Water equivalency evaluation of PRESAGE® dosimeters for dosimetry of Cs-137 and Ir-192 brachytherapy sources

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Abstract. A major challenge in brachytherapy dosimetry is the measurement of steep dose gradients. This can be achieved with a high spatial resolution three dimensional (3D) dosimeter. PRESAGE® is a polyurethane based dosimeter which is suitable for 3D dosimetry. Since an ideal dosimeter is radiologically water equivalent, we have investigated the relative dose response of three different PRESAGE® formulations, two with a lower chloride and bromide content than original one, for Cs-137 and Ir-192 brachytherapy sources. Doses were calculated using the EGSnrc Monte Carlo package. Our results indicate that PRESAGE® dosimeters are suitable for relative dose measurement of Cs-137 and Ir-192 brachytherapy sources and the lower halogen content PRESAGE® dosimeters are more water equivalent than the original formulation.

1. Introduction
Cesium-137 and Iridium-192 are two isotopes commonly used for brachytherapy treatments of gynaecologic and prostate cancer. The low dose rate (LDR) Cs-137 source has a half life of 30 years and emits photons with a mean energy of 0.662 MeV. The high dose rate (HDR) microSelectron Ir-192 source has a half life of 74 days and a spectrum of emitted photons with an average energy of 0.37 MeV. According to the American Association of Physicist in Medicine (AAPM) recommendations, the dosimetry of these sources can be performed with a thermoluminescent dosimeter (TLD) [1]. However, because of the steep dose gradients, dose measurements are difficult close to the source. In addition, the TLDs only provide point dose information and would require a large number of them to provide two or three dimensional dosimetric information. Therefore, 3D dosimetry techniques such as polymer gel dosimetry are needed to improve spatial resolution in brachytherapy dosimetry [2-5].

PRESAGE® is a solid, transparent dosimeter made of polyurethane and is suitable for 3D dosimetry in modern radiation treatment techniques [6]. PRESAGE® has a number of advantages over other 3D gel and polymer dosimeters including: being insensitive to oxygen contamination, being machinable and moldable to variety of shapes and sizes, and being preferentially absorbing rather than scattering which facilitates high accuracy readout by optical CT [7]. A previous study has shown that PRESAGE® with optical CT has the potential to be used for Ir-192 brachytherapy dosimetry [8]. However, for a dosimeter to be used in brachytherapy dosimetry, it should exhibit water equivalent
properties. This means that the absorption and scattering of radiation in a given thickness of material should be comparable to that of water.

PRESAGE® is another formulation of PRESAGE and it was found that the PRESAGE® original formulation has an effective atomic number ($Z_{\text{eff}} = 8.65$) that is 17% higher than the value of water and does not generally exhibit good water equivalent radiological properties [9]. Two new formulations of PRESAGE® dosimeters have recently been developed, with lower halogen contents (giving $Z_{\text{eff}} = 7.69$ and 7.74) to improve performance as a 3D dosimeter and to improve water equivalency.

In this work, we calculated the relative dose distribution in the three different PRESAGE® dosimeters for Cs-137 and Ir-192 brachytherapy sources using the EGSnrc Monte Carlo code. We have compared the relative doses in the dosimeters with the relative depth dose in water.

2. Method and Materials

The elemental composition of each PRESAGE® formulation was calculated using their molecular formulas. These are summarized in Table 1. We henceforth refer to the lower halogen content PRESAGE® formulations as (LHP1) and (LHP2), and we refer to the original PRESAGE® as (OP). All the three PRESAGE® formulations have been provided by the same manufacturer (Heuris Pharma, New Jersey, USA).

