Three-Dimensional Dosimetry of a Beta-Emitting Radionuclide Using PRESAGE® Dosimeters

R L Grant1,2,4, M L Crowder3,4,5, G S Ibbott1,2,4,11, J Simon4, R K Frank6, J Rogers6, H M Loy7,8, J Adamovics9, J Newton10, M Oldham10, S Stearns7,8, and R E Wendt3,4

1Radiological Physics Center and Departments of 2Radiation Physics and 3Imaging Physics, University of Texas MD Anderson Cancer Center, 1515 Holcombe Blvd., Houston, TX 77030 USA
4University of Texas at Houston Graduate School of Biomedical Sciences, Houston, TX 77030 USA
5Abilene Christian University, Abilene, TX 79699 USA
6IsoTherapeutics Group, LLC, 1004 S. Velasco St., Angleton, TX 77515 USA
7The Gabriel Institute, P. O. Box 55603, Houston, TX 77255 USA
8Valco Instruments Co., Inc., 7811 Westview Dr., Houston, TX 77055 USA
9Heuris Pharma, LLC, 412 Sunset Rd., Skillman, NJ 08558 USA
10Duke 3D Dosimetry Laboratory, Box 3085, Duke University Medical Center, Durham, NC 27710 USA

E-mail: gibbott@mdanderson.org

Abstract. Three-dimensional dose distributions from liquid brachytherapy were measured using PRESAGE® dosimeters. The dosimeters were exposed to Y-90 for 5.75 days and read by optical tomography. The distributions are consistent with estimates from beta dose kernels.

1. Background
Recent advances in radiopharmaceutical design have led to the development of a new technique called "liquid brachytherapy"[1]. Liquid brachytherapy is a proprietary formulation that is administered as an injection directly into the tissue to be treated (e.g., an osteosarcoma) and does not migrate from the point of administration. Thus, beta-emitting radionuclides can be used without the undesirable shielding effect of the encapsulation associated with sealed source brachytherapy. Intricately shaped dose distributions that exploit the limited range of beta particles are possible with this method. The work-in-progress reported here is being undertaken to assess the three-dimensional dosimetry of liquid brachytherapy using beta-emitting radiopharmaceuticals.

2. Methods
PRESAGE®[2] polyurethane radiochromic dosimeters [Heuris Pharma, LLC, Skillman, NJ] in the shape of a right circular cylinder measuring 6 cm in diameter and at least 3 cm in height were selected for three-dimensional absorbed dose measurements because of their desirable physical properties. In particular, a dosimeter for this application must be stable for at least seven half-lives of the radionuclide to be studied and resistant to liquids.

Three dosimeters were prepared. The first dosimeter was designed to assess the dose distribution of a point source of a beta emitter. The second dosimeter was designed to assess our ability to measure dose distributions that overlap in two-dimensional projections but not in three dimensions. The third dosimeter was designed to assess the dose distribution from a line source and also from two point sources whose dose distributions overlap in three dimensions.

1To whom correspondence should be addressed.
Holes with a diameter of 0.043” (1.09 mm) were drilled into the plastic dosimeters to allow the radionuclide to be introduced. Particular care was taken to avoid raising the temperature of the dosimeter material (which would have fogged it in the vicinity of the hole). All of the sources were solutions of Y-90 as yttrium chloride in 50 mM hydrochloric acid.

The first dosimeter contained a single hole, 1.5 cm deep, into which 1 uCi (37 kBq) of Y-90 in a volume of 1 uL was introduced in order to approximate a point source in the bottom of the drilled hole. The activity was chosen to give an expected dose of 2 Gy at a distance of 3 mm from the point source with an exposure time of 5.75 days. The second dosimeter had three holes drilled 3 cm apart in a triangular configuration. Each hole was 1.5 cm deep. The holes were filled with 0.25, 1, and 4 uCi (9.25, 37, and 148 kBq) respectively of Y-90, each in a volume of 1 uL. The radii of the 2 Gy isodose surfaces were expected to be 1.6, 3 and 4.8 mm from the respective point sources. The maximum range of the Y-90 beta emissions is about 1.1 cm and thus the dosed volumes from each point source did not overlap in three dimensions. The third dosimeter had three holes. One was 2.5 cm deep and 3 cm from the other two. The other two were 1.5 cm deep and 1 cm apart. The deep hole was filled with 2 uCi (74 kBq) of Y-90 in 9.36 uL, creating a line source with a length of 1 cm. The shallower holes were filled with 4 uCi (148 kBq) of Y-90 in 1 uL. This activity was chosen so that the 2 Gy isodose surface would have a dumbbell shape in three dimensions. After 5.75 days of exposure, the radioactivity was rinsed from the dosimeters using distilled water and hydrochloric acid.

