Mechanical and Radiation Hardness Testing of 3D Printed Scintillators

A thesis submitted in partial fulfillment of the requirements for the degree of Bachelor of Science degree in Physics from the College of William and Mary

by

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Abstract

A scintillator is a type of material that exhibits luminescence when excited by ionizing radiation. When struck by a particle, it can absorb the energy of the particle and emit that energy as light. Scintillators are often used in neutron detection and high energy particle experiments. In this report, I will detail my progress with 3D printing plastic scintillators and the mechanical testing.

1 Introduction & Motivation

My research focuses on 3D printing molds using scintillator resin. Once 3D printed, the resin will become a plastic which gets sent to a mechanical testing lab which punches out the prints into a dog bone shape. The shape was decided in order to accommodate already preexisting ASTM standards for prints in the shape of those dogbones. The motivation for this research is to explore the possibility of using 3D printed scintillators as a resourceful way to print unique shapes for easy detection of field emission electrons and the gamma rays they emit when exposed to an electromagnetic field.

2 Basic Information

2.1 Composition of 3D Printed Scintillators

The monomer, binding agent and scintillator chemicals used in the resin were SR9036, TPO, PPO, and POPOP. PPO and POPOP are the scintillator chemicals used in the resin while SR9036 and TPO are used to polymerize the resin into a polymer. The resin used thus far in the experimentation has been Resin 2.1: a resin comprised of 97.92% SR9036, .5% TPO, 1.5% PPO, and .08% POPOP. This resin was created in Karen Ficenec's research into production of these 3D prints [1].

2.2 Process of 3D Printing

To 3D print the plastic scintillators, an Asiga Pico Plus 39 3D printer was used. The materials other than the printer that were used were a plastic build tray, a metal scraper, a rubber spatula, and a UV oven. To begin the printing process, remove the resin from the refrigerator and let it thaw for 2-3 hours. While the resin is thawing, turn on the printer.

Once the print is sent to the printer and the resin is done thawing, pour the resin into the build tray and remove any abnormalities in the resin. Then, check to make sure that the build platform is in the proper position. Now the printing can commence. When the print is finished, remove the build platform with the print still on and gently scrape the print off using the metal scrape into a solution of rubbing alcohol to clean it. Then place the print inside of the UV oven to cure for 15 to 30 minutes, depending on the size and shape of the print. While curing, pour the remaining resin from the build tray into the container and return it to the refrigerator. All equipment should be cleaned using rubbing alcohol and paper towels.

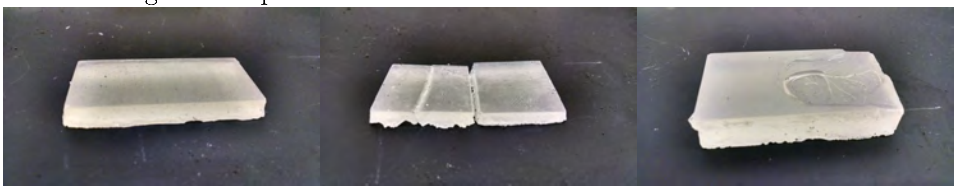
The process for printing and the composition of the resin were compiled through discussions with Karen Ficenec [1].

3 Research & Results

3.1 Fall Research Results

The beginning of my fall research was focused towards familiarizing myself with the process of 3D printing and the software used to compose and make 3D prints. This research led to a couple of prints that can be used to punch out a dog bone shape. The prints were a consistent length of 55 mm and and a consistent width of 29.5 mm. However, the thickness was varied in different prints from around 10 mm to 15 mm. With assistance from Dr. David Kranbuehl in the mechanical testing facility in the ISC at William & Mary, the prints will be able to be punched out in a dog bone shape and be subjected to mechanical strength testing (like Dogbone 1, see Figure 1) and afterwards, prepared to be sent to Jefferson Lab. There, the plan was to subject the prints to an ionizing radiation bath and test the print's radiation hardness. After the first round of printing, there were some with some notable imperfections: one print broke in half as it was being removed from the UV oven (Dogbone 2, see Figure 1). Another print had inconsistent thickness throughout it, which was caused by the print being too thick and not polymerizing properly (Dogbone 3, see Figure 1).

