Neutron Shielding Properties of 3D Printing Filaments

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Motivation

3-D printers have improved significantly as time has passed. This has allowed the cost of printers to go down and has made them more commercially accessible. The increasing accessibility of 3D printing has allowed more and more engineering disciplines to incorporate additive manufacturing. Nuclear engineering is no exception since the costs for any sort of nuclear reactor and apparatus is still quite high, and the ability to create parts that can protect against radiation and be made on-site is very valuable. This research project determined the neutron shielding properties of readily available plastic filaments for 3D printers.

Objectives

Investigate the effectiveness of commercially available 3D printed plastics as additively manufactured neutron radiation shield.

Materials and Process

The procedure was simple in that the plastic was placed in front of a neutron beam and the neutrons that passed through were counted by a detector. The plastic was printed into cylinders thirteen centimeters long using a MakerGear M2 3D printer. They were then cut using a hand saw and sanded down such that they have an even thickness throughout. This was done for two sets with each filament: acrylonitrile butadiene styrene (ABS) ($C_8H_8{\cdot}C_4H_6{\cdot}C_3H_3N$), polylactic acid (PLA) ($C_3H_4O_2$), glycol-modified polyethylene terephthalate (PETG) ($C_{10}H_8O_4$), and nylon 66 ($C_{12}H_{22}N_2O_2$). They were then placed in a hole that goes through two sets of borated polyethylene blocks and positioned in front of a beam port in a canister which houses a plutonium-beryllium neutron source. The neutron source was then raised to the level of the beam tube and the neutrons that passed through were counted using a neutron sensitive lithium iodide scintillation detector for a period of five minutes. The process was then repeated between one and ten centimeters in thickness of the plastic shielding in front of the source. The neutron detector itself had a seven inch polyethylene ball around it so that the higher energy neutrons that would normally pass through the detector would slow down and interact with the detector.

Figure 1: The experiment setup. From left to right: beam stop, neutron detector, borated blocks and cylinders, radioactive source and container.

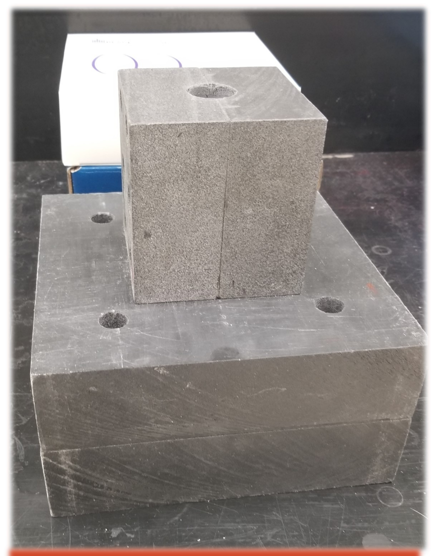

Figure 2: Borated polyethylene blocks which house the plastic cylinders. The hole at the top goes all the way through to allow the neutron beam to pass.

Results

Qualitatively, ABS is the easiest to cut and shape because it is the softest of the plastics and has the ability to be dissolved by acetone which, when joining two pieces together, is very convenient. PLA was the hardest to work with because it is the hardest of all of the filaments. Due to its lower melting point, the friction from cutting made large clumps of plastic on the ends. It was also the most difficult to sand down. A positive point is that due to it being so hard, it would likely be more difficult to deform or break. PETG was very similar to PLA in the hardness and difficulty in sanding and cutting, but it was somewhat softer. Nylon was harder than ABS, but softer than PETG, and was the hardest to sand down due to it not being abrasive and very flexible. The other problem with the nylon is that it is hygroscopic, so before using nylon to print parts, the filament needs to be heated in an oven so that all of the water can be evaporated from it.

The data from the radiation exposure was plotted and a trend line added in the form of $y = A\,e^{-\mu x}$. The attenuation coefficient, "μ" represented the effectiveness of the material as a shield. The larger the "μ", the quicker the trend line would go down, and the better the material is for neutron shielding. The count number, mass, and cylinder height and diameter were all measured, and were used, along with the atomic masses and chemical formulas, to calculate the total atomic density (moles/cm^3) and the carbon and hydrogen atomic density.

