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DOSE VERIFICATION FOR ACCELERATED PARTIAL BREAST IRRADIATION

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ABSTRACT

Noticeable advances have been made in reducing the reoccurrence of breast cancer after a lumpectomy through invasive irradiation of the surrounding participating tissue. One effective postoperative procedure introduces a radionuclide applicator surrounded by an inflatable balloon into the evacuated breast cavity. Through, a series of polyethylene guide tubes, radioactive sources are introduced in a time-controlled program to irradiate tissue surrounding the lumpectomy site to a desired integrated dose of about 30 Gy at a depth of 1cm over a 5-day period in 10 treatment fractions. To be most effective and to minimize collateral radiation damage, reliable and accurate dose estimates must be performed in the patient treatment planning stage. The current treatment uses the TG-43 protocol [1] where radiation transport is estimated in a standard tissue phantom to provide best estimates of the delivered dose. Given today's computational power and comprehensive radiation transport algorithms, it is generally thought by those in the radiation oncology community that we should be able to more precisely predict doses, which is the subject of this presentation.

Key Words: APRI, HDR, Brachytherapy, Ir-192

1. INTRODUCTION

In this study, we model *Contura* multi-lumen Radiation Balloon Applicator (from SenoRx^{TM}) of ^{192}Ir HDR (High Dose Rate) sources for brachytherapy following a lumpectomy. The applicator uses vacuum to remove excess fluid and to closely adhere the inflatable balloon to the often irregularly shaped lumpectomy cavity wall in order to deliver precise radiation dosing through the introduction of multiple seed lumens. The balloon is filled with saline solution to maintain a sufficient distance between the source and tissue in contact with the surface of the balloon and to keep the dose to tissue below that which would produce necrosis while giving the tissue 1cm from the balloon surface 30Gy dose.

2. Materials and Methods

We will model the radiation field through two independent approaches covering both deterministic and probabilistic methods.

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2.1 Source Specification

More detailed specification of VS2000 is found in Angelopoulos et al. [7]. The VariSource VS2000 consists of two, 0.17 mm-radii, 2.5-mm-long cylinders with semispherical endings. The seeds are made of pure iridium metal (density 22.42 g/cm^3). The source is encapsulated at the tip of a 260 cm-long Ti-Ni alloy wire of 0.295 mm in radius. The Ni-Ti alloy has a composition of 44.4% Ti and 55.6% Ni by weight (density 6.5 g/cm^3). The source encapsulation extends 1 mm beyond the distal end of the active core and can be approximated by a 0.59-mm-diameter, 0.705-mm-long cylinder with a semispherical end of 0.295 mm radius. Figure 1 shows the source schematic.

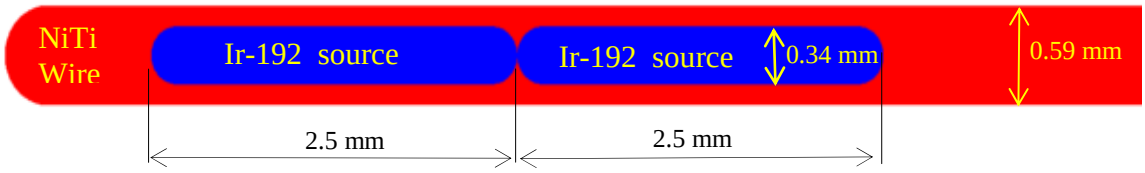


Figure 1. VariSource VS2000 schematic

2.2. Semi-analytical Approach

In a semi-analytical approach, to simulate the absorbed dose a point kernel is integrated over the seeds in various positions along the lumens. Superposition will provide the necessary intensities input as the kernel of a primary and secondary electron dose response function representative of surrounding tissue. There are several unique features of this approach. First, we develop the point source kernel through a highly accurate and reliable numerical Fourier transform inversion. We then combine this with an iterative interpolation that is implemented taking advantage of the flux dependence only on the distance between the target and source. Thus, for targeted dose points in the breast tissue, we can determine all distances from the source in the guide tubes within the applicator. The maximum and minimum distances are therefore known. We then find the intensity or dose from the point source (point kernel) for, say N less than 100, distances between the two limits. The contribution from each Ir seed corresponds to an integration of the point source over the source configuration. Using a rational interpolation between the N intensities, the required point source contributions to compute the total source contribution is therefore found most efficiently to a high accuracy. Finally, to increase accuracy further, the calculation is performed again with say, N+2 interpolations between the maximum and minimum intensities. The interpolation is incremented in this way until convergence. To hasten convergence, we can also apply a convergence acceleration strategy that essentially views the dose at each point as an element of a sequence the limit of which is the desired dose. Figure 2. shows an initial calculation of a source configuration in the inflatable balloon. The dose contours are clearly visible. This particular configuration serves as a test case for the Monte Carlo simulation to follow.

