HDR BRACHYTHERAPY FOR SKIN CANCER USING H.A.M. APPLICATOR

By

Timothy Richard Thatcher

Bachelor of Science – Physics
University of California, Irvine
2009

Master of Science – Medical Physics
University of Nevada, Las Vegas
2016

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School of Integrated Health Science
The Graduate College

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Timothy Richard Thatcher

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Steen Madsen, Ph.D.
Examination Committee Co-Chair

Kathryn Hausbeck Korgan, Ph.D.
Graduate College Dean

Yu Kuang, Ph.D.
Examination Committee Co-Chair

Cephas Mubata
Examination Committee Member

Ryan Hecox
Examination Committee Member

Dharini Bhammar, Ph.D.
Graduate College Faculty Representative

ABSTRACT

Skin cancer is the most common type of malignancy affecting both men and women in the United States. A majority of these cases are nonmelanoma skin cancers (NMSC) such as basal cell carcinoma (BCC) and squamous cell carcinoma (SCC). The goal of any skin cancer treatment is to cure the lesion itself while also preserving function and optimizing superficial cosmesis. High dose rate (HDR) brachytherapy provides an alternative to superficial x-ray or electron beam for skin cancer treatment. Utilizing an Iridium 192 source soldered to the end of a wire, surface dose can be administered at predetermined positions with sharper dose fall off than x-ray or electron beams. A variety of applicators are available to guide the HDR source wire to the specified location. The Harrison Anderson Mick (H.A.M.) applicator is an HDR surface applicator designed to create defined spacing between the source, tissue, and source channels. The pliable nature of the flap allows for customizable contouring to the patient's treatment area. This project is designed around the general implementation and commissioning of a H.A.M applicator flap for HDR skin cancer brachytherapy and the acceptance and commissioning of a Varian Bravos HDR afterloader. Dimensional analysis of the applicators matched manufacturer specifications and each applicator was free from damage. Applicator dosimetry was verified using Gafchromic EBT3 film and RIT113 film analysis software. Prescription depth and dose recommendations are presented and both treatment planning and quality assurance methods were established. End-to-end testing performed using the applicators demonstrated that they are adequate and capable of HDR treatment.

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1) INTRODUCTION

Nonmelanoma skin cancer (NMSC) is the most prevalent malignancy affecting both men and women in the United States. It is estimated that at least 2-3 million people are affected annually (Guinot et al., 2018; Ouhib et al., 2015). Basal cell carcinoma (BCC) and squamous cell carcinoma (SCC) are the most common types of NMSCs, with BCC representing approximately 75% of cases and SCC accounting for the remaining 25% (Alam et al., 2010). NMSC generally has a low mortality rate, but older populations are showing an increased incidence rate which can drastically affect quality of life (Guinot et al., 2018; Ouhib et al., 2015). Treatment options for BCC and SCC are varied. Surgical excision is the most common treatment methodology, but cryosurgery, topical chemotherapy, photodynamic therapy, and radiotherapy are all viable treatment options (Alam et al., 2010; Likhacheva et al., 2017). However, not all patients are candidates for surgical excision and radiotherapy procedures utilizing either external beam radiation or brachytherapy have proven to be an effective alternative.

Radiation treatment options are also varied and include superficial x-rays, external electron beams, electronic brachytherapy, and high dose rate (HDR) radionuclide brachytherapy. Brachytherapy provides an effective means for treating NMSCs that are not able to be surgically removed or conveniently treated with external beam radiotherapy. The word “brachy” is Greek for “short distance” and deals with the placement of radioactive sources either directly onto or into the treatment area. Modern brachytherapy practices can have the source applied inside a body cavity (intracavitary), placed directly into a body tissue (interstitial), directed across a tissue boundary into a bodily passage such as the esophagus or lung (transluminal), or placed on the surface of the body (surface-mold/contact technique). The most commonly used isotope for HDR brachytherapy is Iridium-192 (Ir-192). Ir-192 has a half-life of 74.2 days and emits γ rays

with a mean energy of 380 keV at a dose rate of approximately 7.5 Gy/min at 1.0 cm, allowing for patient treatment times lasting several minutes (Oncology Medical Physics, 2020).

The scope of this project is the implementation of a Harrison Anderson Mick (H.A.M) applicator for HDR brachytherapy skin cancer treatment at Dixie Regional Medical Center and the acceptance and commissioning of the Varian Bravos HDR afterloader. Currently only intracavitary brachytherapy is performed at this clinic, so this project would add the capability to treat both SCCs and BCCs with surface brachytherapy. These types of malignancies are generally treated with external beam electrons because of their shorter range of penetration compared to photons, but there have been times when gantry angle and treatment location have proven challenging. Using a flexible skin applicator would allow for alternative delivery options not previously available. Commissioning of the H.A.M applicator was performed as well as dosimetry verification using Gafchromic EBT3 film. Localization and reproducibility of the applicator between fractions was determined, along with general prescription depths and doses. Treatment planning techniques were also developed for ease of future implementation.

2) MATERIALS AND METHODS

2.1) Varian Bravos HDR Afterloader

The Bravos is a new HDR afterloader developed by Varian. It contains a tungsten safe that houses an Ir-192 source encased in stainless steel with a maximum installable activity of 15 Ci (555 GBq) (Varian, 2020). The source capsule is welded to a flexible wire made of stainless-steel capable of extending to a length of 160 cm and traveling at a maximum speed of 100 cm/s (Bellezzo et al., 2019). There are 30 possible treatment channels with a potential for 100 dwell positions per channel and a wire positioning accuracy of ±1 mm.

The Bravos system also contains several new features that were not present in the predecessor HDR afterloader, the GammaMedplus iX. The transit time algorithm of the source has been reformulated in order to consider the movement of the source from the afterloader to the most distal dwell position. There now exists an option for the differentiation between rigid and flexible applicators which changes the force threshold used for source retraction (Bellezzo et al., 2019). Channel length verification is now performed prior to treatment and the system will automatically adjust for minor discrepancies. Channel length can be adjusted at the treatment console prior to treatment while also retaining the same dwell time and positions relative to channel length. It is now possible to add a distal position correction at a resolution of 1 mm prior to treatment. The treatment system also requires the completion of a pretreatment checklist. Patient identity and treatment setting verification are mandatory checklist fields, but additional checklist items can be added manually. This checklist and the channel length verification must be completed before the initiation of treatment. A comparison of the different features between the Bravos and its predecessor the GammaMedplus iX is presented in Table 1.

Feature	**GammaMedplus iX**	**Bravos**
CamScale device	Absent	Present
Transit time calculation algorithm	Accounts only for transit time between dwell positions	Considers source movement from afterloader to most distal dwell position
Source speed	63 cm/s	100 cm/s
Obstruction verification	Checked twice before treatment	Checked once during pretreatment and again prior to treatment
Number of channels	24	30
Channel length	Fixed at 130 cm	50 – 160 cm
Channel length verification	Absent	Present
Use of coded transfer guide tubes	Absent	Coded guide tubes can be used in channels 1 – 3
Rigid and flexible applicator differentiation	Push test performed only for channels 1 – 19	All channels capable, but push test is optional
Distal position correction	Possible to add offset but not able to correct it during pretreatment	Possible to correct an offset at 1 mm resolution at console prior to treatment
Distal position display at end of channel (ex. 130.0 cm)	1 mm offset from source position to the end of the channel is displayed as if there is no offset (ex. 130.0 cm)	1 mm offset from source position to the end of the channel is displayed (ex. 129.9 cm)
Pretreatment checklist	No mandatory checklist	Treatment can only be delivered after approving a checklist with mandatory fields for patient identity and treatment setting. Additional checklist items can also be added by the user

Table 1: GammaMedplus iX and Bravos HDR afterloader feature comparison. (Bellezzo et al., 2019)

Another new feature of the Bravos is the addition of the CamScale. The CamScale is separate device from the Bravos afterloader and is primarily designed for daily QA and source wire position verification. The CamScale and Bravos are presented in Figure 1.

Figure 1: The CamScale (left) and Bravos HDR afterloader (right). (Varian, 2020)

Correct positioning of the CamScale is critical to proper position verification. The CamScale needs to be placed at approximately 50 ± 1.5 cm and is connected to the afterloader using a special guide tube inserted into Channel 1 (Bellezzo et al., 2019). Figure 2 shows the CamScale properly attached to the Bravos afterloader. A laser is projected from the CamScale onto the afterloader and needs to be aligned with a small box present on the front end of the afterloader. Alignment with this box ensures that the CamScale is at the proper distance to accurately position the dummy and source wire. A close-up view demonstrating appropriate laser alignment is shown in Figure 3.

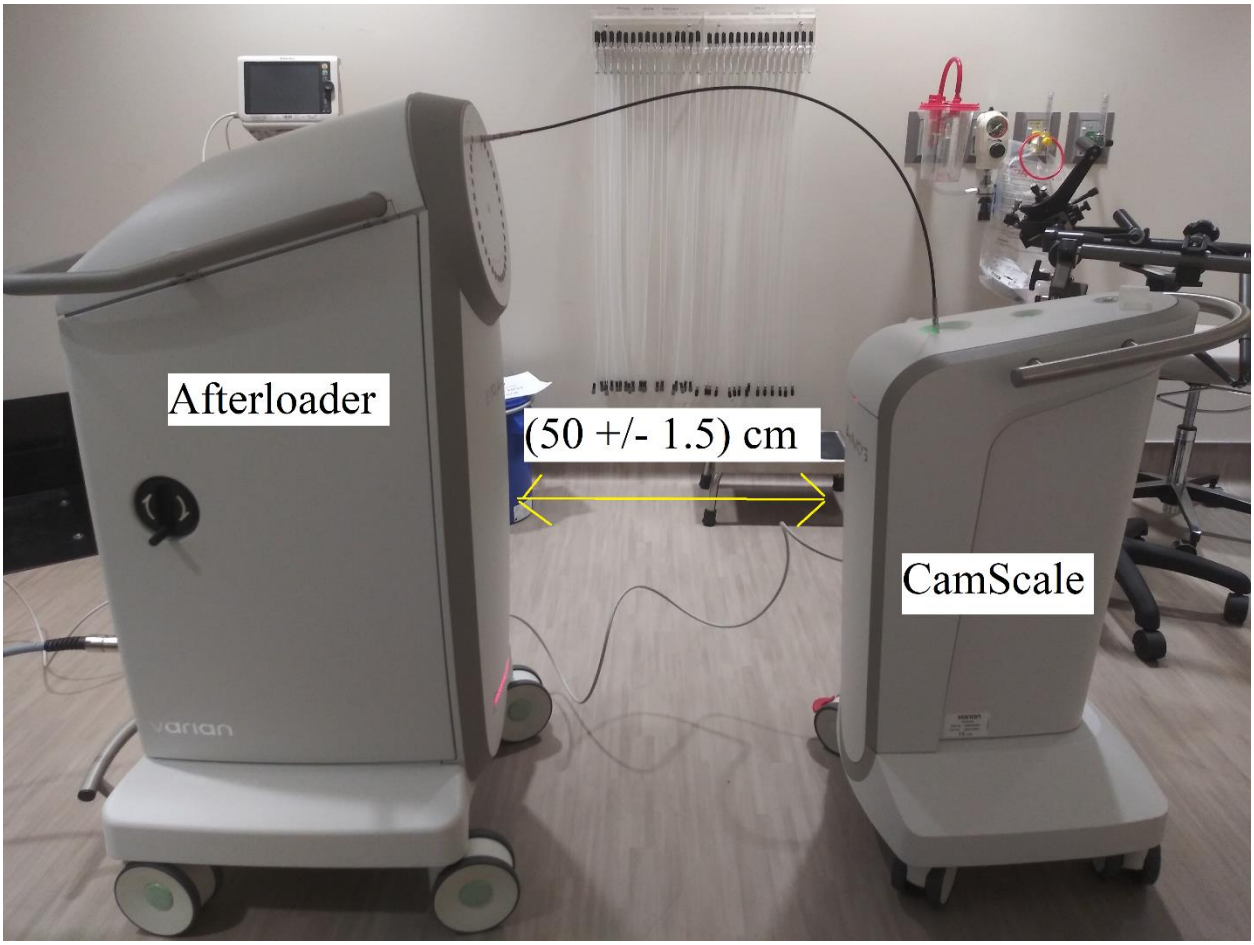


Figure 2: Bravos with attached CamScale. The special guide tube is designed to be inserted into Channel 1 and the red laser projected onto the front of the Bravos ensure proper positioning at 50 ± 1.5 cm.

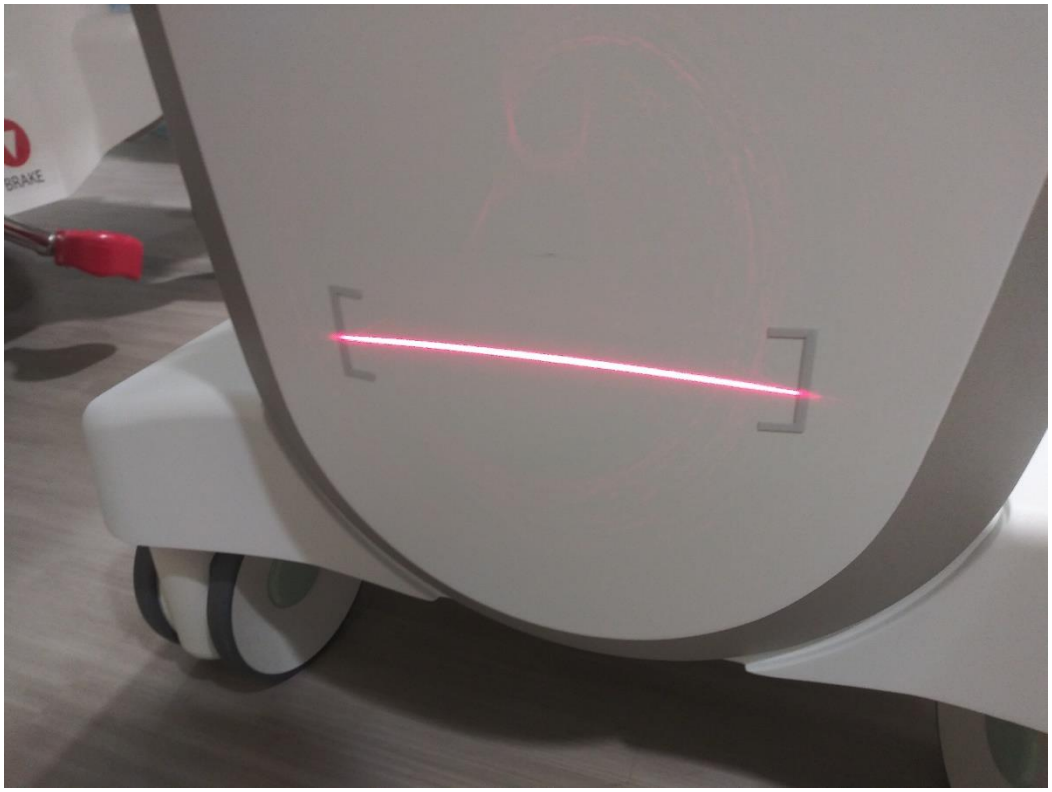
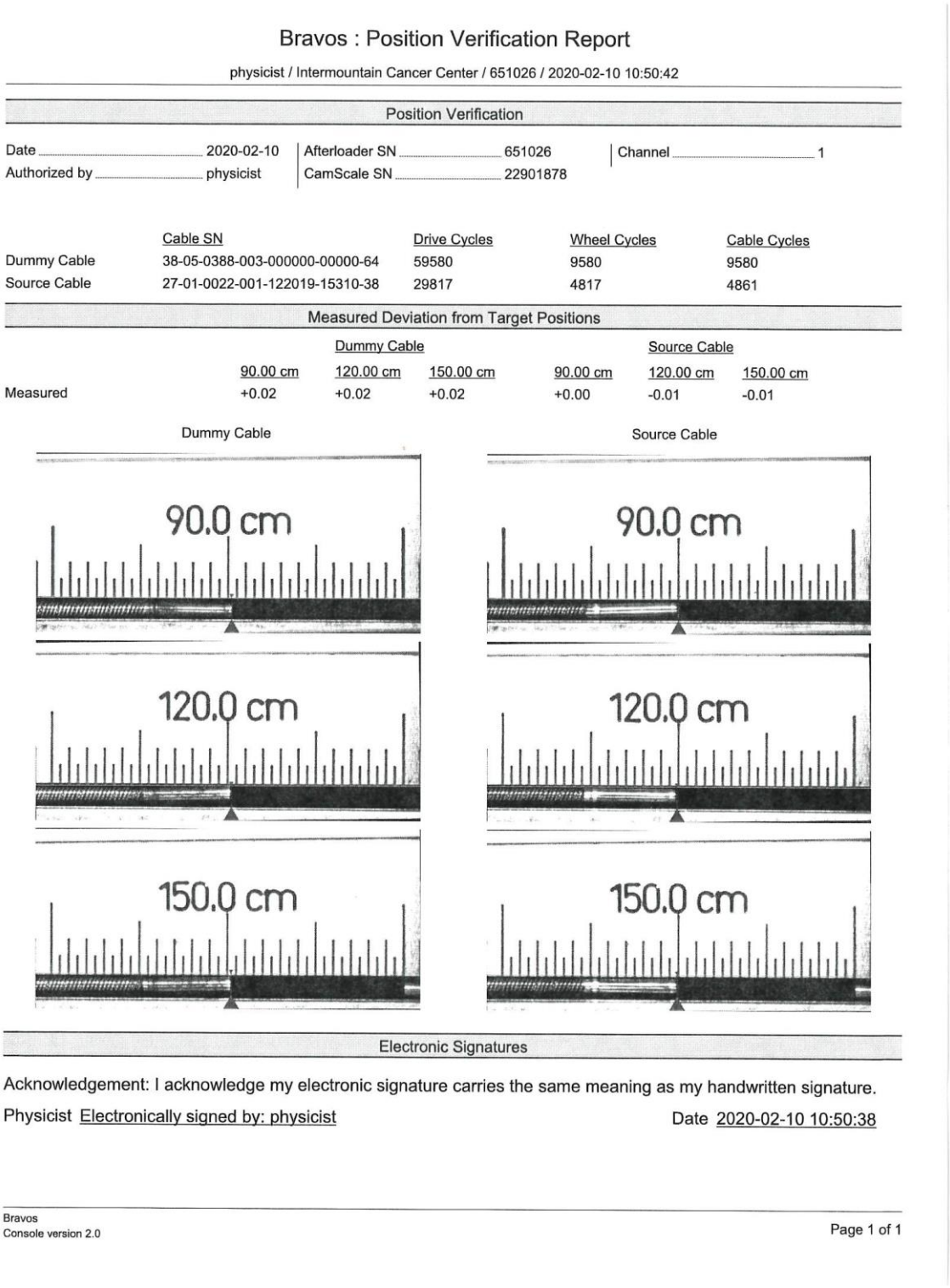


