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Characterizing a Tape Station and β Detector for Radioactive Isotope Beam Experiments

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Introduction

In order to better understand the nucleosynthesis of heavy elements, advanced techniques are needed to study decays of neutron-rich nuclei and to constrain astrophysical models. In conjunction with the Summing NaI(Tl) detector (SuN) at the NSCL, a tape station is being developed to optimize these measurements. Normally there is a foil target in the center of SuN, which would be ideal for capturing isotopes from rare isotope beams. However, these can be far from stability with subsequently daughter isotope decays causing unwanted background radiation. For this reason a new tape station was developed. The present work focuses on the characterization of this tape system and associated equipment

The SuN Detector

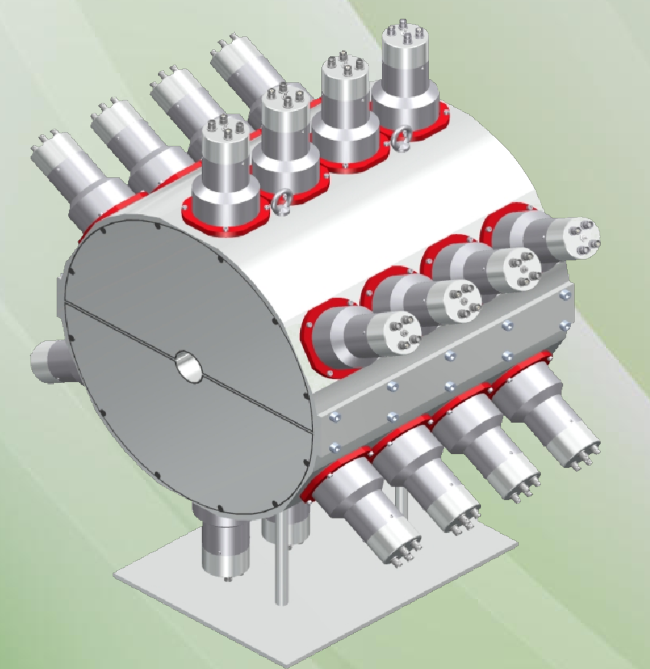

Figure 1. *SuN (Summing NaI(Tl)) is a barrel shaped scintillator detector, divided into eight optically isolated segments. Each of the segments is read by three photomultiplier tubes (PMT), for a total of 24 signals from the detector [1].*

The SuN detector is a high efficiency detector, with a 45mm bore-hole through its center. The tape station along with the a fiber charge-particle detector is designed to fit inside, such that the implantation point for a radiation rich isotope beam will be at the center of the detector. After implantation, the tape is able to rotate and remove the implanted isotopes so that they are isolated from the SuN detector.

Fiber Detector Spectra

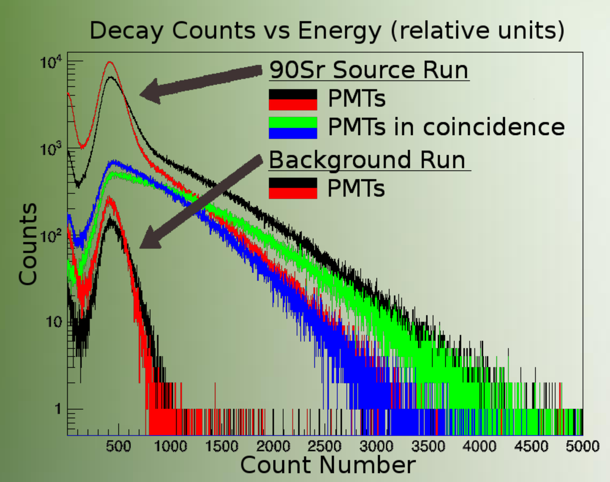

Figure 2. *The β signals received from our two PMTs (black and red) and in coincidence with one another (blue and green) for ^{90}Sr and background runs.*

Demonstrated in the above plot, the settings are adjusted such that the background coincidence signals are negligible when compared to the source signals.