Figure 1: Dogbone 1, Dogbone 2, and Dogbone 3, respectively: 3D prints before being punched with dogbone shape



3.2 Mechanical Strength Testing

For mechanical strength testing, I used the blank resin (99.5% SR9036, .5% TPO) [1] to test mechanical strength since the small amount of scintillator chemicals used in the scintillating prints does not contribute a significant factor to the mechanical strength. During mechanical strength testing, I ran into a couple of issues: the dogbones had to be printed with a thickness of $<$5mm. The punch out for the dogbones would cause fracturing along the sides of dogbones of more than 5mm, making them unreliable for mechanical strength testing. Also, the Asiga Pico Plus 39 3D printer can only print up to 50mm in length, which, coupled with the thickness limitation, eliminates the viability of using the MTS tester to test for mechanical strength. Thus, we decided to use a rheometer. The use of the rheometer also limits the thickness of the dogbones: the grips for the rheometer need to be tightened enough to prevent slipping; but, if tightened too much, they dig into the dogbones and cause the ends to fracture and break. However, there is a "sweet spot" that is thick enough as to where the grips can tighten on it without crushing the ends and limits slipping. This "sweet spot" thickness is at 2mm ($\pm$ .1mm).

I obtained viable data regarding the Young's Modulus and the stiffness from three prints. These three prints were 40 mm long, 11 mm wide and 2 mm thick before being punched out in the dogbone shape (see figure 2). After they were punched out, we tested them in the rheometer and received the following data, which we later analyzed in MatLab to find the true stress and engineering stress on the prints (as seen in Figure 3 and Figure 4).

As we can see from the graphs in Figures 3 and 4, the Young's Modulus averaged out to around 13.33 MPa. However, the yield strength and ultimate strength both showed 0 MPa. I obtained the yield strength by zooming in on the curve at the point where the data begins to deviate away from the initial slope of the stress-strain curve (i.e. the slope that determines stiffness). I employed a similar method when determining the tensile strength

Figure 2: Dimensions of dogbone punch out

and ultimate strength values. The yield strength (σ_y) averaged out to around .247 MPa. The tensile strength and ultimate strength were the same for the first two prints, as the maximum stress the print endured (its tensile strength σ_t) was also the stress when the print broke (its ultimate strengthσ_u), which both averaged out to be .901 MPa. However, the third test ran smoother than the first two with virtually zero slipping of the print. The tensile strength was calculated to be .939 MPa and the ultimate strength was calculated to be .938 MPa.

3.3 Opacity Testing

With the assistance of Dr. Todd Averett and Jacob McCormick, I also tested how the light output changes with respect to certain environmental factors using the OceanView spectroscopy software. There was a control print, which was subjected to basic environmental factors; mainly UV light (sunlight) and oxygen. Then there was a print that was kept in a drawer so no UV light could alter the print. The other prints consisted of: one that were subjected to a helium bath (where we filled the plastic bag the print was held in with helium gas); one was subjected to a UV light bath; one that was kept inside a refrigerator; and one that was sealed inside a vacuum sealed container. (see Figure 6) With these tests, we were testing to see how the transmission spectra of these prints changes with respect to these environmental factors. To determine which prints absorbed the least amount of light, we measured with the light on to determine the maximum light output. Then we began placing the prints in the darkbox to find the how the light output changed. As we can see from

