Establishing the impact of temporary tissue expanders on electron and photon beam dose distributions

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Purpose: This study investigates the effects of temporary tissue expanders (TTEs) on the dose distributions in breast cancer radiotherapy treatments under a variety of conditions.

Methods: Using EBT2 radiochromic film, both electron and photon beam dose distribution measurements were made for different phantoms, and beam geometries. This was done to establish a more comprehensive understanding of the implant's perturbation effects under a wider variety of conditions.

Results: The magnetic disk present in a tissue expander causes a dose reduction of approximately 20% in a photon tangent treatment and 56% in electron boost fields immediately downstream of the implant. The effects of the silicon elastomer are also much more apparent in an electron beam than a photon beam

Conclusions: Evidently, each component of the TTE attenuates the radiation beam to different degrees. This study has demonstrated that the accuracy of photon and electron treatments of post-mastectomy patients is influenced by the presence of a tissue expander for various beam orientations. The impact of TTEs on dose distributions establishes the importance of an accurately modelled high-density implant in the treatment planning system for post-mastectomy patients.

Keywords: high-density, film, tissue expander, dose distribution, magnet.

I. INTRODUCTION

This study examines the dosimetric effects of temporary tissue expanders (TTEs) on radiotherapy treatments. TTEs are used in post-mastectomy breast reconstructions for selected breast cancer patients. Since radiotherapy treatment is usually started 4 to 8 weeks after the mastectomy surgery, some patients undergo radiotherapy with the TTE present.

These TTEs are made of a membrane composed of silicone elastomer, a chemically inert and mechanically robust material. The silicone membrane needs to be periodically filled with a saline solution until the desired expansion is reached. A magnetic disk allows the position of the implant's valve to be determined inside the patient's body. This high-density disk has the potential to seriously compromise the accuracy of radiotherapy treatment planning dose calculations, and hence delivery [1].

Several studies have been reported examining the effects of tissue expanders on radiotherapy dosimetry. Moni *et. al.* [2] completed measurements around the magnetic valve of a McGhan (Inamed/Allergan) tissue expander using film and thermoluminescent dosimeters (TLD) for a 6 MV photon beam. These measurements were designed to look for increased dose around the port, due to scatter from the high density metal, and found that there was no increased dose in the region of the metallic port. However, the results showed a decrease in the dose measured directly under the metallic port of around 25% in a region of 1.7 to 3.7 cm downstream. Damast *et. al.* [3] also investigated the effect of a McGhan Style 133 (Inamed/Allergan) tissue expander in a radiotherapy treatment using films and TLDs. Similar underdosing was identified but the authors concluded that this was not clinically significant due to the small volume of tissue underdosed. Chatzigiannis *et. al.* [4] performed Monte Carlo simulations using CT images of a patient implanted with a McGhan Style 133 (Inamed/Allergan) tissue expander. The magnet of the valve was simulated as being composed by Neodymium-iron-boron. Attenuation of 6–13% was found through all the area in the shadow of the magnetic valve and a dose enhancement around 10% was found near the metallic structure. Thompson and Morgan's [5] diode measurements described an 11% dose enhancement in a region of 5 mm around the valve and an underdosing of 10% to the radiation target when tangential photon beams were used.

Notably, all of these studies [2–5] examined the effects of only one type of tissue expander (McGhan Inamed/Allergan) on photon-beam dose distributions. Their findings showed conflicting reports on backscatter measurements and differing magnitudes of dose reduction. Finally, since breast-cancer patients with tissue expanders continue to be treated with both photon and electron-beam radiotherapy, there is an obvious need for a thorough examination of the effects of these implants on the doses delivered by both tangential photon fields and electron boost fields.

A recently published study by Srivastava *et. al.* [6] compared ion chamber measurements with treatment planning system (TPS) calculations and concluded that high-Z materials should be avoided due to their poor modeling in TPS algorithms. This failure to accurately calculate dose distributions could be attributed to incorrect CT density assignments for high-Z materials [7]. Irrespective of TPS inaccuracies, the avoidance of a high-density port is not a practical option in post-mastectomy radiotherapy and may result in sub-optimal treatments being delivered to the patient. Therefore, in the present study we experimentally examine the effects of a Mentor TTE (Mentor, Magna-Site disk, Santa Clara, CA, USA) on electron and photon beam dose distributions. Exploring different phantoms and beam geometries will provide a more comprehensive understanding of the effects of tissue expanders in post-mastectomy radiotherapy.

