Ion-Beam Analysis of Artificial Turf

By

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Abstract

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There have been considerable concerns in recent years that artificial turf, used in many playing fields around the world, may be unsafe. While the presence of heavy metals and carcinogenic chemicals have been reported in a number of studies, more data and research are needed to determine if there is a real link between artificial turf and adverse health effects. We performed PIXE and PIGE analysis of artificial turf blade and infill samples to search for heavy metals and other possibly toxic substances. The samples were bombarded with proton beams from the 1.1-MV Pelletron tandem accelerator in the Union College Ion-Beam Analysis Laboratory and the emitted X-rays and gamma-rays were measured with Si drift and CdTe detectors, respectively. Some preliminary work on this project was performed using an external beam facility that we constructed from a beam pipe with an aluminum end cap supporting a $\frac{1}{4}$" diameter window made of 7.5-micron Kapton foil which allows us to analyze samples that cannot be put into the vacuum chamber. The majority of this research was done under vacuum and data was taken on 7 different colors of turf and the crumb rubber infill of the turf. Our results allowed us to conclude the composition of the pigments in the turf blades as well as the composition of the crumb rubber which contained zinc, iron, copper and bromine in some samples.

Acknowledgements

I would like to thank the Union College Undergraduate Research Program, and the Union College Department of Physics and Astronomy for their support as well as extend a special thanks to John Sheehan for his help in designing and building the external beam facility. I would also like to thank Scott LaBrake, Josh Yoskowitz, and especially my advisor, Michael Vineyard for their help and guidance in this research.

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Chapter 1

Introduction

1.1 Introduction

There has been a lot of concern in recent years that artificial turf may be unsafe. While nothing conclusive has been determined about the safety of artificial turf, the research being done is continually finding heavy metals and other toxic chemicals in the crumb rubber used in the turf infill [1]. We wanted to search for potentially toxic substances in the artificial turf at Union College to determine if there was reason to believe the turf could be unsafe. Other studies of this nature have found heavy metals, like lead, and other toxic chemicals in artificial turf, but the presence of these has not been universal, nor has it been proven to be dangerous [2].

Our interest in looking into the possible hazards of artificial turf started with an article in the LA Times which discussed a possible connection between young, healthy athletes, specifically soccer goalies and Hodgkins lymphoma diagnoses [1]. The companies that produce artificial turf claim that there are no potentially harmful substances in the infill, however this article discusses the issues with the studies, and how they are often incomplete and inconclusive. These companies claim that their playing surfaces are environmentally friendly, but many of the possible ingredients found in turf by other studies, according to the EPA, are very toxic to wildlife and the environment. The crumb rubber used to build the artificial turf surfaces are made out of crushed up tire rubber, which is known to be composed of carcinogens, like lead and benzene, in some cases [1].

A soccer coach from the University of Washington, Amy Griffin, spends much of her free time visiting young athletes who have been diagnosed with cancer in a local hospital. A few years ago, she visited four former soccer goalies in one week, all of whom had been diagnosed with non-Hodgkins lymphoma [2]. It was then that she realized that there could be a link between the black infill that athletes, especially goalies, are constantly in contact with, and cancer. Since meeting these players, Griffin has come up with a list of 38 American soccer players, most of them goalies, who have all been diagnosed with cancers, mostly lymphoma and leukemia. This list is also not comprehensive. Most of the players are from the state of Washington, or have a connection to a player or coach whom Griffin knows [2]. While no studies have proven the toxicity of the substance, there seems to be a strong correlation between the amount of infill players could inhale during a practice, and the likelihood of them developing cancers. Griffin now has all turf her players play on tested for heavy metals and other toxic substances, and prefers to play on grass [3].

One of the main concerns with artificial turf is that it contains heavy metals, many of which are toxic or known to cause other serious health issues. Many heavy metals, like lead, are known carcinogens, and have been found in artificial turf. Repeated exposure to these volatile chemicals and elements can cause cancers, damage to primary organs, and reproductive issues [3]. Zinc is another heavy metal which has been linked to artificial turf. It is not known to be toxic to humans in small doses, but it is very toxic for animals, especially wildlife in aquatic environments, and can be harmful to the environment as it can leach into plants and water systems [4]. Zinc and lead have both been consistently found in other turf, but the presence of other elements could also have important health consequences.

An in depth study by the Department of Environmental Protection in Connecticut of artificial turf fields in 2009 determined that there were many metals in their turf which leached into the environment because of the turfs constant exposure to the elements [4]. They found high concentrations of many elements, including zinc. The study found that the infill in artificial turf was especially toxic to aquatic life and affected the quality of the water in the community [4]. As a result of this study, the state considered banning artificial turf across the state. While this legislation was not passed, it sparked a lot of discussion about the safety of artificial turf both to people who play on it, and the environment around it.

As the issue of the safety of artificial turf becomes more widespread, more and more studies are being done, and more and more people are discussing the safety of the turf, and what can be done about it. The California EPA has held two hearings, and has a Synthetic Turf Scientific Advisory Panel which has been tasked with determining the toxicity of the turf, and what levels of exposure to these chemicals would be harmful to people [5]. The EPA has also developed a group that is working towards determining the safety of artificial turf, but they have not yet released their findings. The study will continue into 2017, and will include data from fields across the United States [6].

After learning about all of the possibly toxic substances in artificial turf, we decided to do our own research on artificial turf using the infill and turf blades on Bailey Field at

Union College. This research was done in the Union College Ion-Beam Analysis Laboratory with a 1.1-MV tandem Pelletron accelerator. We used PIXE analysis to determine the composition of metals in our sample and the concentrations of these elements within the sample. The samples were bombarded with a proton beam which interacts with the atoms on the surface of the target, and results in the release of x-rays. The energies of these x-rays and the number of x-rays were measured in order to determine the composition and concentration of the elements in our samples. We hoped this technique would allow us to accurately determine the composition of our samples and potentially find heavy metals.

Preliminary data on this research was taken using an external beam facility. This allowed us to bring the proton beam outside of the scattering chamber and take data on samples quickly without having to open and close the vacuum chamber every time we changed samples. We ultimately had to take our data under vacuum because of the difficulty of calculating the amount of charge accumulated on our samples with the external beam facility. However, putting our samples into the scattering chamber also caused problems. Some of our samples collected charge from the beam in the vacuum chamber and had to be coated with gold in order to stop this. We also had some problems creating a flat, homogeneous surface to take data on in the scattering chamber. We attempted to solve this problem by creating pellets of the turf infill. This was not very successful, but did not affect our ability to find possibly toxic substances in the turf infill, or determine the composition of the different colored blades in the artificial turf.