Figure 3: Close up view of positioning laser. The laser is designed to be centered within the confines of the small box on the front of the Bravos afterloader. This allows for an easy visual reference to ensure that CamScale positioning is correct.

The inside of the CamScale consists of a calibrated metal ruler with 0.5 mm resolution and three 1080p video cameras designed to capture the dummy and source wire at positions of 90, 120, and 150 cm (Bellezzo et al., 2019). The images taken at each of these dwell positions are then analyzed by the system to locate the tips of both the dummy and source wires. If the deviation from where the systems thinks the tips are and the visual position verification is greater than 1 mm then it is suggested that a recalibration is performed where the user manually aligns the system to the wire tips and the position is re-verified. An example of the printed report after a position verification test is shown in Figure 4. The full Bravos commissioning report is presented in Appendix A as a supplemental document.



Bravos : Position Verification Report

physicist / Intermountain Cancer Center / 651026 / 2020-02-10 10:50:42

Position Verification

Date	2020-02-10	Afterloader SN	651026	Channel	1
Authorized by	physicist	CamScale SN	22901878		

	Cable SN	Drive Cycles	Wheel Cycles	Cable Cycles
Dummy Cable	38-05-0388-003-000000-00000-64	59580	9580	9580
Source Cable	27-01-0022-001-122019-15310-38	29817	4817	4861

Measured Deviation from Target Positions

	Dummy Cable			Source Cable		
	90.00 cm	120.00 cm	150.00 cm	90.00 cm	120.00 cm	150.00 cm
Measured	+0.02	+0.02	+0.02	+0.00	-0.01	-0.01

Electronic Signatures

Acknowledgement: I acknowledge my electronic signature carries the same meaning as my handwritten signature.

Physicist Electronically signed by: physicist

Date 2020-02-10 10:50:38

Bravos
Console version 2.0

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Figure 4: Position verification test report. Results for the dummy cable at each position is presented on the left and the source cable is presented on the right. Arrows identify the tips of each wire and the report lists the offsets at each dwell position.

2.2) H.A.M Applicator

The Harrison Anderson Mick (H.A.M) applicator is a flexible flab of silicone rubber designed to facilitate the placement of a radioactive source delivered from a remote afterloader for the surface treatment of the skin, mucosa, or tumor bed (Eckert & Ziegler, 2019). The applicator contains a set number of treatment catheters placed inside the flexible rubber pad. This allows for direct connection to an HDR remote afterloader as well as consistent source-to-tissue spacing of 5 mm. H.A.M. applicators containing both five and ten treatment catheters are shown in Figure 5.

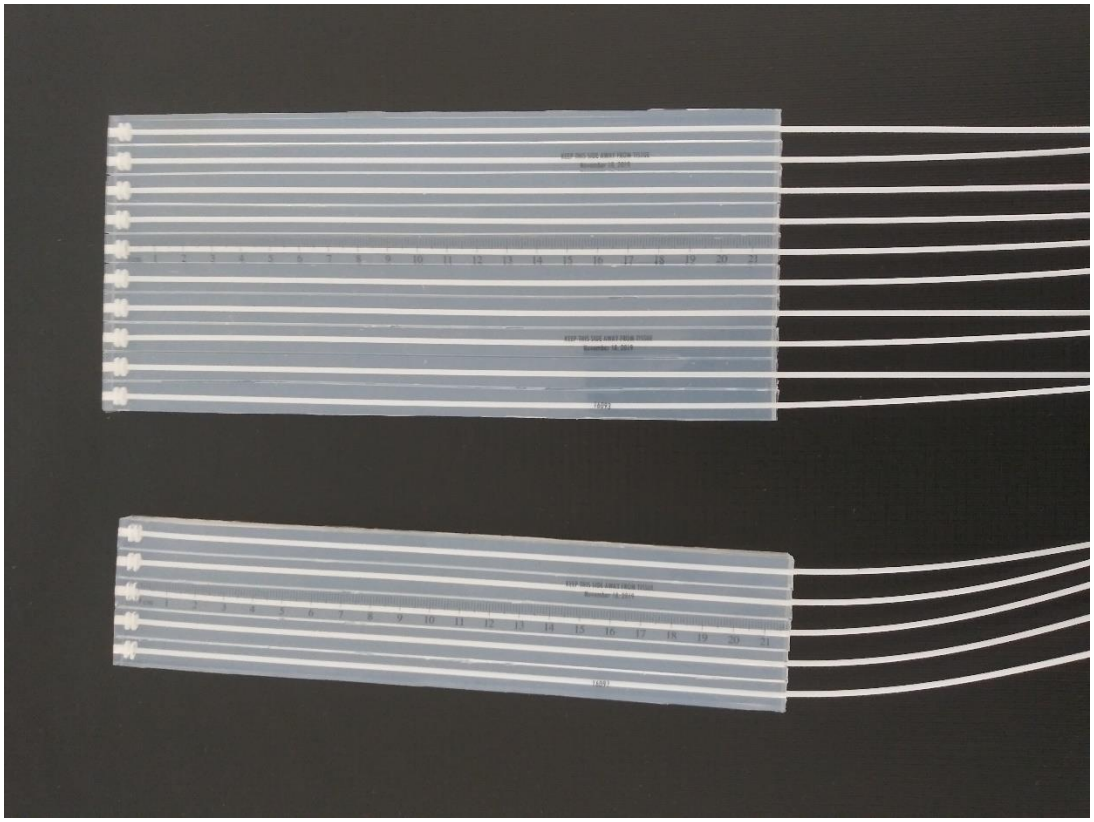


Figure 5: H.A.M. applicators. Applicators containing both five and ten treatment catheters are shown above. The length and thickness of each applicator is the same, as well as the source-to-tissue distance and spacing between catheters. Only the width varies between the two and that correlates with the number of possible channels.

Although the number of treatment catheters will determine the width, the applicators have set dimensions of 22.5 cm length and 0.8 cm thickness. Each treatment catheter is spaced 1 cm apart from each other and the source-to-tissue distance is maintained at 0.5 cm on the treatment side of the applicator. The treatment side of the applicator is clearly labeled, and 0.3 cm deep slits are made in the space between each treatment catheter to allow for additional flexibility. It is advised that these applicators not be cut or modified in order to maintain their material integrity as H.A.M. applicators are designed for single patient use (Eckert & Ziegler, 2019). Because of the asymmetry in the treatment catheter depth (0.5 cm on the treatment side and 0.3 cm on the opposite side) it is imperative that the correct applicator side is applied to the patient prior to treatment. A closer view of the H.A.M. applicator is presented in Figure 6.

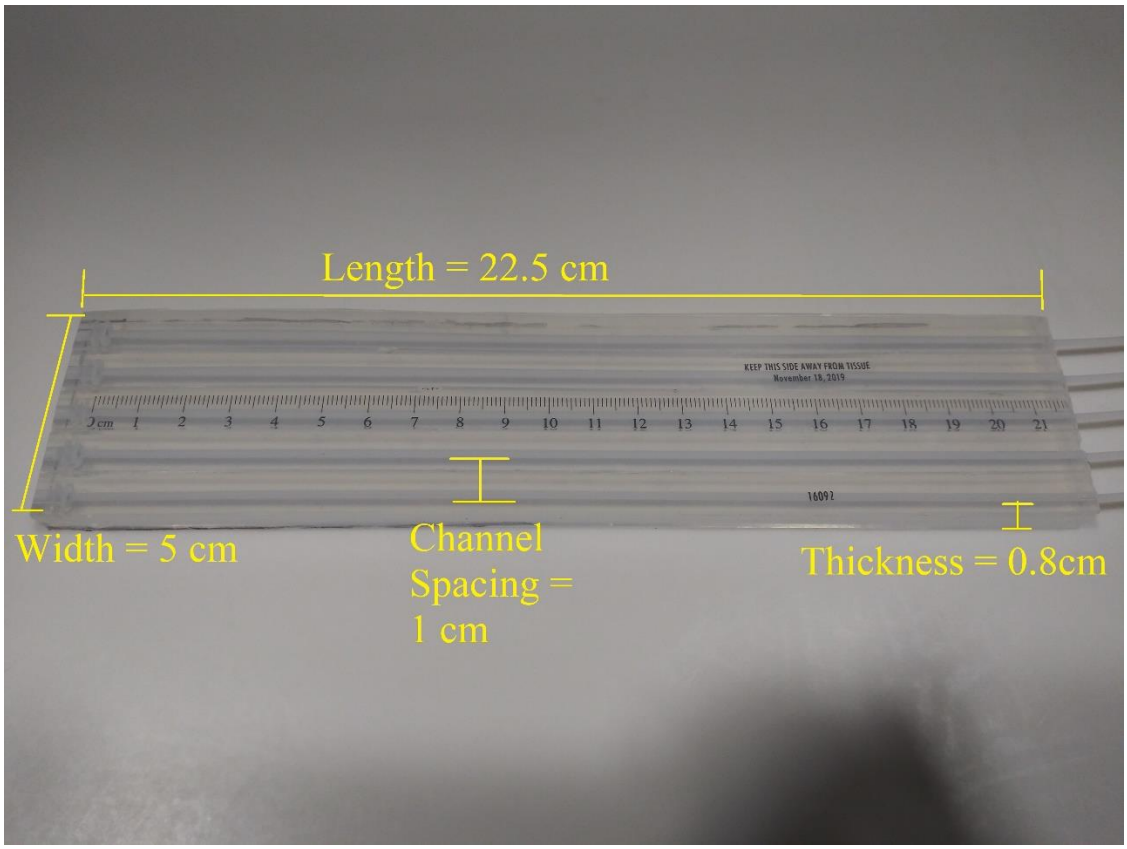


Figure 6: A closer view of the 5 cm H.A.M. applicator. Dimensions of the applicator are shown. Also visible are the markings noting to "KEEP THIS SIDE AWAY FROM TISSUE" and a ruler that allows for easy indexing of applicator positioning on the patient.

Upon initially receiving the applicators, each treatment catheter extends for approximately 1 m from the end of the applicator. This allows for each treatment catheter to be cut to the user desired length. For our purposes, all treatment catheters were cut to a length of 60 cm. The applicators are connected to the Bravos afterloader with the guide tubes normally used for breast treatments. These guide tubes measure 100 cm and have a twist cap that allows for tightening over the flexible treatment catheters. The 160 cm combined length of guide tube and treatment catheters correlated to the maximum allowable length of the Bravos system.

2.3) H.A.M. Applicator Commissioning

Quality assurance and commissioning of the H.A.M applicator was conducted in accordance with the American Association of Physicists in Medicine (AAPM) Task Group (TG) 56 report guidelines that were applicable to these applicators (Howie et al., 2018; Nath et al., 1997). Physical dimensions, and applicator integrity was analyzed for each of the two H.A.M. applicators. Positional accuracy of the source within each treatment catheter was analyzed using the PermaDoc phantom shown in Figure 7. The PermaDoc is a source positioning tool that allows for irradiation of a piece of radiochromic film. It contains line markers spaced 1 cm apart capable of being imprinted on the film at each source dwell position. Each applicator was aligned with the PermaDoc system and a test plan was developed to deliver dwell positions 2 cm apart in each treatment channel. Source positioning was then measured at each treatment channel to ensure that the source had moved the correct distance.

Figure 7: PermaDoc phantom source positioning tool. The upper most marker is 0.5 cm from the next line, but each line after that is consistently spaced 1 cm apart. A strip of film is placed inside the phantom and during HDR source exposure the positioning lines of the phantom are imprinted on the film allowing for source position analysis.

Each applicator was placed on top of two slabs of solid water: a 5 cm thick base and 0.3 cm thick slab chosen so that film dosimetry can be measured at a common prescription depth. CT images using a GE Optima were conducted to verify the absence of occlusions within the treatment catheters. These images were then imported into Eclipse treatment planning system (TPS) for

the dual purpose of verifying that each treatment catheter was visible and clear of occlusions and for treatment planning.

2.4) Dosimetric Verification

Verification of the dose distributions were performed using Gafchromic EBT 3 film. This type of film has near tissue equivalency and is designed for the measurement of absorbed doses of ionizing radiation in the range of 0.2 to 10 Gy (Ashland, 2020). It consists of an active layer of material sandwiched between two layers of a matte-polyester substrate, as shown in Figure 8. The active layer contains a marker dye, stabilizers, and other components that give the film functional energy independence while also allowing for real time development after exposure to ionizing radiation.

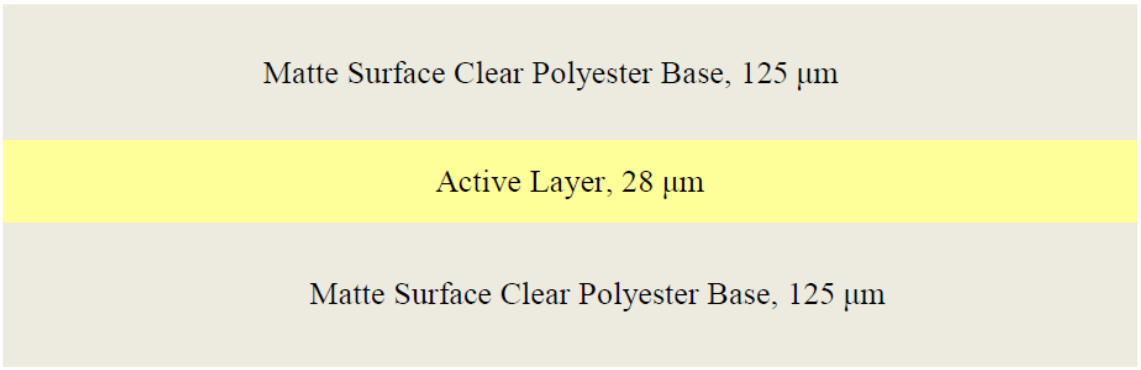


Figure 8: Structure of the Gafchromic EBT3 film. The active layer contains a marker dye and other materials that give the film near energy-independent response and real time development post-exposure. (Ashland, 2020)

After exposure the film was then scanned using an EPSON Expression 10000XL photo scanner and RIT113 v.6.8.64 software was used for all film analysis. Scanner flatbed uniformity

was analyzed by scanning a 33.02 cm by 43.18 cm large blank sheet of EBT3 film and using the RIT software analysis tools to determine the area with the most uniform response. A sheet of black poster board was fitted over the scanner read area and a 15 cm x 15 cm square was cut out over the area of most uniform response. The board minimizes additional light transmission during the scan which may affect the film reading. This setup is presented in Figure 9.

