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A NEED FOR EYE LENS DOSIMETRY IN NUCLEAR MEDICINE

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Abstract. *Background: Changing the individual dose limit for the lens of the eye from a value of 150 mSv per year to a level of 20 mSv (averaged over defined periods of five years or 50 mSv in a single year) means that issues related to routine eye lens dosimetry become interesting from the point of view of radiation protection. This could mean that the dosimeter designed to measure the doses at the level of the eye lens may become the next dosimeter routinely worn by nuclear medicine workers occupationally exposed to ionising radiation. The dosimeters currently used in nuclear medicine are the personal dosimeter and the ring dosimeter. Will this also be the case for nuclear medicine employees? In this interdisciplinary branch of medicine, the factors that cause the highest risk of radiation exposure of personnel are the process of manual handling, i.e. the process of preparing a radiopharmaceutical called labelling. Most of the radiopharmaceuticals used in nuclear medicine are labelled manually. In Poland, the exception from this rule is when radiopharmaceuticals are produced for the needs of positron emission tomography (PET), which are labelled using automatic processes. Manual procedures also include the process of radiopharmaceutical injection to the patients. The aim of the work was to assess the exposure of eye lenses of workers in nuclear medicine, as well as of the personnel in centers that produce radiopharmaceuticals for PET diagnostics, from the viewpoint of advisability of routine eye lens exposure monitoring, taking into account changes in the dose limit for the lens of the eye.* Methods: *The results of own measurements of the personal dose equivalent Hp(3), carried out in five nuclear medicine departments in Poland, as well as in two centers producing radiopharmaceuticals for PET, were subject to analysis. The analysis includes two most frequently used radionuclides for diagnostic purposes, namely ^{99m}Tc, ^{18}F and the less frequently used ^{68}Ga, in addition to ^{131}I, which is used for therapeutic purposes. Dosimetric measurements were made using thermoluminescent detectors of domestic manufacture. Results & Conclusions: Estimated analysis of the annual exposure makes it possible to indicate cases where the maximum annual value of personal dose equivalent, in terms of Hp(3), exceeds threefold the new limit value specified at 20 mSv/year.*

Keywords: *Dose limit, dosimetry, eye lens, Hp(3), nuclear medicine, radionuclide, radiopharmaceutical*

1. INTRODUCTION

The discussion about the exposure received by eye lenses of workers occupationally exposed to ionising radiation has been going on for some time already. Its origin is largely associated with radiobiological aspects and thus with the deterministic effects that ionising radiation is able to induce at the cellular level in the lens of the eye. We are talking here about the cataract. In the present International Commission on Radiological Protection (ICRP) approach, cataract induction is a deterministic effect with a definite threshold. This threshold is between 2 and 10 Gy for acute exposure, and 8 Gy for prolonged exposure [1]. Interventional radiology is the reason for interest in the exposure of the eye lenses of workers occupationally exposed to ionizing radiation. This interest, however – if only due to the dose reduction for the eye lens recommended by ICRP [1] – propagates to other medical branches where ionizing radiation is used, and in particular to nuclear medicine. What makes nuclear medicine special is the form of the radiation source. It uses the so-called open radiation sources in the form of radiopharmaceuticals, which are a combination of a radioactive isotope with a non-radioactive chemical compound. This specific chemical hybrid often requires a complicated process of radionuclide production; the procedure of labeling a chemical compound with a manufactured radionuclide itself requires many complex, often manual, activities. Since most procedures in the field of nuclear medicine are performed manually, the exposure of personnel who perform the procedures using radiopharmaceuticals becomes interesting not just from the point of view of exposure of hands or the whole body, but of eye lenses as well. It should be remembered that the personnel employed in nuclear medicine are covered by individual dosimetry, where the dose is measured on the skin of the hands using a ring dosimeter. The second dosimeter makes it possible to assess the effective dose. However, would the reduction of the

