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# EXPOSURE TO IONIZING RADIATION OF MEDICAL STAFF PERFORMING VASCULAR AND INTERVENTIONAL RADIOLOGY PROCEDURES

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**Abstract**
**Objectives:** Vascular and interventional radiology procedures are characterized by high exposure of personnel to ionizing radiation. This study assessed the exposure of medical personnel to ionizing radiation during vascular radiology and mechanical thrombectomy procedures. **Material and Methods:** During vascular radiology procedures, the exposure of 4 groups of workers participating in the procedures was analyzed, i.e., the main operating physician, an assistant physician, a sterile nurse, and a nurse. Measurements of exposure to ionizing radiation were performed using thermoluminescent dosimetry. **Results:** The registered effective dose during 1 treatment in individual groups is, respectively: mean (M) ± standard deviation (SD) 75±15 μSv, 24±5 μSv, 13±3 μSv, and 8±2 μSv. During mechanical thrombectomy, the operating physician receives an effective dose of M±SD 9±2 μSv. The equivalent doses for the lenses for the operating physician and the doctor assisting during vascular radiology procedures are M±SD 1419±285 μSv and 987±198 μSv, respectively, and for the hands, including the left and right hands, M±SD 4605±930 μSv, 1420±284 μSv, 1898±380 μSv, 1371±274 μSv. **Conclusions:** If the principles of optimizing radiological protection are not applied during vascular radiology procedures, the permissible dose limits and operational limits equivalent to doses to lenses and hands may be exceeded. Exposure during vascular radiology procedures is comparable to exposure during nuclear medicine procedures in terms of the use of glucose labeled with radioactive fluorine. Int J Occup Med Environ Health. 2024;37(4):403–10

**Key words:**
**interventional radiology, effective dose, radiological protection, leukemia, probability of induction of leukemia, vascular radiology**

## INTRODUCTION

Vascular and interventional radiology procedures are characterized by some of the highest doses received by the medical personnel involved [1–6]. Particularly procedures in the field of vascular radiology, due to the long procedure time, pose a significant radiological threat both to medical staff and to treated patients. The use of ionizing radiation in this type of procedure is necessary due to the need to visualize the area of implantation of stent grafts or other elements placed in the patient's blood vessels. These procedures are

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usually quite technically complicated and require extensive experience and skill in the implantation of stengrafts from the operating doctor. The complexity of the procedure results in a long exposure time to ionizing radiation, which in turn results in a significant increase in exposure to, in particular, the operating doctor and the patient [7]. An important element of the safe implementation of vascular and interventional radiology procedures is the use of appropriate radiological equipment such as modern angiographs or C-arm X-ray machines and the application of basic principles of radiological protection by medical staff. A proper assessment of the exposure of medical personnel participating in this type of medical procedure should include an analysis of the employee's exposure to the entire body, eye lenses, and hands; which is the highest in the case of these medical procedures. The obtained results should be analyzed reliably and precisely, and the conclusions obtained should contribute to increasing radiological safety and optimizing medical procedures in terms of exposure to ionizing radiation. In this study a detailed analysis of both the exposure of medical workers participating in vascular and interventional radiology procedures as well as the health hazard was performed.

## MATERIAL AND METHODS

Highly sensitive thermoluminescent detectors (TLDs) type MCP-N (Radcard, Kraków, Poland) were used to assess the exposure of workers performing procedures in the field of vascular and interventional radiology [8–11]. Calibration of the whole-body, lens, ring, and wrist dosimeters was performed by the accredited procedure used at Nofer Institute of Occupational Medicine (NIOM), Łódź, Poland, for routine individual dose measurements, i.e., on slab, head, rod, and pillar phantoms in Hp(10), Hp(3), Hp(0.07) units, respectively for the ISO N-80 reference energy spectrum [12]. An overall 20% measurement uncertainty was estimated, and it is mainly due to the energy dependence of TLDs.

