose to measure only neutron dose as far as possible, lead was used to eliminate prompt gammas. Unfortunately, secondary gammas due to $(n, \gamma)$ reaction of neutrons scattering in the environment contributed to dose detected by dosimeter to sum extent. The gamma dose contribution estimated by MC code is 20%.

Table 4. The absorbed dose for NFIS

<table>
<thead>
<tr>
<th>Irradiation Time (sec)</th>
<th>Meas. BeO (mGy)</th>
<th>Neutron MC (mGy)</th>
<th>Gamma MC (mGy)</th>
<th>Total MC (mGy)</th>
</tr>
</thead>
<tbody>
<tr>
<td>300</td>
<td>0.05</td>
<td>0.04</td>
<td>0.008</td>
<td>0.048</td>
</tr>
<tr>
<td>900</td>
<td>0.13</td>
<td>0.12</td>
<td>0.024</td>
<td>0.014</td>
</tr>
<tr>
<td>1800</td>
<td>0.23</td>
<td>0.24</td>
<td>0.048</td>
<td>0.29</td>
</tr>
<tr>
<td>3600</td>
<td>0.45</td>
<td>0.48</td>
<td>0.096</td>
<td>0.58</td>
</tr>
</tbody>
</table>

*Relative error %10 for experimental data, %1 for MC data

To understand contribution of neutron interaction mechanisms in BeO crystal, spectrum averaged microscopic cross sections are generated using MCNP5 code for fast and thermal neutron sources. The spectrum averaged microscopic cross sections of the BeO crystal are given in Table 5.

Table 5. Microscopic cross sections of the BeO

<table>
<thead>
<tr>
<th>Microscopic cross sections (barn)</th>
<th>Thermal Spectrum Averaged</th>
<th>Fast Spectrum Averaged</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\sigma_{\text{tot}}$</td>
<td>8.84E-5</td>
<td>4.23E-5</td>
</tr>
<tr>
<td>$\sigma_{\text{cap}}$</td>
<td>7.90E-8</td>
<td>6.73E-7</td>
</tr>
<tr>
<td>$\sigma_{\text{cap}}$</td>
<td>7.90E-8</td>
<td>6.73E-7</td>
</tr>
</tbody>
</table>

When Table 5 is examined, the estimated results show that $(n,\alpha)$ reaction is dominant for fast neutrons. $(n, \gamma)$ reaction is dominant for thermal neutron. Since the energy deposition of alpha particles originating from $(n,\alpha)$ reaction is greater than $\gamma$'s originating from $(n, \gamma)$ reaction within the BeO crystal, the fast neutron dose response of the BeO crystal is better than thermal neutron dose response.
4. CONCLUSION

In this study, thermal and fast neutron responses of the BeO OSL dosimeters are investigated experimentally. To predict contribution of gamma and neutron sources separately, MC simulation code MCNP5 is used. In the light of the results, BeO OSL dosimeter could detect dose due to neutron fields. But, with current dosimeter configuration, it is not possible to give the contribution of neutron and gamma doses separately. To give neutron dose even in mix radiation areas, different dosimeter and filter configuration has to be studied and appropriate dose calculation algorithm should be validated. As a feature work, different filter and dosimeter configurations will be studied.

Acknowledgement: The authors would like to thank to the SANAEM neutron irradiation and RADKOR personal dosimetry laboratories for their help.

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1. S. Ohtani, "TSEE Dosimeter For Gamma-Ray and Fast Neutrons Using Ceramic BeO", Division of Health Physics, Japan Atomic energy research Institute, 1976.
ON THE POSSIBILITY OF THE USE OF THE LONG-TERM PHOSPHORESCENCE IN THE \( \text{Li}_2\text{B}_4\text{O}_7:\text{Cu} \) AND \( \text{Li}_2\text{B}_4\text{O}_7:\text{Mn} \) CRYSTALS FOR THE HIGH-CURRENT ELECTRON BEAM DOSIMETRY

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Abstract. Influence of the 10 MeV electrons accelerated by the M-30 microtron (Institute of Electron Physics, Ukrainian National Academy of Sciences) on the luminescent properties (thermoluminescence and phosphorescence) of the LTB:Cu and LTB:Mn single crystal has been studied.

Key words: thermoluminescence, phosphorescence, electron and gamma-irradiation, lithium tetraborate.

1. INTRODUCTION

The use of the lithium tetraborate (LTB) for clinical and personal dosimetry as well as for environmental monitoring has a number of advantages as compared to using other solid-state thermoluminescent dosimeters. First, LTB is a tissue-equivalent material since its effective atomic number value \( Z_{\text{eff}} = 7.42 \) is close to that for the biological tissues and, second, it seems attractive that the use of the \( \text{Li}^6 \) and \( \text{B}^{10} \) isotopes in the LTB matrix may result in a dosimetric material sensitive to thermal neutrons [1] promising in the reactor dosimetry. In this relation, the extensive studies of the influence of different nuclear irradiation types on the thermoluminescent and optical properties of the above materials are being carried out at present. In particular, the influence of the thermal neutron irradiation on the optical properties of LTB enriched by the \( \text{Li}^6 \) and \( \text{B}^{10} \) isotopes has been studied in Ref. [2], while that of the reactor neutrons and gamma-quanta irradiation on the thermoluminescence of undoped LTB single crystals was investigated in Ref. [3].

2. INITIAL LTB MATERIALS AND EXPERIMENTAL CONDITIONS

The initial burden synthesis and the LTB:Cu, LTB:Mn and undoped LTB single crystals growth were carried out in the platinum crucibles at the air with no reloading. The single crystals were grown by the Czochralski method at the \( \text{HX}-620 \) and Donets-1 setups. Taking into account the incongruent evaporation of the LTB melt, this process was realized from the compositions with the \( \text{B}_2\text{O}_3 \) excess up to 0.5 mol%. The impurities were introduced into the initial burden in a form of the \( \text{CuO} \) and \( \text{MnO}_2 \) oxides. Prior to seeding, the initial burden melt was kept at about 1223K for 15–20 hours to reach its composition stabilization. Drawing rate was 3–5 mm/day at the rotation speed of 4–10 rpm, while the axial temperature gradient at the crystal-melt interface was 3–5K/mm. To reduce the thermal stress the crystals detached from the melt were annealed for 12–24 hours and then cooled at the 20K/hour rate [5].

The samples under study were irradiated in the radiation field formed from the accelerated electron beam by scattering at the thin tungsten foil and collimator being accompanied by non-negative Bremsstrahlung from the constructive elements. Electron fluence intensity in place where the samples were mounted was measured by using an absolute Faraday cup with calibrated entrance orifice, whereas the irradiation dose was determined by an integrator.

Thermoluminescence was measured using the experimental setup described in detail elsewhere [6]. A photomultiplier FEP-106 operating in the photon counting mode was used to measure the luminescence intensity. The thermoluminescence curves were obtained as a result of linear heating of the samples under study wit the 0.5°C/s rate to the maximal
temperature 300°C. Phosphorescence was measured starting from the first minute after irradiation, and the thermoluminescence intensities were measured after the phosphorescence reduction to the almost zero value.

3. RESULTS AND DISCUSSION

As our studies have shown, irradiation of the LTB single crystals by accelerated electron beams results in a long-term phosphorescence. Figure 1 illustrates the kinetics of the phosphorescence decrease for the LTB:Cu and LTB:Mn crystals irradiated by the $10^{11}$, $4 \times 10^{11}$ and $8 \times 10^{11}$ e/cm$^2$ fluences with the $3.5 \times 10^9$ e/cm$^2$·s intensity. As seen, the phosphorescence yield in the LTB:Mn crystal is almost an order of magnitude larger than that in the LTB:Cu one.

![Fig. 1](image1)

Another specific feature of the phosphorescence phenomenon in LTB is its dependence on the irradiation intensity. Figure 2 shows the phosphorescence yields for the LTB:Cu and LTB:Mn samples irradiated by the same dose of $10^{11}$ e/cm$^2$ but with different fluence intensities. As seen, the phosphorescence yield increases with the irradiation intensity. At the same time, as our studies have shown, the thermoluminescence yield appeared to be almost independent of the irradiation intensity.

![Fig. 2](image2)

Dependence of the phosphorescence yield on the irradiation dose for the LTB:Cu, LTB:Mn and undoped LTB samples irradiated by the $3.5 \times 10^9$ e/cm$^2$·s fluence intensity is shown in figure 3. It is seen that in such irradiation conditions the phosphorescence yield almost linearly depends on the irradiation dose for all the crystals within the interval under study. Especially promising in the high-intensity accelerated electron dosimetry is the use of undoped LTB, in which the condition of the phosphorescence yield linearity vs the irradiation dose is conserved within a considerable range (see fig. 3 c).

![Fig. 3](image3)
Thermoluminescence of the LTB:Cu, LTB:Mn and undoped LTB samples as a function of irradiation dose is shown in figure 4. As seen from this figure, in the LTB:Cu and LTB:Mn single crystals the low-temperature thermoluminescence peak within the 80–140°C interval is not ambiguously related to the irradiation dose. The reason for this could be the fact that in our case the thermoluminescence measurements in the irradiated samples were carried out after the phosphorescence vanishing only. Evidently, this took place dependent of the irradiation dose for different time intervals and, respectively, of the different degree of depletion of the traps that form the low-temperature thermoluminescence peak. Furthermore, taking into account a complicated character of the phosphorescence decrease kinetics, one may assume that it is due to the mechanism of cascade depletion of different-depth traps, including those of them, which are responsible for the low-temperature thermoluminescence peak. In contrary, the thermoluminescence light sum within the 150–250°C range for the LTB:Cu and LTB:Mn samples appeared to be linearly proportional to the irradiation dose for the fluence interval under study (see figures 4 a, b) and not sensitive to the irradiation intensity. This indicates the possibility to use the above materials for the dosimetry purposes.

As seen from figure, the thermoluminescence curve is shifted with irradiation dose towards the lower temperature region that is typical for the thermoluminescence kinetics described by the quadratic dependence of charge carriers accumulated at the traps on the initial concentration.

Figure 4c illustrates the influence of irradiation with the $10^{12}$ and $10^{13}$ e/cm$^2$ doses on the...
thermoluminescence in the undoped LTB crystals. As these data show, the thermoluminescence curve reveals two closely located peaks: a larger one in the 75–190°C temperature interval and a smaller one at 190–290°C. The appearance of the thermoluminescence and phosphorescence phenomena in the undoped LTB crystals irradiated in the high-intensity radiation fields testifies to the presence in them of several types of uncontrolled structural defects that play a role of both the trapping and the radiative recombination levels.

4. CONCLUSIONS

Thus, the appearance of phosphorescence in the LTB crystals after irradiation by the high-intensity electron beams testifies to the presence in them, besides the deep charge carrier trapping levels causing thermoluminescence, the shallow trapping levels depletion of which results in phosphorescence at room temperature. Obviously, the existence of the long-term phosphorescence indicates that the depletion rate for these levels is much less than their filling rate in the course of irradiation.

Dependence of the thermoluminescence yield only on the dose of irradiation by the high-energy electrons within the 150–250°C interval given the lack of its dependence on intensity, as well as a considerable dependence of the phosphorescence yield on both irradiation intensity and dose, allow the irradiation dose and intensity to be determined in the simultaneous measurements of both phosphorescence and thermoluminescence.

REFERENCES

INSTRUMENTAL NEUTRON ACTIVATION ANALYSIS OF LABORATORY CULTIVATED AND NATURAL IRON BACTERIA PRODUCTS

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Abstract. The sheath-forming bacteria from genera Sphaerotilus and Leptothrix can be found in different natural habitats. We study the elemental constitution of the products of the bacteria Leptothrix after cultivation on different elective media by applying the neutron activation analysis technique. Three types of iron oxide compounds were characterized by X-ray diffraction after cultivation in Adler’s medium: lepidocrocite ($\gamma$-FeOOH), magnetite (Fe₃O₄) and goethite ($\alpha$-FeOOH). The cultivation in the Isolation medium yielded a single phase: goethite. XRD and SEM investigations showed that the biogenic oxides are nanosized. Our study exemplifies the possibilities of the biotechnology approach for obtaining under artificial conditions of large quantities of iron byproducts that could be of further use in appropriate nano- and biotechnologies.

Key words: sheath-forming bacteria, biogenic iron oxides, neutron activation analysis, nanotechnologies

1. INTRODUCTION

The Fe-oxidizing bacteria (FeOB) [1,2] are known for the unique morphology structures they produce, such as powders, sheaths or stalks, that act as organic matrices upon which the deposition of hydrous ferric oxides can occur. The genera Sphaerotilus – Leptothrix [3,4] are typical β-Proteobacteria capable of oxidizing Fe²⁺ and Mn²⁺ and are commonly found in water soluble salts in water basins. As a result of their metabolism, the bacteria form biogenic iron oxides/(oxy)hydroxides accumulated in their “sheaths”. Leptothrix ochracea form short and mostly empty sheaths in contrast with the relatively long sheaths, partly filled with cells, of the typical sewage bacteria Sphaerotilus natans. The presence of the sheath has nutritional and ecological consequences for this group of bacteria. This concerns particularly their growth in slowly running waters low in nutrients, where the presence of the sheath helps the bacteria to attach themselves to solid surfaces. In aquatic environments Leptothrix bacteria produce uniquely shaped hollow microtubules composed of aquatic inorganic and bacterium-derived organic hybrids [4].

Due to the contradictory theoretical explication of their metabolism, studies of “iron” bacteria (FeOs) have lagged behind those of the other important microbial lithotrophic metabolites. On the other hand, these microorganisms offer new opportunities to learn about fundamental biological processes that can be of the practical importance. Numerous investigations were already done and gave information about the possibilities of their important applications as pigments, catalysts, adsorbents, etc. [4].

In the present work we study the elemental composition of the products of the Leptothrix bacteria by applying the neutron activation analysis (NAA) technique known for the capability of quantitative determination of many elements and their isotopes simultaneously. The degree of crystal structure formation of the resulting biogenic ferroxides was also subject of a study aimed to optimize the process time parameters.

2. EXPERIMENTAL PART

1.1. Materials and Methods

The sampling region was located in Vitosha Mountain, the locality “Aleko”, where deposits with specific brown-red color due to ferroxides can be found, Fig. 1.

The bacteria were cultivated under static and dynamic (slow current of nutrient solution) conditions at 20° C for different time and media.
From the media tested the Leptothrix bacteria were selectively grown successfully on two elective media: Adler’s and Isolation. The identification of the pure cultures obtained from enriched culture was performed according to the taxonomic scheme of Bergey Manual of Determinative Bacteriology [5] including morphological, physiological and biochemical characteristics. The confirmation of the taxonomic status of the isolates was by PCR detection assay.

The bacterial cells were harvested by centrifugation (4 500rpm/10 min), the cell pellet was washed with phosphate buffered saline (PBS) and subjected to DNA isolation with Prep Mini Spin Kit (GE Healthcare). The published sequence of mofA gene (GenBank № Z25774.3) was chosen as a specific target for PCR detection of Leptothrix spp. The specific primers were constructed with Primer-BLAST Software. F1_ thrix e 5’-TGT-TCG-ACC-CGG-TGT-TCG-CC-3’, and R1_ thrix 5’-GAA-TCG-ATC-GGA-ACC-ACC-GT-3’. The PCR mixture contained 1 µM of each primer (Sense and Antisense), 0,2 mM dNTPs, Taq buffer 1x (Invitrogen), 1,5 mM MgCl2, 2,5 U Taq polymerase and 5 µl (100-100 ng) total DNA (Ready-To-Go PCR kit (GE Healthcare). Total volume of single reaction was 25 µl. The PCR program consisted of an initial denaturation step 95ºC/5min, followed by 35 cycles (95ºC/1min; 54ºC/1min; 72ºC/1min) and a final extension step at 72ºC for 5 min. All reactions were carried out on an Eppendorf Thermocycler (Eppendorf). A molecular weight marker (GeneRulerTM, 100 bp DNA Ladder Plus) was used to establish the size of the amplified fragments. The reactions were carried out again in an Eppendorf Thermocycler. Checking of the PCR products was performed on 3% agarose gel (Agarose low EEO, AppliChem, Germany).

The Adler’s medium contained sodium lactate (NaC6H5O7) 40 mg, yeast extract 1 g, ascorbic acid (C6H8O6) 0.1 g, MgSO4·7H2O 0.2 g, KH2PO4 0.01 g, (NH4)2Fe(SO4)2·6H2O 0.1 g, iron cuttings 10 % in 1000 ml distilled water.

The isolation medium known as M622 contained glucose (C6H12O6) 0.150, ammonium sulphate ((NH4)2SO4) 0.500, calcium nitrate (Ca(NO3)2·4H2O) 0.010, diopotassium phosphate (K2HPO4) 0.050, magnesium sulphate (MgSO4·7H2O) 0.050, potassium chloride (KCl) 0.050, calcium carbonate (CaCO3) 0.100, cyanocobalamin (Vitamin B12) (C12H17N4OS) 0.0004, iron cuttings 10 % in 1000 ml distilled water.

The isolation medium in Fehrenbach flask; sample 1 Isolation-MY – 103 days cultivation on Isolation medium in an aerobic installation; sample 1 Isolation-MF – 103 days cultivation on Isolation medium in Roux flask.

- The reference sample denoted 4 Natural-A was taken from a natural source in Vitosha at the altitude of 1840 m, Fig.1.

All the samples were filtered and dried, and then subjected to analyses for Fe containing compounds.

The structural characterization of the biogenic iron oxides/(oxy)hydroxides was carried out by laboratory X-ray diffraction using a Bruker D8 diffractometer in the Bragg–Brentano reflection geometry with Cu Kα radiation (λ = 1:5418 Å). SEM and TEM images were taken in studying the products morphology. For the NAA measurements, the irradiation of the samples was carried out at the Budapest Research reactor [6].

1.2. Implementation of k0-NAA technique

For k0-standardization in neutron activation analysis (k0-NAA) the determinations of the neutron flux parameters α (epithermal flux distribution parameter) and f (thermal-to-epithermal neutron flux ratio) has to be performed [7]. Neutron flux parameters have been measured with the "Bare Triple-Monitor" method using Zr and Al-0.1 %Au alloyed foils. Sample irradiations were performed in the vertical channels of the reactor with various time intervals (12 hours for long and 2 minutes for short irradiations in general).

Short-term irradiations of iron bacteria samples and monitors were performed by a fast pneumatic transfer system. At the irradiation position a thermal neutron flux of 4.45 x 1013 n/cm²-s, a thermal to epithermal neutron flux ratio (f) of 34.8 and an α=0.029 were available. Within a maximum decay period of 120 s the samples were packed into inactive polyethylene capsules and measured for 10 min and later for 20-30 min. Elements such as Ca, Mn and S were analyzed.

Long-term irradiation for the determination of elements producing medium- or long-lived isotopes (T1/2≥26 h) was used. Samples together with flux monitors were irradiated for 12 hours in one of the vertical, rotating irradiation channels (No17) of the reactor at a thermal neutron flux density of 1.86 x 1013 n/cm²-s, a thermal to epithermal neutron flux ratio (f) of 42 and an α = 0.031. Each sample was measured three times. After a typical decay time of 2-3 days, the radionuclides 24Na, 47Ca, 42K, and 24Na, were counted for a measuring time of 1800 s. To improve the detection limit for several radionuclides, a second measurement was made after 7-12 days (when the 24Na isotope had decayed). After a decay period of about 20-30 days (when the 82Br isotope decayed), the samples were counted for 5-15 hours and the radionuclide 59Fe was measured.

Detection of gamma rays was performed at a pre-calibrated sample-detector distance with a p-type Canberra HPGe detector, with an energy resolution of 1.82 keV and relative efficiency of 36%
for the 1332.5 keV $^{60}$Co line. Counting losses were corrected with a Westphal-type Loss-Free Counting (LFC) module with dual spectrum storage option providing full compensation.

For spectrum evaluation, the Hypermet-PC (version 5) program was used involving automatic peak search, energy calibration, net peak counts computation with the NonLin and Dual Spectrum LFC Option [8]. For the quantitative evaluation of the measurements an in-house program, RNAACNC was used [9]. This program involves the following quantities and features: absolute activity, alpha value, element concentration, detector efficiency, isotope identification, thermal and fast neutron flux and flux ratio ($f$), nuclear data library, specific activity computation.

The interferences caused by neutron-induced reaction can be important sources of bias in NAA. The interferences due to fast neutron induced threshold reactions i.e. $(n,p)$ or $(n, \alpha)$ can be accurately calculated, and corrections can be accomplished based on the measurement of neutron flux parameters (thermal and fast neutron flux and flux ratio). Interference from the $^{56}$Fe $(n,p)^{56}$Mn reaction was calculated and the Mn content of the samples was corrected on the basis of the Fe content of the samples. The combined uncertainty ($\pm \sigma$) of the results of this analysis is calculated as the square root of quadratic summation of the statistical counting error, and the estimated systematic uncertainty due to all fundamental parameters involved in $k_0$-NAA [10].

3. RESULTS AND DISCUSSION

Electron microscopy analyses of samples from the area of the sampling showed that the iron bacteria are stable component of the microbial community in the selected natural habitat. The electron microscopy images indicated the presence of FeOB both from genera Sphaerotilus and Leptothrix with the expected morphology and the typical sheaths that they create.

The isolates of the bacteria grown in the above described specific elective media (Adler’s or Isolation) were identified as belonging to the genus Leptothrix, Figs. 2 and 3.

The NAA results for iron and manganese are summarized in Table 1 and 2 and illustrate well the possibilities of the biotechnology approach for obtaining significant quantities of iron byproducts under artificial conditions.

| Table 1 INAA results for sample 2 Adler-D |
|-----------------|-----------------|-------|-------|
| Elem./Unit      | Reference sample (Vitosha) | 2DE** | 56 days | 2DP*  | 88 days |
| Fe, g/kg        | 92.9            | 375   | 354    |
| Mn, mg/kg       | 1276            | 22.71 | -      |
| * Enriched; ** Pure |

| Table 2 INAA results for sample 1 Isolation-M |
|-----------------|-----------------|-------|-------|
| Elem./Unit      | Reference sample (Vitosha) | 1MP*  | 56 days | 1MF*  | 88 days | 1MY*  | 103 days |
| Fe, g/kg        | 92.9            | 457   | 486    | 689    |
| Mn, mg/kg       | 1276            | 19.8  | 108    | 39.6   |
| * enriched |

Other elements and their radionuclides were also determined but in very low quantities and were left out of the scope of present discussion. High enrichment level of iron was found in all cultivated samples in comparison with the reference. The strong increase in Fe content depends on the culture medium and is superior in Isolation medium. Comparing the Mn concentration with that of the reference sample (product of nature), where it was in large concentration, to some extent higher enrichment level of Mn$^{3+}$ was established in just one sample grown in Adler’s medium.

| Table 3 Impurities of the chemicals to culture Isolation medium 1M |
|-----------------|-----------------|-------|-------|
| Elem./Unit      | Reference sample (Vitosha) | 1MP** | 103 days | 1MF* | 103 days | 1MY* | 103 days |
| As, mg/kg       | 18.34           | 11.7  | 25.7   | 23.9   |
| Ca, g/kg        | 9.37            | -     | -      | -      |
| K, mg/kg        | 3080            | 1269  | 947    | 254    |
| Na, mg/kg       | 4633            | 401   | 123    | 102    |
| S, mg/kg        | -               | 13.1  | 47.6   | 40.5   |
| * Enriched; ** Pure |
Tables 3 and 4 present the major other impurities established in the sub-products in comparison with the reference sample. A somewhat higher concentration of arsenic was found in two samples. This is most probably due to presence of a small quantity of As processing bacteria and this issue will be the subject of further bio-experiments. Basic elements from the nutrition media except Ca are also present.

