ЗБОРНИК РАДОВА

XXXII Симпозијум
Друштва за заштиту од зрачења
Србије и Црне Горе

04-06. октобар 2023. године

Будва, Црна Гора

ДРУШТВО ЗА ЗАШТИТУ ОД ЗРАЧЕЊА
СРБИЈЕ И ЦРНЕ ГОРЕ

ЗБОРНИК РАДОВА

XXXII СИМПОЗИЈУМ ДЗЗСЦГ

Будва, Црна Гора
04-06. oктобар 2023. године

Београд

2023. године

RADIATION PROTECTION ASSOCIATION OF SERBIA AND MONTENEGRO

PROCEEDINGS

XXXII SYMPOSIUM RPASM

Budva, Montenegro
4^{th}-6^{th} October 2023

Belgrade

2023

ЗБОРНИК РАДОВА

XXXII СИМПОЗИЈУМ ДЗЗСЦГ
04-06.10.2023.

Издавачи:
Институт за нуклеарне науке „Винча“
Друштво за заштиту од зрачења Србије и Црне Горе

За извршног издавача:
Проф. Др Снежана Пајовић

Уредници:
Др Милица Рајачић
Др Ивана Вуканац

ISBN 978-86-7306-169-6

Техничка обрада:

Милош Ђалетић, Милица Рајачић

Електронско издање:

Институт за нуклеарне науке ”Винча”, Мике Петровића Аласа 12-14,
11351 Винча, Београд, Србија

Година издања:

Октобар 2023.

XXXII СИМПОЗИЈУМ ДРУШТВА
ЗА ЗАШТИТУ ОД ЗРАЧЕЊА
СРБИЈЕ И ЦРНЕ ГОРЕ

Будва, 04-06.10.2023. године

Организатори:

ДРУШТВО ЗА ЗАШТИТУ ОД ЗРАЧЕЊА СРБИЈЕ И ЦРНЕ ГОРЕ

Институт за нуклеарне науке „Винча“

Лабораторија за заштиту од зрачења и заштиту животне средине „Заштита“

Центар за екотоксиколошка испитивања Подгорица д.о.о, ЦЕТИ

Организациони одбор:

Председник:

Ивана Вуканац

Чланови:

Милица Рајачић, Институт за нуклеарне науке „Винча“, Београд

Александра Милатовић, ЦЕТИ, Подгорица, Црна Гора

Никола Свркота, ЦЕТИ, Подгорица, Црна Гора

Ранко Зекић, ЦЕТИ, Подгорица, Црна Гора

Гордана Пантелић, Институт за нуклеарне науке „Винча“, Београд

Милош Ђалетић, Институт за нуклеарне науке „Винча“, Београд

Никола Кржановић, Институт за нуклеарне науке „Винча“, Београд

Наташа Сарап, Институт за нуклеарне науке „Винча“, Београд

Јелена Станковић Петровић, Институт за нуклеарне науке „Винча“, Београд

Ивана Коматина, Институт за нуклеарне науке „Винча“, Београд

Јелена Влаховић, Институт за нуклеарне науке „Винча“, Београд

Зорица Обрадовић, Институт за нуклеарне науке „Винча“, Београд

Игор Челиковић, Институт за нуклеарне науке „Винча“, Београд

Јелена Крнета Николић, Институт за нуклеарне науке „Винча“, Београд

Александра Самолов, Институт за нуклеарне науке „Винча“, Београд

XXXII СИМПОЗИЈУМ ДРУШТВА
ЗА ЗАШТИТУ ОД ЗРАЧЕЊА
СРБИЈЕ И ЦРНЕ ГОРЕ

Будва, 04-06.10.2023. године

Научни одбор:

др Владимир Удовичић, Институт за физику, Земун, Универзитет у Београду

др Војислав Станић, Институт за нуклеарне науке „Винча“, Универзитет у Београду

др Душан Мрђа, Природно математички факултет, Универзитет у Новом Саду

др Ивана Вуканац, Институт за нуклеарне науке „Винча“, Универзитет у Београду

др Игор Челиковић, Институт за нуклеарне науке „Винча“, Универзитет у Београду

др Јелена Крнета Николић, Институт за нуклеарне науке „Винча“, Универзитет у Београду

