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THE TRANSMISSION OF DIFFERING ENERGY BETA

PARTICLES THROUGH VARIOUS MATERIALS

By

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Introduction

The transmission of beta particles is frequently calculated in the same fashion as that of gamma rays, where the mass attenuation coefficient is defined by the slope of the exponential function. Numerous authors have used this approximation including Evans (1955), Loevinger (1952), and Chabot et. al. (1988). Recent work by McCarthy et. al. (1995) indicated that the exponential function seemed to fit well over a particular region of the transmission curve. Upon further investigation, I decided to verify McCarthy's results by the use of different absorber materials and attempt to reproduce the experiments. A theoretical method¹ will be used to estimate the transmission of the beta particles through the three absorbers, aluminum, zirconium, and iron. An alternate Monte Carlo code, the Electron Gamma Shower version 4 code² (EGS4) will also be used to verify that the experiment is approximating a pencil beam of beta particles. Although these two methods offer a good cross check for the experimental data, they pose a conflict in regards to the type of beam that is to be generated. The experimental lab setup uses a collimated beam of electrons that will impinge upon the absorber, while the codes are written using a pencil beam. A minor discrepancy is expected to be observed in the experimental results and is currently under investigation by McCarthy. The next process is to perform the experiments and verify if the results can accurately be interpreted by the two other methods.

The theoretical method uses the mono-energetic range distribution as a function of electron energy (E) and atomic number (Z), $p(z,E,Z)$, to calculate the transmission of mono-

¹ McCarthy, William B., Monte Carlo code (1995)

² Nelson, EGS4 Monte Carlo code (1985)

energetic electrons through a foil thickness z : This is done by integrating the electron range distribution from z to ∞ .

$$(1) \quad \eta_e(z, E, Z) := \int_z^{\infty} p(z, E, Z) dz$$

This is interpreted that all electrons that come to rest at a distance greater than the foil thickness, z , will be transmitted. The resulting transmission equation for mono-energetic electrons can be integrated over the range of beta particle energies that lie from 0 MeV up to E_{max} by applying a weighting factor for the beta particle energy distribution. This will yield the beta particle transmission as a function of the atomic number, Z , and foil thickness, z , for a given beta emitting radionuclide. This resultant function is for a pencil beam of beta particles impinging on a foil that is infinite in the x-y plane.

Methodology

The purpose of this study was to evaluate the transmission of beta particles through aluminum, iron, and zirconium absorbers using three pure beta emitters. Pm-147, maximum beta energy of 0.2247 MeV, Sr/Y-90, maximum beta energies of 0.564 and 2.2839 MeV respectively, and Tl-204, maximum beta energy of 0.7634 MeV. By using different absorber and beta emitters an evaluation can be made on the effects of the atomic number of the absorber and energy distribution on the transmission of the beta particles.

The absorbers were placed layer by layer in direct contact above a gas flow proportional counter which was covered by a thin Mylar window (0.83 mg cm^{-2}) as observed in appendix A (Detector Setup Diagram). The collimator was a 1" polyethylene slab with a $9/64$ " diameter hole drilled in the center to allow the transport of the beta

particles, and was placed in direct contact with the absorbers. The collimator configuration was used in the experiment to reduce any air gaps that may exist between the multiple layers of absorbers, and to provide a collimated beam of beta particles. The use of polyethylene as a collimator was to minimize the additional production of bremsstrahlung radiation. It was thick enough to stop the most energetic beta particles.

In order to evaluate the contribution due to bremsstrahlung radiation a sufficient thickness of absorber material was inserted between the detector window and the collimator. The thickness of the absorber exceeded the range of the most energetic beta particle, but was thin enough not to attenuate the x-rays emitted as bremsstrahlung. The count obtained with this absorber was used as a pseudo background count rate during the experiment. Although this does not evaluate the contribution due to bremsstrahlung exactly, it provides a reasonable approximation of the bremsstrahlung count to be subtracted from counts obtained at smaller absorber thickness.