II. METHODS

In this study, dose distribution measurements around a Mentor TTE were performed using EBT2 radiochromic film. The implant was partially filled with 250 cm^3 of a 0.9% saline solution, and then placed atop a planar phantom composed of an arrangement of water and lung equivalent materials, illustrated in Figure 1. Additionally, a 1.5 cm layer of bolus was placed over the top of the implant such that the phantom set-up models the subcutaneous implantation of the expander in a patient. Pieces of film were then positioned 0 cm and 2 cm downstream of the implant as well as one piece of film immediately upstream to measure any backscatter caused by the high-Z material. The TTE was irradiated isocentrically (98.5cm SSD) using a 15x15 cm^2 field of 6 MV photons, as well as 12 MeV electrons, at incidences perpendicular to the heterogeneity.

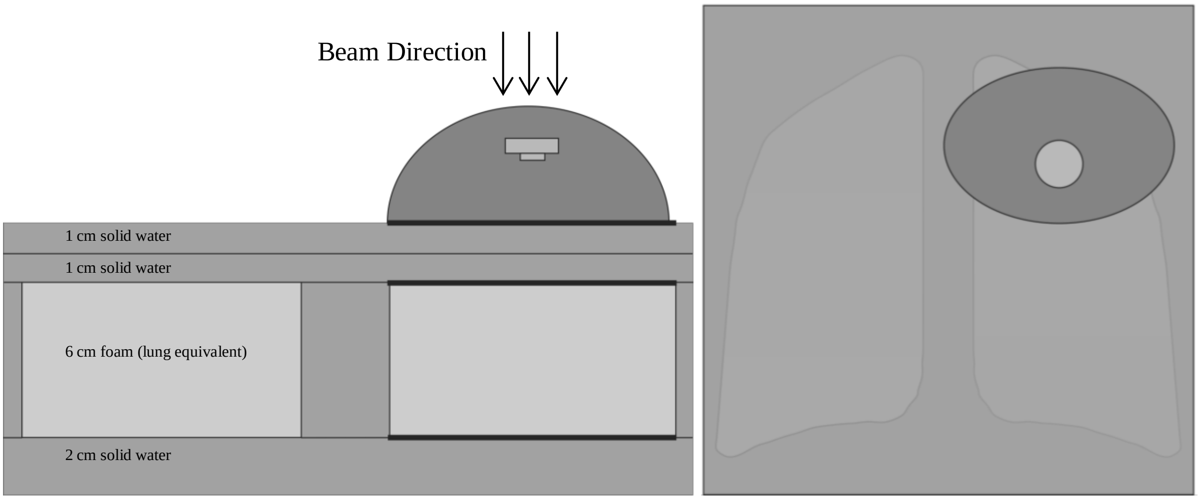

Figure 1 Illustration of the planar phantom arrangement, TTE placement, and film locations (thick black lines) during photon and electron beam irradiations (bolus not shown).

Measurements were also made using a CIRS IMRT thorax phantom, this time with the TTE filled with 400 cm^3 of the saline solution. Once again, a 15x15 cm^2, 6 MV photon field was delivered at an incidence perpendicular to the heterogeneity (gantry angle of 340^o). Once more, film was placed above and below the implant. An additional piece was placed running parallel to the incident beam between slices of the thorax phantom. Fig. 2 demonstrates the alignment of our experimental conditions to a clinical case with a CT slice of the thorax /TTE phantom and overlying bolus compared to an image slice of a patient with the subcutaneous implantation of a tissue expander.