др Јелена Пајић, Институт за медицину рада Србије "Др Драгомир Карајовић", Београд

др Јелица Грујић, Институт за медицинска истраживања, Универзитет у Београду

др Јована Николов, Природно математички факултет, Универзитет у Новом Саду

др Маја Еремић-Савковић, Директорат за радијациону и нуклеарну сигурност и безбедност Србије

др Марија Јанковић, Институт за нуклеарне науке „Винча“, Универзитет у Београду

др Мирјана Ђурашевић, Институт за нуклеарне науке „Винча“, Универзитет у Београду

др Мирјана Раденковић, Институт за нуклеарне науке „Винча“, Универзитет у Београду

др Невена Здјеларевић, ЈП Нуклеарни објекти Србије, Београд

др Оливера Митровић Ајтић, Институт за медицинска истраживања, Универзитет у Београду

др Софија Форкапић, Природно математички факултет, Универзитет у Новом Саду

др Србољуб Станковић, Институт за нуклеарне науке „Винча“, Универзитет у Београду

Организацију су помогли:

Институт за нуклеарне науке „Винча“, Лабораторија за заштиту од зрачења
и заштиту животне средине „Заштита“
Мике Петровића Аласа 12-14
11351 Винча, Београд, Србија
https://www.vin.bg.ac.rs/

Центар за екотоксиколошка испитивања Подгорица д.о.о, ЦЕТИ
Булевар Шарла де Гола бр. 2
81000 Подгорица, Црна Гора
https://mne.ceti.me/

МОЈ ЛАБ
ул. Московска бр. 2б
81000 Подгорица, Црна Гора
https://mojlab.me/

ФАРМАЛАБ
Булевар Михаила Лалића бр. 8
81000 Подгорица, Црна Гора
https://farmalab.me/

ГЛОСАРИЈ ДОО
ул. Војисављевића бр. 76
81000 Подгорица, Црна Гора
https://www.glosarij.me/me/pocetna

Излагачи:

Canberra Packard Central Europe GmbH.
Wienersiedlung 6
2432 SCHWADORF, Austria
Phone: +43 (0)2230 3700-0
Fax: +43 (0)2230 3700-15
Web: http://www.cpce.net/

LKB Vertriebs doo Beograd-Palilula
Cvijićeva 115
11120 Beograd, Srbija
Tel: +381 (0)11 676 6711
Faks: +381 (0)11 675 9419
Web: www.lkb.eu

Овај Зборник је збирка радова саопштених на XXXII Симпозијуму Друштва за заштиту од зрачења Србије и Црне Горе који је одржан у Будви, Црна Гора, 04-06.10.2023. године. Радови су према обрађеној проблематици груписани у једанаест секција. Сви радови у Зборнику су рецензирани од стране Научног одбора, а за све приказане резултате и тврдње одговорни су сами аутори.

Југословенско друштво за заштиту од зрачења основано је 1963. године у Портороже, а од 2005. носи име "Друштво за заштиту од зрачења Србије и Црне Горе". На XXXII Симпозијуму, ове године обележавамо веома значајан јубилеј ***- 60 година организоване заштите од зрачења на нашим просторима.***

Од оснивања, Симпозијуми Друштва за заштиту од зрачења представљају прилику да се кроз стручни програм прикажу резултати истраживања у области заштите од зрачења, представе различите области примене извора и генератора зрачења, анализирају актуелна дешавања, размене искуства са колегама из региона, дефинишу проблеми и правци даљег унапређивања наше професионалне заједнице.

Поред тога, Симпозијуми друштва представљају и прилику да у мање формалном маниру сретнемо старе и упознамо нове пријатеље и колеге, обновимо старе и започнемо нове професионалне сарадње.

Ауторима и коауторима научних и стручних радова саопштеним на XXXII Симпозијуму се захваљујемо на уложеном труду и настојању да квалитетним радовима заједно допринесемо остваривању циљева и задатака Друштва и наставимо традицију дугу импозантних 60 година.