Measurements were performed in a procedure room equipped with an Allura Xper FD20 angiograph from Philips (Amsterdam, The Netherlands). Exposure was assessed for medical personnel participating in vascular and interventional radiology procedures. The first group of people analyzed was personnel participating in vascular radiology procedures involving the implementation of stengrafts in the abdominal cavity, including branched stengrafts [13]. In terms of the implementation of stengrafts, medical personnel participating in 10 procedures of this type were analyzed. The following subjects were measured: the main operating physician, the assistant physician, the sterile nurse, and the auxiliary nurse. The anesthesiologist present in the procedure room was not subject to exposure control because he leaves the radiology room during exposure to ionizing radiation. Doctors participating in the procedure were equipped with whole-body dosimeters placed at the heart level on and under the protective apron, EYE-D dosimeters, wrist dosimeters, and ring dosimeters placed on the index finger of the right and left hand.

The second group of analyzed people consisted of personnel participating in the mechanical thrombectomy procedure performed for the treatment of ischemic strokes [14]. For thrombectomy procedures, the exposure analysis was conducted for the doctor performing the procedure and the assisting nurse. As it turns out during the measurements, the nurse receives doses below the detection threshold of TLDs during one thrombectomy procedure and therefore was excluded from the exposure analysis. The doctor participating in the procedure was equipped with a whole-body dosimeter placed on and under the protective apron, an EYE-D dosimeter, a wrist dosimeter, and a ring dosimeter placed on the index finger of the right hand. Ten mechanical thrombectomy procedures were analyzed. To assess the annual exposure to ionizing radiation, it was assumed, based on the analysis of working time in the radiology laboratory, that each person belonging to the analyzed employee groups participates in treatments using ionizing radiation a maximum of twice a week. This means that each employee participates in 96 treatments using ionizing radiation a year. This number applies to both vascular radiology and thrombectomy procedures. Personnel participating in medical procedures in the field of vascular and interventional radiology are equipped with various types of protective aprons with a lead equivalent of min. 0.5 mm.

Based on the Biologic Effects of Ionizing Radiation (BEIR) VII report [15], the risk of leukemia and other cancers, as well as the risk of death from this cause, was analyzed in the examined medical personnel as a result of receiving a whole-body dose during vascular and interventional radiology procedures. These estimates are obtained as combined estimates based on relative and absolute risk transport and have been adjusted by a dose-rate effectiveness factor of 1.5, except for leukemia, which is based on a linear-quadratic model. In the probability calculations, it was assumed that men work in the age 25–65 years, and women – 25–60 years.

The statistical analysis of the results obtained in this work was performed using Statistica 13.1 software. The statistical tool used to compare 2 groups of results is the Student's t-test. The Pearson's r correlation coefficient and its statistical significance were determined. The significance level adopted was $\alpha = 0.05$, therefore $p < 0.05$ confirms the statistical difference between the tested samples. The uncertainty of measuring dose levels determined using TLDs is the standard uncertainty.

The study was conducted by the Declaration of Helsinki and approved by the Bioethical Commission of the Medical University.

## RESULTS

Tables 1 and 2 present the results of average doses per procedure for different dosimeter locations and for various professional groups participating in vascular radiology procedures. Table 1 shows the doses to the whole body measured under the apron and on the protective apron, and the doses to the lenses while Table 2 contains dose values measured on the hands using both ring (left and right hand) and wrist dosimeters. Due to the relatively large spread of doses measured during the ten analyzed treatments, the minimum and maximum values of the registered doses are also provided.

Table 3 shows the average exposure doses of the radiologist during the mechanical thrombectomy procedure: for the whole body measured under and on the protective apron, for lenses and hands, measured using 2 types of dosimeters.

**Table 1.** Individual whole body dose values measured under and on the protective apron ($WB_{under}$ and $WB_{over}$, respectively) and dose values for lenses (EYE-D) are divided into 4 groups of workers participating in vascular radiology procedures, in a procedure room equipped with the device with an Allura Xper FD20 angiograph, 2023, Poland

| Occupational group | Ionizing radiation dose [μSv] (M±SD (max-min.)) | | |
|---|---|---|---|
| | whole body | | lenses (EYE-D) |
| | $WB_{under}$ | $WB_{over}$ | |
| Main operator doctor | 75±15 (280–10) | 1907±381 (5631–262) | 494±99 (1580–93) |
| Assistant doctor | 24±5 (83–11) | 1005±201 (3189–9) | 461±92 (1080–92) |
| Sterile nurse | 13±3 (15–8) | 128±26 (471–9) | 63±13 (193–8) |
| Nurse | 8±2 (11–6) | 19±4 (38–7) | 17±3 (39–6) |