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dose limit to the eye lens from 150 mSv/year [2] to 20 mSv per year [1, 3-5] mean the necessity of routine application of another dosimeter measuring doses to the eye lens? An attempt to answer this question requires consideration of several issues, including shields against ionizing radiation used in nuclear medicine facilities and centres producing radiopharmaceuticals (CPR) for positron emission tomography (PET). In some nuclear medicine facilities, workstations designed for work with radionuclides are made of lead bricks supplemented in the upper part with a lead glass window. Radiological protection provided by such shields reduces the dose rate of ionizing radiation to the body or to the head (sheltered body parts) by a factor up to 10^8 [6]. Often, special full-protective laminar chambers are also used, adapted to work with radioactive isotopes. In the case of short-lived radionuclides dedicated to the PET technique, their production was largely automated. Another element that may affect the level of personnel exposure is the type of radioactive source used – the radionuclide. In nuclear medicine, a wide range of radioactive nuclides is used, of which ^{99m}Tc, ^{18}F are the most commonly used ones in Poland [7]. In the case of therapy, ^{131}I is used [8]. Within this context, the ^{68}Ga radionuclide is interesting, which is among less frequently used radionuclides, but the degree of complexity in obtaining a radiopharmaceutical labeled with this radionuclide may be of some significance in the assessment of staff exposure. And so the complexity of procedures and manual performance of activities aimed at obtaining radiopharmaceuticals can be reflected in the values recorded by the dosimeter. In this respect, among the above-mentioned radionuclides, the most complicated fully manual process of obtaining the labels themselves concerns generator-originated radionuclides – ^{68}Ga and ^{99m}Tc. In the case of ^{18}F, the production of the label is automated, however manual processes include quality control of labeled fluorodeoxyglucose (^{18}F-FDG).

The aim of the work was to assess the exposure of eye lenses of workers in nuclear medicine, as well as of the personnel in centers that produce radiopharmaceuticals for PET diagnostics, from the point of view of advisability of routine eye lens exposure monitoring, taking into account the changes in the dose limit for the lens of the eye.

2. Materials and methods

In order to measure the doses, high-sensitivity thermoluminescent detectors (TLD), made of lithium fluoride produced in Poland (LiF: Mg, Cu, P – MCP-N), were used. The detectors were calibrated in the Second Standards Laboratory in the Nofer Institute of Occupational Medicine in Łódź. For this purpose, a source of gamma radiation was used – ^{137}Cs (^{60}Co/^{137}Cs irradiator). During the calibration process, we also used *X* radiation generated at 150 kV voltage and additional filtration of 2.5 mm tin. The detectors have been calibrated in accordance with ISO 4037-1 [9] and ISO 4037-3 [10] in kerma units in the air from 0.05 mGy to 30 mGy. Corrections resulting from the differences between the energy of radiation emitted during the calibration exposure and the gamma radiation energy emitted by individual isotopes were taken into account. The conversion factor $H_p(3)$ was obtained by approximating the $H_p(3,0°)/K$ coefficients obtained in the photon energy range from 0.01 MeV to 10 MeV, determined by Vanhavere et al [11, 12]. A 20 cm cylinder was also used. The thermoluminescent detectors were read using a RA'04 reader (Poland) and Fimel (France). The detectors were subjected to a typical annealing process in a PTW-Freiburg oven so that they could be reused in subsequent measurements. During the measurements, the detectors were placed within hoops worn by the staff at the height of the eyebrows in such a way that the TL detector was located directly above the appropriate lens of the eye.

Statistical analysis to compare the left and right eye dosimeters on each person was performed with the Mann—Whitney test using STATISTICA v. 10.0.MR1. Any differences found were considered statistically significant if the p-value was below 0.05.

3. Results and discussion

Figure 1 presents the $H_p(3)/A$ values recorded during procedures performed by personnel using the four different radionuclides.

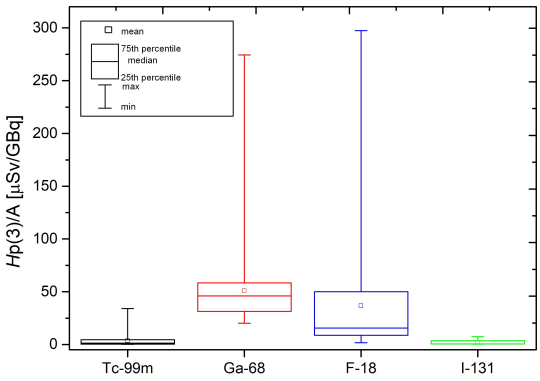

Figure 1. $H_p(3)/A$ values recorded during procedures performed with the following radionuclides: ^{99m}Tc, ^{68}Ga, ^{18}F, and ^{131}I.