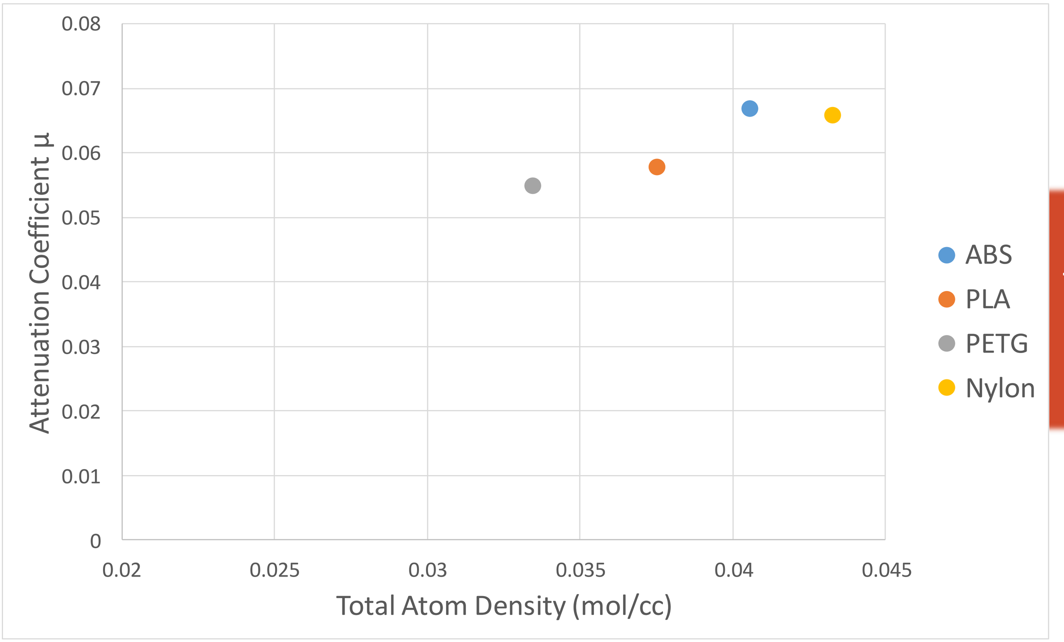

Figure 3: Attenuation coefficient as a function of total atom density.

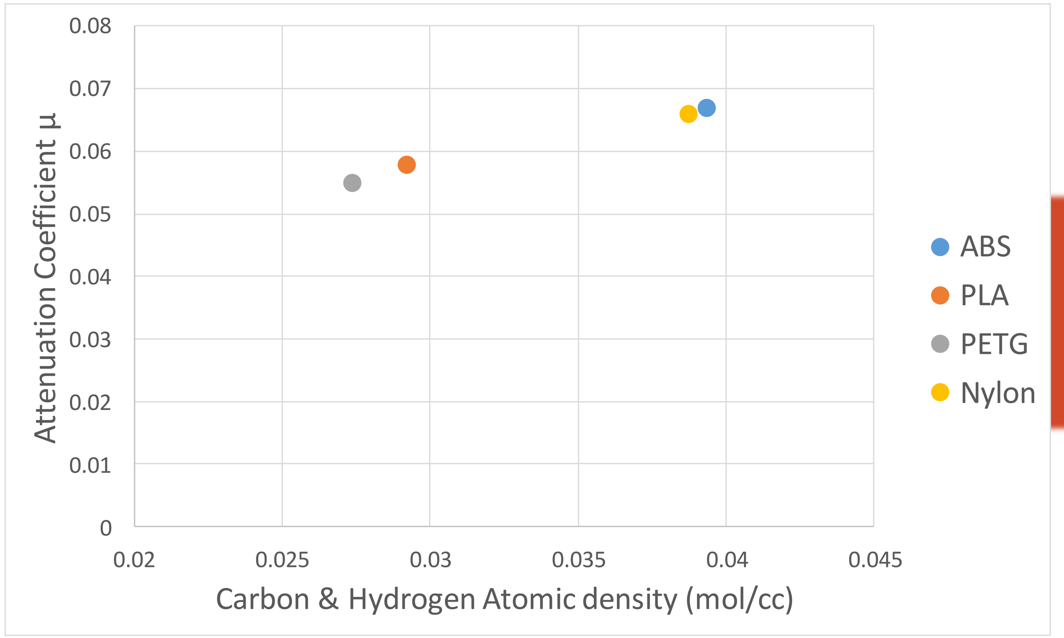

Figure 4: Attenuation coefficient as a function of carbon and hydrogen atom density

As the number of atoms in a given volume increases so does "μ".

