SAND2019-6715PE

Radiation Field Mapping and Filtering

Trevor Drouillard

Bryce Jones

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Introduction

Gamma Irradiation Facility

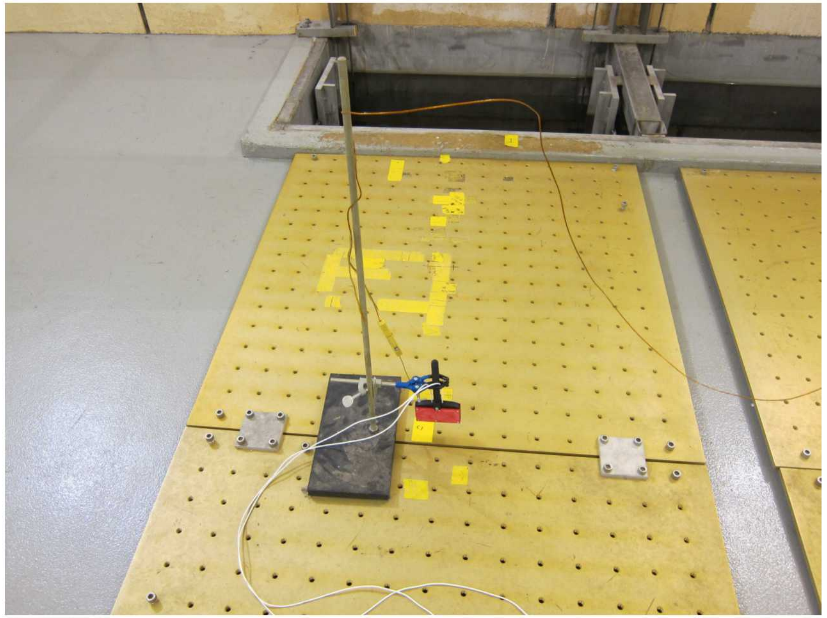
Elevator shaft and array at the GIF

Cobalt-60 source

Inside Cell 3 at the GIF

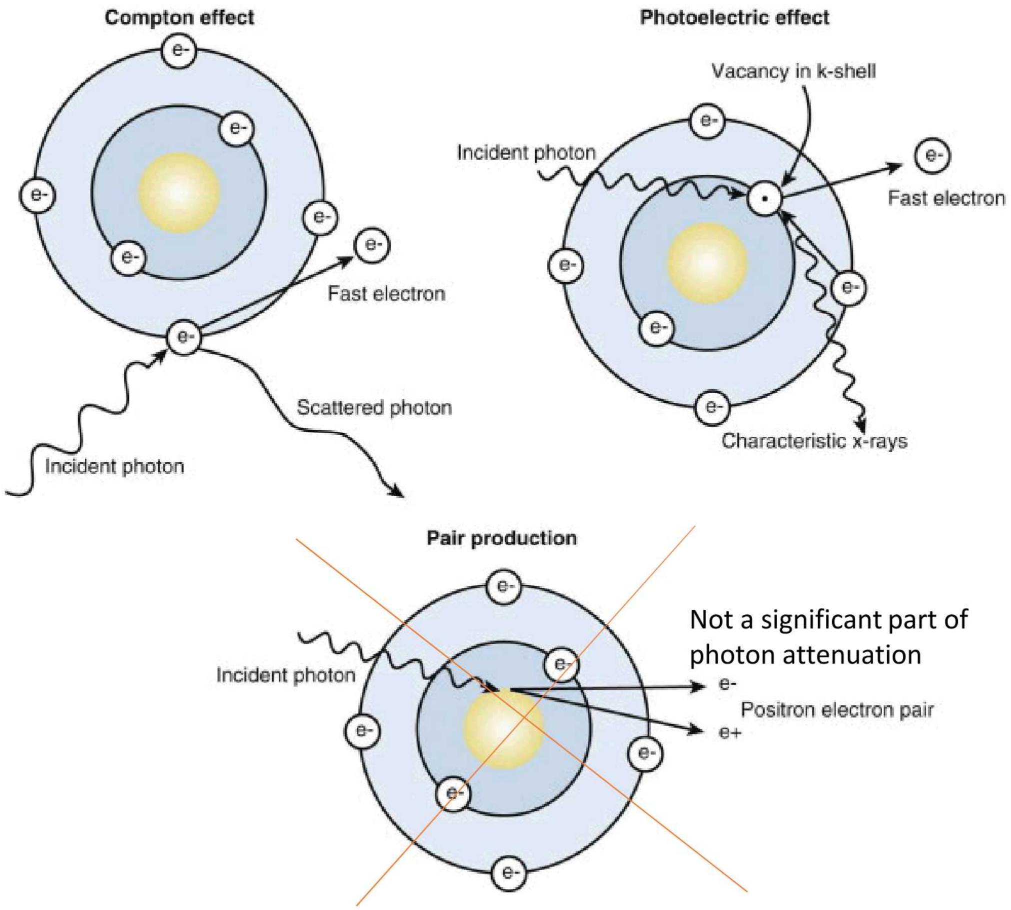
Objectives

- To test designs of filter boxes for high-fidelity gamma-ray tests of electronic parts
- Confirm computer model calculations done in a previous paper
- ‘Map’ the cell in terms of dual ion chamber ratio which implies the amount of scattering
- Determine our own best/worst filter combinations and evaluate how current standards and practices compare