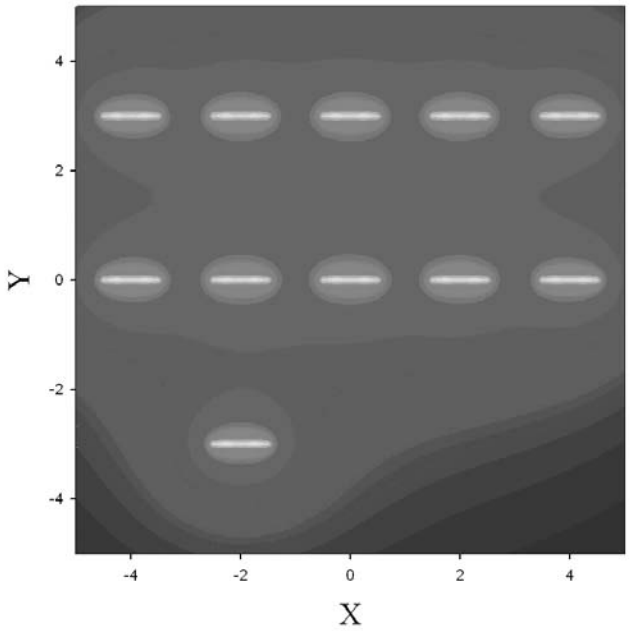


Figure 2. Simulated Ir-192 seed configuration in vitro

2.3 The Monte Carlo Approach

The MCNP5 [4] code based on the Monte Carlo method has been used for simulation of the determined source and applicators. There are numerous HDR sources in today's brachytherapy practices. We model the VariSource™ 200/200t (Varian Oncology) HDR ^{192}Ir source in this case.

Several studies have resolution in need to explore the TG-43 parameters of the new VariSource VS2000. Angelopoulos et al. [7] have studied TG-43 parameters of the mentioned source (call it the new VariSource) along with microSelectron and older VariSource and published TG-43 parameters based on a fine mesh configuration for 150×180 *r* and *theta* respectively. He also compared his results with the previous studies of microSelectron and older VariSource.

Most Recently, Taylor and Rogers [8] employed the EGSnrc Monte Carlo code to estimate the dosimetry parameters of ^{192}Ir and ^{169}Yb brachytherapy sources. The Monte Carlo code BrachyDose (A derivative of EGSnrc) is used to calculate energy-weighted photon spectra, TG-43 dosimetry parameters, and scatter dose functions for 15 high dose rate ^{192}Ir and ^{169}Yb brachytherapy sources using NIST XCOM photon cross sections. TG-43 parameters are tabulated over a spatial extent with higher resolution than previous studies. This study also provides separate tabulations of primary, single-scattered, and multiple-scattered dose data. This separation is useful for calculating the dose surrounding brachytherapy sources using convolution/superposition methods.