**Table 2.** Hand dose values are divided into 4 groups of workers participating in vascular radiology procedures, in a procedure room equipped with the device with an Allura Xper FD20 angiograph from Philips, 2023, Poland

| Occupational group | Ionizing radiation dose [μSv] (M±SD (max-min.)) | | |
|---|---|---|---|
| | wrist dosimeter | ring dosimeter | |
| | | left | right |
| Main operator doctor | 987±202 (2204–109) | 4605±930 (12 176–669) | 1420±284 (3561–287) |
| Assistant doctor | 1419±286 (3432–43) | 1898±380 (4600–77) | 1384±277 (5584–10) |
| Sterile nurse | 85±17 (276–11) | – | 146±26 (280–84) |
| Nurse | 15±3 (31–7) | – | 92±17 (100–87) |

**Table 3.** Exposure of a radiologist during mechanical thrombectomy, in a procedure room equipped with the device with an Allura Xper FD20 angiograph, 2023, Poland

| Measurement point | Ionizing radiation dose [μSv] (M±SD (max-min.)) |
|---|---|
| Whole body | |
| $WB_{under}$ | 9±2 (13–6) |
| $WB_{over}$ | 63±14 (154–9) |
| Lenses (EYE-D) | 115±26 (225–24) |
| Wrist dosimeter | 137±30 (357–6) |
| Right ring dosimeter | 66±13 (189–11) |

$WB_{over}$ – whole body on the protective apron; $WB_{under}$ – whole body under the protective apron.

Based on the measured doses in Table 4, the annual exposure of the analyzed workers was calculated, assuming that they would receive, on average, the doses shown in Tables 1–3 in each procedure. In the case of exposure to hands, exposure values were averaged from measurements for the right and left hands.

Medical personnel performing procedures in the field of interventional radiology are, by law, subject to individual dosimetry. Table 5 shows the information on individual whole body and hand doses of physicians performing vascular radiology procedures as it was measured for the routine individual monitoring. The doses presented cover the year in which the measurements for this study

**Table 4.** Annual exposure of workers calculated based on the doses presented in Tables 1–3, 2023, Poland

| Occupational group | Ionizing radiation dose [mSv/year] (M±SD) | | | |
|---|---|---|---|---|
| | $WB_{under}$ | hands | wirst | lens |
| Vascular procedures | | | | |
| main operator doctor | 7.2±1.4 | 289.2±57.8 | 68.1±13.6 | 47.4±9.5 |
| assistant doctor | 2.3±0.5 | 156.9±31.4 | 136.2±27.2 | 38.7±7.7 |
| sterile nurse | 1.3±0.3 | 14.0±2.8 | 8.2±1.6 | 6.0±1.2 |
| nurse | 0.8±0.2 | 8.8±1.8 | 1.4±0.3 | 1.6±0.3 |
| Mechanical thrombectomy | | | | |
| main operator doctor | 6.0±1.2 | 6.3±1.3 | 13.2±2.6 | 11.0±2.2 |

$WB_{under}$ – as in Table 3.

were made. Table 5 does not present the exposure of nurses and doctors performing mechanical thrombectomy procedures because these medical personnel also participate in other types of radiological procedures.

Tables 6 present the probability of induction and death from leukemia and other cancers as a result of receiving doses in the analyzed medical procedures. The values presented in the tables indicate the number of cases per 100 000 people. In Table 6, the probabilities were calculated for professional groups participating in vascular radiology procedures and mechanical thrombectomy procedures. The results were obtained based on calculations performed using BEIR VII report [15], i.e., tables 12D-1 and 12D-2.