A small quantity of Mn$^{3+}$ was established also in the Isolation medium. Therefore, it was concluded that Mn is due to the iron cuttings and batch impurity of the compound (NH$_4$)$_2$Fe(SO$_4$)$_2$.6H$_2$O, which are major substances in the laboratory media.

Table 4 Impurities of the chemicals to culture Adler’s medium 2D.

<table>
<thead>
<tr>
<th>Elem.</th>
<th>Referenc e sample (Vitosha)</th>
<th>2DE**</th>
<th>2DP*</th>
</tr>
</thead>
<tbody>
<tr>
<td>As, g/kg</td>
<td>18.34</td>
<td>5.46</td>
<td>17.4</td>
</tr>
<tr>
<td>Ca, mg/kg</td>
<td>9.37</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>K, mg/kg</td>
<td>3080</td>
<td>604</td>
<td>940</td>
</tr>
<tr>
<td>Na, mg/kg</td>
<td>4633</td>
<td>309</td>
<td>438</td>
</tr>
</tbody>
</table>

* Enriched; ** Pure

The crystal structures of the biogenic products were determined by powder X-ray diffraction (XRD) as illustrated with Fig. 4. The analyses of XRD patterns provided as well the quantities and particle sizes of the different substances building the material under study. Generally, most the particle sizes were evaluated as being much below 30 nm.

In the 1 Isolation-M samples, the fractions and the size of the constituents were: 1 Isolation-MP: goethite 77.03 % / 2.050 nm, lepidocrocite 22.97 % / 4.226 nm; 1 Isolation-MY: goethite 100 % / 5.306 nm; 1 Isolation-MF: goethite 100 % / 6.198 nm. Only in the sample 1 Isolation-MY it was detected also lepidocrocite. This might result from the different ways of cultivation: in an aerobic installation and a static installation. Phase and size analyses of Adler’s medium sample gave: lepidocrocite 59.67 % / 29.931 nm, magnetite 21.56 % / 23.860 nm, goethite – 18.77 % / 12.025 nm.

4. CONCLUSIONS

Biotechnologies for obtaining of iron biogenic oxides as bacterial sub-products in laboratory conditions were developed. High enrichment level of iron was found by the INAA technique in cultivated isolates as compared to the reference sample (product of nature). The enrichment rate varied between 3.8 times for the Adler medium and 7.4 times for the isolation medium. The XRD analysis demonstrated that in both cases the iron (II) from the nutrition media has been transformed into iron (III) in the form of different (oxy)hydroxides. Three types of iron oxide compounds were found after cultivation in Adler medium: lepidocrocite (γ-FeOOH), magnetite (Fe$_3$O$_4$) and goethite (α-FeOOH). The cultivation in the isolation medium yielded bacterial product identified as a single phase-goethite. XRD and SEM and TEM investigations show that the biogenic oxides are nanosized and could be used in appropriate nano- and biotechnologies.

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REFERENCES

EFFECTS OF ELECTROMAGNETIC FIELD AND NYSTATIN ON SACCHAROMYCES CEREVISIAE FATTY ACID COMPOSITION

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Abstract. The objective of this study was to evaluate the influence of radiofrequency electromagnetic field (RF-EMF) and fungicidal polyene antibiotic nystatin and their combined effects on the fatty acids (FA) composition of Saccharomyces cerevisiae yeast. Two saturated fatty acids (palmitic, stearic) and two monounsaturated fatty acids (palmitoleic, oleic) were obtained from the yeast cells after acid methanolysis. FA pool multiplied in time in both control and treated with RF-EMF or nystatin samples; common tendencies were marked during the first 30 min and disappeared under long-term treatment. Synergistic effects of the combination of RF-EMF, nystatin and temperature were observed. The ratio of C6:SFA and of C16:0 fatty acids changed independently on the applied factors. The decrease of C16:0 fatty acid portion under action of RF-EMF and nystatin was marked. This work contributes to the knowledge of the mechanism of microbial adaptation and stress resistance.

Key words: Saccharomyces cerevisiae, radiofrequency electromagnetic field, nystatin, fatty acids.

1. INTRODUCTION

Microbial antibiotic resistance arose as a puzzling problem that makes ineffective clinical treatment of various diseases in the last several decades [9]. Among different physical, chemical and biological factors affecting fungi and resulting in the origin of resistance the effects of unionizing electromagnetic field were observed recently [15]. Resistance of the yeasts to the fungicidal polyene and azole antibiotics can occur as a result of the radiofrequency (40.68 MHz) electromagnetic field (RF-EMF) exposure [5] (the EMF of this frequency is widely used during VHF-therapy in medicine). A lot of cellular effects occur under the action of RF-EMFs, which include structural, physiological, biochemical and genetic reorganizations [11, 12, 16]. Nevertheless the most probable cause of the yeasts antibiotic resistance is the effects on the cell membrane level. Physical properties of cell membranes and ion channels are thought as the main targets of unionizing EMFs [17]. However, only limited information is available about membrane composition role in the interaction of cells with this kind of radiation.

Membranes of the yeast Saccharomyces cerevisiae are composed of sterols, phospholipids, fatty acids and sphingolipids, constituents that are typical for eukaryotic cells. Action of polyene antibiotics (such as nystatin and amphotericin B) primarily depends on the sterol composition and their state within membranes [1, 10], while action of azole antibiotics (such as clotrimazole, itraconazole, fluconazole) did not directly depend on any of membrane components, but action of these both types of antibiotics may be prevented through changes in membrane permeability, which determined with fatty acid composition. The correct ratio of saturated to unsaturated fatty acids is important for maintaining the optimal levels of membrane fluidity and curvature, which are essential for a variety of cellular processes [20]. Moreover sterol biosynthesis pathway is closely connected with fatty acid metabolism [18] and therefore changes in one of them may cause changes in another one. Fatty acids play a role in biological energy storage, in the integrity and dynamics of biological membranes and also in the control of cellular metabolism and cell physiology [6].

Recently it was showed that EMFs of low frequency and low intensity can affect lipid metabolism at least of rats [7], while ultra-strong static magnetic field of 10 T can significantly alter the composition of fatty acid of Escherichia coli and not of Staphylococcus aureus [22]. Variation in the amount of one component will induce radical rearrangement of the membrane [13] and this may change its regulatory functions leading to various biological effects among which is antibiotic resistance.

Therefore, the aim of this study was to evaluate fatty acid composition stability under the action of unionizing EMF. The influence of RF-EMF and fungicidal polyene antibiotic nystatin and their combined effects on the composition and ratio of fatty acids of Saccharomyces cerevisiae yeast were studied.
Yeast strain and cultivation parameters. The yeast *Saccharomyces cerevisiae* strain Y-517 from the Ukrainian Collection of Microorganisms at Zabolotny Institute of Microbiology and Virology of the National Academy of Sciences of Ukraine, Kyiv, Ukraine, were used in this study. The culture of yeast was initially grown on agar medium at 28 °C during 24 h and then washed off with sterile distilled water, filtered and diluted to 10⁵ cells/ml.

RF-EMF experiments. Solenoid connected to the generator of EMF with frequency 40.68 MHz (27.5 V/m, 22 A/m, capacity of radiation 30 W, polarized in a horizontal plane) was used as a source of electromagnetic radiation. The RF-EMF parameters were measured with Magnetometer TESTLA DKP-B-2827 (Czech Republic). The irradiation of cells was performed under constant temperature (28 °C). The control tests were carried out in the same conditions without irradiation.

Nystatin experiments. Known amount of antibiotic nystatin was prepared daily by dissolving in dimethyl sulfoxide and then sterile distilled water was added to achieve appropriate antibiotic concentrations per ml. Final dimethyl sulfoxide (DMSO) concentrations did not exceed 0.003%. Equal numbers of yeast cells were resuspended in working mediums containing nystatin to a density of 1x10⁸ cells/ml. Additional tests were carried out to see whether used concentration of DMSO had an influence on the yeast FA composition. DMSO did not influence on the output of fatty acids, their percentage and quantitative characteristics in the samples.

Combined effects of RF-EMF and nystatin. Yeast cells were treated with nystatin after preliminary exposure to RF-EMF. RF-EMF exposure was carried out at 28 °C, while nystatin action was studied under normal and increased temperatures up to 46 °C. The temperature factor was used as an additional control to evaluate possible thermal effects of RF-EMF. Therefore, three variables of RF-EMF exposure (15, 30 and 45 min), nystatin (5, 10 and 15 µg/ml) and temperature were used (28 °C, 37 °C and 46 °C). Box-Behnken design has been employed to study the effect of complex of experimental variables.

**Fatty Acid GC/MS Analysis.** Fatty acid methyl esters (FAMEs) were extracted from 10⁵ cells/ml (OD₆₀₀ = 0.5) by acid methanolysis as described elsewhere [2]. Dried FAMEs were resuspended in 200 µl of hexane and separated and quantified by GC/MS with an Agilent 6890 gas chromatograph and 6890N Mass Selective Detector (Palo Alto, CA, USA), helium was used as carrier gas, injector temperature was 250 °C, oven programming temperature was used 150-250 °C with gradient 4 °C per min. The gas-chromatography capillary column was a HP-5MS (30 m length, 0.25 mm i.d., and 0.25 µm film thickness) with a low polarity liquid phase of (5% phenyl)trimethylpolysiloxane from JandW Scientific (Folsom, CA, USA), the gas flow rate was 1.0 ml/min, and the split ratio 1:100. Mass spectra were recorded in electron impact ionization at 70 eV in SCAN mode. Transfer line was kept at 280 °C. Data were processed with Workstation software (Agilent Technologies) and compounds were identified by relative retention time with standards of bacterial FAMEs (Supelco) and from the comparison of mass spectra in NIST02 MS library. The calculations for true FA amounts were based on the correction factors that were extrapolated from the calibration curves as described in [4].

**Statistical analysis.** The experiments were conducted in triplicate and each assay was conducted in triplicate. Statistical data processing was carried out with STATISTICA (data analysis software system), version 6 (StatSoft, Inc. 2001, www.statsoft.com). Analyses of variance (ANOVA) for high-order linear and quadratic main effects of the RF-EMF exposure, nystatin and temperature on the yeast fatty acid composition were carried out by the 3-level factorial design (Box-Behnken design). The error term used for the ANOVA table and for computing the standard errors for the parameter estimates was calculated as the sum-of-squares residual for the dependent variable, after controlling for all effects in the current model. Since runs in the current design were replicated, we provided a lack of fit test.

**3. RESULTS**

**3.1. Saccharomyces cerevisiae fatty acids pool and characteristics**

Two saturated fatty acids (palmitic (C16:0) and stearic (C18:0)) and two monounsaturated fatty acids (palmitoleic (C16:1) and oleic (cis-Δ⁹ C18:1)) were obtained from the yeast *Saccharomyces cerevisiae* cells after acid methanolysis. About 75% of the total fatty acids in the cells belonged to the monounsaturated ones. The fatty acids with more than 20 carbon atoms were not detected in any of the samples.

Quantity of FA extracted from the samples during acid methanolysis characterized by a nonlinear temporal dependence. The maximum output values were marked after about 40 min from the beginning of the experiment (Fig. 1); further 20 min characterized with a lower amounts of FA. In fact, we observed twofold increase of the FA output for the first 40 min (from 1.0 nmol/ml initially to 2.0 nmol/ml after 40 min), and 1.5-fold at the end point of experiment.

The ratio of unsaturated FA (UFA) to saturated FA (SFA) increased linearly from 2.7 to 3.3 as a function of time resulting in the 8% UFA fraction domination over the SFA one.

Ratio of C16/C18 remained constant. Quantity of C16:1 related to the quantity of cisC18:1 characterized with a ratio close to 1:1.1. However, minimal and maximal values of C16:1 were both lower than the same values of cisC18:1. Ratio of the other two FA to C16:1 were 1:0.5 for C16:0 and 1:0.2 for C18:0. Thus, an average ratio for the all studied
FA looked like $1:1:1:0.5:0.2$. This ratio only slightly changed by the action of the RF-EMF and was not affected by the action of nystatin.

### 3.2. Nystatin effects

Increase of antibiotic concentration from 2.5 µg/ml to 15.0 µg/ml resulted in linear decrease of total FA amount extracted from the samples (from 2.0 nmol/ml to 1.5 nmol/ml) at 10 min exposure.

Ratios of UFA to SFA and of C16/C18 fatty acids remained constant.

Prolonged 60 min treatment of cells with the antibiotic in concentrations of 5 µg/ml and 10 µg/ml showed an increased FA output in course of time for both concentrations. Nystatin showed no effect on the total FA quantity during the first minutes of experiment. Differences were observed after 30-40 min of exposure, when amount of FA went down sharply in the nystatin samples, while in control the output of FA still multiplied and reached a maximum (Fig. 1).

![Figure 2: Yeast cells fatty acids quantities under action of RF-EMF.](image)

**Figure 2.** Yeast cells fatty acids quantities under action of RF-EMF.

Common temporal characteristics were marked after comparison of the C16/C18 ratios in the control and exposed to nystatin samples. In the first minutes ratios did not change, although amount of fatty acids increased in all samples, and after 30 min it went down (from 1.25-1.3 to 1.0-1.1). This surely indicated a multiplication of C18:x FA after 30 min of cultivation in all samples and that this multiplication wasn’t stress sensitive. At the same time the ratio of UFA to SFA did not change.

### 3.3. Electromagnetic field effects

Yeast cells were exposed with radiofrequency electromagnetic fields during 60 min. First 30 min of exposure did not differ from the control on any investigated parameter (Fig. 2). After 40 min of exposure the quantity of FA decreased 30% in comparison with control. During next 20 min of irradiation the quantity of FA in the exposed samples again multiplied 25% and finally exceeded the control values.

Ratios of UFA/SFA and of C16/C18 fatty acids did not changed under EMF exposure.

### 3.4. Combined effects of RF-EMF, nystatin and temperature

Complex influences of external factors on fatty acids parameters of yeasts were studied applying the exposure of RF-EMF and subsequent influence of nystatin under different temperature conditions.

C16:0 was alone fatty acid whose percentage of the total fatty acids significantly depended on the RF-EMF exposure time ($p \leq 0.034$) and less significantly on the nystatin concentration ($p \leq 0.067$). Effects of these factors characterized with negative linear dependences indicating that prolonged exposure and increased antibiotic concentrations will decrease the portion of C16:0 from $27.19 \pm 1.60\%$ to $18.65 \pm 1.13\%$, while portions of the other three FA will change in relation to the C16:0 but not in dependence on the values of the studied factors. Temperature variation had no effect on the FA percentage.

The ratio of UFA to SFA varied in the range from 1.7 to 3.2 reflecting the 13% increase in the portion of UFA (from 63% to 76%) and corresponding decrease of the SFA portion (from 37% to 24%). The ratio of C16/C18 varied sligher in the range from 1.12 to 2.05 and caused by 15% increase of the C16:x FA (from 53% to 67%). ANOVA failed to reveal any dependence between variations of these ratios and the levels of investigated factors. Therefore these ratios changed independently on the applied stresses.

### 4. Discussion

In the previous study we marked decrease of membrane permeability after action of the RF-EMF 40.68 MHz [5]. In this study we marked the decrease of C16:0 fatty acid portion under action of RF-EMF and nystatin. The ratios of UFA to SFA and of C16/C18 fatty acids changed independently on the applied factors in response to the hypotonic environment in which the cells were treated. The levels of C16:0 and of UFA may change in response to the changes in the degree of membrane fluidity, which is the primary signal eliciting an adaptive response in fatty acid composition [14, 21]. Changes in these both parameters are considered as a result of an adaptation processes in the yeast cells exposed to the stresses [8, 14, 21]. The all aspects of the mechanism of such resistance left unclear, however, we suppose that both these factors can be reason of the antibiotic resistance of the yeast cells caused by RF-EMF exposure under hypotonic environment [5].

One interesting fact is the dose-dependant decrease of the FA output marked in the presence of
NST. This observation let to suggest an existence of a link between portion of non-connected with nystatin ergosterol [1, 10] and the quantity of FA. One could suppose the cell death as a reason of the sharp decline of the total FA amount marked during prolonged exposure of the cells with antibiotic [19]. We supposed that the sharp decline of the FA output was not connected to the cell death since same effect was observed under the action of RF-EMF, which does not possess any lethal effect [5, 19]. Marked effects can be regarded as the result of influence of stress factors directly on some features of membranes, because both nystatin and RF-EMF are thought to cause their main effects on the cell membranes [1, 10, 17].

The effects of nystatin and RF-EMF were not obvious during the first 30 min of the cells treatment. The 40 min treatment with RF-EMF or nystatin resulted in significant decrease (30-50%) of the FA quantity whereas shorter or longer exposures showed higher levels. The marked dependences allowed to assume an existence of a period in the cellular FA metabolism, which is not depend on the influences of external stress factors. Thus the initial stage of the cellular FA metabolism can be divided into two periods: (i) insensitive and (ii) sensitive to the influences of external physical or chemical stresses. This assumption can be suggested with some data on time-dependant activities of some fatty acid-modifying enzymes (Δ^9-desaturase, a Δ^12-desaturase and an elongase) discovered in another yeast species *Aureobasidium pullulans* under hypo-osmotic shock: a significant increase in the levels of these genes first seen 10 min after the down-shift [3]. In this connection, the nonlinear shift of the total FA quantity observed in the control samples can be related to the activities of the FA desaturases and elongases too.

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THE ROLE OF DOSIMETRY IN CONTROL OF RADIATION PROCESSING - A CASE STUDY AT VINČA RADIATION PLANT

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Abstract

Radiation dosimetry is the essential part of the irradiation process since it assures delivery of absorbed dose to a product that is in accordance with prescribed limits. In this paper, the role of dosimetry in the installation qualification of irradiator, the process qualification, and the routine process control is analyzed on the basis of the case study performed on Vinča Institute Radiation Plant. Two different types of dosemeters are used for measurements: ethanol-chlorobenzene (ECB) and alanine. The measurement traceability is achieved by the Risø National Laboratory in Denmark (by calibration). In this case study the determination of facility parameters through installation qualification and evaluation of dose distribution and uncertainty of delivered absorbed dose are demonstrated.

Key words: radiation processing, ethanol-chlorobenzene dosimetry, alanine dosimetry

1. INTRODUCTION

Radiation processing denotes a number of treatments that utilize large-scale ionizing radiation aimed to improve products and to increase their value. It covers many areas, like radiation sterilization, food irradiation or polymer modification. In all cases, the quality of treatment strongly depends on the precise delivery of absorbed dose during the irradiation process. Therefore, radiation dosimetry is the essential part of the irradiation process since it assures delivery of absorbed dose to a product that is in accordance with prescribed limits. The absorbed dose should be high enough to accomplish the desired effect, but not to cause adverse effects. For this purpose, all measurements of absorbed doses have to be traceable to national or international standards, and the uncertainty of measurements should be in the appropriate confidence limits. These are the prerequisites for use of dosimetry in the validation and routine control of the irradiation process. The irradiation sterilization process at the Radiation Plant of the Vinča Institute of Nuclear Sciences will be the practical example how dosimetry can define the irradiation process.

The Radiation Plant of the Vinča Institute of Nuclear Sciences started to operate in 1978 as a service for sterilization of predominantly medical devices. It was built by scientists from the Vinča Institute with the support of the UN Development Program and technical assistance by the International Atomic Energy Agency. The source of radiation is 60Co. The plant is designed for either continuous or batch operation. In recent years, the Radiation Plant has a lot of activity to implement the international standard ISO 11137 – Sterilization of health care product – Radiation, in its domain of responsibility, and also try to help manufacturers to improve its quality control system.

2. GENERAL TERMS

The Radiation Plant has been described in more detail elsewhere, and only a brief description will be given here. Fig.1 shows a schematic diagram of the arrangement of product boxes around the radiation source. At the present time, the source frame (1 m x 3 m) is loaded with 6.88 x 1015 Bq of 60Co placed into source rods (diameter 11.1 mm, length 451 mm). Several generations of source rods are arranged in this source frame. An automatic conveyer carries boxes through the source. Single irradiation run consists of four sequential irradiation cycles, and in each cycle
each box passes through the irradiation room at one of four vertical levels, i.e. every box is irradiated in the same way.

3. Irradiation process control

An irradiation process requires a minimum absorbed dose in order to achieve the desired effect. On the other hand, there is a maximum absorbed dose that the product can tolerate and keep its functional properties. Having this in mind, the irradiation process control has to define facility parameters through installation qualification of radiation sources, validation of product through process qualification, and routine control of the irradiation process during exploitation. The radiation sterilization and the treatment of food are governed in the most strict way\(^2,3\).

Before an irradiation process can be used, the irradiator must be qualified through the installation qualification. The purpose of the installation qualification process is to establish baseline data for evaluation of the effectivity, predictability and reproducibility of the system under the range of conditions over which the facility will operate\(^3\). The installation qualification is necessary before the first use of the irradiation facility and also after changes in the source loading, source geometry or product transport system. The installation qualification includes the measurements on two different dosemeter systems placed together in at least 5% of the boxes in irradiation cycle\(^4\). In the cases of changes in radiation source loadings, it is performed with 5 boxes in single irradiation cycle.

The principal purpose of the process qualification is to determine the absorbed dose distribution in boxes with products, with the prior knowledge of product density. For absorbed dose mapping, one dosemeter system is used, and dosemeters are placed in the box with product in two planes: one facing the source and one in the center of the box. Each plane contains 9 individual dosemeters, 4 placed in corners of the box, 4 placed at the middle of box edges, and one in the center.