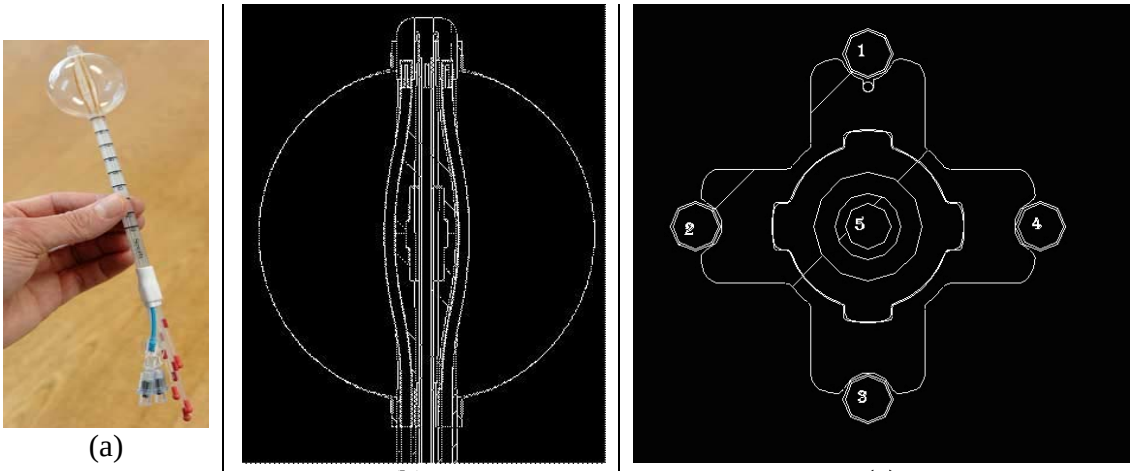
Previous studies data of VS2000 and other brachytherapy sources are currently published online via the Carleton Laboratory for Radiotherapy Physics website [9].

An MCNP5 modeling of the dose distributions of D-shaped AccuBoost applicators studied by Yang [10]. In this study he evaluated the dose distribution and compared the results with experimental data from air ionization chambers (Farmer and Markus), and radiochromic film (GafChromic EBT) in polystyrene and ICRU 44 breast tissue. The results of Yang study indicates that the depth dose measurements in polystyrene using ion chamber and radiochromic film agreed with Monte Carlo results within 2%. Discrepancies between film and Monte Carlo dose profiles at 30 mm depth were within 1%.

In this study, using MCNP5, we model the VariSource VS2000 together with the SenoRx^{TM} balloon applicator to estimate the dose profile in a clinical treatment plan. To verify the calculation, we compare the results with 3-D dose distributions generated by the Varian BrachyVision (SomaVision, Varian Medical Systems, Palo Alto, CA) treatment planning system. Somavision uses TG-43 formalism exclusively to generate 3-D dose distribution.

2.2.2 Applicator Modeling

The balloon applicator is used for the right positioning of the HDR source and for the protection of healthy tissue. The applicator consists of 5 treatment lumens enclosed by a plastic transparent balloon. The brachytherapy sources are loaded into the lumens via the afterloader, and the balloon is filled with saline solution.



(a) (b) (c)

Figure 3. SenoRxTM balloon applicator (Contora), (a) 3D view, (b) axial cross section (c) lateral cross section showing lumens configuration.

2.2.4 MCNP Modeling of Water Phantom

The *Contura* applicator was inserted inside a 30×30×30 cm^3 water phantom. Four treatment plans were carried out. In first and second plans, the source dwelled in lumen #1(Fig. 3.c). Irradiation carried out in two dwells with 1.5 cm apart for 100 seconds. In third and fourth plans, the source dwelled in lumen # 5 (Fig. 3.c), 1.5 cm apart for 100 seconds of irradiation. The source strength at irradiation time was 8294.22 mCi. The plans were selected to investigate the radial

dose distribution and anisotropic factor. Since TG-43 is formulated for an infinite homogeneous medium, we chose a water phantom to be within the limitations of TG-43.
For each plan, a CT image was taken and the dose profile was evaluated by Eclipse Brachytherapy planning (Varian oncology system). Fig. 4 illustrates the CT images illustrating the plan configuration and dose profiles.