In other studies, the heavy metals found in the turf were found in the turf infill. In addition to our own analysis of the turf infill, we also analyzed the turf blades for their trace elemental composition. The results of our study showed that there were very high concentrations of zinc in our artificial turf infill, and bromine in some samples of the infill. We were also able to determine some of the pigments used in the coloration of many of the blade colors. Bromine is known to be harmful to humans, and, while not a known carcinogen, can cause respiratory or even central nervous system damage when ingested, among other health risks [7]. Bromine is often used as a flame retardant in plastics and rubbers, and most likely came from the tires used in the crumb rubber.

Chapter 2

Experimental Methods

2.1 Proton Induced X-Ray Emission

The ion-beam analysis technique we utilized in this research was proton induced x-ray emission, or PIXE [8]. Our samples were bombarded with a beam of protons produced by our accelerator with energies of 2.2 MeV. In PIXE, a beam of ions, in our case protons, interacts with the electrons in the atoms near the surface of a sample, causing energy to be released in the form of x-rays. By measuring the energies and intensities of these x-rays, we can determine the composition and concentration of elements in our samples.

A small fraction of the time, when the beam comes into contact with the target, the ions from the beam will penetrate through the outer electron shells of the atom to knock out an inner shell electron, as shown in the schematic in *Figure 2.1*. An outer shell electron then drops down to fill the hole left by the missing electron, as shown in *Figure 2.2*. The energy the electron loses in order to drop to the lower energy shell is released in the form of an x-ray with an energy specific to the element and the transition which occurred.

We measured the energies and intensities of the x-rays emitted by the atoms in the sample using a silicon drift x-ray detector (SDD), then determined the composition of

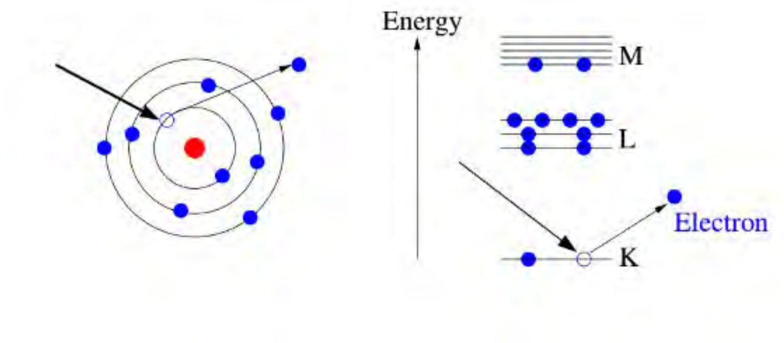


FIGURE 2.1: A diagram of an electron being emitted from the K-shell during PIXE analysis. Once the electron leaves this shell, another electron from a higher energy level will drop down to fill this hole, releasing an x-ray in the process, shown in *Figure 2.2*.

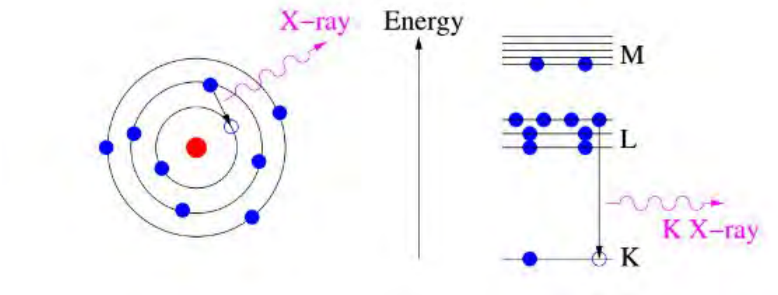


FIGURE 2.2: A diagram of an x-ray being emitted from the atom as the energy is released by the electron falling down to fill the place of the emitted electron. Each transition for each element has a different energy. We measured the energies and intensities of the emitted x-rays to determine the composition of our samples.

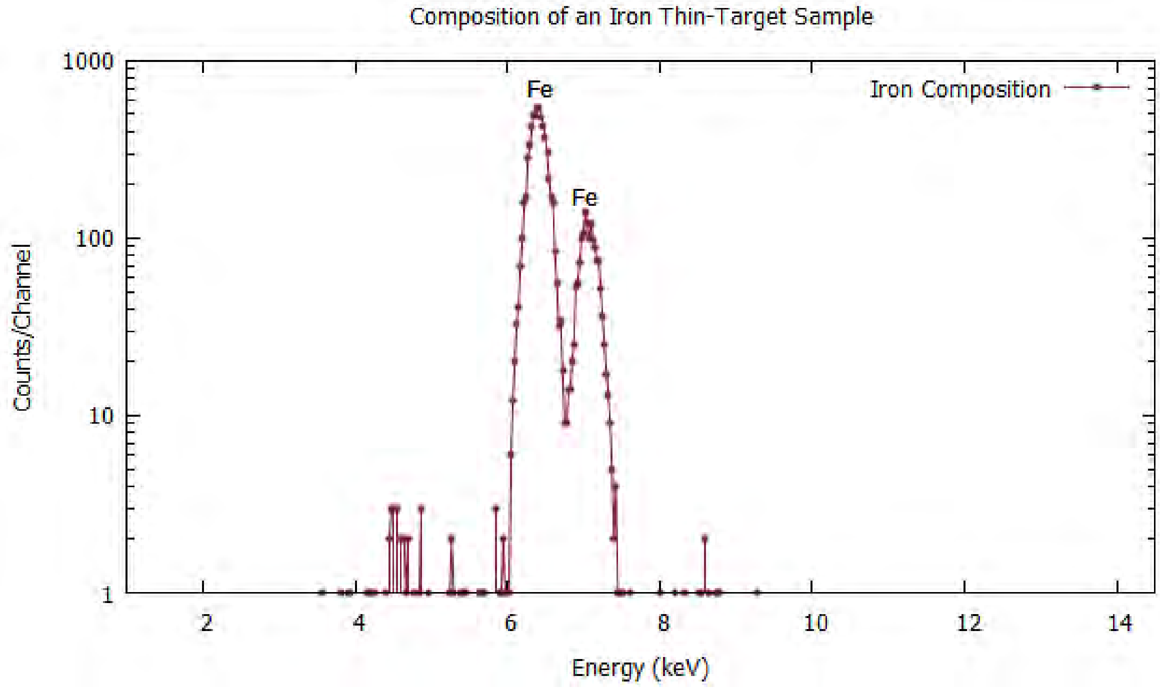


FIGURE 2.3: An x-ray spectrum collected on a thin Fe standard.

the sample as well as the concentrations of specific elements. We plotted spectra of the energies of the x-rays detected versus the number of counts of each energy, then used the peaks to determine the composition and concentration of the sample. A spectrum of an iron standard is shown in *Figure 2.3*. We located the energy of the peaks on this sample, compared the value to a table of known x-ray energies to determine the elements in our spectra, and then measured the area of these peaks to determine the concentrations of the elements.

