

A hand phantom for radiological measurements

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Abstract The paper presents the construction of a hand phantom and its usefulness for radiological measurements. Situations when the hand is exposed to ionizing radiation stimulated the invention of this phantom. An extremity dosimeter was placed on the middle finger of the phantom. All measured doses are relative. The doses were compared with the dose from the extremity dosimeter. The aim of this paper was not to show values of the measured doses in legal units but the authors wanted to show the difference between the dose received by the extremity dosimeter and the doses measured on the inside of the hand phantom. High-sensitive LiF:Mg,Cu,P thermoluminescence detectors were used for the measurements because of their small size and close tissue equivalence. The hand phantom makes it possible to acquire the dose distribution on the inside of the hand. The authors suggested the calculation of the coefficients: the average hand phantom coefficient $C_{HPh_{AV}}$ and the maximum hand coefficient $C_{HPh_{\max}}$ from phantom measurements. The extremity dosimeter dose estimates according to the recommended coefficients allowed to obtain more reliable values.

Key words thermoluminescence dosimetry • TLD • radiological protection • phantom

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Introduction

It was soon recognized after X-rays discovery that the exposure to large doses of ionizing radiation can produce deleterious effects on the human body.

The patient during examination or therapy receives an exactly determined dose and both the applied radionuclide and its activity are known. However, limitation of radiation risk, in relation to the personnel, of X-ray, radioisotope laboratories and nuclear medicine departments assumes that the maximal permissible dose will not be exceeded. The exposure to ionizing radiation must be at the lowest possible level. Sometimes during direct contact with radiation sources the hands of the personnel are most exposed to radiation [4, 6, 7, 10, 14].

Postirradiation damage as a result of γ-radiation depends on the applied doses and the quality of radiation and partially depends on the region of the irradiated skin (places where skin adheres to bone and places with many perspiratory glands are most sensitive) [5]. Repeated irradiation, even with small doses, may induce heavy inflammatory reaction and trophic disturbances as a result of accumulated energy in the skin [2, 5].

For this reason, measurements of the absorbed dose are very important. Thermoluminescence dosimeters (TL) have been used for several years in dose rate measurements. TLD have unique features that make them useful in clinical dosimetry. Due to its high sensitivity for gamma radiation, tissue equivalence, low background, suitable energy dependence and long-term stability, the best material appears to be the LiF:Mg,Cu,P dosimeter. Its sensitivity is by 20 to 50 times higher than that of the LiF:Mg,Ti dosimeter and this is one of its most attractive features. The TLD dosimeter is a passive detector type because neither cables nor high voltage are required. Thus it is useful for personnel dosimetry, moreover it is essential for a variety of application in medicine. The most important application are *in vivo* dosimetry and measurements in anthropomorphic phantoms. It is the best detector for the assessment of skin dose, which is often difficult to predict [1, 11, 13, 16].

In diagnostic procedures, anthropomorphic phantoms can be used to relate operational quantities such as exposure or dose-area product to the absorbed dose in organs [8].

The aim of this paper was to show the dose distribution to the hand in simulated situations when the hand was exposed to irradiation and the difference between the dose from an extremity dosimeter and the doses measured on the inside of the hand. For this purpose, the hand phantom was constructed.

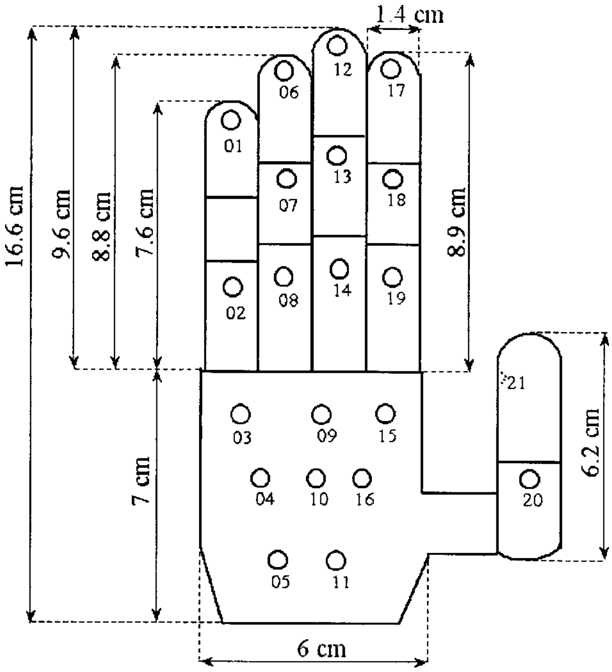


Fig. 1. Hand phantom dimensions and localization of the TL detectors on the hand phantom.