Characterizing a New Scintillating Fiber Beta Detector

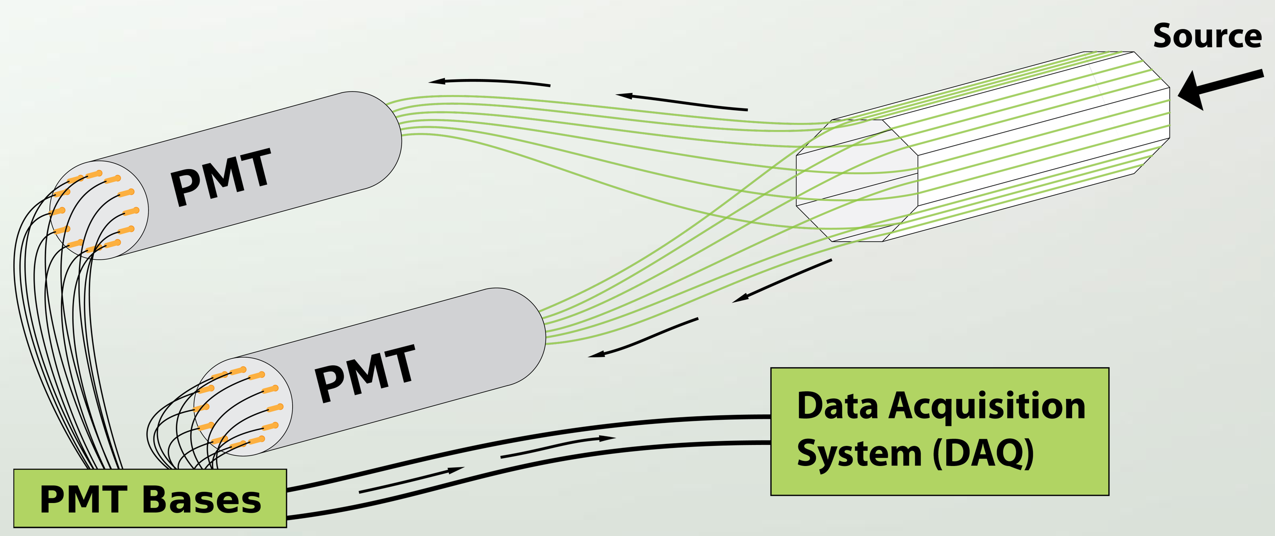

Figure 3. *The scintillating detector attached to wavelength shifting fiber optic cables that carry the signal to two PMTs. After entering the PMTs the signals are recorded via the NSCL digital data acquisition system [2].*

A new scintillating detector developed at Hope College has been studied. It is attached to wavelength shifting fibers to work in conjunction with the tape station for β detection. The detector utilizes two PMTs that are attached to fibers in order to detect β decays in coincidence with one another. This allows detection of a higher percentage of 'real' signals instead of background. The setup is designed to be used under vacuum within the tape station. The main focus of the present work was to study the general characteristics, such as optimal settings, position dependence, and others using ^{207}Bi and ^{90}Sr sources.

The Tape Station (SuNTAN)

The tape station is a system in which a portion of thin film (shown in figure 4) is located such that it can be the target of a radioactive isotope beam in the center of the SuN detector. Instead of a foil target there is a 'tape', which acts as the target, but is actually a long, continuous loop, so the target can be moved to an isolated chamber and replace it with a fresh one.

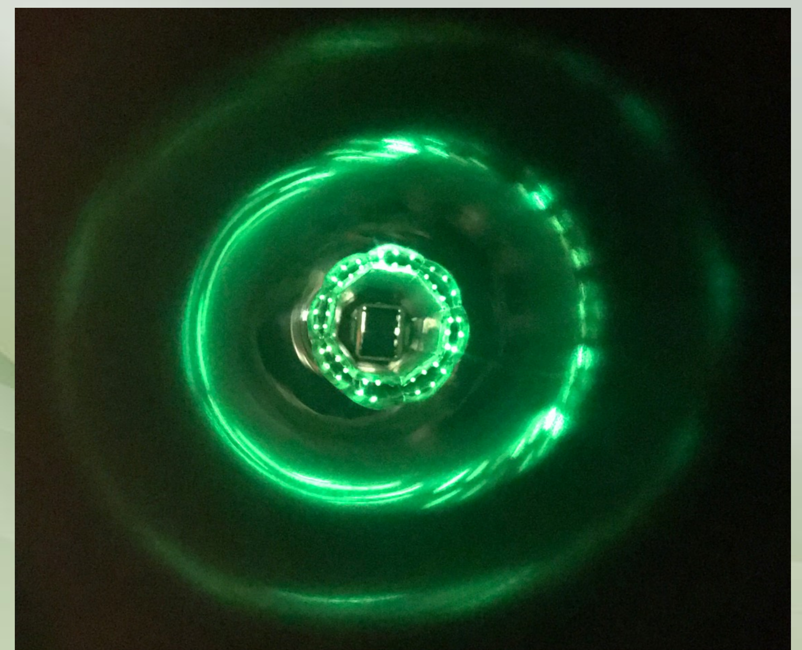

Figure 4. *The scintillating fibers carrying light signals for ambient room lights while closed off in a tube. The implantation point (tape) is centered with the fiber detector around it. The outer two rings are reflections on the beam pipe.*

The tape station is designed so that it can be integrated with the fiber detector described above (figure 5). The design is such that decays from quickly decaying neutron rich isotopes can be studied using the SuN detector alongside the fiber detector while the tape station acts as a mechanism to minimize the contamination.

