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How Does the Type and Thickness of a Material Affect its Ability to Deflect Alpha and Gamma Radiation?

Research Question

Of the two materials, paper and aluminum, which will block the most alpha and gamma radiation from a uranium/thorium sample and what are some of the properties of that material that allow it to do so?

Introduction

Due to the nature of atoms, we are constantly in contact with and bombarded by radiation. With the continual decay of larger atoms all around us, they are always an incredible quantity of alpha, beta and gamma particles moving all around us. The background radiation we all experience every day has almost no effect on us and our health, but in areas of high radiation, such as X-ray machines and nuclear power plants, it's important to be equipped with a way to minimize that radiation. The most common way is through a simple barrier, such as the Hazmat suits or the lead aprons worn in X-ray rooms and dentistry clinics. Barriers like those help ensure that a minimal amount of radiation is experienced by the person themselves. Deciding what materials to use is an important procedure, as different materials block different quantities of radiation. This investigation is an example of such a test to see what materials would be most desirable for that application. When I was designing my IA, I wondered what sort of processes researchers went through to determine the effectiveness of different materials at blocking radiation and I decided to do a similar analysis myself.

For this investigation, a sample of Uranium and Thorium are being used to test the effectiveness of my materials at blocking radiation. The reason I am using two different materials is entirely based on what I have access to, and using of them individually would have given me small changes in counts per minute, making it harder to make a diagnosis about the material's effectiveness. I think it would be interesting to use more radioactive substances to test even better materials, though for my experiment, these were the materials I was able to acquire. Both Thorium[1] and Uranium[2] emit alpha and gamma particles when they decay, meaning that they give off a similar radiation signature that I can test. Alpha particles are essentially a Helium atom (2 protons and 2 neutrons) emitted by the decaying atom while gamma particles are energy rays (photons)[3].

[1] "Radionuclide Basics: Thorium." EPA, Environmental Protection Agency, 8 May 2017
[2] "Radionuclide Basics: Uranium." EPA, Environmental Protection Agency, 11 Jan. 2018,
[3] "Radioactivity." Pass My Exams

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Prediction

Looking at my current list of materials, I believe that aluminum would perform the best. This is because I think that closely connected aluminum atoms will block and absorb radiation better than than the loosely connected cellular structures of paper. This applies to both the alpha particles and the gamma particles. The alpha particles should find less space between the aluminum atoms to pass through (where in paper they could slip between the cells) and the gamma rays will be absorbed by the aluminum atoms as energy (again, they could just pass between the cells of the paper). Aluminum, since it is a metal (more specifically a metalloid, but it has similar properties), also will absorb energy better due to metallic properties, which goes to make it an even better deflector.

Variables

Table 1: Variables	
Variable Type	**Variable Name**
Independent	**Thickness and Type of the Absorbent Material** ● Will be measured in 6 intervals of increasing 1.59mm ($\frac{1}{16}$")
Dependent	**Radiation Detected on the Opposite Side of the Absorbent Material** ● Will be measured with a digital radiation sensor
Controlled	**Radiation Emitted by the Uranium Sample** ● This for the most part controls itself. The decay of the uranium and thorium does not change enough to affect the outcome of my experiment (according to the EPA website, their half lives are in the billions of years) **Distance Between the Sensor and the Sample** ● A set distance will be assigned at the beginning of experimentation that will remain constant. Since distance does affect the amount of radiation detected, the separation distance will be kept to a small 1” **The Mass of my Materials** ● Explained further in my materials section, I will not be adding or removing masses to my experiment, and so the mass of each of my components are constant and controlled.

Materials

For my materials, I didn't find or include masses for any of my substances. Mass was constant throughout my experiment for each of my components, and the mass values of my materials and tools were insignificant. Furthermore, I wasn't able to get the exact mass of my uranium and thorium samples because they were sealed in a container.

Also, most of the length measurements I did while performing my experiment were done in inches. In writing this paper, I have converted those inch values to millimeters to conform to SI units. For instance, I used 4"x4"x $\frac{1}{16}$" Aluminum sheets in my experiment, but in my materials table they are reported as 101.60mm x 101.60mm x 1.59mm Aluminum sheets. This conversion has no bearing on my experiment, I only mention this to give some rationale to the odd measurement values I use throughout this paper.