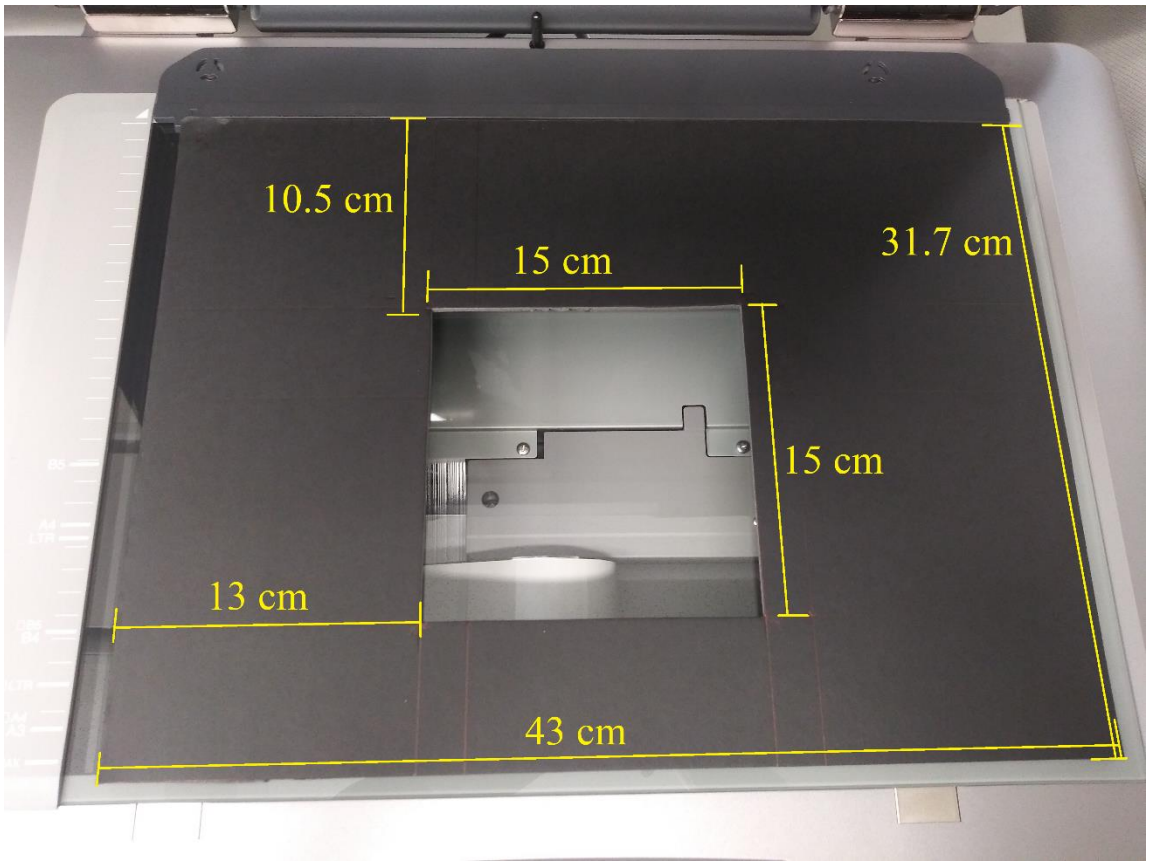


Figure 9: EPSON Expression 10000XL film scan area. The 15 cm x 15 cm square cut out represents the area of the flatbed scanner with the most uniform response. All film used for dosimetry purposes was scanned within this area.

Several sources (Ayoobian et al., 2016; Bassi et al., 2019; Palmer et al., 2013) used linear accelerators for their film dose calibration prior to HDR measurements, so a 6 MV photon fluence pattern with dose ranging from 0 to 950 cGy was created and delivered to film using a TrueBeam linear accelerator. This dose calibration fluence pattern also served to create a flatbed non-uniformity correction for our scanning surface using the RIT software. A random test pattern was then irradiated with 6 MV photons to confirm the calibration.

A film handling and scanning protocol was implemented for each film containing dose. Gloves were worn to prevent smudging on both the film and scanner glass. The large size sheets of EBT3 film were cut into smaller sheets prior to irradiation. Dose calibration was conducted on the film lot that was used for each dose analysis. The film scanning procedures and parameters we used aligned well with other literature sources (Ferreira et al., 2009). At least four test scans were performed in order to warm up the scanner bulb. Films were scanned using 48-bit color and at a resolution of 72 dpi and saved as a Tagged Image File Format (.tif). Scans were zoomed in on the film area. The complete EPSON scanner settings are shown in Figure 10, the save settings are shown in Figure 11, and the zoom settings are shown in Figure 12.

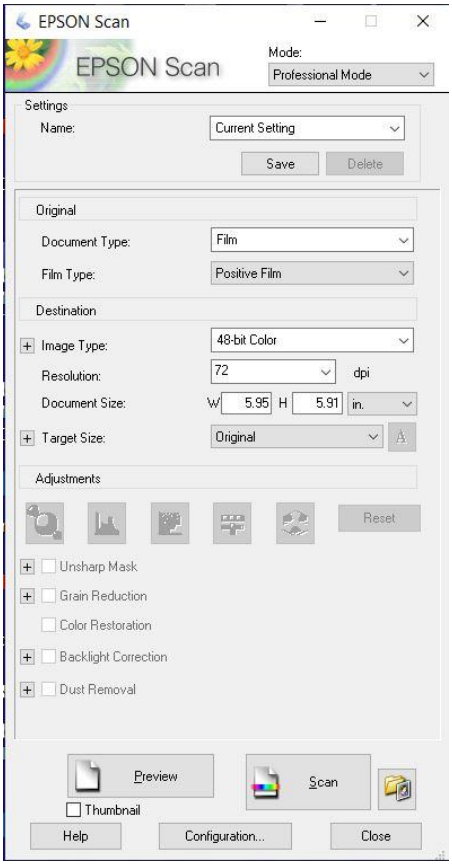


Figure 10: EPSON film scanner settings.

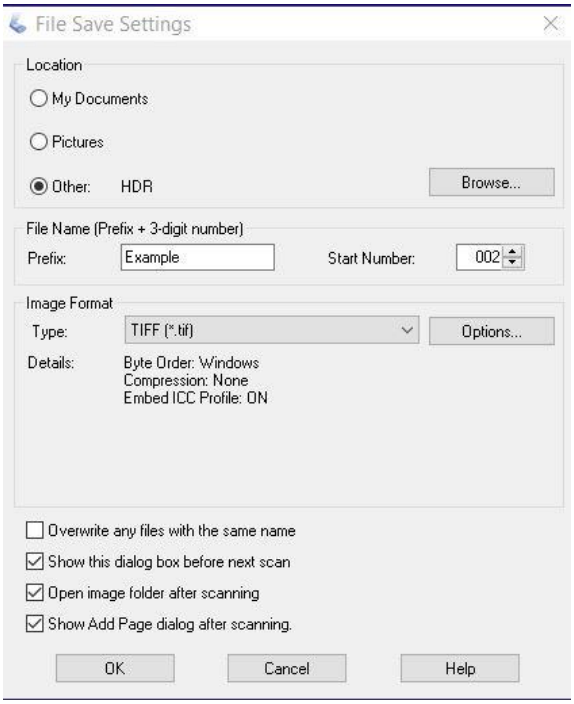


Figure 11: EPSON film file save settings.

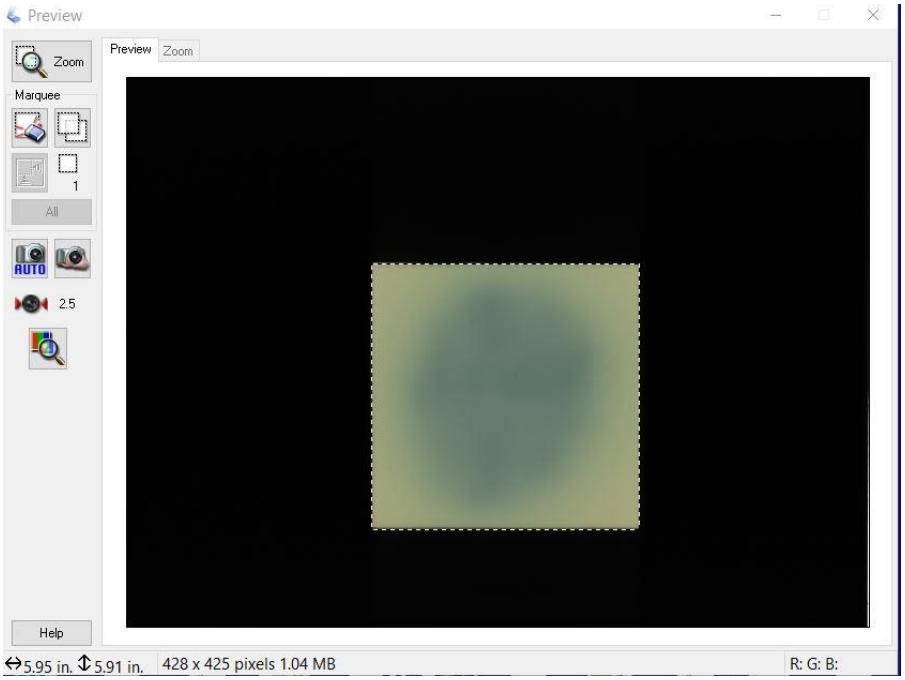


Figure 12: EPSON film zoom settings. Each film was scanned within the 15 cm x 15 cm square area cut out of the poster board.

2.5) Treatment Planning

Treatment planning using the applicator flap was conducted in Eclipse BrachyVision. Dose prescription depth and fractionation schemes were taken from the Groupe Européen de Curiethérapie and European Society for Radiotherapy & Oncology Advisory Committee in Radiation Oncology Practice (GEC-ESTRO ACROP) and American Brachytherapy Society (ABS) recommendations (Guinot et al., 2018; Ouhib et al., 2015). ABS recommend treatment volumes for skin brachytherapy as a 5 mm lateral expansion of the gross tumor volume (GTV) to create the clinical target volume (CTV), an additional 1.5 mm lateral expansion to the CTV to create the planning target volume (PTV), and a margin of 1 mm for depth uncertainty. The standard prescription depth when using surface applicators is 3 – 5 mm under the skin and 5 mm

source-to-tissue distance (Guinot et al., 2018; Iftimia, 2016; Ouhib et al., 2015). Recommended dose prescription and fractionation schemes from various sources are presented in Table 2.

ABS (Ouhib et al., 2015)	40 Gy over 10 fractions 42 Gy over 6 fractions
GEC-ESTRO ACROP (Guinot et al., 2018)	51 – 54 Gy over 17 – 18 fractions 40 – 48 Gy over 10 – 12 fractions 50 – 60 Gy over 10 – 12 fractions 40 Gy over 8 fractions
Iftimia (2016)	51 Gy over 17 fractions

Table 2: Dose prescription and fractionation schedules from various sources.

The H.A.M. applicator is designed to produce an isodose distribution such as that shown in Figure 13.

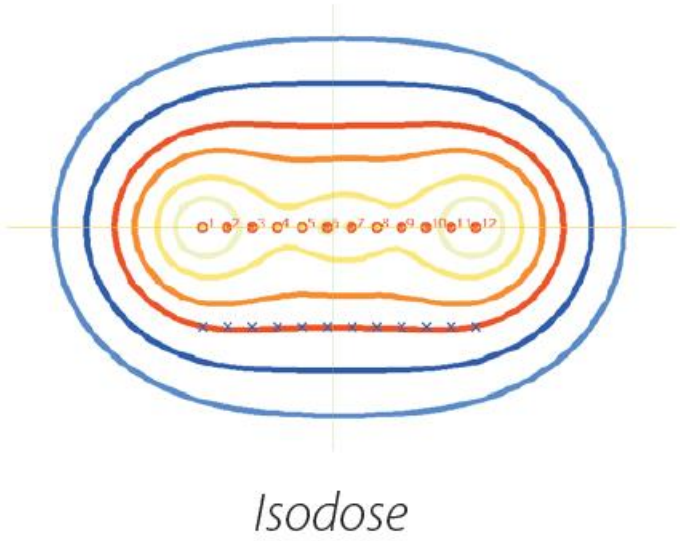


Figure 13: H.A.M. Applicator isodose distribution. The consistent source-to-tissue distance of 0.5 cm and 1 cm spacing between treatment catheters is designed to lower dose to the skin and allow for a more uniform dose distribution at distances of approximately 3 cm. (Eckert & Ziegler, 2020)

A 300 cGy and 500 cGy plan was created and normalized to a central reference line 0.3 cm below the surface of the flap. A sheet of film was sandwiched between the solid water placing it at the point of normalization and the plans were generated. A coronal dose plane was then exported from the TPS at this reference point for analysis with the film. The isodose plan generated in Eclipse and the verification setup are shown in Figures 14 and 15, respectively.

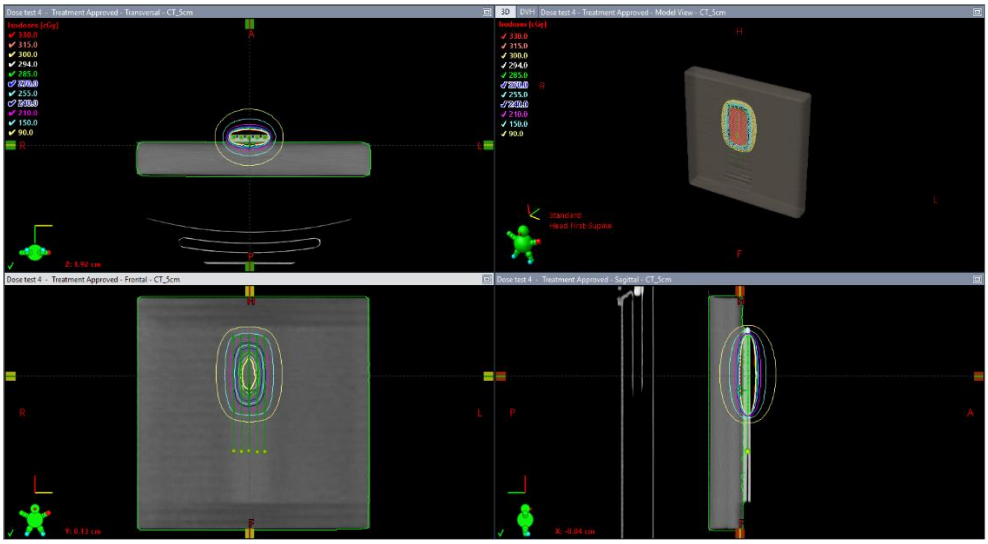


Figure 14: Isodose plan developed in Eclipse. This plan delivered 300 cGy and was normalized to a central reference line 0.3 cm below the surface of the flap. A coronal dose plane was exported from the plan for analysis with irradiated film.