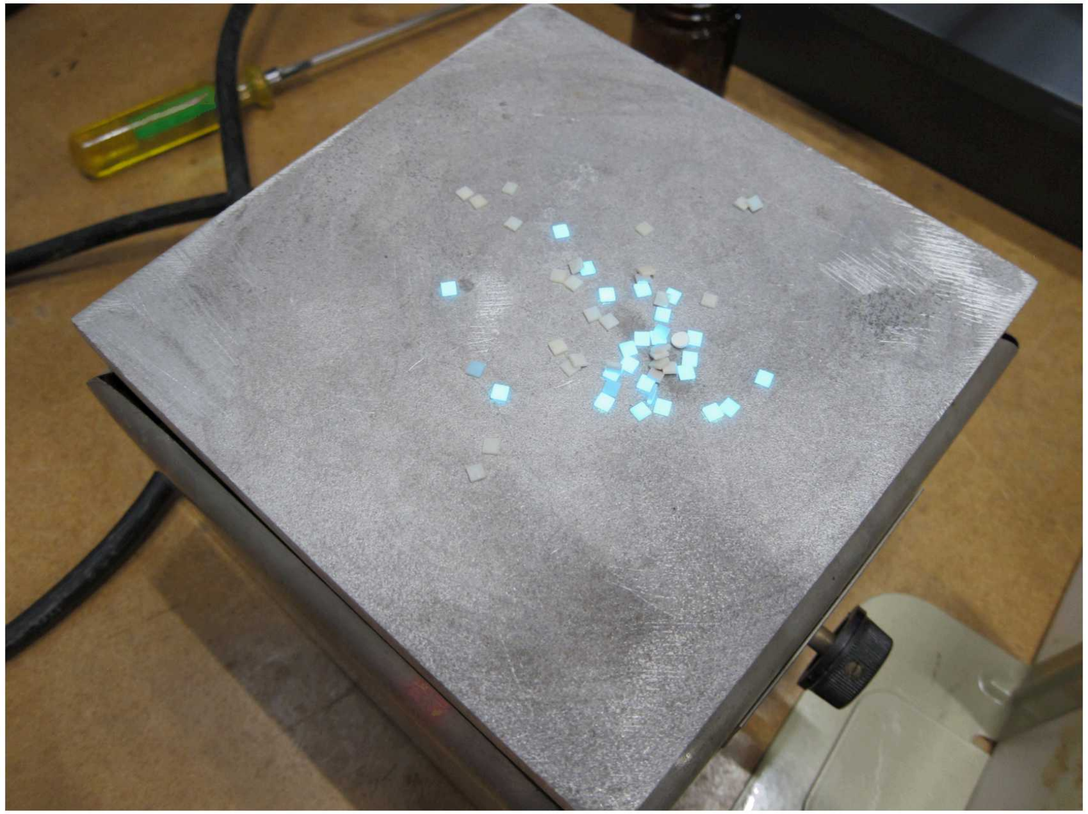
What is scattering?

- Co-60 : 1.17 MeV or 1.33 MeV with equal probability
- In essence, scattering refers to the deviation from straight line trajectory and a decrease in energy of the photons.
- Compton effect and photoelectric effect are the primary causes of scattering for our Co-60 source.



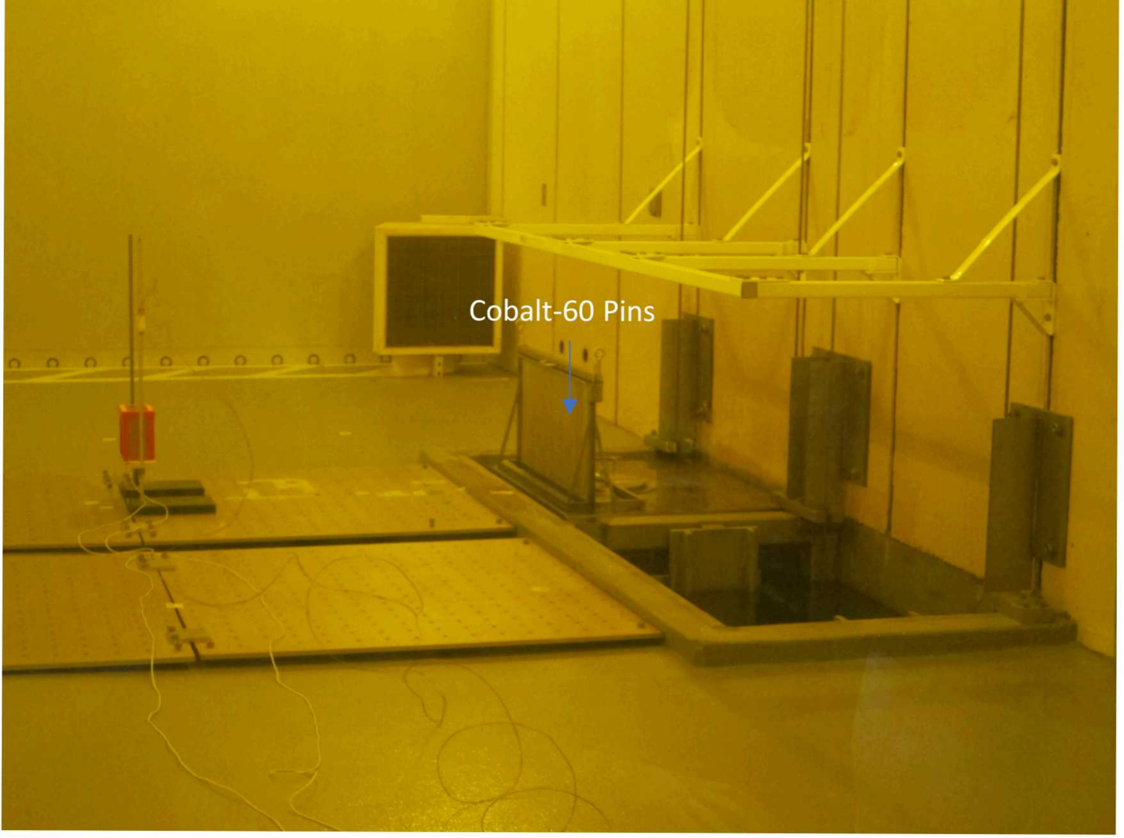
Why do we want filtering?