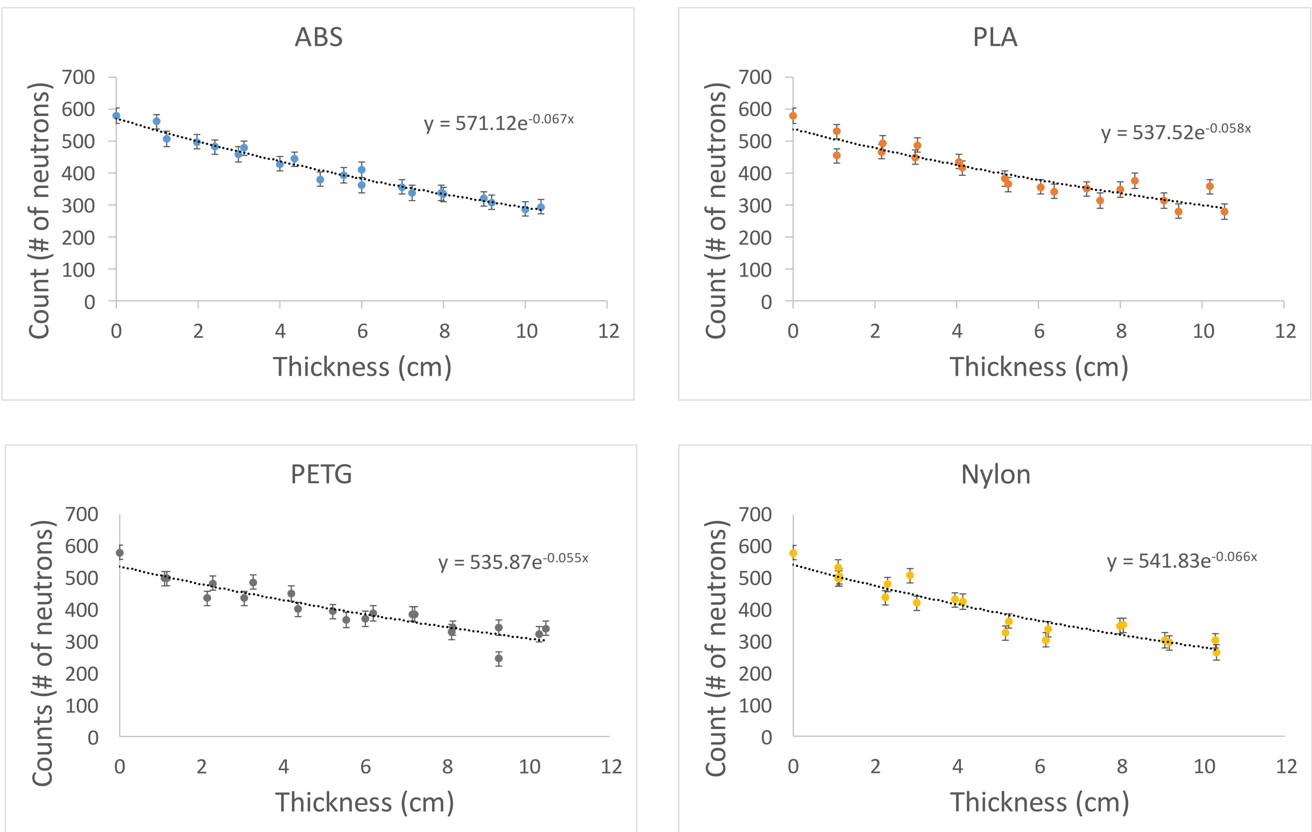

Figure 5: Neutron count for the plastics with their respective trend line and equation. The beginning point was with no plastic shielding and the seven inch polyethylene ball. The measurements had the background subtracted from it and error bars calculated from the standard deviation of the background measurements.

Conclusions and Remarks

The plastics did serve as a decent shield with the maximum ten centimeters blocking about half the neutrons that were emitted. ABS and nylon 66 were the best shields,likely due to the higher density of carbon and hydrogen atoms. Carbon and hydrogen are very good at neutron scattering.

This experiment should be done again with more time and more repeated measurements going up to twenty centimeters to make a more defined curve.

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