COMPARISON OF HEART DOSE OF EBX AND MULTI-CHANNEL HDR BREAST APPLICATORS

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ABSTRACT

- **Purpose**. The heart and lungs can be exposed to potentially significant doses during both external beam irradiation and interstitial or balloon based brachytherapy. In the case of brachytherapy, where radiation fields drop rapidly with distance due to geometric effects, there is a strong dependence on the location of the cavity with respect to the heart, and the pattern of dose through the heart volume is not easy to quantify simply. Furthermore there is not unanimity nor a great deal of data on the effects of heart dose. However there is evidence from patients treated for Hodgkin's disease that there are significant long term (10 years or longer) effects. Thus it is of interest to attempt to quantify heart dose and to see if there are differences among the various options available for breast radiation therapy, particularly brachytherapy. While each case has its own details that would require individual study, a generalized model can be constructed to study global differences in the various treatment modalities available.
- **Materials and Methods.** A two-dimensional computer model was written in LabVIEW to allow placement of an arbitrary number of sources in an arbitrary arrangement, representing a slice perpendicular to the plane of motion of the source(s) in interstitial or balloon based brachytherapy. Dose was calculated along a line outward from the center of the distribution, representing distance to the heart or lungs, assuming continuous water-equivalent material. Ir-192 sources were modeled as simple geometrical point sources with $1/r^2$ depth dose behavior, while the Xoft source was modeled using a 2-exponential fit to TG43 depth dose data. In IORT breast treatments, shielding material is sometimes placed in the cavity to shield the rib wall. Xoft's Flexishield is a 1 mm thick tungsten-silicone matrix which has been considered for this application, as it is thin, highly conformable, and is equivalent to 0.45 mm lead. Attenuation of the material was modeled with a calculation that takes into account the source spectrum and mass-energy absorption curve of tungsten.
- **Results**. Dose was normalized to prescription for a 4 cm diameter balloon (or equivalent structure), with a single source placed either at the center, or 8 sources equally spaced on a circle 1.9 cm from the center. In the 7 source case one of the sources was removed and the depth dose path was aligned with the removed source, representing the maximum sparing that could be achieved. Dose at 4 cm from the "balloon", equivalent to 3 cm from the prescription depth, for standard HDR is 25% of prescription, for 8-source 16%, for 7-source 13% and for Xoft 12%. At 6 cm from the balloon doses are 14.1, 8.9, 7.1 and 4.5% respectively. At 8 cm away, doses are 9.0, 5.5, 4.5 and 1.9% of prescription. The figure (see Poster Results) shows calculated images and plots of dose along circular contours at 6 cm from the balloon surface, for 8 and 7 source Ir-192 cases and the Xoft source.

  Use of the Flexishield attenuator reduces dose in the Xoft 50 kVp case to virtually zero. For Ir-192 configurations, doses are reduced by only about 10% due to the high energy of the emitted gammas.
- **Conclusion**. In a two-dimensional simulation of various source arrangements, typical point doses to critical structures such as the heart and lungs have been calculated for three arrangements of Ir-192 HDR sources – a single source at the center of a balloon, 8 sources arranged around the periphery of a balloon or equivalent structure, 7 sources using the 8 source geometry but with one removed for the purpose of lowering dose in a particular direction, and a single Xoft 50 kVp x-ray source. Results show that highest doses to distant points occur with the single Ir-192 source. Multiple source arrangements typically reduce the distant dose. The reduction is larger in the case of 7 sources, especially closer to the treated region. The Xoft source has significantly lower distant dose than any of the other arrangements, with the advantage increasing with distance, due to attenuation of the 50 kVp radiation.