The concentration is found using the equation

$$C_z = \frac{Y_z}{Y_t H Q \epsilon T} \tag{2.1}$$

where C_z is the concentration of the element; Y_z is the intensity of the x-ray line for the element Z determined from the area of the peaks; Y_t is the theoretical intensity per μC of charge; H is the solid angle of our detector which is calculated by performing calibrations on the experiment and will be discussed later; Q is the charge incident on the sample from the beam which is measured by collecting charge from the beam in a Faraday Cup in the back of the scattering chamber and measuring how much charge is incident on our target from the beam; ϵ is the intrinsic efficiency of the detector, which is another value which has been experimentally determined; and T is the coefficient for the transmission through the absorber, which is another previously determined value which will be discussed later.

2.2 Proton Induced Gamma Ray Emission

PIXE depends on the beam interacting with inner-shell electrons and knocking them out of the atom. Because of this, it works best in atoms with large Z whose electrons have lower ionization energies, and does not work for atoms with a Z less than 13. In order to measure elements below this threshold, another analysis technique was used. In proton induced gamma ray emission (PIGE), the proton beam induces a nuclear transition and a γ-ray is emitted. Unlike in PIXE where an electron is actually removed from the atom, in PIGE, the transition is induced but no particles are knocked out. We did not see anything interesting in the PIGE spectra in this research, they did not show us any elements which we could not measure with PIXE, so they were not used in the analysis.

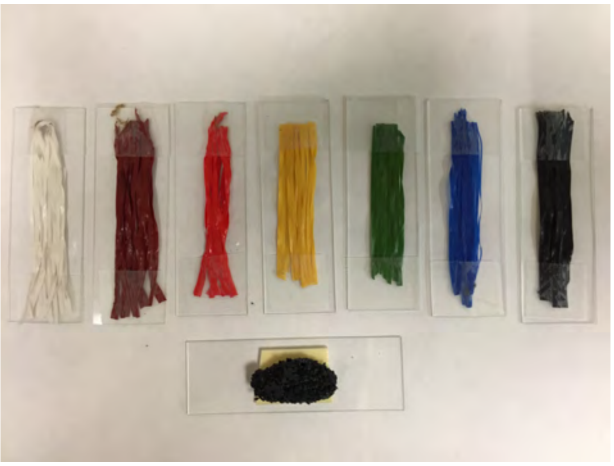


FIGURE 2.4: A photograph of the different colors of turf blades and a chunk of the turf infill. We also collected the loose infill, which is composed of the small pieces of the crushed rubber that can be seen in this photo.

2.3 Collecting Samples

All of the samples used in this study were collected from Bailey Field at Union College and included the turf infill and the synthetic turf blades. For the infill, we gathered small chunks of the black, crumb rubber infill which were already stuck together, as well as the small, individual pieces of the crumb rubber from many different areas of the field. We collected the blades of the turf in seven different colors: white, garnet, red, yellow, green, blue and black. *Figure 2.4* shows both the blade and infill samples.

2.4 The External Beam

I assisted in the design, construction and testing of an external beam facility for the particle accelerator at Union College. The device extends six inches past the scattering chamber, and allows the beam to travel about three inches into air after passing through a 0.25

FIGURE 2.5: A photograph of the external beam pipe showing the opening and the Kapton foil window. In this photograph, the beam pipe is not attached to the scattering chamber of the accelerator.

inch diameter window covered with 7.5 μm thick Kapton foil. *Figure 2.5* shows the external beam pipe and the window before it was attached to the scattering chamber. The external beam facility was an important addition to the lab because it gave us the ability to collect data on samples which are not fit to be put under vacuum such as wet samples or samples which are too big to be put into the scattering chamber.

For this research, the external beam facility was primarily used in preliminary measurements to quickly obtain qualitative data on many samples. Because the beam extends outside of the scattering chamber, it eliminated the need to open and close the vacuum chamber every time we wanted to take data on a new sample, making it very easy to obtain a large amount of qualitative data quickly. The external beam facility can be used to take quantitative data, but a procedure must be developed to measure the charge on the sample before this can be done.

2.4.1 Measurements with the External Beam

We used the external beam facility to take data on our samples by setting up the samples near the window of the beam pipe and measuring the energies of the x-rays and gamma rays with our SDD x-ray and CdTe γ-ray detectors. The setup is shown in *Figure 2.6*. We taped the samples onto a stand 2 cm from the window and pointed our detectors at the sample at known angles. Using SRIM (Stopping and Range of Ions in Matter) simulations, we determined the beam energy 2 cm from the window to be about 1.7 MeV [9]. This method was a great way to obtain initial qualitative data on our turf samples quickly, but did not provide quantitative data.

Even though this method did not provide a good way to obtain quantitative data, we did create a way to compare the different spectra by normalizing the argon peaks in our spectra. There is a fairly constant amount of argon in the air, so the amount of argon seen in the spectra is directly proportional to the amount of charge incident on the sample, and can therefore be used to determine relative concentrations of elements in the sample.

2.5 Measurements in Vacuum

Since we could not obtain quantitative data with our external beam, we put our samples and detectors back into the scattering chamber to take data under vacuum. This allowed us to accurately collect and measure the charge accumulated on the samples and eliminated a lot of the errors we encountered using the external beam. Switching to taking data under vacuum also introduced a few other problems into our data. We attempted to solve these problems by coating the blades in gold and creating pellets with our infill.

FIGURE 2.6: A photograph of the setup of our external beam facility. The detectors, an SDD x-ray detector on the right in the image and a CdTe γ-ray detector on the left, come in at 45 degree angles to the external beam pipe in the center. The samples were attached to the small metal rectangle located in front of the external beam.

2.5.1 Preparing the Samples for Vacuum

When we were performing our analysis with the external beam, we put the tiny pieces of infill as close together as possible on a piece of scotch to take data. This worked well for qualitative data, but did not create a homogeneous target, and we wanted to do better when we collected data in the vacuum chamber. In order to do this, we attempted to create a homogeneous pellet of the infill material.

First, we tried melting the rubber into the shape of a pellet. It seemed like an easy, fairly obvious way to create a pellet, but quickly created a controlled tire fire and a lab that smelled like burning rubber with no pellet. We then attempted to grind the turf into a powder with a simple mortar and pestle, then press the powder into a pellet. We could not grind the crumb rubber at room temperature, so we freeze-dried it with liquid nitrogen, then ground the frozen infill into a powder and pressed it into a pellet with the pellet press. This seemed to work well, at first, but we quickly realized that while we could press the infill into a pellet, the pellet fell apart as soon as it was taken out of the mold. We attempted to hold the pellet together by adding a little bit of polyvinyl alcohol to the mixture, but the alcohol was simply pressed out of the mold, and a pellet was not formed.

