K&S Associates, Inc. Nashville, TN 37210-3718

ACCREDITED
CALIBRATION CERT #1866.01

Attenuation/Transmission Measurements

23-May-19

MATERIAL:
Manufacturer: Artemis Shielding
Model: NanoTek™ XYZ
Serial Number: N/A

SUBMITTED BY:
Artemis Shielding
2107 Gault Avenue North
Fort Payne, AL 35967

Test Number: T191188
Report Number: 192922

Measurment Conditions	
STD Chamber:	PRM D-150 SN 9116
Electrometer:	PTW Unidose SN 000809
SSD (cm):	100 cm
Current (mA):	10
Time (s):	60

Environmental Conditions		
Temperture:	21.7	°C
Pressure:	757.0	mm Hg
Corrected Pressure:	753.71	mm Hg
%Relative Humidity:	41	

Added*	Total Added**	150kVp % Trans	150kVp Norm	120kVp % Trans	120kVp Norm	80kVp % Trans	80kVp Norm
Open	0	100.00	1.0000	100.00	1.0000	100.00	1.0000
1.00	1.00	55.64	0.5564	40.48	0.4048	21.86	0.2186
1.01	2.01	32.03	0.3203	18.19	0.1819	6.15	0.0615
1.01	3.02	20.61	0.2061	9.39	0.0939	1.94	0.0194
0.99	4.01	14.47	0.1447	5.50	0.0550	0.69	0.0069
1.00	5.01	10.68	0.1068	3.51	0.0351		
1.01	6.02	8.09	0.0809	2.32	0.0232		
1.01	7.03	6.20	0.0620	1.57	0.0157		
1.01	8.04	4.89	0.0489				
1.01	9.05	3.86	0.0386				
1.01	10.06	3.09	0.0309				

* mm of Artemis sample material
**mm sum of Artemis sample material

Transmission Data

% Trans	150 kVp	120 kVp	80 kVp
	Amount of Artemis Material (mm)		
95%	0.0867	0.0570	0.0370
90%	0.1787	0.1175	0.0765
HVL 50%	1.1893	0.7683	0.4770
QVL 25%	2.5330	1.5700	0.9164
TVL 10%	5.3100	2.9440	1.5300
HC	0.89	0.96	1.09

This laboratory is accredited by the American Association for Laboratory Accreditation (A2LA). The prodecural measurement set up follows the inverse broad beam geometry procedure described in IEC 61331-1 Edition 2.0 2014-05.

All sample materials were provided by the customer. Sample thicknesses listed in the table above are based upon the addition of the thicknesses of the material provided by the customer. All sample material thicknesses were measured with a calibrated micrometer. The sample measurements are recorded in nano-Coulombs (nC) and normalized to the open field measurement.

The % transmission data was dervived via a 5 coefficient polynomial regression.

The overall uncertaintiy of the measurement is 2.8%. This uncertainty is the combined expanded uncertainty of the measurement with a coverage factor of 2 (95% conficence). The result(s) stated herein are valid under the conditions and parameters specified in this report.

The polynomial regression data was obtained by regressing graphical data of corrected material thickness versus transmission.

HVL = Half Value Layer
QVL = Quarter Value Layer
TVL = Tenth Valule Layer
HC = Homogeneity Coefficient

Procedure: GL14 This is a revision of report #192275

Measured by: Juci Stabin
Title: Health Physicist, Ph.D.

Reviewed by:
Title: Director

Checked By:
Prepared By: JS
Log Book: PA-18

K&S Associates, Inc.
Nashville, TN 37210-3718

ACCREDITED DOSIMETRY CALIBRATION LABORATORY

ACCREDITED
CALIBRATION CERT #1856.01

Attenuation/Transmission Measurements

SUBMITTED BY: Artemis Shielding
2107 Gault Avenue North
Fort Payne, AL 35967

MATERIAL:

Manufacturer:	Artemis Shielding
Model:	Nanotek™ RSM
Serial Number:	H-934066

TEST NUMBER: 182099

REPORT NUMBER: 182768

REPORT DATE: 21-Sep-18

The measurements contained in this report were obtained by direct ion chamber measurments with insturments calibrated by or directly traceable to the **National Institute of Standards and Technology (NIST).** K&S Associates, Inc. is licensed by the State of Tennessee to perform measurments, and is recognized by the **American Association of Physicists in Medicine (AAPM)** as an **ACCREDITED DOSIMETRY CALIBRATION LABORATORY**. As prt of the accreditation, K&S participates in a measurement assurance program conducted by AAPM and NIST. K&S also certifies that he calibration was performed using quality policies, methods, and procedures that meet or exceed the requirements of **ANSI/ISO/IEC 17025:2005**.