INTRODUCTION

- The heart and lungs can be exposed to potentially significant doses during external beam and both interstitial and balloon based brachytherapy. In brachytherapy, where radiation fields drop rapidly with distance, there is a strong dependence on cavity location with respect to the heart.
- Awareness has grown as to the possible negative impact radiation may have on the health of the heart and especially that of the cardiac vasculature.
- Over the past several decades, dose to the heart from radiation therapy for left-sided breast radiation therapy has decreased significantly. Nonetheless, there continues to be support in the literature for the belief that every effort should be made to minimize incidental irradiation of the heart while maintaining adequate coverage of target volumes.
- Thus it is of interest to attempt to quantify heart dose and explore any differences among the various options available for breast brachytherapy. While each case has its own details, a generalized model can be constructed to study global differences in the various treatment modalities available.

METHODS

- A two-dimensional computer model was written in LabVIEW to allow placement of an arbitrary number of sources in an arbitrary arrangement, representing a slice perpendicular to the plane of motion of the source(s) in interstitial or balloon based brachytherapy.
- Dose was calculated along a line outward from the center of the distribution, representing distance to the heart or lungs, assuming continuous water-equivalent material.
  - Since the distance from heart to tumor site is variable from one patient to the next, dose per fraction is plotted as a function of distance.
  - The presence of rib bone as a complicating factor was beyond the scope of this study.
- Ir-192 HDR sources were modeled as simple geometrical point sources with $1/r^2$ depth dose behavior:
  - A single source at the center of a balloon
  - 8 sources arranged around the periphery of a balloon or equivalent structure
  - 7 sources using the 8 source geometry but with one removed to lower dose in a particular direction
- Xoft 50 kVp x-ray source was modeled using a 2-exponential fit to TG43 depth dose data:
  - A single source
- In IORT breast treatments, shielding material may be placed in the cavity to shield the rib wall.
  - Xoft's Flexishield is a 1 mm thick tungsten-silicone matrix which has been considered for this application, as it is thin, highly conformable, and is equivalent to 0.45 mm lead.
  - Attenuation of the material was modeled with a calculation that takes into account the source spectrum and mass-energy absorption curve of tungsten.

RESULTS

- Dose was normalized to prescription for a 4 cm diameter balloon (or equivalent structure), with a single source placed either at the center, 8 sources equally spaced on a circle 1.9 cm from the center, or 7 sources resulting from removal of one of the 8 sources
- Figures 1-14 show calculated images, radial line plots, and plots of dose along circular contours at 6 cm from the balloon surface, for the single, 8- and 7-source Ir-192 cases and the single Xoft source.

RESULTS

Ir-192 - Single Source | Ir-192 - 8 Sources | Ir-192 - 7 Sources | Xoft EBx – 1 Source