Table 1

Voltage volts	Pm-147 cpm	Sr/Y-90 cpm	Tl-204 cpm
1500	2080	1020	1370
1600	7305	2880	6971
1700	12995	7350	19930
1750	14820	10215	26027
1800	16255	13860	31353
1850	17545	16260	33315
1875	17910	15945	33518
1900	18355	17355	33311
1937	17855	17745	33896
1950	18280	17850	34004
1975	18065	17580	34032
2000	18355	17385	34551
2025	18515	18000	35025
2050	19175	20025	34405
2075	-----	-----	34776
2100	-----	-----	34704
2125	-----	-----	34940
2150	-----	-----	34733
2175	-----	-----	34649
2200	-----	-----	34519
2225	-----	-----	35298
2250	-----	-----	35811
2275	-----	-----	128000

Figure 1

**Voltage Plateau for Gas Flow Proportional Counter
using various radionuclides**

Table 2

Pm-147 source with Aluminum absorbers 3/27/96

dead time 6.1E-06 Rb = 8.37

Absorber thickness	Gross counts	time secs	Transmission	sigma T
0.00	15620	120	1.00E+00	1.21E-02
6.86	5223	120	2.89E-01	9.91E-03
13.70	7742	360	1.08E-01	8.82E-03
20.60	7496	600	3.39E-02	8.67E-03
27.50	17533	1800	1.13E-02	8.61E-03
34.30	10530	1200	3.37E-03	
41.16	15057	1800		

r^2 = 0.9995

source cap = 0.0 g/cm^2

Monte Carlo Results

Absorber thickness	Pm-147 expected	% difference	Pm-147 EGS4 code	EGS4 total	% difference
0.00	1	0.0%	8908	1.0E+00	0.0%
6.86	2.9E-01	1.4%	2337	2.6E-01	-10.0%
13.70	9.9E-02	-9.1%	860	9.7E-02	-11.7%
20.60	3.3E-02	-3.1%	263	3.0E-02	-14.7%
27.50	1.0E-02	-9.1%	87	9.8E-03	-15.6%
34.30	3.0E-03	-11.2%	22	2.5E-03	-36.3%
41.16	8.1E-04		5		

Figure 2

Pm-147 beta transmission through aluminum absorbers

Table 3

dead time = 6.1E-06

Rb = 5.57

Absorber thickness	Gross counts	time secs	Transmission	sigma T
0.00	15620	120	1.00E+00	1.18E-02
19.68	4455	360	5.46E-02	8.53E-03
39.35	4151	600	1.08E-02	8.44E-03
59.03	6683	1200	1.52E-06	

$r^2 = 0.9999$

source cap = 0.0 g/cm²

Monte Carlo Results

Absorber thickness	Pm-147 expected	% difference	Pm-147 EGS4	EGS4 Total	% difference
0.00	1.00E+00	0.0%	9241	1.00E+00	0.0%
19.68	2.29E-02	-138.8%	332	3.59E-02	-51.9%
39.35	5.02E-04	-2056.2%	6	6.49E-04	-1566.7%
59.03	5.86E-06	74.1%	0		

Figure 3

Pm-147 beta through Iron absorbers

Table 4

Pm-147 source with Zirconium absorbers 3/27/96

dead time = 6.1E-06 Rb = 6.08

Absorber thickness	Gross counts	time secs	Transmission	sigma T
0.00	8815	60	1.00E+00	1.57E-02
12.98	975	60	7.22E-02	1.17E-02
25.96	1202	180	4.27E-03	1.12E-02
38.94	3665	600	2.32E-04	1.12E-02
51.92	7291	1200	1.60E-06	1.11E-02

$$r^2 = 1.0000$$

source cap = 0.0 g/cm²

Monte Carlo Results

Absorber thickness	Pm-147 expected	% difference	Pm-147 EGS4 code	EGS4 Total	% difference
0.00	1	0.0%	8630	1.00E+00	0.0%
12.98	5.89E-02	-22.6%	435	5.04E-02	-43.2%
25.96	4.46E-03	4.1%	39	4.52E-03	5.5%
38.94	2.75E-04	15.6%	3	3.48E-04	33.2%
51.92	1.28E-05	87.5%			

