MEASUREMENT OF AMBIENT DOSE EQUIVALENT $H^*(10)$ IN THE SURROUNDING OF NUCLEAR FACILITIES IN SERBIA

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Abstract. In the Public Company Nuclear Facilities of Serbia, the measurement of the operational dosimetric quantity, ambient dose equivalent $H^*(10)$, is continuously carried out at measurement points in the surrounding of the radioactive waste storage facilities (hangars H1, H2 and H3) and old reactor buildings (RA and RB), located at Vinca site in Belgrade. For that purpose, two different types of passive dosimeters are used: thermoluminescent (TL) high sensitivity dosimeters (LiF:Mg,Cu,P) and optically stimulated luminescence (OSL) dosimeters (Al_2O_3). The principle of radiation interaction with both types of material is very similar, and the main difference is reflected in the method of detecting the light which is in relation to the dose in the dosimeter. The measurement of the ambient dose equivalent is performed at 34 measuring points in order to monitor the level of radiation exposure in the vicinity of the mentioned facilities. The paper shows the results of the measurements in the period from January to December of 2016. TL and OSL dosimeters were used and read once a month at the same time under the same measurement conditions. The aim of this paper is to present the comparative results of the ambient dose equivalent measurements using TL and OSL dosimeters and compare them with the measurement results of the reference instrument for measuring dose rate (Atomtex AT6101C spectrometer) at the same measuring points. It was found that the differences among the measurement results using different dosimeter types were satisfactory, with a maximum deviation of 35%. The results also show that there is no significant increase in the level of radiation exposure, which is of particular importance to the environment and the population around nuclear facilities in Serbia.

Key words: Ambient dose equivalent, Dosimetry, OSL, TLD

1. INTRODUCTION

One of the places in Serbia in which ambient dose equivalent $H^*(10)$ is being measured is Vinca, in the near proximity of the radioactive waste storage facilities H1, H2, H3 and old reactor buildings RA, RB, which are now within the Public Company Nuclear Facilities of Serbia (PC NFS). Ambient dose equivalent $H^*(10)$ is one of the operational quantities used in dosimetry. This quantity is defined as the dose equivalent at a point in the radiation field that would be produced by the corresponding expanded and aligned field in the ICRU sphere at a depth of 10 mm on the radius vector opposing the direction of the aligned field and it is recommended that this quantity should be used in the area of external exposure monitoring in order to have an assessment of the effective dose [1]. This quantity is used because it provides a conservative estimation of the upper limit for the effective dose in most practical situations of external exposure [1].

The measurement of ambient dose equivalent $H^*(10)$ in the surrounding of nuclear facilities is legally required by the law in the Republic of Serbia [2, 3] and the results obtained in these measurements are used to control the influence of gamma radiation mainly from used medical and industrial sources that are stored in radioactive waste storage facilities H1 and H2 (mainly ^{60}Co , ^{137}Cs and ^{226}Ra). These results can be used in the

assessment of the effective dose [1], which makes them suitable for assessing the effect that nuclear facilities can have on the workers in the PC NFS, the general population, and the environment. The measurement of the ambient dose equivalent are being carried out in the PC NFS once a month with two passive (thermoluminescent (TL) and optically stimulated luminescence (OSL)) dosimetric systems since 2015. Materials that were used in these measurements are LiF:Mg,Cu,P for thermoluminescence dosimetry, and Al_2O_3 for optically stimulated dosimetry.

The principles of the interaction with ionizing radiation of these two materials are very similar - when luminescent material (TL or OSL) is exposed to ionising radiation, the electron from the valence band absorbs energy and moves to the conduction band, leaving a hole in the valence band. The electron from the conduction band is trapped in the forbidden band gap - which is possible because of the impurities in crystal lattice. The number of trapped electrons directly depends on radiation exposure. The electrons are then stored and trapped inside the forbidden band until the crystal is exposed to an external stimulant. After appropriate external stimulation, the trapped electrons are released and recombined with the hole and as a result they emit photons [4, 5]. By collecting the emitted photons, we can determine the dose that the material was exposed to. The main difference between thermo and optically stimulated luminescence is in the external stimulant needed to produce luminescent

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glow. TL materials need to be heated [4], while OSL materials have to be exposed to light of a specific wave length [5].

Further measurements of the ambient dose equivalent rate are carried out with spectrometric portable radiation scanner Atomtex AT6101C [6]. This spectrometer is capable of both determining the rate of the ambient dose equivalent and detecting the type of radioactive source based on the detected gamma energy. The detector that is integrated in this spectrometer is NaI(Tl), which is a scintillated detector suitable for detecting photons in a wide energy range, up to 3 MeV. This type of active system can be used to determine ambient dose equivalent $H^*(10)$ [7, 8]. The results obtained with this spectrometer were used as a reference value in order to check the results obtained using passive dosimetric systems.

The data presented in this paper is the result of the measurements of the ambient dose equivalent and ambient dose equivalent rate that were carried out during 2016. The goal of this paper is to display the relative comparison of the results of thermoluminescent and optically stimulated luminescence dosimetric systems when the reference value is the value measured with a spectrometer. These results are also used to check if the ambient dose equivalent is within legal limits.