Additionally, this laboratory is accredited by the **American Association for Laboratory Accreditation (A2LA)** and the results shown in this report have been determined in accordance with the laboratory's terms of accreditation unless state otherwise in this report.

The calibration result(s) state herein are valid under the conditions and parameters specified in this report. It is the responsibility of the end user to assure that the interpretation of the data in this report is consistent with that intended by K&S Associates, Inc.

K&S Associates, Inc.
Nashville, TN 37210-3718

ACCREDITED
CALIBRATION CERT #1866.01

Attenuation/Transmission Measurements

21-Sep-18

MATERIAL
Manufacturer: Artemis Shielding
Model: Nanotek™ RSM
Serial Number: H-934066

SUBMITTED BY:
Artemis Shielding
2107 Gault Avenue North
Fort Payne, AL 35967

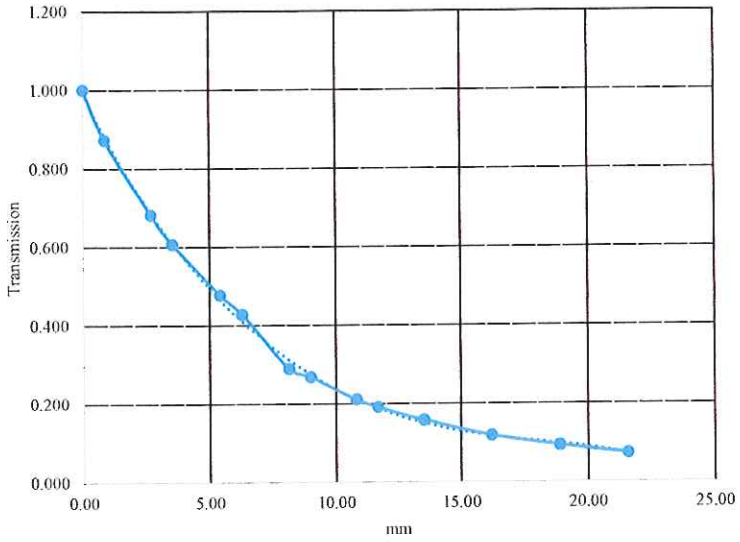
Test Number: 182099
Report Number: 182768

MEASUREMENT CONDITIONS	
Standard Chamber:	Exradin A4
Serial Number:	232
Bias Voltage:	-300
Leakage:	Negligible
Orientation:	White line towards source
Notes:	Distance to center of volume

SOURCE DATA		
Beam:	**Iodine-131**	**Activity (mCi)**
Cal. Date:	9/20/2018 13:00	954.0
Measure Date:	9/20/2018 15:00	947.2
	9/21/2018 8:56	887.9
Gamma (I^{131}):	0.22	mR/h/mCi @ 1m
SCD:	60	cm

ENVIRONMENTAL	
Temperature:	23.3 °C
Pressure:	750.80 mm Hg
Corrected Pressure:	747.68 mm Hg
Relative Humidity:	65 %
ATMOSPHERIC COMM:	Open

Thickness (mm)	Reading (pC)	mR/min @ 60 cm	Corrected Thickness (mm)*	Decay Corrected Rdg (pC)	Transmission
0.00	155.90	9.63	0.00	157.26	1.000
0.86	135.87	9.63	0.86	137.14	0.872
2.70	105.70	9.59	2.69	107.08	0.681
3.56	94.33	9.62	3.55	95.30	0.606
5.45	74.05	9.60	5.42	74.97	0.477
6.31	66.50	9.61	6.27	67.23	0.427
8.17	42.33	9.05	8.12	45.48	0.289
9.03	41.65	9.04	8.97	42.14	0.268
10.90	30.72	9.03	10.82	33.07	0.210
11.76	27.81	9.02	11.67	29.95	0.190
13.61	22.97	9.02	13.51	24.76	0.157
16.30	17.16	8.99	16.19	18.55	0.118
19.02	13.42	8.95	18.89	14.58	0.093
21.73	10.41	8.97	21.59	11.27	0.072



Polynomial Regression Data
x5 = -326.892
x4 = 1031.78
x3 = -1241.95
x2 = 716.348
x1 = -212.73
Intercept = 33.4323
R2 = 0.9996

HVL =	5.18 mm
TVL =	18.18 mm

This laboratory is accredited by the American Association for Laboratory Accreditation (A2LA).

The ionization chamber used for the measurements is NIST traceable and has a well understood spectral response curve.