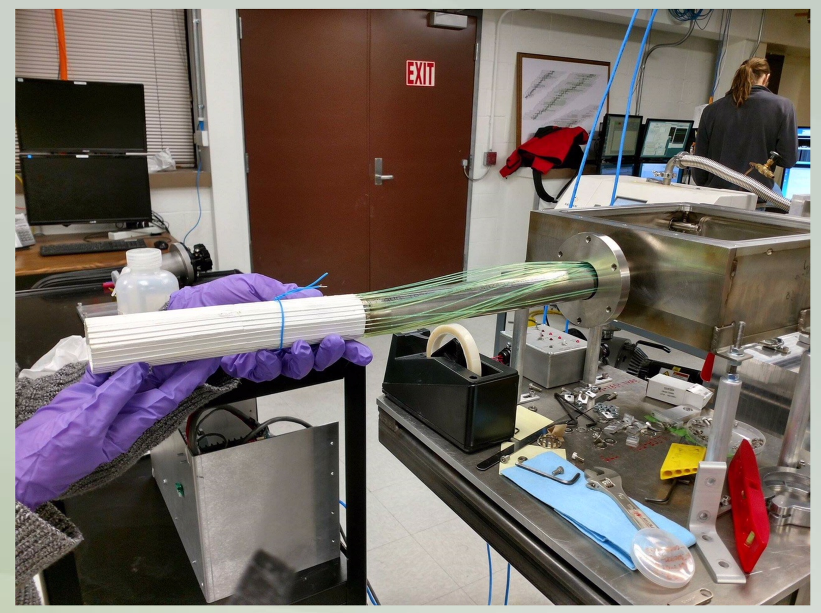

Figure 5. *The scintilating fiber detector integrated with the tape station. The detector itself goes directly over the implantation point of the tape station and the fibers lead into a closed chamber where the PMTs are held.*

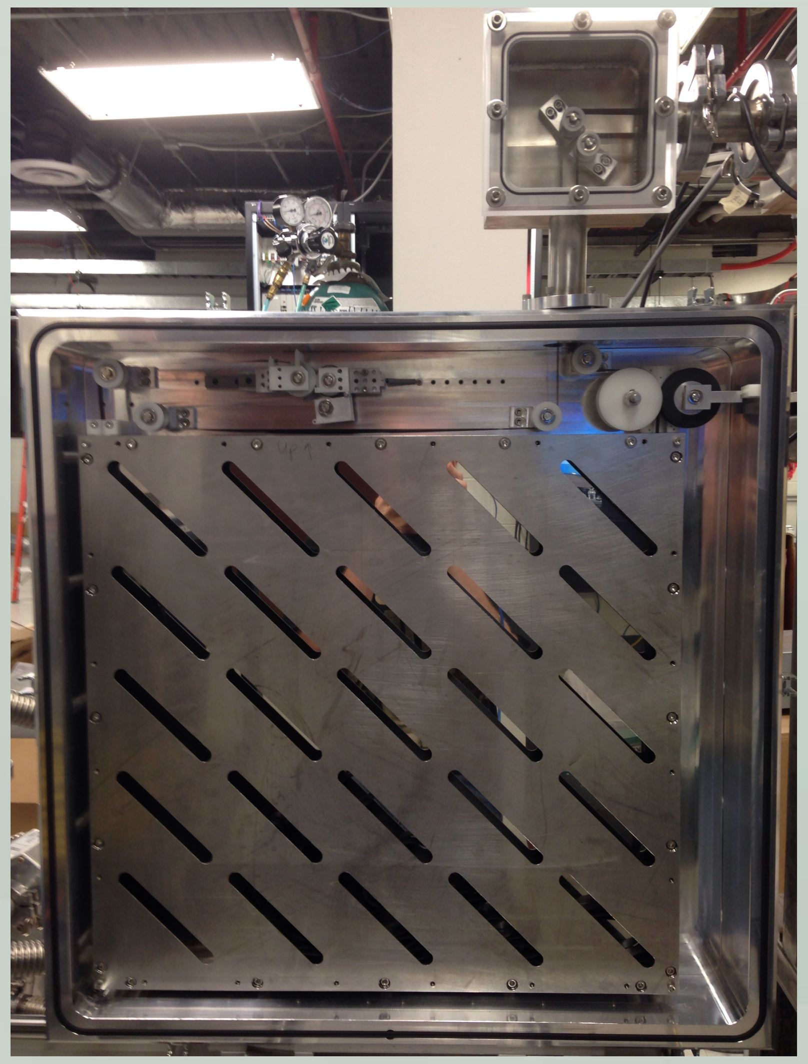

Figure 6. *The isolated tape box where all of the tape is stored and removed to when the tape station is set to rotate.*

The whole system is vacuum sealed. It contains an isolated chamber (figure 6) where many meters of the contaminated tape is moved to. The chamber itself is to be isolated from the SuN detector allowing the removal of unwanted radiation.