Посебно се захваљујемо свима који су подржали одржавање овог Симпозијума.

Свим члановима Друштва, сарадницима и колегама честитамо овај значајан јубилеј!

Организациони одбор XXXII Симпозијума ДЗЗСЦГ

EVALUATION OF DIAGNOSTIC RADIOLOGY DETECTOR PERFORMANCE IN REFERENCE MAMMOGRAPHY RADIATION FIELDS

Nikola KRŽANOVIĆ[1], Andrea KOJIĆ[1,2], Luka BAKRAČ[3], Miloš ŽIVANOVIĆ[1]

1) *Vinca Institute of Nuclear Sciences – National Institute of Republic of Serbia, University of Belgrade, Department for Radiation and Environmental Protection, Belgrade, Serbia;*
2) *Faculty of Physics, University of Belgrade, Belgrade, Serbia*
3) *Ruđer Bošković Institute (RBI), Zagreb, Croatia*

Corresponding author: *Nikola KRŽANOVIĆ, krzanovic@vinca.rs*

ABSTRACT

Recommendations on diagnostic radiology calibrations are defined by the IEC and IAEA documents for molybdenum anode target material and molybdenum primary beam filtration (abbreviated as the RQR-M series). Calibration of diagnostic radiology dosimeters (ionization chambers and X-ray multimeters) can also be performed for other anode/filter combinations, including the tungsten anode / aluminium filtration setup. Performance of dosimeters can significantly vary in radiation fields defined by different anode materials and primary beam filtrations, where different spectra and first half-value layers are obtained for the same nominal X-ray tube voltages. Therefore it is important to calibrate or test dosimeters for the range of radiation qualities or conditions in which they will be used. Performance of two such detectors was evaluated.

Introduction

The International Electrotechnical Commission (IEC) standard 61674 [1] defines performance criteria and limits of variation for diagnostic radiology dosimeters in various diagnostic radiology radiation fields covering different modalities of medical imaging (general radiography, computerized tomography, mammography etc.). Reference radiation fields established under laboratory conditions are defined in such a way to closely correspond to the most common radiation beams encountered in diagnostic radiology procedures. Properties of these radiation fields are defined in IEC 61267 [2]. Besides the two IEC standards describing the requirements for the diagnostic radiology detectors and reference radiation fields, International Atomic Energy Agency (IAEA) Technical Report No. 457 [3] provides guidance on calibration procedures for diagnostic radiology dosimeters as well as descriptions of the reference radiation fields. Radiation fields with known and well-defined photon energy distribution (energy spectra) are termed as radiation qualities. These fields are established under laboratory conditions either by performing spectrometry measurements or by determining certain radiation field parameters. A way to define radiation qualities is to perform 1^{st} and 2^{nd} half-value layer measurements for a known total filtration of the primary radiation beam and known X-ray tube voltage.

Diagnostic dosimeters can have significant energy dependence, and because of this it is important to test them in a range of radiation qualities in which they will be used. In mammography applications, radiation qualities with different anode/filter combination can have significantly different spectra, and it is important to test the dosimeters in appropriate conditions. This paper presents the preliminary results of the tests of several dosimeters in different standard and non-standard radiation qualities.

Diagnostic radiology radiation qualities

Radiation qualities for general radiography are termed as RQR-series (radiation qualities in radiation beams emerging from the X-ray source assembly) and cover radiation fields with X-ray tube voltages from 40 kV up to 150 kV. Similarly, in computerized tomography RQT-series (radiation qualities based on copper added filter) is defined in the voltage range from 100 kV up to 150 kV. These radiation fields are defined for the tungsten (W) anode target material and aluminium (Al) primary beam filtration (with an addition of copper (Cu) in case of RQT-series). RQR radiation quality series cover general radiography applications with the reference radiation quality corresponding to one of the most commonly used tube voltages of 70 kV (RQR5 radiation quality). Even though these radiation qualities are well-defined and are appropriate for many diagnostic radiology applications, in specific situations such as interventional procedures these radiation qualities may not be suitable.