Experimental

The experiment consisted of three parts. The hand phantom was designed and constructed. Than using the phantom several radiological situations were simulated. Finally, the dose distributions graphs were calculated on the basis of the measurements related to the extremity dosimeter value.

The hand phantom construction

The hand phantom was designed and constructed to measure dose distribution to the hand (Fig. 1). It was constructed on the basis of the average female student hands.

The phantom was made of lucite (polymethyl methacrylate) with a density of 1180 kg/m^3. Lucite is a standard material for radiological phantoms. It contained no metal elements. The phantom reflected the palm, five fingers. The manual possibilities of the hand were reconstructed by plastic hinges. Four fingers were made of three phalanxes connected by hinges. The thumb was constructed of two phalanxes like the real hand. All fingers were connected with the palm by hinges, too. The hand phantom thickness was 1.5 cm.

21 hollows were made for TL detectors giving the possibility to measure dose distribution. The picture of the hand phantom, its dimensions and localization of TL detectors were presented in Fig. 1.

Method of TL measurements

The highly sensitive LiF:Mg,Cu,P thermoluminescence detectors made by the TLD POLAND, Cracow (trade name MCP-N type) were used in the experiment. The TL chips were 4.5-mm in diameter and 0.9 mm in thickness. They have been applied because of their small size and close tissue equivalence. The properties of MCP-N detectors and their application in practical measurements of doses in clinical measurements were described in [7].

All TL detectors were marked by symbols F01-F21. During the experiment, the detectors with exact numbers were placed exactly in the same place (Fig. 1). The detectors were individually calibrated at the Institute of Nuclear Physics (INP) in Kraków in the accredited calibration laboratory in terms of air kerma free-in-air by applying a reference 1 mGy gamma ray dose from a ^{137}Cs source. The detectors were subjected to calibration procedure in the hand phantom and in the extremity dosimeter, too. Every time before exposure to radiation all the detectors were annealed at 240°C in air for 10 min, next they were fast cooled on an iron block. After irradiation, the thermoluminescence spectra were taken by the use of a TL Ra-94 reader (MikroLab, Cracow, Poland). During the readout, the temperature was linear increasing with a 4°C/s gradient over the range 50–225°C. The GCANEW glow curve-analyzing program written by J. M. Gomez Ros and A. Delgado was used to calculate individual glow peak parameters [1]. This program determines the positions of peaks, areas under these peaks, corresponding energy and temperature. In analysis, the areas under the 5th peak were taken into consideration because of the most thermodynamic stability and the most sensitivity for ionizing radiation [3, 12].

Radiological measurements

The aim of the experiment was to measure the doses and their distribution to the hand in situations when the hand was exposed to radiation. During the exami-