Figure 4

Pm-147 beta transmission through Zirconium absorbers

Table 5

dead time = 6.1E-06		Rb = 36.49		
Absorber thickness	Gross counts	time secs	Transmission %	sigma in T
0.00	247253	60.0	1.00E+00	7.22E-03
26.25	25141	10.0	6.01E-01	9.05E-03
52.50	18798	10.0	4.45E-01	8.46E-03
78.75	14537	10.0	3.41E-01	8.04E-03
105.00	11516	10.0	2.68E-01	7.73E-03
131.25	18583	20.0	2.14E-01	6.97E-03
157.50	15123	20.0	1.73E-01	6.87E-03
183.75	12786	20.0	1.44E-01	6.80E-03
210.00	14870	30.0	1.10E-01	6.61E-03
236.25	12058	30.0	8.74E-02	6.57E-03
262.50	14510	45.0	6.84E-02	6.49E-03
288.75	11728	45.0	5.36E-02	6.47E-03
315.00	12683	60.0	4.18E-02	6.45E-03
341.25	10321	60.0	3.24E-02	6.44E-03
367.50	8304	60.0	2.43E-02	6.43E-03
393.75	9037	80.0	1.83E-02	6.42E-03
420.00	7503	80.0	1.37E-02	6.42E-03
446.25	9302	120.0	9.80E-03	6.41E-03
472.50	8083	120.0	7.37E-03	6.41E-03
1050.00	21891	600.0	1.94E-06	

Monte Carlo Results								
Absorber thickness	Y-90 expected	Sr-90 expected	Total	% difference	Y-90 EGS4 code	Sr-90 EGS4 code	EGS4 total	% difference
0.00	1	1.000	1.00E+00	0.0%	9974	9710	1.000	0.0%
26.25	0.828	0.243	5.35E-01	-12.2%	8429	2731	0.567	-5.9%
52.50	0.696	0.062	3.79E-01	-17.4%	7358	925	0.421	-5.8%
78.75	0.587	0.014	3.01E-01	-13.5%	6173	276	0.328	-4.2%
105.00	0.496	3.0E-03	2.49E-01	-7.5%	5265	76	0.271	1.2%
131.25	0.418	5.5E-04	2.09E-01	-2.4%	4599	15	0.234	8.6%
157.50	0.352	8.9E-05	1.76E-01	2.0%	3996	3	0.203	15.1%
183.75	0.296	1.3E-05	1.48E-01	2.5%	3439	0	0.175	17.3%
210.00	0.249	1.6E-06	1.24E-01	11.6%	2962		0.150	26.9%
236.25	0.208	1.8E-07	1.04E-01	16.0%	2516		0.128	31.6%
262.50	0.174		8.70E-02	21.4%	2107		0.107	36.1%
288.75	0.145		7.25E-02	26.1%	1696		0.086	37.8%
315.00	0.121		6.03E-02	30.7%	1488		0.076	44.7%
341.25	0.100		5.00E-02	35.3%	1256		0.064	49.2%
367.50	0.083		4.14E-02	41.2%	1024		0.052	53.2%
393.75	0.068		3.41E-02	46.5%	849		0.043	57.6%
420.00	0.056		2.81E-02	51.3%	709		0.036	62.0%
446.25	0.046		2.30E-02	57.5%	600		0.030	67.8%
472.50	0.038		1.88E-02	60.9%	481			
1050.00	0.00020		1.00E-04	98.1%				

Figure 5

Sr/Y-90 beta transmission through Aluminum absorbers

Table 6**Sr/Y-90 source with Iron absorbers 3/27/96****dead time = 6.1E-06****Rb = 21.68**