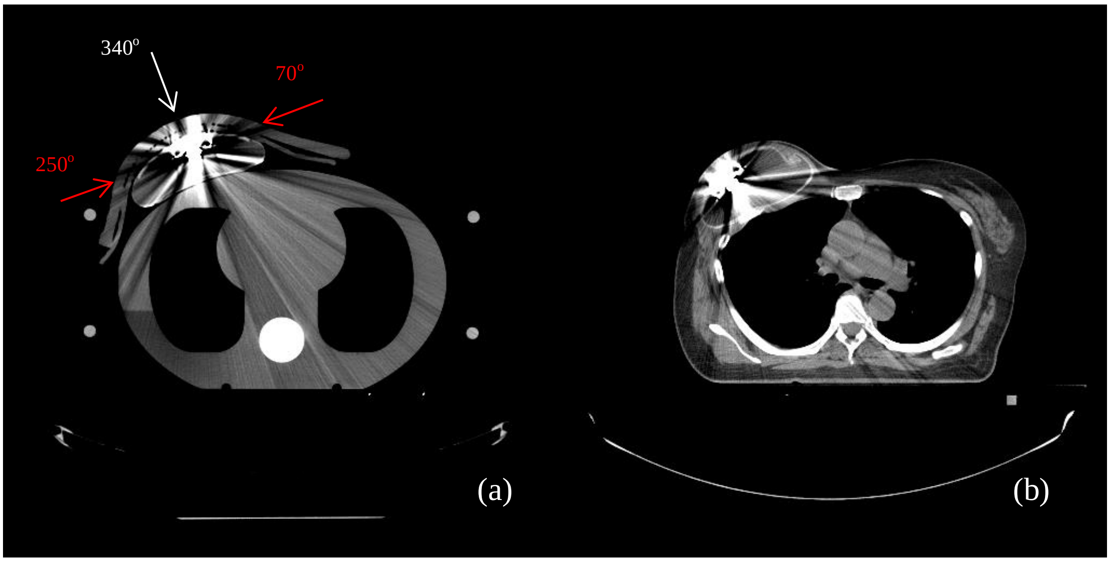

Figure 2 (a) CT slice of the thorax phantom indicating beam angles and TTE placement. (b) Image slice of a patient with implanted tissue expander.

Finally, a beam arrangement was adopted from a clinical plan where photon tangents were modulated using a forward-planned IMRT (field-in-field) technique [8,9]. This involved delivering segmented, tangent photon fields (dynamic wedged fields) at angles of 70^{o} and 250^{o} with film placed immediately upstream and downstream of the implant. The technique has been shown to provide more homogeneous dose distributions in the planning target volume (PTV) and reduced doses in the organs at risk (OAR) [10].

The film was scanned and evaluated as per the protocol outlined in Kairn et. al. [11] and Aland et. al. [12] which minimised the effects of film heterogeneity and scanner output variations. Finally, the dose reduction values presented in this work were calculated as the percentage difference between the average doses outside the shadow of the magnet, relative to the doses in the region directly under the magnet. Measurement uncertainties were taken as the standard deviation of doses in each region.

III. RESULTS AND DISCUSSION

Fig. 3 shows the dose profile of the implant at two different depths, downstream of the breast implant in the planar phantom for a 6 MV photon beam at 0^o gantry. At 0 cm, in the region directly below the magnetic valve, the dose is reduced by as much as 15 ± 3 %. This figure also reports a 12 ± 2 % dose reduction at 2 cm below the bottom edge of the implant. No backscatter dose enhancements were reported in the radiochromic film and were therefore not included in Fig. 1.

