Verification of dose point kernels for ^{192}Ir brachytherapy

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Abstract

Purpose:

Evaluate the use of film in a spiral phantom to verify the dose point kernels and maps required for brachytherapy treatment planning with ^{192}Ir.

Methods and Materials:

EDR2 film (Extended Dose Rate, Eastman Kodak Co. Rochester, NY) and GafChromic EBT film from International Specialty Products, Inc.(Wayne, NJ) were cut to fit the spiral groove of a 18-cm diameter solid water phantom designed for IMRT QA (The Gammex RMI 469 IMRT (Gammex RMI, Middleton, WI) and exposed to acquire a dose versus distance map. The radioactive source pellet of about 7 Ci ^{192}Ir was located at the center of the spiral phantom with the central axis normal to the film. The exposure time was calculated to deliver 7 Gy to the proximal end of the film located 1 cm from the source. The dose point kernel was measured with a 0.6 cc Farmer chamber placed at various distances from the radioactive pellet in a 30 cm stack of Solid Water™ slabs. The recorded Image on each film was scanned with a Vidar 16 bit scanner and analyzed with the Radiological Imaging Technology software (RIT V4.1, Radiological Imaging Technology, Colorado Spring, CO). The doses measured at 1 to 7 cm depth in Solid Water™ were assigned to distances along the spiral image. These data provided a calibration of optical density values measured from the spiral images. Corrections for obliquity was neglected, and the films assumed to be exposed to a broad beam. Thus any change in optical density with energy was obviated. The dose maps furnished from each film were compared with published isodose maps used as input for treatment planning systems and found to be in close agreement.

Conclusions:

This study confirmed that the images recorded on EDR2 and EBT films from an ^{192}Ir pellet source exposed in a spiral phantom can be used to verify the dose point kernels and isodose maps required for treatment planning. The method can be extended to other radionuclides such as ^{125}I and ^{103}Pd used for LDR brachytherapy.

Introduction

Measured dose point kernels in the range of 1mm to 10 cm are important for characterizing the 3-D radial functions required in treatment planning with radionuclides currently employed in HDR and LDR. For prostate, breast and mammocyte HDR, the dwell positions are usually separated by 2.5 to 5 cm. The aim of this study is to test the feasibility of using the image recorded with the extended dose range film EDR2 and the EBT films in a a 18-cm diameter Solid Water™ spiral phantom designed for IMRT quality assurance (QA) to determine the dose point kernel and dose distribution for the ^{192}Ir source pellet used in the Nucletron Microselectron HDR system for planning and treatment.

Methods and Materials:

The spiral IMRT QA phantom was modified by drilling a 1.2 mm diameter hole at the center to hold a catheter for the ^{192}Ir pellet from the Microselectron treatment system. A 3 by 12 inch strip of EDR2 or EBT film was loaded in the spiral groove with one end abutting the proximal end of the groove at 1 cm from the center of the phantom. The time required to deliver 700 cGy to 1cm from a 7 Ci ^{192}Ir source was calculated using the Nucletron Plato treatment planning software. The exposed EDR2 and EBT films were scanned with a Vidar 16 bit scanner and the resultant images analyzed with the RIT software. The dose point kernel for ^{192}Ir was measured using a 0.6 cc Framer chambers in a 30 cm diameter block of solid water. The nC readings at 3 to 15 cm from the ^{192}Ir source were converted to cGy using the TG-21 formalism (Goetsch et al. 1991). The cGy from 1 to 30 cm along the spiral corresponding to 1 to 7 cm radial distance were calculated from the ion chamber readings and used to calibrate the optical densities of the films. The measured dose at various distances was used as input data for the RIT image analysis software along the central axis of the source. The RIT software was then used to provide the dose at all other points of the recorded images.

The resultant dose distributions were compared with published data calculated from the treatment planning system. Good agreement was found with the dose point kernel measured with the ion chamber and TG-43 report data, and the resultant isodose distributions compared with data procured with dose points measured with multiple miniature TLD sampling (A. S. Kirov et al 1995).

