

Spectrometry of pulsed photon radiation

Rolf Behrens¹, Hayo Zutz¹, Julian Busse¹

¹ Physikalisch-Technische Bundesanstalt (PTB), Bundesallee 100, 38116 Braunschweig
Rolf.Behrens@PTB.de

Summary:

The energy distribution (spectrum) of pulsed photon radiation can hardly be measured using active devices. Therefore, a thermoluminescence detector (TLD)-based few-channel spectrometer is used in combination with a Bayesian data analysis.

Keywords: Spectrometry, Pulsed photon radiation, Bayesian analysis, Uncertainty

Background, Motivation and Objective

Pulsed photon radiation arises in more and more situations, e.g. from small pulsed X-ray tubes for material (like weld seam) testing or linear accelerators in tumor therapy. In this work, spectra at such radiation fields are measured.

Measurements and Data Evaluation

For the measurements, a TLD-based few-channel spectrometer (FCS) is used (see Fig. 1) [1],[2]. The photons' penetration depth in the spectrometer depends on the energy so that the energy-resolved and absolute spectrum of the radiation, including the uncertainties of the spectrum, can be determined from the dose values in the TLD layers using Bayesian data evaluation (deconvolution).

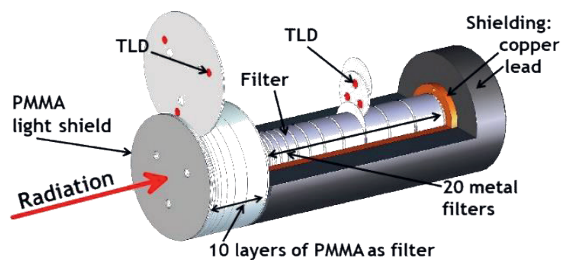


Fig. 1. Sketch of the TLD-based spectrometer. Basic principle: The deeper the radiation penetrates the spectrometer, the higher its energy.

The experimental setups are shown in Fig. 2: At the top, the spectrum of an industrial type open beam X-ray generator, XRS4 with a tube voltage of 370 kV, is measured. In the same way the spectrum of the XR200 with a tube voltage of 150 kV is measured. At the bottom, the spectrum of a medical accelerator at nominal 25 MV (which is actually 20 MV real) high voltage behind a shielding wall, is measured. The latter field is considered as reference field of pulsed high energy photons for dosimeter testing.

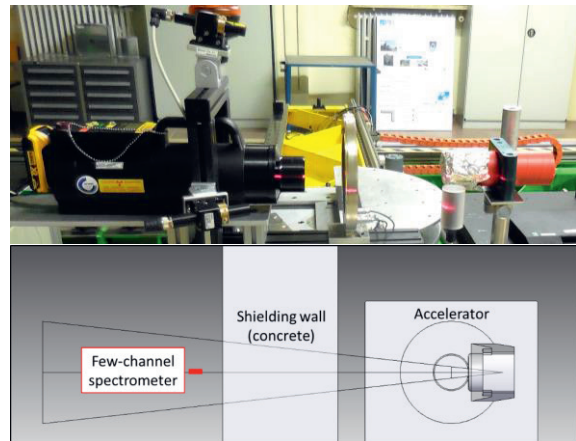


Fig. 2. Experimental setups. Top: industrial type open beam X-ray generator, XRS4, left, and FCS (red), right. Bottom: sketch of the medical accelerator, right, 2 m shielding wall, middle, FCS (red), left.

The TLDs are calibrated absolutely in terms of air kerma at PTB's corresponding reference field (Cs-137 radiation).

The Bayesian data evaluation is performed using the WinBUGS software [3] which, besides the absolute photon spectrum and total doses, also supplies the corresponding uncertainties and coverage intervals.

The following prior information for the photon spectra is included in the data evaluation: i) a smooth rise with increasing energy, ii) an exponential decrease at higher energies and iii) a peak in the spectrum at the energy of the characteristic fluorescence radiation of the anode material (for the XRS4 and XR200). This prior information is used due to the well-known form of bremsstrahlung spectra. Further details, including the validation of the method, (irradiation in known photon fields and subsequent data evaluation with the same prior information) are given in the literature [2],[5],[6].

Results

Fig. 3 shows the absolute photon fluence per pulse from the XRS4 and XR200 normalized to a distance of 1 m, top, and the absolute photon fluence per absorbed dose to water at the ISO center of the medical accelerator (at 1 m distance) at a total distance of 5.5 m from the accelerator. The latter one is measured at two different cross-sectional beam areas (at 1 m from the accelerator): 40 x 40 cm² and 10 x 10 cm². In both graphs, also the spectrum used as starting point for the Bayesian data evaluation is given. The fluence spectra are converted to ambient dose equivalent, $H^*(10)$, using the corresponding conversion coefficients [4]. The resulting doses are given in the legends together with the spectra's mean energies, \bar{E} , and their conversion coefficient from air kerma, K_a , to $H^*(10)$: $h^*_\kappa(10)$.

