Opportunities for Isotope Discoveries at FRIB

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Abstract

Expected production yields of the Facility for Rare Isotope Beams (FRIB) were calculated for a wide range of rare isotopes using the the code LISE⁺⁺ and planned performance parameters [1, 2]. A comparison between isotope discoveries of the last decade and expected particle yields indicates the range of isotopes that can likely be detected at FRIB. This paper will highlight recent isotope discoveries at NSCL's Coupled Cyclotron Facility and deduce how far the limits could be pushed with the Facility for Rare Isotope Beams.

Keywords: Facility for Rare Isotope Beams, isotope discovery, rare isotope beams

1. Introduction

The discovery of an isotope is not only a prerequisite for the future investigation of its nuclear structure, but it also helps us to delineate the limits of nuclear binding and thus has direct implications for fundamental questions in nuclear physics and nuclear astrophysics. Besides the roughly 300 stable isotopes, there are about 2800 that have been identified so far, but there are still several thousand to be discovered [3, 4]. Isotope discoveries are closely linked to the experimental equipment available, and for rare isotope beams this means that a new generation of accelerator facilities offers opportunities for discovery.

10 The nuclear drip lines are important study objects because they are sensitive

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Figure 1: Besides the roughly 300 stable isotopes (black squares), about 2800 radioactive isotopes have been discovered so far (dark grey). Several thousand more are expected to be particle bound (light grey) [3, 5]

to the delineation of the limits of atomic nuclei, dependent on aspects of the nuclear force, influenced by nuclear structure changes, and they are central to astrophysical implications.

2. Methods

15 Production yields for the Coupled Cyclotron Facility (CCF) at the National Superconducting Cyclotron Laboratory (NSCL) were calculated with the code LISE⁺⁺ [1] version 9.2.68, using the optimum primary beam of a list of 26 available beams ranging from oxygen to uranium and EPAX 2.15 [6] production cross sections. For the ²³⁸U beam, projectile fission was also included employing
20 the LISE⁺⁺ 3EER model [8, 9].

A calculation of all possible rare isotope beams and their expected yields was also done for FRIB in a similar way. In this case, an optimum primary beam out of 47 FRIB primary beams was selected for each isotope. Particle

Figure 2: Calculated production yields of NSCL's CCF. Calculations were performed using LISE⁺⁺[1] version 9.2.68. Also indicated (green squares) are NSCL isotope discoveries by Stolz et al. [10], Tarasov et al. [11, 12, 13], and Baumann et al. [14].

yields were calculated using EPAX 3.1 [7] production cross sections, LISE⁺⁺[1]
 25 version 9.2.68, and the LISE⁺⁺ 3EER model for in-flight fission[8].

3. Results and Discussion

Figure 2 shows the calculated production yields for NSCL's Coupled Cy-
 clotron Facility on a color scale ranging from 10^7 particles per second down
 to 10^{-5} particles per second. A rate of 10^{-5} per second corresponds to about
 30 one particle per day. This figure also highlights new isotope discoveries that
 were achieved at NSCL during the past decade. These discoveries are based
 on detecting a small number of particles (3 to 7) during typically 7 to 10 day
 long experiments, and fall into the range of production yield of about one par-
 ticle per day (taking into account statistical uncertainties). The production
 35 cross sections of the most exotic of these isotopes are between 1 pb and 0.01 pb
 [10, 11, 12, 13, 14]

Figure 3: Expected production yields for FRIB. Calculations were done choosing the optimum of 47 available primary beams to create each rare isotope via projectile fragmentation or fission using the code LISE++ [1] version 9.2.68.

Comparing the CCF yields with the discoveries that were possible in the past decade enables us to take a look into the future: What opportunities will there be for isotope discoveries at FRIB?

40 With its high intensity primary beam of 200 MeV/u and 400 kW, FRIB will make a large number of rare isotopes available for the first time. Besides offering the needed particle yields, the 3-stage fragment separator ARIS [15] will also provide the selectivity that is required to identify these very rare isotopes. The calculated production yields are plotted in Fig. 3 for a selected area of the chart
45 of nuclei.

Looking again at production rates of about one particle per day, or 10^{-5} per second, rare isotopes with production cross sections of the order of 10^{-17} barn (10 attobarn) should come into reach. This will result in the neutron drip line becoming accessible up to Fe, while at the moment it is only confirmed
50 experimentally up to oxygen.

Figure 4: FRIB will employ the Advanced Rare Isotope Separator (ARIS) which has been designed as a 3-stage fragment separator for the efficient collection and purification of rare isotope beams [15].

4. Conclusion

FRIB is one of the next generation rare isotope facilities that will ensure a continued stream of rare isotope discoveries together with facilities like the Radioactive Isotope Beam Factory (RIBF) in Japan, the Facility for Antiproton and Ions Research (FAIR) in Germany, and the *Système de Production d'Ions*
 55 *RA*dioactifs en Ligne de 2e génération (SPIRAL2) in France. Of these facilities only RIBF has come online yet, but in its first 7 years of operation it resulted in the discovery of 69 previously not observed isotopes [16].

When FRIB goes online in 2022 [17] it will further extend the reach to even
 60 more exotic nuclei. Besides the new discoveries and expanded delineation of the drip line, FRIB will also enable the study of many key nuclei for astrophysical processes that are beyond the reach of current facilities.

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65 References

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