2. MATERIALS AND EQUIPMENT

As previously stated, two types of passive dosimetric materials were used in this measurement - thermoluminescent (TL) LiF:Mg,Cu,P (MCP) and optically stimulated luminescent (OSL) Al_2O_3 . Both of these materials were chosen because of their high sensitivity to ionizing radiation, which makes them suitable for determining operational dosimetric quantities and also for measurements in both regular and accidental working conditions [9, 10, 11].

The read-out of TL dosimeters is carried out in automatic TLD Rados Reader RE-2000 [12], while the read-out of OSL dosimeters in OSL Landauer microStar mobile reader [13]. Reader RE-2000 uses nitrogen to heat up dosimeters at required temperature and collects the emitted photons, after which the information about the dose in the material can be acquired from a computer with the appropriate software that takes into account the relation between the emitted light and the dose in the material. After the read-out of TL dosimeters, all trapped electrons are released, which means that the same measurements can not be repeated. Landauer microStar reader uses a green-emitting light source to stimulate OSL materials. Unlike TL, OSL measurements can be repeated a few times, because a short light stimulation is not enough to release all trapped electrons.

Both types of dosimetric systems were irradiated in the Secondary Standard Dosimetry Laboratory (SSDL) at the Vinča Institute of Nuclear Sciences, Belgrade before the experiment started in order to measure ambient dose equivalent $H^*(10)$. The calibration was done by using the recommendations given by the manufacturer, and as required by the standard [12, 13, 14, 15]. Ten dosimeters from both TL

and OSL were selected to be exposed to the reference value of 5 mSv ambient dose equivalent determined with ionizing chamber, in Cs-137 field. After this irradiation, dosimeters were read out in their appointed readers. Using calibrating factors obtained with this reading, the calibration of used dosimeters has been performed. Atomtex AT6101C spectrometer was calibrated by the manufacturer to measure the ambient dose equivalent rate. After the whole process of calibration was completed, the preparation of the dosimeters to be used in the experiment started.

3. MEASUREMENT METHODS

In order to make sure the dosimeters traps are emptied and do not keep information from previous irradiations, both types of dosimeters had to be annealed before the measurement. The annealing of the TL dosimeters was performed by placing the dosimeters in an oven heated to 240 °C on a plate made of stainless steel, and leaving them in it for 10 minutes. The OSL dosimeters were annealed by exposing them to light from a fluorescent lamp. The OSL dosimeters were placed 30 cm from the light source and the total time of light exposure was 4 hours. After this procedure, the dosimeters were measured to make sure that the annealing process was successful.

One TL dosimeter was made of 4 MCP crystals. The crystals were in the shape of a disk, with the diameter of 4.5mm, and thickness of 0.9mm. These crystals were placed in a plastic slide with an identification number, which was later placed in a plastic holder that contained an aluminium filter used for energy compensation (2 crystals were covered with both plastic and aluminium filters, 1 crystal was covered only with a plastic one and 1 crystal had no filter) [12]. Filters on both types of dosimeters are used to compensate for the signal response in the energy range of low energy ionizing radiation. The OSL dosimeter was made of Al_2O_3 in powder form, pressed in a thin (0.2mm) layer between two 0.1 mm thick polyester foils [13]. These dosimeters were placed in a holder that contained filters for energy compensation. These filters were made of aluminum, copper and plastic. On the back of the holder of the OSL dosimeter was a number used to identify the position of the dosimeter. After this preparation, one TL and one OSL dosimeter were placed into a plastic bag, which was closed in a way that ensured the protection of the dosimeters from external influences (rain, dirt, etc.). Each plastic bag was marked with a number indicating its measurement position, and after that they were placed inside a plastic mount. This was necessary in order to protect the OSL dosimeters from exposure to light, because light can have an impact on the fading of OSL dosimeters. Figure 1 shows a close-up look of the TL and OSL dosimeters inside the plastic mount that carries the dosimeters.

Dosimeters were placed at one of 34 measuring positions surrounding the nuclear facilities, at 1m above the ground. Each dosimeter was always placed at the same measurement position. The total number of the used dosimeters was 136 (68 TL and 68 OSL),

distributed at these measurement positions within the PC NFS.

On the first of each month, the replacement, collection and measuring of the ambient dose equivalent were carried out. The readers for TL dosimeters, TLD Rados RE-2000 and OSL dosimeters, OSL Landauer microStar mobile reader, underwent reader sensitivity calibration on the day of the measurements. Also, the environmental conditions in the laboratory were checked before the measurements began. This was done in order to minimise measurement uncertainty, which is estimated to be less than 15% ($k=2$).