Figure 1 shows the range of possible $H_p(3)/A$ values recorded by the detectors responsible for measuring the personal eye dose equivalent. The data are particularly interesting for two radionuclides – ^{68}Ga and ^{18}F. Both radionuclides are used for diagnostic purposes, but their production method is different. The ^{68}Ga is a radionuclide from a ^{68}Ge/^{68}Ga generator while ^{18}F is a typical representative of the short-lived radionuclides produced using a cyclotron device. Despite the automated production process of the ^{18}F marker, the manually performed quality control procedures of the fluorodeoxyglucose (^{18}F-FDG) and the ^{18}F-FDG injection process caused the maximum $H_p(3)/A$ values recorded by TL detectors to be potentially close to 300 mSv/GBq. Not much less –

about 280 mSv/GBq – TL detectors registered in the case of procedures performed with ^{68}Ga radionuclide. Less complicated manual procedures carried out by the personnel with the ^{99m}Tc radionuclide – a representative of a group of radionuclides from the short-lived radionuclides generator (^{99}Mo/^{99m}Tc) – resulted in a maximum *H*p(3)/A value of 34 mSv/GBq. In practice, procedures with the use of ^{131}I radionuclide in the form of sodium iodide focus on the ^{131}I unpacking process and measuring the activity of the capsule containing said ^{131}I, hence the last item in the category of TLD-registered values with a maximum *H*p(3)/A value of just over 7 mSv/GBq.

In Poland, a dosimeter measuring the personal eye dose equivalent *H*p(3) has been commercially available for some time. However, it allows dose-measuring only in one position. Therefore, if this dosimeter is to be used in the routine measurement of the dose on the eye lens, will the exposure characteristics of the left and right eye lens of employees in nuclear medicine facilities and radiopharmaceutical production centers be the same or similar? Figure 2 shows the mean *H*p(3)/A (with standard deviation) values recorded by TL detectors placed above the left and right lens of the eye during procedures using the four different radionuclides.

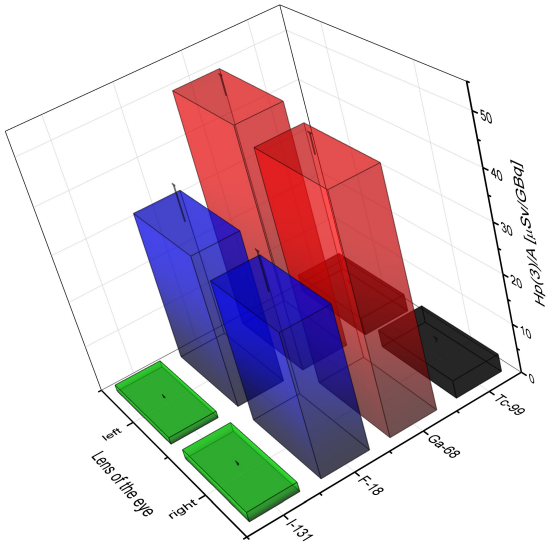

Figure 2. Mean *H*p(3)/A values with standard deviation recorded by thermoluminescent detectors placed over the left and right lens of the eye during the procedures using radionuclides: ^{99m}Tc, ^{68}Ga, ^{18}F, ^{131}I.

Figure 2 shows that even if differences between the *H*p(3)/A values for the left and right eye lens exist, they become apparent only during a detailed statistical analysis involving a comparison of *H*p(3) dose distributions, taking into account the employment structure in a given nuclear medicine facilities and procedures performed [13-15].

Another factor that can affect the level of exposure of the eye lens of personnel of nuclear medicine facilities and centers of production radiopharmaceuticals based on short-lived isotopes is the complexity of procedures performed and the fact that the vast majority of activities that result preparing of radiopharmaceuticals are done manually. Figure 3 presents the percentage of activities performed by staff in the total value of *H*p(3) obtained during the preparation and injection of radiopharmaceuticals based on four radionuclides.

When analyzing the impact of procedures performed by the staff, it should be remembered that each radiopharmaceutical being prepared sometimes requires extremely different procedures, including the production of the radionuclide marker. Whenever the time of contact with the radioisotope is short which may be associated with a small interference of the employee in some of the production processes or preparation of the radiopharmaceutical, which occurs, e.g. during the ^{99}Mo/^{99m}Tc generator elution process or unpacking ready-to-administer capsules of sodium iodide, the percentage of these activities in the total dose reaches a maximum of a few percents.