Absorber thickness	Gross counts	time secs	Transmission	sigma T
0.00	248556	60	1.00E+00	2.85E-03
19.68	31905	10	7.64E-01	4.78E-03
39.35	25889	10	6.17E-01	4.39E-03
59.03	22300	10	5.30E-01	4.15E-03
78.70	19274	10	4.56E-01	3.93E-03
98.38	17013	10	4.01E-01	3.75E-03
118.10	14737	10	3.47E-01	3.57E-03
137.70	24400	20	2.86E-01	2.77E-03
157.40	21629	20	2.52E-01	2.69E-03
177.10	19548	20	2.27E-01	2.64E-03
196.80	17041	20	1.97E-01	2.56E-03
236.10	20623	30	1.58E-01	2.33E-03
275.50	16427	30	1.25E-01	2.27E-03
314.80	17599	45	8.76E-02	2.14E-03
354.20	14032	45	6.88E-02	2.12E-03
393.50	14336	60	5.15E-02	2.07E-03
432.90	22702	120	3.97E-02	2.04E-03
472.20	17990	120	3.04E-02	2.03E-03
511.60	19540	180	2.06E-02	2.03E-03
550.90	15593	180	1.54E-02	2.02E-03
590.30	16329	240	1.10E-02	2.02E-03
629.60	13226	240	7.91E-03	2.02E-03
669.00	10309	240	5.03E-03	2.02E-03
708.30	13404	360	3.68E-03	2.02E-03
747.70	11736	360	2.59E-03	2.02E-03
787.00	14038	480	1.79E-03	
826.40	16204	600	1.26E-03	
865.70	14934	600	7.61E-04	
905.10	29074	1200	6.05E-04	
944.40	13841	600	3.30E-04	
983.80	13217	600	8.41E-05	
1023.00	13055	600	2.02E-05	
1062.00	78033	3600	6.78E-07	

Table 6
(continued)

Sr/Y-90 through Iron continued...

Monte Carlo Results

Absorber thickness	Y-90 expected	Sr-90 expected	Total	% difference	Y-90 EGS code	Sr-90 EGS code	EGS4 total	% difference
0.00	1	1	1.00E+00	0.0%	9973	9717	1	0.0%
19.68	0.901	0.446	6.73E-01	-13.5%	8991	4349	0.678	-12.8%
39.35	0.821	0.221	5.21E-01	-18.5%	8283	2115	0.528	-16.8%
59.03	0.746	0.106	4.26E-01	-24.4%	7576	961	0.434	-22.1%
78.70	0.677	0.048	3.63E-01	-25.7%	6971	412	0.375	-21.6%
98.38	0.613	0.021	3.17E-01	-26.5%	6337	175	0.331	-21.4%
118.10	0.555	8.8E-03	2.82E-01	-23.0%	5859	69	0.301	-15.1%
137.70	0.501	3.5E-03	2.52E-01	-13.1%	5272	24	0.269	-6.2%
157.40	0.452	1.3E-03	2.27E-01	-11.2%	4924	9	0.251	-0.7%
177.10	0.407	4.7E-04	2.04E-01	-11.5%	4390		0.223	-2.0%
196.80	0.367	1.6E-04	1.83E-01	-7.7%	3906		0.198	0.5%
236.10	0.295		1.48E-01	-7.1%	3171		0.161	1.8%
275.50	0.237		1.18E-01	-5.5%	2613		0.133	6.0%
314.80	0.189		9.43E-02	7.1%	2109		0.107	18.2%
354.20	0.149		7.46E-02	7.8%	1668		0.085	18.8%
393.50	0.117		5.87E-02	12.3%	1275		0.065	20.5%
432.90	0.092		4.59E-02	13.5%	1054		0.054	25.9%
472.20	0.071		3.56E-02	14.7%	814		0.041	26.6%
511.60	0.055		2.75E-02	25.1%	606		0.031	33.2%
550.90	0.042		2.10E-02	26.9%	404		0.021	25.1%
590.30	0.032		1.60E-02	31.4%	332		0.017	34.9%
629.60	0.024		1.21E-02	34.6%	247		0.013	36.9%
669.00	0.018		9.07E-03	44.5%	147		7.5E-03	32.6%
708.30	0.014		6.76E-03	45.5%	126		6.4E-03	42.5%
747.70	0.010		5.00E-03	48.3%	95		4.8E-03	46.4%
787.00	7.3E-03		3.67E-03	51.2%	44		2.2E-03	19.8%
826.40	5.4E-03		2.68E-03	52.8%	33		1.7E-03	24.7%
865.70	3.9E-03		1.94E-03	60.7%	21		1.1E-03	28.6%
905.10	2.8E-03		1.39E-03	56.6%	10		5.1E-04	-19.0%
944.40	2.0E-03		9.93E-04	66.8%	7		3.6E-04	7.1%
983.80	1.4E-03		7.02E-04	88.0%				
1023.00	9.9E-04		4.94E-04	95.9%				
1062.00	6.9E-04		3.46E-04	99.8%				

