Characteristic testing (performance) of CaSO₄: Dy thermoluminescent ring dosimeter according to the ISO 12794:2000

Evita Muthia’ul Maula¹, Johan noor², Bunawas³,

¹Magister Physic of Brawijaya University, Malang East Java, Indonesia 65145
²Department of Physics, Brawijaya University, Malang, State, Indonesia-65145
³Nuklindo Laboratory, South Tangerang, Indonesia-15412

*Corresponding author: evitamaula@student.ub.ac.id

Abstract. CaSO₄: Dy thermoluminescent dosimeters (TLD) disc known as TLD-900 is widely used for personal dosimetry purposes. An optimum response dosimeter procedure can be determined from its characteristics. The equivalent dose limitation for hands and feet or skin Hp (0.07) of 500 mSv/year. Therefore, we need a device to measure the radiation dose to optimize the safety of radiation workers so do not exceed the limit detection. The research objective is to produce accurate dosimeters by testing the characteristics of personal dosimeters according to ISO 12794: 2000. Tests of 129 dosimeters were tested with dosage variations of 0.3, 0.5, 1, 3, and 5 mSv in the 90Sr beta, gamma 137Cs, and x-ray voltage 20-100 kV in Secondary Standard Dosimeter Laboratory (SSDL). The results of tests obtained the dosimeter's dependence on angle variations is relatively small and has a high energy dependency. Obtaining a dosimeter limit for the detection of extremities for beta and photon radiation less than 1 mSv with the lowest sensitivity being at 80 keV of 24 μSv. The dosimeter response to extremity is good, evidenced by the reading values within the trumpet curve range set by the IAEA and EURADOS.

Keywords: Extremity dosimeter, Personal dosimetry, TLD-900, TLD CaSO₄: Dy.

1. Introduction
The production of radioisotopes such as nuclear reactors and cyclotrons in Indonesia by BATAN (National Nuclear Technology Agency) is one of which is applied to the world of health in therapeutic and diagnostic needs. It is recorded that 22 hospitals in Indonesia have nuclear technology facilities and are in the process such as SPECT CT and PET-based on data from the Nuclear Medicine Center in Indonesia 2019 [1,2]. In nuclear medicine, radiopharmaceuticals are administered into a patient by a general practitioner by injection [3–5]. Because radioactive sources are used to open radioactive sources, doctors and radiation workers have the potential to be exposed to high levels of beta-gamma radiation and x-rays in the extremity area[6,7]. Therefore a radiation dose-measuring device is needed to monitor the radiation dose received by radiation workers regularly [8–11].

Based on the PERKA BAPETEN (Regulation of the Head of the Nuclear Energy Supervisory Agency ) No. 8 of 2011 concerning radiation safety in the use of diagnostic and interventional radiological x-ray aircraft [12]. PERKA BAPETEN No. 17 of 2012 on radiation safety in nuclear medicine [13]. PERKA KAPETEN No. 2013 concerning radiation protection and safety in the use of nuclear power [14]. The three PERKA BAPETEN provide information is needed for the optimization...
of radiation protection and safety in the use of diagnostic and interventional radiology x-ray aircraft ionizing radiation in nuclear medicine codes. Radiation workers are required to use an extremity dosimeter to monitor the radiation dose received, so as not to exceed the Dose Limit (NBD), which is set at 500 mSv/year. Internal radiation dosimetry in the use of radiopharmaceuticals for diagnostic tests must pay attention to radiation safety by meeting the ALARA (As Low As Reasonably Achievable) rules [15–19].

In Indonesia, the dosimeter used in nuclear medicine is the dosimeter badge/pocket. There are two methods of measuring the dose of the extremities including using a bracelet dosimeter and a ring dosimeter. The location of the maximum distribution of the extremity radiation dose lies in the hand and more specifically at the fingertips [20]. Hence the nuclear medicine standard for both staff and radiation workers is to use ring dosimeters [21]. A personal dosimeter is a measuring device for individual radiation doses [22–25]. The selection of a personal dosimeter to be used must have the same level of conformity with measurement results and dose evaluation according to international regulations. Also adjusted to the type of radiation and the individual dose equivalent Hp (d) to be monitored. Based on International Standard ISO 12794 on Nuclear energy-Radiation Protection-Individual thermoluminescence dosemeters for extremities and eyes.