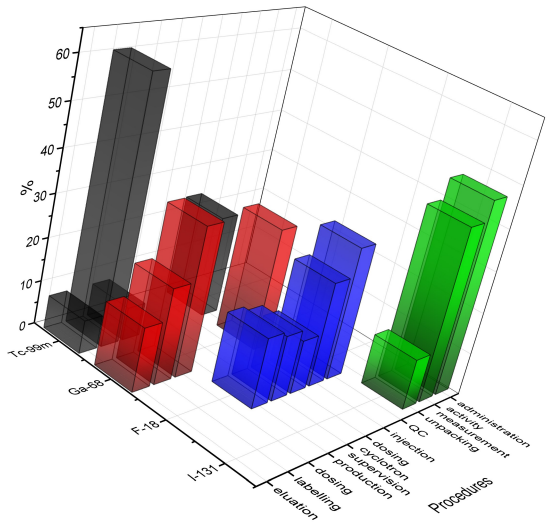

Figure 3. Percentage of activities performed by the personnel in the total dose of *H*p(3) received during the preparation and injection of radiopharmaceuticals based on ^{99m}Tc, ^{68}Ga, ^{18}F, ^{131}I radionuclides.

Wherever a sufficiently long time is required that the employee must devote to the proper preparation of radiopharmaceuticals, such as: the labelling process of radiopharmaceutical with ^{99m}Tc, dispensing the doses of ^{68}Ga-DOTA-TATE for patients or ^{18}F-FDG quality control procedure; the percentage of these activities in the total dose is within the range of less than 40% to close to 55%.

The provision of EU Directive 2013/59/EURATOM [16] obliged Poland, by February 6, 2018, to amend the national law regarding the limit value of ionizing radiation doses, so that the value of the limits corresponds to those contained in the directive (in particular, it concerns eye lenses). Unfortunately, at the time of preparing this work, this change has not yet been legally implemented. Nevertheless, a 7.5-fold

limitation of the dose limit value, which sooner or later must be reflected in legal provisions, may mean for employees, regardless of the specifics associated with the form or type of source emitting ionizing radiation, the need to monitor the value of doses for eye lenses. It is, therefore, important from this point of view to estimate the annual exposure of the eye lens of employees occupationally exposed to ionizing radiation in nuclear medicine centers using ^{99m}Tc, ^{18}F, ^{68}Ga and ^{131}I radionuclides.

The annual Hp(3) was estimated assuming the worst-case scenario: 260 days of work during the year and that all procedures involving the radionuclide are performed by one employee [14, 15]. Figure 4 presents the maximum estimated annual Hp(3) of personnel of nuclear medicine departments and facilities producing radiopharmaceuticals for use in PET, taking into account the current dose limit for the lens of the eye of 150 mSv per year and the new one at 20 mSv/year.

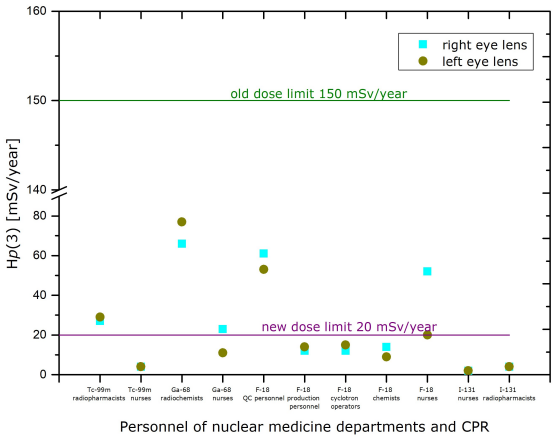

Figure 4. Annual *H*p(3) estimates for the personnel of nuclear medicine departments and the personnel of laboratories producing radiopharmaceuticals for use in PET.

4. Conclusion

Nuclear medicine comprises a variety of radionuclides used, medical procedures, but also a wide spectrum of professional groups involved in working with ionizing radiation. All this means that in the case of nuclear medicine, the need for routine dosimetry of eye lenses of employees of nuclear medicine facilities and radiopharmaceutical production units for positron emission tomography is difficult to determine. Detailed studies carried out, taking into account both the procedures performed by employees and the professional structure of individual facilities, make it possible to indicate the procedures and professional groups that will require more attention from radiological protection inspectors in the near future and where routine monitoring of personal eye dose equivalent Hp(3) is recommended as a pro-optimization procedure. This situation occurs when working with the ^{99m}Tc radionuclide and applies to chemical compounds labelled with this radionuclide and chemists from the quality control departments at ^{18}F-FDG production units. The recommendation for routine monitoring of personal eye dose equivalent Hp(3) also includes radiochemists during the dispensing of the doses of ^{68}Ga-DOTA-TATE for patients. In other cases, the recommendation for the procedures for control of personal eye dose equivalent Hp(3) will be the responsibility of the radiation protection inspector.

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