All sample materials were provided by the customer. Sample thicknesses listed in the table above are based upon the addition of the thicknesses of the material provided by the customer. All sample material thicknesses were measured with a calibrated micrometer. The open and sample measurements are recorded in pico-Coulombs (pC).

The overall uncertaintiy of the measurement is 3%. This uncertainty is the combined expanded uncertainty of the measurement with a coverage factor of 2 (95% conficence). The result(s) stated herein are valid under the conditions and parameters specified in this report.

* The corrected thickness of the sample material was provided by the customer.

The polynomial regression data was obtained by regressing graphical data of corrected material thickness versus transmission.

Measured by: Juci Stabin
Title: Health Physicist, Ph.D.
Checked By:
Prepared By: KW

Reviewed by:
Title: Director
Log Book: B-19

K&S Associates, Inc.
Nashville, TN 37210-3718

ACCREDITED DOSIMETRY CALIBRATION LABORATORY

ACCREDITED
CALIBRATION CERT #1866.01

Attenuation/Transmission Measurements

SUBMITTED BY: Artemis Shielding
2107 Gault Avenue North
Fort Payne, AL 35967

MATERIAL:	Manufacturer:	Artemis Shielding
	Model:	Nanotek™ RSM
	Serial Number:	H-934066; and A-861139
		Pb (99.95% pure)

TEST NUMBER: **182105**

REPORT NUMBER: **182877**

REPORT DATE: 27-Sep-18

The measurements contained in this report were obtained by direct ion chamber measurments with insturments calibrated by or directly traceable to the **National Institute of Standards and Technology (NIST).** K&S Associates, Inc. is licensed by the State of Tennessee to perform measurments, and is recognized by the **American Association of Physicists in Medicine (AAPM)** as an **ACCREDITED DOSIMETRY CALIBRATION LABORATORY**. As prt of the accreditation, K&S participates in a measurement assurance program conducted by AAPM and NIST. K&S also certifies that he calibration was performed using quality policies, methods, and procedures that meet or exceed the requirements of **ANSI/ISO/IEC 17025:2005**.

Additionally, this laboratory is accredited by the **American Association for Laboratory Accreditation (A2LA)** and the results shown in this report have been determined in accordance with the laboratory's terms of accreditation unless state otherwise in this report.

The procedural measurement set up follows the Narrow Beam and Inverse Broad beam geometry procedures described in **IEC 61331-1 Edition 2.0 2014-05**.

The calibration result(s) state herein are valid under the conditions and parameters specified in this report. It is the responsibility of the end user to assure that the interpretation of the data in this report is consistent with that intended by K&S Associates, Inc.

K&S Associates, Inc.
Nashville, TN 37210-3718

ACCREDITED
CALIBRATION CERT #1866.01

Attenuation/Transmission Measurements

27-Sep-18

Test Number: 182105
Report Number: 182877

MATERIAL
Manufacturer: Artemis Shielding
Model: Nanotek™ RSM
Serial Number: H-934066; and A-861139
Pb (99.95% pure)

SUBMITTED BY:
Artemis Shielding
2107 Gault Avenue North
Fort Payne, AL 35967

NARROW BEAM GEOMETRY TRANSMISSION MEASUREMENT CONDITIONS	
Standard Chamber:	Exradin A3
Serial Number:	223
Bias Voltage:	-300
Leakage:	Negligible
Orientation:	White line towards source
Notes:	Distance to center of volume

Environmental Conditions	
Temperature:	23.3 °C
Pressure:	752.20 mm Hg
Corrected Pressure:	748.9 mm Hg
Relative Humidity:	60 %
Atmospheric Conditions:	Open

		Narrow Beam Geometry Transmission X-ray Beam Energy (kVp)														
Material	**mm**	**50**			**70**			**90**			**110**			**150**		
		T	**% T**	**% A**	**T**	**% T**	**% A**	**T**	**% T**	**% A**	**T**	**% T**	**% A**	**T**	**% T**	**% A**
Pb	0.25	0.0056	0.56	99.44	0.0333	3.33	96.67									
	0.35				0.0157	1.57	98.43	0.0450	4.50	95.50	0.0671	6.71	93.29			
	0.50							0.0237	2.37	97.63	0.0366	3.66	96.34	0.0565	5.65	94.35
	1.00													0.0109	1.09	98.91
H-934066	0.74	0.0008			0.0108	1.08	98.92									
	0.88				0.0067	0.67	99.33	0.0242	2.42	97.58						
	1.01							0.0184	1.84	98.16	0.0312	3.12	96.88	0.0486	4.86	95.14
	2.00													0.0091	0.91	99.09

T = Transmission
% T = Percentage Transmission
% A = Percentage Attenution

This laboratory is accredited by the American Association for Laboratory Accreditation (A2LA). The procedural measurement set up follows the narrow beam geometry procedure described in **IEC 61331-1 Edition 2.0 2014-05**.