| Material       | Formula                  | $w_H$ | $w_C$ | $w_N$ | $w_O$ | $w_S$ | $w_{Cl}$ | $w_{Br}$ |
|----------------|--------------------------|-------|-------|-------|-------|-------|----------|----------|
| Low Halogen    |                          |       |       |       |       |       |          |          |
| PRESAGE®1 (LHP1) | $C_{1758}H_{3000}N_{121}O_{442}S_{3}Cl_{30}Br_{1}$ | 0.08850 | 0.6178 | 0.04960 | 0.2069 | 0.003800 | 0.03112 | 0.002300 |
| Low Halogen    |                          |       |       |       |       |       |          |          |
| PRESAGE®2 (LHP2) | $C_{889}H_{1541}N_{60}O_{228}S_{10}Cl_{1}Br_{1}$ | 0.09050 | 0.6224 | 0.04899 | 0.2126 | 0.01870 | 0.002100 | 0.004700 |
| Original       |                          |       |       |       |       |       |          |          |
| PRESAGE® (OP)  | $C_{481}H_{842}N_{30}O_{129}Cl_{9}Br$ | 0.08920 | 0.6074 | 0.04460 | 0.2172 | - | 0.03340 | 0.008400 |
| Water          | $H_2O$                  | 0.1119 | - | - | 0.8881 | - | - | - |

Monte Carlo modeling was performed to determine the differences in depth doses between the different PRESAGE® dosimeters and water for Cs-137 and Ir-192 brachytherapy sources. The Monte Carlo calculations were performed using the EGSnrc package (Version 4 release 2-2-5, Research Council of Canada, Ottawa, Canada)[10, 11].

Cross section data for the three PRESAGE® dosimeters and water were generated by the PEGS4 preprocessor using the elemental compositions and mass densities of the different materials. Each PRESAGE® phantom was defined in the DOSRZnrc user code with a 20.5 cm thickness. The brachytherapy sources were modeled as cylinders with 0.05 cm radius and 0.5 cm length located at 10 cm depth in the phantom. Dose was calculated as a function of radial distance from the source with 0.1 cm intervals. The electron and photon energy cutoff parameters, ECUT and PCUT, were set to 0.521 MeV and 0.001 MeV respectively. Xcom library was used to obtain the photon cross section data.
Bound Compton scattering, PE angular sampling, Rayleigh scattering and atomic relaxations were switched on during the calculation. Dose calculation was performed using 5 billion incident particles. In order to compare calculated central axis depth doses in water and in the PRESAGE® dosimeters, the water equivalent depth was calculated for each case [12].

3. Results

Figure 1 shows Monte Carlo calculated relative dose versus density corrected radial distance from a Cs-137 brachytherapy source for the three PRESAGE® dosimeters and water as well as their difference relative to the value of water. In the first 0.5 cm density corrected distance from the source, the dose gradient is steeper in water than in the three PRESAGE® dosimeters. The difference in relative dose values of water and the three PRESAGE® dosimeters increases with radial distance from 0.02 for the lower halogen content PRESAGE® and 0.035 for the original PRESAGE® to 0.95 and 0.1, respectively. The maximum relative dose difference between the three PRESAGE® dosimeters and water occurs at 0.15 cm radial distance from the source.

![Figure 1. Monte Carlo density corrected relative dose curves for a Cs-137 source along radial distance for the three PRESAGE® dosimeters and water and their difference relative to the value in water (inset).](image)

Figure 2 shows Monte Carlo calculated relative dose to density corrected radial distance from an Ir-192 brachytherapy source for the three PRESAGE® dosimeters and water as well as their difference relative to the value of water. At 0.5 mm radial distance from the source, the difference between the value of density corrected relative dose of the original formulation PRESAGE® with water is twice that of the low halogen content PRESAGE®. The difference with the value of water decreases gradually with radial distance. This relative dose curve suggests that the lower halogen content PRESAGE® dosimeters are only marginally more water equivalent than the original PRESAGE® in terms of dose response to Ir-192. The uncertainty of calculated dose in the all cases was below 0.1%.
Figure 2. Monte Carlo density corrected relative dose curve for a Ir-192 source along radial distance for the three PRESAGE® dosimeters and water and their difference relative to the value of water (inset).

4. Conclusion
Results of this study indicate that like PRESAGE™, the PRESAGE® dosimeters are suitable for depth dose measurement for Cs-137 and Ir-192 brachytherapy sources. The lower halogen content PRESAGE® dosimeters exhibit a more water equivalent depth dose response than the original PRESAGE® formulation.

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