Future Work

A commissioning experiment, using a radioactive ion beam of ^{42}S, is planned for early December. Preparation is underway to determine how the system will perform. The simulation from GINA (figure 7) will be used to determine the optimal frequency at which the tape is rotated.

GINA

GINA (generations of implanted nuclear activity) is a program designed to simulate the contamination and other aspects of an implanted radioactive material. Using an approach similar to numerical integration with steps Δt, one can determine the particle numbers (N_n), decay rates (D_n), and total contamination (C_n) of an implanted isotope (denoted with superscript 0) relative to its daughter nuclei (denoted with superscript i) using their half-lives ($T_{1/2}$) at any given time ($n\Delta t$).

$$N_n^{(0)} = N_1^{(0)} + N_{n-1}^{(0)} e^{-\frac{\Delta t}{T_{1/2}^{(0)}}\ln(2)} \tag{1}$$

$$N_n^{(i)} = N_{n-1}^{(i-1)} - N_{n-1}^{(i-1)} e^{-\frac{\Delta t}{T_{1/2}^{(i-1)}}\ln(2)} + N_{n-1}^{(i)} e^{-\frac{\Delta t}{T_{1/2}^{(i)}}\ln(2)} \tag{2}$$

$$D_n^{(i)} = \frac{dN_n^{(i)}}{dt} = \frac{N_n^{(i)}\ln(2)}{T_{1/2}^{(i)}} \tag{3}$$

$$C_n = \frac{1}{D_n^{(0)}} \sum_{k=1}^{\infty} D_n^{(k)} \times 100\% \tag{4}$$

This program can determine the optimal timing for rotations of the tape station during experiments.

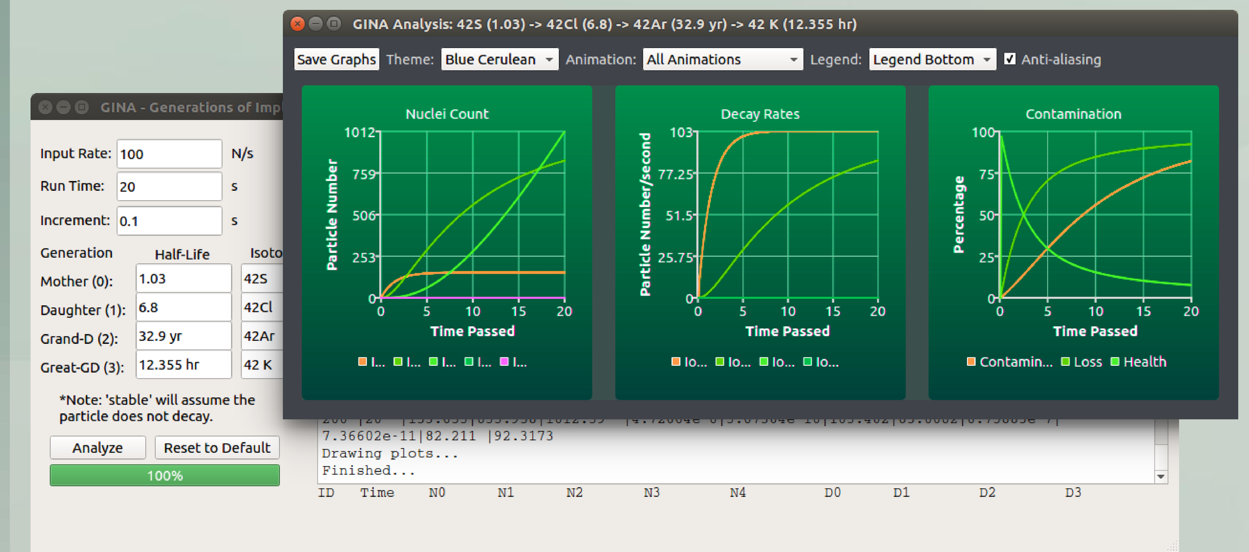

Figure 7. *A snapshot of the GINA program determining particle numbers, decay rates, and contamination for a four isotope decay process [3,4].*

Addendum & References

QR codes for the GINA source and a video of SuNTAN respectively.

[1] Simon, et. al. Nucl. Instr. Meth. A 703 (2013) 16
[2] Prokop et. al. Nucl. Instr. Meth. A 741 (2014) 163
[3] https://msu.edu/ torodean/GINA.html
[4] http://www.nndc.bnl.gov/chart/