**Table 5.** Annual values of effective dose and equivalent doses to the hands of physicians performing vascular radiology procedures, 2023, Poland

| Physician No. | Ionizing radiation dose [mSv/year] | |
|---|---|---|
| | effective | equivalent for hands[a] |
| 1 | 0 | 1.55 |
| 2 | 0 | 0.19 |
| 3 | 0 | 0.26 |
| 4 | 0.37 | 111.40 |
| 5 | 2.09 | 148.96 |
| 6 | 0.20 | 45.62 |
| 7 | 4.99 | 19.62 |
| 8 | 0 | 0.21 |
| 9 | 0.49 | 134.56 |
| 10 | 0 | 0.05 |
| 11 | 1.22 | 30.52 |
| 12 | 0 | 0.20 |
| 13 | 0 | 0.14 |
| 14 | 0 | 0.47 |
| 15 | 0 | 0.12 |
| 16 | 0 | 0.27 |
| 17 | 0.45 | 7.82 |
| 18 | 5.80 | 10.42 |

Zero indicates that the dose was below the lower detection limit which is 0.10 mSv.
[a] Ring dosimeters.

## DISCUSSION

Analyzing the average whole body doses for a single interventional radiology procedure, it can be concluded that the main operating physician is most exposed during the procedure which is not a surprise as he/she stands closest to the X-ray tube and the operating field. The assistant doctor receives a dose that is more than 3 times lower. Nurses participating in the procedure receive on average 9 times lower doses than the main operating doctor. When assessing lens exposure in physicians participating in vascular radiology procedures, no significant difference in lens dose is observed between the primary physician and the assistant physician. The difference between the assistant doctor and the main operating doctor is approx. 7%. In the case of the nurses, the differences in doses in reference to the main operator are much greater (nurses doses 8-fold and 29-fold lower than for the main operator).

Analyzing hand exposure among personnel participating in vascular radiology procedures, it is clear that regardless of the limb (right or left hand), the greatest exposure is observed among the main operating physician. In the case of sterile nurses, there is a 10-fold decrease in the dose to the hands compared to the main operating doctor, regardless of the dosimeter used. For doctors, higher readings were recorded on the left hand. The correlation between the reading from the detector placed on the ring of the right hand and the band placed on the right wrist in doctors is $r = 0.75$ ($p = 0.003$). In the case of the same dosimeters placed on the nurses' limbs, the correlation coefficient was $r = 0.98$ ($p = 0.000$).

The average area doses (dose area product – DAP) in vascular radiology and mechanical thrombectomy procedures are 757 076 mGy/cm$^2$ and 118 253 mGy/cm$^2$, respectively. This 84% decrease in DAP in mechanical thrombectomy procedures translates into an 88% decrease in whole-body exposure for mechanical throm-

**Table 6.** Probability of induction and death from leukemia and other cancers resulting from receiving doses during vascular radiology procedures and mechanical thrombectomy procedures, 2023, Poland

| Risk | Cases [n] | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | vascular radiology procedures | | | | | | | | thrombectomy procedure – main operator doctor | |
| | main operator doctor | | assistant doctor | | sterile nurse | | nurse | | | |
| | males | females | males | females | males | females | males | females | males | females |
| Of cancer incidence | | | | | | | | | | |
| leukemia | 247 | 160 | 79 | 51 | 43 | 28 | 26 | 17 | 206 | 134 |
| all cancers | 1794 | 2271 | 573 | 725 | 311 | 394 | 192 | 243 | 1495 | 1892 |
| Of cancer mortality | | | | | | | | | | |
| leukemia | 204 | 137 | 65 | 44 | 37 | 24 | 22 | 15 | 170 | 114 |
| all cancers | 1066 | 1298 | 341 | 415 | 185 | 225 | 114 | 139 | 889 | 1082 |

bectomy physicians relative to the primary operating physician in vascular radiology procedures. A significant decrease in the DAP value in the types of procedures examined also results in a significant decrease in exposure to the lenses and hands of operating physicians. The reduction in lens dose in the thrombectomy procedure is 75% and in the case of hand dose, it is 96% in primary care physicians. In the case of doctors performing mechanical thrombectomy, the correlation coefficient of readings from the right ring and wrist dosimeters is $r = 0.92$ ($p = 0.000$), with a statistically significant correlation between the readings.