The uncertainties for tools displayed below are all from the tool's manufacturer. The Aluminum sheet measurements were measured with a height gage. The uncertainty for its length and width measurements was one I also gave to its thicknesses. The Aluminum I used was scrap metal meaning I could not find the company who made it. The uncertainty of the height gauge I used was greater than the uncertainty of a company making these pieces of sheet metal (making it a sort of maximum uncertainty), and with that rationale, I made it the uncertainty for my Aluminum thickness.

Table 2: Materials

Material	Quantity	Uncertainty
Digital Calliper[4]	1	±0.01 mm
Vernier Digital Radiation Sensor[5]	1	(±10% $\frac{counts}{minute}$)
101.60mm x 101.60mm x 1.59mm Aluminum Sheets	1	±0.01 mm
101.60mm x 101.60mm x 3.18mm Aluminum Sheets	3	±0.01 mm
Uranium Sample	1	
Thorium Sample	1	
Masking Tape Roll	1	
Sheets of paper	≈50	
Hardback Chemistry Textbooks	4	

[4] "Electronic Digital Caliper." Think MBC Cosmetic Tattoo
[5] "Digital Radiation Monitor." Vernier

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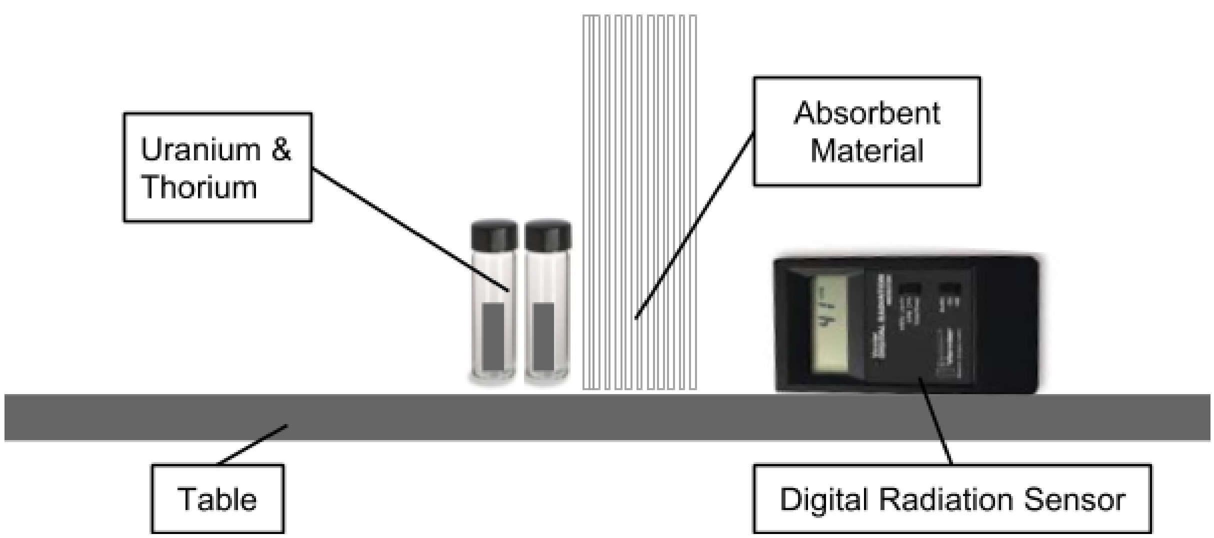
Safety

Even though my experiment is related almost entirely to radioactivity, my experiment is very very safe. According to the EPA website for uranium, "Uranium decays by alpha particles. External exposure to uranium is therefore not as dangerous as exposure to other radioactive elements because the skin will block the alpha particles." This also applies to Thorium due to their similar processes of decay. Furthermore, the samples of Uranium and Thorium I am using are incredibly small, further diminishing their ability to cause any harm. Even with that all said, I will be sure to wear full protective clothing during my experiment. I will also never have to touch the samples directly, due to them being sealed in vials.

