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LOW ENERGY NUCLEAR CROSS SECTION MEASUREMENT FACILITY AT CROCKER NUCLEAR LABORATORY AT THE UC DAVIS*

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Abstract

The vast majority of nuclear physics simulations are dependent on the National Nuclear Database, maintained at Brookhaven National Lab, and these in turn are all based on published experimental measurements. Even today, there are gaps in this database in low energy ranges, which can be filled even by older machines. In addition to the scientific output, these measurements provide a unique educational opportunity. The cyclotron at the Crocker Nuclear Laboratory at UC Davis is capable of accelerating protons, deuterons, or alpha particles to variable energies up to a maximum of 67.5 MeV for protons. We have developed a facility to perform "stack foil" cross section measurements, in which stacks of target foils sandwiched with degraders are exposed to proton or deuteron beams, thus allowing us to exploit the energy loss through the stack to measure energy dependent cross sections in a single exposure. Daughter nuclei are assayed using a high purity germanium (HPGe) detector.

This poster will describe the facility, including the range of available beam parameters and energy and current calibration, as well as presenting some preliminary cross section measurements. Future plans will also be discussed.

INTRODUCTION

The data needs of the nuclear physics community are well-documented [1], and this community relies heavily on measured cross section data for such things as

- astrophysics
- space exploration
- nuclear energy
- clean energy generation
- national security
- nonproliferation
- basic science
- medical isotope production

Cross section data are maintained at the National Nuclear Data Center [2] at Brookhaven National Laboratory.

Although low energy measurements have been going on for a very long time, there are still gaps in the data, and it is our goal to develop this facility to measure them, in addition to providing unique education and training opportunities.

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EXPERIMENTAL TECHNIQUE

Cross Section Measurement

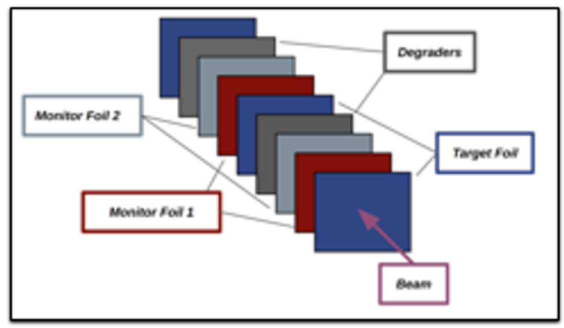

Figure 1: Schematic illustration of the stacked foil technique. Target foils are interspersed with monitor foils and degraders.

We will use a standard "stacked foil technique", as illustrated in Fig. 1 [3]. The target foils of interest are interspersed with both monitor foils and aluminum degraders. The monitor foils are made of materials with well-know production cross sections and are used to calibrate the measurement. The combination of the foils and degraders causes the beam to lose energy through ionization in a precisely predictable way, thus allowing the measurement of energy dependent production cross sections in a single exposure.

After exposure, the target and monitor foils are assayed using a High Purity Germanium (HPGe) detector and the Curie analysis software [4].

Crocker Nuclear Laboratory

The Crocker Nuclear Laboratory [5], at UC Davis, is home to the 76" Cyclotron, which can accelerate protons, deuterons, helions, or alpha particles to variable energies, up to 67.5 MeV for protons. Figure 2 shows the layout. Extracted beam goes through a switch magnet, from which it can be directed to one of 7 beam lines. Three of these are internal to the cyclotron vault and four go to three external caves, as shown. The external lines are limited to 100 nA for radiation safety reasons, while currents can go to at least 5 µA inside the vault. As indicated in the figure, "Line 0", which was historically used for isotope production, has been chosen as the location for cross-section measurements, both because of the higher available current and the ability to attach a vacuum box for extended periods.

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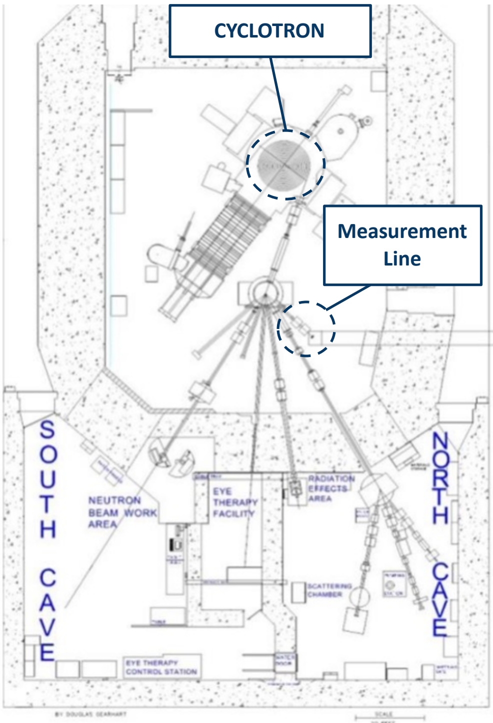

Figure 2: Layout of the cyclotron, showing the location of the cross-section measurement area.

