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Brachytherapy

Experience from long-term monitoring of *RAKR* ratios in ^{192}Ir brachytherapy

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Abstract

***Background*: Ratios of values of brachytherapy source strengths, as measured by hospitals and vendors, comprise constant differences as, e.g., systematic errors in ion chamber calibration factors and measurement setup. Such ratios therefore have the potential to reveal the systematic changes in routines or calibration services at either the hospital or the vendor laboratory, which could otherwise be hidden by the uncertainty in the source strength values.**

***Methods*: The *RAKR* of each new source in 13 afterloading units at five hospitals were measured by well-type ion chambers and compared to values for the same source stated on vendor certificates.**

***Results*: Differences from unity in the ratios of *RAKR* values determined by hospitals and vendors are most often small and stable around their mean values to within ±1.5%. Larger deviations are rare but occur. A decreasing ratio, seen at two hospitals for the same source, was useful in detecting an erroneous pressure gauge at the vendor's site.**

***Conclusions*: Establishing a mean ratio of *RAKR* values, as measured at the hospital and supplied on the vendor certificate, and monitoring this as a function of time are an easy way for the early detection of problems with equipment or routines at either the hospital or the vendor site.**

Keywords: ^{192}Ir; HDR; PDR; Reference air-kerma rate

It is important to determine the absorbed dose in radiotherapy as accurately as possible as the dose is the basis for reliable evaluations and comparisons of treatment techniques and radiation modalities, see, e.g., [1] or [2]. The uncertainty in absorbed dose can be divided into parts of either clinical or physical origin and is in brachytherapy estimated as 5–10%, depending on application ([3]). A major contribution to the physical part of the uncertainty stems from that in the source strength, to which the absorbed dose is directly proportional ([4]). Source strength is determined in terms of the reference air-kerma rate, *RAKR* ([5,6]) or the air-kerma strength, S_K, ([4]) using ionization chambers with calibration factors traceable to standard dosimetry laboratories. The uncertainty in ion chamber calibration factors for high and pulsed dose rate (HDR and PDR) ^{192}Ir brachytherapy is approximately ±2.5% (coverage factor of $k = 2$) when these are calibrated against interim standards ([7–9]). The uncertainty in source strength thus contributes significantly to the total uncertainty and several advisories recommend that hospitals verify the strength of each new source ([3,10,11]).

The uncertainty in source strength can be divided into contributions from measurement of the ionization current (or charge) and from the ion chamber calibration factor. The uncertainty in the ionization current is minimized through the use of well-type ionization chambers designed for brachytherapy (see, e.g., [12]). These instruments are stable and easy to handle, produce high ionization currents, allow for fast and reproducible setups, and are comparatively insensitive to room-scatter ([13]). The use of such chambers at hospitals and secondary standard dosimetry laboratories is recommended by, e.g., the IAEA ([10]). Due to the lack of primary standards (the only exception being the one recently launched at NPL ([14]), calibration laboratories provide calibrations against interim standards based on interpolation between other radiation qualities ([7–9]). Uncertainties in calibration factors traceable to the interim

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standards are around three times higher than those traceable to the primary standard.

^{192}Ir brachytherapy sources used in HDR and PDR treatments are exchanged with an interval of around 3 months due to the 73.83 days half-life of the isotope. Each source is delivered with a vendor-issued certificate stating its strength. Hospitals that verify the strength of each source hence have two independent measures of its *RAKR* value available. The ratio of these two values comprises variations in the systematic errors between the vendor and the hospital. It can be noted that some of these are constant over long-time periods such as that in the traceability of chamber calibration factors. The ratio therefore has potential to reveal systematic differences that could otherwise be hidden by the uncertainty of the *RAKR* values.

This work reports on experience gained from the long-term monitoring of the ratios of *RAKR* values between Swedish hospitals and their vendors. Five hospitals, having followed in total 13 afterloading units, containing sources of 6 different types, participated in the study. The hospitals all use well-type ionization chambers designed for brachytherapy and have calibration factors for these that are traceable to the HDR ^{192}Ir interpolation standard at the University of Wisconsin Accredited Dosimetry Calibration Laboratory ([7]). In 11 of these units one source was also measured using redundant equipment from the Swedish secondary standard dosimetry laboratory, as part of a recent audit on source strength determination ([15]).

