# Correction factors for source strength determination in HDR brachytherapy using the in-phantom method☆

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## Abstract

*For the purpose of clinical source strength determination for HDR brachytherapy sources, the German society for Medical Physics (DGMP) recommends in their report 13 the usage of a solid state phantom (Krieger-phantom) with a thimble ionization chamber.*

*In this work, the calibration chain for the determination of the reference air–kerma rate $\dot{K}_{a,100}$ and reference dose rate to water $\dot{D}_{w,1}$ by ionization chamber measurement in the Krieger-phantom was modeled via Monte Carlo simulations. These calculations were used to determine global correction factors $k_{tot}$, which allows a user to directly convert the reading of an ionization chamber calibrated in terms of absorbed dose to water, into the desired quantity $\dot{K}_{a,100}$ or $\dot{D}_{w,1}$. The factor $k_{tot}$ was determined for four available $^{192}$Ir sources and one $^{60}$Co source with three different thimble ionization chambers. Finally, ionization chamber measurements on three μSelectron V2 HDR sources within the Krieger-phantom were performed and $\dot{K}_{a,100}$ was determined according to three different methods: 1) using a calibration factor in terms of absorbed dose to water with the global correction factor $(k_{tot})_{\dot{K}_{a,100}}$ according DGMP 13 2) using a global correction factor calculated via Monte Carlo 3) using a direct reference air–kerma rate calibration factor determined by the national metrology institute PTB.*

*The comparison of Monte Carlo based $(k_{tot})_{\dot{K}_{a,100}}$ with those from DGMP 13 showed that the DGMP data were systematically smaller by about 2-2.5%. The*

## Korrektionsfaktoren zur Bestimmung der Quellenstärke von HDR-Brachytherapie-Quellen mittels der Phantom-Methode

## Zusammenfassung

*Für die klinische Bestimmung der Quellenstärke von HDR-Brachytherapie-Quellen empfiehlt die Deutsche Gesellschaft für Medizinische Physik (DGMP) in ihrem Bericht Nr. 13 die Verwendung eines Festkörperphantoms (Krieger-Phantom) mit Kompaktionisationskammer.*

*In dieser Arbeit wurde die komplette Kalibrierkette zur Bestimmung der Referenz-Luftkerma-Leistung $\dot{K}_{a,100}$ und der Referenz-Wasserenergiedosis-Leistung $\dot{D}_{w,1}$ mittels Ionisationskammermessung im Krieger-Phantom mit Hilfe von Monte-Carlo-Simulationen nachempfunden. Die Berechnungen wurden genutzt, um einen globalen Korrektionsfaktor $k_{tot}$ zu bestimmen, der es dem Anwender erlaubt, die Anzeige der in Wasserenergiedosis kalibrierten Ionisationskammer in die gewünschte Größe $\dot{K}_{a,100}$ bzw. $\dot{D}_{w,1}$ zu konvertieren. Der Faktor $k_{tot}$ wurde für vier verschiedene $^{192}$Ir-Quellen und eine $^{60}$Co–Quelle mit jeweils drei unterschiedlichen Kompaktionisationskammern bestimmt. Schließlich wurden Messungen mit den Ionisationskammern im Krieger-Phantom an drei unterschiedlichen μSelectron-V2-Quellen durchgeführt und daraus die Größe $\dot{K}_{a,100}$ nach drei unterschiedlichen Methoden bestimmt: 1)*

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*experimentally determined $(k_{tot})_{\dot{K}_{a,100}}$, based on the direct $\dot{K}_{a,100}$ calibration were also systematically smaller by about 1.5%. Despite of these systematical deviations, the agreement of the different methods was in almost all cases within the 1σ level of confidence of the interval of their respective uncertainties in a Gaussian distribution. The application of Monte Carlo based $(k_{tot})_{\dot{K}_{a,100}}$ for the determination of $\dot{K}_{a,100}$ for three μSelectron V2 sources revealed the smallest deviation to the manufacturer's source certificate. With the calculated $(k_{tot})_{\dot{K}_{a,100}}$ for a $^{60}Co$ source, the user is now able to accurately determine $\dot{K}_{a,100}$ of a HDR $^{60}Co$ source via in-phantom measurement. Moreover, using the presented global correction factor $(k_{tot})_{\dot{D}_{w,1}}$, the user is able to determine the future source specification quantity $\dot{D}_{w,1}$ with the same in-phantom setup.*