In the routine process control the nominal absorbed dose, prescribed in process qualification, is checked in each irradiation cycle. The assessment is performed with one dosemeter for each product type in irradiation cycle, placed at the position in the box where the minimum absorbed dose is expected. However, the minimal number of dosemeters is 4.

\[
\text{Fig. 1 Horizontal (a) and vertical (b) arrangements and movements of box carriers within the irradiation room}
\]

The absorbed dose measurements in radiation processing must have measurement traceability to national or international standards. Measurement traceability is defined as the ability to demonstrate by means of an unbroken chain of comparisons that a measurement is in agreement with acceptable limits of uncertainty with comparable nationally or internationally recognized standards\(^5\). For this purpose, all dosemeter calibrations for radiation processing in Vinča Radiation Plant are based on the values obtained from Risø National Laboratory, Denmark\(^6\).

4. Results and discussion

4.1. Installation qualification after changes in the source loading

The standard irradiation run is used for installation qualification. The dwell time is calculated from the proportion:

\[
T_b : T_a = A_a : A_b
\]  

(1)
where $T_b$ is dwell time before source loading, $T_s$ dwell time after source loading, $A_s$ source activity after source loading, and $A_b$ source activity before source loading. The calculated dwell time for delivery of approximately 25 kGy absorbed dose was 416 s. Their irradiation run used for installation qualification was the run marked VII-MMXII (in the Vinça Radiation Plant log). The irradiation run was split in two parts. In the first part, the dwell time was 200 s, i.e. approximately half of calculated dwell time. Two pairs of two different types of dosemeters, ethanol-chlorobenzene (ECB) and alanine, were put in 6 boxes along with products. After first irradiation part, one pair of dosemeters was measured using a calibration curve made earlier. The results were 11.6 kGy ± 2.6% for measurements by alanine dosemeters and 11.6 kGy ± 3.2% by ECB dosemeters. The dwell time for the second part of irradiation run was calculated for target dose 26 kGy, so it was 250 s. The results after second irradiation part were: 25.9 kGy ± 3.2% alanine dosemeters and 26.3 kGy ± 3.3% ECB dosemeters. In this way, the new dwell time after source loading was determined as 450 s. This dwell time is increased by 1% each month to compensate the decrease in radiation source activity.

4.2. Process qualification after changes in the source loading

The determined dwell time is for plastic product loading, i.e. for density of approximately 0.15 g/cm³. The product loading configuration is arbitrary, but it should be homogeneous inside the box (48 cm x 48 cm x 45 cm). The process qualification concerns a dose mapping of products to identify the locations and magnitudes of minimum and maximum absorbed doses. Therefore, the objective of process qualification is to ensure that absorbed dose requirements are satisfied. The irradiation run marked XV-MMXII was used for dose mapping inside the boxes with plastic products. For the test, the dwell time was set to 454 s. The dosemeters were alanine tablets placed in the box with products, in the center and at the box surface planes parallel to source plane. The measured absorbed doses after completion of irradiation run are presented in Fig. 2. One can see that the maximum dose is achieved at the top of the inside surface plane of the box while the minimum values are in bottom corners in the center plane. The relationship between the maximum and minimum doses gives the rate of dose homogeneity in the box, in this case estimated at 23%.

<table>
<thead>
<tr>
<th>Front (back) plane</th>
</tr>
</thead>
<tbody>
<tr>
<td>32kGy</td>
</tr>
<tr>
<td>30.7kGy</td>
</tr>
<tr>
<td>29.8 kGy</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Centre plane</th>
</tr>
</thead>
<tbody>
<tr>
<td>26.1 kGy</td>
</tr>
<tr>
<td>26.9 kGy</td>
</tr>
<tr>
<td>26 kGy</td>
</tr>
</tbody>
</table>

4.3. Routine process control

Routine product dosimetry is part of the verification process, the process aimed to verify that the product irradiation is done according to prescribed parameters. The irradiation run XV-MMXII had five ECB dosemeters, each placed in one of five boxes

Fig. 2 Absorbed dose in kGy in box with plastic product after irradiation cycle.

with different plastic products in a minimum dose location. The average absorbed dose measured by these dosemeters after completing irradiation was 26.6 kGy ± 3.5%. The difference between measurements is caused by variation in product densities, and the value of 3.5% can be used as the uncertainty of the minimum absorbed dose in the sterilization process of different plastic products.

5. Conclusion

Dosimetry plays an essential role in process control in radiation processing:
• Enables determination of facility parameters through installation qualification. In this case, enables determination of dwell time.

• Enables determination of dose distribution in irradiated products through process qualification. In this case, the determined dose homogeneity in a box with products is 23%.

• Enables routine control of the irradiation process. In this case study, the uncertainty of absorbed dose in a product in a certain location in the box is 3.5% caused by variation in the product density.

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REFERENCES


VERTICAL DISTRIBUTION PATTERN OF $^{137}$Cs IN UNDISTURBED ARENOSOLS OF THE BANAT SANDS, SERBIA

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Abstract. The gamma-ray spectrometry analysis of $^{137}$Cs has been carried out in the undisturbed soil profiles collected from area of Banat Sands. The mean $^{137}$Cs activity concentration across all nine undisturbed soil profiles (each soil layer was considered equally) ranged from 0.20 to 139 Bq kg$^{-1}$, with a mean value of 12.8 Bq kg$^{-1}$. About 52.7% of the total $^{137}$Cs in analyzed soil profiles was found in the first layer (0-5 cm) 26 year after Chernobyl accident. The $^{137}$Cs activity concentration in soil profiles increased with increasing organic matter and silt content, and with decreasing sand content.

Key words: $^{137}$Cs, soil profiles, soil particle size fractions.

1. INTRODUCTION

After Chernobyl accident, in May 1986, radioactive clouds contaminated the large areas of Europe, and the $^{137}$Cs was major pollutant involved in this airborne contamination. The $^{137}$Cs is one of the most significant radionuclide in the environment due to its long half-life (30.2 years) and significant contribution to external and internal radiation exposure to man. Soil is the main reservoir for $^{137}$Cs, and represents the medium for its migration/retention and transfer to biological compartments. The $^{137}$Cs undergoes vertical and horizontal migration [1]. Retention/migration of $^{137}$Cs in soil is affected by physicochemical forms of Cs, intensity and quantity of precipitation, soil permeability, texture, mineralogy, organic matter content, various exchangeable cations, biological activity of microorganisms of the soil etc. Therefore, resulting profile distributions and migrations of $^{137}$Cs are site specific. Many studies have demonstrated the influence of above mentioned parameters on the behavior of $^{137}$Cs in soil [1-7]. The aims of this study were: (1) to investigate the vertical distribution of $^{137}$Cs activity concentration in undisturbed soil profiles of Banat Sands and (2) to assess the influence of organic matter content and soil particle size on the vertical distribution of $^{137}$Cs in soil.

2. MATERIALS AND METHODS

2.1. Description of the studied area

Banat Sands is located in southeastern sector of Pannonian Plain in the southern part of Serbian geographic region Banat. It extends the length about 35 km and maximum width of about 15 km. It covers an area about 300 km$^2$, with elliptical shape stretch in southeast-northwest direction. The landscape of Banat Sands is unique among other parts of Pannonian Plain because altitudes gradually increase from southeast to northwest but also from southwest to northeast. The dune-deflation relief dominates, as the result of intensive eolian and accumulation processes. The relief of Banat Sands is created by phase action of southeastern wind, by deflation and sand sedimentation [8]. The major part of sand-loess complex of Banat Sands is composed of eolian sand sediments, initially formed as alluvial sands which were then blown up by southeastern wind and accumulated as aero-sediments at the places of the lower wind intensity. The pure eolian sands are of coarse-grained and pulverulent texture, composed mainly from quartz, feldspar, mica, granat, epidote and iron oxides [8]. According to Milojević (1949) the eolian sands are of Pliocene age [9]. Sandy-loess accumulations spread over northwestern part of Banat Sands are presented by fine-grained sands, which are accumulated either over eolian ones or lake sands. The sandy loess is characterized by the combine intergrain and capillary porosity [8]. The belts of loess accumulation spread over western part of Banat Sands, characterized by intergrain and capillary porosity in their surface horizons [8]. The climate of the investigated area is semi-arid continental with elements of steppe climate and belongs to $b$ type according to Köppen (1936) climate classification [10]. The mean annual temperature is 10.4 °C, with minimum values by end of January and the beginning of February and maximum values by the end of July and the beginning of August. The mean annual precipitation is 660 mm, with two maxima, in June and November. According to values of Lang (1920) rain coefficient (calculated as ratio between mean annual precipitation and mean annual temperature) of about 60 (with decreasing values
towards peripheral areas up to 40), the area belongs to the climate of low forests [11]. The wind Košava significantly influences the climate of the area, blowing from Carpathian Mountains in southeast. Soils are represented by number of varieties of basic soil types. Among undeveloped soils the most abundant is Albic Arenosols. Above them the fragments of Cambisols and Eutric Cambisols occur. The soils have high calcium carbonate content and low humus and clay content. They are characterized by low water-holding capacity.

2.2. Soil sampling and preparation
A total of nine undisturbed soil profiles were collected from grass-covered area of Banat Sands during 2012 (see Table 1). Soil samples were collected at 5 cm intervals from the uppermost layer down to 40 cm. At the point of sampling the samples were cleaned of residual plant material, packed in plastic bags and transported to the laboratory where were further cleaned from foreign material. The samples were air-dried, homogenized mechanically and then sifted through a sieve (mesh size 2 mm). Finally the samples were packed in Marinelli beakers of 0.5 L volume. Total weight of each sample was recorded.

<table>
<thead>
<tr>
<th>Profile</th>
<th>Location geographic coordinates</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>44° 55' 37.9&quot; N 21° 08' 40.3&quot; E</td>
</tr>
<tr>
<td>II</td>
<td>44° 55' 37.9&quot; N 21° 08' 40.3&quot; E</td>
</tr>
<tr>
<td>III</td>
<td>44° 55' 37.9&quot; N 21° 08' 40.3&quot; E</td>
</tr>
<tr>
<td>IV</td>
<td>44° 48' 16.0&quot; N 21° 07' 2.8&quot; E</td>
</tr>
<tr>
<td>V</td>
<td>44° 48' 16.0&quot; N 21° 07' 2.8&quot; E</td>
</tr>
<tr>
<td>VI</td>
<td>44° 48' 16.0&quot; N 21° 07' 2.8&quot; E</td>
</tr>
<tr>
<td>VII</td>
<td>44° 51' 31.4&quot; N 21° 18' 55.4&quot; E</td>
</tr>
<tr>
<td>VIII</td>
<td>44° 51' 31.4&quot; N 21° 18' 55.4&quot; E</td>
</tr>
<tr>
<td>IX</td>
<td>44° 51' 31.4&quot; N 21° 18' 55.4&quot; E</td>
</tr>
</tbody>
</table>

2.3. Analytical methods
The $^{137}$Cs activity concentration in soil samples was determined by the ORTEC-AMETEK HPGe gamma-ray spectrometer (34% relative efficiency and 1.65 keV FWHM for $^{60}$Co at 1.33 MeV) using its gamma-ray line at 661.6 keV. The energy calibration and relative efficiency calibration of the gamma-ray spectrometer were carried out using a 0.5 L Marinelli calibration source MBBS2 supplied by Czech Metrological Institute, Prague. For analysis of the gamma-ray spectra Gamma Vision 32 MCA emulation software was used [12]. The soil organic matter content was determined according to Walkley-Black procedure [13]. The pipette method was used for particle size analysis analysis to determine the following fractions: clay (<0.002 mm), silt (0.002–0.05 mm) and sand (0.05–2 mm) [14].

2.4. Statistical analysis
The software package SPSS 16.0 for Windows was used for descriptive statistic of the data [15] and for assessment of significant relationships between physicochemical soil properties and $^{137}$Cs activity concentration by Spearman’s correlation analysis.

3. RESULTS AND DISCUSSION

3.1. Vertical distribution of $^{137}$Cs in the soil profiles
Vertical distribution of $^{137}$Cs activity concentration at 5 cm interval samples in the undisturbed soil profiles is presented in Figure 1. In soil profiles I–V, VII and VIII the $^{137}$Cs activity concentration was the highest in the first layer (0–5 cm) and decreases with depth. The decrease was rapid from the first layer (0–5 cm) to the depth of approximately 10 cm in profiles II, IV and VII; 15 cm in profiles I, III and V; and 25 cm in profile VIII. Below specified depth, the $^{137}$Cs activity concentration decreased slowly or was nearly constant. The $^{137}$Cs activity concentration showed exponential decline with soil depth in the mentioned soil profiles, which is a typical distribution of $^{137}$Cs in undisturbed stable soil. In the soil profile IX the lower level of $^{137}$Cs activity concentration was present in the first layer (0–5 cm) followed by increases in the second layer (5–10 cm) and then decreased irregular to the last layer. In the soil profile VI upper peak corresponds to the Chernobyl deposition 1986 whereas the lower peak reflects the weapons fallout depositions about 1963. Numerous studies have shown that $^{137}$Cs activity concentration decreases with soil depth [16-19], and that the vertical migration of $^{137}$Cs in soil is a very slow process [20-21]. Kirchner and Baumgartner (1992) reported low migration rates for $^{137}$Cs from 0.3 to 1 cm per year [22]. In Table 2 basic descriptive statistics of $^{137}$Cs activity concentration across all nine undisturbed soil profiles of Banat Sands is presented (all soil layer are consider as equal). The $^{137}$Cs activity concentration in soil profiles ranged from 0.20 to 139 Bq kg$^{-1}$, with the mean of 12.8 Bq kg$^{-1}$. In the first layer (0–5 cm) the $^{137}$Cs activity concentration showed a wide range of values from 24.9 to 139 Bq kg$^{-1}$, with a mean value of 46.9 Bq kg$^{-1}$, which could be attributed to non-homogeneous surface contamination. The mean value of 52.3% (21.7-83.0%) of the total $^{137}$Cs activity concentration was retained in the upper 5 cm of undisturbed soil profiles of Banat Sands 26 years after Chernobyl accident. Numerous studies have shown that many years after the accident in Chernobyl the high percentage of total $^{137}$Cs activity still retained in the topsoil [19, 23-24].

3.2. The physicochemical characteristics of analyzed soils
Different physical, chemical and biological characteristics of soil horizons influence the migration and retention of $^{137}$Cs through the soil profiles [1]. In order to assess the relationships between physicochemical soil properties and $^{137}$Cs activity concentration, the organic matter content and soil particle size of all soil profiles were analyzed. The basic descriptive statistics of physicochemical soil characteristics across the all nine soil profiles (each soil layer was considered equally) are summarized in Table 2. The organic matter content in profiles ranged from 0.70 to 8.68%, with a mean value of 3.36%, the organic matter content characterized a slight decreasing trend with depth in soil profiles. These results are in accordance with values reported for
organic matter content in grasslands of Banat Sand [25]. Low humus content in grasslands can be explained by a lower production of organic matter due to the influence of semi-arid steppe climate [25]. The clay content in analyzed soil profiles was very low with mean value of 6.43%. These results are in accordance with earlier findings for clay content in grasslands and forest soils of Banat Sand [25-26]. The sand and silt contents in soil profiles were very high with mean values of 50.1% and 43.4%, respectively.

![Fig. 1 Vertical distribution of 137Cs in the soil profiles (5 cm depth interval samples).](image)

Table 2 Basic descriptive statistics of 137Cs activity concentration, organic matter content, clay, sand and silt content across all nine undisturbed soil profiles (each soil layer was considered equally).

<table>
<thead>
<tr>
<th>Parameter</th>
<th>137Cs (Bq kg⁻¹)</th>
<th>Organic matter (%)</th>
<th>Clay (%)</th>
<th>Sand (%)</th>
<th>Silt (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>12.8</td>
<td>3.36</td>
<td>6.43</td>
<td>50.1</td>
<td>43.4</td>
</tr>
<tr>
<td>Median</td>
<td>3.85</td>
<td>3.41</td>
<td>6.46</td>
<td>50.1</td>
<td>43.7</td>
</tr>
<tr>
<td>Mode</td>
<td>0.45</td>
<td>3.48</td>
<td>6.48</td>
<td>53.6</td>
<td>40.1</td>
</tr>
<tr>
<td>Std. deviation</td>
<td>21.9</td>
<td>1.48</td>
<td>0.79</td>
<td>12.6</td>
<td>12.5</td>
</tr>
<tr>
<td>Range</td>
<td>139</td>
<td>7.98</td>
<td>4.04</td>
<td>48.7</td>
<td>48.6</td>
</tr>
<tr>
<td>Minimum</td>
<td>0.20</td>
<td>0.70</td>
<td>5.00</td>
<td>27.9</td>
<td>17.1</td>
</tr>
<tr>
<td>Maximum</td>
<td>139</td>
<td>8.68</td>
<td>9.04</td>
<td>76.6</td>
<td>65.7</td>
</tr>
</tbody>
</table>

3.3. Relationship between physicochemical characteristics and 137Cs

The relationships between physicochemical soil properties and 137Cs activity concentration was analyzed through Spearman’s correlation analysis and the results are summarized in Table 3. In analyzed soils, positive Spearman’s correlation coefficient was found between 137Cs activity concentration and organic matter content (p < 0.01). Positive correlation between 137Cs activity concentrations and organic matter content was reported in a number of studies [2-3, 5-7]. Due to large cation exchange capacity the role of organic matter in the retaining and preventing downward migration of 137Cs through soil profile is very important. In the organic horizons, soil microflora and -fauna can immobilize the 137Cs. Brückmann and Wolters (1994) reported that the soil microflora strongly contributes to the immobilization of 137Cs in the organic layer of forest soils [27]. Positive Spearman’s correlation coefficient was also found between 137Cs activity concentration and silt content, while negative one was found between 137Cs activity concentration and the sand content (p < 0.01). Lee et al. (1997) indicated that role of clay content in retention and relative mobility of 137Cs in the soil is less significant in comparison with organic matter [2], while Kim et al. (1998) confirmed the role of clay in the retention of 137Cs, based on positive correlation between clay content and concentrations of 137Cs in soil [3]. Dragović et al. (2012) reported positive correlations between 137Cs activity concentration and clay and silt content in soil profiles [5]. Petrović et al. (2015) reported a positive correlation between silt content and 137Cs, but did not found correlation between clay content and 137Cs activity concentration in soil profiles [6].

Table 3 Spearman’s correlation coefficients between physicochemical soil characteristics and 137Cs activity concentration across all nine undisturbed soil profiles.

<table>
<thead>
<tr>
<th>Organic matter</th>
<th>Clay</th>
<th>Sand</th>
<th>Silt</th>
</tr>
</thead>
<tbody>
<tr>
<td>137Cs</td>
<td>0.469*</td>
<td>0.144</td>
<td>-0.410***</td>
</tr>
</tbody>
</table>

*, Correlation is significant at the 0.05 level (2-tailed).
***Correlation is significant at the 0.01 level (2-tailed).

3. CONCLUSIONS

The 137Cs activity concentration in undisturbed soil profiles of Banat Sands determined by gamma-ray spectrometry ranged from 0.20 to 139 Bq kg⁻¹, with the mean value of 12.8 Bq kg⁻¹. The 137Cs activity concentration decreases in the most of analyzed soil profiles in an exponential manner. The relationships between physicochemical soil properties and 137Cs activity concentration, was analyzed through the Spearman’s correlation analysis. Negative Spearman’s correlation coefficient was found between sand content and the 137Cs activity concentration, while positive values of this coefficient were found between organic matter and silt content and 137Cs activity concentration.

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REFERENCES

NEW ASPECTS OF LEGISLATION CONCERNING EMF EXPOSURE TO MEDICAL PERSONNEL IN MRI

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Abstract. In recent years, magnetic resonance imaging (MRI) is one of the most powerful diagnostic methods in medical practice. At the same time there is a concern that the medical staff involved in these diagnostic procedures is at high risk of overexposure to static magnetic fields, mainly due to their non-homogeneity. Serious concerns were expressed by medical community to the potential impact of the implementation of EMF Directive on the use of medical procedures based on medical imaging. That is one of the reasons for postponing transposition deadline of Directive 2004/40/EC into national law of the EU Member States and reconsidering the text of the document. Last year the European Commission published new EMF Directive 2013/35/EU repealing Directive 2004/40/EC. The paper presents new aspects in legislation concerning EMF exposure to medical personnel in MRI units. The paper presents data of EMF measurements in the working environment around magnetic resonance imaging (MRI) devices as well. Several MRI systems are considered mainly 1.5 T devices. Measurements are performed in two premises – procedure chamber with MRI where incidental stay of the personnel is possible (on procedures of children, patients with claustrophobia; disabled, on giving anesthesia or in case of sedated patients) and personnel/command hall – outside the chamber – where the process is viewed and controlled and a permanent workplace for the personnel. Data are compared to the limit values according to the existing national legislation and the new Directive for the different frequency EMF emitted by the devices.

Key words: MRI legislation, exposure assessment, non-ionising radiation, occupational exposure

1. INTRODUCTION

In recent years magnetic resonance imaging (MRI) is one of the most powerful diagnostic methods in medical practice. Meanwhile there is concern that medical personnel involved in such diagnostic procedures is at high risk of overexposure to static magnetic fields, mainly its non-homogeneity. That is one of the reasons for the impossibility for implementing Directive 2004/40/EC into national legislation in Member states up to now.

MRI is more often recommended to the patients rather than computer tomography (CT) to reduce the hazardous effects of X-ray radiation. Unlike of CT technology, MRI allows stay of the medical personnel inside the working premise for support patients with specific health problems. It should not be forgotten that MRI also emits hazardous physical factors in the workplace, although it does not emit ionizing radiation. At workplaces with MRI non-ionizing radiation is the main hazardous factor.

From 2011 there is no any standard for occupational exposure to electromagnetic fields (EMF) for frequencies above 60 kHz in Bulgaria. Fortunately, Ordinance No.7 [1] concerning health and safety at work deals with protection of the workers in EMF with frequencies from 0 Hz up to 60 kHz. The major part of the EMF emitted by MRI equipment is within this frequency range.

2. EXPOSURE STANDARDS AND LEGISLATION

2.1. National Legislation

Ordinance No.7, 1999 [1].

There, the following maximum permissible levels (MPLs) are accepted:

Static magnetic fields

Art.151. “... the magnetic flux density at the working place should not exceed 60 mT (600 G), averaged over the working day, and the ceiling value should not exceed 2 T nevertheless of time duration of exposure.”

