The mean photon energy $\bar{E}_{\mathrm{F}}$ at the point of measurement determines the detector-specific radiation quality correction factor $k_{\mathrm{Q,M}}$ in ^{192}Ir brachytherapy dosimetry

Ndimofor Chofor*, **Dietrich Harder**, **Hans-Joachim Selbach**, **Björn Poppe**

Medical Radiation Physics Group, University of Oldenburg and Pius-Hospital Oldenburg, Germany

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Abstract

The application of various radiation detectors for brachytherapy dosimetry has motivated this study of the energy dependence of radiation quality correction factor $k_{Q,M}$, the quotient of the detector responses under calibration conditions at a ^{60}Co unit and under the given non-reference conditions at the point of measurement, M, occurring in photon brachytherapy. The investigated detectors comprise TLD, radiochromic film, ESR, Si diode, plastic scintillator and diamond crystal detectors as well as ionization chambers of various sizes, whose measured response-energy relationships, taken from the literature, served as input data. Brachytherapy photon fields were Monte-Carlo simulated for an ideal isotropic ^{192}Ir point source, a model spherical ^{192}Ir source with steel encapsulation and a commercial HDR GammaMed Plus source. The radial source distance was varied within cylindrical water phantoms with outer radii ranging from 10 to 30 cm and heights from 20 to 60 cm. By application of this semiempirical method - originally developed for teletherapy dosimetry - it has been shown that factor $k_{Q,M}$ is closely correlated with a single variable, the fluence-weighted mean photon energy $\bar{E}_F$ at the point of measurement. The radial profiles of $\bar{E}_F$ obtained with either the commercial ^{192}Ir source or the two simplified source variants show little variation. The observed correlations between parameters $k_{Q,M}$ and $\bar{E}_F$ are represented by fitting formulae for all investigated detectors, and further variation of the detector type is foreseen. The herewith

Die mittlere Photonenenergie $\bar{E}_{\mathrm{F}}$ am Messort bestimmt den detektorspezifischen Strahlungsqualitäts-Korrektionsfaktor $k_{\mathrm{Q,M}}$ für die ^{192}Ir-Brachytherapie-Dosimetrie

Zusammenfassung

Angesichts der Typenvielfalt der für die Dosimetrie in der Brachytherapie eingesetzten Strahlungsdetektoren wird in dieser Arbeit die Energieabhängigkeit des zum Detektor gehörenden Strahlungsqualitäts-Korrektionsfaktors $k_{Q,M}$ analysiert. Dieser ist als Quotient aus den Ansprechvermögen unter Kalibrierbedingungen an einer ^{60}Co-Anlage und unter den in der Photonen-Brachytherapie am jeweiligen Messort M auftretenden Nicht-Referenz-Bedingungen definiert.

Untersucht wurden TLD-Detektoren, Radiochromfilme, ESR-Detektoren, Si-Dioden, ein Plastik-Szintillator, ein Einkristall-Diamant-Detektor und verschieden große Ionisationskammern unter Verwendung von Literaturdaten ihres energieabhängigen Ansprechvermögens. Monte-Carlo-Simulationen von Photonenfeldern der ^{192}Ir-Brachytherapie in zylindrischen Wasserphantomen mit Radien von 10 bis 30 cm und Höhen von 20 bis 60 cm bei Variation des radialen Quellenabstandes wurden für eine isotrope Punktquelle, ein kugelförmiges Quellenmodell mit Stahl-Ummantelung und eine kommerzielle HDR-GammaMed-Plus-Quelle durchgeführt. Mit Hilfe dieser bereits für die Teletherapie entwickelten

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* Corresponding author: Ndimofor Chofor, RadioOnkologische BerufsAusübungsGemeinschaft, Strahlentherapie Leer, Annenstraße 7, 26789 Leer, Germany.

E-mail: cmark23@hotmail.com (N. Chofor).

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established close correlation of radiation quality correction factor $k_{Q,M}$ with local mean photon energy $\bar{E}_F$ can be regarded as a simple regularity, facilitating the practical application of correction factor $k_{Q,M}$ for in-phantom dosimetry around ^{192}Ir brachytherapy sources. $\bar{E}_F$ values can be assessed by Monte Carlo simulation or measurement. A technique describing the local measurement of $\bar{E}_F$ will be published separately.