Ring dosimeter in Indonesia has not been implemented due to the unavailability of service for testing and evaluating the ring dosimeter calibration dose. Along with Presidential Regulation No. 60 of 2019 II.Alα (ν) regarding efforts to develop individual dosimeters We also support the realization of this program to research ring dosimeter characteristics testing. The purpose of this study is to perform a ring dosimeter characteristic test treatment of CaSO4: Dy based on ISO 12924.

2. Method

2.1. Material and Method

Ring dosimeter in this study using TLD CaSO4: Dy in the shape of a disk with a diameter of 6 mm and a thickness of 0.9 mm made by BARC India. TLD was annealed for 2 hours at 230°C using a Maiter Oven for annealing (Model UN 55) to remove the remaining electrons. Then the TLD was radiated and grouped into groups that had a uniform response with a coefficient of variation of less than 10% (according to ISO provisions).

TLD CaSO4: Dy irradiated with gamma Cs-137, beta Sr-90 and x-rays with radiation doses of 0.3 mSv, 0.5 mSv, 1 mSv, 3 mSv and 5 mSv at 4 TLDs respectively. The phantom used is a Rod Phantom with a diameter of 19 mm and a length of 190 mm. After being stabilized for 2 x 24 hours the TLD was read using TLD reader nucleonics 10091 and the application of the TL Research Reader Software. TLD readings are carried out for 180 minutes with 4 temperature points from room temperature (natural cooling) to a maximum temperature of 320 °C at 120 seconds-150 minutes and 180 minutes back at normal temperature. As in Figure 1. The peak temperature of TL intensity occurs when the temperature shows 220 °C.

3. Result and Discussion

3.1. Performance Test

3.1.1. Linearity

a response linearity test was carried out for a group of 15 irradiated dosimeters. Fig. 1 shows the reading of dosimeters as a function of a nominal dose for the dosing interval between 0.3 to 5 mSv. irradiated using a Cs-137 beta Sr-90 gamma source and x-ray 40-250 keV.
3.1.2. Energy Dependence of Response
In this reach, the Hp (0.07) response was considered for photons with different average energy and gamma Cs-137. Photons of mean energies 32, 48, 65, 83, 118 and 207 keV and 137Cs. Fig. 2 shows normalized values concerning the 137Cs response.

3.1.3 Angle Dependence of Response (Isotropy test)
Fig. 3 describe the angle dependence of the response of the dosimeters when irradiated at photons of average energy 80 keV produced by an X-ray source, a. The dosimeters were irradiated at 0°; 15°; 45°, and 60° concerning the beam incidence direction, and the detector geometrical center was considered the reference point. The results obtained and normalized to the response at 0° showed a maximum variation of 5%.
3.1.4 Detection Threshold
The boundary detection resulted from the calculation by substituting the background mean values of several TLDs into the Gamma Cs-137, Beta Sr-90, and X-ray linearity equations with a voltage of 80 keV. The detection limit value of the CaSO₄: Dy ring dosimeter in this study can be seen in Table 1.

**Table 1. A Detection Threshold of TLD-900.**

| Radiation Source | Detection Threshold (µSv) |
|------------------|----------------------------|
| X-ray 80 keV     | 24                         |
| X-ray 100 keV    | 40                         |
| Beta Sr-90       | 143                        |
| Gamma-137        | 147                        |

4. Conclusion
the angle dependence is relatively small, where the change to the normal angle changes by a maximum of 9%. Dosimeter dependence on angle variation does not have a big effect, the change in response to the normal angle is a maximum of 9% of 54 nC and has a considerable energy dependence. The detection limit of the extremity dosimeter for beta and photon radiation less than 1000 µSv with the lowest sensitivity is at 80 keV of 24 µSv. The response of the extremity dosimeter is good as evidenced by the readings being within the trumpet curve range established by the IAEA and EURADOS

Reference
[1] Hatazawa J Sabih D Li Y Pradhan P K and Paez D, 2020 Nuclear Cardiology in Asia *Semin. Nucl. Med.* **50** 270–279.
[2] Agusbudiman A, 2018 Sm For Calibrating Nuclear Medicine Instruments In Indonesia *Semin. Nucl. Med.* **10** 241–246.
[3] Ljungberg M Celler A Konijnenberg M W Eckerman K F Dewaraja Y K and Sjögreen-Gleisner K, 2016 MIRD pamphlet no. 26: Joint EANM/MIRD guidelines for quantitative 177Lu SPECT applied for dosimetry of radiopharmaceutical therapy *J. Nucl. Med.* **57** 151–162.
[4] Graydon I Beatty E Paul S Us M N and Hauck J A, 2006 ( 12 ) United States Patent 1.
[5] Vermeulen K Vandamme M Bormans G and Cleeren F, 2019 Design and Challenges of
Radiopharmaceuticals Semin. Nucl. Med. 49 339–356.