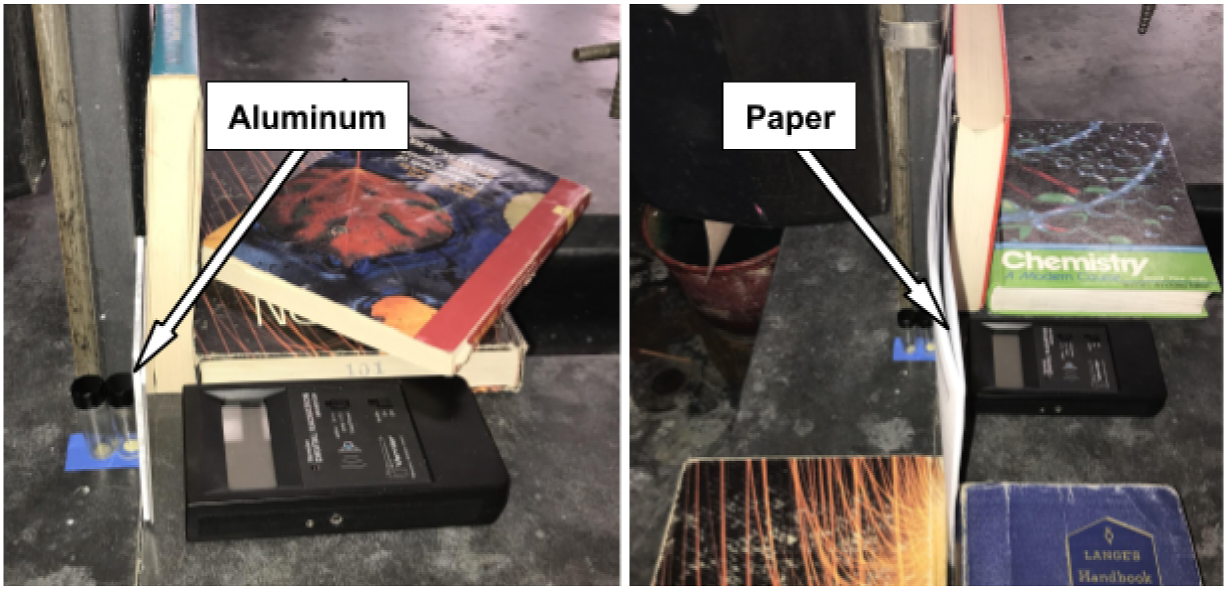
Outside of my samples, I will take some safety precautions with my Aluminum plates. Aluminum can be dangerous if ingested or if a shard gets under your skin. I am also machining my own Aluminum plates, and machining anything comes with its own risks. When making the plates, I will follow all metalshop protocols, ensuring that I wear also protective clothing and that I use all the tools correctly. During the course of making the plates, I will also round out all of the edges on my plates so that they will not be able to cut me while I perform my experiment. Doing all this ensures that the risk is very minimal.

All my other materials are almost entirely risk free, and as long as I am not intentional about doing any dangerous, there is no risk from anything else.

Method



Graphic 1: A physical diagram of my experiment.



Graphics 2&3: Real photos of my setup

In my experiment, the absorbent material extends outwards to block radiation coming around the side. Masking tape is used to hold both the samples and the digital radiation sensor at a constant position (1” from each other). Chemistry textbooks were positioned to hold the paper in an upright position (they were placed on each side of the paper sheets as to not interfere with the radiation’s ability to travel directly through the sample to the sensor). For my experiment, I used paper from my classroom and then personally constructed squares of aluminum (of different thicknesses) in my metalshop for my experiment. All other materials were available in my classroom. As mentioned before, my measurements were initially done in inches for my supplies but they have been converted to SI units for the purpose of keeping to the International Baccalaureate’s standard of measurement.