Dose Distribution

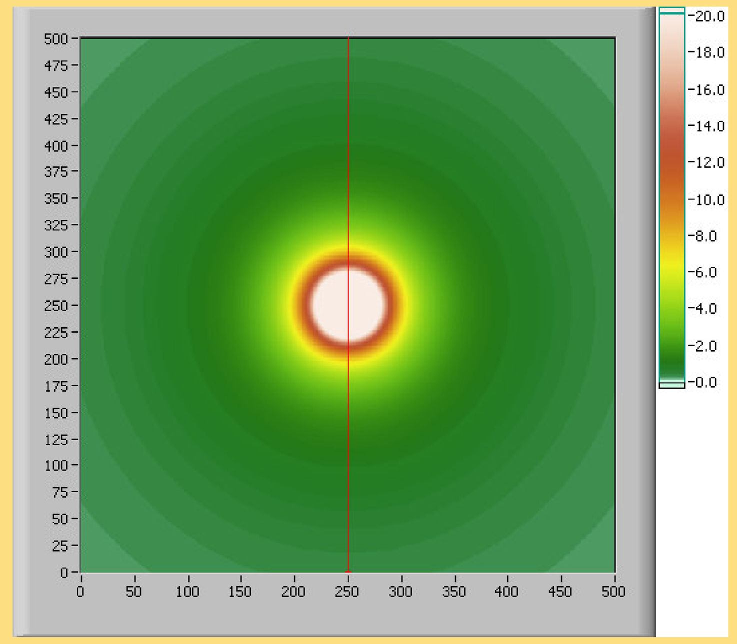

Figure 1. Image of dose from a single Ir-192 source, over a range of ± 10 cm

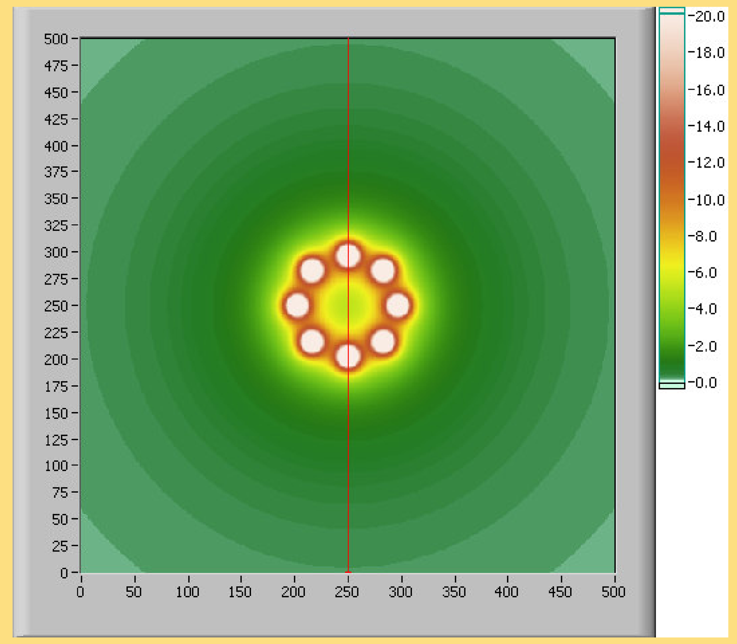

Figure 4. Dose image 8 sources of Ir-192 at located at 1.9 cm from center, representing a 4 cm diameter applicator.

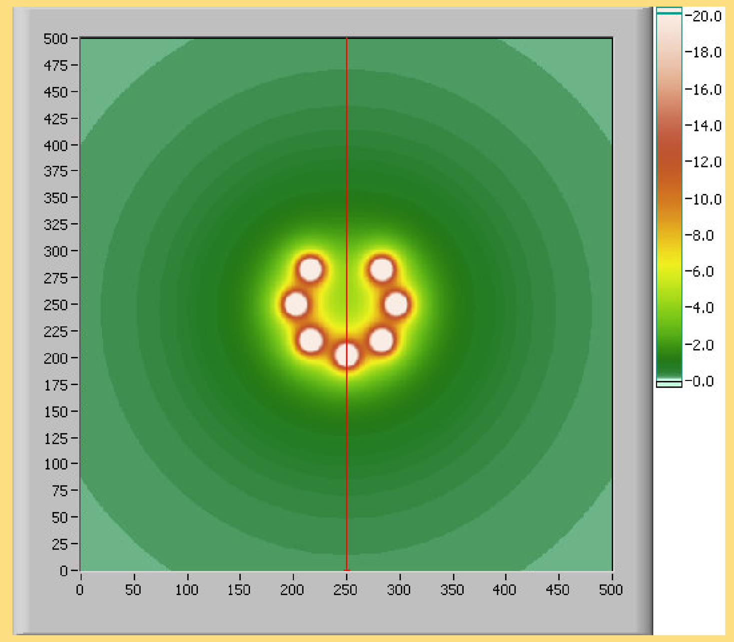

Figure 8. Image of 7 source configuration, which has one source "turned off" to lower dose to the heart(taken as being in the upward direction)