Figure 1. IMRT Phantom components

A CT scan image of the phantom was acquired to verify its geometry. Figure 2 shows the spiral groove and small cavities for MOSFET detectors or TLD capsules. The film is loaded in the spiral groove and exposed with a light tight cover for a dwell time.

Figure 2. Shows the process of converting the linear distance along the spiral to the radial distance from the source in the central axis.

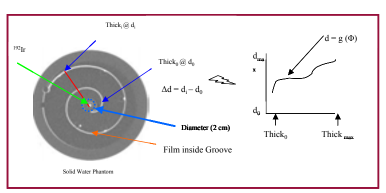


Figure 2. CT image of IMRT phantom- showing spiral groove.

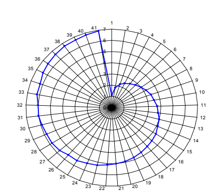


Figure 2.1a Polar representation of curve in figure 2.1

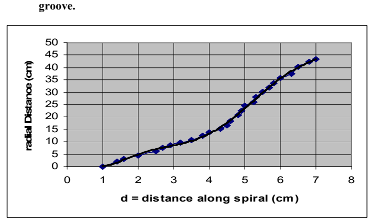


Figure 2.1b Functional relationship between the radial distance to a point and its distance along the spiral from a reference point

Radial Distance (cm) = $0.0213d^6 - 0.529d^5 + 5.0413d^4 - 23.064d^3 + 52.943d^2 - 53.102d + 18.882$ R2 = 0.9985

Where d is the linear distance along the film

Figure 3 illustrates the steps followed to calibrate each film. Each film was irradiated with the Iridium source using different thickness of Solid Water™. The dose was also calculated with the Plato brachytherapy software.

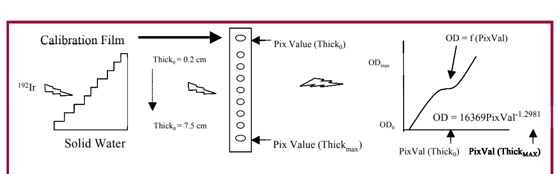


Figure 3. Procedure to calibrate EDR2 & EBT films

Figure 4. Shows the ion chamber in a solid water stack to measure the dose point kernel. The conversion of film optical density to dose was procured by measuring the dose at selected points in the solid water with a 0.6 cc Farmer ion chamber. The nC recorded at selected distances from the source was converted to cGy using the TG-21 formalism

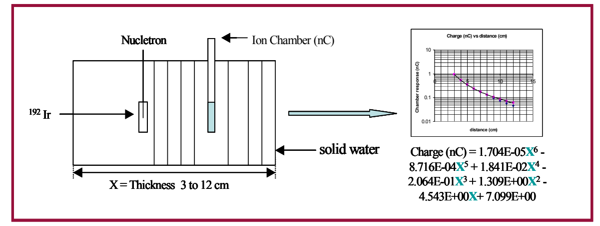


Figure 4. Solid Water™ thickness vs. dose calibration

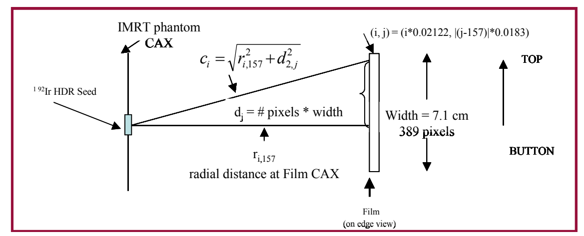


Figure 5. Side view of calculation geometry

Figure 6 shows the angles ϕ and θ formed by the radial distance from the center of the source to the reference line (line 157) on the EDR2 film and the superior and inferior edges of the film. the angles ϕ_1 and θ_1 at the shortest radial distance to the film and ϕ_2 and θ_2 at the farthest radial distance to the source.