[6] Sarria G R Petrova V Wenz F Abo-Madayan Y Sperk E and Giordano F A, 2020 Intraoperative radiotherapy with low energy x-rays for primary and recurrent soft-tissue sarcomas Radiat. Oncol. 15 1–7.

[7] Lima F et al., 2017 Exposure to Low-Dose X-Ray Radiation Alters Bone Progenitor Cells and Bone Microarchitecture Radiat. Res. 188 433–442.

[8] Dauer L T et al., 2017 Guidance on radiation dose limits for the lens of the eye: Overview of the recommendations in NCRP commentary no. 26 Int. J. Radiat. Biol. 93 1015–1023.

[9] Safari M J et al., 2016 Real-time eye lens dose monitoring during cerebral angiography procedures Eur. Radiol. 26 79–86.

[10] James J R Pavlicke W Hanson J A Boltz T F and Patel B K, 2017 Breast radiation dose with CESM compared with 2D FFDM and 3D tomosynthesis mammography Am. J. Roentgenol. 208 362–372.

[11] Barnard S G R Ainsbury E A Quinlan R A and Bouffler S D, 2016 Radiation protection of the eye lens in medical workers-based and impact of the ICRP recommendations Br. J. Radiol. 89 1060.

[12] BAPETEN, 2019 Pedoman Teknis Penyusunan Tingkat Panduan Diagnostik Atau Diagnostic Reference Level (DRL) Nasional : Rev 02 2019 8.

[13] Badan K and Tenaga P, 2012 jdh.bapeten.go.id.

[14] Badan K and Tenaga P, 2013 Indonesia Tahun 1997 Nomor 23, Tambahan Lembaran Negara Nomor 3676.

[15] Doss M, 2017 Disavowing the ALARA concept in pediatric imaging Pediatr. Radiol. 47 118.

[16] Orton C G and Hendee W R, 2012 Controversies in Medical Physics: a Compendium of Point / Counterpoint Debates 2.

[17] Cohen M D, 2017 Reply to Dr. Andronikou: Disavowing the ALARA concept in pediatric imaging Pediatr. Radiol. 47 116–117.

[18] Beirne G C Westerway S C and Ng C K C, 2016 National survey of Australian sonographer knowledge and behaviour surrounding the ALARA principles when conducting the 11-14-week obstetric screening ultrasound Australas. J. Ultrasound Med. 19 47–55.

[19] Tomá P et al., 2019 Protecting sensitive patient groups from imaging using ionizing radiation: effects during pregnancy, in fetal life and childhood Radiol. Medica 124 736–744.

[20] Covens P Berus D Caveliers V Struelens L and Verellen D, 2011 The contribution of skin contamination dose to the total extremity dose of nuclear medicine staff: First results of an intensive survey Radiat. Meas. 46 1291–1294.

[21] Wrezesień M Olszewski J and Jankowski J, 2008 Hand exposure to ionising radiation of nuclear medicine workers Radiat. Prot. Dosimetry 130 325–330.

[22] Park K et al., 2019 Ambient dose equivalent measurement with a CsI(Tl) based electronic personal dosimeter Nucl. Eng. Technol. 51 1991–1997.

[23] Tchistiaikova E Kim A Song W Y and Pang G, 2017 MR-safe personal radiation dosimeters J. Appl. Clin. Med. Phys. 18 180–184.

[24] Yasuda H Yajima K and Sato T, 2020 Investigation of using a long-life electronic personal dosimeter for monitoring aviation doses of frequent flyers Radiat. Meas. 134 106309.

[25] Lee Y Seo S and Jin Y W, 2020 Assessment of working environment and personal dosimeter-wearing compliance of industrial radiographers based on chromosome aberration frequencies Assessment of working environment and personal dosimeter-wearing compliance of industrial radiographers base.

Acknowledgments
The author would like to thank warmly to all the people from Nuklindo JKRL (Radiation and Environmental Safety Services) Laboratory for their help and support in collecting these data research. This research was financially supported by the Nuklindo JKRL Laboratory.