Because we could not create a pellet, we decided that we would use the larger chunks of the turf that we found in the field as our targets and aim our beam at the flattest, densest areas of these clumps. In order to put the samples onto the target ladder, we taped the chunks of the pellet onto the ladder with double sided tape that we know would not interfere with our spectra.

Our samples were not conductive, so when the beam hit them, they collected charge which caused unwanted background in the x-ray spectra. In order to solve this problem, we coated the samples with a thin layer of gold. This allowed the charge to be dissipated off of the surface, preventing background in the spectra that interfered with the data.

First, we took data on the turf blades. We removed them from the sample slides and taped them directly onto the target ladder as shown in *Figure 2.7*. When we looked at the x-ray spectra, we noticed a lot of background due to the charging of our sample: Because the blades were composed of non-conductive plastic, the charge from the proton beam built up on the surface of the samples and produced a lot of background in the spectra which hindered our ability to find peaks. We solved this issue by coating the blades in a thin layer of gold which created a metal surface on the blades. When we connected the sample to the outside of the target ladder with a thin wire, the charge was allowed to dissipate. Our spectra now included extra gold peaks from this coating, but the spectra

FIGURE 2.7: A photograph of the target ladder which we put into the scattering chamber. When we put the turf on the ladder, we simply taped a flat surface of the plastic onto the ladder. When we ran on the turf infill, we taped a small chunk of the infill into the center of the square.

are free of the background produced by the charge build-up.

At first, the larger chunks of the infill also accumulated charge, so we coated them with gold. This stopped the charging, and reduced the noise in the spectra, but introduced gold peaks at energies that could obscure peaks from heavy metals in the samples. In order to reduce the charging, but still be able to see peaks from the heavy metals, we attached the small metal wires onto the sample and allowed it to dissipate the charge into the target ladder. This gave us relatively clean spectra without interfering with the peaks from heavy metals. The reason we could use the gold to correct our blade spectra, but not our infill spectra was that we did not find any heavy metals in the blade samples with peaks near the energies of the gold peaks.

2.5.2 Taking Data on our Samples

The accelerator used in this experiment was a 1.1 MV tandem Pelletron accelerator which allowed us to put 2-4 nA of current onto our sample. In order to determine the concentrations of the elements in our samples using *Equation 2.1*, we needed to measure the amount of charge incident on the samples. We did this by measuring the amount of charge which accumulated on a Faraday cup attached to the back of the scattering chamber in the same amount of time which we ran on our samples for. When we put our samples onto the target ladder, shown in *Figure 2.7*, we left the center hole open. This allowed the beam to go through the ladder directly into the Faraday cup. We assumed that the beam current was approximately constant, and measured the charge collected by the Faraday cup for half of the amount of time we took data on the samples. By multiplying the measured charge in the Faraday cup by two, we obtained the amount of charge incident on our sample during data collection. This amount of charge was recorded in the file-name of the sample so that it could be used later to calculate the concentrations during data analysis.

To take data, we put our samples on the target ladder two at a time, as shown in *Figure 2.7* and put the ladder inside of the scattering chamber under vacuum. We bombarded the sample with protons and used PIXE to determine the composition of the sample by measuring the x-rays emitted by the sample with an SDD detector. Using the data from this detector, we created spectra showing the energies detected and the number of counts of each energy. The energies of the peaks in our spectra correspond to known transitions. The areas of these peaks correspond to the concentration of these elements in our samples. By utilizing a program called *Gupix*, we determined the composition and concentration of the elements in our sample which can be seen using PIXE [8]. We collected data on each sample and on standard samples for calibration. The standard samples accumulated exactly one μC of charge, while the charge accumulated on the infill and blade samples ranged from seven to thirteen μC.

The SDD detector we use to take our PIXE measurements has an an aluminum filter attached to the front of the detector. Because PIXE requires an inner shell electron to be knocked out of the atom by the beam, it works best for atoms with a large Z, and the larger Z elements are the elements we are interested in seeing. The filter attenuates x-rays from elements lighter than Z which keeps the size of the peaks from lighter elements down, and allows us to see the heavier elements. Without the filter, our peaks from the lighter elements would be so much larger than our peaks from heavier elements, it could be difficult to distinguish them from the background in the spectra.

Chapter 3

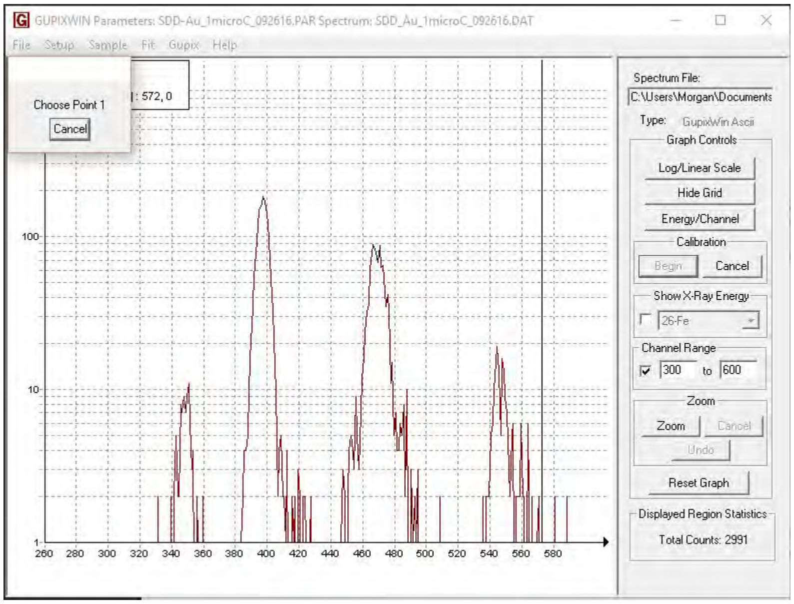
Analysis

3.1 Analyzing the Data

After collecting the data, we analyzed our spectra in a software program called *Gupix* [10]. We then calibrated the software and used it to determine the elements in our samples and the elemental concentrations of them. To calibrate the system, we took data on known standard targets, then used these standard spectra to set our calibration parameters. These calibrations were used on our unknown targets to determine the composition and concentration of elements in our target turf samples.