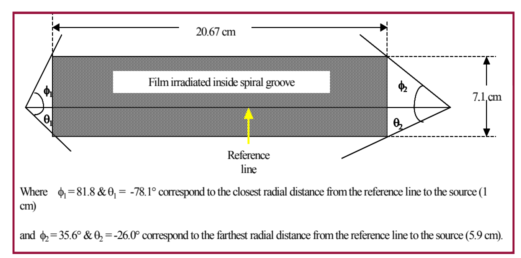


Figure 6 Diagram showing the angles ϕ and θ.

Figure 7 shows the pixel size calculated from the number of pixels and the dimensions of the scanned film.

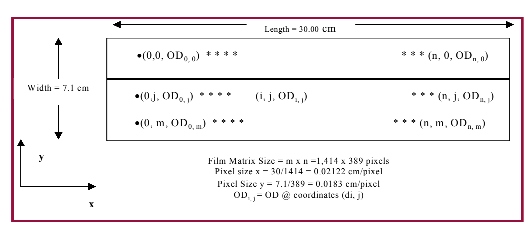


Figure 7 Diagram showing the calculation of pixel size

Figure 8 shows the process of conversion of optical density or pixel value to dose. In this study all conversion and calculations were performed using the MathCad mathematical software version 12.1

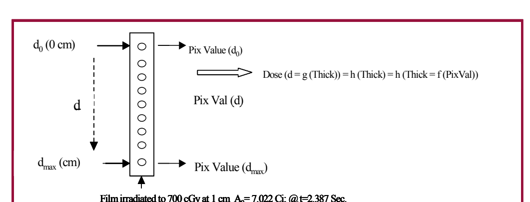
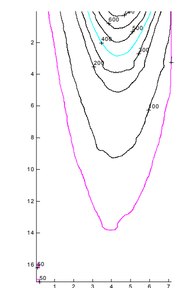


Figure 8. Calculation of Dose (cGy)/Pixel for the film in the spiral phantom.

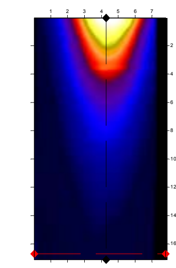
Results

After the films were scanned either with a Vidar 16-bit scanner (EDR2 film) or with a mocrodensitometer (Photoelectron Co.) they were analyzed using the RIT film analysis software. The isodose map and dose profile along the length of the spiral were calculated to a number of selected distances from the center of the source. The resultant dose point kernel was compared with published data. Corrections for obliquity and sensitivity of the chamber with energy were ignored since these are less than 2 %. The dose for a particular thickness of Solid Water™ was fit to a 6-degree polynomial.

Figure 9a shows an isodose profile in a plane that intersects the center of the cylindrical source. Figure 9b shows a color map of the irradiated EDR2 film.



9a Isodose profile along spiral



9b. Orthogonal profile along the longest dimension of the image

Figure 10. Dose profile along the spiral CAX of the EDR2 film The radial dose is calculated from this profile.

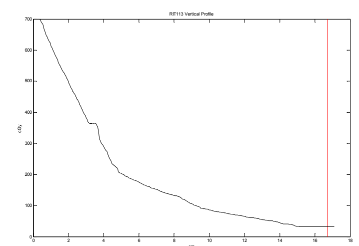


Figure 10. A profile along the longest dimension of the EDR2 film

Figure 11. Shows the dose versus the radial distance in the spiral and the corresponding dose along the EDR2 film.

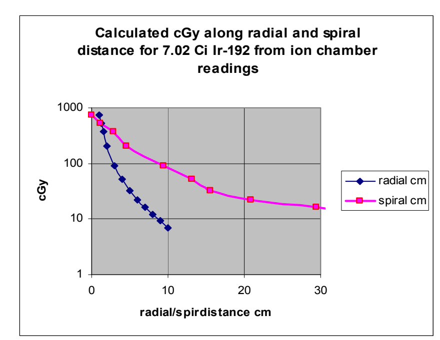
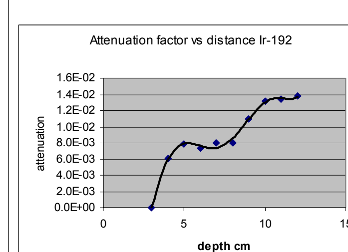


Figure 11. Radial function and dose along the EDR2 film in the spiral phantom.