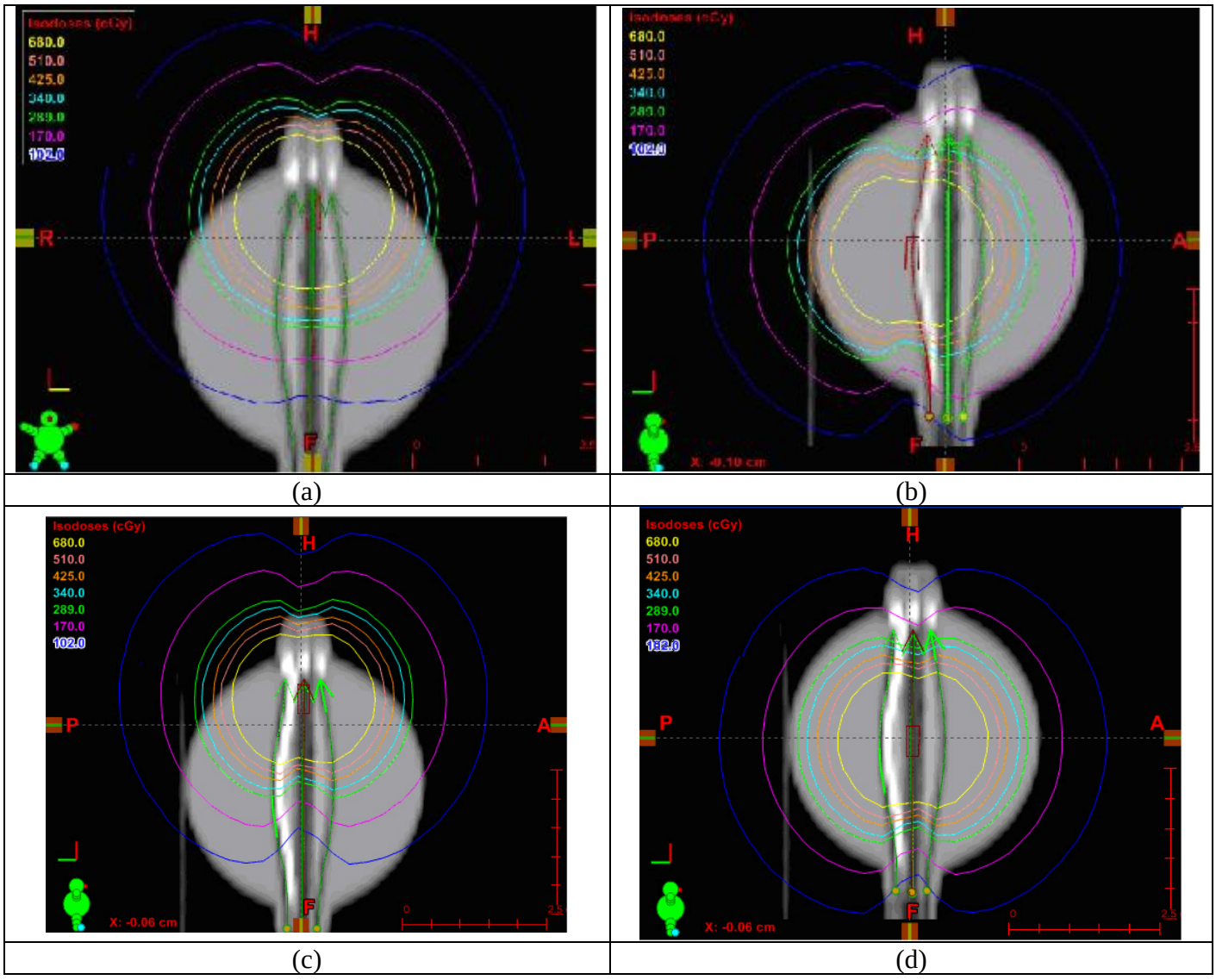


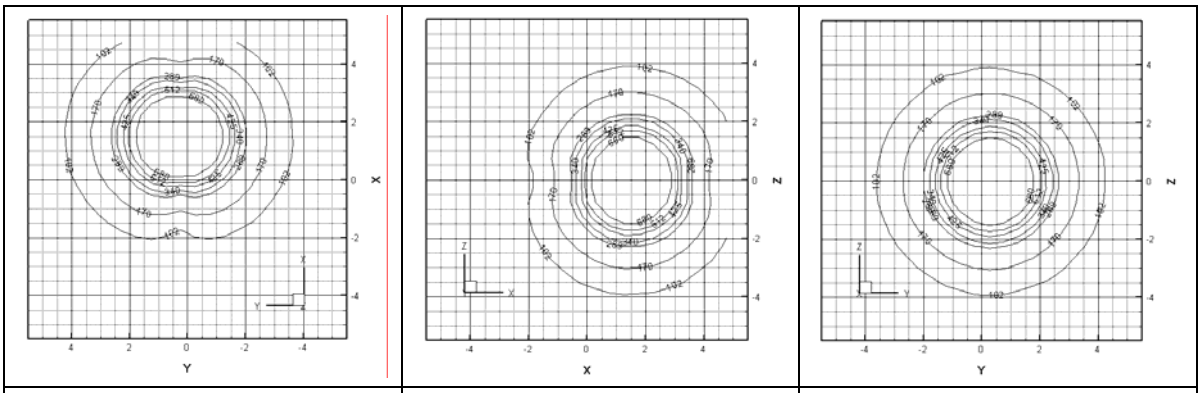
Fig. 4 Dwell positions and dose profiles in (a) plan 1, source is in 150 cm dwell in lumen # 1, (b) plan 2, source is in 148.5 cm dwell in lumen # 1, (c) plan 3 , source is in 150 cm dwell in lumen # 5 (d) plan 4 , source is in 148.5 cm dwell in lumen # 5.

The MCNP Version 5 Monte Carlo radiation transport code was used at the University of Arizona for all simulations [5]. The code allows the choice of 4 photoatomic cross section libraries. We used the latest cross section library (ZAID.04p) which was introduced in 2002 and contain the first completely new data set since 1982. These tables were processed from the ENDF/B-VI.8 library. (The ENDF/B-VI.8 photoatomic and atomic relaxation data are in turn based upon the

EPDL97[12] library.) They include incoherent, coherent, and photoelectric and pair production cross sections for incident energies from 1 KeV to 100 GeV and Z equal to 1 to 100.
The Photon spectra were taken from the National Nuclear Data Center (NNDC) [11] with isotropic ^{192}Ir photon emission probability. The HDR ^{192}Ir source was simulated with radiation emissions originating from a solid 0.34 mm diameter