Art.154. “For persons with pacemakers, MPLs should be less than following values:

\[ B_{\text{max}} = 1.0 \, \text{mT at } f < 6 \, \text{Hz}. \]

Extremely low and low frequencies:

Art.152. “MPLs should not exceed the following values:

At frequencies from 0 to 100 Hz - \( E_{\text{max}} = 23 \, \text{kV/m}; \)

At frequencies from 100 Hz to 4 kHz - \( E_{\text{max}} = 2.5 \times 10^6/f \) where \( f \) is in Hz;

At frequencies from 4 kHz to 60 kHz - \( E_{\text{max}} = 625 \, \text{V/m}. \)
**Art.153.** MPLs should correspond to the following equation:

\[ B_{\text{max}} = 60/f \, \text{mT, where } f \text{ is in Hz.} \]

**Art.154.** For persons with pacemakers MPLs should be less than:

\[ B_{\text{max}} = 0.1 \, \text{mT at } f = 50 \, \text{Hz}; B_{\text{max}} = 1.0 \, \text{mT at } f < 6 \, \text{Hz.} \]

**Radiofrequency fields** – there are no any legislation in the country.

2.1. International Guidelines and European Directive

1. **ICNIRP Guidelines, 2009** [2]

These guidelines apply to occupational and general public exposure to static magnetic fields. They do not apply to the exposure of patients undergoing medical diagnosis or treatment. Detailed consideration of protection of patients is given in an ICNIRP statement on protection of patients undergoing a MRI examination. [3, 4]

Because of potential indirect adverse effects, ICNIRP recognizes that practical policies need to be implemented to prevent inadvertent harmful exposure of persons with implanted electronic medical devices and implants containing ferromagnetic material, and dangers from flying objects, which can lead to much lower restriction levels such as 0.5 mT.

2. **ICNIRP Guidelines 2010** [5]

Occupational exposure in these guidelines refers to adults exposed to time-varying electric, and magnetic fields from 1 Hz to 10 MHz at their workplaces, generally under known conditions, and as a result of performing their regular or assigned job activities.

There two types of non-thermal effects are considered: on central nervous system (retinal phosphenes, possible effects on brain functions) and on peripheral nervous system (direct nerve and muscles stimulation).

Reference levels itself are derived by modelling and calculation from basic restrictions expressed in induced electrical fields inside the tissue.

In this document there are specific measures for direct non-thermal effects, also for indirect effects.


This standard covers the whole frequency range. Because of the implementation of the both cited above documents of ICNIRP [2,5], this recommendation applies for frequencies above 10 MHz where thermal effects are expected.

Reference levels for frequencies up to 400 MHz for magnetic field are the same as those implemented in [5]. Only for frequencies 1 – 25 Hz there is a difference in the frequency dependence.


This standards implements basic restrictions and maximum permissible exposure levels (MPE) for controlled (occupational) and uncontrolled (public exposure) areas for frequencies above 3 kHz. That is the reason that we will not discuss these exposure limits here. IEEE develops new standard now where the frequency range starts at 0 Hz (static fields) up to 300 GHz:


In the preamble of the Directive the philosophy of the exposure limits as some special requirements for MRI equipment are explained. Lets’ see some of them:

(3) Following the entry into force of Directive 2004/40/EC...., serious concerns were expressed by stakeholders, in particular those from the medical community, as to the potential impact of the implementation of that Directive on the use of medical procedures based on medical imaging.

(28) …However, such a system may conflict with specific conditions in certain activities, such as the use of the magnetic resonance technique in the medical sector. It is therefore necessary to take those particular conditions into account.

The final point gives the possibility for derogation of some medical applications as MRI.

For the purposes of this Directive, the following definitions shall apply (Art.2): ....

(ii) **non-thermal effects**, such as the stimulation of muscles, nerves or sensory organs. These effects might have a detrimental effect on the mental and physical health of exposed workers. Moreover, the stimulation of sensory organs may lead to transient symptoms, such as vertigo or phosphenes. These effects might create temporary annoyance or affect cognition or other brain or muscle functions, and may thereby affect the ability of a worker to work safely (i.e. safety risks); and

(iii) **limb currents**.

(c) ‘indirect effects’ means effects caused by the presence of an object in an electromagnetic field, which may become the cause of a safety or health hazard, such as:

(i) **interference with medical electronic equipment and devices**, including cardiac pacemakers and other implants or medical devices worn on the body;

(ii) **the projectile risk from ferromagnetic objects** in static magnetic fields;

(v) **contact currents**.

By way of derogation..., the following shall apply (Art.10):

(a) **exposure may exceed the exposure limit values (ELVs)** if the exposure is related to the installation, testing, use, development, maintenance of or research related to magnetic resonance imaging (MRI) equipment for patients in the health sector, provided that all the following conditions are met:

(i) the risk assessment carried out in accordance with Article 4 has demonstrated that the ELVs are exceeded;

(ii) given the state of the art, all technical and/or organisational measures have been applied;

(iii) the circumstances duly justify exceeding the ELVs;
(iv) the characteristics of the workplace, work equipment, or work practices have been taken into account; and

(v) the employer demonstrates that workers are still protected against adverse health effects and against safety risks, including by ensuring that the instructions for safe use provided by the manufacturer in accordance with Council Directive 93/42/EEC of 14 June 1993 concerning medical devices are followed;

ELVs for external magnetic flux density from 0 to 1 Hz are based "on the sensory effects ELV... for normal working conditions and is related to vertigo and other physiological effects related to disturbance of the human balance organ resulting mainly from moving in a static magnetic field".

The health effects ELV for controlled working conditions are applicable on a temporary basis during the shift when justified by the practice or process, provided that preventive measures, such as controlling movements and providing information to workers, have been adopted.

Health effects ELVs for internal electric field strength from 1 Hz to 10 MHz are related to electric stimulation of all peripheral and central nervous system tissues in the body, including the head.

They all are based on ICNIRP Guidelines. The reference levels in the Directive are Action levels (ALs).

3. MAIN SOURCES OF NON-IONIZING RADIATION IN MRI

**Magnet** - the largest part of MR system; frequency 0 Hz; allows the orientation of the hydrogen nuclei in the body. It provides field of measurement with diameter 50 cm at maximal possible homogeneity. MR medical equipment typically applies static magnetic fields from 0.2 T to 3 T.

**Gradient system** - alternating magnetic field (100 - 1000 Hz). It is used to determine the speed of measurement and spatial resolution. It locates the part of the body to be measured. It consists of an amplifier and gradient coil system. Gradient systems generate low frequency (up to 1 kHz) magnetic pulses mainly trapezoidal shape. Amplitude and speed of switching gradient pulses are such as to avoid stimulation of peripheral nerves of the patient.

**RF system (10 to 100 MHz)** - it could be differentiated transmitting and receiving parts of the system. Transmitting part consists of an amplifier and antenna which creates pulses for deflecting the hydrogen nuclei from their orientation. Receiving part consists of receiving antennae that detect signals emitted by the body tissues and convert them for further processing. RF fields emitted from the antenna increase the temperature of the patient's tissues, as capacity is limited so that the temperature rise is less than 1 °C.

3. MATERIALS AND METHODS

**Objects**: Nine, 1.5 T Magnetic Resonance Image devices; different producers.

EMF parameters evaluated according to the frequency range:
- \( f = 0 \text{ Hz} \) - magnetic flux density, B, T;
- \( f = 10 \text{ Hz} \div 300 \text{ kHz} \) - electric field strength E, V/m and magnetic flux density, B, T;
- \( f = 60 \text{ kHz} \div 350 \text{ MHz} \) - electric field strength E, V/m.

**Measuring equipment**
1. Measuring device for magnetic field type HI-3550 (USA)
2. Measuring device for ELF electric and magnetic field type HI-3604 (USA)
3. Measuring device for LF and RF electric and magnetic field type HI-3603 (USA)
4. Measurement device for RF electric and magnetic field NFM - 1 (Germany).

**Measuring method**

Frequency-non-selective methods corresponding to the frequency range for the particular measurement devices were used at measurements.

Measurements are performed in two premises - procedure chamber with MRI where incidental stay of the personnel is possible (on procedures of children, patients with claustrophobia; disabled, on giving anesthesia or in case of sedated patients); and personnel/command hall – outside the chamber – where the process is viewed and controlled and it is permanent work place for the personnel.

During the measurements all MRI are working in a typical regime with phantom of a head placed inside the gentry (bore).

5. RESULTS AND DISCUSSION

**Static magnetic field** - The results are presented in Fig 1 and Fig 2.

![Fig. 1 Average values of magnetic flux density, static fields, in relative units](image)

ELF and LF fields up to 2 kHz - The results are presented in Fig 3 and Fig 4.

Average values on different distances are compared to the reference levels corresponding to the upper limit of the dynamic range of equipment ("worst case”).

As it could be seen from the figures, workers are in condition of overexposure from static magnetic field only compared to the national legislation. This is not the same for workers with active implants (as
pacemakers) where the exposure limits are exceeded both compared to national legislation and ICNIRP guidelines.

Fig. 2 Average values of magnetic flux density, static fields, in relative units, for workers with pacemakers

Fig. 3 Average values of magnetic flux density, ELF and LF fields, in relative units

Discussion of the ELF and LF fields, data show compliance with the limits both for Bulgarian legislation and for ICNIRP guidelines.

Data outside the procedure chamber (both for electric and magnetic fields) are with very low levels, and are not presented in figures. Electric field strengths measured inside the chamber are with very low levels.

The RF electric field strengths out of the procedure chamber are very low: $E < 2$ V/m, below the MPLs. Inside the chamber measured values of RF electric field strength are from $< 2$ V/m up to 11 V/m.

The electric field strength and magnetic flux density at 50 cm from VDUs are within the MPLs - national legislation for all installations.

CONCLUSION

This study of NIR around MRI systems doesn’t not show exceed of the limits values outside the protective chambers (procedure chamber).

The temporary stay inside the protective chambers in MRI is permitted under the following required conditions:

- Restricted stay duration in locations with high magnetic flux density values;
- Using of a separation distance if appropriate; it should be taken into consideration that the field decreases approximately as the reciprocal of the cube of the distance to the source;
- Restrictions for individuals with active implants in order to avoid risks from magnetic interference with surgical and dental implants.

Personal protective equipment like clothing, face masks, etc. is not appropriate and not effective for magnetic fields.

The new European Directive ensures good basis for health and safety of workers in MRI nevertheless of the derogation proposed in the document. It doesn’t stop the development of the MRI technology and its application in diagnostics. It is very important that the Directive demands the development of Practical Guide for its application where all requirements for health and safety of medical personnel working with MRI should be covered.

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RESEARCH ONTO IMPROVEMENT OF MICROCAPSULES EMBEDDING BY AIR-PLASMA TREATMENT

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Abstract. The research presented in the paper is based on the idea of optimising the processing and use of cosmetotextiles. The production of these materials involved: use of a textile knitted support with 3D surface geometry (in order to create a massaging effect) made of bamboo yarns (for improved comfort characteristics); functionalisation of the textile support with air-plasma treatment that improves hydrophilic characteristics and increases surface energy available, facilitating the bonding of microcapsules. The paper highlights the improvement of microcapsules embedding by the functionalisation of a textile knitted support with 3D surface geometry, made of bamboo yarns. The surface of the bamboo knitted fabric was pre-functionalized by an air-atmospheric plasma treatments before applying microcapsules the characterization and quantification of the amount of microcapsules being carried out using gas chromatography and mass spectrometry (GC-MSD), scanning electron microscopy (SEM), and electric parameters analysis (zeta potential ξ) and determination of air permeability.

Key words: Bamboo fabric, air-atmospheric plasma, gas chromatography, mass spectroscopy, Zeta potential

1. INTRODUCTION

In the 90's, textile materials started to be used as support for different active substances with controlled release (perfumes, insecticides, cosmetics, drugs). The cosmetic applications for this type of products showed a good market potential and it led to the development of the so-called cosmetotextiles. A large range of textile products and raw materials (clothing, decorative textiles and non-implantable medical textiles) can be used for cosmetotextiles.

The functionalization of textile materials for the controlled release of active substances can be obtained through different processes: re-impregnation of textile fabrics by spraying it with an aqueous solution containing at least one active component [1]; grafting cyclic compounds like β-cyclodextrin on the textile support using a cross-linking agent [2]; introducing microcapsules containing an active substance on the textile support [3].

The grafting of the microcapsules on the fibres presents several advantages: improved wear and washing durability, the textile products do not lose their flexibility and touch, while the vapour permeability is higher than when binders are used.

It is known that plasma treatments improve hydrophilic properties [4-6] and induce changes in a thin layer at the surface of textile materials.

The paper presents the elaboration of the functionalisation of a textile knitted support with 3D surface geometry, in order to create a massaging effect, made of bamboo yarns. The surface of the bamboo knitted fabric was pre-functionalized by an air-atmospheric plasma treatments before applying microcapsules the characterization and quantification of the amount of microcapsules being carried out using gas chromatography and mass spectrometry (GC-MSD), scanning electron microscopy (SEM), and electric parameters analysis (zeta potential ξ) and determination of air permeability.

2. EXPERIMENTAL PROCEDURE

2.1. Materials

The sample used in the experiment is a knitted fabric with tubular evolution and transfer pattern, made of
bamboo yarns Nm 24/1 (Abtex International Ltd). The five treated samples were left for an hour in an exhaustion bath at a pH 7 containing 50 g/l lavender oil microcapsules, 20 g/l Mikracat B, 5 g/l cross-linking product, 15 g/l Sapamine softener.

The solution was extracted from the fabrics, using 3 bars pressure between rollers and was crosslinked for 1 minute at 30°C.

Mikracat is an agent similar to a cross-linker developed for thermal cross-linker developed for thermal processes. The microcapsules with essential lavender oil were purchased from Devan (Belgium) and have an average dimension of 1.95 μm. The lavender oil has antioxidant, sedative, smooth muscle relaxation, anti-inflammatory, antifungal and antibacterial characteristics [7, 8].

2.2. Methods

2.2.1. Air plasma treatment

Air-plasma treatment is intended to modify polymer surfaces using plasma gases made of a mixture of charged particles (electrons and ions), excited atoms (free radicals and meta-stable molecules) and photons [9].

The name of the equipment used is Coating Star (Ahlbrandt System).

The prepared sample was subjected to an air-plasma treatment with different powers: 0, 300W, 700W, 1000W and 1000 W (two times on the same side or twice on the same side).

2.2.2. Functionalization of samples with microcapsules

The microcapsules were deposit on the bamboo knitted by the method of padding which is a traditional technique in textiles finishing. The fabric continuously passed into a bath containing the solution with active agents, and then is squeezed between two rollers. The wet pick-up ratio of the padding is calculated using the following equation:

\[
\text{wetpick-up} = \frac{\text{wetweight} - \text{dryweight}}{\text{dryweight}} \times 100
\]

Where:
- Wet weight: weight of sample after padding (g)
- Dry weight: weight of sample before padding (g)
- The knitted fabric with the embedded microcapsules was dried at room temperature.

2.2.3. Sample washing

The samples with embedded microcapsules (4x10cm) were washed using a Washtech laboratory washing machine, according to EN ISO 105-C06 [10]. The samples were washed in 150 ml of distilled water, with no detergent, for 30 min, at 40°C.

After washing, the samples were rinsed twice in distilled water, for 1 min, at 30°C, in order to observe the wash durability.

2.3. Characterization techniques

2.3.1. XPS Analysis

Analyses were performed using a VG ESCALAB 220XL (group THERMO) spectrometer equipped with an un monochromatized Mg Kα X-ray source (1253.6 eV) at 300 W. Spectra were recorded in the CAE mode with a pass-energy of 30 eV. The binding energy of the carbon 1s orbital for the -CH2-CH2- groups was fixed to 285 eV and used as the internal reference for the binding energy scale. Samples (~15x15 mm²) were mounted on double-sided conducting adhesive tape. The typical pressure during analyses was 10⁻⁷ Pa. All quantifications were carried out with the ECLIPSE software from VG SCIENTIFIC.

2.3.2. GC-MSD analysis

The lavender microcapsules and the textile support with microcapsules were characterised using gas chromatography-mass spectrometry (GC-MSD) analysis.

The fabric was cut into 5 samples, each of the same mass (1.157 g). The samples were subjected to air-plasma treatment of different powers and after the lavender microcapsules were embedded, they were introduced in sealed glass bottles with 4 g ethylic alcohol.

A solution containing lavender microcapsules diluted in distilled water was placed on a glass and the water was left to evaporate at room temperature, in order to form a film. An amount of 1 mg of dry microcapsules was placed in a sealed bottle with another solvent, meaning 0.5 g of diethyl ether. All bottles were shacked for 30 min, at 50°C and then cooled in an ice bath, for another 30 min. The resulting solutions were analysed using gas chromatography coupled with GC-MSD in order to identify the compounds extracted from the knitted samples and from the lavender microcapsules.

GC-MSD was carried out using a 6890N Agilent chromatograph with 5975 inert XL Agilent selective mass detector, working at 70 eV, open at HP5-MS (30m x 0.25 μm), column filled with 5% phenyl-methylpolysiloxane. The following parameters were used: injector -250°C, for 2 min., then increasing with 10°C/min., up to 300°C (7min).

2.3.3. Zeta potential

The enhancement of the functional properties can be explained through the modification of thermal dynamic properties at surface level, especially surface energy and electrical parameters, quantified through zeta potential [11].

The following parameters are determined at column extremities: pressure (P, mbar), voltage (E, mV), solution conductivity γ, (S·cm⁻²) and device temperature (T, °C). Zeta potential ξ is calculated with the following relation:

\[
\xi = 13.55 \times 10^{-4} \times C \times \gamma \times E_{AP} \times \Delta p
\]

where ξ and E are expressed in mV, P in mbar and γ in S·cm⁻². Constant C gathers the medium permittivity and the solution viscosity, both dependent on temperature. The phenomenological law can be then written as:

\[
C = 16.32 - 0.3519 \times T + 0.003519^2
\]

The zeta potential of the samples was determined using a Zeta-cad equipment (see Fig. 1). The sample is maintained in column (1) with filters (2). The Ag/AgCl electrodes (3) were placed on both sides of the filters. A quantity of 1 litre of electrolyte was displaced between
the recipients (4) with pressure (0 ÷ 500 mbar) through an admission valve (5). The displacement direction was controlled by a set of circulation and ventilation valves (8). The pressure and voltage variations were recorded at cell extremities.

Before measuring, each sample was maintained in the KCl electrolyte solution with a concentration of 0.001 mol/L, for 12 hours, in order to become balanced. For each sample in number of five measurements were carried out. The electrolyte solution, subjected to pressure varying between 20 and 100 mbar, passed through the sample placed in a glass tube. The study of zeta potential took into consideration the pH of the KCl solution that was varied between 4 and 10 by adding drops of HCl or KOH solution, concentration 0.1 mol/L.

3. RESULTS AND DISCUSSIONS

3.1. XPS analysis results

3.2. GC-MSD analysis

The GC-MSD analysis of the lavender microcapsules shows a set of chemical compounds, most important being: limonene (peak area - 8.91), linolool (10.04), camphor (10.84), isoborneol (11.02), borneol (11.15), linalyl acetat (12.37), isoborneol acetat (12.94), lilial (16.08) and isopropyl myristate (19.26), as illustrated in Fig. 3.a. The above listed compounds were hardly found in the diethyl ether solutions from the bottles containing the textile samples since only a small quantity of compounds in the lavender microcapsule solution remained fixed on the textiles, since the active principle has migrated in the solvent.

Table 1 shows that the peak area for compound isopropyl mystrate increases from 260,053 for the reference sample with microcapsules to 5,527,191 for the sample with microcapsules treated twice at 1000 W. The peaks intensities after the first wash increase three, four or five times, in comparison with the reference sample.

Figure 4 illustrates the direct relation between plasma treatment power and the quantity of microcapsules extracted from the samples, quantified through the peak area for isopropyl mystrate compound.

The GC-MSD analysis of the lavender microcapsules shows a set of chemical compounds, most important being: limonene (peak area - 8.91), linolool (10.04), camphor (10.84), isoborneol (11.02), borneol (11.15), linalyl acetat (12.37), isoborneol acetat (12.94), lilial (16.08) and isopropyl myristate (19.26), as illustrated in Fig. 3.a. The above listed compounds were hardly found in the diethyl ether solutions from the bottles containing the textile samples since only a small quantity of compounds in the lavender microcapsule solution remained fixed on the textiles, since the active principle has migrated in the solvent.

Figure 5 presents the morphology of microcapsules bonded bamboo fibers to the on the knitted samples, after air-plasma treatment of 1000 W. It is relevant that, air plasma treatment plays its important role of bonding system/crosslinking, subsequently the microcapsules are directly attached onto the fibers, without any ligand.
3.3. Zeta potential

The zeta potential of microcapsules in suspension was measured to be -46.78 for a pH equal to 4. The five measurements are presented in Table 2.

<table>
<thead>
<tr>
<th>Number of measurements</th>
<th>Values of Zeta potential for microcaps</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>-46.7</td>
</tr>
<tr>
<td>2</td>
<td>-47.2</td>
</tr>
<tr>
<td>3</td>
<td>-47.2</td>
</tr>
<tr>
<td>4</td>
<td>-46.3</td>
</tr>
<tr>
<td>5</td>
<td>-46.5</td>
</tr>
<tr>
<td>Average</td>
<td>-46.78</td>
</tr>
<tr>
<td>St dev.</td>
<td>0.408656</td>
</tr>
</tbody>
</table>

Fig. 6 reveals the variation of zeta potential ($\xi$) with pH values (acid, neutral and basic) for all types of treated and untreated samples. The graphic (a) shows the variation of zeta potential determined after the microcapsules were embedded, while the second graphic (b) illustrates the same variation after the first wash.

A notable remark is that there is an obvious difference between the fibres surface belonging to the reference sample and the one functionalized sample. The negative values of zeta potential could indicate a higher density of hydroxyl and (-NH) groups at fiber surface level that facilitates the chemical bonding process.

Conclusion

All outcomes presented in the paper lead to the conclusion that the power of air-plasma treatment is in direct relation with the amount of microcapsules bonded to the fibers, inducing the increasing of the amount of carboxyl, hydroxyl and aldehyde groups increases, determining the bonding of a higher number of microcapsules to the fibers. The amount of microcapsules present at fabric surface for non-treated and air-plasma treated samples was determined using gas chromatography analysis combined with mass spectrometry (GC-MSD), and electrical parameters through zeta potential $\xi$ and determination of air permeability. Moreover, zeta potential allows noticing that after washing, the microcapsules show a better affinity, after atmospheric air plasma of 1000 W power on each side of sample. The experimental data shows that the best variant is obtained for the sample subjected each side to 1000 W air-plasma treatment.

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REFERENCES

ESTIMATION OF UNCERTAINTY OF HPGE EFFICIENCY CALCULATED BY EFFTRAN USING VIRTUAL POINT DETECTOR MODEL

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Abstract. Experimental efficiency calibration of high purity germanium (HPGe) detectors is often expensive and time consuming. That is why many methods, such as Monte Carlo simulations and analytical methods have been proposed and examined. One of those methods is virtual point detector (VPD) method, the approximation of whole bulk detector with a point detector, located at the effective interaction depth. Also, one of efficiency transfer programs is EFFTRAN, the software that calculates efficiency and coincidence summing. The aim of this paper is to use EFFTRAN software for obtaining effective interaction depth of the detector, needed for virtual point detector method calculations. Since the effective interaction depth represents the geometry of the detector, the discrepancy between the calculation and measurement can be used to estimate uncertainty, originating from the defining of detector geometry when EFFTRAN is used. For the purpose of estimation of uncertainty, semiempirical formula based on VPD, will be utilized.