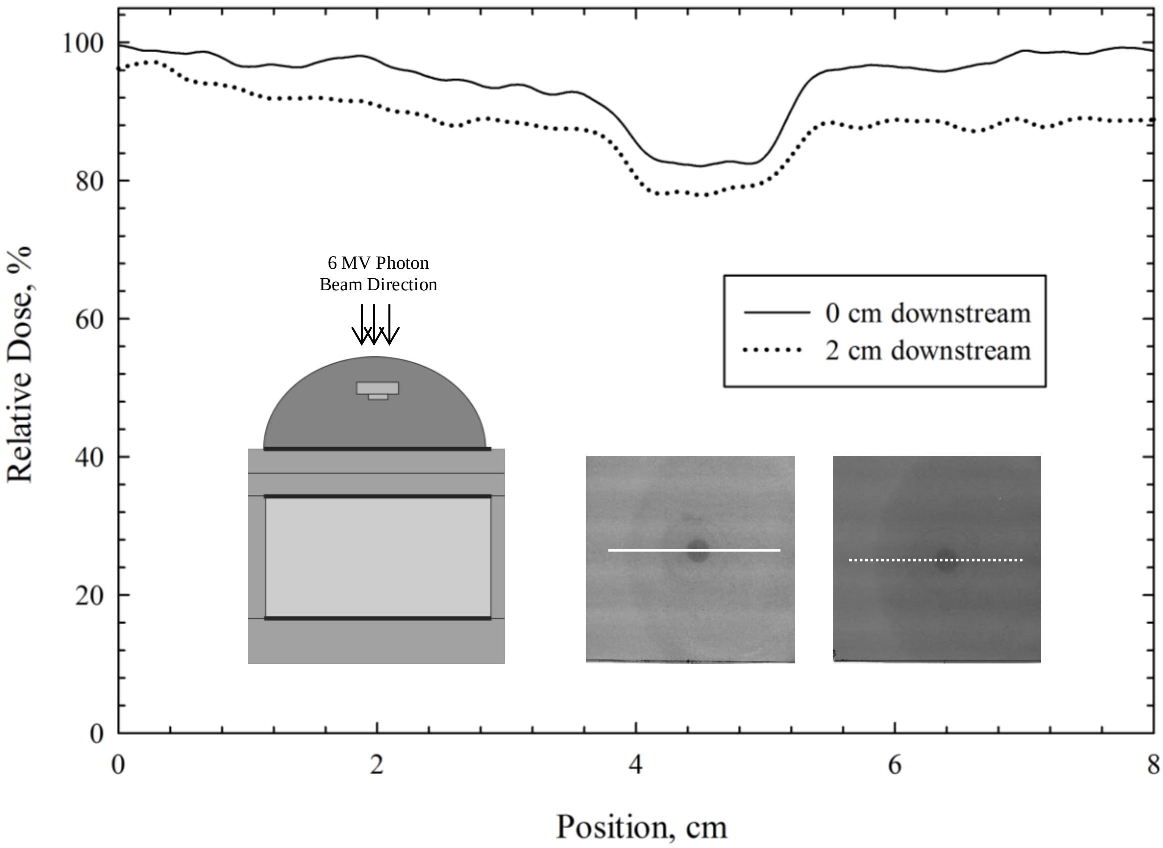

Figure 3 Dose profiles of a 6 MV photon beam at different depths downstream of the implant. *Inset* indicates beam direction, film locations (thick black lines), and profile positions.

The qualitative data, displayed in Fig. 4 (a), clearly illustrates the perturbation effects the high-density magnetic port, as well as the silicone elastomer in the 12 MeV electron beam at different depths. Increased bremsstrahlung around the edges of the implant is also visible.