3.1.1 Calibrations

There are a few different calibration parameters which had to be determined before we could obtain concentrations from our *Gupix* software. We started with the energy calibration. We took 1 μC of charge on a number of thin standard targets with known concentrations of a specific element, gold, copper, iron, germanium, lead, tin and titanium. Using *Gupix*, we picked out the channel numbers of the centroids of the peaks, and then entered the energies that these peaks correspond to (which we found in a table that shows


GUPIXWIN Parameters: SDD-Au_1microC_092616.PAR Spectrum: SDD_Au_1microC_092616.DAT

Choose Point 1

|: 572, 0

Spectrum File: C:\Users\Morgan\Documents

Type: GupixWin Ascii

Show X-Ray Energy: ☐ 26-Fe

Channel Range: ☑ 300 to 600

Displayed Region Statistics

Total Counts: 2991

FIGURE 3.1: A screen-capture image of the Gupix window used to determine the centers of the peaks for the energy calibration. A cursor is used to determine the channel numbers of the centroids of the peaks in the spectrum. These channel numbers and the known energies of the peaks are used to determine the energy calibration.

the known energies of these transitions). *Figure 3.1* shows what this process looks like in *Gupix*.

Once the peaks in the spectra taken on the standards had been calibrated, we plotted the channel number versus energy for each peak and fit a line to the plot, as shown in *Figure 3.2*. This line, $y = 39.218x + 17.573$ described our energy calibration parameters which can be seen in *Figure 3.3*. The slope of the line shown in *Figure 3.2* became the *A1* parameter, the y-intercept *A2*. Because we used a linear fit, $y = 39.218x + 17.573$, the *A3* parameter was set to 0. If we had used a quadratic fit to fit our energy versus channel data, we would have had a constant that went in front of the $(energy^2)$ term.

The other two parameters, *A4* and *A5* were calculated from known constants, our

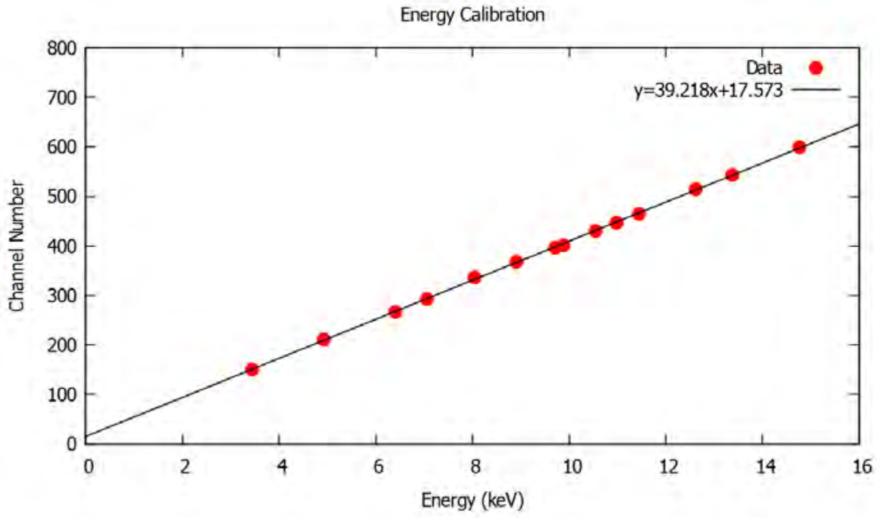
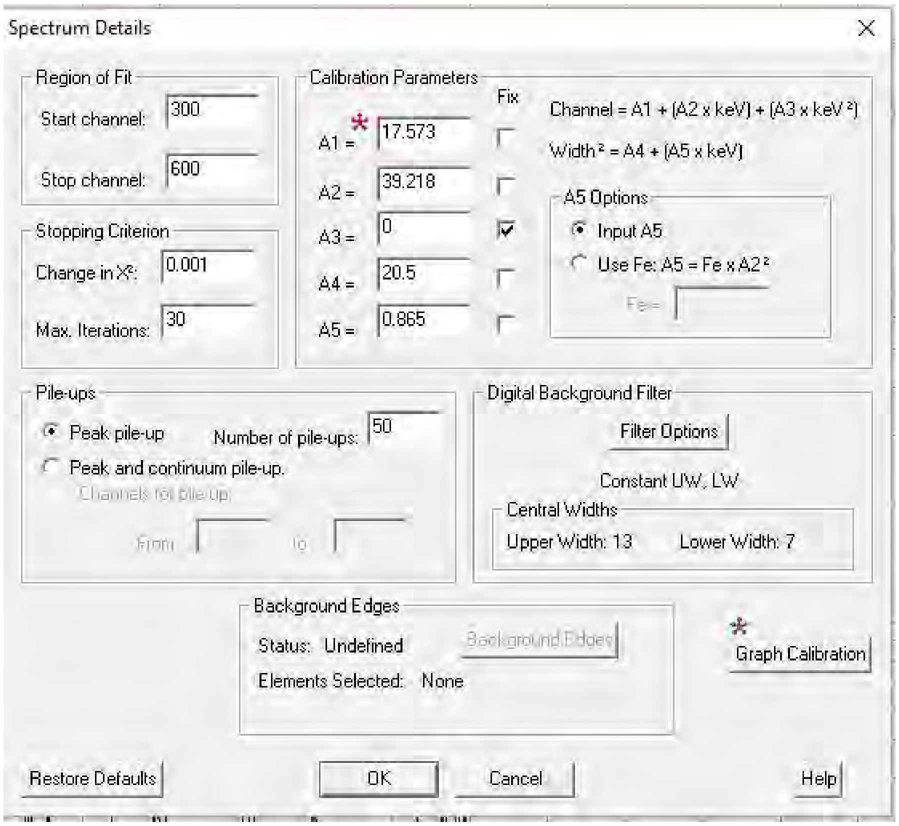


FIGURE 3.2: A plot of the channel numbers determined by *Gupix* versus the known energies of the peaks. The line is a fit to the data whose slope and y-intercept determine the energy calibration constants.

other two values, and other constants we measured from our standards. *A5* was resolved by the equation $A5 = Fe * A2^2$ where Fe is the energy of the K-alpha transition of iron. The *A4* parameter was a little bit more complicated. It was determined by measuring the width of the Fe-peak, then subtracting *A5* from that number. We measured the width by finding the halfway point of the Fe peak, then used the energy calibration tool in *Gupix* to determine how wide the peak was at that point.

