Measuring ^{nat}La(p,x) Cross Sections from 35-60 MeV by Stacked Foil Activation

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Introduction

Proton induced nuclear reactions in the tens of MeV range can be used for the production of radioactive isotopes with minimal contaminants, which makes them a compelling production mechanism for medical diagnostic and therapeudic isotopes [1, 2].

In this experiment, we measure the ^{nat}La(p,x) reaction cross sections with a particular interest in the (p,6n) reaction on ^{139}La (99.9119% n.a.) [3] for the production of ^{134}Ce.

Methodology

Measurement of these reaction cross sections was performed using the stacked foil activation method:

- Calibrate the HPGe γ-ray detector
- Measure the mass and dimensions of the target foils
- Assemble the stack and secure in the beamline

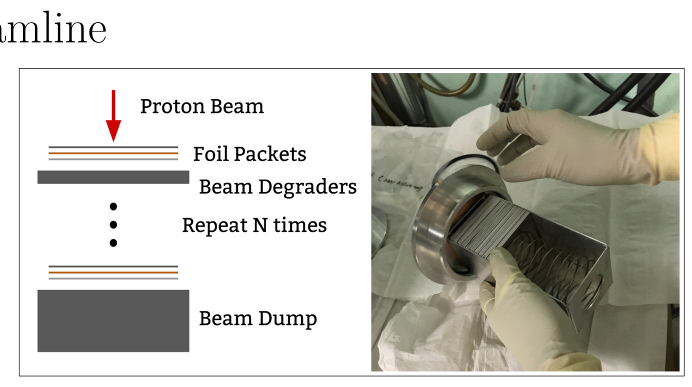

Figure 1: Schematic of the foil stack (left) and photograph of stack prior to irradiation (right).

- Irradiate for fixed duration and proton current
- Count irradiated foils with HPGe detector
- Fit peaks in the monitor and target foil spectra (Fig. 2)

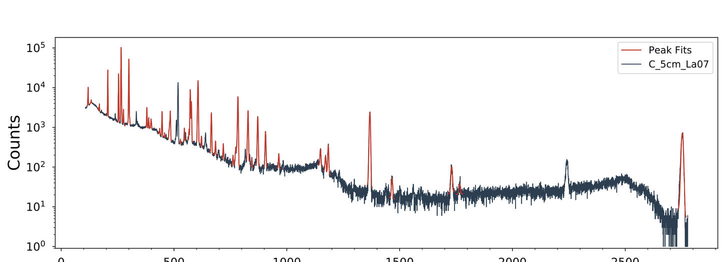

Figure 2: Example of γ-ray spectrum from the 7^{th} lanthanum foil, with peak fits indicated in red.

- Determine end-of-beam activities (A_0) in each foil
- Determine beam current and energies
- Calculate cross-sections
- Compare results to EXFOR, TALYS, EMPIRE, and ALICE

Data Analysis

The cross section can be determined by the indiced activity of a reaction product using the following equation:

$$\sigma = A_0[I_p\rho\Delta r(1-e^{-\lambda t_i})]^{-1} \qquad (1)$$

where A_0 is the activity of a given reaction product (at the end of irradiation), I_p is the proton beam current, $\rho\Delta r$ is the areal number density. The factor $(1-e^{-\lambda t_i})$ is the ratio of induced activity to the saturation activity, where λ is the decay constant for a given reaction product and t_i is the total irradiation time.