**Keywords:** HDR brachytherapy, source strength, Monte Carlo simulations, solid state phantom, ionization chamber, global correction factor

*unter Verwendung des Wasserenergiedosis-Kalibrierfaktors in Kombination mit dem globalen Korrektionsfaktor $(k_{tot})_{\dot{K}_{a,100}}$ nach DGMP 13, 2) Verwendung des globalen Faktors aus einer Monte–Carlo–Simulation, 3) mit Hilfe des von der Physikalisch–Technischen Bundesanstalt (PTB) bestimmten direkten Referenz–Luftkerma–Kalibrierfaktors. Der Vergleich der Monte-Carlo-basierten Faktoren $(k_{tot})_{\dot{K}_{a,100}}$, mit denen des DGMP Bericht 13, zeigte, dass die DGMP–Daten systematisch um etwa 2-2.5% geringer sind. Die experimentell bestimmten Faktoren $(k_{tot})_{\dot{K}_{a,100}}$, welche auf der direkten $\dot{K}_{a,100}$-Kalibrierung basieren, waren ebenfalls systematisch um etwa 1.5% geringer. Trotz dieser systematischen Abweichungen lag die Übereinstimmung der verschiedenen Methoden in nahezu allen Fällen innerhalb des 1σ-Konfidenzintervalls einer Gaußverteilung ihrer entsprechenden Unsicherheiten. Die Anwendung des Monte-Carlo-basierten Korrektionsfaktors zur Bestimmung von $\dot{K}_{a,100}$ für drei unterschiedliche Quellen vom Typ μSelectron V2 ergab die geringste Abweichung zum Quellenzertifikat des Herstellers. Mit dem berechneten Faktor $(k_{tot})_{\dot{K}_{a,100}}$ für eine $^{60}Co$-Quelle ist der Anwender in der Lage $\dot{K}_{a,100}$ einer HDR $^{60}Co$-Quelle mittels der Phantom-Methode zu bestimmen. Weiterhin ist es mit den präsentierten globalen Korrektionsfaktoren $(k_{tot})_{\dot{D}_{w,1}}$ möglich, mit Hilfe des bekannten Phantom-Messaufbaus, die zukünftige Quellen-Spezifikationsgröße $\dot{D}_{w,1}$ zu bestimmen.*

**Schlüsselwörter:** HDR–Brachytherapie, Quellenstärke, Monte-Carlo-Simulationen, Festkörperphantom, Ionisationskammer, globaler Korrektionsfaktor

## 1 Introduction

A key step for accurate dose delivery in radiotherapy is the determination of the *absorbed dose to water* $D_w$. All current dosimetry protocols [1,2] in teletherapy are based on this quantity and ionization chambers are nowadays usually calibrated in terms of $D_w$. In contrast, the dosimetry of photon brachytherapy is usually still based on the concept of air-kerma [3]. Therefore, the ICRU (international commission on radiation units) recommends the use of *reference air-kerma rate* $\dot{K}_{a,100}$ [4–6] for the specification of brachytherapy photon sources. The AAPM (American Association of Physicists in Medicine) recommends the use of the *air-kerma strength* $S_k$ [7,8], which is slightly different concerning the definition. Nevertheless, both quantities provide the same numerical value at a source distance of 1 m. Prior to the calculation of dose distributions in water, it is necessary to convert the kerma based measure into *absorbed reference dose rate to water* $\dot{D}_{w,1}$ (absorbed dose rate to water in water for a reference distance of 1 cm to the source). This further requires the application of a *dose rate constant* $\Lambda = \dot{D}_{w,1}/S_k$ [8]. However, the determination of this source type specific constant is associated with comparatively large standard uncertainties of up to 3% [9].

The reason for the inconsistency between the metrological base quantities $D_w$ and $\dot{K}_{a,100}$ is based on the fact that primary standards as well as secondary or transfer standards of *absorbed dose to water* $D_w$ were not available for brachytherapy photon sources up until now. However, as part of a European research project (EMRP) [10] those standards were developed in the past three years [11–15] and *absorbed reference dose rate to water* $\dot{D}_{w,1}$ is the intended base quantity of the future. With the newly developed primary standards, Selbach *et al.* [11] were able to determine *dose rate constants* $\Lambda$ for different types of $^{192}$Ir high dose rate (HDR) brachytherapy sources with combined standard uncertainties of <2%. Accordingly the uncertainty in the determination of absorbed dose rate to water at a distance of 1 cm from the source $\dot{D}_{w,1}$