Development and Commissioning of an External Beam Facility

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1. Introduction

We have developed an external proton beam facility at the Union College Ion Beam Analysis Lab to analyze samples without having to put them under vacuum. The facility was commissioned by performing proton induced X-ray emission (PIXE) analyzes of artificial turf infill, running track material, and a human tooth with an amalgam filling.

2. PIXE

Proton induced X-ray emission is an ion-beam analysis technique in which a sample is bombarded with a proton beam with an energy of a few MeV that will occasionally knock out an inner shell electron from an atom in the sample [1]. Figure 1 shows a proton ejecting an electron from an atom. An outer shell electron fills the vacancy and in doing so, loses energy in the form of an X-ray, as shown in Figure 2. The energies of the emitted X-rays identify the elements present in the sample and the intensity of the X-rays can be used to determine the concentrations. The concentration $\mathbf{C}_Z$ of an element Z in the sample can be calculated using the equation

$$C_Z = \frac{Y_Z}{Y_t * H * Q * \varepsilon * T}$$

where Y_Z is the intensity of the principle X-ray line for element Z, Y_t is the theoretical intensity per μC, H is an experimental constant determined by taking data on a set of standards, Q is the measured beam charge incident on the sample, ε is the intrinsic efficiency of the detector, and T is the coefficient for transmission through any filters or absorbers between the target and the detector.

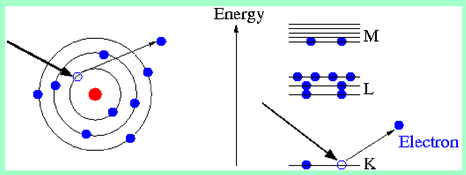

Figure 1: *Diagram of the ejection of an inner shell electron by a proton.*

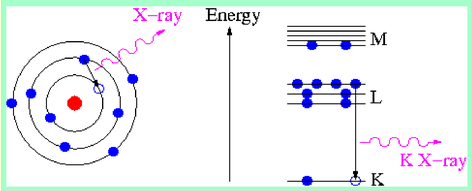

Figure 2: *An X-ray is emitted when an outer shell electron fills the vacancy.*

3. External Beam Facility

An external beam facility was developed for the Union College Pelletron accelerator shown in Figure 3. It was constructed with a 1.25" outer diameter aluminum beam pipe with a 7.5-μm thick Kapton window supported by an end cap with a 1/4" diameter hole. Photographs of the Kapton foil used for the window and the external beam facility along with X-ray and γ-ray detectors are shown in Figures 4 and 5, respectively. Simulations were performed with SRIM [2] to determine the energy of the proton beam at the target position 2 cm away from the window. The results of the simulation for a 2.2-MeV proton beam traveling through the Kapton window and about 8 cm of air are shown in Figure 6. It was determined that the energy of the proton beam 2 cm away from the window was 1.7 MeV. Shown in Figure 7 is a photograph of the proton beam in air. The blue-violet glow of the beam is the deexcitation of nitrogen in the air.

Figure 3: *A photograph of the Union College Pelletron accelerator.*

Figure 4: *A photograph of the 7.5-μm thick Kapton foil used for the vacuum window.*

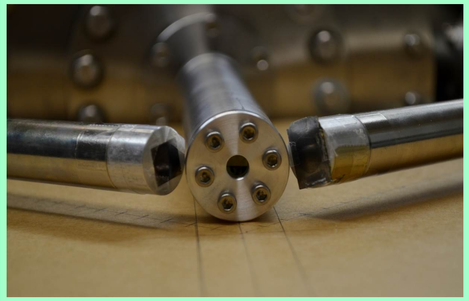

Figure 5: *A photograph of the external beam facility with an X-ray detector (left) and a γ-ray detector (right).*

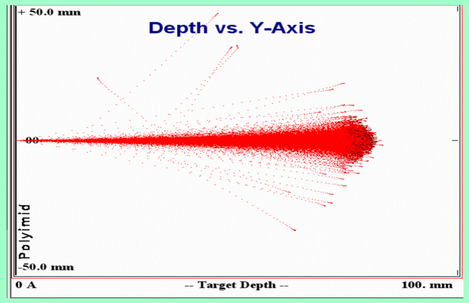

Figure 6: *The results of a SRIM simulation [2] of a 2.2-MeV external proton beam after travelling through the Kapton window.*