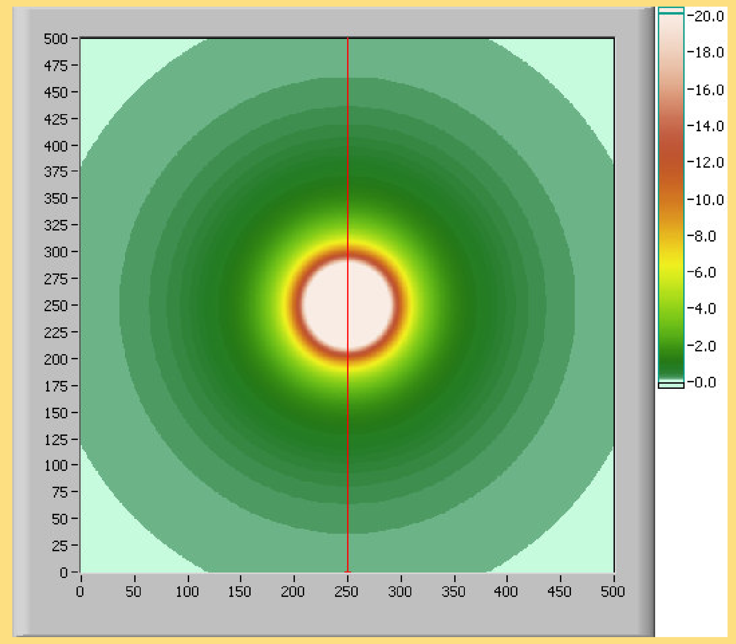

Figure 12. Dose image for a single Xoft source, with strength adjusted to deliver 3.4 Gy at 3 cm, corresponding to a 4 cm diameter balloon.

Circle Plot at Prescription Depth (1 cm from balloon)

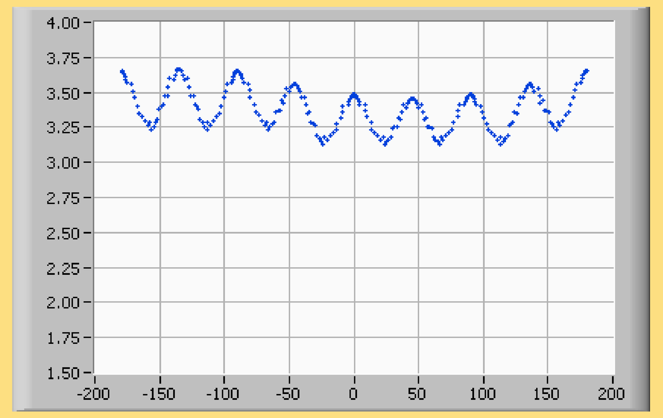

Figure 6. Circle plot of dose at prescription depth, 1 cm from applicator surface. Average is 3.4 Gy, while the modulation is approximately 15% max to min.

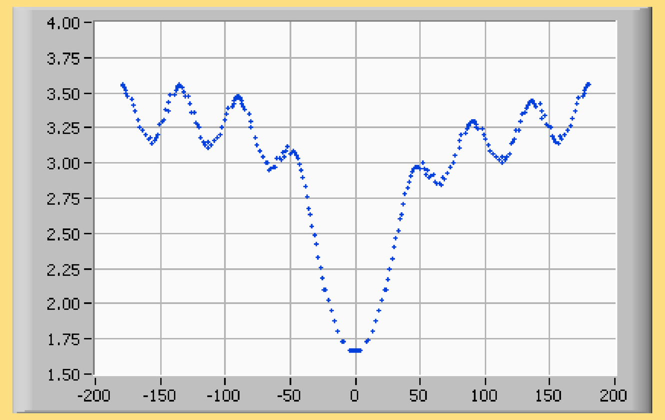

Figure 10. Effect of 7 sources at the prescription depth of 3 cm (1 cm from applicator surface). Dose in direction of the heart is less than half the prescription.