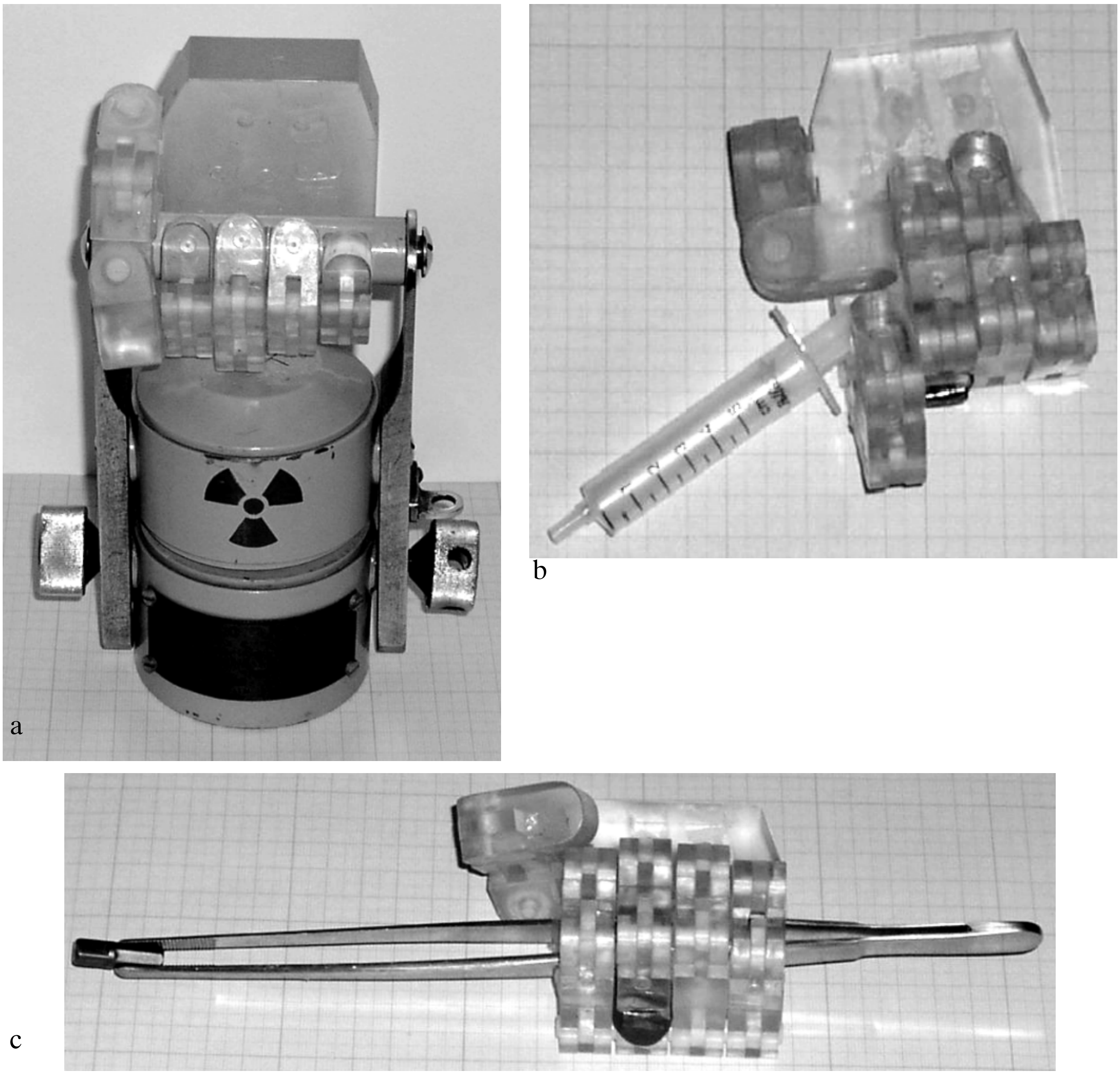


Fig. 2. Radiological situations simulated in the experiment: a – the hand phantom on the handle of lead container; b – a syringe in the hand phantom; c – tweezers with the Co-60 source in the hand phantom.

nations, the most frequent situations when the medical personnel is exposed to ionizing radiation were simulated with the use of the hand phantom. Besides, the extremity dosimeter was applied and placed on the middle finger where it is usually worn in radiation protection measurements [7, 17].

The hand phantom was tested with two typical lead containers made in POLON which are used to transport of radionuclides in radiological laboratories [15]. The Co-60 source was placed inside the container and the hand phantom with the thermoluminescence detectors and the extremity dosimeter was placed on the handle of container. This is shown in Fig. 2a.

