Dosimetry of the Amersham 6711 Oncoseed™ using PRESAGE™ and optical CT

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1. Introduction
In the UK, prostate cancer is the most commonly occurring cancer in men, responsible for the death of approximately 10,000 men every year. The number of prostate cancer incidents is expected to increase due to improved screening and diagnostic techniques, whilst the mortality rate continues to fall as the variety of available treatments increases.

One such treatment is prostatic brachytherapy. Typically, a total of 80-90 I-125 seeds is surgically implanted and left inside the prostate permanently to obtain local control of the malignant prostate cancer. Prior to the surgical procedure, a treatment plan is created on a computer planning system. There is currently no 3-D method to verify whether the planning system model matches the actual delivery of radiation dose to the prostate.

2. Dosimetry of the 6711 Seed
The Iodine-125 seed Model 6711 (see Figure 11), manufactured by Amersham Health also known as OncoSeed™, with average energy of 28 keV and half-life of 59.4 days is commonly used throughout oncology centres worldwide. The seeds are available singly or in strands of ten and marketed as the RAPID Strand™ Model IMC 7000. To investigate the feasibility of solid polymer dosimetry as an accurate 3-D dose verification applied to prostatic brachytherapy, the model 6711 Oncoseed™ was

Figure 1. I-125 Model 6711 Oncoseed™
selected for a pilot study comparing experimental methods and Monte Carlo simulations. This study is presented as a typical case study of what can be achieved using solid polymer dosimetry. The dosimetric characteristics of the Oncoseed™ have been well documented by different authors. This enables the verification and cross comparison with this study.

The updated Dosimetry of Interstitial Brachytherapy Sources Report [1], was compiled by Task Group 43 of the Radiation Therapy Committee of the American Association of Physicists in Medicine (AAPM) to review publications on the dosimetry of interstitial brachytherapy sources. The report includes recommendations for a dosimetry protocol together with formalism for dose calculations and a data set for the values of dosimetry parameters. The report defines the necessary physical quantities for dosimetry of brachytherapy sources. One of the parameters is the anisotropy function, \( F(r, \theta) \), defined in Eq. (1). It describes the variation in dose as a function of radial distance \( r \) from the source centre and polar angle \( \theta \) with respect to the longitudinal source axis.

\[
F(r, \theta) = \frac{D(r, \theta)}{D(r, \theta_0)} \frac{G_{1}(r, \theta_0)}{G_{1}(r, \theta)}
\]

The plane corresponding to \( (r, \theta_0) \) is the transverse bisector of the source \( \theta_0 = 90^\circ \). \( D(r, \theta) \) is the dose rate at \( (r, \theta) \), \( G_{1}(r, \theta) \) is the geometry function, which takes account of the non point-source nature of the seed. Note that the source is axially symmetric, so the dose rate, geometry function and anisotropy function are the same for all azimuthal angles. \( F(r, \theta_0) \) is unity by definition, on the transverse plane but decreases as \( \theta \) approaches 0\(^\circ\) or 180\(^\circ\), as encapsulation thickness increases, and as photon energy decreases.

3. Current Published Results
Nath et al [2] measured the anisotropy function in 1993 in a solid water phantom using TLD dosimeters. In 2001, Capote et al [3] calculated \( F(r, \theta) \) in an EGS4 Monte Carlo study. At angles over 40\(^\circ\), both Nath and Capote’s \( F(r, \theta) \) results show anisotropy values greater than unity close to the source.

To date, the EGS4 Monte Carlo dataset published by Weaver in 1998 [4] is the most uniform and complete as compared to the “noisy” anisotropy functions by Nath et al and Capote et al. It has been recommended by the updated AAPM TG-43 as the consensus \( F(r, \theta) \) values for seed model 6711.

It is a matter of considerable concern that even for a well characterised and widely used seed there are differences of up to 21% in \( F(r, \theta) \) between the various published values. The differences are found to be high at distances close to the seed (1 cm to 3 cm) and translate directly to the dose rate. This is a severe error compared with that typically found in external beam therapy.

The large differences in anisotropy functions found in both Nath and Capote results suggest that further investigation at distances close to the seed is required. With the predicted precision in relative measurements of < 5\%, the use of solid polymer dosimetry measurements may be the solution and this provides the rationale for this study. Furthermore, one suggested explanation for the discrepancies between previous studies is that the physical characteristics of the seeds themselves (e.g. weld thickness) are not constant and hence the correct inputs to the Monte Carlo simulation are unknown. If this is so, then a routine experimental validation of each seed batch might be of considerable utility.

4. Methods
Previous polymer gel dosimetry studies [5, 6] have not been totally successful, due to oxygen contamination and other complications. The solid polyurethane-based dosimeter PRESAGE™ [7] is a new type of solid dosimeter currently applied to prostatic brachytherapy dosimetry in our centre. The dosimeter is transparent, rigid and easily machineable, is stable during a prolonged irradiation period, and has good post-irradiation storage properties. It has a linear response at low energies and is insensitive to oxygen, unlike many previous polymer gels.
Table 1. Percentage difference comparison of \( F(r, \theta) \) with the consensus values at 1cm

| Authors                                   | Polar angle \( \theta \) (degrees) | Percentage differences with consensus results |
|-------------------------------------------|-------------------------------------|-----------------------------------------------|
|                                           | 0        | 10      | 20      | 30      | 40      | 50      | 60      | 70      | 80      | 90      |
| Weaver (Consensus) Anisotropy functions   | 0.370    | 0.537   | 0.705   | 0.834   | 0.925   | 0.972   | 0.991   | 0.996   | 1.000   | 1       |
| Nath (TLD)                                | -5.41    | -21.23  | -10.92  | -0.96   | 3.03    | 2.88    | 3.94    | 4.42    | 2.00    | 0.00    |
| Capote (EGS4)                             | -15.41   | -10.24  | -0.57   | 0.72    | 0.32    | 1.75    | 3.43    | 4.32    | 4.20    | 0.00    |

Figure 2. (a) PRESSAGE™ dosimeter side view inside scanning tank, (b) Optical-CT single projection (Total of 1000 projections over 180°), (c) Optical-CT single slice reconstruction (Pixel size: 0.36 mm², slice thickness: 0.18 mm), (d) Line profile across reconstruction image

A brachytherapy experiment was conducted over a period of six weeks. A hole 1.3 mm in diameter and 1.5 cm in depth was drilled in the PRESAGE™ solid dosimeter. A seed was inserted via the prepared channel and allowed to reside for a set amount of time. The average dose at 1 cm after one week of irradiation was around 1 Gy. The optical-CT results (Figure 2) have been cross-compared with Monte Carlo calculation results.

The anisotropy functions obtained through the initial Optical-CT experiment [8] and Monte Carlo results have shown good mutual agreement. This is a work in progress, but first estimates suggest that the average percentage difference with the consensus values by Weaver et al will be below 5%.

5. References

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