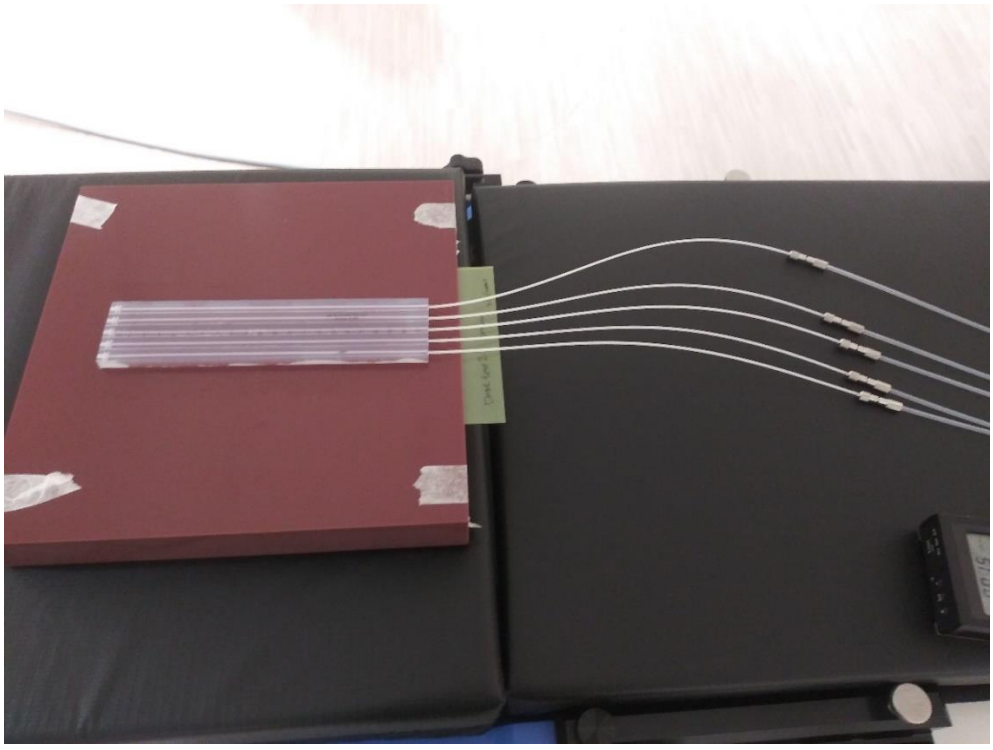


Figure 15: Isodose verification experimental setup. A sheet of EBT film was placed between two slabs of solid water (5 cm and 0.3 cm). The isodose plan was then run and the irradiated film was scanned and compared to the equivalent dose plane exported from the TPS.

Initial calibration of the EBT3 film was conducted using 6 MV photons delivered from a TrueBeam linear accelerator and delivering a fluence pattern with a dose range of 0 – 950 cGy. A random test pattern was irradiated and then compared with the isocenter dose plane exported from Eclipse. This is shown in Figure 16. The excellent agreement between the two affirmed that the dose calibration was sufficient for photons but still needed to be tested for HDR.

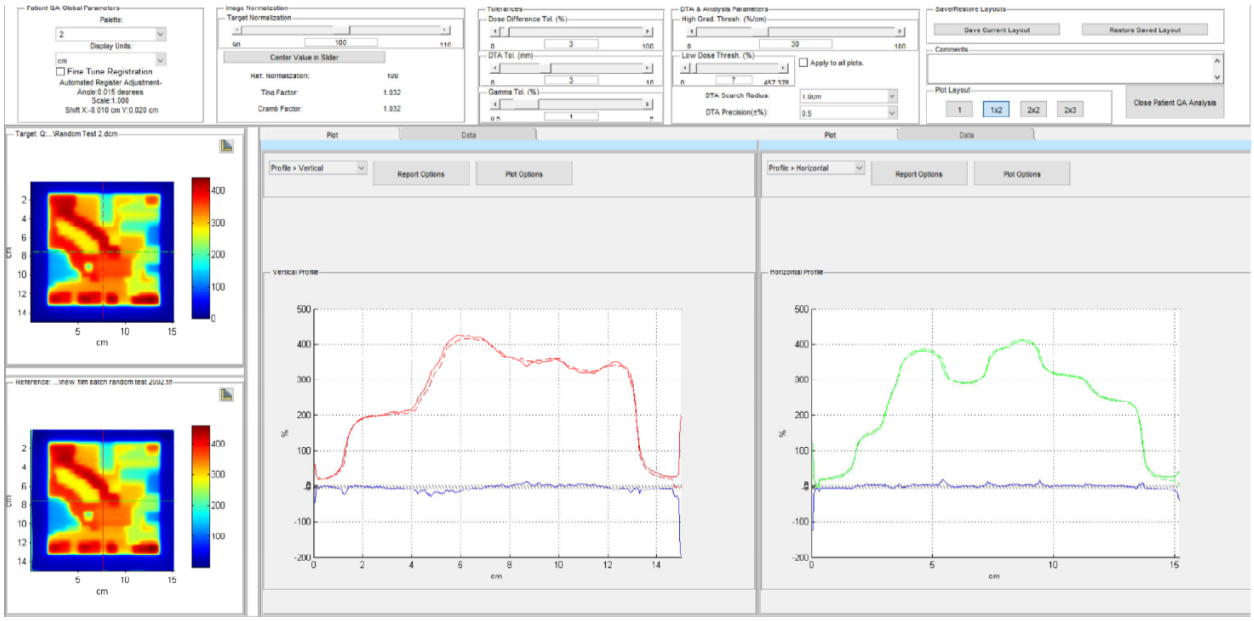


Figure 16: Test pattern for film dose verification. Vertical and horizontal dose profiles are shown comparing the scanned film to the exported dose plane from the TPS. Excellent agreement is shown between the two confirming the dose calibration was for external beam photons. This test pattern had a dose range from 0 to 550 cGy.

Uniformity of the HDR isodose distribution under a bolus was measured by irradiating film and comparing it to the appropriate dose plane. Both low (300 cGy) and high (500 cGy) isodoses were analyzed with an applied median 5 x 5 filter. The results for the 300 cGy and 500 cGy HDR dose tests are shown in Figure 17 and 18, respectively. The dose plane for the HDR

was taken 0.8 cm from the source dwell positions, placing it at the spot of the film (0.5 cm source-to-tissue distance + 0.3 solid water depth). As shown in Figures 17 and 18, there is very good agreement between the planned and delivered doses at a depth of 0.3 cm, the nominal treatment prescription depth. This verified that the dose calibration conducted using photons on a linear accelerator was suitable for use of an HDR source.

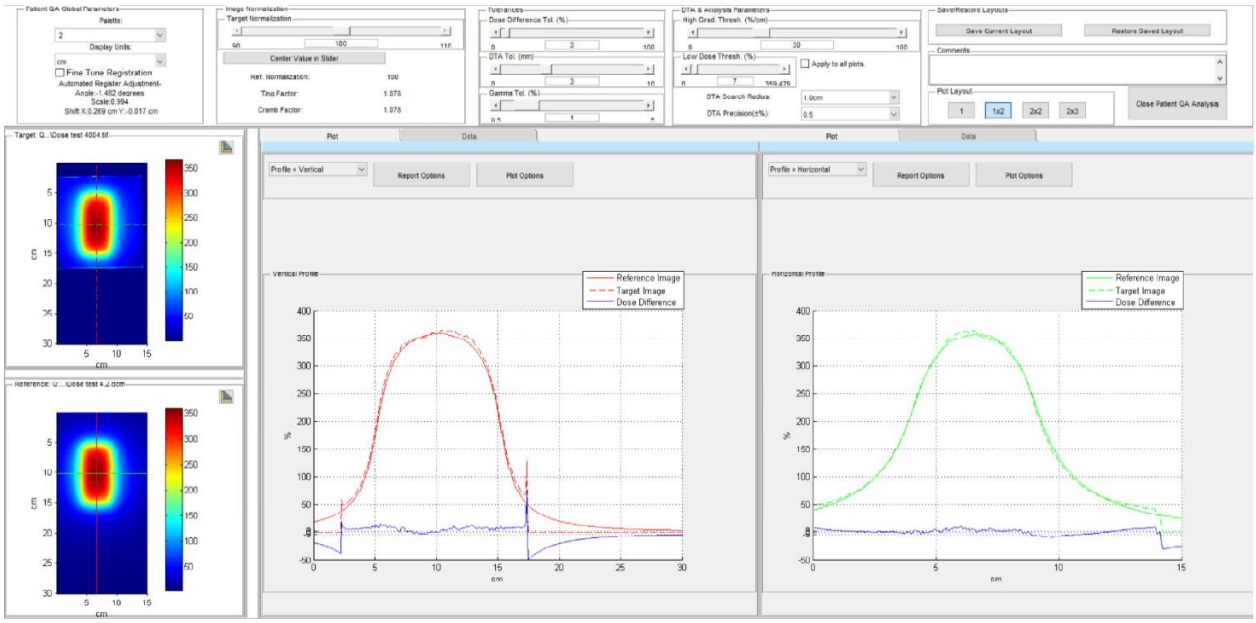


Figure 17: 300 cGy isodose delivered from H.A.M. applicator. Vertical and horizontal dose profiles are shown. Comparison between the planned and delivered dose is very good. The biggest inconsistency is only seen in the spots near the film edges of the vertical profile.

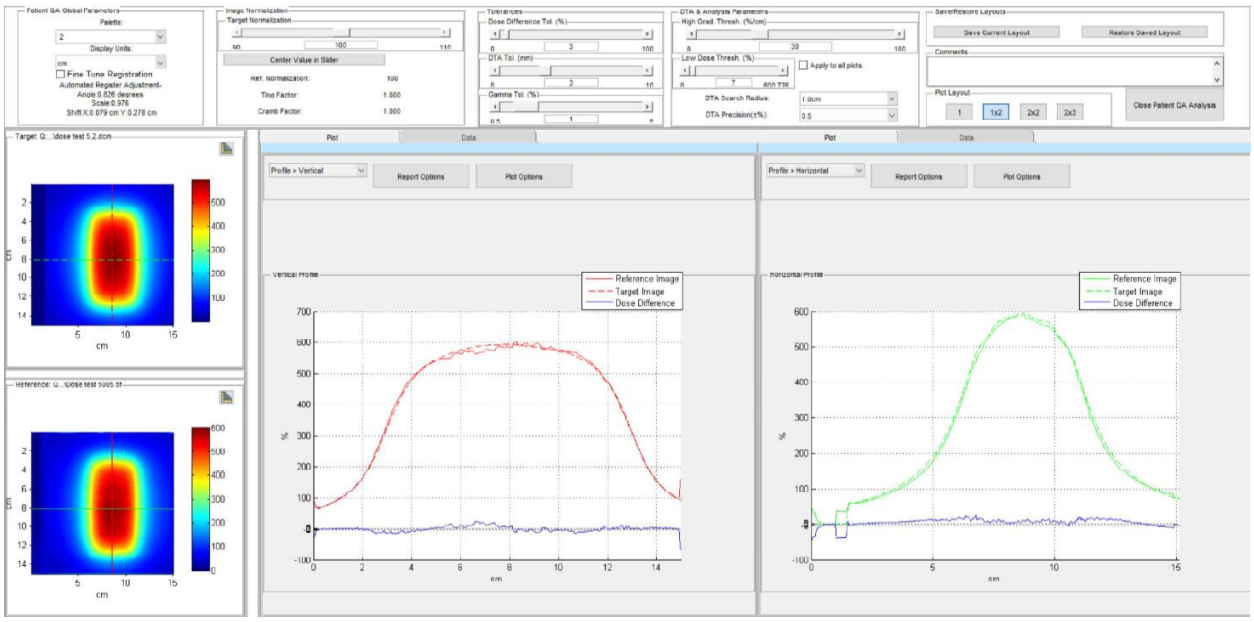


Figure 18: 500 cGy isodose delivered from H.A.M. applicator. Vertical and horizontal dose profiles are shown. Very good agreement is shown between the planned and delivered dose. Minor inconsistencies between the two can be attributed to variations in the film uniformity.

Validation of the treatment planning techniques were conducted in two stages: initial dose verification under bolus material followed by end-to-end testing using a Stereotactic End-to-End Verification (STEEV) phantom. Initial planning dose verification used the 10 cm applicator. A 0.3 cm thick flexible bolus was placed on top of a 5 cm slab of solid water. CT marker wire was used to designate a PTV for planning purposes. The 10 cm H.A.M. applicator flap was placed over the wire and a CT scan was taken. The flexible bolus material was chosen to minimize the air gaps present when placing the applicator over the wire. A slab of solid water 0.3 cm thick was tested, but the air gaps present with the applicator placed over the wire was unacceptable. This setup is presented in Figure 19.

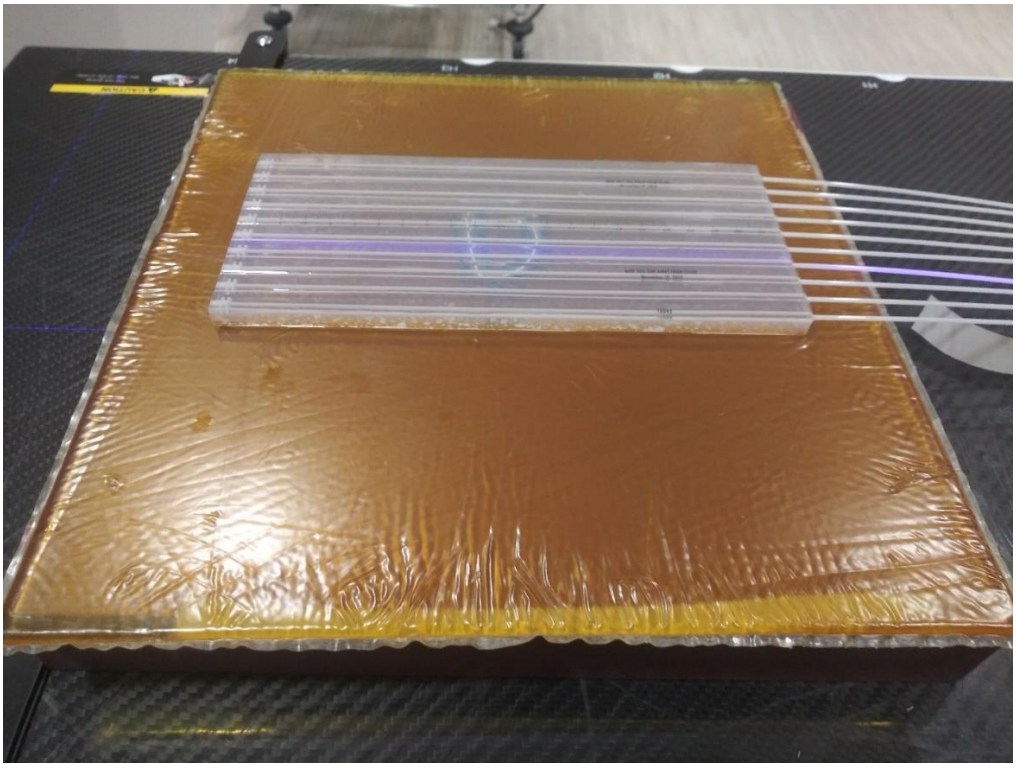


Figure 19: Initial TPS plan verification setup. The 10 cm H.A.M. applicator was used to treat a designated PTV designated by the CT marker wire. General prescription treatment depth is 0.3 cm, so a 0.3 cm flexible skin bolus was used. After planning, EBT3 film was placed under the skin bolus for analysis.

After the scans were imported to the TPS the following structures were contoured: Body, Skin, Wire, PTV, Loading Volume, any additional OARs. The Body structure is automatically contoured during import, but it may need editing in order to separate it from the applicator. The Skin is a 2 – 3 mm inner wall extracted from the body. The Wire is necessary to outline the PTV and must be manually contoured. After the wire is contoured, the PTV is defined by extracting a 3 mm inner wall from the skin under the area outlined by the marker wire. With the PTV contoured, margins are added in order to define the Loading Volume. Dwell positions can then be placed within this Loading Volume if desired. Finally, depending on the treatment location, appropriate OARs can be contoured if needed.

A dose of 300 cGy was prescribed to a depth of 3 mm. Applicators were added to each of the 10 treatment channels and equal dwell times were initially added. A volume optimization was then performed using the following DVH objectives for the PTV and Skin: PTV D90% > 100% Rx; PTV V100% > 95%; Skin D0.04cc < 145% Rx; Skin D1cc < 125% Rx. When the volume optimization was completed, the dose was manually shaped in order to better conform to the PTV and the plan was exported to the Bravos for treatment. A piece of EBT3 film was placed underneath the 0.3 cm flexible skin bolus and the plan was generated. A coronal dose plane at the location of the film was then exported from the TPS for comparison to the irradiated film.