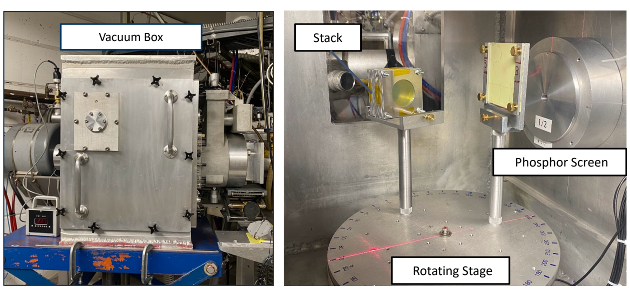

Figure 3: The vacuum box. At left is shown the box closed up, while the right shows the turntable that can be used to swap in the phosphor screen and the target stack.

Exposure Area

Fig. 3 shows the vacuum box, which has been mounted at the end of Line 0. A remotely operated turntable allows one to rotate in a phosphor screen for beam tuning, and then rotate the target stack into place for exposure.

As series of profile measurements using gafchromic film show that the beam profile remains uniform over the length of the stack, as shown in Fig. 4. Gafchromic film was also used to produce a Bragg Peak distribution, which was consisted with the nominal beam energy of 67.5 MeV.

FIRST MEASUREMENT

Two cross section measurements were attempted in the Summer of 2022, under the auspices of the Nuclear Science and Security Consortium NSSC [6]. The first was during the Nuclear Analysical Techniques (NAT) Summer School [7].

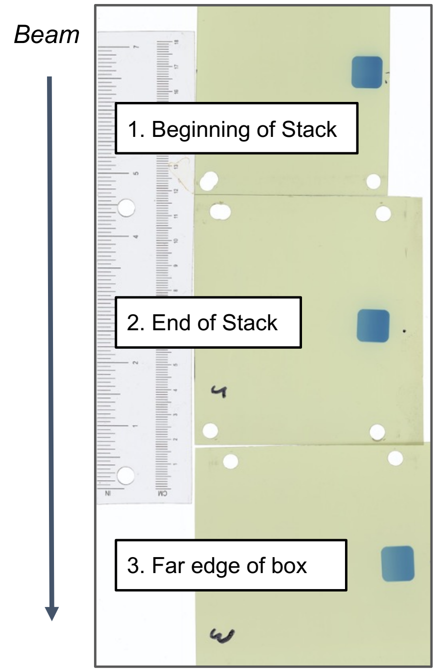

Figure 4: Gafchromic profile measurements made over the range of he stack, showing that the profile remains uniform.

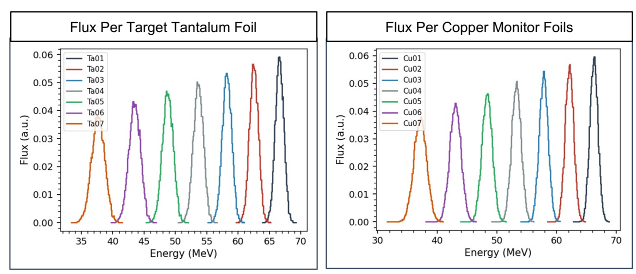

Figure 5: Flux simulation for 67.5 MeV incident beam, in both the copper monitor foils and the tantalum target foils.

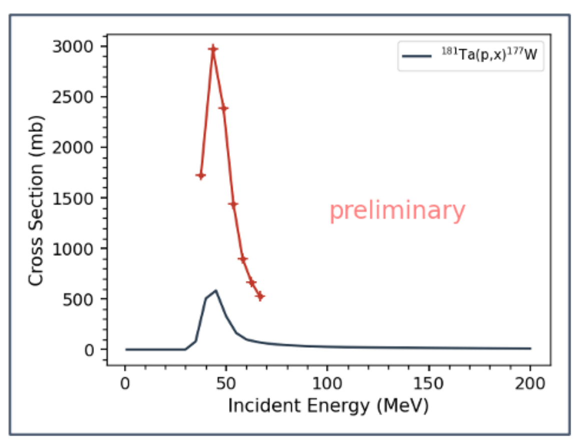

Figure 6: Preliminary result for the reaction ^{181}Ta(p,x)^{177}W.

This was done in air, which resulted in some problems and ambiguous results. The second was done in conjunction with Nuclear Data Summer School [8], using the vacuum chamber described in the previous section.

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For an initial measurement, a ^{181}Ta target was chosen, as the ^{177}Ta, ^{180}Ta, and ^{178}W, daughter products are all Auger electron emitters, with potential use for cancer treatment [9]. The tantalum foils were interspersed with natural copper monitor foils, which have several well-known calibration reactions [10], as well as aluminum degraders.

Fig. 5 shows the predicted flux as a function of energy in both of these foils, showing that this allows us to measure cross sections over a range of 35 to 67.5 MeV.

Fig. 6 shows the preliminary result for ^{181}Ta(p,x)^{177}W, compared to a simulation using the TALYS package [11]. As you can see, the shape is correct, but there appears to be an overall scale disagreement. We are working to understand whether this is real or an artifact of the measurement technique.

CONCLUSIONS AND FUTURE PLANS

We have commissioned a facility at Crocker Nuclear Laboratory to measure low energy production cross sections from proton, deuteron, helion, or alpha beams. These measurements are interesting in their own right, as input to the NNDC or as data for nuclear models, but the facility also offers unique education and training opportunities for both undergraduate and graduate students.

We will continue to improve the facility, working to gain confidence in the normalization. We also plan improvements to the vacuum box to allow more flexibility to alternate between exposure and beam monitoring.

This facility will continue to be part of our training programs and hopefully will start generating useful nuclear data soon.

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