Procedure:

1. Set the radiation sensor to “Counts per Minute.”
2. Turn the radiation sensor on and wait until it makes a loud beep (it will beep softly but the louder beep is an indication that it’s found an average count per minute value).
3. Record the background radiation on a data table.
4. Repeat steps 2-3 three times to get an average background radiation.
5. Tape the Uranium and Thorium samples to a spot in the table.
6. Using the measuring device, mark a line 25.4cm (1”) away from the samples and tape the digital radiation sensor to that spot.
7. Place the chemistry textbooks on either side of the sensor and use them as a clamp to hold paper and aluminum. These are simply used to hold the paper and aluminum

upright, and as long as they aren't in the way of allowing the radiation to pass to the sensor, their positions are insignificant.

8. Stack papers together until they are 1.59mm thick (Use measuring device to verify) and place that right up against the samples between the samples and the sensor.
9. Turn the radiation sensor on and wait until it makes the loud beep
10. Record the counts per minute in a data table
11. Repeat steps 8-10 three times to get three trials, use those trials to get an average.
12. Repeat steps 8-11 for 3.18mm, 4.77mm, 6.36mm, 7.95mm and 9.54mm
13. Repeat steps 8-12 for aluminum instead of paper.

Results

Table 3: Radiation Penetrating Each Material

TRIAL #	Radiation experienced through each medium (±10% counts/minute)												
	Back-ground Radiation	Paper (±0.01 mm)						Aluminum (±0.01 mm)					
		1.59	3.18	4.77	6.36	7.95	9.54	1.59	3.18	4.77	6.36	7.95	9.54
1	19	55	51	39	30	26	25	42	31	27	28	23	24
2	22	59	44	35	29	25	27	41	31	27	29	24	25
3	20	61	47	41	27	29	35	43	34	25	27	25	23
Avg	21	58.3	47.3	38.3	28.7	26.7	29	42	32	26.3	28	24	24

For the graphs of this data displayed below, I decided to add a logarithmic trendline. My rationale for this was mostly based on how closely the data fit compared to other types of trendlines. I would have thought that an exponential curve would have fit better, that thought being mostly predicated around nuclear decay's relationship with exponential equations. I realize now though that I'm not directly measuring decay, more just radiation's ability to pass through a medium, and so having a logarithmic trendline is both fine and seemingly more accurate.

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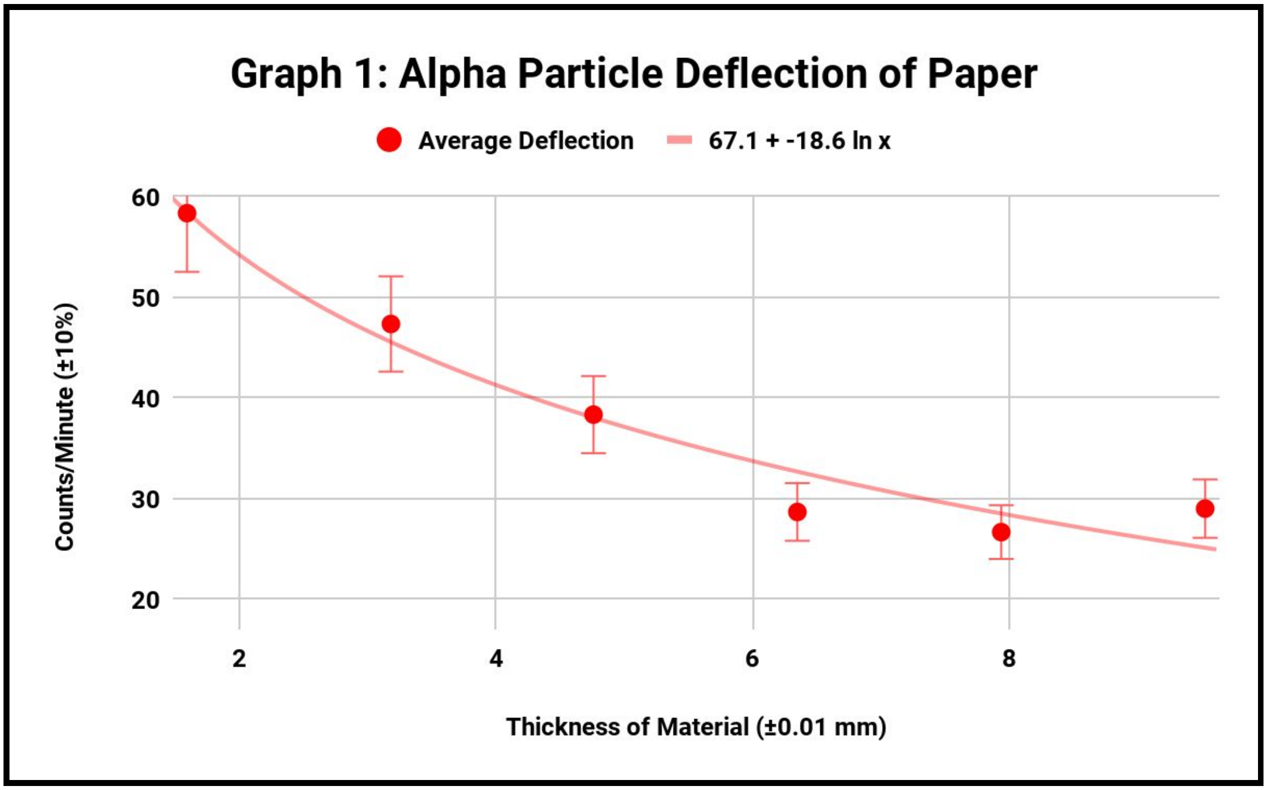