Radiation qualities in mammography are defined for a narrower X-ray tube voltage range from 25 kV up to 35 kV. The IEC defined radiation qualities [2, 3] are termed as RQR-M and represent the molybdenum (Mo) anode target material and Mo filtration of the primary beam. These radiation qualities are based on widely used mammography units prior to the development of digital mammography which has introduced several different anode material / primary beam filtration setups. Many novel mammography units utilize tungsten anode with different primary beam filtrations, such as rhodium (Rh), silver (Ag) etc.

RQR, RQT and RQR-M radiation quality series are defined with respect to the minimum scatter environment where only primary beam is considered. This setup is in accordance with the corresponding diagnostic modalities where exclusively primary beam is useful for production of the medical image of the patient, and any scattered radiation does not contribute to the useful signal.

Besides the primary beam radiation qualities, radiation beams representing beams transmitted through the patient (PMMA phantoms of different thicknesses) are also of importance for quality control in diagnostic radiology. For mammography these radiation qualities are termed as RQA-M, and are also defined for the Mo/Mo anode target/primary beam filtration setup.

Standard Dosimetry Laboratories which have established reference fields for general diagnostic radiology utilize tungsten (W) anode and aluminium (Al) filtration of different thicknesses. On the other hand, reference radiation fields for mammography (RQR-M) are often not available in the Dosimetry Laboratories due to unavailability of Mo/Mo setup. Alternatively, a non-standard radiation quality series was developed with W/Al setup which utilizes additional filtration of 0.5 mm Al. Even though this series is not part of the IEC standard, at least one primary laboratory has established it and is able to provide traceable calibrations in terms of air kerma.

Even though W/Al radiation fields can be used for dosimeter calibration, it is important to assess performance of dosimeters in the standard radiation qualities (RQR-M). As mentioned, many different anode/filtration setups are in use today, so assessment of dosimeter performance in these radiation fields is needed as well. The situation where various anode/filtration combinations are used may introduce the need for redefining reference radiation conditions introduced by digital mammography.

Diagnostic radiology dosimeters

Dosimeters used for Quality Assurance (QA) of X-ray generators in diagnostic radiology are based on ionization chambers or solid state detectors. Ionization chambers are proven to have more stable and flatter response over a wider range of photon energies (and tube voltages) and therefore, are preferable for reference air kerma measurements (usually under laboratory conditions), ensuring traceability to the primary standard. Solid state detectors are more compact and easy to use, therefore more suitable to be used for regular QA routines. Additionally, these detectors are usually incorporated in multi-element dosimeters which are able to measure several parameters of importance for quality assurance. These devices are termed as X-ray multimeters (XMMs) and are able to measure dose, dose rate and X-ray tube voltage non-invasively. Besides these conventional quantities some of these devices are able to estimate total-filtration of the radiation beam (TF), irradiation time, current time product, as well as 1st half-value layer (HVL). XMMs usually utilize several different filters for energy compensation of the detectors and for establishing correction factors which are applied to the measured value based on the chosen software setting. The settings of the multimeters usually cover the diagnostic radiology modality, the anode/filtration setup and the X-ray tube voltage. Depending on these settings the data produced by the XMM can greatly differ in the same radiation field.

Performance tests

Traceability to the primary standard at the Vinča Institute of Nuclear Sciences Secondary Standard Dosimetry Laboratory (VINS SSDL) is available for the W+Al radiation qualities in the X-ray voltage range from 25 kV to 35 kV, with the Exradin A600 (Standard Imaging) ionization chamber. Since only tungsten anode X-ray tube is available in the laboratory, XMM and ionization chamber performance was also evaluated at the Ruđer Bošković Institute (RBI) SSDL where both W+Al and RQR-M radiation qualities have been established. Performance of two ionization chambers and eight solid state detectors will be evaluated in the standard Mo/Mo radiation fields. For comparison purposes performance of these dosimeters will be also assessed in the W/Al radiation fields in the same X-ray tube voltage range in both laboratories. Additionally, performance of these detectors in the RQA-M radiation qualities will be examined. Tested IEC and non-standard radiation qualities and their parameters are tabulated in Table 1.