Figure 6

Sr/Y-90 beta transmission through Iron absorbers

Table 7

Sr/Y-90 source with Zirconium absorbers 3/27/96

dead time = 6.1E-06 Rb = 21.83

Absorber thickness	Gross counts	time secs	Transmission	sigma T
0.00	41432	10	1.000	6.98E-03
25.96	27018	10	0.644	6.35E-03
51.92	20286	10	0.481	6.03E-03
77.88	16321	10	0.385	5.83E-03
103.84	26836	20	0.315	5.32E-03
129.80	22178	20	0.259	5.26E-03
195.00	14010	20	0.161	5.14E-03
260.20	27169	60	0.102	4.98E-03
325.40	17043	60	0.062	4.97E-03
390.60	21723	120	0.038	4.95E-03
519.00	18841	240	1.3E-02	4.94E-03
647.40	14085	360	4.1E-03	
775.80	15877	600	1.1E-03	
904.20	27345	1200	2.3E-04	
974.00	78597	3600		

Monte Carlo Results

Absorber thickness	Y-90 expected	Sr-90 expected	Total	% difference	Y-90 EGS4 code	Sr-90 EGS4 code	EGS4 Total	% difference
0.00	1	1	1.00E+00	0.0%	9975	9712	1	0.0%
25.96	0.839	0.265	5.52E-01	-16.7%	8578	3026	0.589	-9.3%
51.92	0.714	0.074	3.94E-01	-22.0%	7462	1076	0.434	-10.8%
77.88	0.609	1.9E-02	3.14E-01	-22.5%	6461	370	0.347	-10.9%
103.84	0.520	4.3E-03	2.62E-01	-20.0%	5675	108	0.294	-7.2%
129.80	0.444	8.9E-04	2.22E-01	-16.4%	4951	23	0.253	-2.5%
195.00	0.297	1.0E-05	1.48E-01	-8.7%	3453		0.175	8.1%
260.20	0.196		9.80E-02	-4.3%	2484		0.126	19.0%
325.40	0.128		6.38E-02	2.6%	1582		0.080	22.7%
390.60	0.082		4.09E-02	7.8%	1004		0.051	26.1%
519.00	0.032		1.60E-02	16.1%	375		1.9E-02	29.6%
647.40	1.2E-02		5.84E-03	29.9%	109		5.5E-03	26.1%
775.80	4.0E-03		1.99E-03	44.8%	37		1.9E-03	41.7%
904.20	1.3E-03		6.28E-04	63.9%	9		4.6E-04	50.4%
974.00	6.9E-04		3.44E-04	100.0%	3		1.5E-04	100.0%

Figure 7

Sr/Y-90 beta transmission through Zirconium absorbers

Table 8

TI-204 source with Aluminum absorbers 3/27/96

dead time = 6.1E-06

Rb = 282.25

Absorber thickness	Gross counts	time secs	Transmission	sigma T
0.00	74242	10	1.00E+00	5.40E-03
13.72	60527	10	8.01E-01	5.14E-03
27.43	44467	10	5.72E-01	4.83E-03
41.15	32058	10	3.99E-01	4.57E-03
54.86	23986	10	2.87E-01	4.39E-03
68.58	18198	10	2.08E-01	4.26E-03
82.29	13890	10	1.49E-01	4.16E-03
96.01	21505	20	1.07E-01	3.95E-03
109.72	17049	20	7.67E-02	3.93E-03
123.44	13938	20	5.57E-02	3.91E-03
137.15	17331	30	3.97E-02	3.87E-03
150.87	14903	30	2.88E-02	3.86E-03
171.50	25043	60	1.82E-02	3.84E-03
205.70	20669	60	8.40E-03	3.83E-03
240.00	37768	120	4.41E-03	3.82E-03
274.30	35253	120	1.61E-03	
308.60	169352	600	6.50E-05	