End-to-end testing using the STEEV phantom was performed after verifying planned dose using the solid water and flexible bolus. This phantom was chosen to test how the applicator operates during delivery over a curved surface. The STEEV phantom is a head and neck phantom constructed of tissue-equivalent materials that simulates the internal anatomy of a real patient. This phantom is presented in Figure 20.

a)

b)

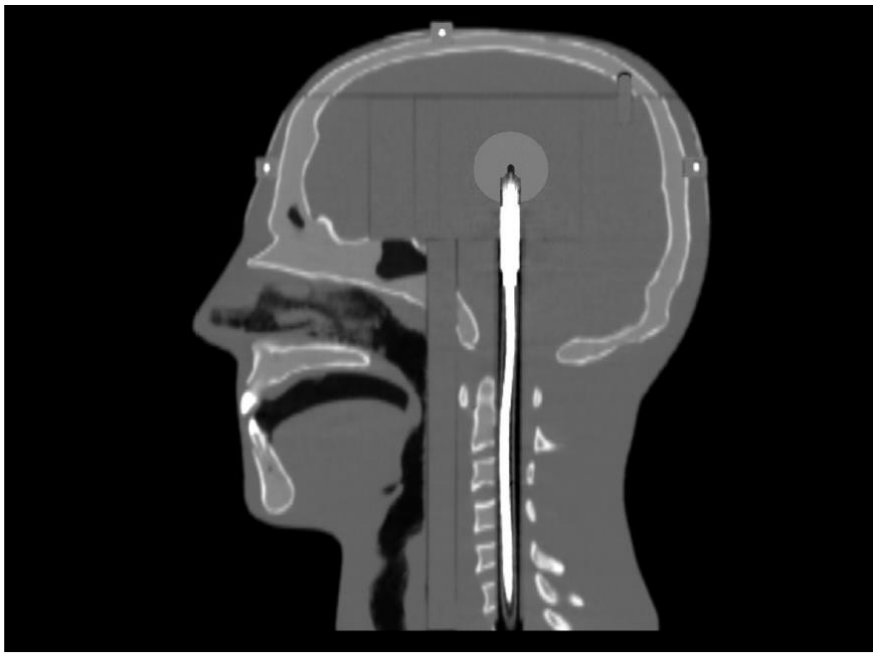


Figure 20: STEEV phantom. **a)** An external view of the phantom. **b)** The internal anatomy of the phantom designed to simulate a real patient. (CIRS, 2013)

A marker wire was placed on the scalp of the phantom to designate a PTV. A thermoplastic mask was stretched over the phantom and a marker was used to outline the wire. The 5 cm H.A.M. applicator was placed over the wire and a complete outline of the applicator was drawn on the mask. The applicator was taped to the mask and a CT scan was taken. To minimize the air gaps from the marker wire, the mask was cut around the wire outline and the wire removed. The applicator was then taped back in to place and a second CT was taken. This setup is presented in Figure 21.

Figure 21: End-to-end test setup on the STEEV phantom.

In Eclipse, the two scans were fused. The wire was contoured on the scan that contained it, and with the two scans registered together, that structure was then transferred to the scan without the wire. The body, skin, PTV, and loading volume were all contoured on the scan without the wire. Applicator placement required going through each slice to accurately locate the treatment channel tips and place each of the five applicators. Dwell positions were placed into the loading volume located over the PTV. A 300 cGy dose was prescribed to the PTV at a depth of 0.3 cm. A volume optimization was performed using the same DVH metrics as before. Because the location of the dwell positions was offset from the treatment channel tips, a copy of the plan was created for qualitative dose and positioning analysis using EBT3 film. Four reference points were added to the plan and a TG-43 second check was conducted using a document acquired from Utah Valley Hospital. The applicator was repositioned on the phantom and the plan was run to ensure that delivery was not hindered by the curved surface.

3) RESULTS

3.1) H.A.M. Applicator Commissioning

Measured dimensions of both H.A.M. applicator flaps are presented in Table 3. Each applicator fit the measurement criteria listed by the manufacturer with a slight difference seen in the depth of the applicator. This measured difference was only applicable on the side that is not facing the patient and the advertised 0.5 cm source-to-tissue distance was measured and verified for each applicator.

SN# 16092	Length (cm)	Width (cm)	Depth (cm)
Manufacturer	22.5	5.0	0.8
Measured	22.5	5.0	0.9
Difference	0.0	0.0	0.1
SN# 16093	Length (cm)	Width (cm)	Depth (cm)
Manufacturer	22.5	10.0	0.8
Measured	22.5	10.0	0.9
Difference	0.0	0.0	0.1

Table 3: Measured dimensions of each H.A.M. applicator flap compared to manufacturer specifications.

No signs of damage were visible on either of the H.A.M. applicators. There is a slight crease in between each of the treatment channels on the side that is furthest away from the patient's skin. This allows for greater flexibility of the flap while still maintaining a solid barrier

and consistent 0.5 cm source-to-tissue distance around curved surfaces. There were no air gaps present between the slab and the skin. Each treatment channel was measured to be 1 cm apart. Treatment channels measured 0.2 cm in diameter and extended 21.7 cm into the flap and approximately 1 m outside of the flap.

The long length of the catheters allowed them to be cut to any desired length. Each catheter was cut to 60 cm for consistency. When connected to a 100 cm guide tube the source can travel the maximum length of 160 cm consistently from the afterloader. This distance was verified for each treatment channel of both applicators using a length verification device and the Bravos system push test.

Source positioning using the PermaDoc phantom was verified with Gafchromic EBT3 film and is shown in Figure 22. Planned dwell positions 2 cm apart were created for each treatment channel. The tip of the treatment channel was aligned with the second line from the top of the PermaDoc which accounts for the slight discrepancy in alignment. However, consistency in source spacing is apparent and measured from the image.

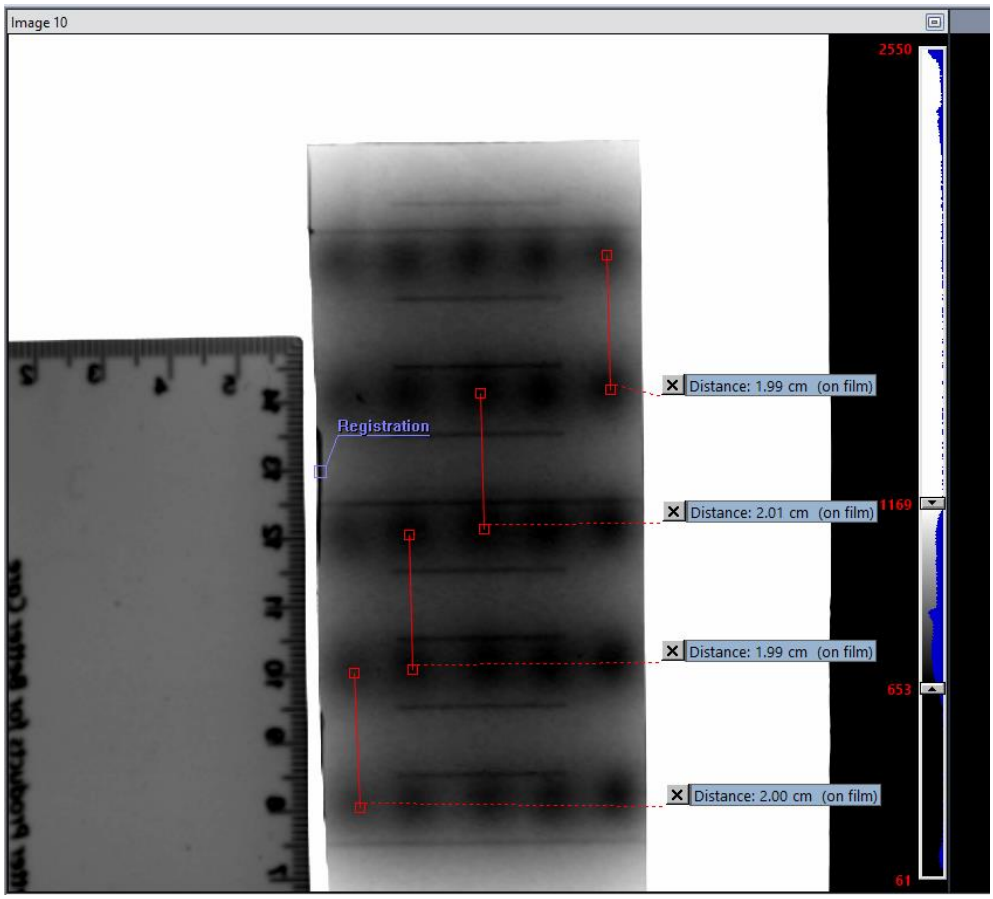


Figure 22: 5 cm applicator source position verification. The PermaDoc phantom system was utilized for these measurements. Consistency in the 2 cm planned dwell positions in each treatment channel verified from the film. Slight offset from line markers caused by aligning applicator index to second line from the top.

A CT scan of each applicator verified that all the treatment channels are visible and were free from occlusion. This is presented in Figure 23.

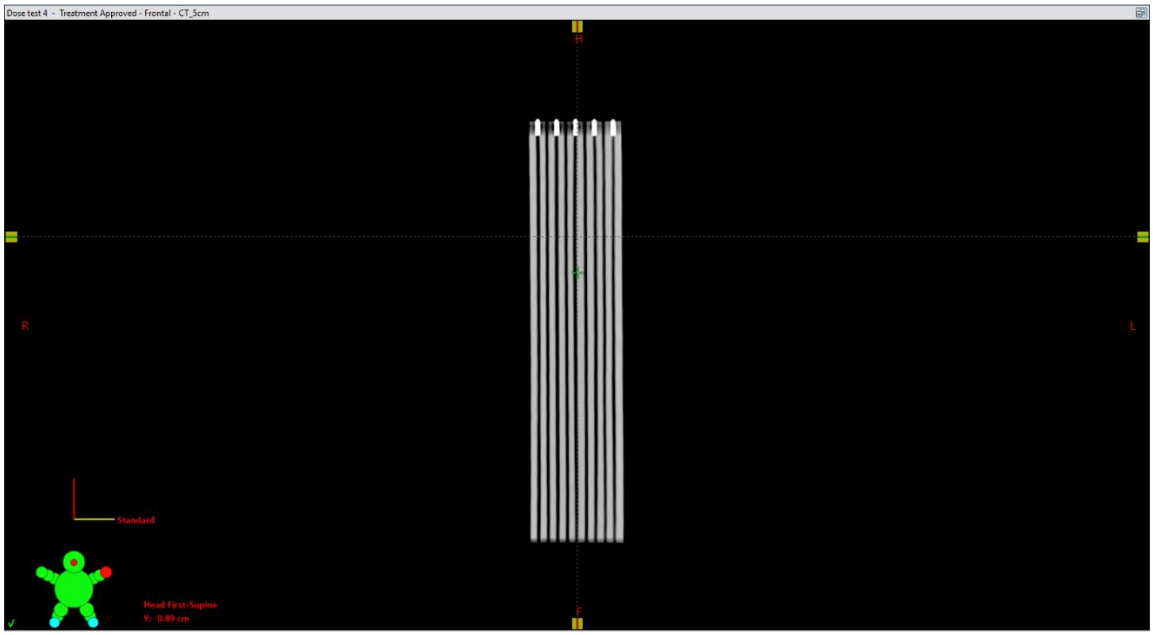


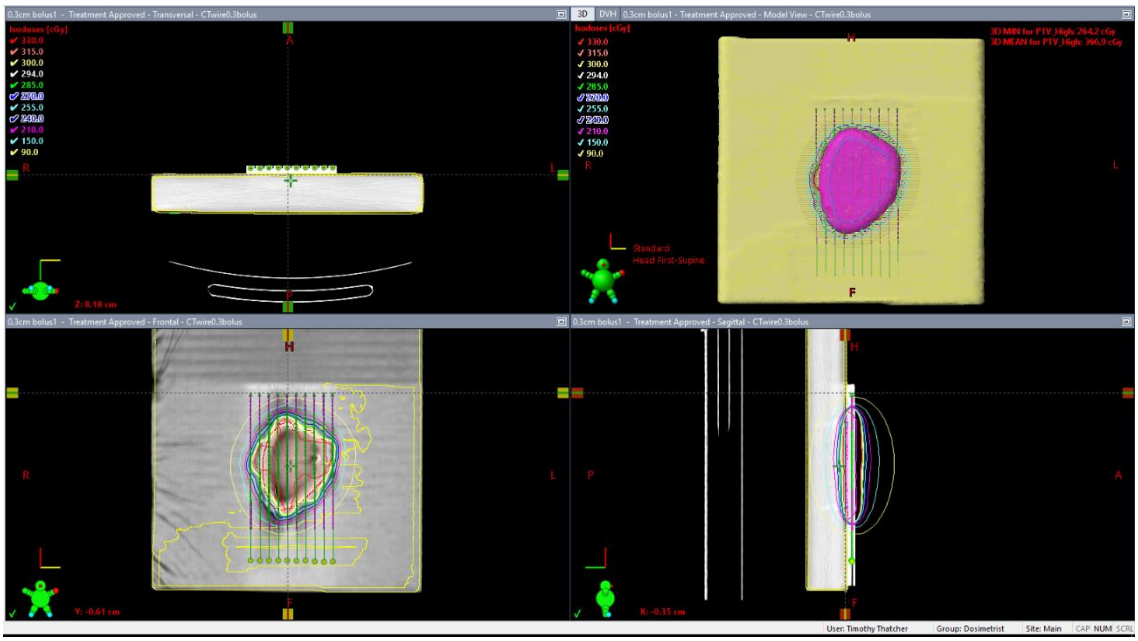
Figure 23: CT scan of the 5 cm applicator. Viewing planes were placed at the center of treatment channels. The black lines are air and verifies that each channel is easily viewable and there is nothing inside the channel that can block the wire.

3.2) Treatment Planning

3.2.1) Initial TPS Verification

Dwell positions of this plan were offset from the tip of the applicators and a qualitative analysis of the exposed film verified their positioning. Qualitative comparison between the planned dose distribution and delivered dose to film is presented in Figure 24. This shows that the delivered plan fits within the expected size and shape of the PTV. Verification of the treatment planning dose showed good agreement when compared to the TPS dose plane and is presented in Figure 25. This initial analysis of dose distribution and film dose at depth verified that the system could deliver a multi-channel plan to the H.A.M. applicator.

a)



b)

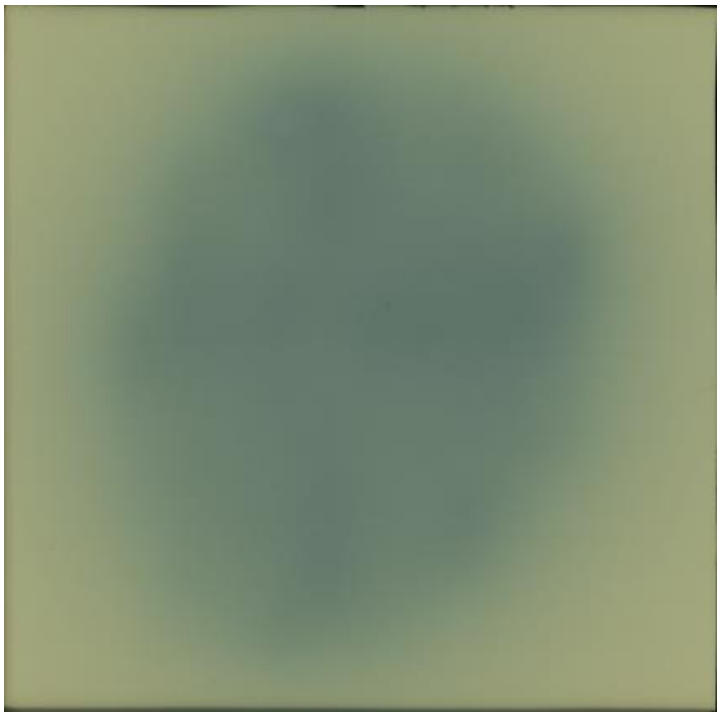


Figure 24: Qualitative comparison between the treatment planning and delivered dose. **a)** Planned dose distribution generated to treat a PTV under a 0.3 cm flexible bolus. Initial dwell positions were offset from the tip of the applicator. **b)** The same plan delivered to film. The film was placed at the prescription depth of 0.3 cm under the bolus and compared to the coronal plane of the TPS. Qualitative comparison between to two shows the expected size and shape of the PTV to be treated.