Key words: HPGe, calibration, virtual point detector, EFFTRAN

1. INTRODUCTION

Gamma ray spectrometry with high purity germanium (HPGe) detectors is widely used for measurements of activity concentration of naturally occurring and artificial radionuclides in environmental samples. The determination of activity concentration requires a prior knowledge of the full-energy peak efficiency of the measuring system, which, in turn, depends not only on the detector, but also on the geometry, density and chemical composition of the calibration source [1].

The most accurate way of efficiency calibration (direct measurement of the sources of known activity and adequate geometry and chemical composition) is often time consuming and expensive, so many methods have been examined in order to avoid this problem. There are examples of analytical methods of efficiency transfer from point sources to bulk sources and Monte Carlo simulations developed to complement or replace the measurement of efficiency using bulk calibration sources. When choosing between different approaches to efficiency calibration, one is guided by the requirements of the measurement itself and requirements for the accuracy and precision.

If the circumstances in the laboratory dictate that an analytical method of calibration should be used, there are several approaches examined and tested in papers lately. The idea behind some of those methods is that the whole active volume of the detector can be represented by a point located at the effective interaction depth (EID) within the detector [2, 3]. In this case, the geometrical considerations used in calibrations of the detector would be much simpler. This simplification is important, especially in measuring radioactivity of bulky samples. It was shown [2-4] that such a virtual point can be specified by measuring the activity of the point sources located on the symmetry axis of HPGe detector.

Many software packages were developed in order to, with known set of parameters, perform efficiency transfer calculations, and coincidence summing corrections. One of such software is EFFTRAN [5]. The efficiency transfer calculation in EFFTRAN is based on the assumption that the ratio between the efficiency at two different positions of the source in respect to the detector crystal is proportional to the ratio between two solid angles subtended on these two positions [6]. In order to calculate the unknown efficiency, program requires relatively precise information on geometry of the detector (crystal geometry, housing geometry and composition, active and inactive layers etc). This data is not always known and can not be precisely defined, thus contributing to the measurement uncertainty and that contribution has to be estimated as accurately as possible. The most obvious solution for this problem is to gradually vary the parameters that are of interest and try to approach the experimental results, as close as possible. But, in turn this requires large computational time and great number of variations that can be time consuming and too complicated.
However, software can be utilized to calculate efficiency for point source on different heights, needed for determination of EID, provided that the efficiency for one fixed position is known (measured). Since EID is a representation of the whole active volume of the detector, the calculated value should be virtually the same as the measured value, if the program and all the needed parameters are well defined.

Since the EID is conceived to be an approximation of the geometry of the detector, the discrepancy between the calculation and measurement can be used to estimate uncertainty for the efficiency calculated by EFFTRAN, originating from the definition of detector geometry. All that is needed then is to calculate the uncertainty propagation. For that purpose, we can use the virtual point detector model for calculation of efficiency. This should prove useful when using EFFTRAN for calculation of efficiency in daily practice, because it would greatly diminish the time needed for defining the uncertainty budget. However, this can be used only as an assessment of influence of detector geometry on total uncertainty budget and further analysis is needed in order to precisely determine the uncertainty.

2. MATERIALS AND METHODS

In order to determine effective interaction depth of the detector, a set of measurements should be performed. Namely, assuming that the detector volume can be replaced by a virtual point detector placed at effective interaction depth along the axis of the crystal, the counting efficiency at different distances of the source from that point obeys the quadratic inverse law, due to different solid angles [2-7]. If the distance of the source from the detector cap is \( x \), the ratio between efficiency at the distance \( x \) and distance \( x_0 \) is given by

\[
\frac{\varepsilon(x)}{\varepsilon(x_0)} = \frac{N(x)}{N(x_0)} = \left( \frac{x + h_0}{x_0 + h_0} \right)^2 \Rightarrow \sqrt{\frac{N(x)}{N(x_0)}} - 1 = \frac{x - x_0}{x_0 + h_0} \quad (1)
\]

where \( \varepsilon(x) \) is detector efficiency at the distance \( x \), \( h_0 \) is the effective interaction depth and \( N(x_0) \) is count rate at that distance. If we choose that \( x_0 = 0 \), the equation simplifies. By measuring count rate at several different distances \( x \), and plotting \( (N(x)/N(x_0))^{\frac{1}{2}} \) against \( x \) we obtain the linear function, and the slope of that function represents \( 1/h_0 \). From this equation, one can obtain \( h_0 \).

In [8], the proposed efficiency formula for a point source at the extension of the HPGe detector axis is given in Equation 2:

\[
\varepsilon_{\text{point}}(x, E) = \sigma(x + h_0(E))^2 \quad (2)
\]

where \( \varepsilon_{\text{point}} \) is the detector efficiency in the point source configuration at source-detector distance \( x \) and definite energy \( E \). \( h_0(E) \) is defined in Equation (1) and \( \sigma \) can be interpreted as an effective area that varies with photon energy and possibly crystal radius. Since point source was used for both measurement and EFFTRAN calculation of EID, Equation (2) should prove adequate for uncertainty propagation for EFFTRAN. According to [9], combined standard uncertainty of a function of uncorrelated input values is the positive square root of the combined variance \( u^2(y) \):

\[
u^2(y) = \sum_{i=1}^{n} \left( \frac{\partial y}{\partial x_i} \right)^2 \Rightarrow u(y) = \sqrt{\sum_{i=1}^{n} \left( \frac{\partial y}{\partial x_i} \right)^2} \quad (3)
\]

where \( \delta h_0 \) is the relative uncertainty of the calculated EID, namely the discrepancy between the calculated and experimentally obtained values, expressed as ratio \( (h_{\text{experimental}} - h_{\text{EFFTRAN}})/h_{\text{EFFTRAN}} \).

According to [8], the VPD model can also be used in case of cylindrical samples of different composition. For that purpose, integration over the height of the cylinder of contribution of elemental disc source to the total count should be performed. After that, uncertainty propagation should produce \( u(\varepsilon_{\text{cylinder}}) \) as a function of \( h_0 \). In this study, only point source case was investigated.

3. RESULTS AND DISCUSSION

The measurements of EID were performed in Institute for Nuclear Sciences Vinča, Radiation and Environmental Protection Department, on two high purity germanium (HPGe) detectors named D1 and D2. The characteristics of the detectors are given in Table 1. For a total of 7 energies, measurement was conducted using point sources \(^{241}\text{Am}, ^{109}\text{Cd}, ^{133}\text{Ba}, ^{137}\text{Cs}, ^{54}\text{Mn}, ^{60}\text{Co} \) produced by LMRi Coffret d’étalons gamma ECGS-2, placed at the detector cap (\( x = \text{ocm} \)). The count was used to calculate experimental efficiency for both detectors [10], as a starting point for efficiency transfer calculation and for experimental EID also, according to Equation (1).

Efficiency transfer was calculated for 4 distances \( x \) and efficiencies obtained were used to calculate theoretical count at these distances. The count was calculated according to the following Equation:

\[
N(x) = \left( A e^{-\frac{\ln(2)}{T_{1/2}}} \right) P_e \cdot 1000 s \cdot \varepsilon(x) \cdot C(E) \quad (4)
\]

where \( A e^{-\frac{\ln(2)}{T_{1/2}}} \) represents the activity of the point source with the decay correction, \( P_e \) is the emission probability, 1000 s is the duration of the measurement, \( \varepsilon(x) \) is efficiency at a given energy at the distance \( x \) obtained by efficiency transfer and \( C(E) \) is coincidence summing correction factor at the energy \( E \), obtained also using EFFTRAN. After that, the results of the calculation were fitted by a linear function as indicated in Equation (1), and EID was calculated from the slope of the graph. Linear fits of calculated counts for 3 energies 59 keV, 88 keV and 2332 keV at two detectors are represented in Figure 1. The linear fit agrees well with calculated points (99.7% for D1 and 97% for D2). However there are some discrepancies for D2. The reason for that is that the efficiency transfer for low energies is greatly influenced by the definition of geometrical characteristics of the detectors.

The discrepancy between experimental and calculated EID was then placed in Equation (3) in order to calculate the uncertainty of EFFTRAN.
calculated efficiency, due to the geometry of the detectors. The results of the calculations using EFTRAN, the results of measurements and uncertainty $u(E_{point})$ are presented in Table 2.

Table 1. The characteristics of the detectors

<table>
<thead>
<tr>
<th>DETECTOR</th>
<th>$D_1$</th>
<th>$D_2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geometry and type of detector</td>
<td>Close end - coaxial</td>
<td>Close end - coaxial</td>
</tr>
<tr>
<td>$p$ type</td>
<td>$p$ type</td>
<td></td>
</tr>
<tr>
<td>Resolution at 122 keV</td>
<td>0.850 keV (certificate)</td>
<td>1.00 keV (experimental)</td>
</tr>
<tr>
<td>at 1332 keV</td>
<td>1.8 keV (certificate)</td>
<td>1.9 keV (experimental)</td>
</tr>
<tr>
<td>Peak/Compton ratio</td>
<td>51:1 (certificate)</td>
<td>65:1 (certificate)</td>
</tr>
<tr>
<td>Cryostat</td>
<td>Vertical dipstick</td>
<td>Vertical dipstick</td>
</tr>
<tr>
<td>Detector</td>
<td>+ preamplifier</td>
<td>+ preamplifier</td>
</tr>
<tr>
<td>Crystal Diameter</td>
<td>49.5 mm</td>
<td>65 mm</td>
</tr>
<tr>
<td>Crystal length</td>
<td>56.5 mm</td>
<td>67 mm</td>
</tr>
<tr>
<td>Crystal to window distance</td>
<td>5.5 mm</td>
<td>5 mm</td>
</tr>
<tr>
<td>Entry window</td>
<td>Al</td>
<td>Al</td>
</tr>
<tr>
<td>Relative efficiency</td>
<td>20%</td>
<td>18%</td>
</tr>
</tbody>
</table>

Figure 1. Point source count, obtained using EFTRAN and Equation (4), versus the distance from the detector cap. Linear fits of calculated counts for energies 50keV, 88keV and 1332keV at different distances $x$.

Measurement uncertainty for both calculation and measurement results was obtained according to the following Equation [11]:

$$u = \sqrt{(u(A_p))^2 + (u(N))^2 + (u_{fit})^2}$$  

where $u(A_p)$ represents uncertainty of the point source activity, estimated to be 3% according to the certificate given by the manufacturer, $u(N)$ $u(N)$ is the counting uncertainty (1%) and $u_{fit}$ is the uncertainty of the linear fitting of the data. Measurement uncertainty is presented at 1σ level.

Table 2. EID calculated using EFFTRAN denoted as $h_{calc}$, and experimental EID denoted as $E_{exp}$.

<table>
<thead>
<tr>
<th>$E$ [keV]</th>
<th>$D_1$</th>
<th>$D_2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>59.5</td>
<td>2.53±0.11</td>
<td>2.62±0.09</td>
</tr>
<tr>
<td></td>
<td>2.73±0.12</td>
<td>2.98±0.10</td>
</tr>
<tr>
<td>88</td>
<td>2.61±0.11</td>
<td>2.73±0.09</td>
</tr>
<tr>
<td></td>
<td>2.92±0.13</td>
<td>3.25±0.11</td>
</tr>
<tr>
<td>661.7</td>
<td>2.73±0.12</td>
<td>2.84±0.09</td>
</tr>
<tr>
<td></td>
<td>3.24±0.14</td>
<td>3.62±0.12</td>
</tr>
<tr>
<td>302.85</td>
<td>2.76±0.12</td>
<td>2.70±0.10</td>
</tr>
<tr>
<td></td>
<td>3.35±0.15</td>
<td>3.41±0.09</td>
</tr>
<tr>
<td>834</td>
<td>2.76±0.12</td>
<td>2.94±0.10</td>
</tr>
<tr>
<td></td>
<td>3.31±0.14</td>
<td>3.75±0.12</td>
</tr>
<tr>
<td>1173.2</td>
<td>2.81±0.12</td>
<td>2.92±0.10</td>
</tr>
<tr>
<td></td>
<td>3.35±0.15</td>
<td>3.39±0.08</td>
</tr>
<tr>
<td>1332.5</td>
<td>2.82±0.12</td>
<td>2.95±0.10</td>
</tr>
<tr>
<td></td>
<td>3.36±0.15</td>
<td>3.53±0.08</td>
</tr>
</tbody>
</table>

As it can be seen from the Table 2, calculated and measured values show relatively good agreement for Detector 1. In this case, the uncertainty calculated using Equation (3) from discrepancy between calculated and measured values span from 4.3% to 13%. However, the uncertainty for Detector 2 is significantly larger, spanning from 2.4% to as much as 26.6%. The source of the discrepancy and, consequently, the uncertainty of EFFTRAN calculated efficiency is the large efficiency of the said detector at lower energies, producing large measurement dead time and large coincidence summing effects. Also, the thickness of the dead layer of the detector, as well as the depth and diameter of the detector central cavity can greatly influence the result of the calculation [12], and in this case, they obviously were not accurately defined in the software settings. For both detectors, the maximum uncertainty was calculated for 834 keV, the energy that has the smallest emission probability of all investigated. The smallest uncertainty was also detected at the same energy for both detectors (302.85 keV and 1173.2 keV) showing that there is similar dependence of uncertainty versus energy for both detectors.

All this leads to conclusion that the geometrical characteristics of the detectors should be revised in such manner that minimizes the uncertainty. Such minimized uncertainty should then be used in the calculation of expanded uncertainty of the efficiency obtained using EFFTRAN software. All these considerations are valid for cylindrical sources as well, according to Equation (7).

CONCLUSION

The measurements of EID were performed in Institute for Nuclear Sciences Vinča, Radiation and Environmental Protection Department, on two high purity germanium (HPGe) detectors. One set of results was obtained by using EFTRAN efficiency transfer software, while for the other, a realistic measurement was performed. It has been shown that the discrepancy between experimental and calculated EID can be used to estimate the uncertainty of EFFTRAN calculated efficiency, arising from the geometry of the detectors. Uncertainty was between 4.3% and 13% for Detector 1 and from 2.4% to as much as 26.6% for Detector 2. Obtained results can be used as an estimation of uncertainty due to definition of detector geometry in the software, to the uncertainty budget. This indicates that some revision should be performed regarding the definition of the geometrical characteristics of the
detectors defined in EFFTRAN software settings. The revised geometrical data should provide minimization of the uncertainty and produce better results. The same reasoning can be utilised for efficiency transfer for cylindrical sources. This would greatly simplify the defining of the uncertainty budget when using efficiency transfer method for large number of measurements.

Acknowledgement: The investigation was supported by the Ministry of Education and Science of the Republic of Serbia under the Project III43009.

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STUDY OF TL AND OSL DOSIMETRIC PROPERTIES OF ELECTROFUSED ALUMINA PELLETS

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Abstract Aluminum oxide is a popular TL and OSL radiation dosimetry material. The aim of this work was to make a preliminary study the TL and OSL dosimetric properties of white electrofused alumina commercially available as abrasive material. Sintered pellets of electrofused alumina were obtained using soda-lime glass. a relatively inexpensive, chemically stable, reasonably hard, and extremely workable material, capable of being re-softened and re-melted numerous times. The electrofused alumina and soda-lime glass powders and electrofused alumina-glass pellets (AEG) samples were analyzed by X-rays diffraction. Preliminary results on TL glow curves, OSL decay curves and dosimetric properties such as repeatability, dose response curves and useful dose range were evaluated.

Key words: aluminum oxide, thermoluminescence, optically stimulated luminescence, dosimetric materials

Introduction: For a long time TL has been an important method for radiation dosimetry. The theory about TL phenomenon and its properties are abundantly available in the literature [1]. Recently OSL has gained significant importance and both of these methods are applied in many radiation dosimetry fields, including personal, environmental, retrospective, space, neutron and medical dosimetry [2,3,4].

The carbon-doped aluminum oxide represented by α-Al₂O₃:C was introduced as a highly sensitive thermoluminescent detector [5] and, afterwards, this material has been shown to be also an OSL dosimeter [6].

Aluminum oxide (Al₂O₃) exhibits a variety of forms and characteristics. It may have adsorbent, abrasive, dielectric or refractory properties depending on the manufacturing process.

The abrasive Al₂O₃ commercially available as electrofused alumina is a very cheap material obtained by electrofusion of bauxite or alumina in an electric furnace at temperatures higher than 2000 °C. This material is produced in blocks that are gradually crushed and milled, setting the size distribution and morphology of the grains. The grains have a chemical purity guaranteed by a rigorous decontamination process through powerful magnetic separators and a quality control by means of physical and chemical analysis [7]. There are two types of alumina produced for abrasives: brown and white. The basic difference between the brown and white is the chemical composition, in which brown presents approximately 97.0% Al₂O₃ and 2.50%TiO2 and white 99.5% Al₂O₃. Therefore, the difference in the chemical composition has a direct influence on product applications.

The Al₂O₃ commercially available as white electrofused alumina is a very cheap material and was found to show TL and OSL properties.

Soda-lime glass (soda-lime-silica glass) is a relatively inexpensive, chemically stable, reasonably hard, and extremely workable material, capable of being re-softened and re-melted numerous times. Soda-lime glass is divided technically into glass used for windows, called flat glass, and glass for containers, called container glass. The two types differ in the application, production method (float process for windows, blowing and pressing for containers), and chemical composition. Flat glass has a higher magnesium oxide and sodium oxide content than container glass, and lower silica, calcium oxide, and aluminum oxide content [8]. From this follows the slightly higher quality of container glass for chemical durability against water, which is required especially for storage of beverages and food [9].

Sintered pellets of white electrofused alumina, named AEG, were obtained using soda-lime container glass as binder material.

The obtained AEG pellets were characterized with the purpose of being applied as radiation detectors [9]. Results on TL glow curve, OSL decay curve and dosimetric properties such as repeatability, dose response curves and useful dose range were evaluated.

Materials and methods: The white electrofused alumina supplied by Elfusa Geral de Electrofusão Ltda. was sieved and grains with sizes between 75 and 180 μm were selected. The certificate of analysis of the white electrofused alumina indicates that the main impurities are Ca, Fe, K, Mg, Na, Si and Ti.

The alumina powder was mixed with polyvinyl alcohol solution (10%) and soda-lime glass powder with particles size smaller than 75 μm, in the 1:1 ratio by weight. The mixture was cold pressed and sintered in air using a microwave muffle furnace (MAS-7000™ model, CEM Corporation) in three temperature steps 90 °C, 600 °C and 732 °C, during 40 minutes.
The electrofused alumina and soda-lime glass powders and EAG pellets were previously analyzed by X-ray diffraction using an X-ray diffractometer RIGAKU, model Multiflex (copper anode; Cu-Kα radiation; 40 kV and 20 mA).

Irradiation systems
- 60Co Panoramic Irradiator – 1.346 × 10^3 Bq - irradiations performed free in air at electronic equilibrium conditions;
- 90Sr/90Y beta source – 1.4 × 10^9 Bq – dose rate of 0.1 Gy s⁻¹ - irradiations performed inside the OSL reader.

TL and OSL reader
The TL and OSL responses were performed using a RISO reader TL/OSL-DA-20 model. The OSL measurements were performed in reading mode CW-OSL (Continuous Wave OSL) using blue LEDs as a light source and a Hoya filter U-340.

Results and Discussion
EAG pellets
The general characteristics of AEG pellets obtained are summarized in Table 1. The apparent density and the volume were calculated by their weight and external dimensions.

Table 1. General characteristics of AEG pellets

<table>
<thead>
<tr>
<th>Composition</th>
<th>Weight (51.4 ± 0.4) mg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diameter (5.53 ± 0.02) mm</td>
<td></td>
</tr>
<tr>
<td>Thickness (1.04 ± 0.02) mm</td>
<td></td>
</tr>
<tr>
<td>Volume (25.1 ± 0.3) mm³</td>
<td></td>
</tr>
<tr>
<td>Density (2.05 ± 0.03) g cm⁻³</td>
<td></td>
</tr>
<tr>
<td>Sintering 732°C</td>
<td></td>
</tr>
</tbody>
</table>

X-ray diffraction
Figure 1 presents the X-ray diffraction pattern obtained to the soda-line glass (a) and electrofused alumina (b) powders and AEG pellets (c).

TL and OSL response curves
The typical TL glow curve obtained to electrofused alumina powder irradiated with 60Co gamma radiation at electronic equilibrium conditions free in air presents two peaks, the first at 123 °C and the second at 226 °C, using a heating rate of 5 °C s⁻¹ (Figure 2).

The typical TL glow curve of AEG pellets to the same irradiation and reading conditions is shown in Figure 3. The first peak appears at 175 °C and the second at 307 °C (Figure 3a) The temperature shift of the TL peaks can be explained by the thermal gradient, whereas the glass is a insulating material.

The first peak can be easily eliminated by a post-irradiation heat treatment of 120°C during 15min (Figure 3 b).

The soda-lime glass profile is typical of vitreous materials.

Figure 1- X-ray diffraction pattern obtained to the soda-line glass (a) and electrofused alumina (b) powders and AEG pellets (c)

Figure 2- TL glow curve of ELFUSA white electrofused alumina powder irradiated with 60Co gamma radiation.

Figure 3. TL glow curve of AEG pellet obtained using white electrofused alumina irradiated with 60Co gamma radiation (a), glow curve after heat treatment post irradiation of 120°C/15min (b).

The OSL response curves of AEG pellets irradiated with 90Sr/90Y beta radiation source with absorbed doses between 0.1 and 2 Gy are shown in Figure 4. The OSL readout was performed using blue LEDs and CW-OSL illumination.
Repeatability of TL and OSL response
In order to evaluate the repeatability of TL and OSL responses a batch of ten pellets selected with TL and OSL response better than ± 5% was submitted to ten cycles of heat treatment at 400°C / 1h, irradiation with the same standard beta dose and read out. The TL responses presented a standard deviation of the mean (10) of ± 2.8 % and the OSL response ± 3.5 %.

Dose Response
The TL response of AEG pellets irradiated with 60Co gamma radiation at electronic equilibrium conditions with doses ranging from 0.2 to 10 Gy are presented in Figure 5, where can be observed a linear behavior in the dose range studied to doses up to 2 Gy. For doses higher than 2 Gy a supra linear tendency is observed. The average TL reading of non-irradiated samples was subtracted of each presented point.

The OSL dose response curve presents similar behavior, with a same linear response region between 0.1 and 2 Gy.

