Radiation Test Report for Chabner XRT^{TM} Garment Materials

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1 Introduction

The following report details the buildup and attenuation measurements for materials used in the Chabner XRT^{TM} garments that were performed by the University of Wisconsin Medical Radiation Research Center (UWMRRC) .

2 Methods and Materials

2.1 Material samples

Seven fabric samples were provided for radiation testing. The name and composition of each material, as provided by the customer, are shown in Table I. The thickness of each material, which was measured using a pair of digital calipers, is also shown in this table. Measurements were performed

Table I: Name and composition of material samples for transmission testing.

Material Name	Composition	Thickness (mm)
Cotton	100% cotton	0.64
Tricot	85% nylon, 15% spandex	0.56
TPU	100% elastomeric compound	1.01
Elastic	90% nylon, 10% spandex	1.40
Velcro	100% nylon	2.54
Mesh	70% nylon, 30% spandex	0.38
Nylon/spandex	92% nylon, 8% spandex	1.09

Table II: Details on the radiation beams used for transmission measurements.

Beam Quality	Tube potential (kVp)	Average energy (keV)	Photons (P) or Electrons (E)
UW-M30	30	19.5	P
UW-M100	100	52.8	P
Cobalt-60	—	1250*	P
6 MV	—	—	P
6 MeV	—	—	E

*The average energy of this therapy-level ^{60}Co beam is actually 1050 keV because of internal scatter in the source and treatment head; however, it is listed as 1250 keV as is commonly assumed.

using a rectangular piece (approximately 10 cm x 15 cm) that was cut out of each large sample that was provided. For the materials that could not accommodate these dimensions, a sample that was as close as possible in size was cut. Specifically, the elastic sample was 5 cm x 15 cm and the velcro sample was 2.5 cm x 7 cm. Transmission measurements were performed through a single layer of each material, with the exception of the velcro which was tested with the two layers attached.

2.2 Measurements

Measurements were performed for each of the material samples using five different radiation qualities. See Table II for details on the radiation beams that were used. These beams were selected because they span the range of radiation qualities seen in clinical applications. The UW-M30 and UW-M100 qualities were selected because they are representative of beams used in diagnostic applications. Specifically, the UW-M30 beam is representative of a mammography beam, and UW-M100 is representative of a general diagnostic beam. Cobalt-60 was selected because it is the standard beam quality for megavoltage radiation. The specific linear accelerator beams that were used were chosen because they are representative of beams used in therapeutic applications. The 6 MV beam is the most commonly used photon beam in linac-based treatments, and, of all of the available electron beams, the 6 MeV beam is expected to show the greatest effect with the transmission and build-up studies. Note that the only beams where build-up would have an effect on measurements would be the megavoltage beams (cobalt-60, 6 MV photons, and 6 MeV electrons). Measurement of the cobalt-60 beam was performed only at the depth of maximum dose because shallower depths were not achievable. Measurements of the linac beams were performed at a depths shallower than and deeper

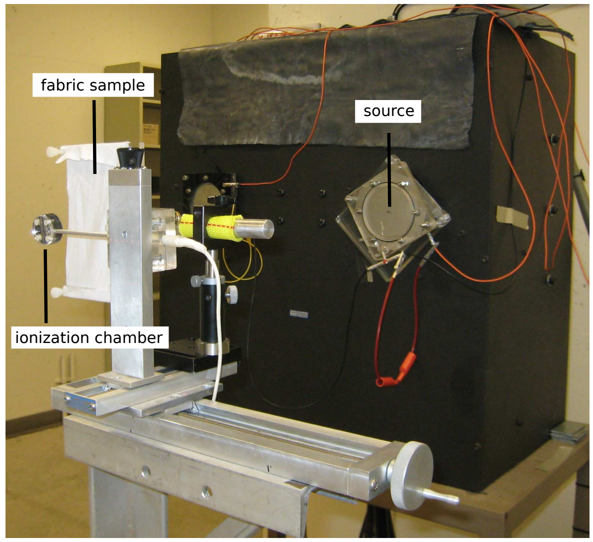

Figure 1: Photograph of the apparatus for transmission measurements performed on the AXI low-energy x-ray unit.

than the depth of maximum dose for the build-up and transmission measurements, respectively.

Each measurement apparatus consisted of a radiation unit, ionization chamber, and electrometer. Three irradiation units were used to create the various beam energies. The ionization chamber and electrometer used for each measurement depended on which radiation quality was used. The details of these measurements are specified in the following sections.

For the low-energy x-ray and cobalt transmission measurements, the samples were secured within an acrylic holder that was placed between the source and ionization chamber (see Figure 1). The exact location of the material sample varied with each irradiation unit as described in the following sections. The sample was placed directly on the phantom that held the ionization chamber holder for the photon and electron transmission measurements made with the linear accelerator. A reference measurement was performed for each beam quality, as well. This measurement was used to normalize the transmission measurements. No material sample was placed in the acrylic holder or on the phantom for the reference measurements. In all cases the source-to-chamber distance was 100 cm.

Three measurements were performed at each radiation quality for each material sample and for each reference case. In all cases, the standard deviation of these three measurements was under 0.15%. The average of the three transmission measurements was divided by the average reference measurement to determine the transmission ratio.

Table III: Properties of the low-energy x-ray beams used for transmission measurement studies.