Monte Carlo Results

Absorber thickness	TI-204 expected	% difference	TI-204 EGS4 code	EGS4 Total	% difference
0.00	1.00E+00	0.0%	9796	1.00E+00	0.0%
13.72	6.69E-01	-19.7%	6405	6.54E-01	-22.5%
27.43	4.81E-01	-19.0%	4707	4.81E-01	-19.1%
41.15	3.47E-01	-14.8%	3445	3.52E-01	-13.4%
54.86	2.50E-01	-15.0%	2567	2.62E-01	-9.6%
68.58	1.78E-01	-16.7%	1857	1.90E-01	-9.7%
82.29	1.26E-01	-18.8%	1338	1.37E-01	-9.3%
96.01	8.75E-02	-22.0%	980	1.00E-01	-6.7%
109.72	6.02E-02	-27.4%	727	7.42E-02	-3.3%
123.44	4.08E-02	-36.5%	492	5.02E-02	-11.0%
137.15	2.73E-02	-45.5%	349	3.56E-02	-11.4%
150.87	1.80E-02	-60.4%	260	2.65E-02	-8.6%
171.50	9.33E-03	-94.8%	123	1.26E-02	-44.7%
205.70	2.88E-03	-191.3%	37	3.78E-03	-122.4%
240.00	8.01E-04	-451.4%	14	1.43E-03	-208.9%
274.30	1.98E-04	-710.2%	5	5.10E-04	-215.0%
308.60	4.37E-05	-48.8%			

Figure 8

TI-204 beta transmission through Aluminum absorbers

Table 9

TI-204 source with Iron absorbers 3/27/96

dead time = 6.1E-06

Rb = 63.92

Absorber thickness	Gross counts	time secs	Transmission	sigma T
0.00	76092	10	1.00E+00	5.17E-03
19.68	43649	10	5.58E-01	4.59E-03
39.35	24041	10	3.00E-01	4.20E-03
59.03	14661	10	1.79E-01	4.00E-03
78.70	6998	10	8.07E-02	3.82E-03
98.38	8727	20	4.72E-02	3.71E-03
118.05	5299	20	2.55E-02	3.69E-03
137.73	7020	40	1.41E-02	3.67E-03
157.40	5222	40	8.43E-03	3.67E-03
177.08	4124	40	4.96E-03	3.66E-03
196.75	5146	60	2.77E-03	
216.43	4405	60	1.20E-03	
236.10	4158	60	6.84E-04	
255.78	8277	120	6.43E-04	
275.45	7899	120	2.44E-04	
295.13	7670	120		

Monte Carlo Results

Absorber thickness	TI-204 expected	% difference	TI-204 EGS4 code	EGS4 Total	% difference
0.00	1.00E+00	0.0%	9741	1.00E+00	0.0%
19.68	5.13E-01	-8.9%	4855	4.98E-01	-12.0%
39.35	2.93E-01	-2.4%	2774	2.85E-01	-5.4%
59.03	1.68E-01	-6.7%	1624	1.67E-01	-7.3%
78.70	9.45E-02	14.6%	949	9.74E-02	17.2%
98.38	5.23E-02	9.7%	531	5.45E-02	13.4%
118.05	2.82E-02	9.8%	320	3.29E-02	22.5%
137.73	1.49E-02	5.4%	162	1.66E-02	15.1%
157.40	7.67E-03	-9.9%	82	8.42E-03	-0.2%
177.08	3.84E-03	-29.1%	47	4.82E-03	-2.8%
196.75	1.87E-03	-47.7%	16	1.64E-03	-68.4%
216.43	8.85E-04	-36.0%	4	4.11E-04	-66.5%