Circle Plot at 8 cm Radius (6 cm from balloon)

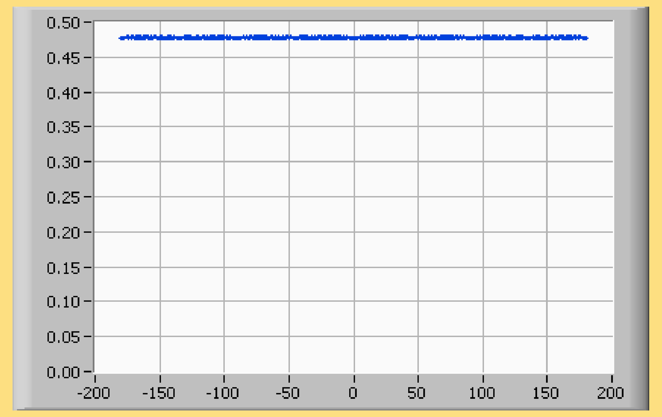

Figure 2. "Circle plot" of dose along a circle at 8 cm. At the prescription distance of 3 cm dose is 3.4 Gy. 8 cm was chosen as a nominal distance to the heart. Average dose at this distance is 0.48 Gy.

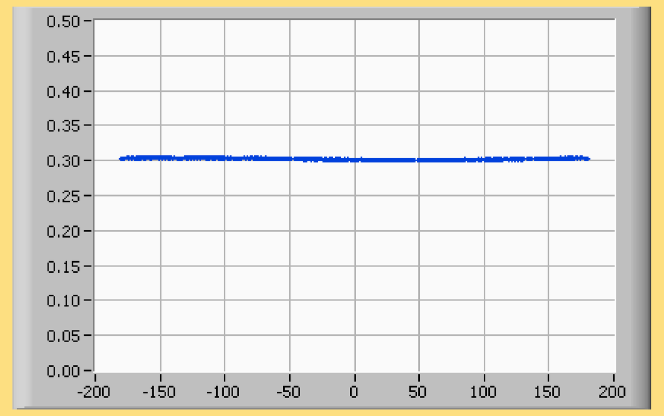

Figure 5. Circle plot of 8 Ir-192 sources at 8 cm radius, where the intensity has been adjusted to deliver 3.4 Gy at 3 cm, as in the single source case. Dose at heart is 0.30 Gy, less than the 0.48 Gy with a single Ir-192 source.

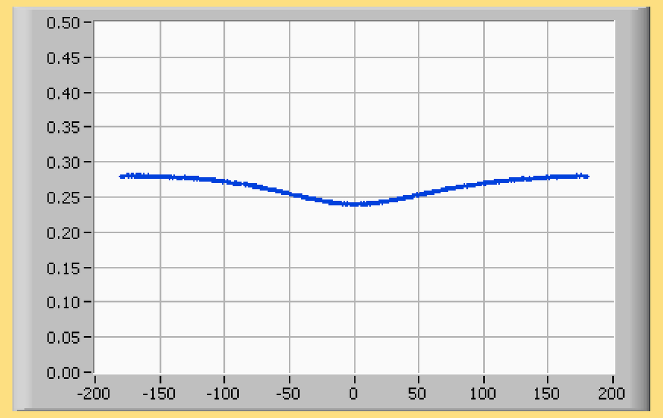

Figure 9. Circle plot of 7 source configuration at 8 cm. Heart is located at 0 degrees. Dose has been lowered from 0.30 to 0.24 Gy. Overall dose has also been lowered, from 0.3 to 0.28 Gy

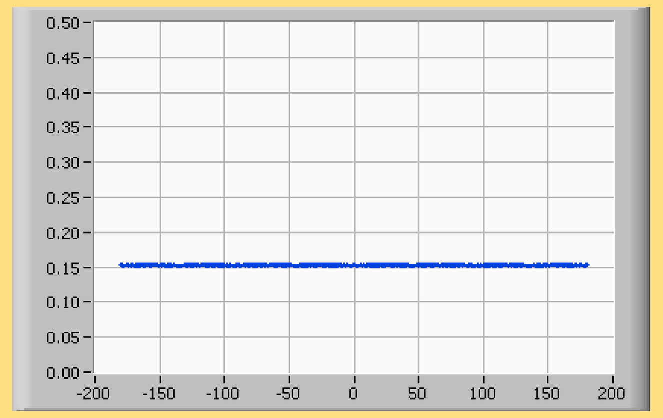

Figure 13. Circle plot at 8 cm for single Xoft source.