After we determined the energy calibration parameters, we had two more parameters to find: the thickness of the aluminum filter and the H-factor, or solid angle of the detector, which we found at the same time. We entered our energy calibration parameters into *Gupix* and an estimate for the thickness of the aluminum filter. The samples were composed of a known concentration of specific elements. We entered what element or



Spectrum Details

Region of Fit
Start channel: 300
Stop channel: 600

Stopping Criterion
Change in X^2: 0.001
Max. Iterations: 30

Calibration Parameters
Fix
A1 = 17.573 ☐
A2 = 39.218 ☐
A3 = 0 ☑
A4 = 20.5 ☐
A5 = 0.865 ☐

Channel = A1 + (A2 x keV) + (A3 x keV ^{2})
Width^2 = A4 + (A5 x keV)

A5 Options
● Input A5
○ Use Fe: A5 = Fe x A2^2
Fe =

Pile-ups
● Peak pile-up
Number of pile-ups: 50
○ Peak and continuum pile-up.
Channels for pile up
From to

Digital Background Filter
Constant UW, LW
Central Widths
Upper Width: 13
Lower Width: 7

Background Edges
Status: Undefined
Elements Selected: None

FIGURE 3.3: A screen-capture image of the calibration screen in *Gupix*, we use our energy calibration to determine constants *A1* through *A5*.

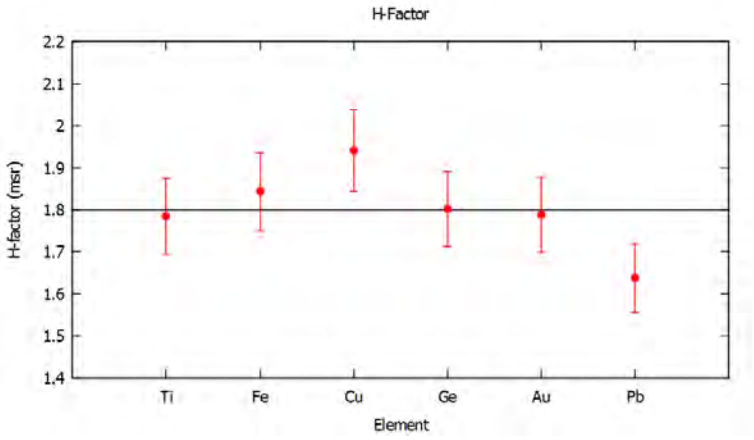


FIGURE 3.4: A plot of the H-factor versus Z which is simply the measured concentration found with H set to 1, divided by the known concentration. The average value for the H-factor was 1.8 msr.

elements we knew were in the target into Gupix, then had Gupix use *Equation 2.1* to calculate the concentrations of the standard targets. Using a spreadsheet, we recorded the actual concentration of the standards and the *Gupix*-measured values on the same table. We divided the measured concentrations by the actual concentrations, which gave us an H-value for every sample, each with a different Z and plotted these H-values versus Z. Based on the general trends of these points on the plot, we adjusted the value of our aluminum filter. When the points on the plot fell into as horizontal of a line as possible, we used the average H-value as our H-factor. The thickness of the aluminum filter was kept at the value which gave us our H-factor. Our plot of the H-factor vs. Z is shown in *Figure 2.10*.

3.1.2 Gupix Calibrations

As soon as we had all of the parameters needed to calibrate the system, we used *Gupix* to determine the elements in the sample and calculate the concentrations of these elements. We opened up our data in the software and told the computer the amount of charge on the sample and which elements we wanted to identify. *Gupix* searched for these elements and determines whether or not they are in the sample, then used *Equation 2.1* to determine the concentrations of the elements. It then gave us values for all of the statistical errors and plot fit errors for the concentrations. When *Gupix* gave us back our composition and concentration results, it also gave us a Chi^2 value for the quality of the fit of the spectrum as well as plots of the fitted spectra and a plot of the differences between the fit and the data. The quality of the fit, and the error associated with the fit was related to all of our calibration parameters as well as the elements we search for in the sample. This feature is great for ensuring we are not missing any elements that could be in our sample, as a missing element causes the errors in the fit to be rather large.

As soon as we were satisfied with the results which *Gupix* gave us, we exported the data to create plots which made comparing the data from one sample to another much easier. For the results of this study, we plotted the concentrations and compositions of two of our clumps of infill as well as the concentrations and compositions of our turf blades.

Chapter 4

Results

4.1 Results

Because of recent concerns of the health risks involved in artificial turf, we decided to perform this study to search for the composition of artificial turf infill in order to determine possibly toxic elements in the turf. We also looked at the concentrations of these elements in the artificial turf and turf blades in order to determine the level of toxicity in artificial turf. We found some interesting results for both the turf infill and the blades, including the presence of bromine in the infill samples.

4.1.1 Turf Blades

We did not find any toxic substances in the turf blades, but we did find other interesting results. As can be seen in *Figure 4.1*, the composition of the material was different for each color of blade, as well as the concentrations of each element, shown in *Figure 4.2*. The gold peaks in all of the samples were caused by the gold coating we put onto the blades to keep them from charging. Differences in the elemental composition in the different colored samples were due to the pigments used to dye the plastic different colors

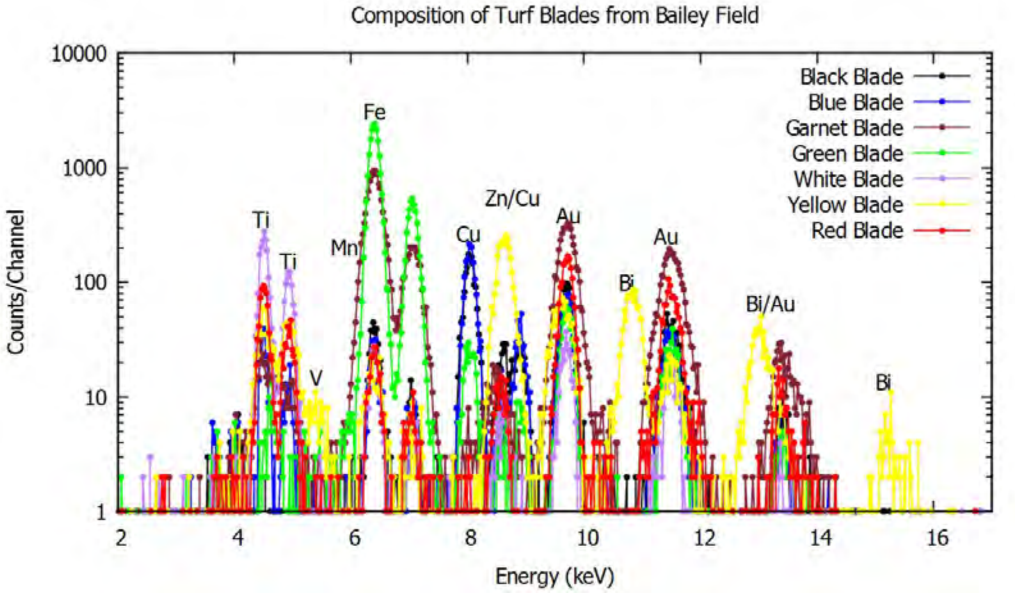


FIGURE 4.1: A comparison of the PIXE spectra taken on the seven different colors of turf blades. The most interesting thing about this plot is simply how different the composition of each color of the turf is. The peaks on the right end of the spectrum come from the gold we coated the blades in to prevent charge from accumulating on them.