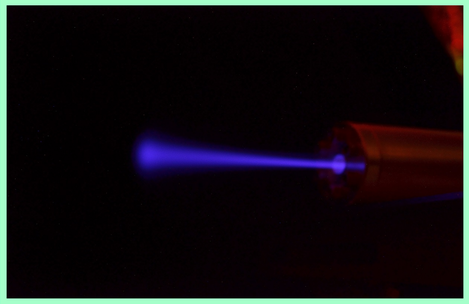

Figure 7: *A photograph of the external proton beam in air.*

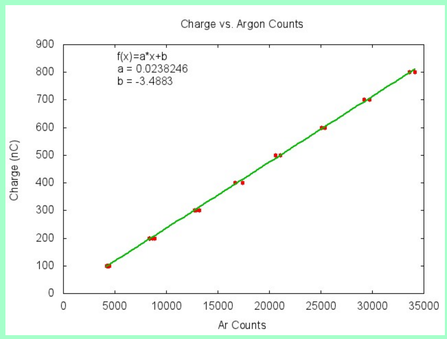

Figure 8: *A graph of the accumulated charge vs. the measured argon counts.*

4. PIXE Analysis

The PIXE experiments were performed using 1.7-MeV external proton beams with currents of 1-12 nA. The beams were incident on samples positioned 2 cm from the exit window. The emitted X-rays were detected with a silicon drift detector after passing through a 76-μm thick Be filter and 4 cm of air. X-ray spectra were acquired for each sample and a set of standards [3]. The relative normalization of the spectra was determined using the strong X-ray peaks from Ar in air (see the blue spectra in Figures 9-11). To estimate the beam charge incident on the samples, we measured the charge in a Faraday cup positioned 2 cm from the window as a function of the X-ray yield from Ar in air. The results shown in Figure 8.

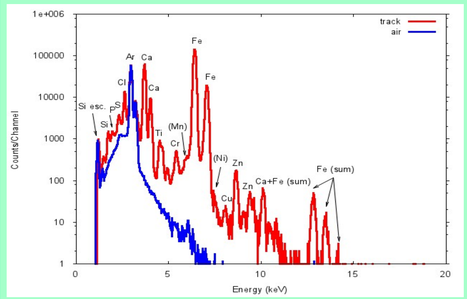

Figure 9: *PIXE spectra of the running track sample and air.*

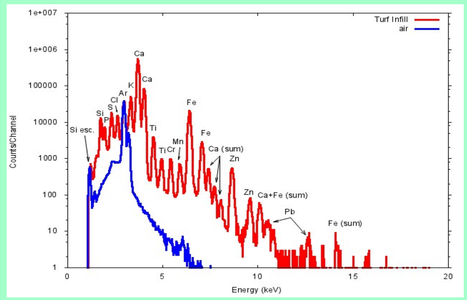

Figure 10: *PIXE spectra of the turf infill sample and air.*

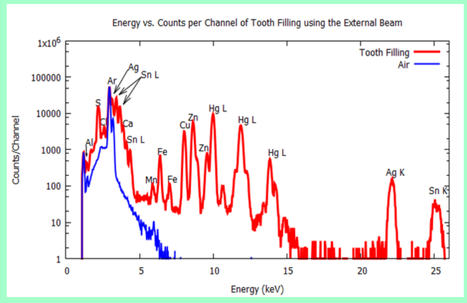

Figure 11: *PIXE spectra of the amalgam tooth filling and air.*

5. Results

Figures 9 and 10 show PIXE spectra from artificial turf infill and running track samples taken at Union College. Elements ranging from silicon to zinc were detected in both samples. Trace amounts of lead were found in the turf infill sample, perhaps justifying recent concerns about the safety of artificial turf [4]. Shown in Figures 11 and 12 are PIXE spectra taken on an amalgam tooth filling and the tooth containing the filling. Comparing these spectra, we see that there are significant concentrations of heavy metals such as silver, tin, and mercury in the tooth filling, but only trace amounts of these metals have leached into the tooth itself.

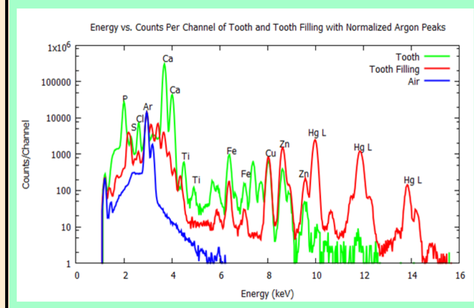

Figure 12: *PIXE spectra of the tooth, amalgam tooth filling, and air.*

6. Acknowledgements

We would like to thank the Lee L. Davenport Fellowship Program and the NY NASA Space Grant Program for research funding and the Union College Department of Physics and Astronomy for research support. We would also like to thank John Sheehan for his help in the development of the external beam facility.

References

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[2] J. F. Ziegler, J. P. Biersack, and M. D, Ziegler. SRIM-The Stopping and Range of Ions in Matter. V 15 (2015) (www.SRIM.org).

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[4] Hannah Rappleye. How Safe Is the Artificial Turf Your Child Plays On? NBC. October 8, 2014.