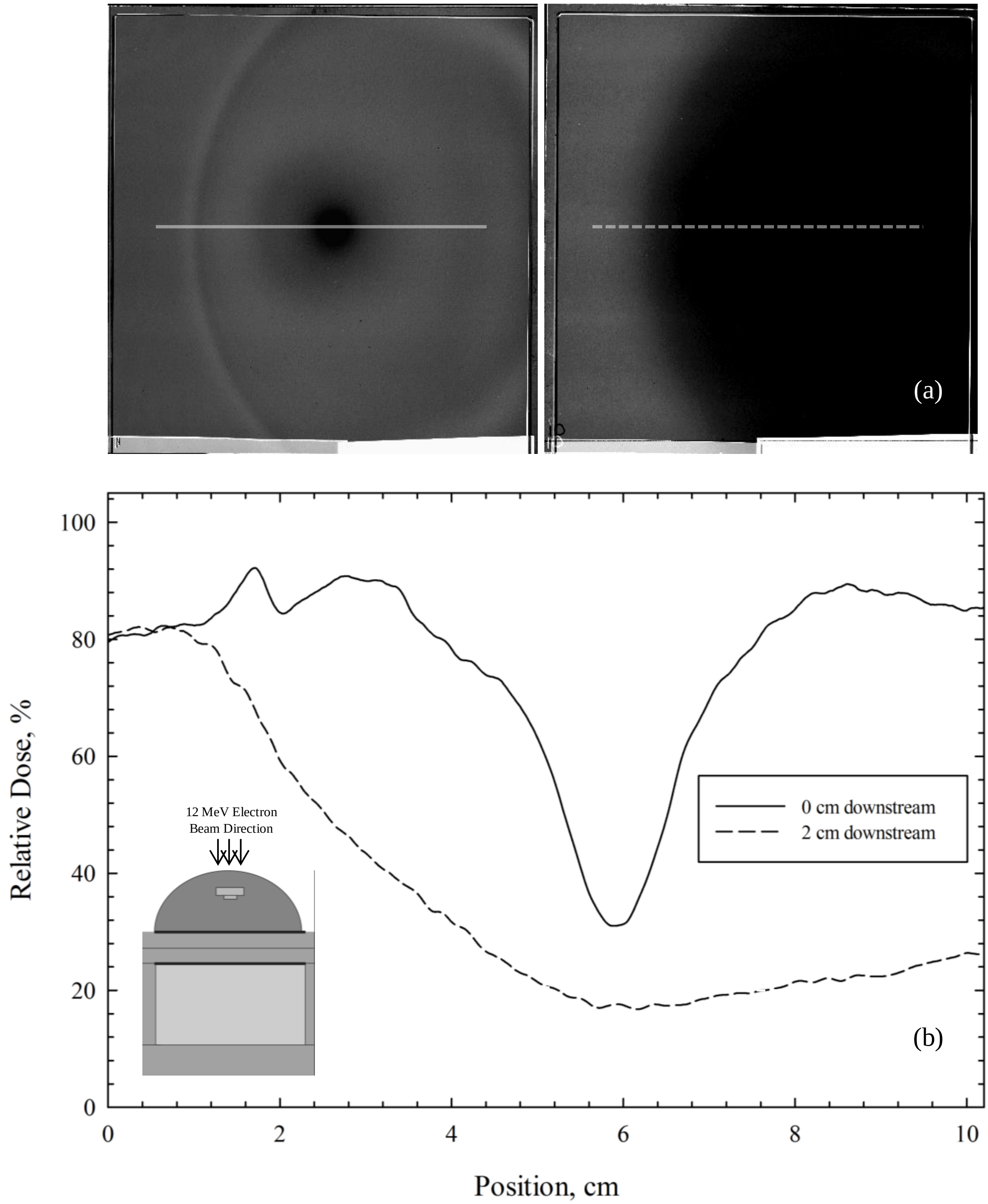

Figure 4 (a) Images of scanned EBT2 film showing attenuation of the 12 MeV electron beam through the temporary tissue expander at 0 cm (left) and 2 cm (right) downstream. (b) Corresponding central-axis profile plots at different depths downstream of the tissue expander. *Inset* indicates beam direction and film locations (thick black lines).

Fig. 4 (b) shows the dose profile of the TTE in a 12 MeV electron boost field at two distances downstream of the implant in a planar phantom. At 0 cm a substantial dose reduction of approximately 56 ± 6 % is reported compared to the dose recorded outside the magnet's field shadow. It should be noted that the at the location of the profile taken outside of the magnet's shadow there is a slight difference of overlaying tissue thickness compared to that taken in the magnet's shadow due to the curvature of the implant surface, however the difference to the dose profile is negligible in comparison to the effect of the metallic port. Given that boost fields are typically delivered as per this experimental setup, electron treatments of post-mastectomy patients with TTEs would be compromised by the presence of this high-Z material. The effects of the silicon elastomer are also much more apparent in the electron beam than the photon beam.

Photon beam measurements in the CIRS IMRT thorax phantom illustrate the perturbation effects of each component of the implant and are shown in Fig. 5. Moving averages have been applied to smooth the data which helps illustrate the magnitude of each component's attenuation.