CONCLUSIONS
The soda-lime glass is a transparent and convenient material for sintering electrofused alumina at a temperature as low as 732 °C. This cold press and sintering procedure made possible to study TL or OSL properties of the electrofused alumina in pellet form. The TL and OSL responses present interesting characteristics. The dose response curves present a desired linear behavior in a dose range between 0.2 and 2 Gy.

The AEG pellets are promising dosimeters, the obtained results indicate that AEG pellets can be used as an alternative detector in TL and OSL dosimetry, since characteristics such as thermal and optical fading, energy dependent response be analyzed.

Acknowledgement: The authors are grateful to Elfusa Geral de Eletrofusão Ltd. that supplied the white electrofused alumina.

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DETECTORS FOR IONIZING RADIATION BASED ON CRYSTAL SCINTILLATORS


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Abstract. The main topics of the presented research are design, development and manufacture of detectors for ionizing radiation with high precision and reliability to diagnose physical processes in nuclear-energy facilities, in particular to control the radiation in nuclear power plants. There are described works on experimental validation of applicability of detectors on base of CsI(Tl), BGO and LSO and on base of YAlO3(Ce) and LaBr3(Ce).

INTRODUCTION.

The purpose of the research is to design and develop high precision and reliability radiation detectors intended to physical processes diagnostics in nuclear power facilities and for radiation control on nuclear power plants. Relevance of the research is connected to two crucial aspects of radiation safety of nuclear-based technologies such as control of level of general radioactivity of gas media, detection and measurements of reference radionuclides in their substances which is useful for estimating the condition of a reactor unit equipment.

Detectors should be able to provide measurements of gaseous products of 85Kr, 85mKr, 88Kr, 133Xe and 135Xe fission in more wide range of 104 — 3.7 * 1014Bq/m3 ± 15% in compare with existing monitors and to identify radionuclide in controlled gas-air sample. They should have the ability to detect gamma-rays in liquid media monitoring volumetric activity of 137Cs with maximum measured value of 5 * 107Bq/kg ± 15% and to identify 134Cs, 136Cs, 138Cs, 131I, 133I, 24Na radionuclides. They should provide detection of 60Co activity in gaseous medium with maximum measured value of 1012Bq/m3[1]

SELECTION OF A DETECTION TECHNOLOGY.

The most important technological conditions applied to detectors with such tasks are: energy resolution on isotope 137Cs should be no less than 4—5% (the energy resolution is ratio of the full width at half maximum (FWHM) of given energy peak to the peak’s energy); upper limit of working temperature range no less than +80°C; detector material should be stable under the stress temperature influence; lack of hydroscopicity is desirable; dependence of the detection efficiency on temperature should be negligible; detection time for the single quantum no more than ~ 100 ns.

Assuming that the goal is to achieve the best performance abilities for power plant unit conditions the best way lies in application of scintillator crystal detectors. Crystal detectors made from inorganic scintillators have high efficiency and high performance. They could be used in high temperature range, have good resistance to external mechanical influences and could be sufficiently large [2]. Considering the requirements listed previously and proceeding from table data it is advisable to analyze following detectors: Bi4Ge3O12 [BGO]; LaBr3(Ce); Lu2SiO5:Ce [LSO]; Lu1.8Y0.2SiO5(Ce) [LYSO] и YAlO3(Ce) [YAP(Ce)].[3]

EXPERIMENTAL VERIFICATION OF THE APPLICABILITY OF DETECTORS BASED ON CsI(Tl), BGO AND LSO.

On the first stage following cases were studied CsI(Tl);Be4Ge3O12 (BGO);Ce - Lu2SiO5 (LSO) (manufactured by Ltd. Ametrin, Alexandrov, RF) Appearance and design of the detection unit shown in Figure1.
Figure 1. Appearance and design of the detection unit: 1 — lead collimator, 2 — scintillator detector, 3 — PMT containing aluminum case, 4 — power supply unit, 5 — amplifier, 6 — detachable body part.

The construction of the detection unit was developed with the condition that it should be easy to replace one detector by another.

In this work experiments were conducted with each of the described scintillators. The general method of the experiment included following things: registration of a pulse shape; accumulation of gamma ray spectrum using the exemplary spectrometric gamma-ray sources; sensitivity parameter calculation for each of the scintillators. One of the processed spectrum is shown in figure 2. As a result of the experiments we can conclude that using CsI(Tl), BGO or LSO crystals for spectrometry in high level activity measuring channels is impractical due to their resolution (less than 10%) insufficient for current spectrometric channel and the ensemble of identified nuclides.

Figure 2. 137Cs spectrum with BGO scintillator.

Experimental verification of the applicability of detectors based on YAlO₃(Ce) and LaBr₃(Ce).

Other series of experiments were conducted with YAlO₃(Ce) (manufactured by Ltd. Ametrin, Alexandrov, RF). Spectra shown on figure 3 were obtained using ø70×10 mm YAlO₃(Ce) and FEU-183 and R6233-100 PMTs.

As can be seen from the experimental data the best energy resolution for this crystal equals to 7% for the 137Cs source, which, considering size of the crystal, is much better than previous samples have. In consideration that this type of crystal has fast decay time about 27 ns., weak temperature dependence and also negligible hygroscopicity thus it can be regard as a potentially capable to purposes of radionuclide identification and activity measurements in controlled media up to 3.7 *10¹⁷Bq/m³.

Figure 3. Energy spectrum with YAlO₃(Ce) scintillator.

The next sample was LaBr₃(Ce) ø25x25 cylindrical crystal (manufactured by Institute of Solid State, RF) with PMT-183 (manufactured by Ekran Optical Systems, RF). Energy resolution for this sample is 4.2% for 661 keV. LaBr₃(Ce) has significant light yield and low decay time (16 ns). The feature of LaBr₃(Ce) crystals is high inner activity due to decaying 138La isotope. To determine the contribution of the external background the detector was surrounded by a lead shield 10 centimeters thick. The measurements shows that inner background of the sample equals to 0.25 samples/(cm³s) in 1700—3000 keV energy range. It was concluded that crystal scintillator detectors YAlO₃(Ce) and LaBr₃(Ce) can be used for the assigned tasks. Developing and testing YAlO₃(Ce) and LaBr₃(Ce) based prototypes is expedient.

The manufacturing procedure of LaBr₃(Ce) and YAlO₃(Ce) scintillator detectors.

Three experimental prototypes were constructed: LABR-1 — the prototype based on ø25x25 mm LaBr₃(Ce) crystal is placed in optical contact with 46 mm photocathode of Hamamatsu R6231-100 PMT; LABR-2 — the prototype based on ø25x25 mm LaBr₃(Ce) is placed in optical contact with 72 mm photocathode of FEU-183 PMT; and IAP-1 - the prototype based on YAlO₃(Ce) 10mm height and 70 mm diameter is placed in optical contact with 70 mm photocathode of Hamamatsu R6233-100 PMT. (see fig.4).

Figure 4. Appearance of prototypes: a) LABR-1; b) LABR-2; c) IAP-1.
CRYSTAL SCINTILLATOR DETECTORS STUDY BY MEASURING THE GASEOUS MEDIUM ACTIVITY.

"Green Star" SBS-77 operation modes and accumulated spectra are shown on a PC monitor [4]. A hermetic box with inner and outer nozzles for gas pumping has been constructed to provide and test gaseous medium activity measurements. The box construction allows installing any of the constructed detector prototypes. Several measurements of the energy resolution of the prototypes were carried out. Obtained results show the ability of any of the designed prototypes to identify radionuclides in a mixture of gaseous 85Kr, 85mKr, 88Kr, 133Xe, and 135Xe fission products. Identification of 137Cs, 134Cs, 136Cs, 138Cs, 131I, 133I, 24Na nuclides in liquid media could be obtained by using LaBr3(Ce) based LABR-1 and LABR-2 detectors. The resolution of the YAlO3(Ce) detector is insufficient for such measurements. 60Co detection and identification can be obtained by any of the presented detector prototypes.

Count rate linearity measurements in the total absorption peak of the gaseous 85Kr activity were carried out for LABR-1 and IAP-1 detectors. The results are shown in fig. 4—7.

| Figure 4. 85Kr spectrum obtained with LABR-1 |
| Figure 5. 85Kr spectrum obtained with IAP-1 |

Figure 6. LABR-1 counting rate function of 85Kr volumetric activity for full spectrum measuring range.

Figure 7. IAP-1 counting rate function of 85Kr volumetric activity for full spectrum measuring range.

From the LABR-1 inner background measurements for 500–600 keV energy range the crystal background value was obtained to be less than 15% of the overall background. Due to that the crystal should be placed in a radiation shielding providing reduction of the background up to 10 times. For all of the prototypes the linear dependence of the counting rate on 85Kr concentration in the measuring chamber was confirmed experimentally (figures 8 and 9).

From the results we can estimate concentration limits for 85Kr which could be measured by current prototypes in measuring conditions listed above. The upper level of activity (activity which may be registered by proposed devices) depends on a processing time of a single interaction which equals to 10–6 s for modern processors. Thus overall counting rate must not exceed 106 samples/s. For LABR-1 and IAP-1 we can determine such activities:

\[ A_{LABR-1} = \frac{(2.9 *10^9 \text{Bq/m}^3 * 10^6)}{250\text{s-1}} = 1.16*10^9 \text{Bq/m}^3 \]

where

\[(2.9 *10^9 \text{ Bq/m}^3) / 250\text{s-1} = \text{rate for activity per one detector count (see fig. 6)},\]

106- limit for detecting count rate.

Using the same approach for IAP (rates from fig. 7) A \[ A_{IAP-1} = (2.86*10^9 \text{Bq/m}^3 * 106) / 160 \text{ s-1} = 1.8*10^9 \text{Bq/m}^3, \]

If the measurement time equals to 1 s then a number of events in the total absorption peak will be about 5*104 which is sufficient for providing 1% measuring accuracy. Flux attenuation should increase the upper activity threshold for the detectors. The lower level of activity which possible to be registered by proposed devices is determined by a detector efficiency, background and a measuring time. The values for LABR-1 and IAP-1 are shown below.
N signal should be ≥3ΔN background
I signal(s-1)=N signal/t measurement

Taking into account that 7.5×10⁻³ (s⁻¹keV⁻¹)-1 count rate for background in LABR-1 in range of 1 FWHM for pick of full absorption, 18 keV- weight of pick on the range of summing
A LABR-1=0.21/(t measurement)⁰.⁵
And following the same approach for IAP-1
A IAP-1=0.45/(t measurement)⁰.⁵.

With 100s measuring time the lowest activity will be 2.1×10⁷Bq/m³ for LABR-1 prototype and 4.5×10⁷Bq/m³ for IAP-1.
For 15% accuracy number of events in the total absorption peak area should be no less than
N=(1/0.15)² ≈ 45.
For the minimal activity the values will be:
NFWHM=2.1×10⁻²/0.189×100=11 for LABR-1
NFWHM=4.5×10⁻²/0.501×100=9 for IAP-1
To obtain the required accuracy it is necessary to increase measuring time up to 400-500s.

**CONCLUSION.**

In this study prototyping and experimental research of opportunities of crystal scintillator detectors were conducted. It was demonstrated, that the minimum measuring level of gas medium activity with 100s measuring time will be 10⁷Bq/m³ and the maximum of activity will be 10¹³ Bq/m³ for LABR-1 and IAP-1 based detectors.

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INTERLABORATORY COMPARISON OF MEASURING AND CALCULATION RESULTS OF ELECTRIC FIELD STRENGTH NEAR 35 KV OVERHEAD POWER LINE

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Abstract: The paper presents interlaboratory comparison of measuring and calculation results of electric field strength near 35 kV overhead power line, in which three testing laboratories participated. This interlaboratory comparison was performed for the purpose of ensuring confidence in the quality of testing results. Measuring and calculation results are analyzed with standard method, using \( E_n \) number, based on which the valuation of the laboratories was performed.

Key words: electric field strength, non-ionizing radiation, interlaboratory comparison.

1. INTRODUCTION

The paper presents interlaboratory comparison of measurement and calculation results of electric field in the vicinity of the 35 kV overhead power line. Besides the Laboratory of the Electrical Engineering Institute Nikola Tesla (Laboratory 1) as a coordinator, two more laboratories, (Laboratory 2 and Laboratory 3) participated in this comparison. During the comparison, all three laboratories performed measurements, while the Laboratory 1 also performed calculations of the electric field strength. According to the information which the authors of this paper posses, a described comparison presents the first interlaboratory comparison of the measurement and calculation results of the power frequency electric field strength performed in the Republic of Serbia, as well as one of the first comparisons performed and coordinated by the Electrical Engineering Institute Nikola Tesla. According to the request of the Accreditation Body of Serbia all accredited laboratories and laboratories which have applied for accreditation have to participate in the available and appropriate interlaboratory comparisons [1].

2. INTERLABORATORY COMPARISON PROCEDURE

2.1 Quantity under testing

Quantity under testing is the intensity of the variable ELF (extremely low frequency) electric field strength vector, \( E \).

2.2 Measurement equipment

All three testing laboratories used calibrated measurement equipment and isotropic probes for the measurement of the electric field strength. The isotropic probe provides the simultaneous measurement of all three spatial components of the electric field strength vector in discrete moments of time and the instrument shows their resultant value.

2.3 Electric field strength calculation

The calculation is based on a two-dimensional simplified analysis using the charge simulation method, where the certain assumptions, which are described below, are adopted.

The overhead power line is simulated by a set of infinitely long, straight-line phase conductors and ground wires. The conductors are parallel to each other and to the ground surface. The ground is assumed to be a perfect conductor. The presence of the ground is accounted for using the images of the conductors. The images have the same charge as the original conductors but with opposite polarity.

The electric field is considered to be static, having in mind that the wavelength of the field is much larger than the dimensions under consideration [2].

It is assumed that the permittivity of air is equal to the permittivity of vacuum, and that it is independent of the changes in ambient conditions (humidity, temperature). The detailed description of the model for calculating the electric field strength is given in [2, 3].
2.4 Selection of location for interlaboratory comparison

For maintaining the interlaboratory comparison a location situated at the route of the 35 kV overhead power line No. 320 was chosen. The tests have been carried out along the lateral profile P located between the towers No. 1875 and 1876.

A position of the selected lateral profile P with GPS coordinates, as well as the location of the testing points are shown in Figure 1.

Marks in Figure 1 have the following meaning:

- P – lateral profile along which the testing of the electric field strength is done;
- x [m] – horizontal distance of the testing point at the lateral profile P from the overhead line axis.

The site selection for the interlaboratory comparison has been influenced by terrain configuration, where it has been taken into account that near the selected lateral profile there should not be any object which could affect the level of the electric field strength by its presence.

The basic information about the selected lateral profile is given in the following table. The measurements of the phase conductor clearances and their mutual distances have been made by using a laser telemeter.

<table>
<thead>
<tr>
<th>Numbers of towers</th>
<th>Ground (soil)</th>
<th>Phase conductor clearances</th>
<th>Phase conductors mutual distances</th>
</tr>
</thead>
<tbody>
<tr>
<td>1875, 1876</td>
<td>dry soil</td>
<td>h1=13 m; h2=11 m; h3=9.7 m</td>
<td>d12=3.2 m; d23=3.3 m</td>
</tr>
</tbody>
</table>

The relative humidity of the air during the comparison was between 17% and 24%.

2.5 Testing procedure

The tests have been carried out along the profile P which is nearly perpendicular to the overhead power line axis [4, 5, 6]. Along the profile 31 testing points have been chosen, the layout of which is shown in Figure 1. At each testing point the measurements and calculations of the electric field strength have been done.

Ten measurements of the electric field strength have been performed at each testing point, with the time interval of 6 s between every measurement. At each testing point the measurement of the RMS values of the electric field strength has been performed at 1 m height from the ground. During the measurements of the electric field strength the measuring probe has been placed on the insulating wooden tripod and connected to the measuring instrument by the optical cable in order to reduce the influence of the operator (person who performs measurements) on the measurement results. Described methodology has been applied by all participating laboratories. The participating laboratories have not performed the measurements at the same time, but one after the other, with a few meters distance between them, in order to prevent the deviations of the results caused by the field perturbation.

3. Comparative review of the results

In Figure 2 and Table 2 the comparative review of the obtained results is given. The marks in Figure 2 and Table 2 have the following meaning:

- n – ordinal number of testing point;
- $E_1, E_2, E_3$ [V/m] – values of electric field strength of laboratories 1, 2 and 3, which are calculated for each laboratory as arithmetic mean of 10 measured RMS values of electric field at the same testing point;
- $E_4$ [V/m] – values of electric field strength obtained by calculation.

![Fig. 2 Comparative review of results](image)

Based on the measured and calculated values of the electric field strength, it can be concluded that the obtained results are in accordance with each other.
Table 2 Comparative review of results

<table>
<thead>
<tr>
<th>n</th>
<th>x [m]</th>
<th>$E_1$ [V/m]</th>
<th>$E_2$ [V/m]</th>
<th>$E_3$ [V/m]</th>
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</table>

After conducting the interlaboratory comparison the participating laboratories have independently estimated the uncertainty of their results [7, 8]. The estimated values of the extended uncertainties ($U$) that should be added to the measurement and calculation results are: $U_1 = \pm15.60\%$, $U_2 = \pm9.42\%$, $U_3 = \pm28.86\%$ and $U_4 = \pm11.36\%$.

4. Evaluation of results of interlaboratory comparison

For the evaluation of the results of the interlaboratory comparison the $E_n$ number is used and it is calculated according to the following formula [9]:

$$E_{n_i} = \frac{E_i - E_{ref}}{\sqrt{U_i^2 + U_{ref}^2}}$$

where:

$E_{ref}$ – assigned value of the electric field strength (adopted correct value);

$U_{ref}$ – extended uncertainty of the assigned value.

The correct value of the electric field strength is not known so the question is which $E_{ref}$ and $U_{ref}$ values should be adopted. When one testing laboratory performs testing with more accurate measuring equipment and has significantly lower measurement uncertainty, it is reasonable to use its results for the evaluation of the actual level of the measured value [9]. However, when all laboratories perform measurements with the equipment of the similar accuracy, the average value of their results can be used for the assessment of the correct value [9]. In the described case all three laboratories have performed measurements at the same testing points using calibrated measuring equipment with similar characteristics. In addition, it is obvious that the results match one another, which can be concluded from the data presented in Table 2 and Figure 2.

The deviation of the calculated results in comparison to the measurement results of the electric field strength would be expected if near the lateral profile $P$ existed objects which, by their presence, could affect the level and distribution of the field since the used calculation does not have the possibility of modeling these objects. In case when the field is perturbed due to the presence of the surrounding objects, the usage of the results of the calculations for the estimation of the assigned value of the electric field strength would not be appropriate. Since the location for the interlaboratory comparison has been chosen in such a way to avoid the presence of these objects, the calculation results can be used for the estimation of the assigned value of the electric field strength.

Due to the reasons mentioned above, it is reasonable in this case to adopt the average value of the results obtained by measurements and calculation for the assigned value:

$$E_{ref} = \frac{E_1 + E_2 + E_3 + E_4}{4}$$

The extended uncertainty of the assigned value the average value of all expanded uncertainties has been adopted:

$$U_{ref} = \frac{U_1 + U_2 + U_3 + U_4}{4}$$

According to [9] the criteria for the evaluation is the following:

$|E_n| < 1$ – correct result;

$|E_n| > 1$ – unsatisfactory result.

The calculated absolute values of the $E_n$ number are shown in Figures 3 - 6.
5. CONCLUSION

From the presented results it can be concluded that the values of the $E_n$ number are lower than 1 at all measuring points and for all three laboratories, which means that all obtained results are correct [9]. This conclusion is referring both to the measurement and calculation results of the electric field strength.

According to the requirements of the Accreditation Body of Serbia all accredited laboratories, as well as the laboratories which have applied for accreditation, have to participate in the available interlaboratory comparisons. The interlaboratory comparisons give the significant contribution in ensuring confidence of the testing results quality. The results of the interlaboratory comparisons can also be used for the permanent monitoring of the laboratory performances as well as for the validation of calculated measuring uncertainty.

The significance of the interlaboratory comparisons is also in the evaluation of the laboratory performances and in determining the differences between them, as well as in the exchange of the experiences between the participating laboratories.

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RETROSPECTIVE DOSE EVALUATION BY MEANS OF CLASSIC CYTOGENETIC METHOD

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Using routine methods over 25 years, changes in the registered levels of chromosomal aberrations were studied in the peripheral blood lymphocyte cultures of 74 patients who were irradiated as a result of the Chernobyl accident. The initial dose estimations by mean dicentric frequency varied from 0.2 to 9.8 Gy. Generally, a double exponential type model was most adequate for the quantitative description of the elimination of cytogenetic indexes associated with different types of unstable chromosomal aberrations. Great individual variability of the elimination rate of chromosomal aberrations and its dependency on the value of the originally estimated dose were found during the first period. A computer method for retrospective dose estimation was developed based on this data. The method is based on analysis of cell distributions in accordance with the number of dicentrics and all unstable chromosomal aberrations contained in them.

Key words: peripheral blood lymphocyte cultures, elimination of chromosome aberrations, retrospective dose estimation, computer method

1. INTRODUCTION

The problem of the estimation of the dose long after the irradiation occurred has always been topical for both physical and biological dosimetry, which is due to the sometimes late admission of people to specialized clinics and the necessity of the verification of the fact of irradiation and determination of the value of the possible dose during the determination of the relationship between the disease and the irradiation effect. Two groups of methods based on the usage of unstable and stable chromosomal aberrations can be applied. Knowledge of the patterns of the elimination of unstable chromosomal aberrations is needed, as well as confirmation of the fact that the frequency of stable aberrations (in agreement with their name) does not change in time. It is important for interpretation of the data that were received from the examination of patients who have experienced prolonged irradiation.

The general tendency towards the elimination of unstable radiation-induced chromosomal aberrations in cultures of lymphocytes for human peripheral blood was more or less little known until recently (1, 2). These data were received using materials from people who underwent total and local therapeutic irradiation for malignant diseases and the atomic bombings of Hiroshima and Nagasaki, as well as several accidents. However, these are insufficient for quantitative calculations for retrospective estimation of the dosage and the identification of time intervals, when this is possible. As well, differences occur between the results from various authors. In addition, accurate and prolonged cytogenetic examination of irradiated Japanese individuals began about 22 years after the atomic bombing (3) without the source data. Therefore, the study of the dynamics of the levels of chromosomal aberrations in individuals irradiated in the accident at the Chernobyl APP was relevant and important both with respect to science and practice. The results of the first cytogenetic analysis of the lymphocyte cultures that were obtained several days or weeks after irradiation for numerous irradiated patients are sufficient to allow correct comparison of the data received during a certain period with initial indexes by following their dynamics.