Line Plot through Vertical Center of Image

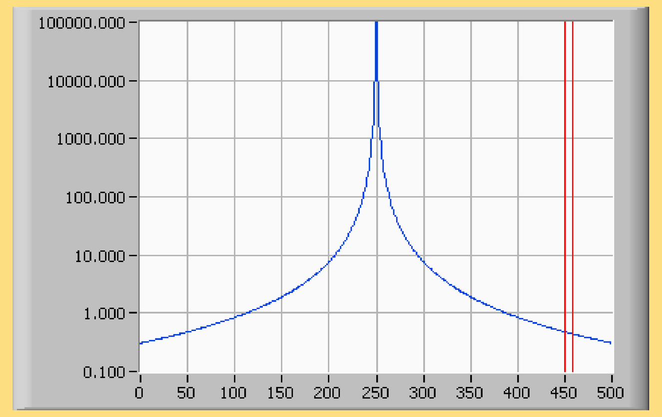

Figure 3. Line plot through vertical center of image. Dose at first cursor (at 8 cm) is 0.48 Gy, with a slope of 2.4% per mm

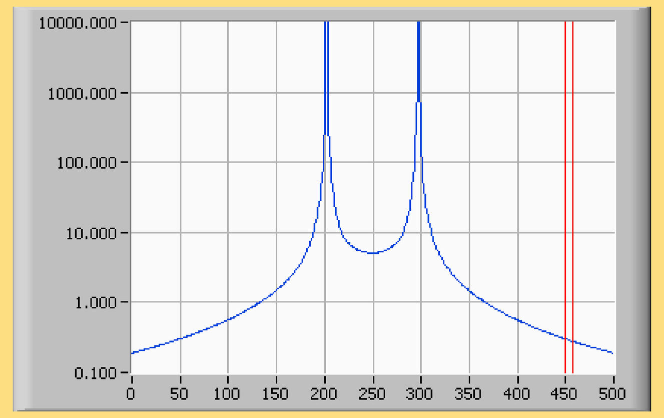

Figure 7. Line plot through vertical center of image. Dose at 8 cm (cursor location) is 0.30 Gy, with a slope of 2.5% per mm

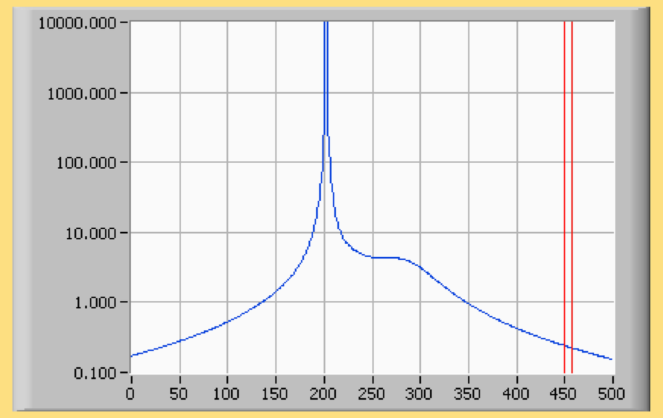

Figure 11. Line plot through vertical center of image. At cursor, dose is 0.24 Gy with a slope of 2.3% per mm.

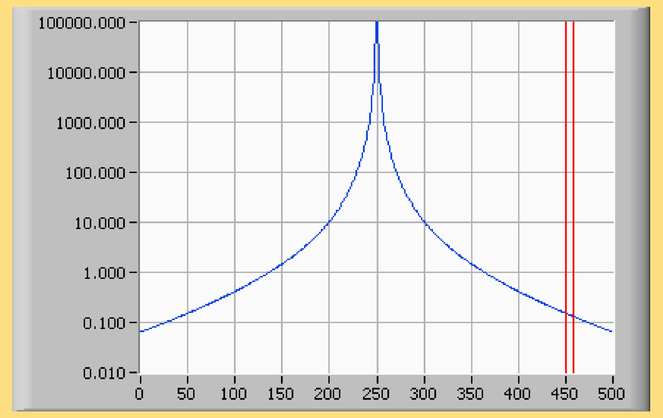

Figure 14. Line plot through vertical center of image. At 8 cm, dose is 0.152 Gy with slope = 4.2% per mm

RESULTS

- The Dose in Gy and percent of prescription dose (3.4 Gy at 1 cm) delivered at various distances from the "balloon" surface is shown in Table 1 and Figure 15.