Figure 3: True stress and Engineering stress, including Young's Modulus

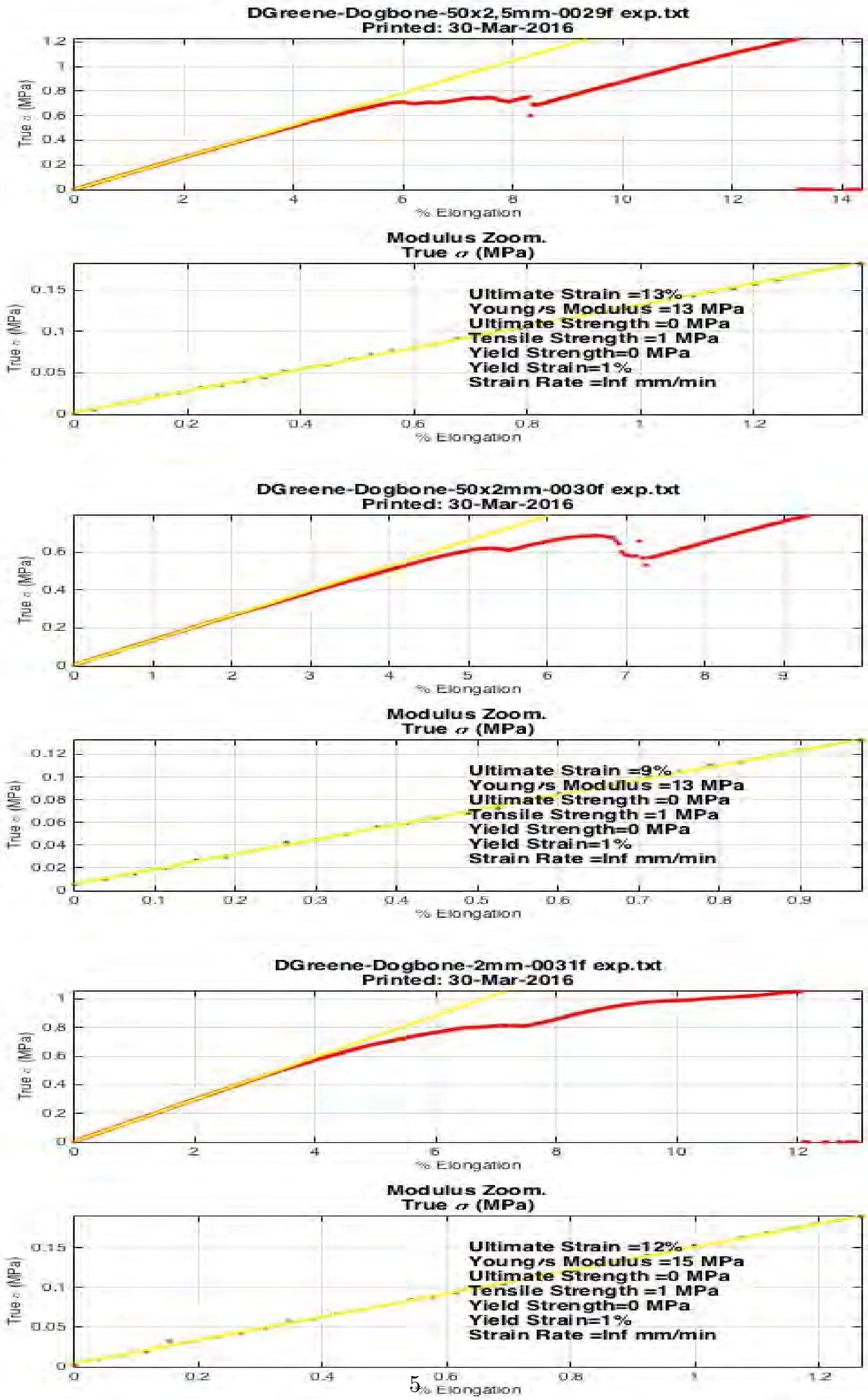


Figure 4: True stress and Engineering stress, including Young's Modulus

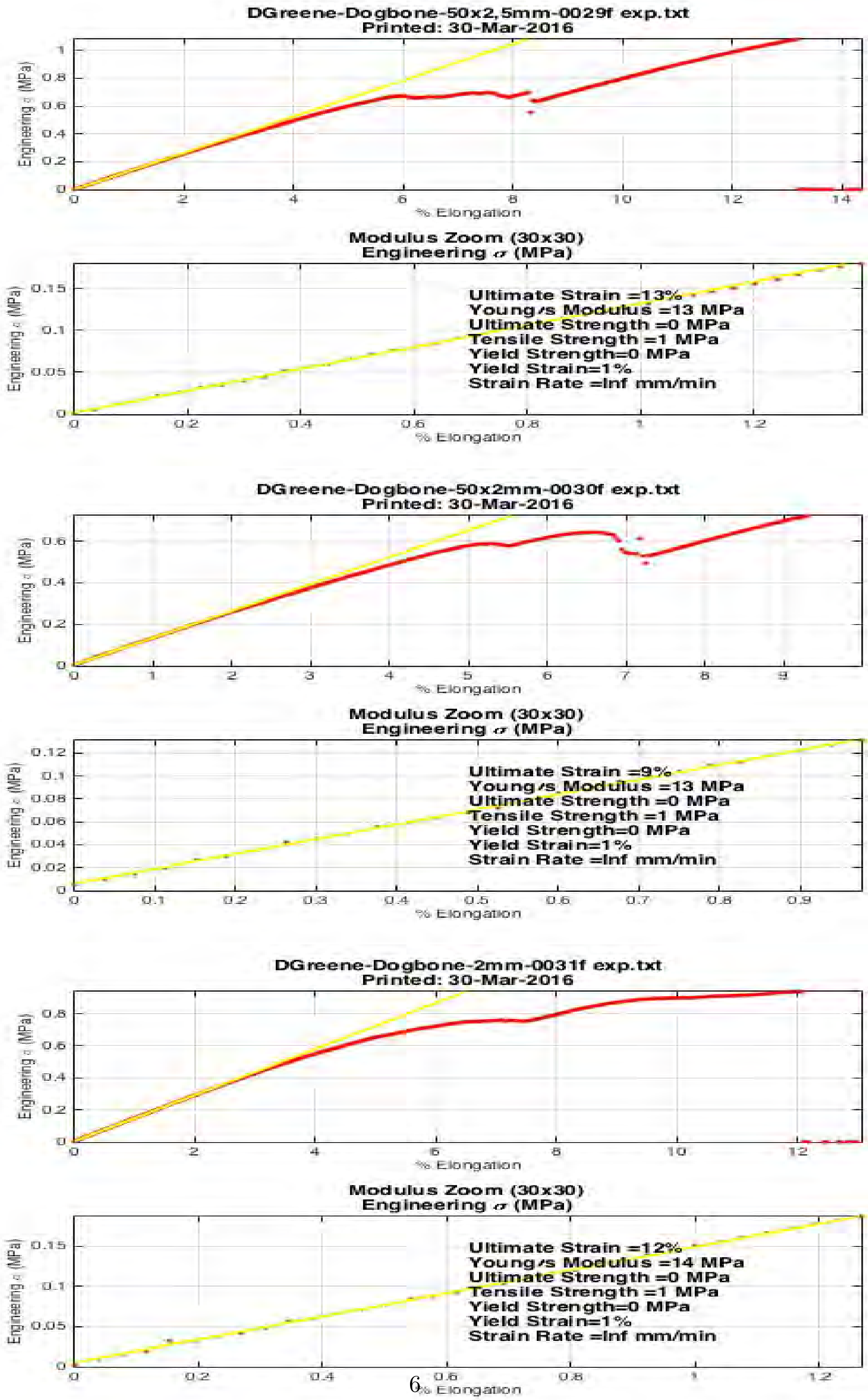


Figure 5: Comparison photo of the UV light bath sample and a new print side by side

Figures 7 and 8, I found that the UV light bath sample absorbed the least light with the helium bath sample absorbing the second least light. The other samples absorbed similar amounts of light (given the slight error induced by the spectroscopy software) compared to the new sample, which was printed a day prior to testing. The mechanical properties of some of the samples also changed. The UV light bath sample was noticeably stiffer but also more brittle while the sample kept in the helium bath was more ductile.