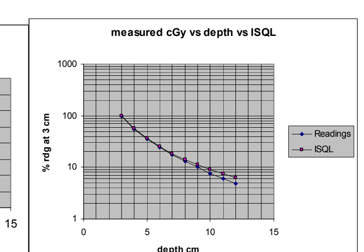
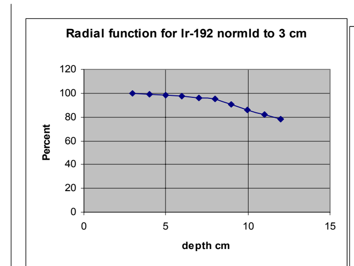


Figure 12a and 12b. Show the attenuation factor of the ^{192}Ir spectrum through different thickness of Solid Water.™ and the corresponding ion chamber reading vs. the inverse of the square of the thickness of Solid Water.™



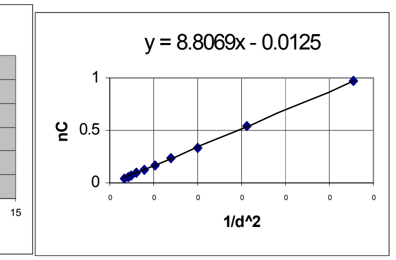


Figure 13a. Shows the measured radial function normalized at 3 cm, figure 13b shown the location of the virtual source.

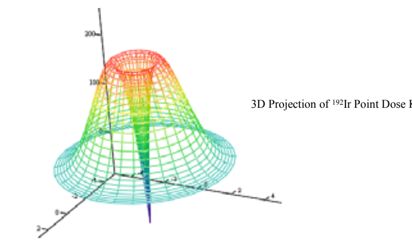


Figure 14 shows a 3D rendering of the radial function generated using MathCad version 12. All the data from 1 cm to the source are set to zero.

Figure 15a. Shows the calibration of the EBT GafChromic film with the ^{192}Ir source and a 6 MV photon beam from a Varian linear accelerator. There is not an energy dependence. Fig 15b. Shows three pieces of EBT film irradiated to 7, 14, and 28 Gy respectively.

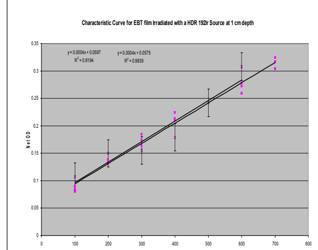


Figure 16a. Comparison of optical density vs. dose (cGy) to the EBT GafChromic film

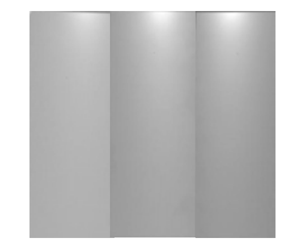


Figure 16b. EBT GafChromic Film irradiated inside spiral phantom.

a. 7 Gy b. 14 Gy c. 28Gy

Conclusions

Excellent agreement was found between the dose point kernel measured with a Farmer chamber and published values for ^{192}Ir. The RIT software could be calibrated simply along the central axis of a source pellet and used to convert the optical density at adjacent locations/distances from the source. The attenuation data observed for ^{192}Ir from ion chamber measurements separated the attenuation of low energy from the photons emitted from 300 to 400 KeV.

This simple approach was used to verify the dose point kernel currently used for ^{192}Ir. The method could be extended to verify the dose point kernels for other radionuclides such as ^{125}I and ^{103}Pd for LDR brachytherapy and ^{169}Yb proposed as an alternative for HDR. Special software should further developed to translate the dose map from the spiral to a 3-D volume dose distribution. A larger spiral phantom can be designed to verify the dose point distribution above and below the source pellet. The spiral groove should be extended to verify the dose maps from 1 to 10 mm. This method can also be used to test the resultant doses from 2 or more individual dwell times and/or separated by typical step sizes of 2.5, 5 and 10 mm.

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