Table 1. Dose and Percent of Prescription Dose Delivered

Distance	Ir-192	8 source	7 source	Xoft
1 cm	3.4/100%	3.4/100%	1.66/49%	3.4/100%
2 cm	1.91/56%	1.46/43%	0.95/28%	1.48/44%
4 cm	0.85/25%	0.56/16%	0.43/13%	0.42/12%
6 cm	0.48/14%	0.30/8.9%	0.24/7.1%	0.15/4.5%
8 cm	0.31/9.0%	0.19/5.5%	0.15/4.5%	0.065/1.9%
10 cm	0.21/6.2%	0.13/3.8%	0.11/3.2%	0.031/0.9%

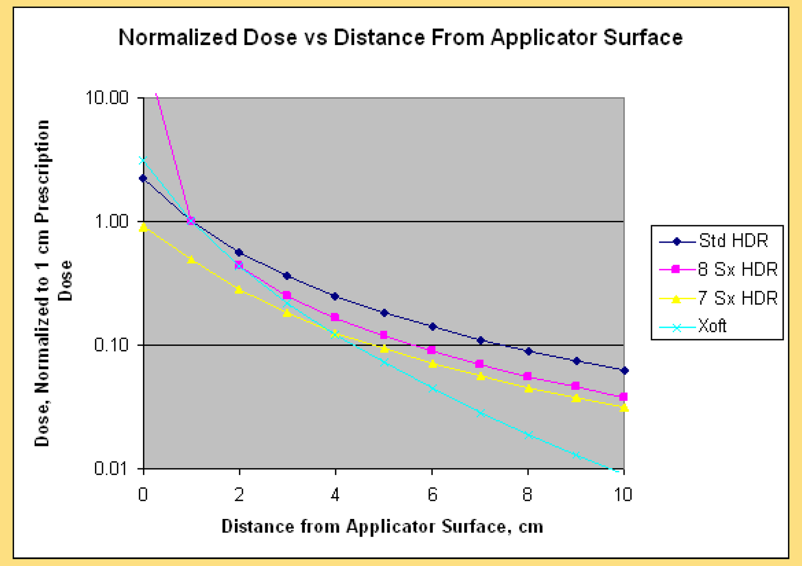

Figure 15. Comparison of normalized dose vs. distance from applicator surface for the four source (Sx) arrangements.

- Multiple source arrangements typically reduce the distant dose. In the 7-source case, one of the sources was removed and the depth dose path was aligned with the removed source, representing the maximum sparing that could be achieved. However this resulted in lower dose along the entire path toward the heart and so represents an underdose of tissue close to the balloon.
- Use of the Flexishield attenuator reduces dose in the Xoft 50 kVp case to virtually zero.
- For Ir-192 configurations, doses are reduced by only about 10% due to the high energy of the emitted gammas.

CONCLUSION

- In a two-dimensional simulation of various source arrangements, typical point doses to critical structures such as the heart and lungs have been calculated for Ir-192 HDR sources, a single source at the center of a balloon, 8 sources arranged around the periphery of a balloon or equivalent structure, 7 sources using the 8 source geometry but with one removed for the purpose of lowering dose in a particular direction; and a single Xoft 50 kVp x-ray source.
- Results show that highest doses to distant points occur with the single Ir-192 source.
- Multiple source arrangements typically reduce the distant dose. The reduction is larger in the case of 7 sources, especially closer to the treated region. However this comes at the cost of underdosing tissue in the treatment volume.
- The Xoft source has significantly lower distant dose than any of the other arrangements, with the advantage increasing with distance, due to attenuation of the 50 kVp radiation.

Funding provided by Xoft

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