Figure 6: Prints after Subjugation to Environmental Factors, in order from top left: Control, Vacuum, Darkness, UV bath, Helium bath, Fridge

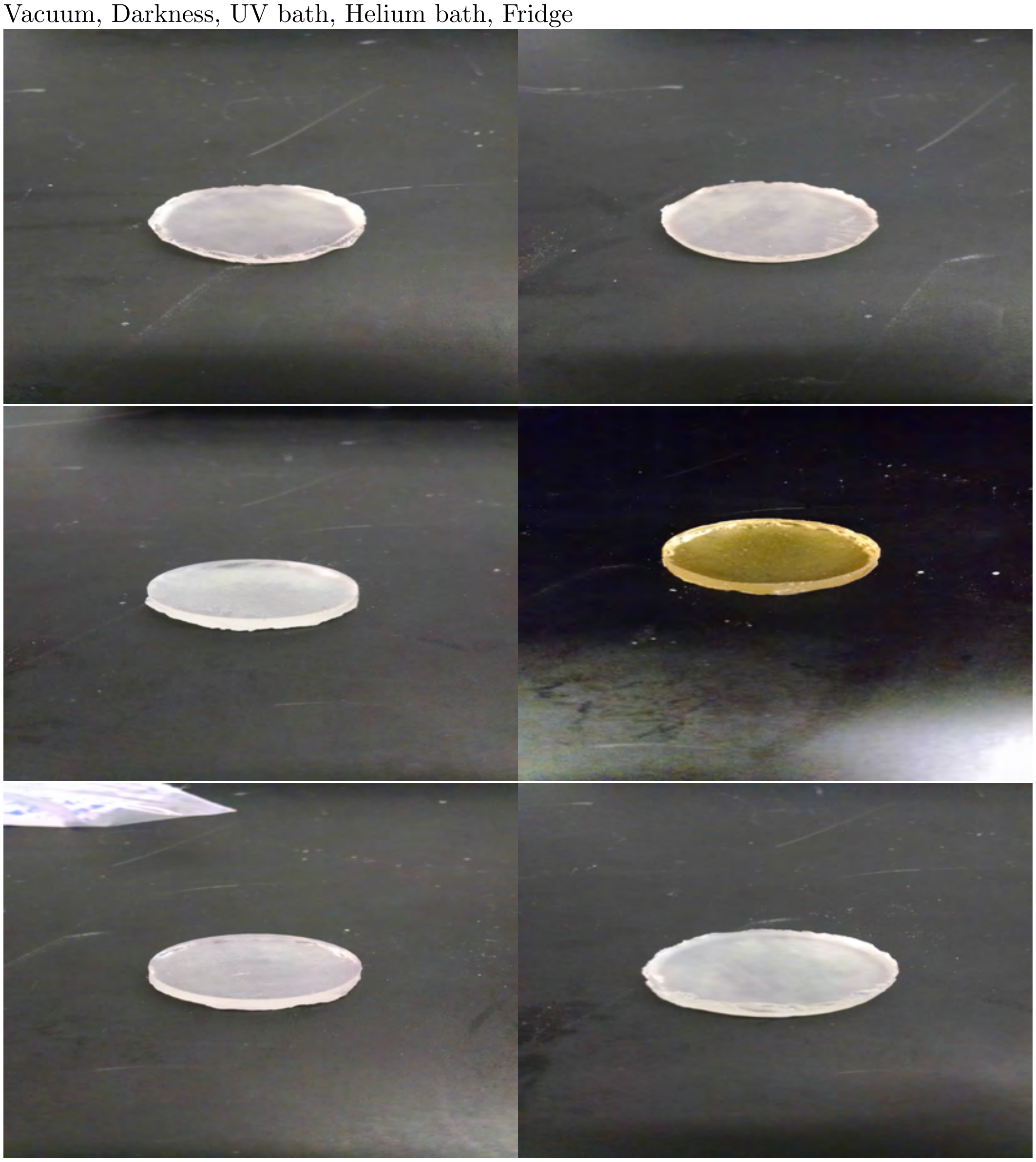


Figure 7: Absorption Spectra, in order from top left: No print, New print, Blank resin, Control