2. MATERIALS AND METHODS

2.1. Patients

The venous blood of 74 patients who were irradiated in the accident at the Chernobyl APP and who were recurrently admitted to clinics for examination within a total time period from the 61st day until approximately 25 years after the irradiation served as the material for cytogenetic studies. Cytogenetic analysis immediately after the irradiation showed the relatively uniform character...
of the irradiation of the main body mass in most patients (4). The first estimates of the mean absorbed dosage based on the number of dicentrics per 100 cells per patient varied from 0.2 to 9.8 Gy. The patients were divided into three groups depending on the received dose: 31 individuals received 0.2–2.4 Gy (101 recurrent cultures with a frequency of sampling from 1 to 19 times in separate persons), 28 individuals received 2.6–4.4 Gy (119 recurrent cultures with a frequency of sampling from 1 to 15 times) and 15 individuals received 4.6–9.8 Gy (75 recurrent cultures with a frequency of sampling from 2 to 17 times).

In connection with the disintegration of the Soviet Union number of examined individuals irradiated during the accident at the Chernobyl APP during the last 20 years decreased because most of them live in the territory of Ukraine. Blood of 71 patients, 19 patients and only 9 patients was sampled during the first 6 years; from 7 to 12 years and from 13 year until the present accordingly.

2.2. Cytogenetic analysis

The blood was sampled in sterile flasks with heparin. Variants of standard techniques (1) were applied for the cultivation of lymphocytes and for chromosome preparations. A modification of the fluorescent + Giemsa (FPG) method (5) was used for analysis of unstable aberrations (dicentrics, centric and acentric rings, pair fragments, and chromatid aberrations) and atypical chromosomes. The cultivation period was generally 48–50 h and sometimes for certain indexes reached 66–95 h. Chromosomal aberrations were calculated only in the cells of the first mitosis that contained 45–46 chromosomes. In this case, the FPG method can be considered as a variant of the classical chromosomal analysis. Depending on the successful growth of lymphocytes in the culture and considering unstable aberrations, from 30 to 1419 metaphases per patient over 6 years and from 500 to 1000 metaphases during the following periods (until 25 years) were analyzed. Regression analysis was carried out using the Statistica v. 6.0 computer program.

3. RESULTS AND DISCUSSION

3.1. Dynamics of chromosomal aberrations in the postirradiation period

This chapter describes the results of cytogenetic examinations of patients who survived the accident at the Chernobyl APP that were carried out in the Burnasyan Federal Medical Biophysical Center of the Russian Federal Medical-Biological Agency (Moscow) over a 25 year period after the accident. The dynamic of unstable chromosomal aberrations and the possibilities of retrospective biological dosimetry in the postirradiation period were analyzed. The main results of the cytogenetic analysis in this work are represented in graphic form due to great volume of data.

By analogy with the study of cytogenetic effects of radiation in Goiania city (Brazil) (6) a double exponential function was used for analysis of dynamics chromosome aberrations in the postirradiation period. The formula was as follows:

$$Y_T/Y_0 = a_1 \exp(b_1 T) + a_2 \exp(b_2 T), \quad (1)$$

where $Y_0$ and $Y_T$ are frequencies of chromosomal aberrations at the initial time and a remote period after irradiation, respectively; $T$ is the time after irradiation (years); and $a_1$, $a_2$, $b_1$, $b_2$ are regression coefficients.

Fig. 1 shows the dynamics of the reduction of the ratio of frequencies of dicentrics in remote period to their initial values in three selected dose groups of patients who were affected by the accident at the Chernobyl APP. It is obviously that the rate of elimination dicentric depends on the value of received dose: the more received dose, the higher elimination rate. Similar relationships were obtained for all unstable aberrations (Fig. 2). It is necessary to note also high individual variability of elimination process.

![Fig. 1. Change of ratio of observed dicentric frequencies to their initial frequencies with time in patients irradiated by different doses in the accident at the Chernobyl APP (the 0.2–2.4 Gy dose group is designated by dotted line, 2.6–4.4 Gy by broken line, and 4.6–9.8 Gy by solid line)](image)

![Fig. 2. Change of ratio of observed unstable aberration frequencies to their initial frequencies with time in patients irradiated by different doses in the accident at the Chernobyl APP (the 0.2–2.4 Gy dose group is designated by dotted line, 2.6–4.4 Gy by broken line, and 4.6–9.8 Gy by solid line)](image)
It must be recognized that the definition of the “half life” of aberrant lymphocytes during retrospective estimations is applicable only for irradiation in low doses and/or at a low dosage rate when the total induced frequencies of chromosomal aberrations are not high and damage to the hematopoietic system is minimal. Higher doses are characterized by a two component exponential model for the elimination of unstable chromosomal aberrations, including dicentrics, and are probably determined by the relatively rapid dose-dependent initial decrease in the frequencies of unstable aberrations, which is related to the reduction of the number of lymphocytes after their death caused by radiation.

3.2. Retrospective dose estimation

It should be noted that application of stable chromosomal aberrations at remote periods is better proven and is preferable compared with unstable aberrations. G-banding is the most accurate method of analysis of stable aberrations, but it is very labour-intensive, while FISH staining is relatively expensive and requires specific equipment. As well, the results of the investigation of the patterns of elimination of unstable chromosomal aberrations showed that the “half life” of dicentrics is not a constant value that is suitable for application at all levels of received doses and all periods after irradiation and the Qdr value on average has a tendency to decrease during the time after irradiation. All these conclusions must be used for correction of the methods that were suggested for practical application within the IAEA recommendations (1).

One of authors of this study participated earlier in publication of an original computer program for the retrospective estimation of dose developed by Dr. I.V. Filushkin (7). The cell distribution according to the number of dicentrics was used as the source data. This approach is based on conformity to the theoretical Poisson distribution during relatively regular irradiation and stimulation of the irregularity of the radiation effect during the elimination of chromosome aberrations, even if the initial radiation effect was regular. Thus, so-called “unirradiated” nonaberrant cells appear in a population of cells that was initially irradiated with one dose. Therefore, I. V. Filushkin transformed the initial (multichannel) version of his computer program that was proposed for the estimation of the dosage distribution within lymphocytes during an irregular radiation effect (8) to a new (two-channel variant of Dr. Filushkin computer program. The dose values were averages of two estimates.

The dependence of initial dose estimates \(D_0\) on the values obtained by the computer method described above during the entire postirradiation period of observations \(D_{ir}\) Gy was obtained by linear regression analysis. As the result the following common equation \((r = 0.829, p < 0.0001)\) was received:

\[
D_0 = (1.120 \pm 0.116) + (0.902 \pm 0.035)*D_{ir},
\]  

\[
(2)
\]

However a significant average shift in the estimates to lower dose values compared to the first dose estimates was observed.

To overcome this effect a multiple regression equation for determination of the dependence of the initially estimated dose \(D_0\) Gy on the value \(D_{ir}\) Gy was obtained by the computer method and the time \((T, \text{year})\) after irradiation was obtained. This was expressed as \((r = 0.864, p < 0.0001):\)

\[
D_0 = (0.386 \pm 0.136) + (0.971 \pm 0.032)*D_{ir} + (0.111 \pm 0.013)*T
\]

\[
(3)
\]

This equation allows making a retrospective dose estimate. Fig. 3 shows the graph of the linear relationship between the initially estimated dose and the dose calculated by equation (3) i.e., the retrospective dose estimation is produced. On average both estimations are similar because the graph begins at the start point of the coordinates and extends at an angle of 45°.

![Graph showing Dependence of initial cytogenetic dose estimation from its retrospective estimation calculated by equation (3) in patients irradiated during the accident at the Chernobyl APP (dotted lines, 95% CI for regression curve; dashed lines, 95% CI for individual values)](image330x137 to 550x357)
Taking the conserved actual differences between the levels of atypical chromosomes in separated dose groups long after irradiation into account, dependence of the initially estimated values of dose \(D_0\) (Gy) on the values obtained by the computer method \(D_T\) (Gy) was observed during repeated observations of the frequencies of atypical chromosomes per 100 cells \((A_m)\). The multiple regression equation was as follows: 

\[
D_0 = (1.136 \pm 0.100) + (0.518 \pm 0.048) \times D_T + (0.145 \pm 0.014) \times A_m
\]  

(4)

This is another method for retrospective estimation of dosage, along with equation (3). The graph of the linear dependence of the initially received dosage assessment on the retrospective assessments of dose calculated using equation (4) is shown in Fig. 4. As in the previous section the estimates of dose on average are not shifted relative to each other. The comparison of earlier cytogenetic examinations of patients during periods less than 6 years \((9)\) showed that the 95% CI for individual values was approximately two times shorter than in this study, which indicates an increase in mistakes during retrospective dose estimations of dose with an increase in the time period between irradiation and cytogenetic analysis.

Fig. 3 and 4 show clear overestimation during retrospective estimates in the region of initially received doses lower 1 Gy. However, in our opinion irradiation at doses of at least 0.5 Gy can be actually be estimated in distant time periods using the suggested approach.

4. CONCLUSIONS

Thus a large group of irradiated Chernobyl patients were cytogenetically examined over a 25 year period. The unique feature of this group lies in the cytogenetic data on unstable and stable aberrations in numerous patients at early and distant times. Important conclusion have been made about the parameters of processes of the elimination of dicentrics and all unstable aberrations in the postirradiation period: a double-exponential model is best. Computer approach of retrospective dose estimation based on classic cytogenetic method was developed.

REFERENCES

(SAMPLES FOR SERIAL, BOOK, PROCEEDING, THESIS, PATENT - STYLE REFERENCE)

IMMUNOCYTOGENETICS INVESTIGATION OF THE PATIENTS WITH CHRONIC LYMPHOCYTIC LEUKEMIA, WHO HAD CONTACT WITH RADIATION

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Abstract. CLL is the only hematological disease with an unproved participation of radiation mutagenesis in its pathogenesis. Recurrent cytogenetic aberrations in CLL and radiation-specific aberrations were find by G-banding and FISH-method. Immunophenotyping was studied by flow cytometry. In this work the chromosome aberrations in CLL patients were analyzed before the start of the treatment. Dicentric chromosomes (dic) were detected in 6 of 24 patients, 2 of these 6 had dic and chromosomes translocations (t). As a rule dic and t were seen in different chromosomes with different broken loci. Another 18 patients had only t. The absolute correlation between immunological and cytogenetic indexes was seen. Both methods determined: 1. Bad prognosis (CD38 expression and chromosome 12 trisomy); 2. Deviation from the classic CLL (specific injuries for irradiation (dic), CD38 and CD79b expression on the surface of majority of the cells). Our results show that ionizing radiation may participate in CLL pathogenesis.

Key words: CLL, radiation, dicentrics, translocation, immunophenotyping.

INTRODUCTION

B-Chronic lymphocytic leukaemia (B-CLL) is a monoclonal malignancy characterized by an accumulation of terminally differentiated small B lymphocytes. This disease comprises about 25% of all leukemia (1). In classical form of the disease expressing antigens are CD19+CD20dimCD23+CD5+-FMC7-CD22-CD79b-Smlgk+ or λ+, sometimes weak expression of CD22 is observed. Recurrent cytogenetic aberrations in CLL are well known. About 1/3 of patients have deletion in (13q), pointing to good prognosis. Deletion in 17p (or TP53 loss) points to bad prognosis, connected with resistance to all kinds of therapy. Deletion in (11)(q23) (or deletion of ATM gene) is linked with the bad prognosis, too (2). CLL with trisomy 12 and deletion in (11q) often transforms into malignant diffuse large-cell lymphoma (Richter’s syndrome) (3). CLL is the only hematological disease with an unproved participation of radiation mutagenesis in its pathogenesis. In the last years some papers appeared, discussing high risk of CLL in persons, irradiated in Chernobyl accident (4). On the opposite, some data exist, showing no link between CLL and irradiation. Maybe, this discrepancy is caused by long time between the debut of the illness and the beginning of treatment (5). In this work we had analyzed the radiation-specific chromosome aberrations in patients with CLL.

MATERIALS AND METHODS

Peripheral venous blood samples from 96 patients with chronic lymphocyte leucosis were stimulated with PHA in RPMI-1640 medium with bovine embryonic serum. 52-hour cultures were used for preparation of metaphase chromosomes for analysis of chromosomal injuries specific for irradiation. Chromosomal injuries were analyzed with the aid of microscopy using G-banding and, in some cases, by fluorescent in situ hybridization, using DNA-probes for complete chromosomes were used.

Analysis of specific for CLL aberrations was made in lymphocyte specimens, stimulated with PWM for 72 hours. Differential chromosome staining and, in some cases, FISH were also used for CLL chromosome analysis. DNA-probes (ABBOTT) for typical CLL
injuries (ATM, P53 gene deletions, deletion of q in the arm of chromosome 13 and trisomy of chromosome 12) were used performing FISH (fluorescent microscope 90i, Nikon, Japan). Blood samples from 20 healthy donors, 30-50 years old, were used as a control. Each analysis comprised from 100 to 370 metaphase plates. For identification of chromosomal injuries an International System for Human Cytogenetic Nomenclature 2009 (6) was used.

Immunophenotyping of the patient’s bone marrow samples was performed using flow cytometer “Cytomics FC500” with the triple-stained combinations of monoclonal antibodies (“Beckman Coulter”, USA).

Statistical method included Student’s t-criterion, Fisher’s exact criterion, correlation analysis, using Microsoft Excel 7.0 and “Statistica 6.0” package for Windows.

RESULTS AND DISCUSSION

From 96 CLL patients observed a group of 24 patients having dicentric chromosomes and translocations was revealed and chosen for detailed analysis. In this group 6 patients had dicentric chromosome (dic) and 2 of them additionally had chromosome translocations. The content of dic varied from 0.67% to 2.9% including one patient who had dic and translocations. Typically, different chromosomes with the breaks in different loci were engaged into origin of both translocations and dic. We suppose this fact points to radiation exposure impact on lymphoid cells in development of CLL. In other 18 patients only translocations were detected. The content of these translocations varied from 0.46% to 1.67% and all loci engaged into translocation exchange were unique. Besides, this group of patient differed from other CLL patients by the high content of aberrant cells (ac). In the control group 1.34 ±0.40% ac was observed, in CLL patients with dic 3.70±1.20% and in CLL patients with specific for radiation aberrations and stable aberrations content of ac reached 7.11±1.0% (Table 1). This high content of aberrant cells caused by instability of lymphoid cell genomes may also be the consequence of radiation effect on the patients.

Immunophenotyping revealed some deviations in dic-group of patients distinguishing this group from the classic CLL phenotype. The transformed B-lymphocytes in this group were CD22(dim) and CD79b(dim to mod) and MFI CD79 PE was 91.9-103 units. In two patients CD38 was exposed on the majority of malignant cells (76.3% and 99.3%). One of these patients had heterogenic and the other – homogenic expression of CD38, corresponding expression value of mod to bright expression of CD38. In 1/3 of this group of patients the CD38 antigen was not expressed at all. Hence, the main characteristics of CLL patients with dic are the joint expression of the CD22 and CD79b antigens and intense CD38 expression. It correlates with results (7).

One CLL patient, 78 years old, who previously had a long time contact with radiation was thoroughly explored. With the aid of FISH (fig.1) and differential chromosome staining the trisomy-12 was detected.

Additionally, exploring with the aid of differential chromosome staining had revealed dic in a 52-hour culture and trisomy 12 in

<table>
<thead>
<tr>
<th>Group</th>
<th>Age, years</th>
<th>Cells with aberrations, %</th>
<th>Cells with dicentrics, %</th>
<th>Cells with translocations, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Controls</td>
<td>46.0±2.6 n = 20</td>
<td>1.34±0.40</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>CLL patients with dic</td>
<td>54.2±4.6 n = 6</td>
<td>3.70±1.20</td>
<td>0.015±0.01</td>
<td>0.011±0.002</td>
</tr>
<tr>
<td>CLL patients without dic</td>
<td>66.2±5.2 n = 18</td>
<td>7.11±1.00</td>
<td>0</td>
<td>0.014±0.020</td>
</tr>
</tbody>
</table>
72-hour culture. The dic exchange was detected between chromosomes 13 and 20 – dic(13;20) and between 5 and 12 – dic(5;12) (fig.2).

Furthermore, isochromosome (17q) x2 and some cells with chromosome endoreduplications, the events, also typical for radiation, were detected.

The translocation with participation of chromosome 1 (fig.3) was detected with the aid of FISH.

Immunophenotyping had revealed the joint expression of CD22(dim) and CD79(dim to mod). The bad prognosis indicator CD38 (8) was present on 99,3% of malignant cells (fig.4).

Consequently, this patient shows the absolute correlation between the cytogenetic and immunologic
indexes. In general, the two methods used had revealed:

1. The difference of the data obtained from the classic CLL consisting in combination of the injuries, specific for radiation - dicentric chromosomes with expression of CD38 and CD79d on the surface of the most part of the cells.
2. Bad prognosis of the CLL revealed by expression of CD38, trisomy-12 and defects in chromosome 17.

Conclusion: The ionizing radiation participates in the mechanism of CLL development.

REFERENCES

INFLUENCE OF SOIL PROPERTIES ON SOIL-TO-PLANT TRANSFER FACTORS OF NATURAL RADIUOCLIDES IN THE VICINITY OF COAL FIRED POWER PLANTS IN SERBIA

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Abstract. Study of coal fired power plants environmental impact have been performed analyzing activity concentrations of natural radionuclides ²³⁸U, ²²⁶Ra, ²³⁲Th and ⁴⁰K in the samples of soil and native vegetation collected in the vicinity of TE “Kolubara”, TE “Morava” and TE “Nikola Tesla” A and B power plants. Soil-to-grass transfer factor values (kg kg⁻¹ dry mass) were calculated. Some soil characteristics such as particle size distribution, soil pH, organic matter content and carbonate content were determined in order to examine their influence on natural radionuclides soil-to-plant transfer factors, assuming TFs are mostly controlled by root uptake.

Key words: natural radionuclides, soil properties, soil-to-grass, transfer factors, CFPP

1. INTRODUCTION

Natural radionuclides of uranium and thorium series and ⁴⁰K contained in coal are of terrestrial origin and the levels of their activity concentrations are of the same order of magnitude as those found in soil (UNSCEAR, 2000). Soft brown coals (lignites) from Kolubara basin, used as feed coals for combustion in coal fired power plants (CFPPs) in Serbia, contain low amounts of uranium and thorium (Životic et al., 2000).

For those coals, ²³⁸U activity concentration (Bq kg⁻¹) was determined to be in the range 18-71 and, after combustion in CFPPs, in the range 26-145 in slag and 21-264 in fly ash (Janković et al., 2011). There is approximately an order of magnitude enhancement of the radioactivity concentrations from coal to ash, after elimination of the organic component of the coal in the process of combustion. If coals are low in natural radionuclides content, factors as a very long period of the utilization of coal, the large amount of coal burned, or the low fly-ash retention efficiency in the plant could contribute to the increase of natural radioactivity background (Charro et al., 2012).

During the operation of CFPP, radionuclides released into the atmosphere in the particulate or gaseous form or resuspended by wind from the coal and ash wastes accumulations can be removed further into the environment by dry deposition (to the ground and vegetation) and wet deposition, by rainout or washout. In the vicinity of active coal combustion facilities and coal ash disposal sites natural background gamma radiation can be modified by redistribution of radionuclides in the surrounding environment (IAEA, 2010). Levels of natural radionuclides concentrations for soil samples collected within a radius of 1 km and/or in the upper soil layers were elevated compared to the deeper layers around the CFPPs (Baeza et al., 2012, Papp et al., 2002). In the vicinity of CFPPs, higher activity concentration values of natural radionuclides compared to local were found in samples of native vegetation in Romania (Botezatu et al., 2004), but the foodstuff samples (broad-leaf plants and apples) showed no evidence of any increase in Spain (Baeza et al., 2012). There are scarce data about the content of natural radionuclides in vegetation samples from CFPPs surroundings.

The radionuclides activity concentration of a bulk soil is not the amount available for plant uptake but it is the “available” concentration. This is the fraction of radionuclides present in soil as free ions, soluble complexes or in other labile forms (Alloway, 2013). Changes in soil physico-chemical properties affect the amount of radionuclide in soil solution that is available for root uptake. Vandenhove et al. (2009a) reviewed solid–liquid distribution coefficients (Kd) in soils for the natural radionuclides U, Ra, and Th and concluded that Kd values are largely texture-independent. In the study of Rodriguez et al. (2008), total and labile activity concentration of ²³⁸U, ²³²Th, and ²²⁶Ra were determined in different granulometric fractions of soil samples collected at a rehabilitated uranium mine. For uranium, the greater percentage of the available fraction was in the coarser fractions (sand or fine sand) and for radium it was in the finest (fine silt + clay) fractions.

The IAEA (2010) adopted the transfer factor (TF) to describe soil-to-plant uptake of a radionuclide defined as the ratio of the dry weight concentration in the plants to the dry weight concentration in a specified soil layer (0 - 10 cm for grasses/pastures). Among all plant species highest TF values were obtained for fodder, pastures and grasses plant group (IAEA, 2010). Study of Vandenhove et al. (2009b) showed that uranium, thorium and radium transfer factors decline from sandy, through loamy to clay soils.
but the range of observed TF values is very large for each soil texture. Also, other soil characteristics (such as pH, cation exchange capacity, organic matter or content of amorphous Fe) did not significantly affect TF factors. Transfer factor is important as evidence of radionuclides uptake by biota allowing further investigation for the risk assessment of soil contamination to human health.

2. MATERIALS AND METHODS

Samples of soil and native vegetation were collected in the vicinity of TE “Kolubara” (TEK), TE “Morava” (TEM) and TE “Nikola Tesla” A and B (Tent A and Tent B) power plants. In 2012, surface soil samples were collected from the 0-5 cm depth. Samples of soil were air-dried at room temperature, crushed and sieved through 2 mm mesh sieve. Standard soil analysis techniques were used. Soil reaction in water (1:2.5) was measured potentiometrically. Content of CaCO3 was determined volumetrically according to method of Scheibler calcimeter. Organic matter content was determined by Tjurin method, modified by Simakov. Particle size distribution analysis was conducted by pipette method. Soil fractions determined were coarse sand (2-0.02 mm), fine sand (0.02-0.005 mm), coarse silt (0.005-0.01 mm), fine silt (0.001-0.0002 mm) and clay (<0.0002 mm).

For determination of natural radionuclide activity concentration, soil samples were packed in 500 ml Marinelli beakers sealed and covered with a film of beeswax and left for 4 weeks to 226Ra and 232Th attain secular equilibrium with their decay products. Applying the gamma-ray spectrometry method, measurements were performed with the HPGe detector (Canberra) with 20% relative efficiency and energy measurement was performed with the HPGe detector (Canberra) with 20% relative efficiency and energy resolution of 1.8 keV at the 1332 keV gamma ray energy of 60Co. The detector was calibrated using standard reference material (Silicone resin with homogeneously dispersed radionuclides 241Am, 109Cd, 137Cs, 60Co, 144Ce, 65Zn, 85Sr, 88Y, and 203Hg; total activity 40.624 kBq at 15.04.2008.; Czech Metrological Institute Praha, 9031-OL-208/08) in the same geometry as measured samples (Marinelli beaker, 500 cm3).