The top of Fig. 3 reveals that the data evaluation clearly identifies the end point energies of the X-ray tubes. Furthermore, for the XRS4 compared to the XR200, the mean energy is approximately 1.5 times, the dose per pulse 2 times and the conversion coefficient rather similar. The differences are as expected due to the larger tube voltage of the XRS4.

The bottom of Fig. 3 shows that the data evaluation also identifies the end point energy of the accelerator. Furthermore, for the 40 x 40 cm² field compared to the 10 x 10 cm² field, the mean energy is approximately 30 % smaller, the dose per reference dose almost 2 times larger and the conversion coefficient nearly the same. The differences are as expected due to the larger beam area of the 40 x 40 cm² field resulting in a larger contribution of stray radiation at the spectrometer's position from within the shielding wall. As the photons lose energy during their scattering in the wall, the mean energy is smaller.

Conclusions

The measurements clearly show that the few-channel spectrometer in combination with the Bayesian data evaluation can be used in different areas of application to reliably measure the spectrum of pulsed photon radiation, including uncertainties, coverage intervals and doses.

Funding

This work is supported by the Bundesamt für Strahlenschutz (BfS) with project no. 3619S2236 / FV-63014 „Aufbau und Charakterisierung eines Referenzfeldes zur Sicherstellung des Strahlenschutzes an Beschleunigeranlagen in Medizin und Forschung und zur Prüfung und Kalibrierung entsprechender Messgeräte“.

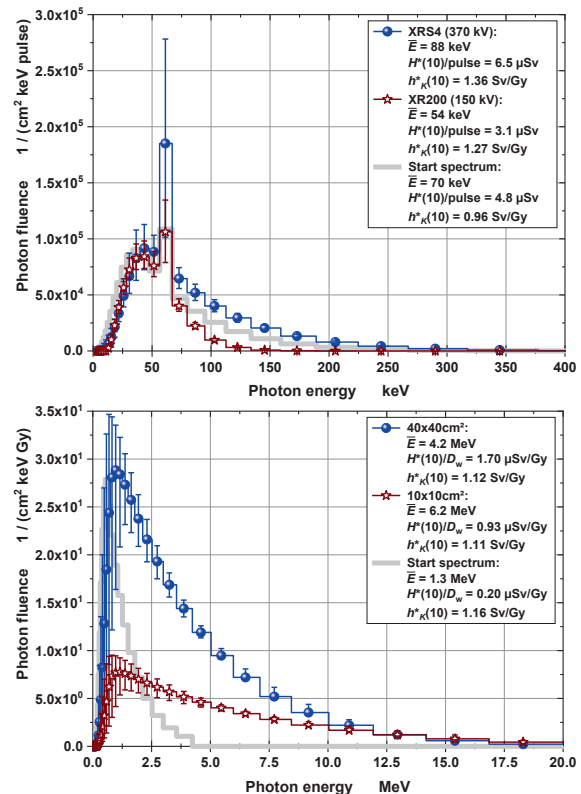


Fig. 3. Photon fluence spectra together with their 95 % coverage intervals. Top: X-ray generator, XRS4 (370 kV tube voltage) and XR200 (150 kV tube voltage); bottom: shielded, pulsed high energy photon field from a medical accelerator at nominal 25 MV high voltage.

References

- [1] R. Behrens and P. Ambrosi, A TLD-based Few-channel Spectrometer for Mixed Photon, Electron, and Ion Fields with High Fluence Rates, *Radiat. Prot. Dosim.* **101**, 73 (2002) doi: 10.1093/oxfordjournals.rpd.a006062
- [2] R. Behrens, A spectrometer for pulsed and continuous photon radiation, *J. Instrum.* **4**, P03027 (2009) doi: 10.1088/1748-0221/4/03/P03027
- [3] D.J. Lunn, A. Thomas, N. Best, D. Spiegelhalter, WinBUGS – a Bayesian modelling framework: Concepts, structure, and extensibility, *Statistics and Computing* **10**, 325 (2010) doi: 10.1023/A:1008929526011
- [4] International Commission on Radiation Units and Measurements (ICRU), Conversion Coefficients for use in Radiological Protection against External Radiation. *ICRU Report 57* (1998) doi: 10.1093/jicru/os29.2.Report57
- [5] R. Behrens, B. Pullner, M. Reginatto, X-Ray Emission from Materials Processing Lasers, *Radiat. Prot. Dosim.* **183**, 361-374 (2019); doi: 10.1093/rpd/ncy126
- [6] R. Behrens, M. Reginatto, Bayesian Spectrum Deconvolution Including Uncertainties and Model Selection: Application to X-Ray Emission Data Using WinBUGS, *Radiat. Prot. Dosim.* **185**, 157-167 (2019); doi: 10.1093/rpd/ncy286