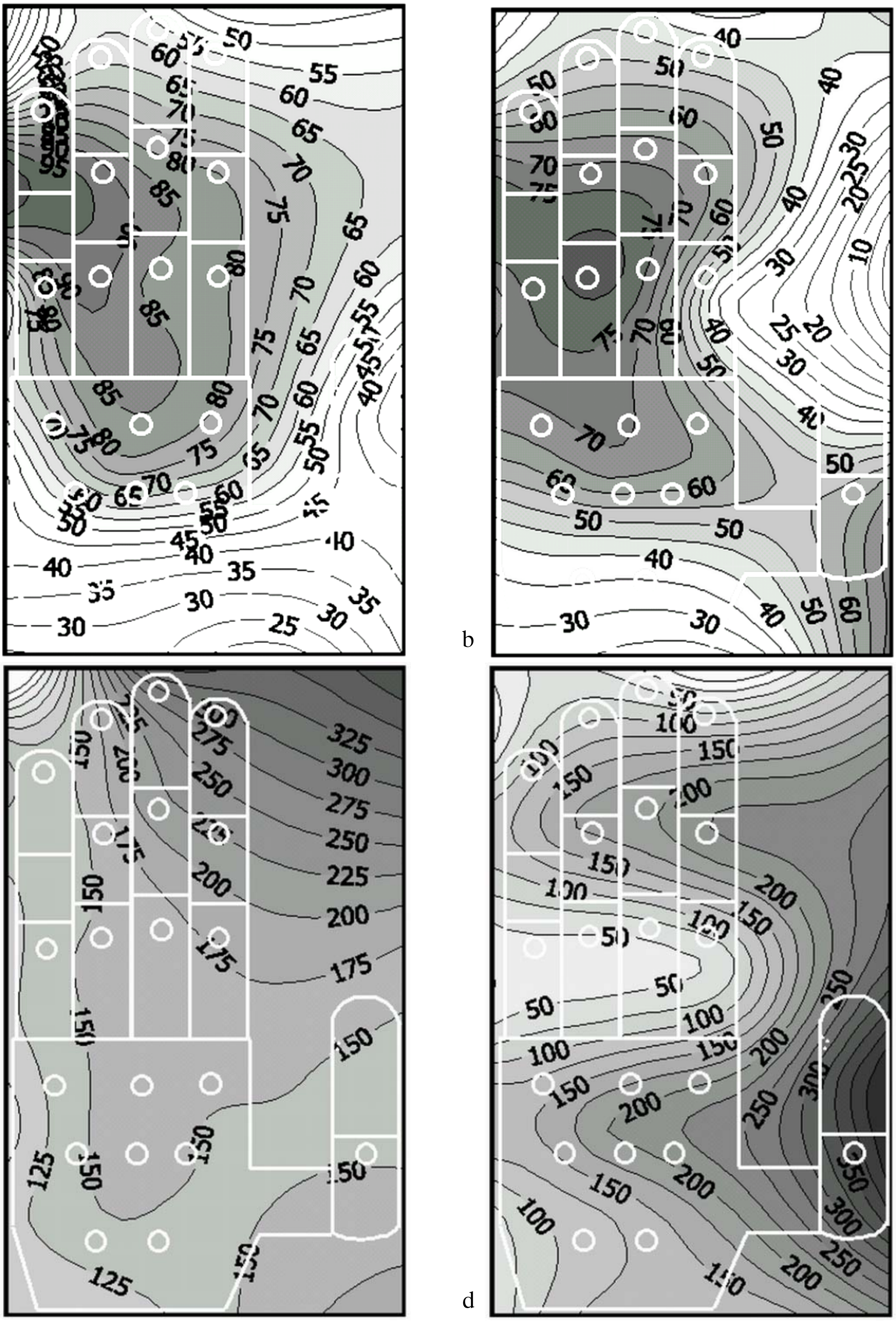
A situation when a radioisotope is administered intravenously to the patient was also simulated. To this end, the Co-60 source was inserted in a syringe and then the syringe was placed in the hand phantom. Fingers of the hand phantom were arranged like in the real hand holding the syringe as presented in Fig. 2b.

Another simulated situation was the insertion of the radioactivity source in to tweezers. The tweezers were placed in the hand phantom and the Co-60 source were caught by them as presented in Fig. 2c.

The Co-60 source was applied in all simulated situations to simplify the discussion about measurements results.