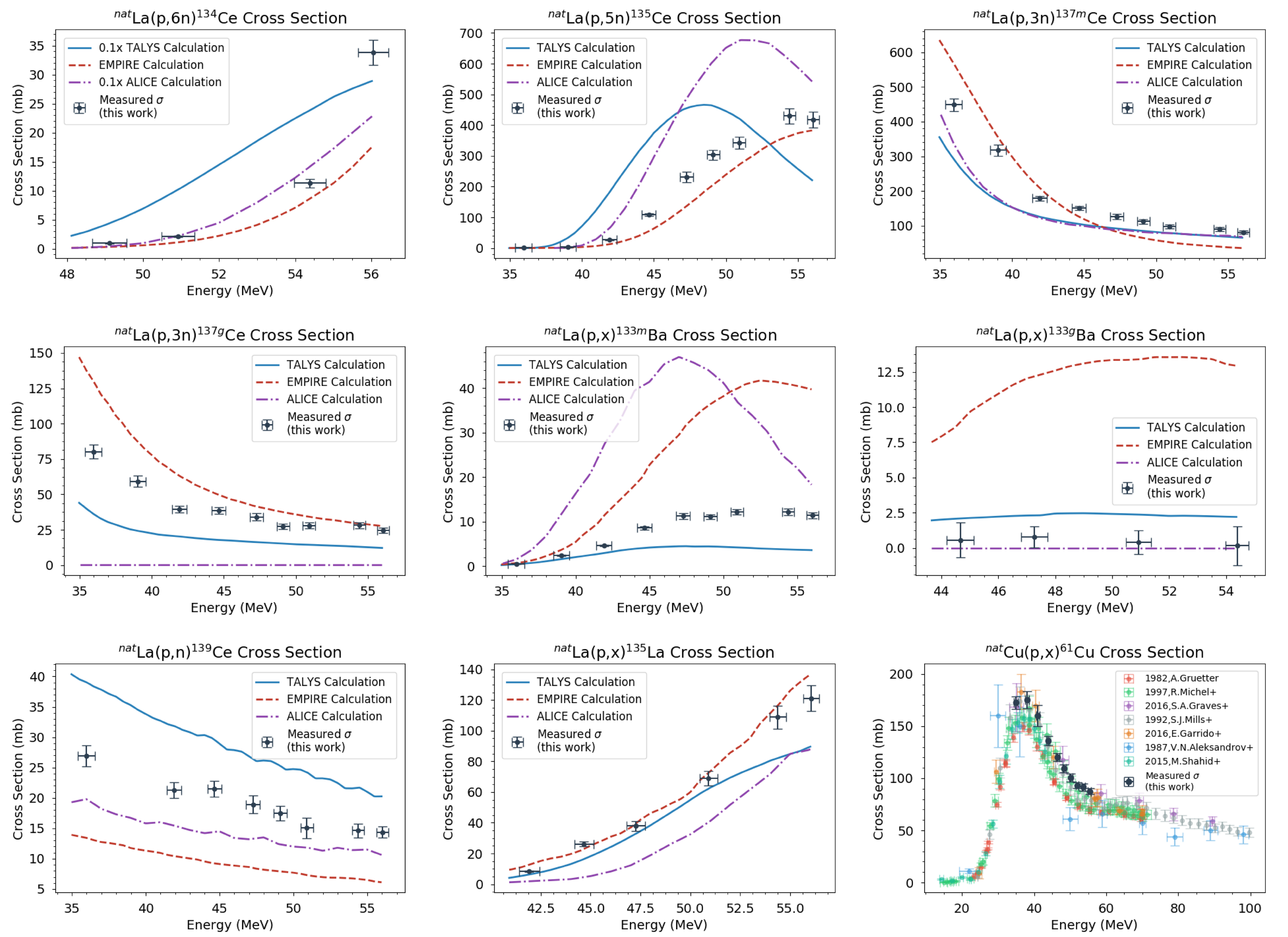

Figure 3: Measured excitation functions in ^{nat}La and ^{nat}Cu (lower right). TALYS, EMPIRE and ALICE default calculations are shown in solid blue, dashed red, and dashed/dotted purple respectively.

The end-of-beam activity is determined by collecting a spectrum of γ-rays with a HPGe, identifying and fitting characteristic peaks in the spectrum, and calculating A_0 according to

$$A_0 = \frac{\lambda N_c}{(1-e^{-\lambda t_m})e^{-\lambda t_d} I_\gamma \epsilon} \qquad (2)$$

where N_c is the number of counts in a peak, t_m and t_d are the measurement and decay times, I_γ is the γ emission fraction per decay and ϵ is the detector efficiency at a particular photopeak energy.

Energy Assignments

The energy centroids (and σ_E) were first estimated using MCNP, however the estimates using the Anderson-Ziegler stopping power tables proved closer to actual measurements.

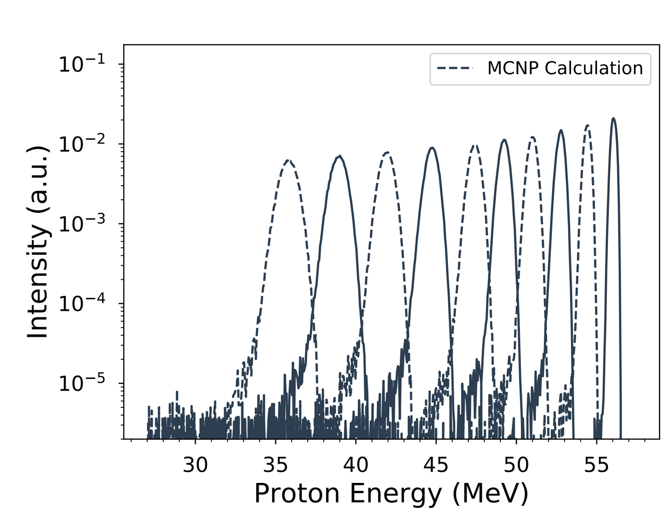

Figure 4: Plot of the proton energy spectra for each lanthanum foil in the target stack.

The beam current was also calculated using equation 1, but for a known cross-section (instead of known current). The effective foil density was varied slightly to minimize the variance in beam current measured by the monitor foils. This procedure simultaneously optimizes the energy assignments and the beam current.

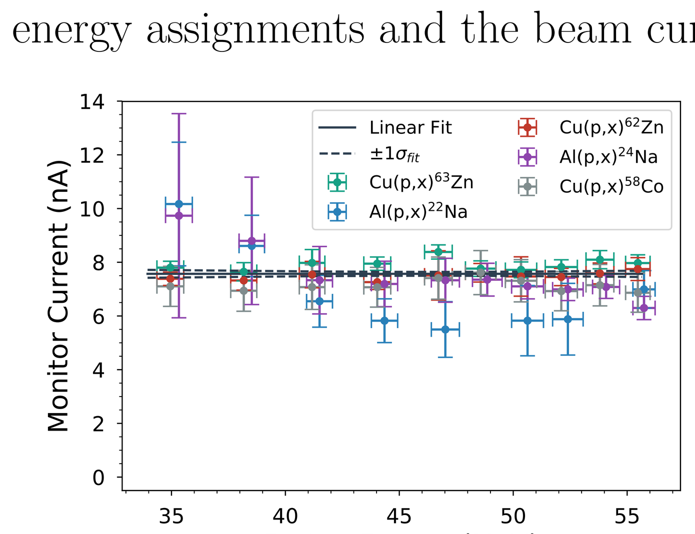

Figure 5: Plot of the beam current measured by each monitor foil reaction, with a linear fit (and $\pm1\sigma$) plotted in black.

Results

The measured cross sections are plotted above, in Figure 3. The codes TALYS, EMPIRE, and ALICE were ran with default parameters for comparison, although the predictions were quite poor in general. The ^{nat}Cu(p,x)^{61}Cu cross section was also compared to existing data from the EXFOR database.

References

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