and 5 mm long right cylindrical of ^{192}Ir (22.4 g/cm^3) surrounded by a 0.59 mm diameter and 6 mm long right cylinder capsule of NiTi to approximate the model VS2000 HDR ^{192}Ir source by Varian Corporation. The cell transformation card (TRCL) allowed flexible source positioning to implement different dwell positions. We also examined relative source weighting to simulate different dwell times. This improves dose uniformity at the phantom surface.

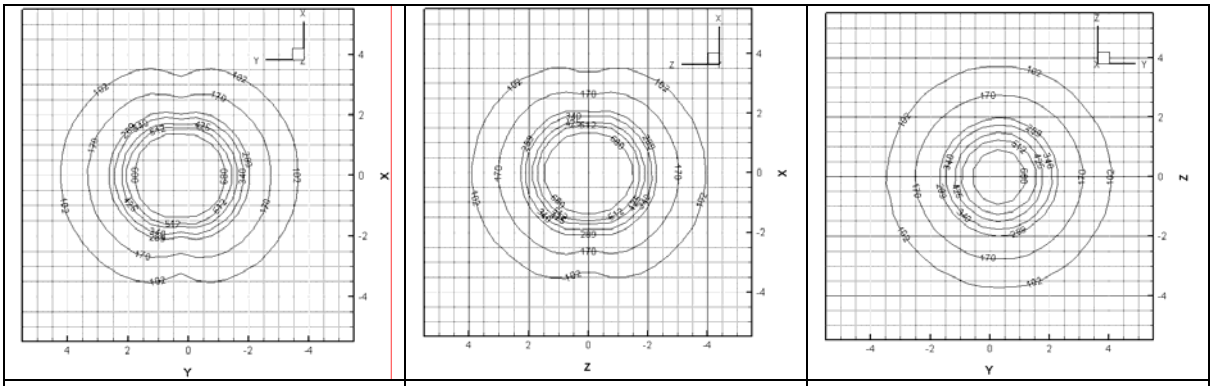
Three dimensional dose distributions in the phantom were calculated using the *FMESH tally card in MCNP which used track-length estimator to convert photon energy fluence to relative absorbed dose in MeV/gr. A mesh optimization study carried out to determine the size of voxels, which would satisfy statistical checks in shortest time. Mesh sizes of 0.2 to 0.5 cm were found to be the optimum mesh when dose distribution calculations is beyond the balloon surface (2.26 cm). We used 0.2×0.2×0.2 cm^3 voxel to grid the phantom volume. Sufficient number of histories to satisfy all the statistical checks is 5×10^7 histories without using any variance reduction methods. The results of MCNP calculations are illustrated in Figs. 5 -8.