The non-standard radiation qualities have a slightly increased HVL values for the same X-ray tube voltages. Nevertheless, these radiation quality series have quite different photon energy distribution due to molybdenum target characteristic X-radiation peaks in this photon energy range. The spectra for 28 kV X-ray tube voltage radiation fields (W+Al28 and RQR-M2) are generated by using SpekPy [4] and presented in Figure 1.

Table 1. Mammography radiation qualities used for the assessment of diagnostic radiology dosimeters' performance: IEC 61267 [2] reference radiation quality series RQR-M and RQA-M, and non-standard W/Al anode/filtration radiation fields.

Radiation Quality	X-ray tube voltage [kV]	Added filtration [mm]	1st HVL [mm Al]
RQR-M 1	25	0,033 Mo	0,28
RQR-M 2	28	0,033 Mo	0,31
RQR-M 3	30	0,033 Mo	0,33
RQR-M 4	35	0,033 Mo	0,36
W+Al 25	25	0,5 Al	0,31
W+Al 28	28	0,5 Al	0,35
W+Al 30	30	0,5 Al	0,38
W+Al 35	35	0,5 Al	0,43
RQA-M 1	25	0,033 Mo + 2 Al	0,56
RQA-M 2	28	0,033 Mo + 2 Al	0,60
RQA-M 3	30	0,033 Mo + 2 Al	0,62
RQA-M 4	35	0,033 Mo + 2 Al	0,68

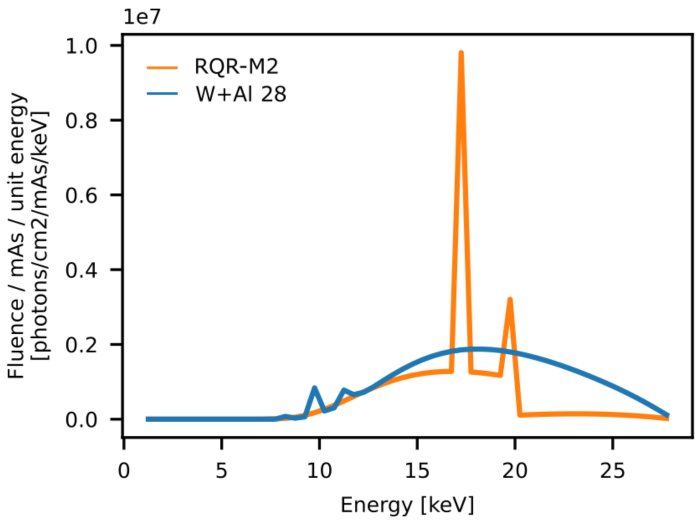

Figure 1. SpekPy [4] generated spectra for the RQR-M2 and W+Al28 radiation fields.

One of the most important influence quantities on the detector response is the photon energy. Dosimeter response was determined by comparing the reference air kerma value (corrected for changes in air density, i.e. ambient temperature and atmospheric pressure) and measured value. The reference and measured value were corrected for collected charge by the PTW 34014 plane parallel ionization chamber (monitor chamber) to account for variations in the X-ray generator output. In Figure 2, preliminary results of performance tests on two XMMs performed in the RQR-M, RQA-M and W+Al radiation fields are presented.