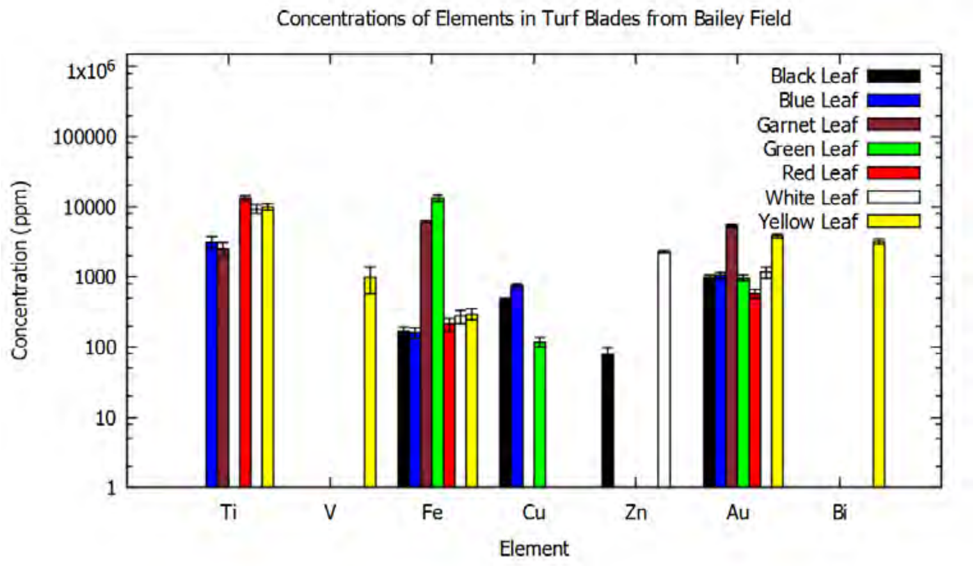


FIGURE 4.2: A comparison of the concentrations of elements in the seven different colors of turf blades. The large, and varying amounts of gold come from the coating we put on the blades so that they did not hold charge.

before the blades were created in a mold. By looking at the composition of the elements, *Figure 4.1*, we determined the most likely pigment used for each color blade. The bismuth and vanadium peaks in the spectrum taken on the yellow blades indicates the pigment bismuth vanadate, which is a bright yellow pigment commonly used as an environmentally friendly yellow pigment [11]. The titanium peak in the spectrum taken on the white pigment indicates a common white pigment, titanium dioxide. The garnet blade is probably composed of an iron-oxide pigment, often used in red and brown pigments. The two dominating elements in the green pigment are copper and iron, but these elements are found in most green pigments, so we cannot identify the exact green that was used [11]. The red and black blades also do not have enough distinctive elements to conclude a pigment, and could both be a variety of common pigments of their respective colors.

We would like to have more chemical information in order to determine the pigments we do not know, but the results of these spectra are still interesting and allow us to wonder if we would see the same pigments used in other turf blades, or if other manufacturers used different pigments to color their blades.

4.1.2 Turf Infill

The turf infill also provided us with some interesting results. *Figure 4.3* shows a comparison of PIXE spectra collected on two of the infill samples. The concentrations of the heavy metals measured in these two samples are compared in *Figure 4.4*. All of the infill samples that were analyzed contained a rather large concentration of Fe, Cu and Zn. The two samples which are shown in *Figure 4.3* also contained bromine. As can be seen in *Figure 4.4*, the concentration of the bromine is much less than most of the other metals. *Figure 4.4* also shows a relatively constant concentration of the zinc, copper and iron, but the concentration of bromine is very different between samples. Coupled with the fact that we only saw bromine in two of the targets, we can infer that the material is not homogeneous.

The presence of the bromine is the most interesting part of these spectra. Bromine is a common element used in flame retardants, and is likely used in racing tires as a flame retardant [12]. The infill is normally made of crumb rubber which is often old crushed up tires. Racing tires are changed and used up so frequently that it would not be surprising if these racing tires were a large part of what makes up crumb rubber. This would mean that small amounts of the flame retardant are being put into the infill.

The maximum concentration of bromine was 1400 ± 200 ppm. While it is only a small amount, not harmful for the average person, it could pose a larger problem for someone who spends extended periods of time on this surface and could be potentially inhaling it, like a professional soccer goalie, for example [3]. Bromine is not known to cause cancer, but being exposed to it regularly can cause a malfunctioning of the central nervous system and even DNA damage [12].

The larger issue of having bromine in the turf is the environmental effects. Bromine can be corrosive to human tissue, and also animal tissue. Studies have determined that extended exposure to bromine by animals can corrode their tissue, and cause central nervous system damage or even damage to their DNA [12]. Another interesting feature of our results is a large zinc peak in all of our samples. While zinc is not toxic to humans at this concentration, it is very dangerous for animals. Animals also do not have to come into direct contact with the turf in order to have these health effects. The bromine and other toxic substances, like zinc, can leach into the environment through the water. Not only do the animals drink this water, but the chemicals leech into the plants, which animals eat [4].

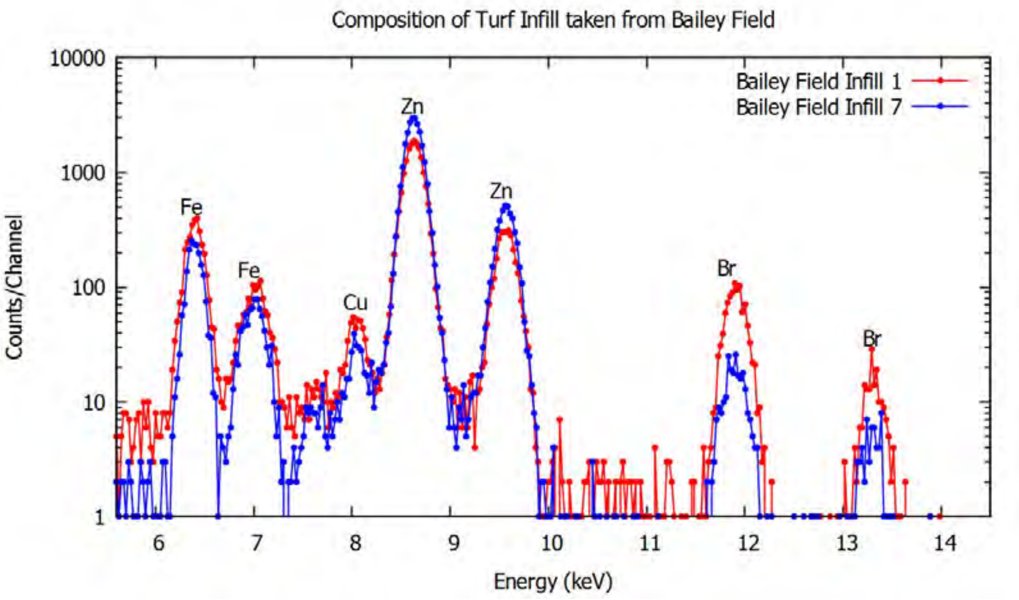


FIGURE 4.3: A comparison of PIXE spectra collected on two infill samples.