Comparing dose contours in Figs. 5a, 6a, 7a and 8a with Figs. 4a, 4b, 4c and 4d, for different we observe a complete agreement. We already anticipated this agreement since the TG-43 parameters are originally extracted from the Monte Carlo simulations in infinite medium [1].



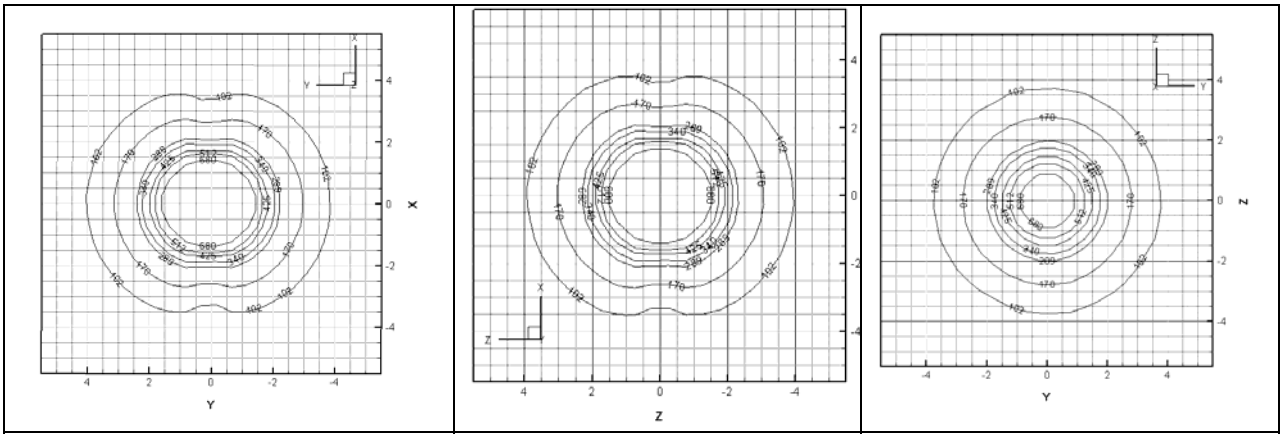
(a) xy contours	(b) xz contours	(c) yz contours

Fig. 5 MCNP dose distribution contours for plan 1.



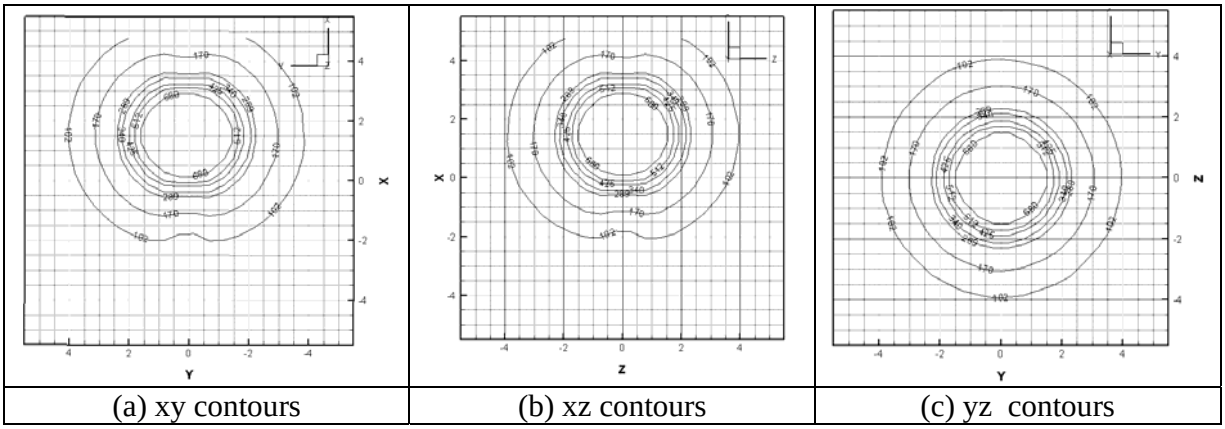
(a) xy contours | (b) xz contours | (c) yz contours

Fig. 6 MCNP dose distribution contours for plan 2.