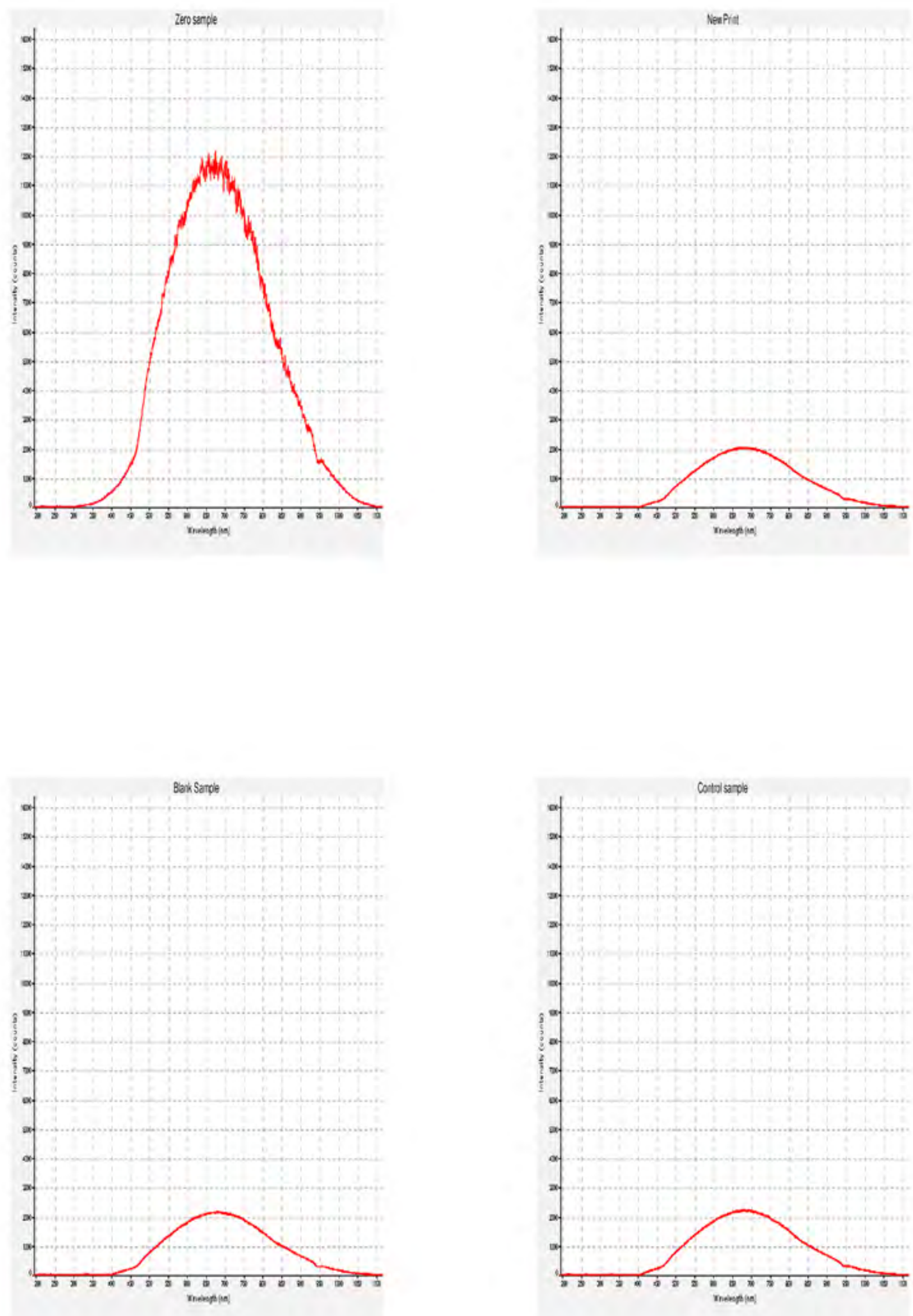
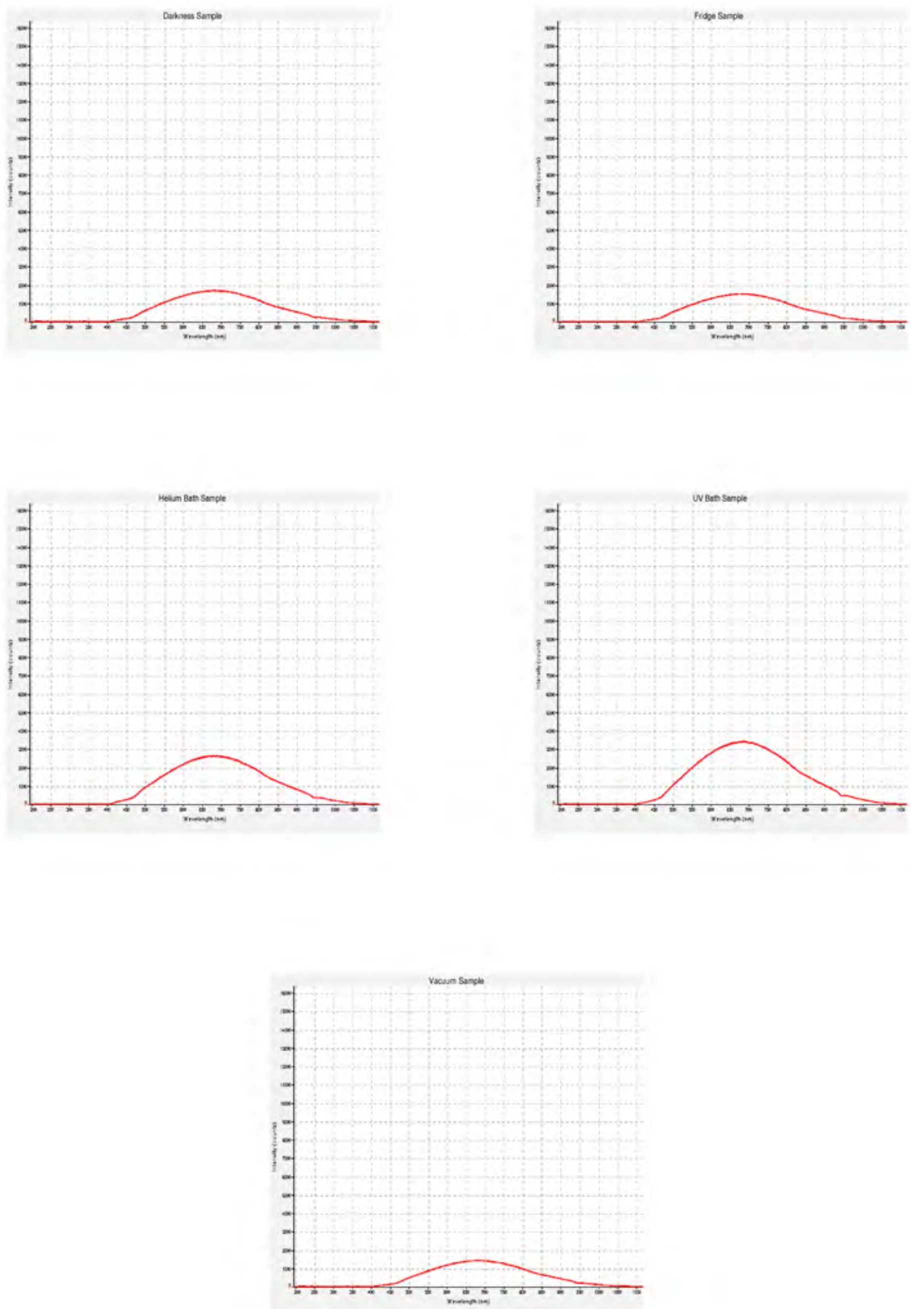


Figure 8: Absorption Spectra, in order from top left: Darkness, Fridge, Helium Bath, UV Bath, Vacuum



4 Conclusion

After testing both the mechanical hardness and the change in light output of these scintillators, I have determined that these prints may not be a viable option to use at Jefferson Lab, since they show an undesirable mechanical strength. However, something to be considered further about these scintillators is why do they become less opaque when exposed to UV light? Similarly, why did the helium impact opacity as well, but more so than the oxygen? It would be interesting to see how the scintillators' opacity reacts to radiation and how they change over time.

References

[1] Karen, Ficenec. *Production of 3D Printed Scintillators For Use in Field Emission Detection and Other Nuclear Physics Experiments*. 2015.