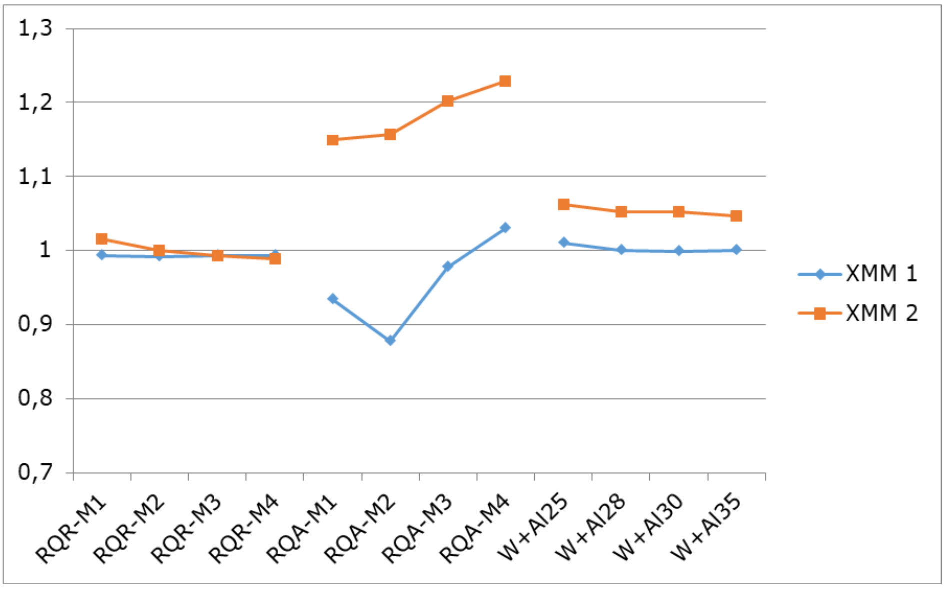

Figure 2. Absolute response of two XMMs in the RQR-M and RQA-M IEC radiation quality series and the non-standard W+Al radiation fields.

The responses of examined XMMs are stable for the reference RQR-M radiation quality series where the deviations are within ±5 % from the reference value. In the non-standard radiation fields of W+Al one of the XMMs has displayed an increase in response of approximately +5 % for the whole X-ray tube voltage. It should be noted that for both of the direct beam radiation quality series appropriate software settings in the multimeters were selected. In the case of RQA-M series one of the XMMs has displayed an under response with the maximum deviation greater than 10 % (for the 28 kV radiation field), while the other XMM has exhibited a great overresponse of 20 % at the 35 kV radiation field. Examination of the response in the transmitted beams through the patient has not been performed for the W+Al radiation fields, because such beams have not been established so far.

Conclusion

Diagnostic radiology dosimeters are used for verification and quality assurance of the X-ray generator output in the hospitals. Performance of the diagnostic radiology detectors can differ for the same X-ray tube voltage due to differences in the X-ray beam spectra and HVL. These dosimeters should be calibrated and traceable to the primary standards for one or more reference radiation qualities, depending on their intended use. Due to the unavailability of the IEC defined Mo/Mo radiation qualities in many calibration laboratories, traceability is often established for the non-standard W/Al radiation qualities.

The presented performance tests are a work in progress and the results produced in this research will be published in a peer-reviewed journal upon completion of the performance tests for all of the dosimeters.

Acknowledgement

This work was funded by The Ministry of Science, Technological Development and Innovation of the Republic of Serbia under contract 451-03-47/2023-01/ 200017, International Atomic Energy Agency (IAEA) under the research contract No: 24688, which is part of the IAEA Coordinated Research Project E24024, entitled ‘Evaluation of the Dosimetry Needs and Practices for the Update of the Code of Practice for Dosimetry in Diagnostic Radiology (TRS-457)’, and the project (22NRM01 TraMeXi) which has received funding from the European Partnership on Metrology, co-financed from the European Union's Horizon Europe Research and Innovation Programme and by the Participating States.

References

[1] International Electrotechnical Commission, Medical electrical equipment - Dosimeters with ionization chambers and/or semiconductor detectors as used in X-ray diagnostic imaging, IEC 61674:2012

[2] International Electrotechnical Commission, Medical diagnostic X-ray equipment – Radiation conditions for use in the determination of characteristics, IEC 61267:2005.

[3] International Atomic Energy Agency, Dosimetry In Diagnostic Radiology: an International Code of Practice, Technical Report Series No. 457, IAEA TRS 457:2007.

[4] Poludniowski G, Omar A, Bujila R, Andreo P. Technical Note: SpekPy v2.0-a software toolkit for modeling x-ray tube spectra. Med Phys. 2021 Jul;48(7):3630-3637. doi: 10.1002/mp.14945. Epub 2021 Jun 10. PMID: 33993511.