- Dose enhancement affects small samples and microelectronics the most as equilibrium dose rates cannot be established.
- Dose enhancement effects either increase or decrease the total absorbed dose at a location.
- We want to minimize the dose enhancement effects of low energy photons because they are a main source of errors for the TLD dosimetry.
- Metal combinations surrounding these samples/electronics help eliminate secondary particle generation therefore allowing for more accurate dose rates/total dose



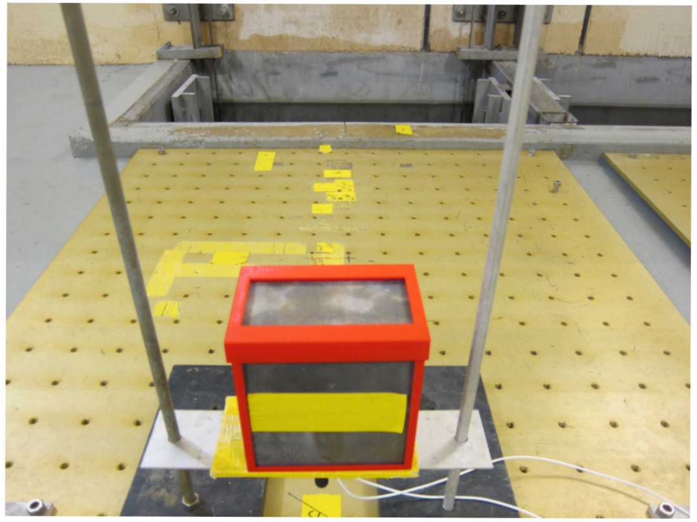
TLDs glow on hot plate

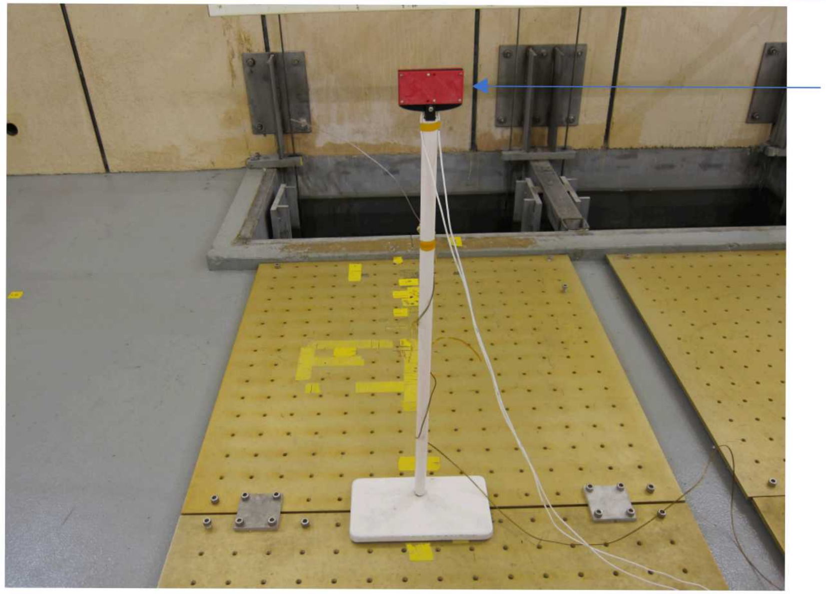
Experimental Setup



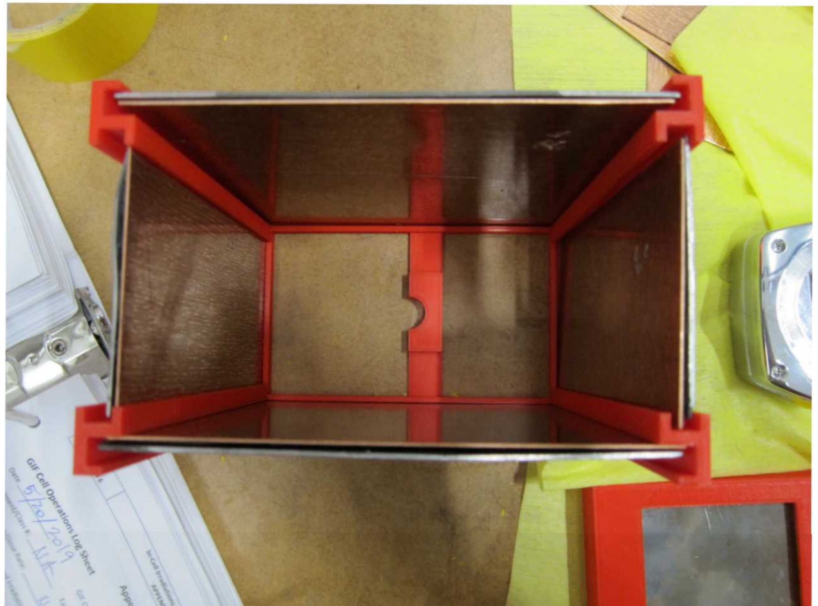
Electrometer

Assembled filter box facing elevator



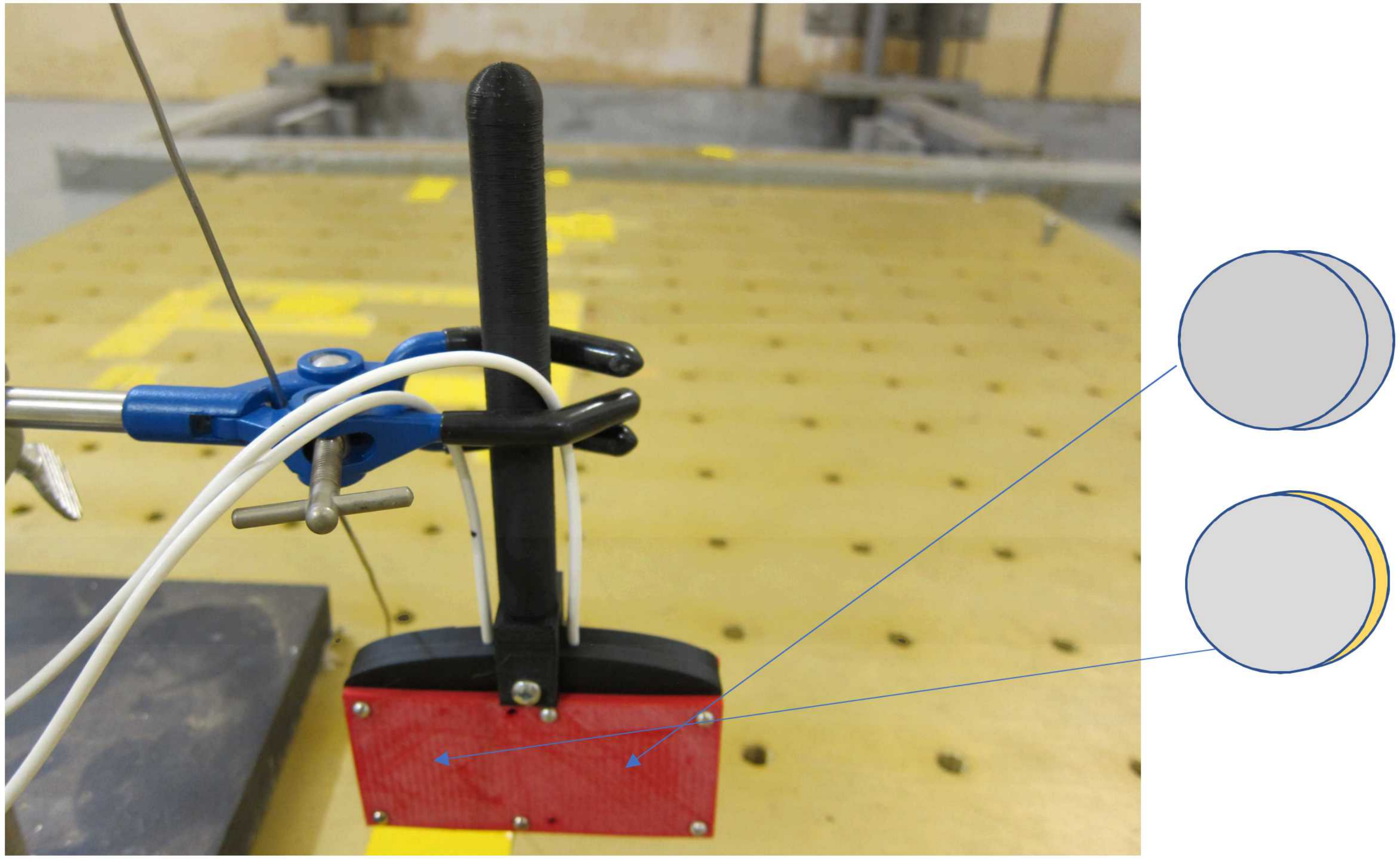


Dual ion chamber



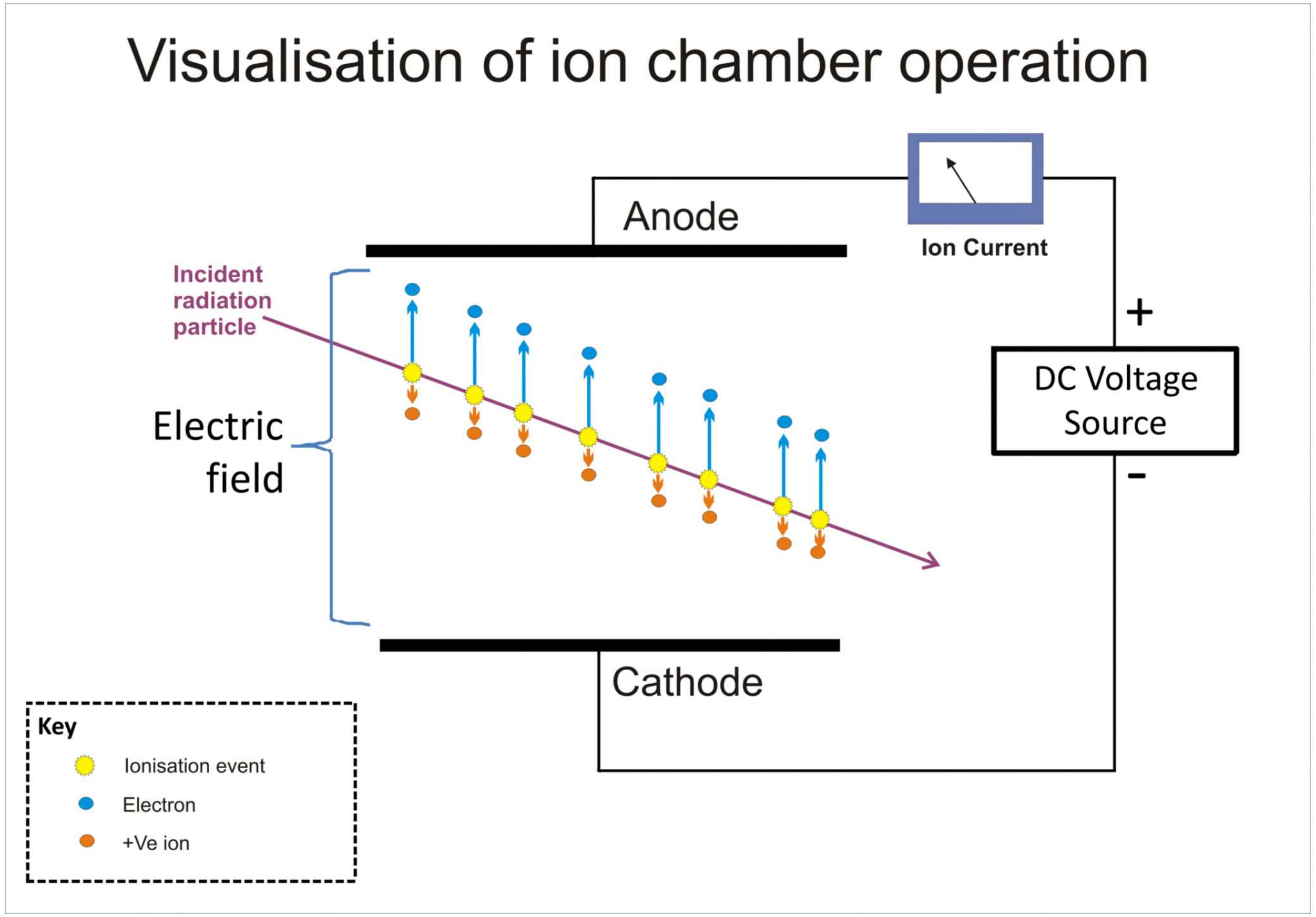
Gold/Aluminum Dual Ion Chamber

Position	Chamber 1 Current	Chamber 2 Current	Difference	Notes
C1	37.8	38.2	1.06%	Facing Source
C1	38.5	37.6	2.39%	33° Angle
C3	5.49	5.7	3.83%	