(a) xy contours | (b) xz contours | (c) yz contours

Fig. 7 MCNP dose distribution contours for plan 3.



(a) xy contours | (b) xz contours | (c) yz contours

Fig. 8 MCNP dose distribution contours for plan 4.

2.2.4 MCNP Modeling of a Clinical Treatment Plan

Once the MCNP model optimized with the water phantom plans, we modeled the 3D dose distribution of a treatment plan. In this plan, all five lumens are injected with the 5 sources and the sources dwell in each location for a different period. The treatment plan is shown in Table 1.

Table 1. Dwell positions and timing for 5 sources in lumens 1 to 5.

		Dwell 1	Dwell 2	Dwell 3	Dwell 4	Dwell 5	Dwell 6	Dwell 7	Dwell 8	Dwell 9
Lumen 1	Position (cm)	2.2	1.7	1.2	0.7	0.2	-0.3	-0.8	-1.5	
	Time (s)	8.7	16	18.1	15.8	12.9	10.9	9.5	8	
Lumen 2	Position (cm)	2.2	1.7	1.2	0.7	0.2	-0.3	-0.8	-1.5	
	Time (s)	0.9	6.4	9.8	11.9	13.2	13.8	13.2	11	
Lumen 3	Position cm)	2	1.5	1	0.5	0	-0.5	-1	-1.5	
	Time (s)	0.4	5.8	9.5	11.9	13.7	14.7	14.3	12	
Lumen 4	Position (cm)	2.1	1.6	1.1	0.6	0.1	-0.4	-0.9	-1.5	
	Time (s)	5.3	11.1	13.5	13.5	12.9	12.1	11.1	10	
Lumen 5	Position (cm)	2.5	2	1.5	1	0.5	0	-0.5	-1.1	-2.5
	Time (s)	4.3	9.4	11.7	12.4	12.3	12.1	11.5	10	3.7

Fig. 9 illustrates the CT image and Dose evaluation by Eclipse brachytherapy treatment planning. Although a variety of dose schedules have been used in APBI (Accelerated Partial Breast Irradiation) treatments, the most common prescription dose (and the dose selected for the planned American phase III clinical trial) is 34 Gy delivered in ten fractions, with fractions given twice daily over a period of 5 days. In this treatment, a prescription 375 cGy in 1 fraction source treatment with a source activity of 5722.95 mCi was planned.

Due to different dwell times, relative source weighting was used to advance dose uniformity at the phantom surface. A grid of 500×500×500 voxels of 0.008 cm^3 was employed for this simulation. A total of 5×10^8 histories used for each dwell to passed all statistical checks by MCNP.

The results of MCNP5 simulations are illustrated in Fig. 10. As observed, MCNP results of the axial dose distribution contours show more anisotropic behavior than the TG-43 formalism. This is due to the detailed modeling of the Contura applicator by MCNP5.