When analyzing the annual exposure of workers presented in Table 4, particular attention is paid to the exposure of hands and lenses of doctors who perform procedures in the field of vascular radiology. These values exceed the permissible dose limits. However, attention should be paid to the very high variability of exposure during various types of vascular radiology procedures. For the main operating physician, doses to the lenses recorded in the 10 analyzed procedures range 93–1580 μSv, and for the assistant physician 92–1080 μSv. Hand doses measured for the primary physician were in the range of 478–7869 μSv and for the assistant physician in the range of 44–5092 μSv. Therefore, considering the minimum doses measured during the analyzed treatments, annual dose limits are not exceeded. Moreover, this high variability of doses observed in both wide ranges and coefficients of variation of doses indicates that it is rather unlikely. This fact is confirmed by Table 5, which presents the annual exposure of workers based on individual dosimetry. On an annual basis, we do not see any exceedances of dose limits. Not all treatments performed by doctors involve long exposure times and, therefore, increased levels of doses received. The values obtained from the measurements are average values that are obtained during the procedure. It should be remembered that the employees of the vascular surgery department often rotate during procedures to reduce the doses received, which means that during the year the doctor performs much <96 procedures included in the calculations. Doctors also rotate in terms of position during the procedure – sometimes they are the main operating doctors and sometimes they are assistant doctors. The introduction of appropriate work organization significantly reduces the exposure of individual employees to ionizing radiation.

Table 5 shows how important it is to use protective gowns during procedures. They significantly reduce the dose to the entire body. Compared to the values recorded during procedures on a protective gown (Tables 1 and 3), the effective dose values are significantly lower (Table 5). Measuring the dose on the gown allows you to estimate the dose in the lenses. By analyzing the obtained values, the relationship between the dose on the gown and under the gown and the doses in the lenses for doctors and nurses participating in vascular radiology procedures was determined. The correlation coefficients of the dose on the gown with the dose in the lenses and the dose under the gown with the dose in the lenses for physicians are $r = 0.97$ ($p = 0.000$) and $r = 0.86$ ($p = 0.000$), respectively. In the case of the group of nurses, the correlations are $r = 0.98$ ($p = 0.000$) and $r = 0.81$ ($p = 0.008$), respectively. A better correlation is observed between the readings between the dose recorded on the gown and the lenses, therefore, for a group of doctors and nurses, relationships were determined that allow calculating the dose in the lenses knowing the dose on the protective gown. For the group of doctors, this relationship is $D_{EYE} = 0.281 \times WB_{over}$, while for nurses it is $D_{EYE} = 0.428 \times WB_{over}$. The dosimeter, which is worn on the apron, allows you to determine the dose in the lenses with high accuracy.

The final element of the analysis of doses measured during procedures was the calculation of the probability of induction and death from leukemia and other cancers. The obtained values indicate that the calculated probabilities are at a similar level to those of employees performing medical procedures using glucose labeled with radioactive fluorine, i.e., employees performing activities involving open radioactive sources. Physicians in vascular radiology procedures have the probability of induction and death from leukemia and other cancers at the level of nurses administering a radioisotope to patients before a positron emission tomography (PET) scan and workers controlling the quality of radiopharmaceuticals. It should be strongly emphasized here that the exposure of medical staff performing procedures in the field of interventional radiology is at a similar level to that of staff performing quality control procedures for radiopharmaceuticals in nuclear medicine. Interventional radiology and nuclear medicine are basically 2 fields of medicine in which the exposure of medical personnel to ionizing radiation may significantly affect the health and life of medical staff. Therefore, the use of appropriately optimized medical procedures in these areas is important for reducing the doses of ionizing radiation received by medical workers and increasing occupational safety [16].

## CONCLUSIONS

The presented results show that among the analyzed vascular and interventional radiology procedures, the lowest exposure is observed during mechanical thrombectomy. The exposure of medical personnel during vascular radiology procedures is at a similar level to that during medical procedures using glucose labeled with radioactive fluorine. Without optimization of radiological protection consisting of appropriate rotation of personnel performing procedures using ionizing radiation, the permissible dose limits and operational limits assigned to the appropriate categories of exposure to ionizing radiation may be exceeded. Similarly, as it was in the mentioned above nuclear medicine procedures, the wrist dosimeter significantly underestimates the dose to the hand. However here, a preliminary correlation analysis shows that the results are promising, and an attempt can be made to estimate an appropriate correction factors.