Result and discussion

The radiation doses were applied to 21 measurement points placed inside of the hand phantom and the dose measured by the extremity dosimeter for all simulated situations. The dose distribution on the hand phantom was compared with the dose from the extremity dosimeter that latter showing the dose only in one point outside of the hand. To show the results of experiment (strength of dose) the co-ordinates were assigned to all



a b c d

Fig. 3. The dose distribution to the hand phantom in radiological situations: a – transport of the Co-60 source in a lead container type L-20; b – transport of the Co-60 source in a lead container type L-35; c – a syringe with the C-60 source in the hand phantom; d – transport of the Co-60 source in tweezers.

detectors. The doses were normalised to the extremity dosimeter dose. All values from the hand phantom were converted to the proportional dose from the extremity dosimeter in the following formula:

$$D[\%] = \frac{D_{HPh}[Gy]}{D_{EXD}[Gy]} \cdot 100\%$$

where: D [%] – proportional dose; D_{HPh} [Gy] – dose value registered by the dosimeter in the hand phantom; D_{EXD} [Gy] – dose value registered by the extremity dosimeter.

On the basis of these values in all measurement points the dose distribution graphs were made using Surfer Program Version 6.01 (Surface Mapping System Copyright © 1993-95, Golden Software, Inc.). Surfer is a grid based contour program. Gridding is the process of using original data points (observations) to generate calculated data points on a regularly spaced grid. Interpolation schemes estimate the value of the surface at locations where no original data exists, based on the known data values (observations). Surfer then uses the grid to generate the contour map or surface plot. The "Kriging" method was used in gridding process. "Kriging" is the default gridding method because it generates the best overall interpretation of most data sets. This method uses a variogram to express the spatial variation, it also minimizes the error of predicted values which are estimated by spatial distribution of the predicted values. Graphs for all situations were presented in Fig. 3a–d.

When the Co-60 source was in the lead containers no detector in the hand phantom showed a dose higher than the extremity dosimeter. It is necessary to notice that in this case the extremity dosimeter was closer to the radiation source and it was most open to ionizing radiation.

While the syringe with the Co-60 source was in the hand phantom no dosimeter on the phantom showed a dose lower than the extremity dosimeter. The average dose registered by the dosimeters in the hand phantom was 165.1% of the extremity dosimeter dose.

In the experiment with the Co-60 source in the tweezers nine dosimeters showed lower doses than the extremity dosimeter, but twelve dosimeters showed higher doses. The average dose registered by the dosimeters in the hand phantom was 136.9% of the extremity dosimeter dose.

It is needful to remember that there may be places on the hand receiving a higher dose than shown by the extremity dosimeter. If the situation is regular recurring the permissible dose in this places may be exceed.

The application of two coefficients was suggested which enable to get more reliable information from the extremity dosimeter measurement.

The first coefficient is the average hand phantom coefficient $C_{HPh_{AV}}$ in the following formula:

$$C_{HPh_{AV}} = \frac{\frac{1}{N}\sum_{i=1}^{N} D_i}{D_{EXD}}$$

where: $C_{HPh_{AV}}$ – average hand phantom coefficient; N – quantity of dosimeters in the hand phantom; D_i – dose value from the ith dosimeter, D_{EXD} – dose value from the extremity dosimeter.

Another coefficient is the maximum hand phantom coefficient $C_{HPh_{\max}}$ in the following formula:

$$C_{HPh_{\max}} = \frac{D_{i_{\max}}}{D_{EXD}}$$

where: $C_{HPh_{\max}}$ – maximum hand phantom coefficient; $D_{i_{\max}}$ – maximum dose value from the hand phantom dosimeter; D_{EXD} – dose value from extremity dosimeter.

According to these formulas, both coefficients were estimated and their values were included in Table 1.

Conclusion

The hand phantom makes it possible measurements of dose distribution in various radiological situations. The experiment showed that the standard method using the extremity dosimeter sometimes is not sufficient in radiological protection. It is necessary to remember that in some situations the extremity dosimeter may show the dose a few times lower than in some places inside of the hand.