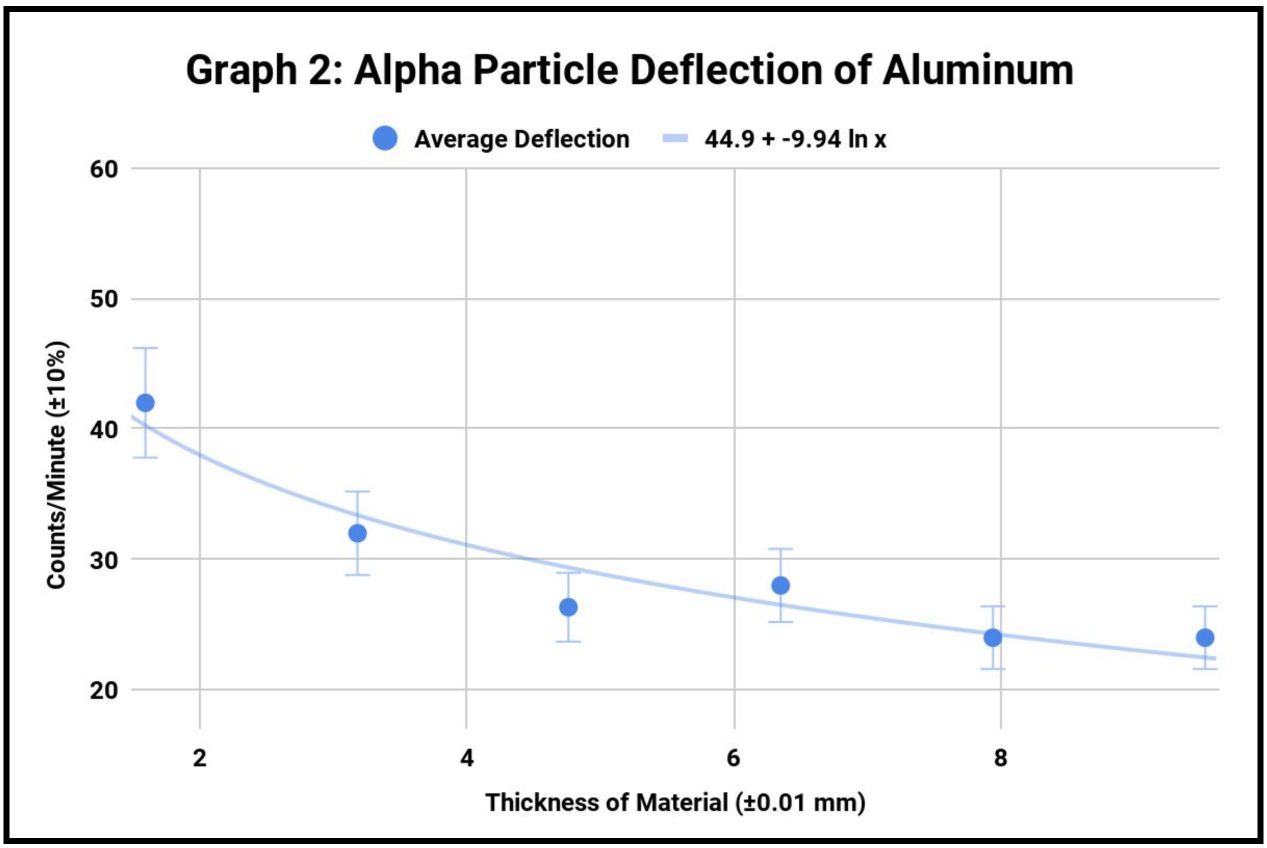

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