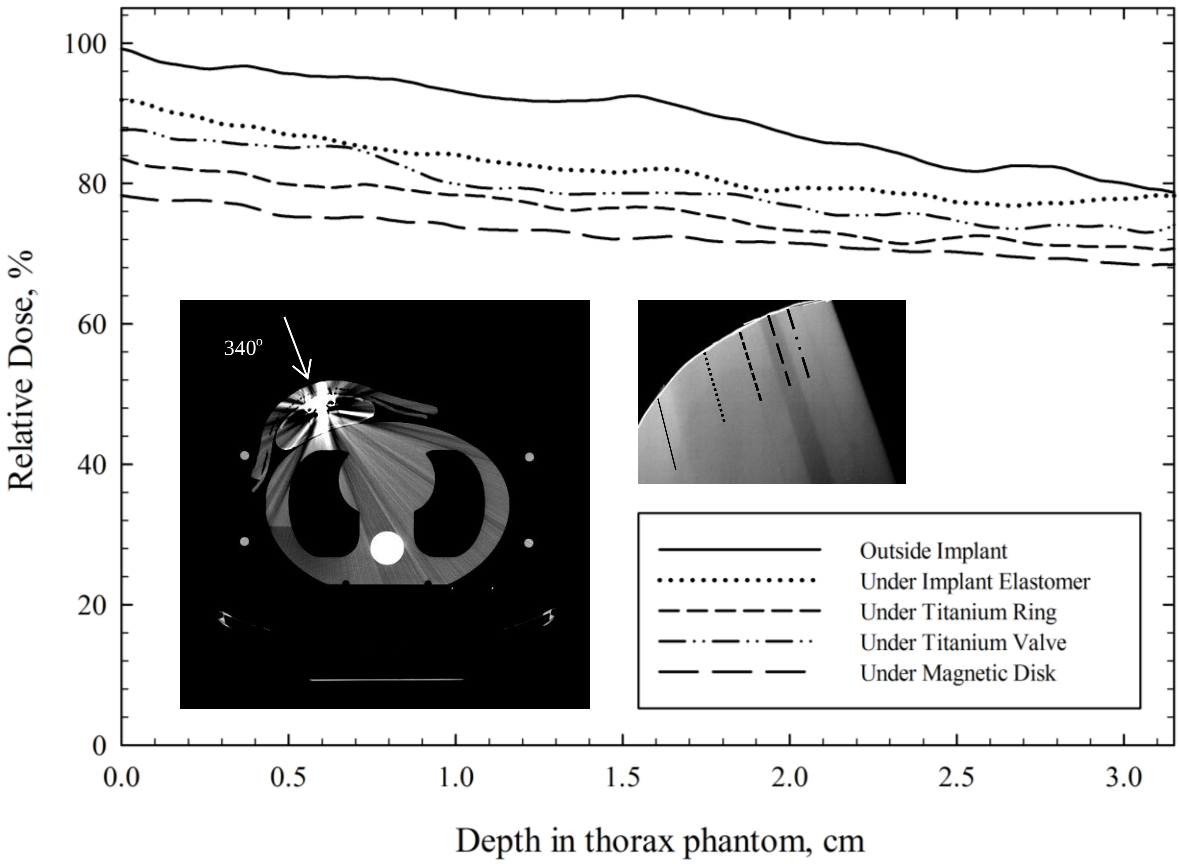

Figure 5 6 MV photon depth dose profiles in the CIRS thorax phantom downstream of different components in the implant with filled volume. *Insets* indicate approximate profile locations and beam direction.

From Fig. 5, it was determined that profiles downstream of the silicone elastomer/saline interface averaged doses around 8% lower when compared to profiles taken outside the implant's shadow. Differences for profiles taken under the titanium case, titanium ring and neodymium magnet were approximately 12%, 15% and 19% respectively. These results agree with what is expected when considering the scaled depth of each implant component and its density. It should be noted that there are slight differences in depth caused by the curved shape of the implant; however, this would have no effect on the order of which components attenuate the most. This highlights the importance for an accurately modelled high-density implant in the treatment planning system.

Photon tangent fields were also delivered to the thorax phantom and the results in Fig. 6 illustrate a combined dose reduction of 20% caused by the high-density magnet in both treatment directions, calculated once again using the percentage difference between the average dose values outside the shadow of the magnet, relative to the dose value in the region directly downstream of the magnetic port. Given that post-mastectomy treatments are typically delivered as per this experimental setup, the impact of the TTE on photon dose distributions would be significant if it's not accurately accounted for in planning. The *insets* indicate in Fig. 6 indicate the approximate profile locations as well as pictographically demonstrating the perturbation caused by the TTE's internal magnet and silicone elastomer shell.