Modern nuclear medicine is conducive to the use of new radiopharmaceutical preparations in diagnostics

Table 1. Results of the experiments with the hand phantom

	Transport of Co-60 source in lead container type L-20	Transport of Co-60 source in lead container type L-35	Syringe with the Co-60 in the hand	Transport of Co-60 source in tweezers
The average dose	58.3%	52.2%	165.1%	136.9%
Values below the extremity dosimeter dose	100%	100%	0%	57.1%
Values above the extremity dosimeter dose	0%	0%	100%	42.9%
The average hand phantom coefficient $C_{HPh_{AV}}$	0.6	0.5	1.7	1.4
The maximum hand phantom coefficient $C_{HPh_{\max}}$	0.9	0.8	3.3	3.8

and therapy [9]. The present authors suggest the application of the hand phantom to measure the dose distribution in new radiological situations with new types of radioactive sources or in new radiological procedures. These measurements will enable to estimate values of the proposed coefficients: $C_{HPh_{AV}}$ and $C_{HPh_{\max}}$ for specific radiological situations. The reliable value of the dose may be calculated by multiplying these coefficients by the extremity dosimeter dose.

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References

1. Bonamini D (1999) Low dose measurements in a routine personal dosimetry service. Radiat Prot Dosim 85:117–120
2. Elder D (1997) Lever's histopathology of the skin, 8th ed. Lippincott-Raven Publishers, Philadelphia
3. Gomez Ros JM, Saez Vergara JC, Romero AM, Budzanowski M (1999) Fast automatic glow curve deconvolution of LiF:Mg,Cu,P curves and its application in routine dosimetry. Radiat Prot Dosim 85:249–252
4. Hall EJ (2000) Radiobiology for the radiologist. Lippincott Wiliams & Wilkins Publishers, Philadelphia, Baltimore, New York
5. Jabłońska S (1973) Diseases of the skin, 4th ed. PWN, Warszawa (in Polish)
6. Janiak M, Wójcik A (2004) The medicine of dangerous and radiation injuries. PZWL, Warszawa (in Polish)
7. Jankowski J, Olszewski J, Kluska K (2003) Distribution of equivalent doses to skin of the hands of nuclear medicine personnel. Radiat Prot Dosim 106;2:177–180
8. Kron T (1999) Applications of thermoluminescence dosimetry in medicine. Radiat Prot Dosim 85:333–340
9. Królicki L (1996) Nuclear medicine. Fundacja L. Rydygiera, Warszawa (in Polish)
10. Lindner O, Busch F, Burchert W (2003) Performance of a device to minimise radiation dose to the hands during radioactive syringe calibration. Eur J Nucl Med Mol Imaging 30;6:819–825
11. Moscovitch M (1999) Personnel dosimetry using LiF:Mg,Cu,P. Radiat Prot Dosim 85:49–56
12. Muniz JL, Alves JG, Delgado A (1999) Detection and determination limits using glow curve analysis for LiF:Mg, Ti and LiF:Mg,Cu,P based TL dosimetry. Radiat Prot Dosim 85:57–61
13. Niewiadomski T, Bilski P, Budzanowski M, Olko P, Ryba E, Waligórski MPR (1996) Progress in thermoluminescent dosimetry for radiation protection and medicine at the Institute of Nuclear Physics. Nukleonika 41;2:93–104
14. Pawlicki G, Pałko T, Golnik N, Gwiazdowska B, Królicki L (2002) Medicinal physics, vol. 9. In: Nałęcz M (ed.) Biocybernetics and biomedical engineering. Akademicka Oficyna Wydawnicza EXIT, Warsaw (in Polish)
15. "POLON" Laboratory containers type L. User's guide (1972) United Industries of Nuclear Equipment – standard K-67/72. POLON, Cracow (in Polish)
16. Waligórski MPR (1999) What can solid detectors do for clinical dosimetry in modern radiotherapy? Radiat Prot Dosim 85:361–366
17. Yuen PS, Freedman NO, Frketich G, Rotunda J (1999) Evaluation of BICRON♦NE MCP DXT-RAD passive extremity dosimeter. Radiat Prot Dosim 85:187–195