Theory

Proportionality between source strength and absorbed dose

Most brachytherapy treatment planning systems are currently based on the TG-43 formalism, which allows the calculation of 3D dose-distributions around brachytherapy sources in terms of absorbed dose to water. This absorbed dose is directly proportional to the brachytherapy source strength in terms of either the reference air-kerma rate, *RAKR* (used in this report) or the air-kerma strength, S_K, for definitions see references [4—6].

Uncertainty in source strength determination

Using a calibrated well-type ion chamber, the *RAKR* of an ^{192}Ir source is determined as

$$RAKR = N_{RAKR,^{192}\mathrm{Ir}} \cdot I_{\mathrm{ion}} \tag{1}$$

where $N_{RAKR,^{192}\mathrm{Ir}}$ is the ion chamber calibration factor and I_{ion} is the ionization current measured in accordance with the conditions set up in the chamber calibration certificate and corrected for influence quantities such as temperature and pressure, using calibrated equipment (see reference [10] for further details). The uncertainty in $N_{RAKR,^{192}\mathrm{Ir}}$ is, when traceable to interim standards, typically around ± 2.5% at a coverage factor of $k = 2$ ([7—9]). It decreases to ±0.8% for the NPL primary standard ([14])).

Vendor issued certificates often state an uncertainty in *RAKR* of ±5% at a coverage factor of $k = 3$ which equals ±3% at $k = 2$. Assuming that vendors determine *RAKR* according to Eq. (1) and are traceable to interim standards, yields an uncertainty in their determination of I_{ion}, that is, ±1% at $k = 2$ (following the Guide to Expression of Uncertainties in Measurements in adding uncertainties [16]). For comparison, an uncertainty in I_{ion} of ±0.4% at $k = 2$ was estimated, using equipment from the Swedish secondary standard dosimetry laboratory ([15]).

The ratio of *RAKR* values

The ratio of *RAKR* values between a hospital and a vendor is given by

$$\frac{RAKR_{\mathrm{hospital}}(t)}{RAKR_{\mathrm{vendor}}(t)} = \frac{N_{RAKR,^{192}\mathrm{Ir,hospital's\ chamber}}}{N_{RAKR,^{192}\mathrm{Ir,vendor's\ chamber}}} \cdot \frac{I_{\mathrm{ion,hospital}}(t)}{I_{\mathrm{ion,vendor}}(t)} \tag{2}$$

where decay corrections to compare the values at the same time, t, must be performed.

A mean value of the ratio can be established after a number of source exchanges have taken place. The ratio comprises differences between the hospital and the vendor and it can be noted that some of these are constant. Examples of constant differences are that between the two chamber calibration factors but also differences in setup of equipment, room-scatter conditions etc. are included in the ratio. For these reasons, the ratio can differ from unity and be source type and hospital specific. For periods without significant changes to either the vendor's or the hospital's calibration factors and provided that the same measurement routine is used each time, it should be possible to reproduce the mean value of the ratio to within the limit set by the uncertainty in the ratio of the two ionization currents.

The uncertainty in the ratio of the two currents can be estimated as approximately ±1.5% at a coverage factor of $k = 2$ (assuming that hospitals determine ionization currents with similar uncertainty as vendors, i.e., ±1% at $k = 2$, and following the Guide to Expression of Uncertainties in Measurements in adding uncertainties [16]). The ratio of *RAKR* values can thus be expected to be reproducible within ±1.5%, which is a more sensitive figure than the ±3% uncertainty in the *RAKR* value alone. The ratio could hence reveal also minor changes in measurement routines and changes to ion chamber calibration factors used by either the hospital or the vendor.

Methods

The *RAKR* of each new source was measured by physicists at the hospitals using well-type ion chambers designed for brachytherapy. Calibrated electrometers, thermometers and pressure gauges were used. An identical procedure was used each time, following written protocols. The time since recalibration of ion chambers was longer than the 2-year period recommended by, e.g., the IAEA ([10]); however, constancy controls were performed regularly. Some hospitals use ^{60}Co beams or ^{137}Cs check sources to control the constancy of their equipment, while some instead check their equipment against a redundant system. The participating hospitals are listed in Table 1, which also lists their afterloading units, source types and the corresponding vendors.