Plants were collected at the same time as the samples of soil. Depending on the sampling location, samples were composed differently from several types of grass species taken at the same growth period. Because of the large native crop diversity it is impossible to separate one crop type to monitor the radioactivity changes from year to year. In the process of preparation, plant parts (root, stem, leaves) were not separated. Integral grass samples were dried at air temperature, after which they were mineralized at a temperature of 450°C, and then sealed with a film of beeswax. The geometry of the measurement is a 100 cm3 plastic cylinder. Geometric calibration was performed with a secondary reference material obtained from the primary reference material (mineralized grass with homogeneously dispersed radionuclides 241Am, 109Cd, 137Cs, 60Co, 85Sr, 88Y, 113Sn, 54Mn, 133Ba, and 210Pb total activity 72.40 kBq at 31.08.2012.; Czech Metrological Institute, Praha 9031-OL-116/8, type ERX).

The activity 238U was determined through its daughter product in equilibrium in soil samples 234Th (63 keV). The activities of 226Ra were determined by its decay products: 214Bi (609, 1120, and 1764 keV) and 214Pb (295 and 352 keV) and 232Th activities by its decay product 228Ac (358 and 911 keV). Activity of 40K is obtained from its single gamma ray line of 1460 keV energy. Counting time was about 70 000 s. Measurements uncertainty is expressed as an expanded measurement uncertainty for the factor k = 2 that corresponds to a normal distribution with a confidence level of 95%.

Soil-to-plant natural radionuclide transfer factor TF (kg kg⁻¹ dry mass) is determined as the ratio of the radionuclide content in the plant to that in the soil (Bq kg⁻¹ dry weight integral plant tissue/Bq kg⁻¹ dry weight soil). To find relationships between natural radionuclides TFs mutually and between radionuclides TFs and soil properties, Pearson’s linear correlations were performed. Significance were considered at p < 0.05 level.

3. RESULTS AND DISCUSSION

3.1. Soil properties

Investigated soils are Fluvisols, distributed along the river valleys where power plants are situated. Results of the soil analysis showed that all calcareous (0.40 - 3.87%) samples were neutral to slightly alkaline except at two locations, weakly acidic. Soil organic matter (SOM) content ranged from 1.2% to 4%. Particle size analysis revealed uneven distribution of sand, silt and clay particles. Sand fractions varied wide (~80%). Silt and clay fractions varied notably less, 29% and 33%, respectively. Compared to sand percentage whose average value was 17%, silt and clay fractions with average 54% and 31%, respectively prevailed in all soil samples. Soils belong to loam group of mineral soils according to Vandenhoove et al. (2009b).

3.2. Soil and plant activity concentration

Radioactivity measurements in the upper soil in the surroundings of the investigated CFPPs showed values ranging (Bq kg⁻¹): 31 - 56 for 238U, 26 - 56 for 226Ra, 24 - 71 for 232Th and 324 - 736 for 40K which are in agreement with the values for background gamma surroundings of the investigated CFPPs showed values ranging (Bq kg⁻¹): 31 - 56 for 238U, 26 - 56 for 226Ra, 24 - 71 for 232Th and 324 - 736 for 40K which are in agreement with the values for background gamma radiation reported for soils worldwide (UNSCEAR, 2000). Results of activity concentration (Bq kg⁻¹ dry mass) of natural radionuclides determined in plant samples ranged: 3.2 - 8.1 for 238U; 1.3 - 8.3 for 226Ra; 0.6 - 3.5 for 232Th and 180 - 940 for 40K. In the samples of spontaneous vegetation in the vicinity of CFPPs similar natural radioactivity levels were found in Romania (Botezatu et al., 2004), but with higher maximum values compared to that determined in plants in Serbia.

3.3. Soil-to-plant transfer factors

Soil-to-plant transfer factor values (kg kg⁻¹ dry mass) in the vicinity of CFPPs were in the range: 0.068 - 0.279 for 238U; 0.031 - 0.319 for 226Ra; 0.015-0.117 for 232Th and 0.321-1.958 for 40K. Those values (except for 40K) were in agreement with the soil-to-grass transfer factors for temperate environment given by IAEA
For 238U, TFs were determined for plant samples near the CFPPs and at further distances uranium activities in plants were below the MDA. It could be noted that TFs for radium are generally higher than for uranium and thorium at each site (Table 1). This could be explained by the fact that uranium and thorium are both actinides with more analogous chemical behaviour, unlike radium which is an alkaline-earth element (Vera Tome et al., 2003).

Pearson’s linear correlation analysis between soil properties (particle size distribution, soil pH, content of organic matter and carbonates) and TFs for natural radionuclides were performed. Correlations with soil carbonate content for each natural radionuclide were strong but not statistically significant and only correlations with soil texture were (p<0.05). Fine silt were correlated with TFs for 40K (Fig.1) and 226Ra (Fig.2) and coarse silt with TFs for 232Th (Fig.3). Correlations were established if data for both or one of nearest points to the CFPP (100 m away; TEM1 and TentA1) were excluded from analysis. Those two sites differed by their soil properties from group of soils at distances >100 m and had much higher fraction (~70%) of coarse particles in total (2-0.01 mm) (Table 2). At site TEM1 the highest TF values were determined for all natural radionuclides.

Radionuclides activity concentration of a bulk soil is not the amount available for plant uptake; it is their “available” concentration which is the fraction of radionuclides present in soil in some labile chemical form. In Fluvisols, variations of soil-to-plant transfer factors of natural radionuclides were associated with various silt-size distributions which mean that sorption/desorption processes that affected natural radionuclides lability in soils emerged from fine silt and coarse silt fractions.
Table 2 Properties of soil samples collected in the vicinity of CFPPs studied.

<table>
<thead>
<tr>
<th></th>
<th>SOM (%)</th>
<th>Coarse sand (%)</th>
<th>Fine sand (%)</th>
<th>Coarse silt (%)</th>
<th>Fine silt (%)</th>
<th>Clay (%)</th>
<th>Carbonate s (%)</th>
<th>pH_H2O</th>
</tr>
</thead>
<tbody>
<tr>
<td>TEK 1</td>
<td>2.47</td>
<td>1.35</td>
<td>7.83</td>
<td>46.15</td>
<td>15.80</td>
<td>28.87</td>
<td>0.40</td>
<td>6.1</td>
</tr>
<tr>
<td>TEK 2</td>
<td>3.87</td>
<td>2.30</td>
<td>7.59</td>
<td>40.12</td>
<td>20.21</td>
<td>29.78</td>
<td>0.40</td>
<td>7.1</td>
</tr>
<tr>
<td>TEM 1</td>
<td>2.43</td>
<td>9.10</td>
<td>1.23</td>
<td>62.61</td>
<td>14.75</td>
<td>12.32</td>
<td>3.87</td>
<td>7.6</td>
</tr>
<tr>
<td>TEM 2</td>
<td>2.59</td>
<td>1.48</td>
<td>0.08</td>
<td>38.82</td>
<td>30.47</td>
<td>29.15</td>
<td>0.20</td>
<td>6.2</td>
</tr>
<tr>
<td>Tent A1</td>
<td>3.97</td>
<td>14.82</td>
<td>26.55</td>
<td>25.61</td>
<td>5.02</td>
<td>27.91</td>
<td>2.69</td>
<td>7.4</td>
</tr>
<tr>
<td>Tent A2</td>
<td>4.00</td>
<td>4.15</td>
<td>18.22</td>
<td>25.74</td>
<td>16.75</td>
<td>35.14</td>
<td>2.78</td>
<td>7.5</td>
</tr>
<tr>
<td>Tent B1</td>
<td>1.20</td>
<td>21.26</td>
<td>9.44</td>
<td>22.08</td>
<td>18.07</td>
<td>29.16</td>
<td>2.34</td>
<td>7.9</td>
</tr>
<tr>
<td>Tent B2</td>
<td>3.70</td>
<td>3.39</td>
<td>4.71</td>
<td>33.61</td>
<td>19.40</td>
<td>38.88</td>
<td>1.14</td>
<td>7.1</td>
</tr>
</tbody>
</table>

Potassium is a primary macronutrient for plant growth and 1 g of stable K in soil contains 31.3 Bq of 40K. The soil-to-plant transfer factors for 40K vary greatly in Fluvisols and are higher by one order of magnitude compared to TFs for 238U, 226Ra and 232Th. High TFs (and >1) could be explained by increasing availability of K by non-exchangeable potassium, fixed in clay mineral interlayers, that could be transferred to soil solutions induced by root activities that significantly contribute to the potassium nutrition of plants. This is in accordance with high correlations that were found for 40K TFs with fine silt + clay fractions (Fig. 4).

4. CONCLUSION

In the vicinity of CFPPs, soil-to-plant transfer factor values (kg kg⁻¹ dry mass) for natural radionuclides were in the range: 0.068 - 0.279 for 238U; 0.031 - 0.319 for 226Ra; 0.015-0.117 for 232Th and 0.068 - 0.279 for 40K. The soil-to-plant transfer factors for 40K vary significantly with soil texture and relationships with other soil properties could be established if the scattering of the data due to difference in the plant samples composition are minimized. In the power plant surroundings, beside the soil-to-plant, investigations should be extended to ash-to-plant transfer factor because it is valuable information for keeping track of radionuclides in the soil-plant-animal chain.

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REFERENCES
RADIATION MEASUREMENT TECHNOLOGY USING AN OPTICAL FIBER AND AN OPTICALLY STIMULATED LUMINESCENCE AND ITS APPLICATION TO A RADIATION MONITOR FOR NUCLEAR POWER PLANTS

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Abstract. The suppression of false alarms given by an area monitor used in nuclear power plants has been desired for a long time. A radiation monitor with an optical fiber using optically stimulated luminescence (OSL) was investigated for an area monitor. The sensitivity for gamma-ray was examined using a prototype instrument and the value of 700 counts/mSv was obtained. It was estimated the measurement interval of an area monitor was 15 min in the range of 102 to 103 mSv/h. Furthermore, the situation following the March 2011 accident at the Fukushima Dai-ichi Nuclear Power Station (FJS) has shown needs for a radiation monitor that can expand multipoint measurements easily and detect the occurrence of radioactive water, which includes 90Sr, leaking from the storage tanks. The performance for beta-ray detection instrument was examined using a prototype instrument for beta-ray detection in order to evaluate the applicability to a leaking monitor. It was estimated that the measurement interval for beta-ray was 81 s when the concentration of leaking water was 1.0 × 105 Bq/cm2.

Key words: Optically stimulated luminescence, optical fiber, multipoint measurement, gamma-ray, beta-ray

1. INTRODUCTION

A process radiation monitor, which gives an alarm when the radiation level is above a threshold, and an area radiation monitor, which measures gamma-rays and analyzes the air dose rate at various areas in nuclear power plants, are commonly installed in the plants. Si semiconductor detectors, ionization chambers and NaI:Tl scintillation detectors are applied for these radiation monitors(1). The suppression of false alarms by the radiation monitors has been desired for a long time; these alarms are due to electrical noise occurring in the transmission to a main control room through signal cabling. In addition, the situation following the March 2011 accident at the FJS has shown the needs for radiation monitors that can expand multipoint measurements easily, cover a wide area (for example, more than 100,000 m2 in the FJS(3)) and detect the occurrence of leaking water from the storage tanks for holding water contaminated by fission products such as 90Sr.

Based in this background, a radiation monitor with an optical fiber using OSL (an OSL radiation monitor) was investigated. Other studies have concluded that an radiation monitor using Al2O3:C was investigated as a monitor for radioactive containments and a real-time dosimeter for radiotherapy(4)(5). In order to apply the OSL radiation monitor to the plants, it is necessary to balance measurement interval, sensitivity and background discrimination. Therefore prototype instruments that use BaFBr:Eu or BaFBr:Eu which have high detection efficiency were manufactured. The objectives of this study are to develop an OSL radiation monitor which analyzes a dose rate in the range of 102 to 103 mSv/h in the measurement interval of 60 min for an area monitor, and that for a leaking monitor which analyzes the occurrence of leaking water, the concentration of which is 1.0 × 105 Bq/cm2, in the measurement interval of 10 min by detecting beta-rays irradiated from 90Sr/90Y.

2. MONITORING AND CONFIGURATION OF OSL RADIATION MONITOR

2.1. Monitoring Method for OSL

The principal characteristic of OSL is that the electrons in an OSL sensor are excited to a meta-state level from the ground state by irradiation and they remain at this level until stimulated by light(6)(7). The measurement procedure of an OSL radiation monitor is conceptualized in Fig. 1. The sensor is initialized by light irradiation. After being initialized, the energy corresponding to exposure dose is accumulated in the sensor. After some time, the sensor is irradiated by light and the luminescent intensity as an OSL measurement is measured by a photon counter. In order to decrease the noise by light irradiation and dark current due to a photon counter, the response as a background measurement is measured immediately after measuring the
luminescent intensity. The net value for the luminescent intensity is calculated by

$N_{\text{net}} = N_{\text{gross}} - N_{BG}$ \hspace{1cm} (1)

where $N_{\text{gross}}$ is the measured count of luminescent intensity, $N_{BG}$ is the count of background response and $N_{\text{net}}$ is the net count. A dose rate is calculated by

$D = \alpha \times \frac{N_{\text{net}}}{t_r}$ \hspace{1cm} (2)

where $D$ is the dose rate, $t_r$ is the irradiation time and $\alpha$ is the conversion factor. This dose rate is shown as a mean dose rate in an irradiation time.

2.2. Configuration of OSL Radiation Monitor

The configuration of a prototype instrument is shown in Fig. 2. An OSL sensor is set into a sensor head. One end of an optical fiber is connected to the sensor head and the other is connected to an optical switch. The switch is connected through an optical coupler to a laser and a photomultiplier tube (PMT) with an optical filter. The PMT is connected to a counter through a preamplifier. Data obtained are processed as a time analysis spectrum and a pulse height spectrum by a data acquisition instrument.

This prototype instrument consists of the parts described below. A BaFBr:Eu plate (Fuji Film, Ltd.) for x-ray imaging or a BaFBr:Eu crystal, which was grown using the pulling-down method, are used as a sensor. The sensor head is made of aluminum. The optical fiber is a multi-mode fiber made from silica which has a core diameter of 114 \mu m. The optical switch has 10 channel numbers and the channels can be switched mechanically. The optical coupler is branched into two channels and the optical power is divided equally. The laser diode which is a semiconductor laser emits light of 639 nm wavelength. A blue spectral filter, which is set in front of the PMT, is used for background discrimination as the optical filter. The counter functions as a multichannel scalar (MCS) and a multichannel analyzer (MCA). Using the functions, the detection timing and pulse height information of each input pulse to the data acquisition instrument is outputted for time analysis and pulse height spectra.

3. RESULTS AND DISCUSSION

3.1. Sensitivity for Gamma-ray Irradiation and Applicability to Area Monitor

3.1.1. Time and pulse height analysis

The time analysis and the pulse height spectra were observed using the prototype instrument in order to examine the suitability of measurement procedure. The BaFBr:Eu plate and the optical fiber of 2 m were used. The BaFBr:Eu plate was exposed to 0.25 mSv using a $^{35}$Cs source. The time analysis and the pulse height spectra obtained are shown in Fig. 3. It was confirmed from the time analysis spectra that a waveform with a peak was observed and decreased at a constant level after the first laser irradiation for an OSL measurement. Furthermore, a waveform that counts rose slightly and saturated to a constant level after the second light irradiation was observed. Therefore it was clear that the luminescent intensity was obtained using the prototype instrument. The constant level after emitting the luminescence implied that the energy accumulated was initialized. From the pulse height spectra, it was not confirmed clearly that the profile of a spectrum obtained from an OSL measurement was different from that obtained from a background measurement. It appeared that main background contribution was due to laser irradiation based on the results of timing analysis and pulse height spectra.

3.1.2. Exposure dose dependence of OSL intensity and sensitivity

The net counts with exposure doses were analyzed to examine the exposure dose dependence of luminescent intensity and the sensitivity for gamma-ray. The BaFBr:Eu plate was exposed to 0.1 mSv/h using the $^{35}$Cs source. An exposure dose was regulated by changing an irradiation time. The exposure dose dependence of OSL intensity is shown in Fig. 4. It was confirmed that the measurement error at doses from 0.05 to 10 mSv was within \pm 10 %. The lower limit detectability for the prototype instrument was estimated from the result in Fig. 4. The measured count of luminescent intensity was 140 obtained in the exposure dose of 0.05 mSv. The standard deviation of the count was \pm 11.8. The count of background response was approximately 100. From the results, the standard deviation of the net count was \pm 15.5. When the lower limit detectability was defined as the net count was larger than 3 \sigma, it was estimated that the lower limit detectability was 0.05 mSv. Furthermore, it was confirmed that the count loss of 62.8 % at 405 mSv occurred. This was caused by the measured count rate exceeding the upper limit of count rate for the counter instantaneously. When the luminescent intensity is analyzed at a high exposure dose, the
current measurement should be applied as an alternative.

The sensitivity for gamma-ray was estimated from the result in doses from 0.05 to 10 mSv in Fig. 4. The sensitivity was calculated by

\[ S_{\text{gamma}} = \frac{dN_{\text{net}}}{dD_0} \frac{c}{a} \]  

where \( S_{\text{gamma}} \) is the sensitivity for gamma-ray, \( \frac{dN_{\text{net}}}{dD_0} \) is the differential value obtained from Fig. 4, and \( D_0 \) is the accumulated dose. It was confirmed that the sensitivity for gamma-rays was 700 counts/mSv.

3.1.3. Applicability of area monitor

The measurement interval of an area monitor was evaluated in consideration of the count loss of the high dose and the optical attenuation of the optical fiber. The cabling length was approximately 200 m to the main control room. The measurement interval was calculated by

\[ T_{\text{mg}} = \frac{N_{\text{lower}}}{S_{\text{gamma}} D} \times \frac{d_{\text{zoom}}}{d_{\text{m}}} \]  

where \( T_{\text{mg}} \) is the measurement interval, \( N_{\text{lower}} \) is the net count at the exposure dose of 0.05 mSv, and \( d_{\text{zoom}} \) and \( d_{\text{m}} \) are the attenuation values for the optical fibers of 200 m and 2 m, respectively. From Eq. (4), it was estimated that the measurement interval was 15 min in the range of \( 10^3 \) to \( 10^4 \) mSv/h. Thus this interval was reasonable for an area monitor.

3.2. Sensitivity for Beta-ray Irradiation and Applicability to Leaking Monitor

3.2.1. Discriminability of beta-ray from gamma-ray

In order to examine applicability as a leaking monitor, the discriminability of beta-rays from gamma-rays were investigated. First, the time analysis spectra were analyzed for 8 mSv/h using the \(^{137}\text{Cs}\) source with and without a \(^{90}\text{Sr}\) source of 2.1 MBq. The BaFBr:Eu plate and the optical fiber of 50 m length were used. The irradiation time was 5 min. The time analysis spectra obtained are shown in Fig. 5. It was confirmed that the measured count with \(^{90}\text{Sr}\) and \(^{137}\text{Cs}\) sources was 7.3 times larger than the count with just the \(^{137}\text{Cs}\) source. The air dose rate around the storage tanks in the F1 has been about 1.5 mSv/h\(^{(3)}\) and the concentration of contaminated water has been about \( 1.0 \times 10^5 \) Bq/cm\(^3\)\(^{(8)}\). A measured count was assumed to be 18.5 times larger than a background count when the volume of leaking water was 10 cm\(^3\). It was clear that the OSL radiation monitor could be operated as a beta-ray monitor under the condition of an existing gamma-ray background.

3.2.2. Sensitivity and applicability of leaking monitor

In order to optimize the sensitivity for beta-ray irradiation, a BaFBrI:Eu crystal which had been grown using the pulling-down method was used as a OSL sensor. Furthermore, the thickness of a BaFBrI:Eu crystal and the detection window of a sensor head were designed as 1 mm and 11 \( \mu \)m, respectively, based on the calculation results from EGS5\(^{(9)}\). Two prototype sensors with a BaFBrI:Eu crystal and a BaFBr:Eu plate were manufactured. These sensors were covered with a polypropylene sheet of 10 \( \mu \)m thickness for waterproofing. These sensors were placed in contact with a \(^{90}\text{Sr}\) solution source having a concentration of 10 or 40 kBq/cm\(^3\). The irradiation time dependence of luminescent intensity is shown in Fig. 6. It was confirmed that the sensitivity for beta-ray using the prototype sensor with a BaFBrI:Eu crystal was \( 2.2 \times 10^{-2} \) counts/h/(Bq/cm\(^3\)). This sensitivity was 3.6 to 4.9 times larger than that with a BaFBr:Eu plate.
The measurement interval for leaking detection was estimated from the sensitivity obtained. The measurement interval was calculated by

\[ T_{mb} = \frac{N_{lower}}{S_{beta} \times A} \]  

(5)

where \( T_{mb} \) is the measurement interval for beta-ray, \( S_{beta} \) is the sensitivity for beta-ray and \( A \) is the concentration of leaking water. From Eq. (5), it was estimated that the measurement interval was 81 s when the concentration was \( 1.0 \times 10^5 \) Bq/cm\(^3\). The measurement interval was also 13.5 min when the concentration was diluted to 1/10 due to rainwater. These measurement intervals were reasonable for detecting leaking water at the F1.

Fig. 5. The time analysis spectra for 8 mSv/h using \(^{137}\)Cs source with and without \(^{90}\)Sr source of 2.1 MBq.

Fig. 6. The irradiation time dependence of luminescence intensity. The two prototype sensors with a BaFBrI:Eu crystal and a BaFBr:Eu plate were used.

4. CONCLUSION

The OSL radiation monitor with an optical fiber using a BaFBr:Eu plate or a BaFBrI:Eu crystal was developed and its applicability was investigated as an area monitor for the plants and a leaking monitor for the F1. The sensitivity for gamma-rays was 700 counts/mSv for the BaFBr:Eu plate and the lower limit detectability was 0.05 mSv. From the results, it was estimated that the measurement interval for an area monitor was 15 min in the range of \( 10^9 \) to \( 10^4 \) mSv/h. Thus this interval was reasonable for an area monitor. Furthermore, the sensitivity for beta-ray was \( 2.2 \times 10^2 \) counts/h/(Bq/cm\(^3\)) for a BaFBrI:Eu crystal. From the result, it was estimated that the measurement interval for beta-ray was 81 s when the concentration of leaking water was \( 1.0 \times 10^5 \) Bq/cm\(^3\). Thus this interval was reasonable for a leaking monitor.

REFERENCES