Figure 9

TI-204 beta transmission through Iron absorbers

Table 10

TI-204 source with Zirconium absorbers 3/27/96

dead time = 6.1E-06

Rb = 68.76

Absorber thickness	Gross counts	time secs	Transmission	sigma T
0.00	76384	10	1.00E+00	5.17E-03
12.98	46381	10	5.92E-01	4.63E-03
25.96	29496	10	3.69E-01	4.30E-03
38.94	19339	10	2.38E-01	4.09E-03
51.92	13102	10	1.58E-01	3.95E-03
64.90	9042	10	1.06E-01	3.86E-03
77.88	6384	10	7.20E-02	3.80E-03
90.86	8909	20	4.76E-02	3.71E-03
103.84	6421	20	3.18E-02	3.69E-03
116.82	9505	40	2.13E-02	3.67E-03
129.80	7116	40	1.38E-02	3.66E-03
142.78	8875	60	9.98E-03	3.66E-03
155.76	7332	60	6.74E-03	3.66E-03
168.74	6364	60	4.71E-03	3.66E-03
194.70	5185	60	2.23E-03	
220.66	9411	120	1.22E-03	
246.62	8611	120	3.82E-04	
272.58	8251	120		

Monte Carlo Results

Absorber thickness	TI-204 expected	% difference	TI-204 EGS4 code	EGS4 Total	% difference
0.00	1.00E+00	0.0%	9740	1.00E+00	0.0%
12.98	5.91E-01	-0.2%	5441	5.59E-01	-6.0%
25.96	3.87E-01	4.6%	3627	3.72E-01	0.8%
38.94	2.58E-01	7.7%	2463	2.53E-01	6.0%
51.92	1.71E-01	8.1%	1652	1.70E-01	7.1%
64.90	1.14E-01	6.9%	1102	1.13E-01	6.5%
77.88	7.48E-02	3.7%	786	8.07E-02	10.7%
90.86	4.88E-02	2.5%	494	5.07E-02	6.2%
103.84	3.16E-02	-0.9%	336	3.45E-02	7.7%
116.82	2.02E-02	-5.4%	233	2.39E-02	10.9%
129.80	1.28E-02	-7.5%	156	1.60E-02	14.1%
142.78	8.03E-03	-24.4%	96	9.86E-03	-1.3%
155.76	4.97E-03	-35.5%	64	6.57E-03	-2.6%
168.74	3.05E-03	-54.4%	35	3.59E-03	-31.0%
194.70	1.11E-03	-101.6%	13	1.33E-03	-67.0%
220.66	3.82E-04	-219.6%	4	4.11E-04	-197.5%
246.62	1.26E-04	-203.2%	2	2.05E-04	-85.9%

Figure 10

Tl-204 beta transmission through Zirconium absorbers

Discussion

The discussion below evaluates the results for each radionuclide, considering how the atomic number of the absorber and the energy spectrum of the beta particles affect the transmission.

Promethium 147 has a maximum beta energy of 0.2247 MeV, and was the lowest energy beta emitter used in this experiment. The transmission through aluminum, atomic number of thirteen, appeared to follow an exponential function fairly well out to approximately eighty percent of the range, having an experimental attenuation coefficient of $168.8 \text{ cm}^2/\text{gm}$ as observed in Figure 2. The experimental theory and the EGS4 code were in close agreement with the experimental data. Using iron, atomic number of twenty six, yielded poor results due, at least in part, to having only four data points in the experiment. Thinner absorbers could have avoided this problem but were not available. The experimental data indicates more beta particles pass through the material than predicted by the theory or the EGS4 code. This discrepancy could be in part due to the relatively higher atomic number which generates a larger fraction of bremsstrahlung, thus increasing the count at a greater absorber thickness. The experimental mass attenuation coefficient at eighty percent of the range was evaluated to be $147.8 \text{ cm}^2/\text{gm}$ as observed in Figure 3. The results of the transmission experiment with the zirconium absorbers, atomic number of forty, were nearly exactly as the expected theory and the EGS4 code predicted. The calculated mass attenuation coefficient was $215.2 \text{ cm}^2/\text{gm}$, which is slightly higher than that of the aluminum and iron.