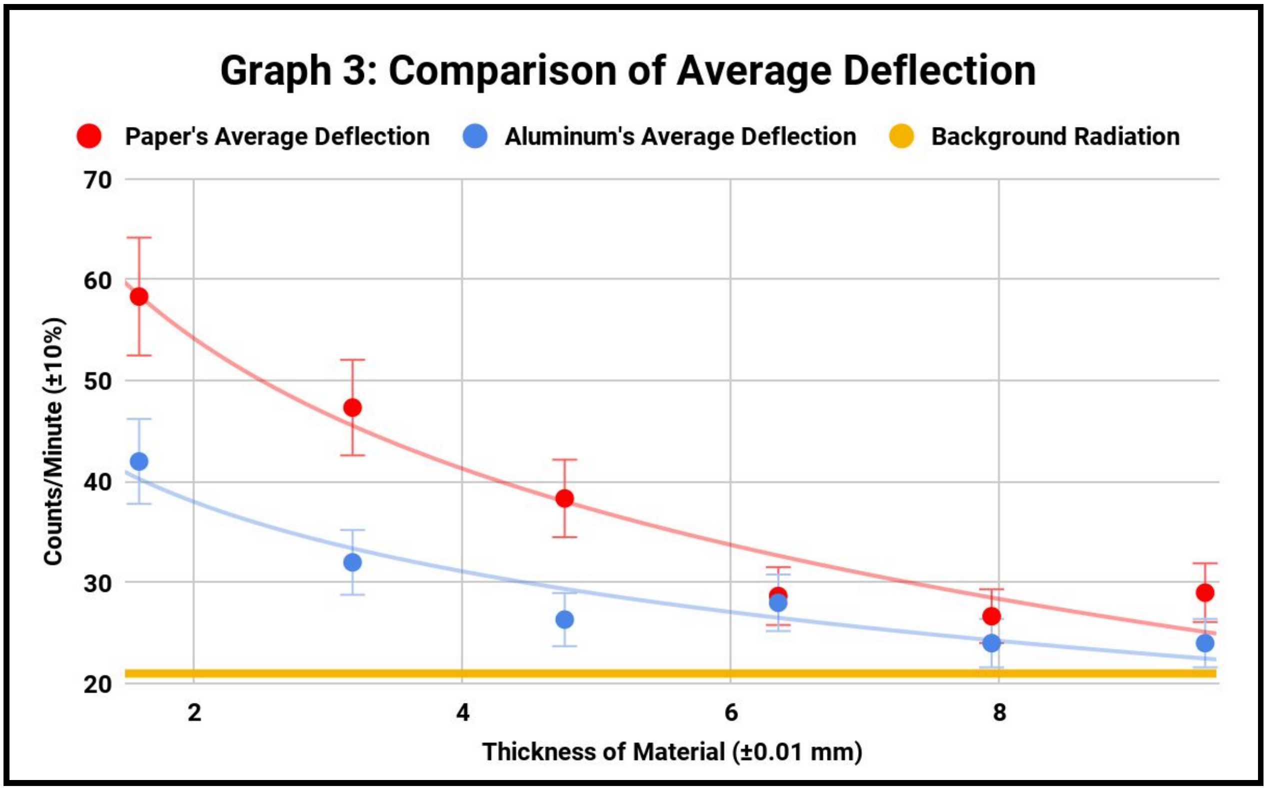
Data Analysis

