The 2019 REU experiment: Rare isotope beam production from the $^{54}Fe+^{58}Ni$ and $^{40}Ca+^{58}Ni$ reactions with MARS

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During our Research Experience for Undergraduates (REU) program for summer 2019, a dedicated experiment for the undergraduate students was conducted using the Cyclotron Institute facilities. The experiment was designed to give the students some "hands-on" experience with the setting up and execution of a real nuclear physics experiment. The REU students received one day of introductory lectures prior to their participation in the experiment, followed by two days of experiment. During the experiment, the students aided in debugging the detector electronics, tuning rare isotope beam through the MARS spectrometer [1], and analyzing the online data as it was collected. In addition, the REU student directly associated with the project, I. Richardson, participated in the planning of the experiment by performing simulations prior to the experiment. The student also analyzed the data in detail following the experiment and reported the results in a poster at the Fall 2019 meeting of the Department of Nuclear Physics of the American Physical Society.

Leading up to the experiment, I. Richardson participated in the $^{54}Fe+^{58}Ni$ beam production experiment with the Momentum Acromat Recoil Separator (MARS) [1]. For that experiment, a $^{54}Fe^{18+}$ beam at 36 MeV/u from the K500 cyclotron impinged on a natural nickel target 50 μm thick. Analysis of this data for production rates is ongoing.

Next, I. Richardson conducted simulations for the $^{40}Ca+^{58}Ni$ experiment with the model of the MARS in the program LISE++ [2]. He was instructed to study the reaction $^{40}Ca+Ni$ for the purpose of investigating what isotopes could be produced and separated near the proton dripline in the region near mass A=40, such as ^{35}Ca. To maximize production of these isotopes, he performed simulations to optimize the predicted beam energy, intensity, target thickness, and whether or not a stripper foil following the target could improve the production. Following extensive calculations, it was determined that ^{40}Ca at 40 MeV/u on a nickel target 100 μm would give the best results based on the beam intensities available at the Cyclotron Institute. Reactions for ^{40}Ca on ^{9}Be and ^{27}Al targets were also simulated for comparison.

The $^{40}Ca+Ni$ and $^{40}Ca+Be$ experiment was conducted over two days with one day for each target. For the $^{40}Ca+Ni$, a 40 MeV/u $^{40}Ca^{14+}$ beam from the K500 impinged on a 100 μm natural nickel foil at the entrance of MARS [1]. About 50 electrical-nA of beam intensity was available for most of the measurement. To investigate the nuclei produced near the proton dripline, MARS was tuned for magnetic rigidities consistent with the production of ^{35}Ca. This allowed a search for isotopes near the dripline for all elements Ca and lighter. The results for a data run taken for about 11 hours are shown in Fig. 1. To remove background due to scattered primary beam, the particle identification plot ΔE vs. Y-position shown was gated with a large gate in the ΔE versus E spectrum. This ensures that only particles with the proper predicted energy losses are taken into account for the identification. As shown, isotopes with neutron (N) number vs. proton number (Z) in the N=Z-5 line, such as ^{35}Ca and ^{31}Ar, were clearly populated. A production rate of about 80 counts/hour for ^{35}Ca was observed. Lighter "even-Z" isotopes with N=Z-4 such as ^{36}Ca, ^{32}Ar, ^{28}S and ^{26}P were also observed with production rates about 10 times higher than those for the N=Z-4 nuclei.

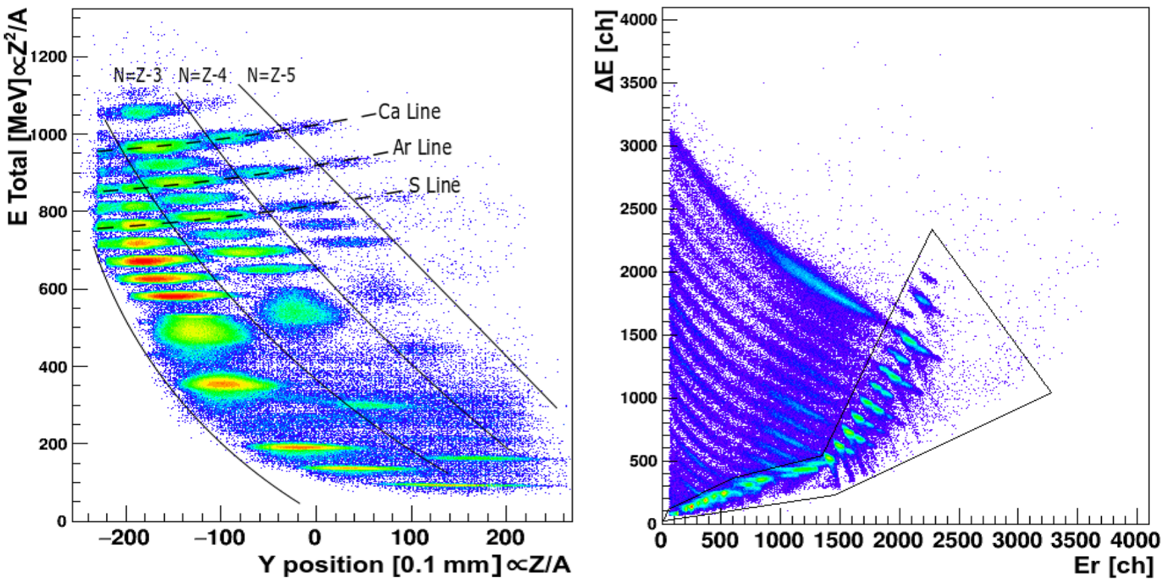

Fig. 1. Particle identification plots for the ^{40}Ca+Ni data. The data shown represent about 11 hours of beam on target. N=Z-4 and a few N=Z-5 isotopes were populated. For the Z-5 nuclei, ^{35}Ca, ^{31}Ar, and ^{27}S were produced. See text for explanation.

For the ^{40}Ca+Be target data, the same ^{40}Ca beam at 40 MeV/u from the K500 cyclotron impinged on a Be foil 456 μm thick. The reaction was measured for about 3 hours. In that case, about 10 counts/hr consistent with N=Z-5 isotopes were observed. This result was consistent with comparisons of the Ni vs. Be targets from previous beams [4].

In conclusion, N=Z-4 and N=Z-5 nuclei in the mass region of A < 40 have been produced and observed using a beam, in this case ^{40}Ca at 40 MeV/u, available at the Cyclotron Institute. However, contrary to the predictions of LISE++ [2,3], more exotic isotopes closer to the proton dripline were produced with the Ni target as opposed to the Be target, contradicting what was predicted by the model. This is part of an on-going study that has shown that using nickel as a production target produces nuclei further from stability and removes more particles from the primary beam than a beryllium target. Analysis of the data to determine the final production rates for the dripline nuclei is ongoing.

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