Figure 1. Position of the OSL (left) and TL (right) dosimeter inside the plastic mount

To get the results from the TL dosimeters, dosimeters were subjected to short-term annealing inside the reader. This was done by heating the dosimeters at the temperature of 150 °C for 12 s. After the annealing procedure, the dosimeters were measured in the reader for 25 s using nitrogen heated to 240 °C, in order to get the data values of the ambient dose equivalent. Immediately after the measurement, the value of the collected dose could be read out. The OSL dosimeters were not required to go through the annealing procedure. Upon arrival to the laboratory, the dosimeters were identified by using a bar code scanner, and then placed inside the reader. The dosimeters were exposed to light inside the reader in order to get information about the measured quantity. Given the fact that the information was not lost after the initial reading (which was not the case for the TL dosimeters), every dosimeter was read-out five times.

The reading of the passive dosimeters was performed at the same time, in the same laboratory with controlled working conditions. After the reading, the dosimeters were left in the same room, in order to be kept in the same environment conditions.

The measurement with Atomtex AT6101C spectrometer was performed at all measurement positions once a month, at the same time while the

dosimeters were collected and replaced. Each position was measured 5 times, and the average value of the ambient dose equivalent rate was used as the reference value of the dose rate for that month on that position.

After the completion of whole measurement process, the obtained results were compared to each other. The readers of the passive dosimetric system showed the value of operational dosimetric quantity $H^*(10)$ immediately after the reading, because of the appropriate calibration of the dosimetric systems. Unlike them, the spectrometer measured the ambient dose equivalent rate. This quantity is expressed in mSv/h, so it is necessary to perform the conversion of the obtained value in order to get information about the ambient dose equivalent in mSv. This is done by simply multiplying the measured ambient dose equivalent rate with the number of hours in that month.

The results obtained from the passive dosimetric systems were compared to each other for each month and each position, while the reference value was taken to be the value of the ambient dose equivalent measured with the spectrometer.

4. RESULTS AND THEIR INTERPRETATION

Figure 2 shows the total annual ambient dose equivalent for each of the measuring positions by using the data obtained with all three measurement methods. The x-axis marks the position of the measuring points, and the y-axis contains the values of the ambient dose equivalent in mSv. It can be noticed that the maximum measured value is at measuring position 7. That result is expected given the fact that that measuring point is nearest to the radioactive waste storage facilities H1 and H2, where most of the legacy waste is stored. The results show that the relative difference between the values of the ambient dose equivalent received by the TL or OSL dosimeter in relation to the results of the measurements with AT6101C spectrometer is not greater than 35%. These results are good and in agreement with the standard recommendations [14, 15].

Figure 2. Annual value of the ambient dose equivalent measured with all three methods

The results also show good agreement when it comes to the values for each month. Figures 3-6 present monthly data for the ambient dose equivalent measured in February, May, August and December, respectively, with all three methods. These graphs show that the ambient dose equivalent did not have a significant change of value during the year.

Figure 3-6. Comparison of the results of the ambient dose equivalent measured in February, May, August and December (from top to bottom)

Figures 7 and 8 show a 3D view of all the results obtained in the measurements during the whole year using the TL and OSL dosimeters, where the positions of the measuring points, ambient dose equivalent and the months in which the measurements were performed are shown on the x-, y- and z-axis, respectively. With this 3D graphic, it can be noticed that the greatest value of each of the measurements using both measurement methods was in position 7. The largest measured value of the ambient dose equivalent for the TL measurements was measured in January and amounted to 0.594 mSv, while the maximum value measured with the OSL dosimeters was also measured in January and amounted to 0.595 mSv. This maximum value is probably due to the fact that the highest background radiation was measured in January. All results of ambient dose equivalent in this paper are presented with included background. Also, TL and OSL readers use different algorithms to calculate the ambient dose equivalent, so that is also one of the factors that can contribute to the difference in results.

Figure 7-8. 3D representation of the measurement results of the ambient dose equivalent obtained with TLD (up) and OSL (down) in 2016

5. CONCLUSION

During 2016, the comparison of three measurement methods was performed and it involved the passive TL and OSL dosimetric systems, and AT6101C active spectrometer. These methods were used to measure the

ambient dose equivalent around nuclear facilities in Serbia. The obtained result show that the relative difference of results from the TL and OSL measurements is not greater than 35% compared to the value measured with the spectrometer. This relative difference between the results can be due to stochastic nature of the interaction of ionizing radiation with dosimetric materials, as well as the fact that there are many sources of measurement uncertainty when it comes to the measurement of operational dosimetric quantities (temperature, sensitivity of crystals, etc.). However, these results are still satisfactory and in accordance with international standards [14, 15]. This can lead to the conclusion that both TL and OSL dosymetric systems can be used to measure the ambient dose equivalent $H^*(10)$. It can also be observed that there is no significant change of the ambient dose equivalent throughout the year, which indicates that safety and security regulations are being followed. One last indicator of this is the fact that the highest measured dose value is within legal limits defined for occupational exposure to ionizing radiation of 20 mSv [3]. Also, because the highest value was measured in the immediate proximity to the entrance to radioactive waste storage hangars, and the positions that are approximately 100 m from these hangars measured only background radiation, and that the closest houses are located more than 300 m from the hangars, we can conclude that nuclear facilities present no danger for the nearby population and environment.

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