The ionization chamber used for the measurements is NIST traceable and has a well understood spectral response curve.

All sample materials were provided by the customer. Sample thicknesses listed in the table above are based upon the addition of the thicknesses of the material provided by the customer. All sample material thicknesses were measured with a calibrated micrometer. The open and sample measurements are recorded in pico-Coulombs (pC).

The overall uncertaintiy of the measurement is 3%. This uncertainty is the combined expanded uncertainty of the measurement with a coverage factor of 2 (95% conficence). The result(s) stated herein are valid under the conditions and parameters specified in this report.

Measured by: Juci Stabin
Title: Health Physicist, Ph.D.
Checked By: **Prepared By:**

Reviewed by:
Title: DIRECTOR

Log Book: SE-31

K&S Associates, Inc.
Nashville, TN 37210-3718

ACCREDITED
CALIBRATION CERT #1866.01

Attenuation/Transmission Measurements

27-Sep-18

MATERIAL
Manufacturer: Artemis Shielding
Model: Nanotek™ RSM
Serial Number: H-934066

SUBMITTED BY:
Artemis Shielding
2107 Gault Avenue North
Fort Payne, AL 35967

Test Number: 182105
Report Number: 182877

INVERSE BROAD BEAM GEOMETRY TRANSMISSION MEASUREMENT CONDITIONS	
Standard Chamber:	PRM D-150
Serial Number:	9116
Bias Voltage:	-300
Leakage:	Negligible
Orientation:	Serial number toward source
Distance:	5 mm to testing sample

Environmental Conditions		
Temperature:	23.3	°C
Pressure:	752.0	mm Hg
Corrected Pressure:	748.7	mm Hg
Relative Humidity:	60	%
Atmospheric Conditions:	Open	

		Inverse Broad Beam Geometry Transmission X-ray Beam Energy (kVp)														
Material	**mm**	**50**			**70**			**90**			**110**			**150**		
		T	**% T**	**% A**	**T**	**% T**	**% A**	**T**	**% T**	**% A**	**T**	**% T**	**% A**	**T**	**% T**	**% A**
Pb	0.25	0.0084	0.84	99.16	0.0421	4.21	95.79									
	0.35				0.0210	2.10	97.90	0.0565	5.65	94.35	0.0844	8.44	91.56			
	0.50							0.0311	3.11	96.89	0.0486	4.86	95.14	0.0806	8.06	91.94
	1.00													0.0175	1.75	98.25
H-934066	0.74	0.0015			0.0155	1.55	98.45									
	0.88				0.0101	1.01	99.00	0.0350	3.50	96.50	0.07228	7.23	92.77			
	1.01							0.0265	2.65	97.35	0.0419	4.19	95.81	0.0704	7.04	92.96
	2.00													0.0149	1.49	98.52

T = Transmission
% T = Percentage Transmission
% A = Percentage Attenution

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The overall uncertaintiy of the measurement is 3%. This uncertainty is the combined expanded uncertainty of the measurement with a coverage factor of 2 (95% conficence). The result(s) stated herein are valid under the conditions and parameters specified in this report.

Measured by: Juci Stobin
Title: Health Physicist, Ph.D.
Checked By: **Prepared By:** KPW

Reviewed by:
Title: DIRECTOR
Log Book: PS-17

Versant
Medical Physics and Radiation Safety

Attenuation Measurements of Artemis XYZ Material at 6 MV and 15 MV

for

Artemis Shielding, LLC
2107 Gault Avenue North
Fort Payne, AL 35967

9 September 2019

Lee T. Myers, PhD, DABMP
Jaclyn Joan Carroll, MS

Versant
Medical Physics and Radiation Safety

Attenuation Measurements for Artemis XYZ material with 6MV and 15MV X-rays.

9 September 2019

Introduction

On August 22, 2019, Joe Priest, Chief Operating Officer of Artemis Shielding LLC asked Versant Medical Physics and Radiation Safety to perform attenuation measurements on their XYZ material using X-ray energies used for radiation therapy. The purpose of these measurements was to assess the shielding attenuation and relative lead equivalence of the XYZ material for therapeutic X-ray energies. Lee Myers and Jaclyn Carroll performed attenuation measurements at Anne Arundel Medical Center (AAMC) on August 27, 2019 using 6 MV and 15 MV X-rays. This report describes those measurements and the calculated lead equivalence that was determined.