Thin gold sheets placed on one side of aluminum disks

Ionization chamber in action

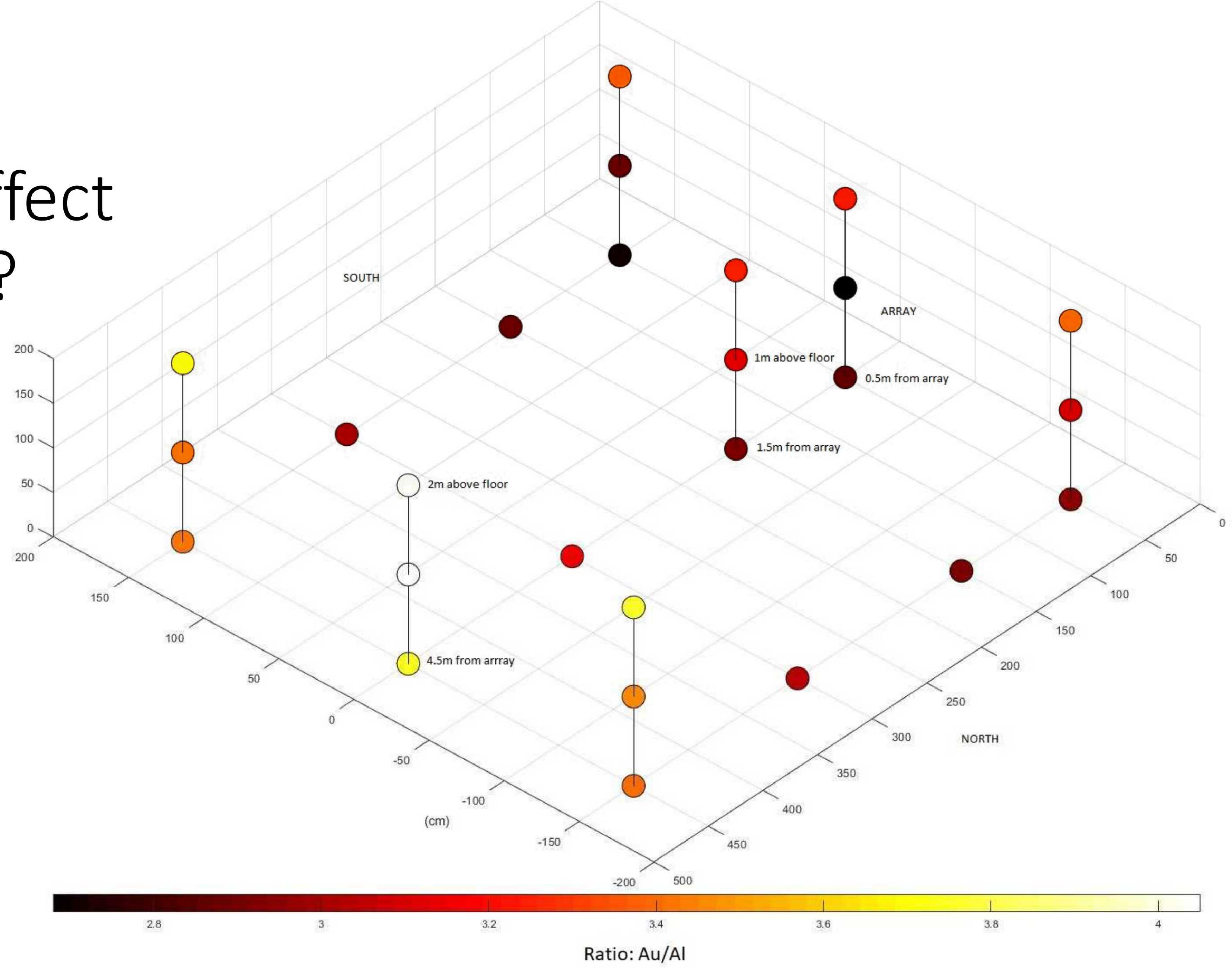


- Low energy photons are more likely to Interact with the gold than the aluminum

- Gold will much more readily absorb the photons, releasing photoelectrons which subsequently interact with the air generating charge which is measured as current.

Thus from a ratio of the two currents we can comparatively determine which environments contain more low energy photons.

How does location effect scattering?



Results of filter combination testing

Material	Thickness (mm)
Copper	0.81
Thin Aluminum	1.59
Thick Aluminum	4.13
Lead	1.4
Tungsten	1.09

α	Color Scale
< 1.80	
1.80 - 1.89	
1.90-1.99	
2.00 - 2.09	
2.10 - 2.19	