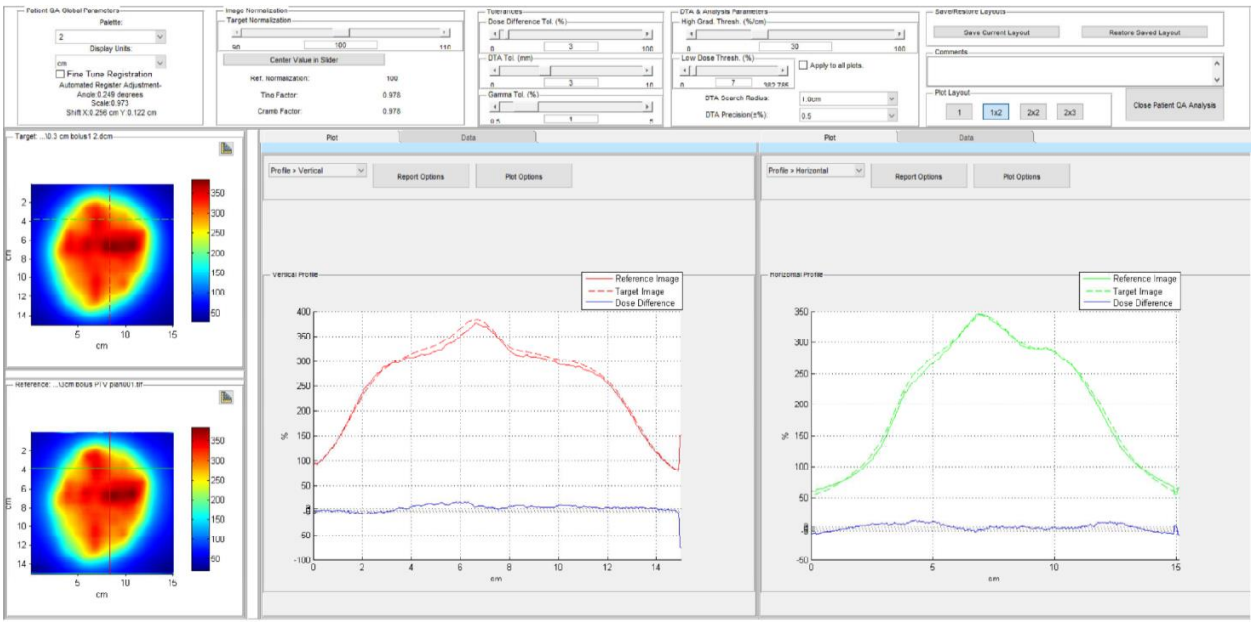


Figure 25: Initial treatment planning dose verification. Film was placed under the 0.3 cm flexible skin bolus and showed very good agreement with the planned dose from the TPS.

3.2.2) End-to-end Testing

A thermoplastic mask was successfully placed over the STEEV phantom to simulate patient immobilization as shown in Figure 21. The H.A.M. applicator was positioned over the PTV and a marker was used to outline the applicator for accurate repositioning. Two CT scans of the STEEV phantom were taken: one with the marker wire present and another with the marker wire removed. These scans were successfully fused and contoured. Planning was conducted on the scan without the marker wire present. All dwell positions were placed into the Loading Volume structure, which was designated as a 1.5 cm volume above the PTV. This meant that the first dwell position for each treatment channel was placed a distance from the tip of each channel. Volume optimization was performed using the following objectives for the PTV and

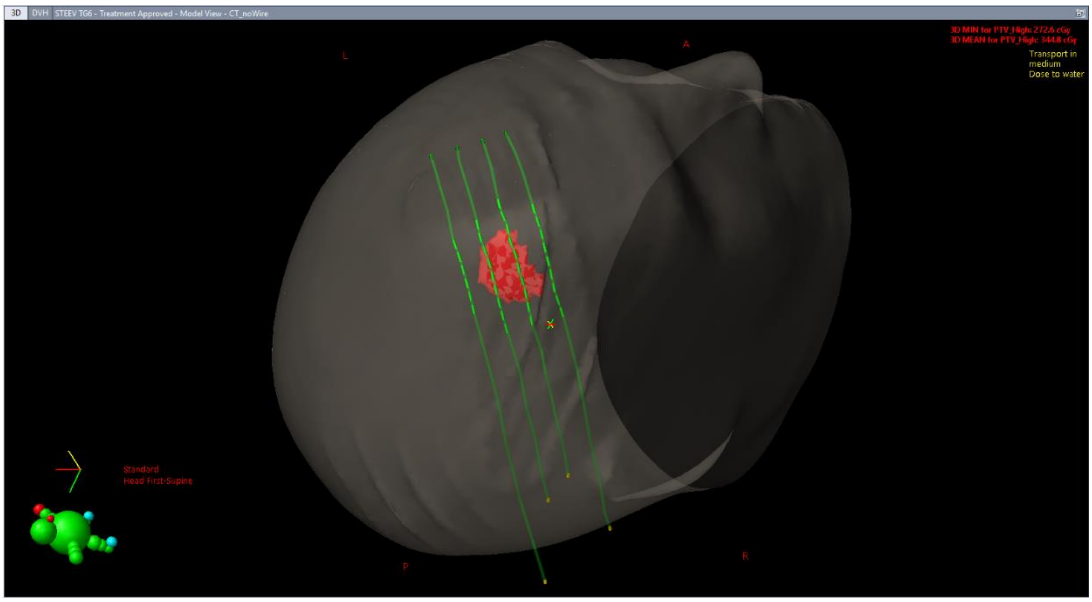
Skin: PTV D90% > 100% Rx; PTV V100% > 95%; Skin D0.04cc < 145% Rx; Skin D1cc < 125% Rx. This plan is presented in Figure 26.

Figure 26: End-to-end STEEV test plan.

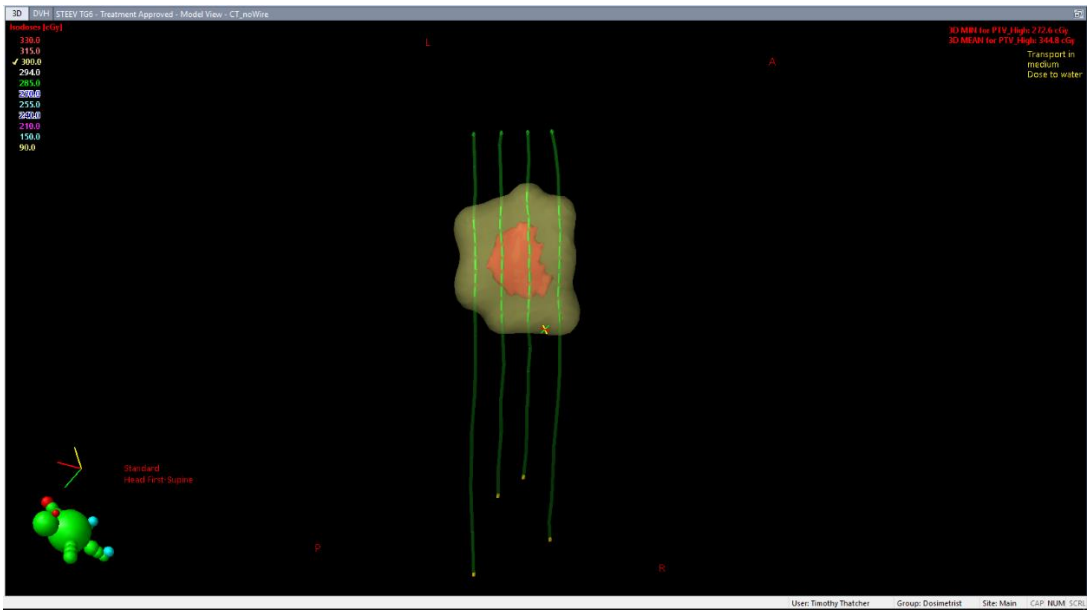
3.2.3) Quality Assurance

Pre-treatment quality assurance was conducted prior to treatment of the STEEV phantom. Since the initial source dwell positions can often be located a distance away from the tip, a qualitative assessment of dwell position and dose shape was performed. A copy of the treatment plan was created, and the applicator was placed on a strip of EBT3 film. The tip of each treatment channel was aligned with a dark line drawn on the film and the planned treatment performed. The first dwell positions were then measured from this line and confirmed with the

planning system. The measured film confirmed the dwell positions and overall shape of the PTV. This is presented in Figure 27.



a)



b)

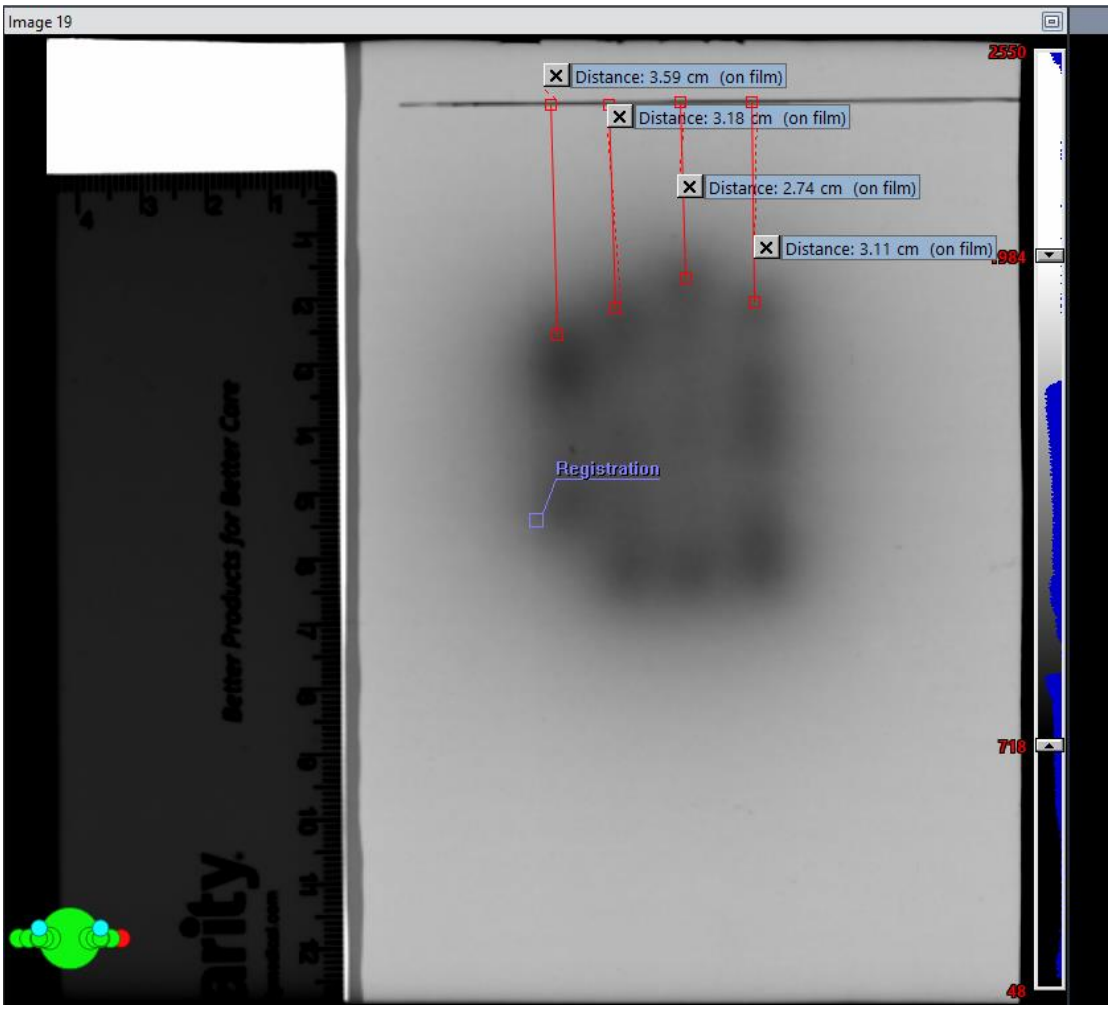
c) 

Figure 27: Qualitative verification of dwell positions and tumor shape. **a)** Contoured PTV to be treated. The loading volume structure would encompass the PTV and is where the source dwells will be placed. **b)** 3D view of the 100% isodose encompassing the PTV. Planned dwell positions are noticeably offset from the applicator tips in order to provide the appropriate dose coverage. **c)** Qualitative analysis using film verified the shape of the dose shown above. Since the first dwell position of each treatment channel was offset from the applicator tip, this was also measured and verified using EBT3 film.

An independent second check of the treatment plan was conducted using a document acquired from Utah Valley hospital. This document uses the 1D point source TG-43 formalism for dose calculation along with four reference points at different locations on the treatment plan. Monte-Carlo dosimetry of the source calculated by Ballester et al. (2001) was used to determine

the dose rate constant and radial dose function. The cartesian coordinates of each source dwell position is used to calculate the point dose to the designated reference points. The dose to the reference points from each dwell position was summed and compared to the point dose from the treatment planning system. Calculated dose difference between the treatment planning system and the independent second check was shown to be under 5%. This second check verified that the created plan was capable of being delivered correctly.

4) DISCUSSION

This project effectively demonstrated the commissioning of H.A.M. applicators for surface brachytherapy in the treatment of nonmelanoma skin cancer. Each applicator measured within the manufacturer's specifications and was free from damage. There was a consistent 0.5 cm source-to-tissue spacing for each applicator. All treatment catheters for both applicators were cut to 160 cm and verified with both the length verification device and the Bravos system push test. All treatment catheters were free from occlusion and visualized well from a CT scan. Using the breast guide tube, each treatment catheter could easily connect to the Bravos afterloader and deliver an accurate treatment. Source positioning was consistent in spacing and delivery, and planned dose was shown to be accurately delivered even with the applicator placed on a curved surface. Criteria established by the AAPM TG-56 report for quality assurance of applicators used for HDR brachytherapy required the "evaluation and measurement of dimensions/serial numbers; dosimetric evaluation of applicators; and applicator radiographs to determine correct source position and mechanical integrity" (Nath et al., 1997). Based on those criteria these applicators are suitable to use for an HDR brachytherapy treatment.

Treatment planning using the applicators was an interesting process. Contouring was straightforward and the recommended structures used for planning worked very well (Iftimia, 2016). Creating a Loading Volume structure using margins over the PTV was a novel idea and allowed for a simple method of placing dwell positions within the PTV treatment region. What ended up being the biggest challenge during the treatment planning process was determining the position of each treatment channel within the applicator. When the flap was pressed flat against a piece of film or solid water there is no issue at all, as evidenced in Figure 20. However, locating each individual channel becomes increasingly challenging over a curved surface. When

the H.A.M. flap was placed over the STEEV phantom it was positioned in a way to maximize coverage of the PTV while avoiding placing the flap over the patient's eyes. This placed the flap at such an angle that none of the available viewing planes were able to easily detect the channel positioning. The tips of each channel had to be located first in the sagittal viewing plane, and then moving all viewing planes to that tip. Once that happened, each slice was analyzed in all planes to determine channel location. This process was then repeated for each of the five treatment channels. All channels were accurately located, but special care is going to have to be taken when planning with larger applicator flaps over highly curved surfaces. The addition of marker wires placed in every other treatment channel may help with applicator placement

Dose prescriptions for this project followed recommendations established by the ABS, GEC-ESTRO ACROP, and Iftimia (2016) as presented in Table 2. These resources took aggregated data to make their recommendations and was the primary source for the prescription planning in this work. The recommendations made generally prescribed dose to a depth of 0.3 – 0.5 cm under the skin surface. These prescriptions were usually not deeper than 0.5 cm because that would result in considerably higher skin surface doses. Fractional doses ranged from 3 – 7 Gy per fraction over a schedule of 6 – 18 fractions. The goal of these doses and fractionation schemes is to achieve a BED target of 65 – 70 Gy (Ouhib et al., 2015). All film measurements of this project were prescribed to a depth of 0.3 cm. From the literature this appeared to be the most common prescription depth, so it was important to verify the dosimetric accuracy at that distance under the skin. The prescription dose during testing was chosen to be on the lower end of the generally prescribed doses at 300 cGy. Isodose testing of the applicator showed that higher doses could still be used and present very good agreement at the prescription depth, so the actual fractional dose prescribed for treatment would be the decision of the radiation oncologist.