Experimental Setup

Measurements were made using the AAMC Varian linear accelerator (linac) with a narrow beam geometry as shown in Figure 1 and with an inverse broad beam geometry where the attenuators were placed adjacent to the detector. The detector used was a 0.6 cc Farmer chamber (PTW TN30013, S/N 007086), calibration due date- July 15, 2020, . The detector was placed 150 cm from the source of X-rays (50 cm from isocenter) with an appropriate build-up cap. All measurements were made in air. The linac was operated at 600 monitor units per minute (600 MU/min) and the linearity of the detector response was verified before measurements were made.

The linac collimator was set to 2 cm x 2 cm. Narrow beam geometry measurements were made by stacking the XYZ attenuator next to the treatment head with thickness varying from 0 cm to 54.5 cm. Inverse broad beam geometry measurements were made by stacking the XYZ attenuator next to the detector. The data collected for each energy, 6 MV and 15 MV, with each geometry, narrow beam geometry and inverse broad beam geometry, are shown in Table 1 (narrow beam) and Table 2 (inverse broad beam).

Data Analysis

The data measured for each attenuation thickness were normalized to the unattenuated measurement. By taking the natural logarithm of each of these normalized values plotting as a function of attenuator thickness, we obtain curves that can be used to determine the linear attenuation coefficient, μ, which is given by the slope of the linear fit to the data points. These curves are shown in Figure 2. The linear fits are included on the curves.