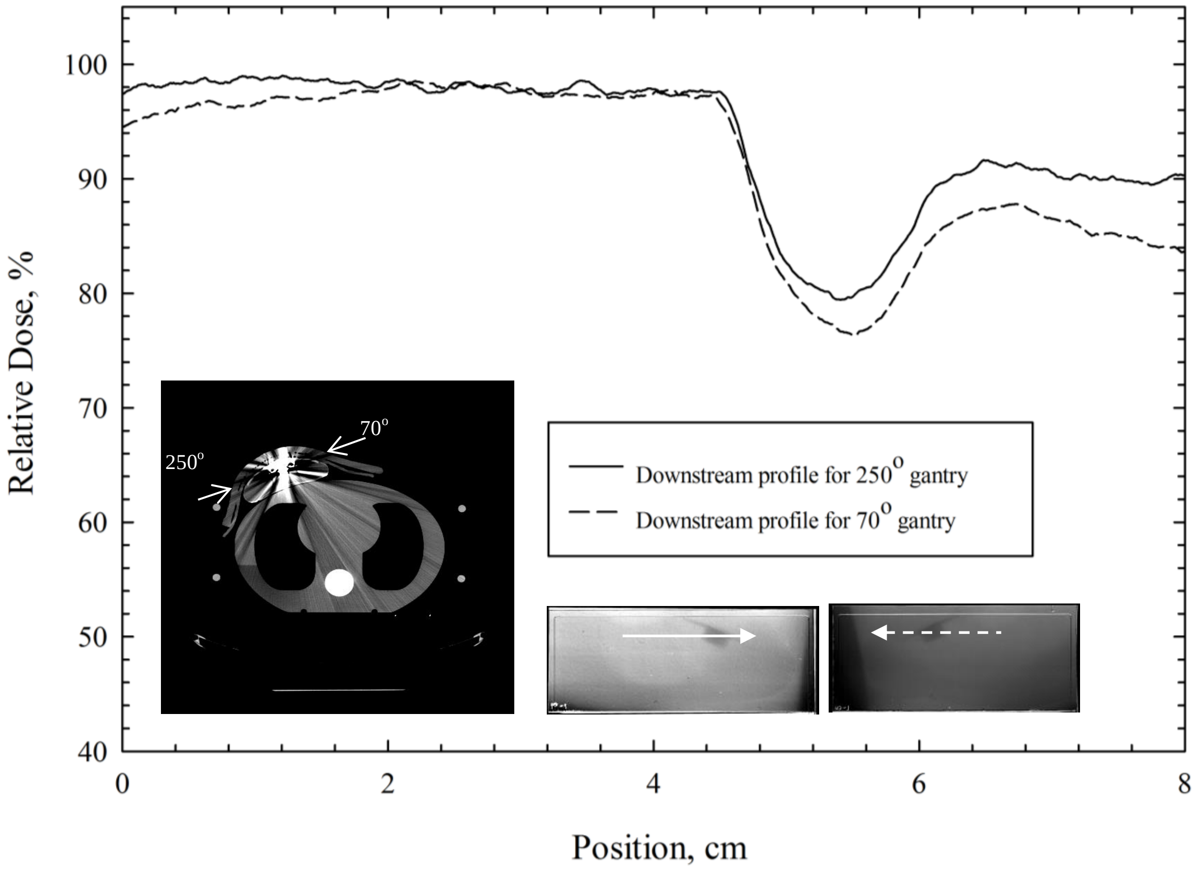

Figure 6 Dose profiles of a 6 MV photon treatment for two beam tangents at gantry angles of 70° and 250°. The data has been smoothed with the application of a moving average filter. *Insets* indicate beam directions and approximate profile locations/directions on downstream film pieces.

IV. CONCLUSIONS

This work indicates that the magnetic disk present in a tissue expander causes an average dose reduction of approximately 20% in photon tangent fields and 56% in electron boost fields immediately downstream of the implant. The silicone elastomer shell of the Mentor implant has also been shown to reduce the dose to a section of the target volume by as much as 8% in a 6 MV photon field, which in turn reduces the probability of tumour control. Evidently, each component of the TTE attenuates the radiation beam to different degrees. This highlights the importance for an accurately modelled high-density implant in the treatment planning system for post-mastectomy patients.

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