> 2.19	

		Outside Material								
		None	Thin Al (1)	Thick Al (1)	Cu (1)	Cu (2)	W(1)	W(2)	Pb (1)	Pb (2)
Inside Material	None	2.89					2.00	1.87	1.97	
	Thin Al (1)		X		2.91		2.08		2.07	
	Thick Al (1)			X			2.17		2.16	
	Cu (1)		2.90			X	2.05		2.06	
	Cu (2)				X	X			2.11	
	W(1)	2.00	2.01	2.02	2.01		1.87	X	1.84	
	W(2)	1.87					X	X	1.76	
	Pb (1)	1.97	1.97	1.97	1.96	1.96	1.82	1.75		X
	Pb (2)								X	X

How does this compare to current filter designs?

- Currently ASTM Standard is ASTM 1250 (1.0-1.5 mm Pb and 0.7-1.0 mm Al)

2.07

Pb outside

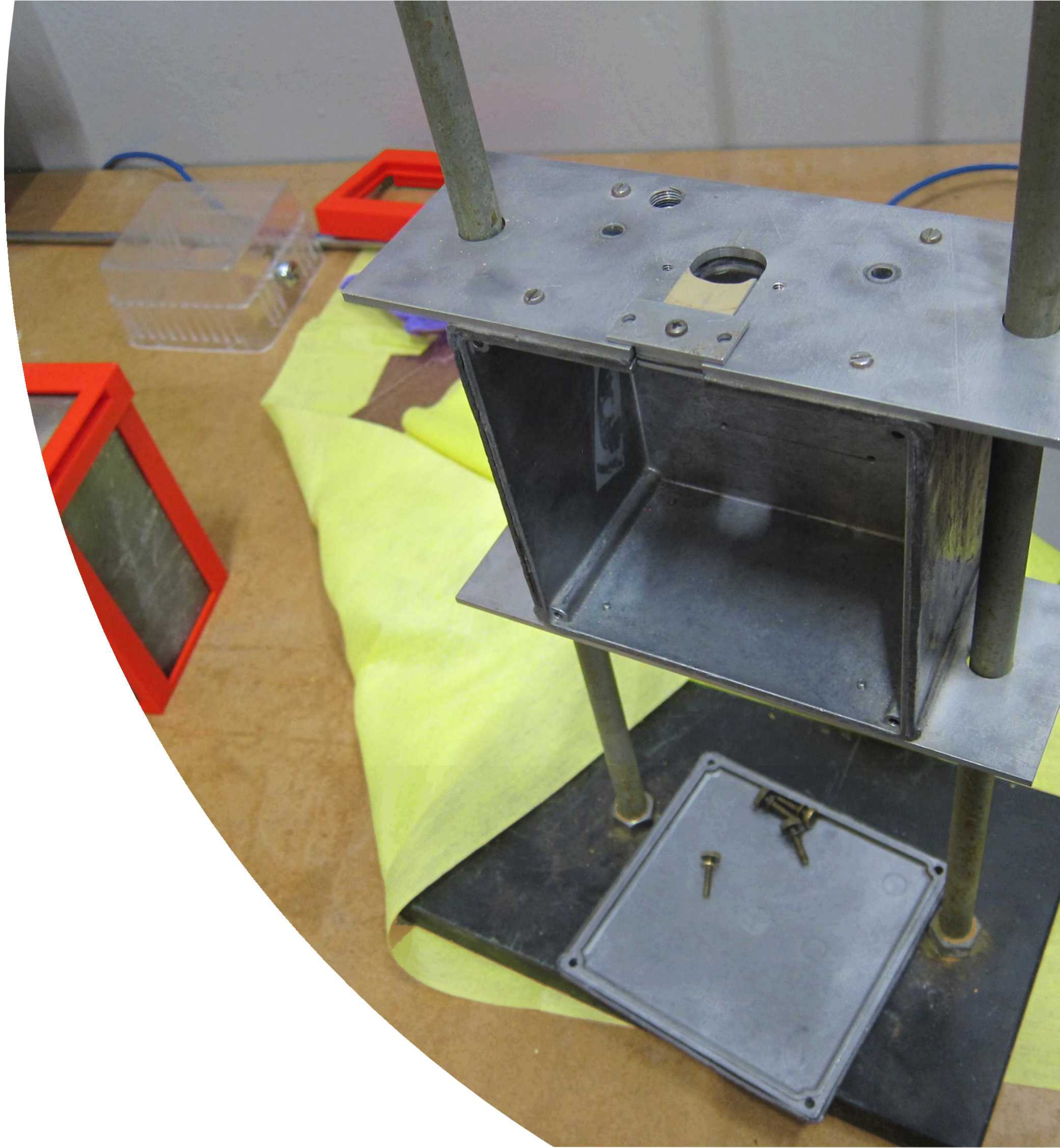
- Filter combination testing suggests that thicker High-Z materials in combination (in our case 2*1.09mm W and 1*1.4mm Pb) reduce scattering the most