UW Beam Code	Added Filtration (mm Al)	HVL (mm Al)	HC
UW30-M	0.36	0.356	65
UW100-M	4.63	4.98	72

2.2.1 Low-energy x-rays

Low-energy x-ray beams with kilovoltage tube potentials of 30 kVp and 100 kVp were generated using the UWMRRC Advanced X-ray (AXI) system. The AXI system consisted of a COMET MXR 320/26 bipolar x-ray tube with a tungsten anode. The system was powered by a Gulmay 320 constant potential generator and was operated with a tube current of 25 mA. The UWMRRC maintains a set of kilovoltage beams that are matched to the moderately-filtered (M-series) beams (in terms of tube voltage, half-value layer [HVL], and homogeneity coefficient [HC]) at the National Institute of Standards and Technology. Two of these beams, UWM-30 and UWM-100, were used in this work. The properties of these beams are shown in Table III.

A Precision Radiation Instruments model LE-0.8 ionization chamber (S/N 8835; Los Angeles, CA) was used for transmission measurements of the UWM-30 beam, and an Exradin A3 ionization chamber (S/N XR022483; Standard Imaging, Middleton, WI) was used for measurements of the UWM-100 beam. In both cases, the chambers were connected to a SUPERMax electrometer (S/N P111024; Standard Imaging, Middleton, WI) with an applied bias of +300 V. Measurements were performed in air. For these measurements, the material samples were placed a distance of 95 cm from the radiation source (i.e., 5 cm in front of the ionization chamber).

2.2.2 Cobalt-60

Therapy-level ^{60}Co irradiations were performed using the UWMRRC's Theratron 1000 (T1000) treatment unit (MDS Nordion, Kanata, ON, Canada) that was equipped with a 2.0 cm-diameter INIS-SF-2.7-4-SD ^{60}Co source (International Isotopes, Inc., Idaho Falls, ID). An Exradin A12 ionization chamber (S/N 192; Standard Imaging, Middleton, WI) with a build-up cap was used for transmission measurements of this beam. The chamber was connected to a Standard Imaging MAX-4000 electrometer (S/N E992941; applied bias, +300 V). Measurements were performed in air for a field size of (5 x 5) cm^2. The material samples were placed a distance of 90 cm from the radiation

Table IV: Transmission ratios of radiation garment materials for five radiation beam qualities. The values in bold represent transmission ratios deviating from unity by more than 0.5%. For the UWM-30 beam, results are given both as a ratio and in terms of attenuation per unit thickness.

	Radiation Quality					
Material	UWM-30		UWM-100	Cobalt	6 MV photons	6 MeV electrons
	Ratio	% Atten. per mm				
cotton	**0.969**	4.88	0.996	0.999	1.000	1.000
tricot	**0.969**	5.55	0.996	0.998	1.000	1.001
TPU	**0.986**	1.38	0.998	0.999	1.000	1.000
elastic	**0.933**	4.80	**0.988**	0.996	1.001	0.999
velcro	**0.925**	2.95	**0.986**	0.996	1.000	**0.993**
mesh	**0.987**	3.41	0.998	0.999	1.000	1.001
nylon/spandex	**0.970**	2.75	**0.995**	0.998	1.000	1.000

source (i.e., 10 cm in front of the ionization chamber).

2.2.3 Linear accelerator

A Varian Clinac iX linear accelerator was used to create 6 MV photon and 6 MeV electron beams. Measurements were performed using an Exradin A12 ionization chamber (S/N XA060332) with a Standard Imaging MAX-4000 electrometer (S/N E010243; applied bias, +300 V). For the build-up measurements, the chamber was placed inside a solid water phantom that provided 5 mm of build-up. For the transmission measurements, additional build-up was added to provide a total of 1.2 cm of build-up for the photon beam and 1.0 cm for the electron beam. Measurements were performed for field sizes of (5 x 5) $cm^2$and (6 x 6) cm^2 for photon and electron measurements, respectively.The material samples were placed directly on the solid water slab.

3 Results

The results of the transmission measurements are shown in Table IV. Of the radiation qualities that were tested, only the UWM-30, UWM-100, and 6 MeV electron beams were significantly affected by the presence of the materials. For the UWM-30 beam, the elastic and velcro were the most attenuating; however, all materials resulted in a transmission ratio differing from unity by more

Table V: Build-up ratios of radiation garment materials for two megavoltage beam qualities. These measurements were performed with an ionization placed inside a solid water phantom that provided 5 mm of build-up.

	Radiation Quality	
Material	6 MV photons	6 MeV electrons
cotton	1.005	1.005
tricot	1.006	1.005
TPU	1.003	1.003
elastic	1.013	1.017
velcro	1.008	1.009
mesh	1.003	1.005
nylon/spandex	1.006	1.009

than 1%. For the UWM-100 beam, only the elastic and velcro caused significant attenuation. The beam was not affected by any other materials. The cobalt and linac beams were unaffected by any of the materials, with the exception of the 6 MeV electron beam when tested with velcro.

The results of the build-up measurements for the megavoltage linac beams are shown in Table V. The beams that are not listed in this table did not have a build-up effect (see Table IV for transmission data). For both radiation qualities, it was found that the material samples acted as build-up. At shallow depths, the presence of the materials tended to increase the ionization chamber reading. This indicates that skin dose and dose at shallow depths may increase with the presence of the garment.

4 Conclusion

Build-up and transmission measurements were performed for seven material samples. The samples were tested in radiation beams with qualities in the kilovoltage and megavoltage ranges. The materials caused attenuation in the low-energy photon beams. Notably, the UWM-30 beam (simulating a mammography beam) was affected by all materials. The UWM-100 beam was affected only by the elastic and velcro samples. For the megavoltage beams, the materials provided build-up for measurements shallower than the depth of maximum dose. For the transmission measurements, the velcro caused attenuation in the megavoltage electron beam beyond the depth of maximum dose. All other radiation beams were unperturbed by the presence of the garment samples.