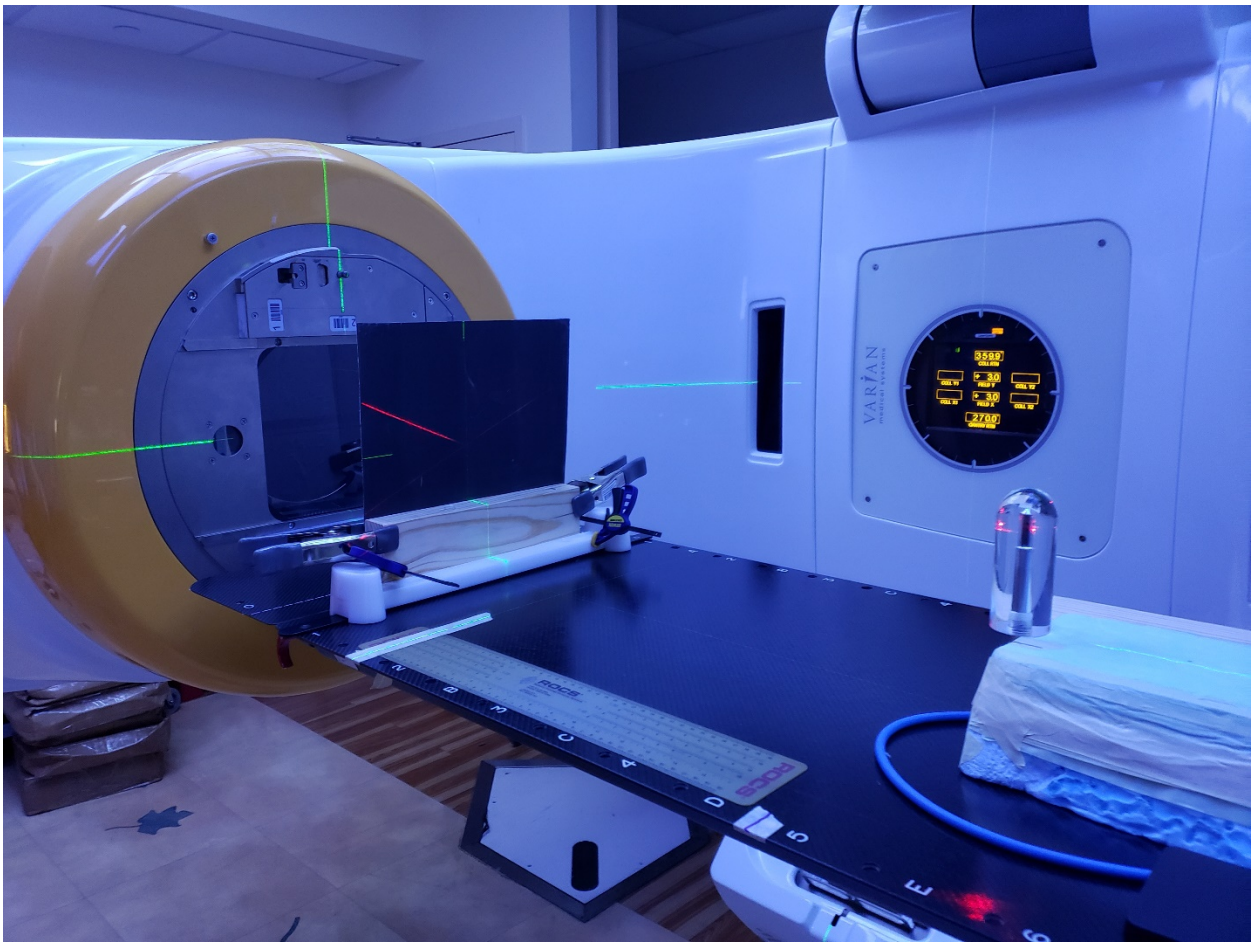

Figure 1: Measurement Setup for Narrow Beam Geometry with Linear Accelerator

Table 1

Narrow Beam Geometry Measurements

Narrow Beam Geometry Measurement Data					
6X	thickness (mm)	reading (nC)	Normalized rdg	Ln(norm rdg)	Fit
	0	35.69	1.0000	0.0000	-0.0746
	3.45	34.04	0.9538	-0.0473	-0.1132
	6.9	32.45	0.9092	-0.0952	-0.1519
	13.8	29.58	0.8288	-0.1878	-0.2292
	27.6	24.69	0.6918	-0.3685	-0.3837
	55.2	17.62	0.4937	-0.7058	-0.6928
	110.4	9.025	0.2529	-1.3749	-1.3111
	165.6	4.758	0.1333	-2.0150	-1.9293
	220.8	2.547	0.0714	-2.6400	-2.5476
	276	1.384	0.0388	-3.2499	-3.1658
	386.4	0.4195	0.0118	-4.4436	-4.4023
	496.8	0.1356	0.0038	-5.5729	-5.6388
	545.1	0.08528	0.0024	-6.0367	-6.1797
15X	545.1	0.1538	0.0044	-5.4306	-5.4823
	496.8	0.2404	0.0068	-4.9839	-4.9993
	331.2	1.198	0.0341	-3.3778	-3.3433
	165.6	6.293	0.1792	-1.7190	-1.6873
	55.2	19.59	0.5580	-0.5835	-0.5833
	27.6	26.19	0.7459	-0.2931	-0.3073
	0	35.11	1.0000	0.0000	-0.0313

Table 2

Inverse Broad Beam Geometry Measurements

Inverse Broad Beam Geometry Measurement Data					
6X	thickness (mm)	reading (nC)	Normalized rdg	Ln(norm rdg)	Fit
	0	33.89	1.0000	0.0000	-0.0386
	55.2	18.44	0.5441	-0.6086	-0.6000
	110.4	9.84	0.2904	-1.2367	-1.1614
	220.8	2.949	0.0870	-2.4417	-2.2841
	331.2	0.9005	0.0266	-3.6279	-3.4069
	441.6	0.2835	0.0084	-4.7837	-4.5297
	496.8	0.1609	0.0047	-5.3501	-5.0911
	545.1	0.1007	0.0030	-5.8187	-5.5823
15X	0	33.22	1.0000	0.0000	0.0775
	55.2	22.16	0.6671	-0.4049	-0.4414
	110.4	13.06	0.3931	-0.9336	-0.9603
	220.8	4.604	0.1386	-1.9762	-1.9980
	331.2	1.592	0.0479	-3.0382	-3.0358
	441.6	0.5495	0.0165	-4.1019	-4.0735
	496.8	0.3267	0.0098	-4.6219	-4.5924
	545.1	0.2078	0.0063	-5.0743	-5.0464