X	1.76
1.75	

Pb outside

- If we want to move away from lead, two sheets tungsten proved effective on its own

1.87



Hi-Z /Low-Z and do we need Low-Z?

- For *every* combination the Low-Z to High-Z gradient out performed standard gradient.
- Adding a Low-Z material either shows no significant improvement to standalone High-Z or increases scattering.

Material Combinations		Figure of Merit, α		Difference (Reverse minus Standard)
Material 1	**Material 2**	**Standard Gradient**	**Reverse Gradient**	
Cu(1)	Thin Al(1)	2.91	2.90	**-0.5%**
W(1)	Thin Al(1)	2.08	2.01	**-3.4%**
W(1)	Thick Al(1)	2.17	2.02	**-7.2%**
W(1)	Cu(1)	2.05	2.01	**-2.1%**
Pb(1)	Thin Al(1)	2.07	1.97	**-5.5%**
Pb(1)	Thick Al(1)	2.16	1.97	**-9.6%**
Pb(1)	Cu(1)	2.06	1.96	**-4.8%**
Pb(1)	Cu(2)	2.11	1.96	**-7.2%**
Pb(1)	W(1)	1.84	1.82	**-1.1%**
Pb(1)	W(2)	1.76	1.75	**-0.5%**

*Reverse gradient performs better

Material Selection		Figure of Merit
Outside	**Inside**	
Pb(1)	**None**	1.97
	Thin Al(1)	2.07
	Thick Al(1)	2.16
	Cu(1)	2.06
	Cu(2)	2.11
	W(1)	1.84
W(1)	**None**	2.00
	Thin Al(1)	2.08
	Thick Al(1)	2.17
	Cu(1)	2.05

*Adding low-Z increases ratio

How do these results compare to the previous paper?

Table 4 – GIF Cell 3 Dose Enhancement Factors for Various Filter Boxes

Filter Box Details	Density Thickness (g/cm²)	DEF in Active Silicon Layer	Dose Reduction Ratio
1.587 mm Pb / 0.686 mm Cu	2.42	1.25	0.53
1.587 mm Pb / 0.813 mm Cu	2.53	1.22	0.52
1.587 mm Pb / 1.016 mm Cu	2.71	1.27	0.53
1.981 mm Pb / 0.813 mm Cu	2.98	1.24	0.51
2.387 mm Pb / 0.813 mm Cu	3.44	1.22	0.49
3.175 mm Pb / 0.813 mm Cu	4.33	1.27	0.49
1.5875 mm Bi / 0.813 mm Cu	2.28	1.32	0.57
3.175 mm Bi / 0.813 mm Cu	3.82	1.31	0.52
4.7625 mm Bi / 0.813 mm Cu	5.37	1.33	0.49
1.016 mm Ta / 0.813 mm Cu	2.39	1.25	0.54
1.270 mm Ta / 0.813 mm Cu	2.81	1.23	0.52
1.524 mm Ta / 0.813 mm Cu	3.23	1.25	0.52
2.032 mm Ta / 0.813 mm Cu	4.06	1.19	0.48
1.524 mm W / 2.540 mm Al	3.63	1.32	0.54
1.524 mm W / 3.175 mm Al	3.80	1.40	0.57
1.524 mm W / 4.064 mm Al	4.04	1.36	0.55
1.524 mm W / 0.686 mm Cu	3.56	1.20	0.49
1.524 mm W / 0.813 mm Cu	3.67	1.20	0.49
1.524 mm W / 1.016 mm Cu	3.85	1.22	0.50