The zirconium appears to have the highest mass attenuation coefficient corresponding with the largest atomic number as well, although no correlation can be made with confidence seeing as the iron's mass attenuation coefficient did not follow this pattern.

Thallium 204, emitting a maximum energy beta particle of 0.7634 MeV, showed very good results for all of the three absorbers. Using aluminum as the absorber, as shown in Figure 8, the experimental data agree quite well with the codes out to approximately seventy percent of the range, and then the two codes show relatively greater attenuation of the beta's emitted by the thallium. Again, this is due in part to the fact that the two codes do not take into account the production of x-rays generated from bremsstrahlung that interact within the detector, and the codes do not take into account the buildup of electrons as they pass through the absorber. The mass attenuation coefficient calculated for the aluminum absorber is $23.7 \text{ cm}^2/\text{gm}$, which is fairly reasonable for this higher beta energy spectrum impinging upon the absorber. More beta particles are transmitted through the absorbers generating a more gradual slope than was observed for the lower energy beta emitters. Iron again had very good agreement with the codes and yielded a mass attenuation coefficient of $30.5 \text{ cm}^2/\text{gm}$ (Figure 9). The thallium source using zirconium absorbers had perhaps the best results, following the codes quite well. A mass attenuation coefficient of $31.1 \text{ cm}^2/\text{gm}$ was calculated for this absorber (Figure 10). A correlation may appear to exist with atomic number when using a higher energy beta emitter, as seen in the increase in the slope while using thallium and the three absorbers.

Strontium/Yttrium 90, emitting a maximum energy beta particle of 2.28 MeV, was also used in the transmission experiment and the results are shown in Figures 5, 6 and 7.

Using aluminum as an absorber, the experimental data did not agree with the predicted values out beyond thirty to forty percent of the range. The data demonstrated greater attenuation of the beta particles than expected by the theory and the EGS4 code. This is mainly due to the setup of the experiment. As stated in the introduction, the experiment was setup for a collimated beam of beta particles to impinge upon the absorbers, while the theory and the EGS4 code assumed a pencil beam of beta particles. The difference in geometry's may account for the discrepancy between these results seeing that a collimated beam from a point isotropic source would appear to have relatively fewer beta particles impinging normally upon the surface because the beam tends to spread out as it approaches the absorbers therefore those beta particles at the outer edge of the cone will travel a greater distance through the absorber, and thus the appearance of greater attenuation through the absorber. The pencil beam appears as a mono-directional beam of beta particles with an infinitesimal diameter, and would have a greater transmission value through the absorbers. The calculated mass attenuation coefficient using the aluminum, iron, and zirconium absorber are 9.2, 7.9, and 8.5 cm²/gm, respectively.

Table 11. Mass absorption coeff. of beta particles in Al, Fe, and Zr, in cm² gm⁻¹

Radionuclide	Energy (MeV)	Aluminum	Iron	Zirconium
¹⁴⁷ Pm	0.2247	168.8	147.8	215.2
⁹⁰ Sr/Y	2.2839	9.2	7.9	8.5
²⁰⁴ Tl	0.7634	23.7	30.5	31.1

Conclusion

The results of this project supported the theory that the beta mass attenuation coefficient was accurately represented by the slope of an exponential function, but only for that particular region of the transmission curve that has a minimal absorber thickness. By fitting the data beyond 50% of the beta particle range this theory does not hold true. The theory generated by McCarthy (1995) and the EGS4 Monte Carlo code indicated that the transmission curve for a pencil beam was not accurately represented by an exponential function. The results of this experiment appeared to provide additional support to this assumption.

The average depth of penetration in the infinite medium appears to be a function of the electron energy and the associated atomic number of the absorber. The fraction of the electrons that backscattered from the absorber is a function of absorber thickness, and by assuming that the fraction backscattered from the foil is a constant, the integral form of the transmission was represented by equation (1).

Table 11 summarizes the behavior of the mass attenuation coefficient by varying atomic number and electron energy, but further research will need to be performed using additional sources and generating better statistical results than those presented for the iron experiment, seeing as a significant evaluation cannot be made based on poor statistics for the iron absorption experiment.

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Appendix A

Detector Setup Diagram

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