Keywords: Radiation quality, brachytherapy dosimetry, detector response, non-reference conditions, mean photon energy

semiempirischen Methode wurde eine enge Korrelation zwischen dem Faktor $k_{Q,M}$ und der fluenzgewichteten mittleren Photonenenergie $\bar{E}_F$ am Messort festgestellt. Im radialen Verlauf von $\bar{E}_F$ bestehen zwischen der kommerziellen Quelle und den beiden Quellenmodellen keine signifikanten Unterschiede. Für die untersuchten Detektoren wurden Anpassungsformeln für $k_{Q,M}$ als Funktion von $\bar{E}_F$ erstellt; Untersuchungen weiterer Detektoren sind vorgesehen. Die hier gefundene enge Korrelation zwischen dem Strahlungsqualitäts-Korrektionsfaktor $k_{Q,M}$ und der mittleren Photonenenergie $\bar{E}_F$ am Messort ist als eine einfache Gesetzmäßigkeit anzusehen, welche die praktische Anwendung von $k_{Q,M}$ bei der Dosimetrie in Phantomen in der Umgebung von ^{192}Ir-Quellen für die Brachytherapie erleichtert. Werte von $\bar{E}_F$ können sowohl durch Monte-Carlo-Simulation als auch durch Messung ermittelt werden. Eine Methode zur Messung von $\bar{E}_F$ soll in einer weiteren Publikation beschrieben werden.

Schlüsselwörter: Strahlungsqualität, Brachytherapie-Dosimetrie, Detektor-Ansprechvermögen, Nicht-Referenzbedingungen, mittlere Photonenenergie

1 Introduction

In the dosimetry of photon fields, the “radiation quality correction factor” $k_{Q,M}$ at the point of measurement, M, is the factor accounting for the energy dependence of the response of a radiation detector. The term “response” is here defined as the quotient of the detector reading and the absorbed dose to water at the point of measurement of the detector [1]; it has the same meaning as the term “absorbed dose sensitivity” [2]. Factor $k_{Q,M}$ (previous symbol: k_Q) is one in the group of correction factors to be applied in the conversion from the bias-corrected detector signal M into the desired absorbed dose to water D_Q at the point of measurement at radiation quality Q [1,2]

$$D_Q = M N_{Q_0} \prod_i k_i k_{Q,M} \tag{1}$$

where N_{Q_0} is the detector’s calibration factor, obtained at calibration radiation quality Q_0, and the product comprises all other correction factors k_i. The numerical value of factor $k_{Q,M}$ has to account for the photon spectrum at the point of measurement, M. Since the spectral contribution by Compton-scattered photons with reduced energies will depend not only on the spectrum of the photon source but also on the geometry of the scattering medium and on the position of the detector in this medium, the knowledge of $k_{Q,M}$ is essential for experimental dose determinations.

In the dosimetry of brachytherapy photon fields, dose measurements in phantoms - compared with dose calculations - have fewer applications, such as system controls, in-phantom and in-vivo treatment plan verifications when indicated, and dosimetric studies in unusual geometries not accounted for in standard computation codes [3,4]. But these applications give sufficient reason to provide reliable knowledge about the $k_{Q,M}$ values of the applied detectors. It is the goal of the present investigation to essentially reduce the uncertainties of experimental dosimetry in brachytherapy by providing a practicable access to determine the values of $k_{Q,M}$.

It has been a new insight that the quality correction factor $k_{Q,M}$ of gas- and liquid-filled as well as of solid-state dosimetric detectors is essentially a function of the mean photon energy $\bar{E}_F$ at the point of measurement, where $\bar{E}_F$ is the arithmetic mean of the spectral fluence $\Phi_E(E)$ of the photons at the point of measurement

$$\bar{E}_F = \int E\Phi_E(E)\mathrm{d}E \Big/ \int \Phi_E(E)\mathrm{d}E \tag{2}$$

This hitherto unknown regularity was first described by Scarboro *et* al for 6 MV photons and thermoluminescent detectors [5] as well as for optically stimulated luminescent detectors [6]. The same observation was made by Chofor *et al* for 6 and 15 MV photon beams, including beams without flattening filters, when the $k_{Q,M}$ values of an ionization chamber, of thermoluminescent detectors and of silicon diodes were studied [7,8]. In a communication concerned with ^{60}Co photon sources, the concept of the $k_{Q,M}$ vs. $\bar{E}_F$ correlation was introduced into brachytherapy photon dosimetry as well [9]. This project is here continued for three types of ^{192}Ir photon