		Outside Material								
		None	Thin Al (1)	Thick Al (1)	Cu (1)	Cu (2)	W(1)	W(2)	Pb (1)	Pb (2)
Inside Material	None	2.89					2.00	1.87	1.97	
	Thin Al (1)		X		2.91		2.08		2.07	
	Thick Al (1)			X			2.17		2.16	
	Cu (1)		2.90			X	2.05		2.06	
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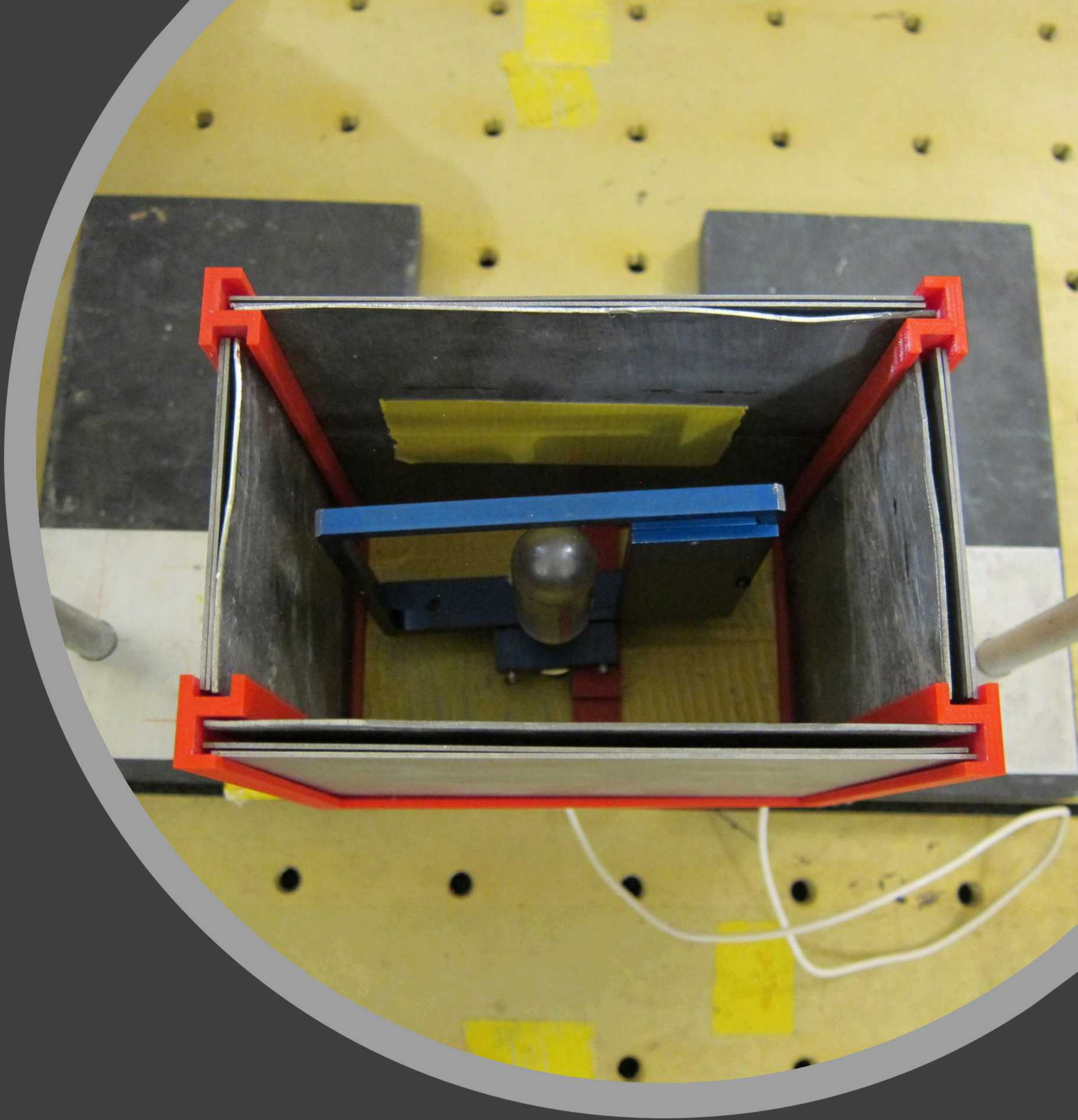
	W(1)	2.00	2.01	2.02	2.01		1.87	X	1.84	
	W(2)	1.87					X	X	1.76	
	Pb (1)	1.97	1.97	1.97	1.96	1.96	1.82	1.75		X
	Pb (2)								X	X

- Lead performed marginally better than tungsten in some cases in our experiment while tungsten/copper performed the best in the model.
- Tungsten/thick aluminum performed the worst out of the standard combinations as predicted by the model
- We still need model calculations for reverse gradient and High-z only combinations to see how our work compares overall.

Conclusion/Next Steps

- High-Z/Low-Z standard has demonstrated to be less effective than reverse gradient.
- Combination of lead and tungsten was most effective and greatly outperformed standard lead/aluminum combination.
- The ASTM Standard should be reviewed.
- We need further computer modeling and tests using combinations of High-Z materials and reverse gradients, and possibly three layer combinations.



Acknowledgements

- Don Hanson
- Tom Quirk
- David Vehar
- Maryla Wasiolek
- DTRA
- SNL
- USNA