With these two sets of data, I can set them next to each other to compare:



At about 9.54mm (⅜”), the radiation that passes through the aluminum and paper samples both converges to about the background radiation, showing that at that point, the materials are so thick that the relatively small amount of radiation released from the uranium/thorium sample is too little to pass through. Before that however, it is apparent that aluminum does a much better job at deflecting the alpha particles than paper does, as evidenced by the much smaller starting value and also the fact that the line of average values for aluminum always stayed below the line for paper. As I stated in my hypothesis, I believe this is because of the structure of each of these materials. Paper is made up of cellular like structures that on the molecular level are very open. Aluminum on the other hand is made of of tightly knit aluminum atoms that would leave less space to allow radiation to pass through.

I was intrigued by how close paper was to aluminum however, I didn’t expect them to be as close as they were and I did have a hypothesis about why that was. Since I used sheets of paper, the radiation had to pass through different mediums on it’s way to the sensor. I think that going from air to paper to air to paper had an effect on the radiation’s ability to travel and actually added to the material's ability to stop radiation. An interesting future experiment might include an analysis about how radiation acts around a solid block of a material and many touching sheets of that same material. Other future improvements and investigations could examine how atomic structures affect radiation transfer through a material or maybe even look at how materials retain radiation and how that could be a concern when using it as a barrier against radiation.

Evaluation

All of my measured uncertainty within my experiment was made up of the uncertainty from the manufacturers of the tools I was using. For measurement, I used a digital calliper that had an uncertainty of ±0.01 mm, and the digital radiation sensor I was using had an uncertainty of ±10% counts/minute. In my experiment I noticed a jump in both of my lines, which was weird because it went against my data's general consensus that more material means less radiation. Below is a collection of random error that I identified beforehand and the steps I took to minimize that error.

Table 4: Error

Potential Source of Error	Description/ Effect	Significant?	Attempt to Minimize
The placement of the uranium and thorium samples and their angle/proximity to the sensor	Radiation from the samples directed to the sensor at an angle would have been harder to detect.	**No**, the sensor area was large enough to pick up radiation from slight angles.	The samples and the sensor were lined up as straight as possible from each other.
Some radiation from the samples seem to leave a residual on my materials.	After using some of the aluminum plates for a while, I would see higher radiation values that would disappear once I replaced that plate with a new one.	**Yes**, and the effect of that error can be noticed on my graphs where the line moves back upwards as if more radiation is somehow being detected even though the thickness increased.	Materials were traded out after a few trials with newer ones.

Some radiation could have gotten around the edges of my material.	I don't know how likely it is that the radiated particles could have gone around on abject, but especially with my Aluminum, which was kind of small, I think there was a chance that something like that could happen.	**No**, I don't think radiation can really turn corners and if some did get around, I don't think it would have had a profound effect. I also had textbooks lining each side of the deflector and it would have had to go around those too.	I tried to use the largest area possible for my deflectors.
The output radiation of my simples was still very small and could have easily been affected by outside sources.	Even by utilizing both Thorium and Uranium, my radiation output of those amount I had was still small and so small environmental factors like background radiation (which, at that level, if there's variation then it can be disastrous) and the area I was in.	**Sort of**, my radiation were samples were still strong enough to show a trend, there probably was an effect but it didn't prevent me from being successful in my data collection.	I got more than one radioactive sample, which probably helped but it wasn't the most ideal situation in my own opinion for trying to see a greater shift in radiation detection.

Citations

"Digital Radiation Monitor." Vernier, www.vernier.com/products/sensors/radiation-monitors/drm-btd/.

"Electronic Digital Caliper." Think MBC Cosmetic Tattoo, mbccosmetictattoo.com.au/product/electronic-digital-caliper/

"Radioactivity." Pass My Exams, www.passmyexams.co.uk/GCSE/physics/alpha-beta-gamma-rays.html.

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