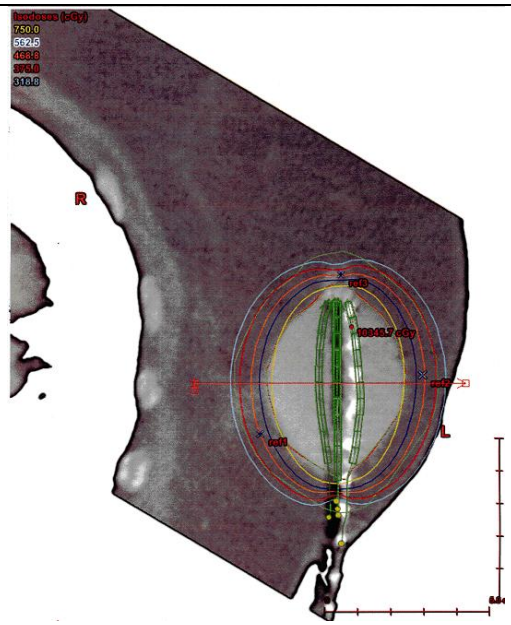
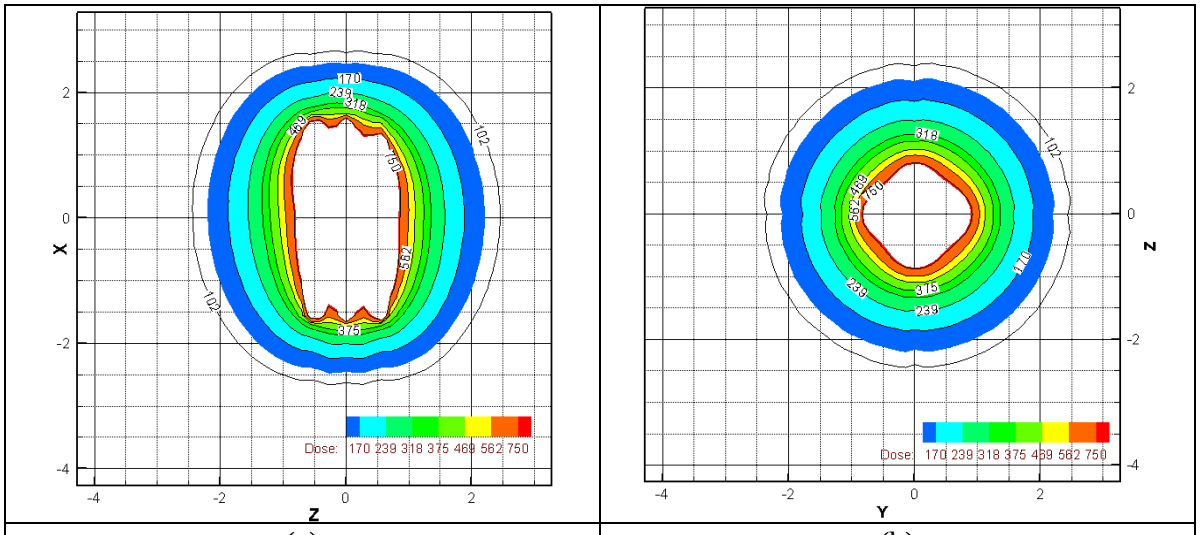


Fig. 9 CT image together with the dose distribution profile calculated by Eclipse brachytherapy treatment planning (b) Lateral Dose by MCNP and (c) Axial Dose distribution by MCNP.



(a) (b)

Fig. 10 Dose distribution by MCNP for the treatment plan in Table 1. (a) Axial and (b) Lateral.

3. CONCLUSIONS

Presently, the TG-43 protocol is the clinical formalism used in brachytherapy and has the benefit of very fast calculation time. However, assuming the patient tissue composition is equivalent to water is among many simplifications in this protocol. For high energy brachytherapy seeds such

as ^{192}Ir seeds, it is of interest to evaluate the dosimetric differences between calculations based on Monte Carlo simulations, the TG-43 formalism and an analytic benchmark.

With the Monte Carlo approach, a 3-D model of the applicator catheter together with the ^{192}Ir source specifications in a standard brachytherapy implant is the input for MCNP5 Monte Carlo code. The isodose contours for 4 plans have been compared with the results of the Eclipse brachytherapy planning software using TG-43 protocol. The results illustrated in Figs. 5-8 show good agreement between the two methods. We modeled a typical clinical treatment plan with MCNP and the results are illustrated in Figs. 9-10. The Monte-Carlo simulation shows a higher level of anisotropicity than predicted by TG-43. However, the isodose contours agree with 10% discrepancy when the dose varies 200 to 750 cGy.

We also used our analytical approach to predict the general flux distribution. We are planning to tune the Monte Carlo model with the analytical model, instead of TG-43 that is used in this presentation. Further study in this regard is under consideration at this time. It is hoped that the results of this study will be used for clinical applications as or as benchmark data to verify the results of the treatment planning predictions.

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