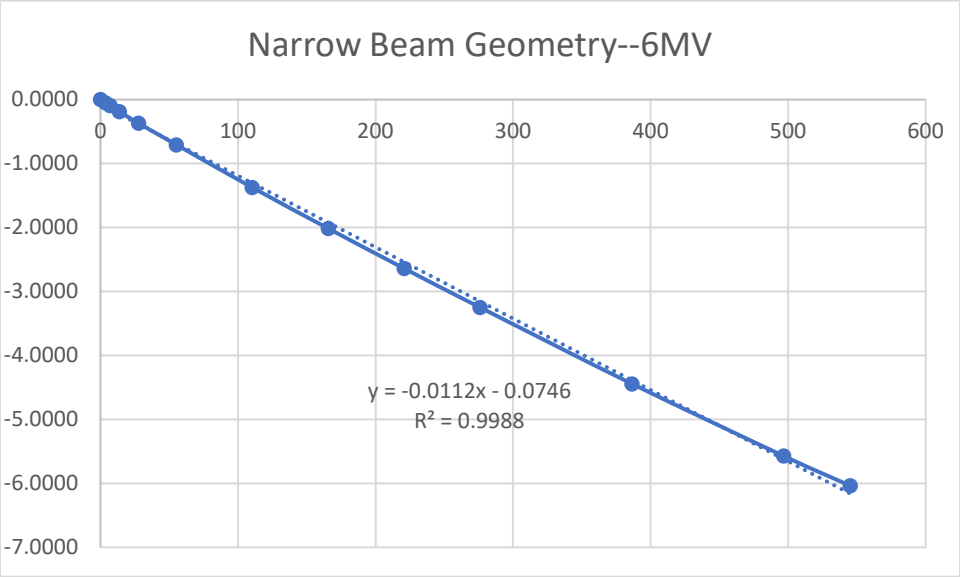

Figure 2(a): Ln (I_0/I) vs. attenuator thickness (mm) for Narrow Beam Geometry—6MV

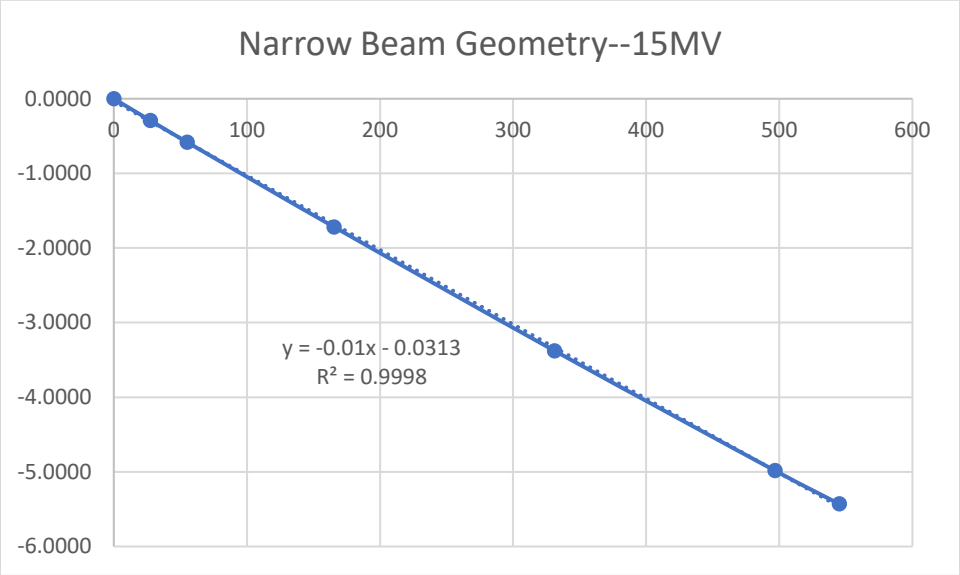

Figure 2(b): Ln (I_0/I) vs. attenuator thickness (mm) for Narrow Beam Geometry—15MV

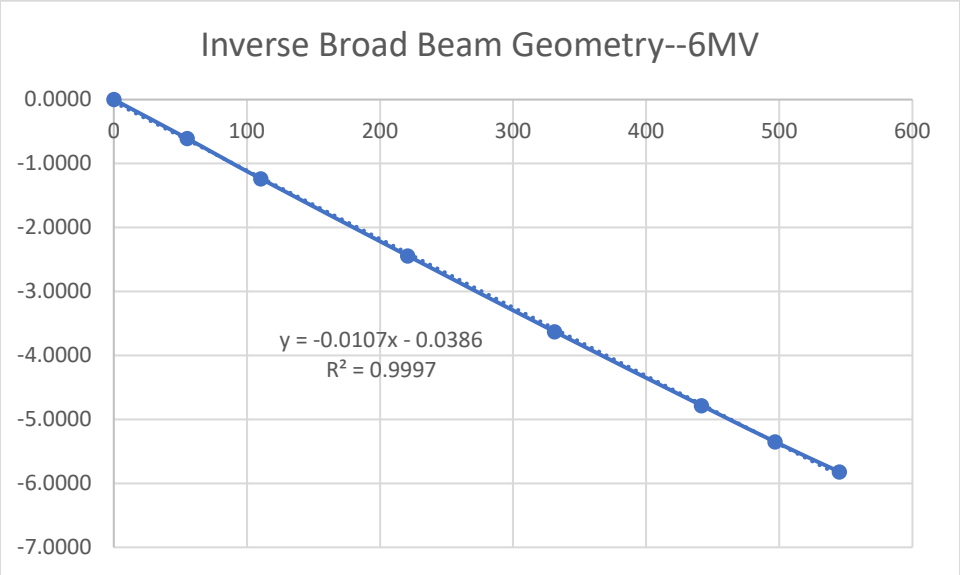

Figure 2(c): Ln (I_0/I) vs. attenuator thickness (mm) for Inverse Broad Beam Geometry—6MV