Volume optimization utilizing TG-43 formalism for calculating dose was used for this project. Investigations into the limitations of TG-43 dose calculation formalism by Boman et al. (2017) make note that increasing scatter conditions with the addition of bolus placed on top of the applicator would help to improve dose agreement at a prescription depth of 1 cm. However, placement of an additional 1 – 2 cm of bolus on top of the applicator could lead to possible discomfort of the patient for particularly large lesions on the scalp. Furthermore, 1 cm is also much deeper than is generally prescribed for treatment. In contrast, Granero et al. (2014) notes that when using an Ir-192 source at a typical prescription depth of 0.5 cm, no bolus is necessary as at those clinical prescription depths the dose differences is not clinically relevant. The recommendation of not including a bolus during treatment was also made by Ouhib et al. (2015). One of the questions that arose during the planning optimization process was the use of AcurosBV or TG-43 for dose calculation. Both calculation methods used the following criteria: PTV D90% > 100%; goal PTV V100% > 95%; skin D0.04cc < 145% Rx; goal skin D1.0cc < 125% Rx (Iftimia, 2016). This criterion was input during the dose optimization process and worked consistently well for the plans tested. Differences between the optimized plans using AcurosBV were minimal compared to those using TG-43. The benefits of using TG-43 for planning purposes were the real-time dose shaping and the point dose dwell time modification. Using TG-43 formalism for dose calculation also simplified the dose point independent second check process. With slight modifications to the Utah Valley QA document, dose discrepancies between the calculated dose and TPS were well below 5%.

Positional accuracy and reproducibility between fractions will be one of the primary challenges during treatment. Set-up photos are going to be extremely important for use as a reference. Communication between staff regarding the appropriate set-up is also going to be

paramount. Drawing the associated PTV on the patient's skin and making sure that the marking remains between fractions will help with reproducibility. The benefits to using the H.A.M. applicator flaps regarding repositioning include the fact that they are translucent and contain an indexing ruler already printed on the side facing away from the patient. This should allow for ease of repositioning of the applicator prior to placement if proper set-up notes are taken during simulation.

For this project a thermoplastic mask was used for patient immobilization. A marker wire was placed directly on the patient's skin delineating the PTV and the mask was stretched over it. The applicator was positioned and outlined with a marker prior to being taped to the mask and a scan was taken. To prevent potential air gaps caused by the wire on the skin, the area around the PTV was cut out of the mask, the applicator was reapplied on the skin, and another scan was taken. This type of process will likely not be used on an actual patient in order to limit the number of CT scans the patient receives, but the concept of multiple simulations will be necessary. Iftimia (2016) recommended two simulations: the first simulation places the immobilization device on the patient and delineates the PTV, then the second simulation scans the patient with the applicator flap attached to the immobilization device used. This process allows for ensuring that options for applicator placement are taken into consideration prior to simulation and treatment.

While this project was focused on the application of H.A.M. flaps for surface brachytherapy, the next step in establishing a surface brachytherapy program will be the use of Valencia style applicators. These are conical applicators made of tungsten alloy that place the source 1 – 1.5 cm above the surface of the skin. Circular or oval apertures attached to the applicator allow for treatment of surface lesions of various sizes. A set of these surface

applicators was recently acquired, and work has already started in the characterization of dose and output factors at clinically relevant depths (surface to 0.5 cm). Furthermore, 3D printing of custom surface molds is also being considered. These would enable patient specific molds to be created and used with the H.A.M. applicator for treatment.

5) CONCLUSION

The H.A.M. applicator was commissioned and tested for use during HDR brachytherapy in the treatment of skin cancer. Both applicators were free from any damage and each measured accurately to manufacturers specifications. Dosimetry of each applicator was verified using Gafchromic EBT3 film and RIT113 film analysis software. End-to-end testing was able to accurately transfer and deliver a treatment plan. An independent second check of the dose and dwell position location away from the tip verified that the plan would be delivered accurately. Prescription dose and treatment depth recommendations are made, but that will ultimately be an oncologist decision. Patient immobilization techniques were discussed and will be primarily dependent on the individual patient and treatment location.

The Varian Bravos HDR afterloader was also accepted and commissioned during the course of this project. It contains several upgrades to usability compared to its predecessor the GammaMedplus iX and the capability of housing a 15 Ci source allows for faster patient treatment times. The push test verification prior to treatment accurately accounts for any offsets to ensure that source position is accurately placed. Being able to adjust the length of the treatment channel from the computer console while maintaining source dwell timing and position is also a benefit of the Bravos system. The addition of the CamScale is a novel inclusion as well. This device allows for position verification and calibration of the source prior to treatment and is simple to set up and use.

Future implementation of Valencia style applicators for surface brachytherapy use is currently underway. Comparison of TG-43 and AcurosBV dose calculation algorithms at clinically relevant depths has currently been completed. Output factor measurements using a diamond detector at clinical depths as well as determination of applicator placement and

reproducibility is planned. With the use of both the H.A.M flap and Valencia applicators, a comprehensive HDR surface brachytherapy program can be instituted at Dixie Regional Medical Center.

APPENDIX A: Bravos Commissioning Report

Varian Bravos HDR Afterloader (SN# 651026) Commissioning Report

The Bravos by Varian is an HDR remote afterloader capable of housing and delivering an Ir-192 source with a maximum source strength of 15 Ci. It contains 30 treatment channels and a maximum source travel distance of 160 cm. Varian Bravos commissioning consisted of measuring source hot spot, source output, verifying source dwell positioning, independently verifying system dwell timing, interlock testing, and CamScale position verification calibration. The CamScale is a source positioning device that is developed by Varian to operate in conjunction with the Bravos system. Interlocks were tested and verified through the Bravos computer console and with a survey meter.

Measurements:

Source Hot Spot and Output

Source hot spot and output was measured using the Standard Imaging HDR 1000 Plus ionization well chamber and a Standard Imaging CDX-2000B electrometer. A treatment channel length of 132 cm was programmed into the Bravos system. Hot spot was determined by having 10 dwell positions with a step size of 0.5 cm going from 129 cm to 124.5 cm. A 10 second dwell time was used. Hot spot was determined to reside at 127.5 cm.

Source output was measured by using a 20 second dwell time at the determined hot spot position of 127.5 cm.

Data is saved on Q: HDR > Dixie > QA

CamScale Position Calibration

The CamScale is a source position verification and calibration tool unique to the Bravos system. A laser projected from the CamScale onto the Bravos allows for accurate positioning and a designated guide tube is used to connect the two systems. 3 cameras inside the system show dummy and source cable position at 150.0 cm, 120.0 cm, and 90.0 cm. Cable tip and offset from these positions can be measured and calibrated.

A position verification test (PVT) is automatically built into the Bravos computer system. The test was conducted, and the cable tips were calibrated. Another PVT was performed after calibration for confirmation.

Data is saved on Q: HDR > Dixie > QA

Source Positioning

Source positioning was performed using a Mick Radio-Nuclear Instruments PermaDoc Phantom. A new catheter tube capable of connecting to the Bravos guide tubes was installed into the phantom. A strip of Gafchromic EBT3 film was placed inside the phantom and underneath the treatment catheter. 10 dwell positions spaced 1 cm apart were programmed with a 2 second dwell time. Source position was analyzed on the film and imprinted marker lines.

System position accuracy with a programmed offset was also analyzed. The Bravos has a new feature where a push test will determine the channel tip and automatically correct for positional discrepancy. A 0.2 cm and 0.5 cm offset to the catheter tip was programmed into the

PermaDoc test. In both cases the Bravos automatically corrected to the appropriate treatment length.

Data is saved on Q: HDR > Dixie > QA

System Dwell Timing and Interlock Test

System dwell timing was verified independently with a stopwatch. A single 60 second dwell time was programmed. Timer was started when the source reached its dwell position and stopped when source began retraction.

The 60 second dwell time also allowed for interlock testing. Each interlock was triggered with the source in position and verified automatic source retraction. Opening the door; turning the system key to off position; interrupting treatment manually from computer console; and pressing Emergency Off button were tested and source retraction verified inside treatment room with survey meter.

Bravos **Date** **1/10/20**

Bravos SN 651026700108

Electrometer: Standard Imaging CDX-2000B SN J051886 **Source #** **55**

Ionization Well Chamber: Standard Imaging HDR-1000 Plus SN A051401

Well Type: Chamber Volume 245 cm^2 AE Plastic Inner Diameter: 2.64 cm

Electrometer Calibration Factor for Scale 10-9 Amperes **Bias: = +302 V**

University of Wisconsin ADCL Calibration: 12/18/19

Source Installed 1/10/2020

Source Model #: Bravos

Source SN **27-01-0022-001-122019-15310-38**

				Half Life	73.831
				Current Calculated Activity:	**12571** **mCi**
	Original Calibration	12/20/19			
	Activity	15310	mCi	12571.3	Calculated Output
	Cal Reference Air Kerma	62.31	mGy/hr		
	Todays Calc'ed Air Kerma	**51.29**		**51.0**	mGy/hr Meas Air Kerma
	Electrometer Readings	**100.23**			
		100.23			
Corrected Pressure= 698.3 mmHg	Aver. Electrometer reading	**100.23**	nA		
Chamber Temp.= **21.8** deg C			1 x 10^8 Ci/Amp		
CTP= 1.0877		0.999	Scale factor	**-0.52** %	Difference
	Calibration for Well Chamber	4.685	x 10^5 Gy*m^2/h/A		
			Measured Activity	12506 mCi	
			Calculated difference		
	BravosMultiplication factor (FROM Calibration Chart)	**79.5**	Calculated Multiplication factor	**80**	

Hot Spot Check to confirm spot at 125.5

129	98.65
128.5	99.51
128	100.03
127.5	100.23 ****
127	100.11
126.5	99.69
126	98.94

Figure 28: Source Hot Spot and Output

Bravos : Position Calibration Report

vservice / Intermountain Cancer Center / 651026 / 2020-01-09 17:35:34

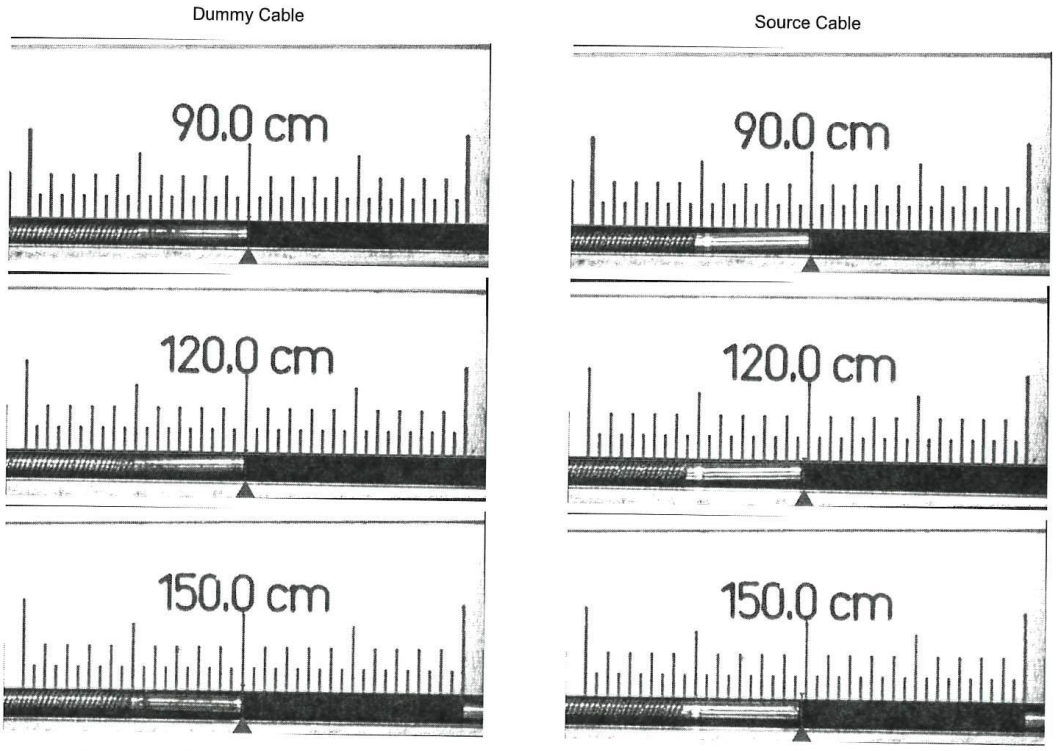
Position Calibration

Date	2020-01-09	Afterloader SN	651026	Channel	1
Authorized by	vservice	CamScale SN	22901878		

	Cable SN	Drive Cycles	Wheel Cycles	Cable Cycles
Dummy Cable	38-05-0388-003-000000-00000-64	59885	9885	9885
Source Cable	27-01-0022-001-122019-15310-38	29949	4949	4993

Measured Deviation from Target Positions

	Dummy Cable			Source Cable		
	90.00 cm	120.00 cm	150.00 cm	90.00 cm	120.00 cm	150.00 cm
Pre-Calibration	-0.02	-0.02	-0.02	+0.04	+0.04	+0.05
Post-Calibration	+0.00	+0.00	+0.00	+0.00	-0.02	-0.02



Electronic Signatures

Acknowledgement: I acknowledge my electronic signature carries the same meaning as my handwritten signature.

Service Electronically signed by: vservice

Date 2020-01-09 17:35:34

Bravos
Console version 2.0

Page 1 of 1

Figure 29: CamScale Position Verification and Calibration

Figure 30: Source Position Verification

APPENDIX B: H.A.M. Applicator Commissioning Report

H.A.M. Applicator Commissioning Report

The Harrison Anderson Mick (H.A.M.) applicator is a silicone rubber flab designed for the use of HDR surface brachytherapy. Treatment catheters are embedded into the applicator and can be cut to a user desired length. Commissioning of H.A.M. applicator flaps consisted of measuring the dimensions of the applicator and comparing them to manufacturer specifications; visual inspection of applicator integrity; source positional accuracy within each treatment channel; and CT scanning verification of treatment channel visibility. Dosimetric assessment was also performed for each applicator using Gafchromic EBT3 film and compared to associated dose planes exported from Eclipse treatment planning system (TPS).

Measurements:

Applicator Dimensions and Integrity Analysis

The applicator was physically measured using a meter length ruler. Width, length, and thickness of the applicator was measured and compared to the manufacturer specifications. Specified 0.5 cm source-to-tissue distance from the center of each treatment catheter was verified. All treatment catheters were cut to 160 cm and this length was verified using a cable wire length verification device.

Each applicator was visually inspected for signs of damage. No signs of damage were found but it needs to be noted that on each applicator there is a slight crease in between each treatment channel that allows for additional flexibility. This is inherent to applicator design and

does not affect applicator integrity. Designation of which side is to face away from the patient's skin is clearly marked on each applicator.

Source Position Accuracy

Source position accuracy was measured using a Mick Radio-Nuclear Instruments PermaDoc phantom. A strip of Gafchromic EBT3 film was placed underneath the applicator. The tip of the applicator was aligned with the first long line of the phantom. A test plan was programmed to deliver dwell positions every 2 cm with a 4 second dwell time in each channel of the applicator. Source alignment and dwell positioning in each treatment channel was verified after by scanning the film using an EPSON Expression 10000XL photo scanner and measuring in Eclipse Brachytherapy 2D Entry

Data is saved on Q: HDR > Surface

CT Image Verification

The applicator was placed on top of a slab of solid water and a CT scan was taken. Each scan was imported into Eclipse treatment planning system (TPS). Visualization of the applicator and each treatment channel verified that they were all free from occlusion.

Data is saved on Q: HDR > Surface

Dosimetric Evaluation

Accurate delivery of dose using the applicator was verified using Gafchromic EBT3 film. A 300 cGy and 500 cGy plan was created in Eclipse that utilized all treatment channels. The plan was normalized to a central reference line 0.8 cm from the source. The EBT3 film was placed under a slab of 0.3 cm thick solid water and the film was irradiated. The film was scanned and compared to the TPS exported dose plane using RIT113 film analysis software.

Another plan was created simulating possible treatment. A marker wire was placed on a 0.3 cm flexible skin bolus to outline a potential PTV. The applicator was placed over this marker wire and scanned. A 300 cGy plan prescribed to a 0.3 cm depth was created. A piece of EBT3 film was placed under the bolus and the irradiated film was scanned and compared to the TPS exported dose plane.

Data is saved on Q: HDR > Surface

Conclusion

Using applicable TG-56 guidelines for applicator quality assurance, the H.A.M. applicator is suitable for use during HDR procedures.