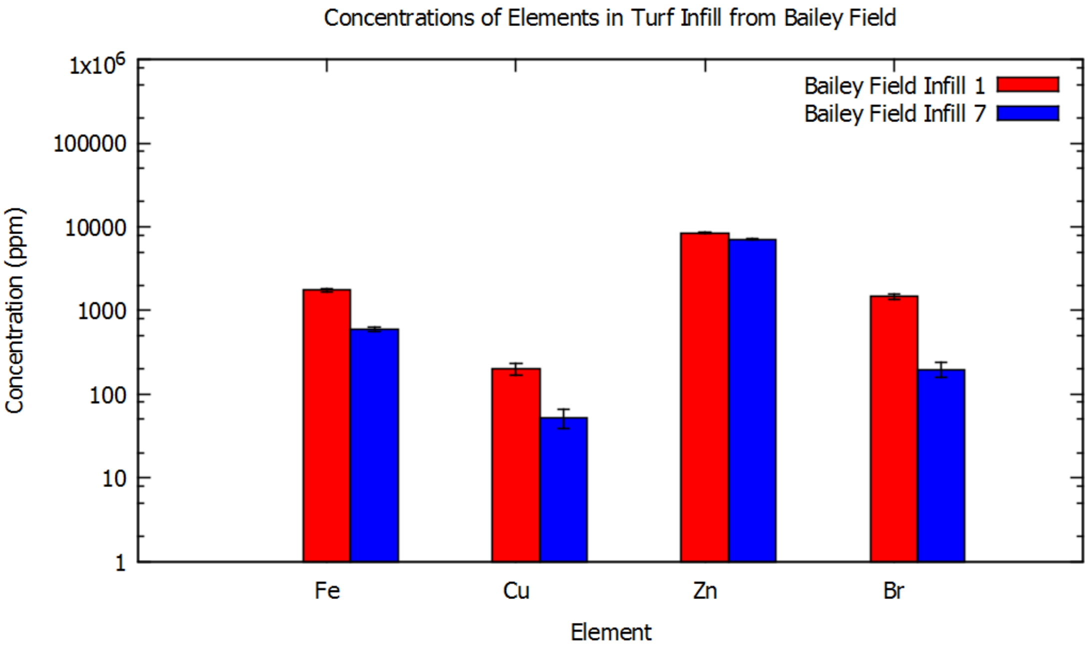


FIGURE 4.4: A comparison of the concentrations of the elements in two turf samples which contained Bromine.

Chapter 5

Summary

5.1 Summary

We set out in this research to determine if there could be potential health risks linked to artificial turf. Recent studies have found heavy metals and flame retardants in crumb rubber used in artificial turf, which is thought to be linked to an increase in lung cancer among soccer goalies [3]. We performed this research in the Ion-Beam Analysis Laboratory at Union College and collected all of our samples from Bailey Field at Union College. We used PIXE analysis and the *Gupix* software program to determine the composition and concentrations of elements of our samples. We took our preliminary data using an external beam facility at Union College, but ultimately discovered it could not give us the quantitative data we were looking for. We also took PIXE data on the blades of the artificial turf. We did not find any toxic substances in the blades, but it was interesting to attempt to identify the pigments used to color the plastic blades. While we did not find significant concentrations of heavy metals in the turf infill, we determined that there was bromine, a common flame retardant and sanitizer, in some of the turf. Bromine is not a known carcinogen, but it can cause health problems in humans. We also found high concentrations of zinc in our samples which is not hugely toxic for humans, but is hazardous for animals and the environment.

All of these results are preliminary, we plan to expand this research in the future by examining the turf on other fields to see if we obtain the same results. We also plan to create pellets out of the crumb rubber in order to create a more homogeneous target which will give us more accurate data. Finally, we would like to take data on turf that has been exposed to different extreme temperature conditions to determine if any of the toxic substances are radiated into the air when the turf heats up. Bromine is especially volatile in its gaseous state [7], so we want to determine if heat causes the bromine in the samples to escape pellets and become air-born.

Bibliography

[1] David Wharton. "Are synthetic playing surfaces hazardous to athletes' health? The debate over 'crumb rubber' and cancer". *The LA Times*, 28 Feb 2016.

[2] Hannah Rappleye. "How Safe is the Artificial Turf Your Child Plays On" *NBC News*. 8 October 2014.

[3] Sabine Martin, Wendy Griswold. "Human Effects of Heavy Metals". *Center for Hazardous Substance Research, Center for Hazardous Substance research. Kansas State University* Issue 15. March, 2009. www.engg.ksu.edu/CHSR/

[4] Connecticut Department of Environmental Protection. *Artificial Turf Study: Leachate and Stormwater Characteristics*. July 2010.

[5] "OEHHA Synthetic Turf Scientific Advisory Panel Meeting". *CalEPA*. Sacramento, CA. March 10, 2017.

[6] "Federal Research on Recycled Tire Crumb Used on Playing Fields". *United Stated Environmental Protection Agency*

[7] "Bromine: Toxicological Overview" Public Health England. Toxicology Department, CRCE, PHE. 2009.

[8] S.A.E. Johansson, J.L. Campbell, K.G. Malmqvist, *Particle-Induced X-Ray Emission Spectrometry* (PIXE), Wiley, New York, 1995.

[9] J.F. Ziegler, M.D. Ziegler, and J.P. Biersack, “SRIM-The stopping and range of ions in matter,” Nucl. Instr. Meth. Phys. Res. B 268, 1818 (2010).

[10] J.A. Maxwell, W.J. Teesdale, and J.L. Campbell, “The Guelph PIXE software package II,” Nulc. Intrum. Meth. Phys. Res. B 95, 407 (1995).

[11] Julie C. Sparks. "Pigments: Historical, Chemical, and Artistic Importance of Coloring Agents". *The Painted World*. 2000.

[12] "Bromine: Health Effects of Bromine, Environmental Effects of Bromine and Chemical Properties of Bromine". *Lenntech*. Delft, Netherlands. 2017. lenntech.com