A control dosimeter was exposed to ambient light for the same lengths of time as were the test dosimeters during their drilling, filling and rinsing.

Two calibration dosimeters were exposed to 4 cm x 4 cm external beams of 16 MeV electrons to ascertain the relationship between optical density of the PRESAGE dosimeter and absorbed dose from calibrated electron beams. The beams were designed to deliver a dose of 2 Gy to one dosimeter and 3 Gy to the other at $d_{max}$.

The dosimeters were then scanned with the Duke Midsized Optical Scanner dedicated for the RPC (DMOS-RPC) [Duke University, Durham, NC] using 0.5 degree per step to produce 720 projection images consisting of 798x600 pixels that were 0.140 mm on a side. Transverse images were reconstructed by filtered backprojection with a pixel size of 0.185 mm. These images were exported to the CERR software [3] [Computation Environment for Radiotherapy Research, Washington University, St. Louis] and calibrated using the electron beam data.

The calibrated radionuclide dose distributions were compared to estimates based upon the beta-ray dose kernel of Cross, et al[4].

3. Results
Irradiation of two dosimeters with electron beams yielded the calibration curve shown in figure 1. Only the pixel values at the depth of $d_{max}$ were used for this curve. The relationship between scanner signal and dose was applied to scans of the other dosimeters to calibrate them. Figures 2-4 show isodose curves from the Y-90 dose distributions.

**Figure 1.** The calibration curve based on two points at 0 Gy, ~2 Gy and ~3 Gy. Dose (Gy) = 145.3 x Pixel Value - 0.0204.

**Figure 2.** Coronal view of dosimeter block with single hole showing unintended uniform dose along the length of the hole. The isodose contours are plotted for 3, 4, 10 and 15 Gy.
Figure 3. a) Axial view of dosimeter block with three equidistant holes showing that the diameters of the 3, 5, 10 and 15 Gy isodose lines are proportional to the activity of Y-90 (and the dose). b) Log display of dose estimate from Y-90 beta dose kernel. Gray < 3 Gy, pink >= 3 Gy.

Figure 4. a) Axial view of dosimeter block with two nearby holes showing overlapping dumbbell-shaped dose distribution with isodose contours at 3, 5, 10 and 15 Gy. b) Log display of Y-90 dose kernel estimate. Gray < 3 Gy, pink >= 3 Gy.

4. Discussion and Conclusion
Good agreement was observed between a dose kernel estimate of the three-dimensional dose distribution from Y-90 and the measurements in PRESAGE dosimeters. The isodose distribution shown in figure 2 demonstrates that the Y-90 solution did not remain as a point source, but in fact was drawn up the sides of the drilled hole by capillary action or contamination during application, yielding a line source in this particular dosimeter. The dose distributions shown in figure 3 indicate clearly that the dosimeter response was proportional to the activity placed in each of the three wells. Finally, the distribution shown in figure 4 demonstrates the overlap between two nearby wells filled with Y-90 solution, and the increase in dose midway between the two holes.

References
[1] Simon J, Stearns S, McMillan K, Loy HM, Frank RK. Liquid Brachytherapy, Direct Administration of Therapeutic Isotopes into Tumors. Journal of Nuclear Medicine. 2008;49(Supplement 1):293P.
[2] Adamovics J, Maryanski M. Characterisation of Presage(TM): A New 3-D Radiochromic Solid Polymer Dosemeter for Ionising Radiation. Radiation Protection Dosimetry. 2006 Sep;120(1-4):107-112.
[3] Deasy J, Blanco A, Clark V. CERR: A Computational Environment for Radiotherapy Research. Medical Physics. 2003 May;30(5):979-985.
[4] Cross W, Freedman N, Wong P. Tables of Beta-Ray Dose Distributions in Water. Chalk River, Ontario, Canada: Atomic Energy Canada Limited; 1992.