**Author contributions**
**Research concept:** Michał Biegała
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**Interpretation of results:** Michał Biegała, Joanna Domienik-Andrzejewska
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**REFERENCES**


1. Mussmann B, Larsen TR, Godballe M, Abdi AJ, Kantsø A, Jakobsen AR, et al. Radiation dose to multidisciplinary staff members during complex interventional procedures. Radiography 2024;30(2):512-16. https://doi.org/10.1016/j.radi.2024.01.010.
2. Chida K, Kaga Y, Haga Y, Kataoka N, Kumasaka E, Meguro T, et al. Occupational dose in interventional radiology procedures. AJR Am J Roentgenol. 2013;200(1):138-41. https://doi.org/10.2214/AJR.11.8455.
3. Vano E, Fernandez-Soto JM, Ten JI, Sanchez Casanueva RM. Occupational and patient doses for interventional radiology integrated into a dose management system. Br J Radiol. 2023;96(1143):20220607. https://doi.org/10.1259/bjr.20220607.
4. Howells P, Eaton R, Patel AS, Taylor P, Modarai B. Risk of radiation exposure during endovascular aortic repair. Eur J Vasc Endovasc Surg. 2012;43(4):393-7. https://doi.org/10.1016/j.ejvs.2011.12.031.
5. Lipsitz EC, Veith FJ, Ohki T, Heller S, Wain RA, Suggs WD, et al. Does the endovascular repair of aortoiliac aneurysms pose a radiation safety hazard to vascular surgeons? J Vasc Surg. 2000;32(4):704-10. https://doi.org/10.1067/mva.2000.110053.
6. Haqqani OP, Agarwal PK, Halin NM, Iafrati MD. Minimizing radiation exposure to the vascular surgeon. J Vasc Surg. 2012;55(3):799-805. https://doi.org/10.1016/j.jvs.2011.08.055.
7. Geijer H, Larzon T, Popek R, Beckman KW. Radiation exposure in stent-grafting of abdominal aortic aneurysms. Br J Radiol. 2005;78(934):906-12. https://doi.org/10.1259/bjr/72629938.
8. Kron T, Lonski P, Yukihara EG. Thermoluminescence dosimetry (TLD) in medicine: five 'W's and one how. Radiat Prot Dosimetry. 2020;192(2):139-51. https://doi.org/10.1093/rpd/ncaa212.
9. Rivera T. Thermoluminescence in medical dosimetry. Appl Radiat Isot. 2012;71 Suppl:30-4. https://doi.org/10.1016/j.apradiso.2012.04.018.
10. Niewiadomski T, Bilski P, Budzanowski M, Olko P, Ryba E. Progress in thermoluminescent dosimetry for radiation protection and medicine. Nukleonika 1996;41(2):93–104.
11. Waligórski M P R, Lesiak J, Babula E, Byrski E, Ryba E, Olko P, et al. Application of individually calibrated solid LiF: Mg, Ti (MTS-N) detectors in clinical dosimetry. Radiat Prot Dosim. 1999;85(1–4):377-80.
12. International Organization for Standardization (ISO). X and gamma reference radiation for calibrating dosemeters and doserate meters and determining their response as a function of photon energy. Part 3: Calibration of area and personal dosemeters and the measurement of their response as a function of energy and angle of incidence. Geneva: ISO; 1999. International Standard ISO- 4037-3.
13. Kaatsch HL, Schneider J, Brockmann C, Brockmann MA, Overhoff D, Becker BV, Radiation exposure during angiographic interventions in interventional radiology – risk and fate of advanced procedures. Int J Radiat Biol. 2022;98(5):865-72. https://doi.org/10.1080/09553002.2021.2020362.
14. Pawłowski K, Dziadkiewicz A, Klaudel J, Mączkowiak A, Szołkiewicz M. Acute ischemic stroke treatment model for Poland in the mechanical thrombectomy era – which way to go? Adv Interv Cardiol. 2022;18(1):4-13. https://doi.org/10.5114/aic.2022.115269.
15. National Research Council of the National Academies. Health Risks from Exposure to Low Levels of Ionizing Radiation: BEIR VII Phase 2. Washington, DC: The National Academies Press; 2006:245.
16. Biegała M, Brodecki M, Jakubowska T, Domienik-Andrzejewska J. Evaluation of exposure to ionizing radiation of medical staff performing procedures with glucose labeled with radioactive fluorine – $^{18}$F-FDG. Nucl Eng Technol. 2024;56(1):335-9. https://doi.org/10.1016/j.net.2023.10.005.