SN# 16092	Length (cm)	Width (cm)	Depth (cm)
Manufacturer	22.5	5	0.8
Measured	22.5	5	0.9
Difference	0	0	0.1
SN# 16093	Length (cm)	Width (cm)	Depth (cm)
Manufacturer	22.5	10	0.8
Measured	22.5	10	0.9
Difference	0	0	0.1

Table 4: Applicator Dimensions

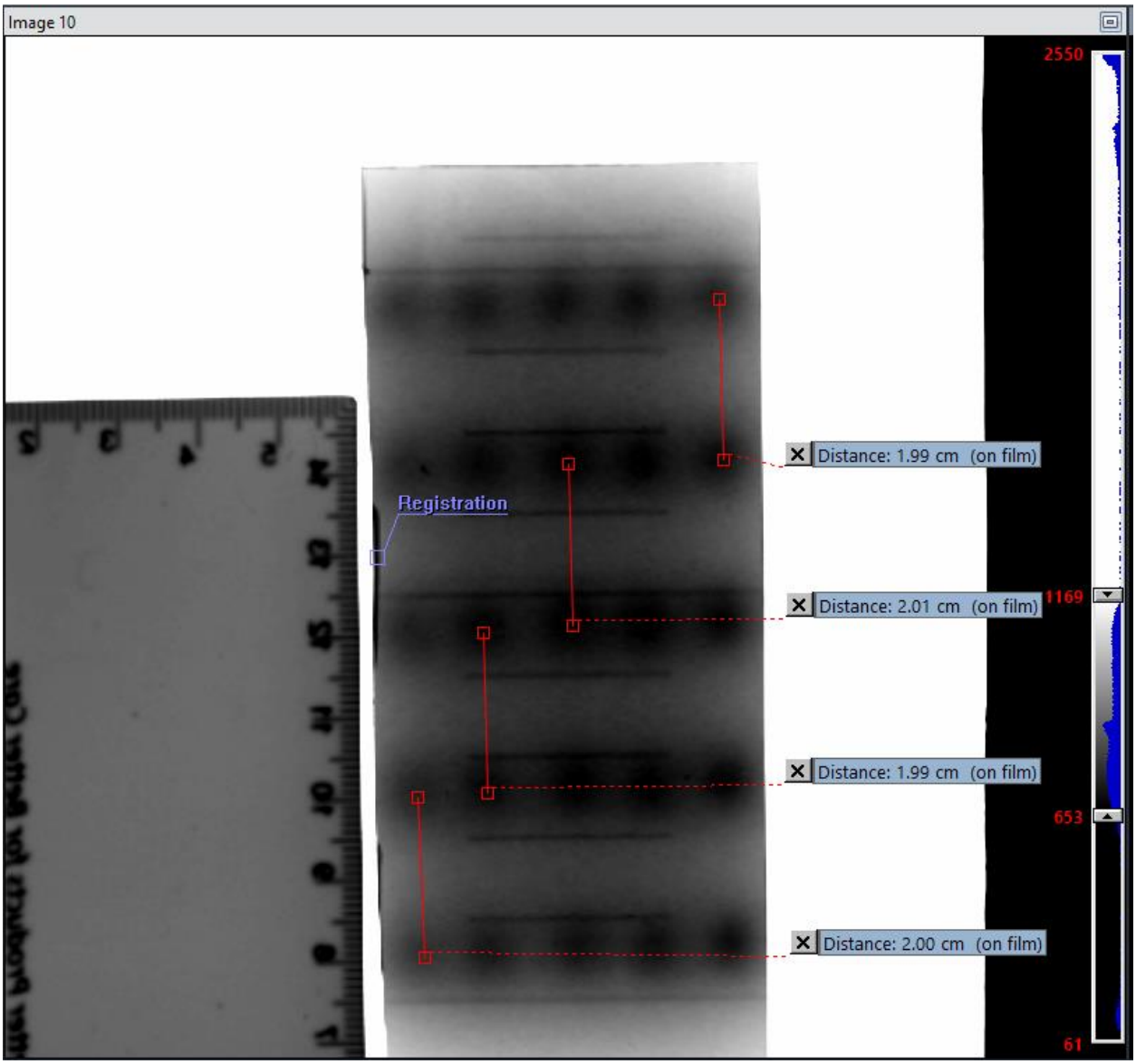


Figure 31: Source Position Accuracy

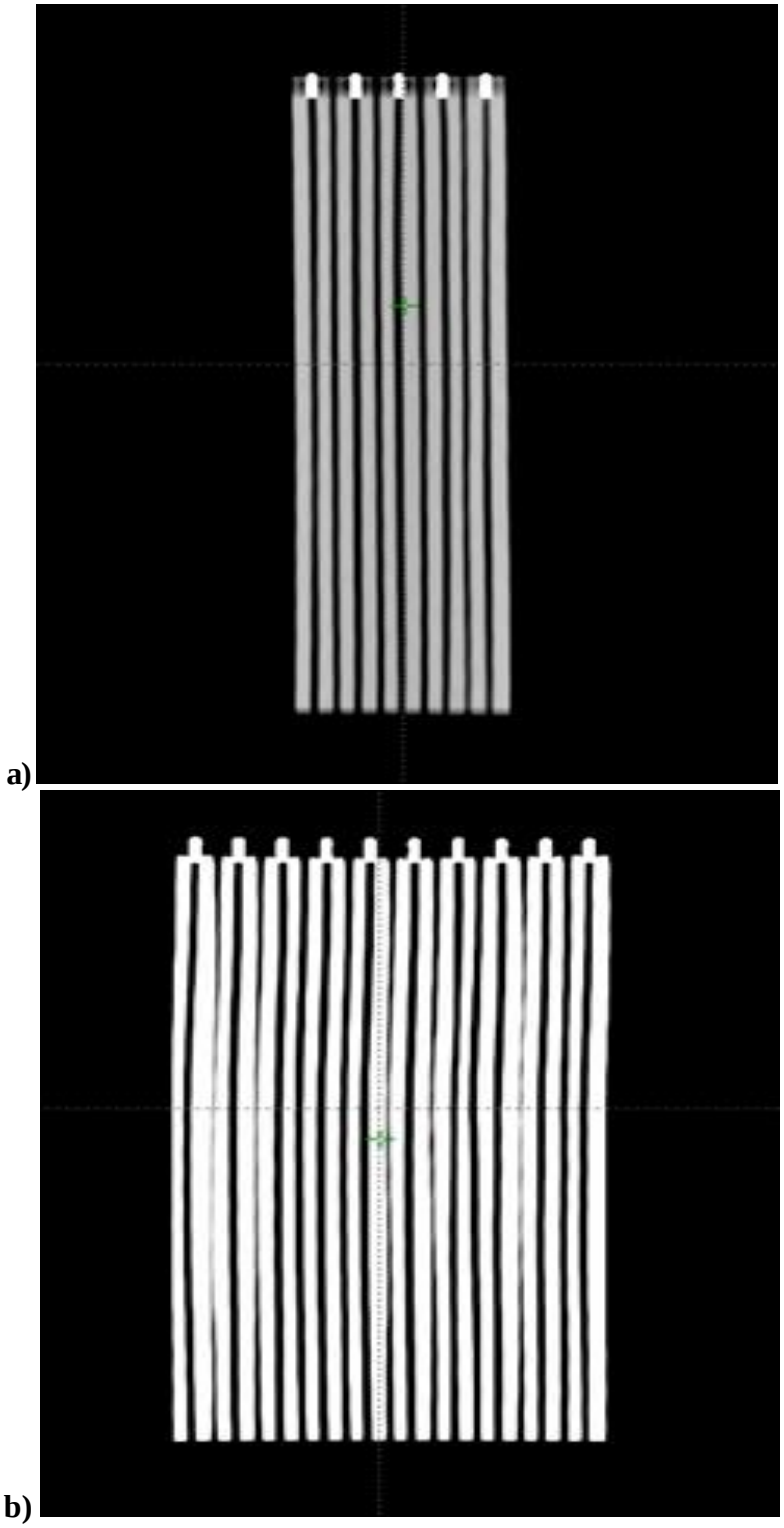


Figure 32: CT Image Verification. **a)** 5 cm applicator. **b)** 10 cm applicator.

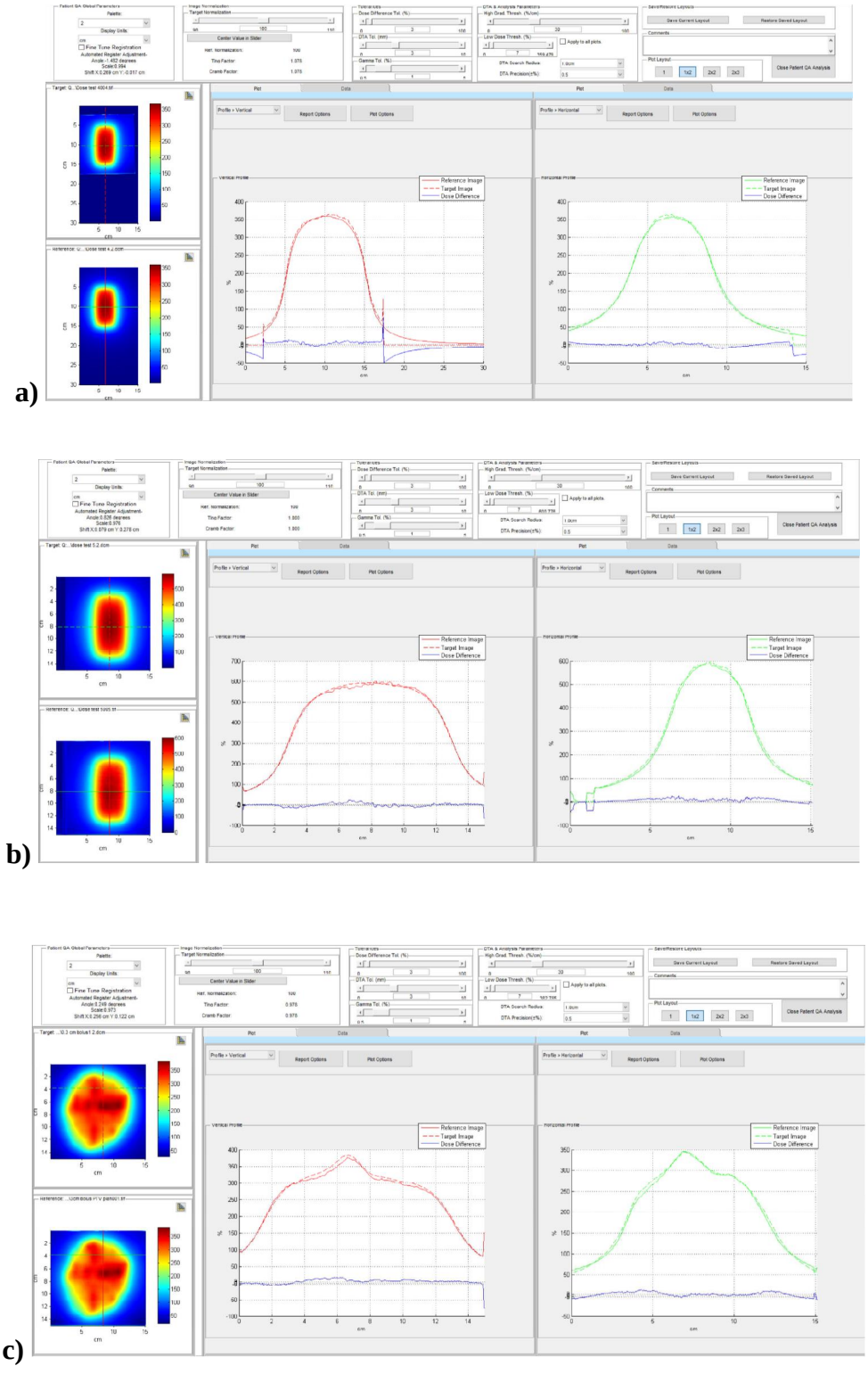


Figure 33: Dosimetry Verification. **a)** 300 cGy. **b)** 500 cGy. **c)** 300 cGy planned PTV

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CURRICULUM VITAE

Timothy Thatcher

Doctor of Medical Physics Resident

Eligible for Part 2 of ABR Therapeutic Medical Physics Exam

thatchet87@gmail.com

Education

8/2017 – Present	**University of Nevada, Las Vegas**, Las Vegas, NV 89154 *DMP in Medical Physics*
8/2013 – 8/2016	**University of Nevada, Las Vegas,** Las Vegas, NV 89154 *M.S. in **Medical Physics*** Thesis title: "Measurement of Neutron Activation from High Energy Varian Linear Accelerators" Advisor: Steen Madsen, Ph.D
9/2005 – 6/2009	**University of California, Irvine,** Irvine, CA 92697 *B.S. in Physics with a Biological Emphasis*

Research/Academic Experience

5/2018 – 5/2020	**Dixie Regional Medical Center**, St. George, UT 84770 *Medical Physics Resident* Medical Physics resident as part of the Doctor of Medical Physics (DMP) program. Responsibilities included comprehensive QA of CT, Linac, and HDR treatment devices; Patient treatment planning using Eclipse; Acceptance and Commissioning of Varian TrueBeam and Bravos HDR afterloader treatment devices; Treatment integration of Optical Surface Monitoring System (OSMS); Assisted in the ACR accreditation of site
11/2017 – 5/2018	**Center for Academic Enrichment and Outreach**, Las Vegas, NV 89154 *Graduate Student Mentor* Graduate student mentor to undergraduates as part of the Southern Nevada, Northern Arizona Louis Stokes Alliance for Minority Participation (SNNA-LSAMP)
10/2017 – 5/2018	**University of Nevada School of Allied Health Sciences**, Las Vegas, NV 89154 *Graduate Teaching Assistant* Independent instructor for the undergraduate core course "Inquiry and Issues in Health Sciences"
10/2017 – Present	**University of Nevada**, Las Vegas, NV 89154 *Vice Chair*

	Vice Chair of the GPSA Graduate Student Organization Funding Committee
11/2017	**University of Nevada**, Las Vegas, NV 89154 *Judging Chair* Volunteer judging chair member for the Undergraduate Research SLAM
1/2015 – 8/2015	**Comprehensive Cancer Centers of Nevada**, Las Vegas, NV 89169 *Clinical Student* Assisted with and learned about the clinical duties of a medical physicist.
1/2014 – 8/2016	**University of Nevada,** Las Vegas, NV 89154 *Graduate Researcher* Measurement of Neutron Activation from High Energy Varian Linear Accelerators.
7/2015	**American Association of Physicists in Medicine (AAPM) Conference 2015**, Anaheim, CA 92802 *Presenter* Presented poster for research project "Measurement of Neutron Activation from High Energy Varian Linear Accelerators"
8/2014 – 5/2015	**University of Nevada,** Las Vegas, NV 89154 *Graduate Assistant in School of Allied Health Sciences* Independent Instructor for Undergraduate Core Course: Inquiry and Issues in Health Sciences.
1/2014 – 5/2014	**University of Nevada,** Las Vegas, NV 89154 *Graduate Assistant in School of Allied Health Sciences* Independent Instructor for Undergraduate Core Course: Radiation Science.
8/2013 – Present	**University of Nevada,** Las Vegas, NV 89154 *Graduate and Professional Student Association (GPSA)* Health Physics Representative to UNLV Student Government for Graduate and Professional Students.
3/2015	**University of Nevada,** Las Vegas, NV 89154 *Technology Coordinator - GPSA Research Forum* Served as Technology Coordinator for the Graduate and Professional Student Research Forum.
8/2013 – 5/2014	**University of Nevada,** Las Vegas, NV 89154 *Bookstore Advisory Committee* Served as GPSA liaison to UNLV Bookstore Advisory Committee.
6/2007 – 6/2009	**University of California,** Irvine, CA 92697 *Research Assistant in Physics Department* Collected and interpreted data on phase transitions of a bubble raft to low amplitude oscillatory shear.

9/2007 – 3/2009	**University of California,** Irvine, CA 92697 *Math & Physics Tutor* Worked one on one with students teaching Calculus and Physics at the California Alliance for Minority Participation office.
10/2008	**Society for Advancement of Chicanos/Hispanics and Native Americans in Science (SACNAS) Conference,** Salt Lake City, UT 84101 *Presenter* Presented poster for research project "Response of Foam to Low Amplitude Oscillatory Shear"

Professional Memberships

2015 – Present	**Phi Kappa Phi Honors Society** – Member
2015 – Present	**American Association of Physicists in Medicine (AAPM)** - Member
2013 – 2016	**Graduate and Professional Student Association –** Health Physics Representative

Certification

8/2016 – Present	**American Board of Radiology (ABR)** – Therapeutic Medical Physics Passed ABR Therapeutic Medical Physics Part 1 in August 2016