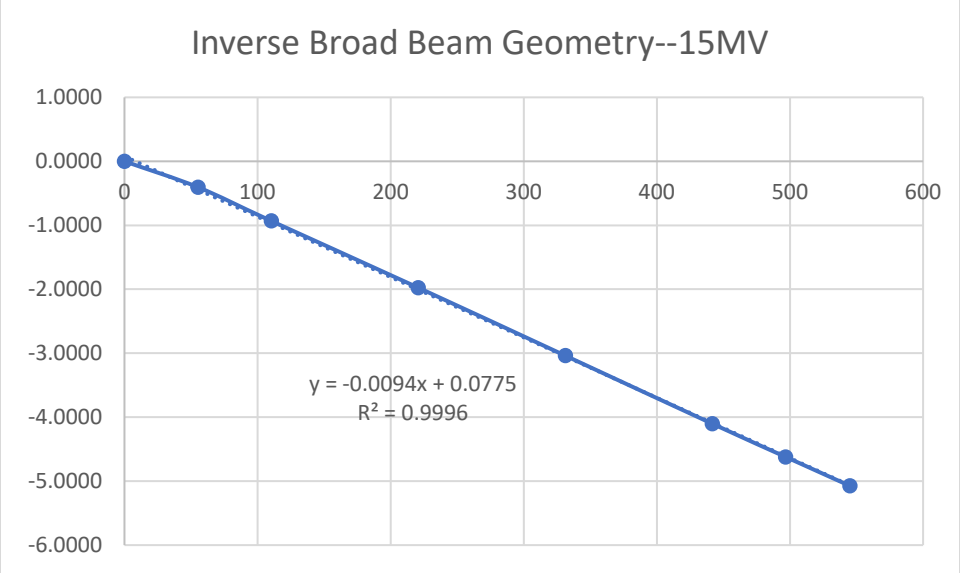

Figure 2(d): Ln (I_0/I) vs. attenuator thickness (mm) for Inverse Broad Beam Geometry—15MV

Tenth-value layers (TVL) can then be determined with the relation:

$$TVL = Ln(10)/\mu$$

Table 3

Material Attenuation Comparison

Comparison XYZ and Pb				
Narrow Beam Geometry				
	XYZ	XYZ	Pb	
	linear attenuation (1/mm)	**TVL(mm)**	**TVL(mm)**	**Ratio**
6MV	**0.011**	**205.588**	**57.000**	**3.607**
15MV	**0.010**	**230.259**	**57.000**	**4.040**
Inverse Broad Beam Geometry				
6MV	**0.011**	**215.195**	**57.000**	**3.775**
15MV	**0.009**	**244.956**	**57.000**	**4.297**

The calculated TVL's are shown in Table 3. The linear attenuation coefficients are taken from the linear fits to the curves shown in Figure 2 and do not vary appreciably as is expected in this energy range. The TVL for lead at these energies is 5.7 cm. For 6 MV, the ratio is similar to the ratio of the densities of the two materials. Lead is 11.35 g/cc and XYZ is 3.1 g/cc, which implies a ratio of 3.66. The ratio increases by about 14% for 15 MV. This reflects the fact that the density ratio is reasonable to use where the Compton effect is dominant (~80 kV to 10 MV). Below 80 kV, the photoelectric effect becomes significant and has a strong dependence on the atomic number. Above 10 MV, pair production (threshold energy of 1.022 MeV) becomes important. Pair production also has a strong dependence on the atomic number.

Summary

A standard 2” lead brick provides about 1 TVL of attenuation for therapeutic X-rays. To accomplish the same level of attenuation with the XYZ material would require about 4 bricks of comparable thickness. If the intent is to make a standard brick that could be used for both 6MV and 15MV, 1 TVL of XYZ material will be about 9” on average, which could be accommodated with 4 blocks, each being 2.25” in thickness.

References:

NCRP Report No. 151, Structural Shielding Design and Evaluation for Megavoltage X- and Gamma-Ray Radiotherapy Facilities, December 31, 2005.

Determination of lead equivalent values according to IEC 61331-1:2014—Report and Short Guidelines for Testing Laboratories, Journal of Instrumentation, IOP Publishing, September 2016.