PROCEEDINGS OF SCIENCE

New experiments on neutron rich r-process Ge – Br isotopes at the NSCL

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Previously unknown properties of neutron rich Ge-Br isotopes have been studied at the NSCL at Michigan State University. Production was by fragmentation of a 120 MeV/u ^{136}Xe beam on a Be target. The A1900 fragment separator blocked unwanted species produced in this reaction. The transmitted nuclei were implanted in a dual-sided silicon detector, which was part of the Beta Counting System detector. Implanted nuclei were identified by the ΔE-time of flight method. Beta decays were then identified as low gain signals from the same pixel as a previous implant. Beta-delayed neutrons were detected by the NERO neutron counter, which surrounded the Beta Counting System. This provided measurements of the β decay half-lives and β-delayed neutron emission probabilities.

1. Introduction

The astrophysical r-process is responsible for synthesis of roughly half of the elements heavier than iron. In spite of this significance, there are many uncertainties regarding the site of the r-process and the neutron-rich nuclei involved. Studying these nuclei presents an experimental challenge, as they lie far from the valley of stability. Nuclear properties such as β decay half-lives and β-delayed neutron emission probabilities are critical inputs for r-process models. However, because most r-process nuclei remain unstudied experimentally, predictions for β decay half-lives and β-delayed neutron emission ratios must be used. These predictions can vary greatly for nuclei far from stability. The neutron rich Ge-Br isotopes are in the region just after the N=50 bottle neck in the “classical” r-process, or may serve as seed material for the high entropy neutrino-wind r-process[1].

Neutron rich nuclei play an important role in both nuclear astrophysics and nuclear structure [2]. Central to the study of nuclear structure are the shape of a nucleus and how that shape changes from spherical to deformed. In some regions there is a smooth change in deformation as nucleons are either added or subtracted, and yet in other regions this transition is very rapid. The Ge-Br isotopes to be measured lie between the N=56 sub-shell closure and the onset of deformation at N=60, just below the Sr-Zr region, for which the most pronounced transition from spherical to deformed ground-state shapes have been observed[3]. Nuclear deformation is important for the r process because deformed nuclei can have greatly different beta decay half-lives and neutron emission probabilities than spherical nuclei.

Isotope	$T_{1/2}$ [ms]	P_n [%]	$T_{1/2}$ [ms]	P_n [%]	$T_{1/2}$ [ms]	P_n [%]
	spherical		deformed		experiment	
Ge-85	832	8.3	186	5.4	540(50)	14(3)
Ge-86	627	31.5	177	5.4		
Ge-87	364	33.9	56.7	6.3		
Ge-88	171	69.4	45.8	6.7		
As-86	834	19.4	286	11.7	945(8)	26(7)
As-87	739	46.7	238	82.9	560(110)	17.5(25)
As-88	445	32.1	70.7	41.9		
As-89	218	77.0	63.0	93.3		
As-90	21.1	8.9	22.8	42.5		
As-91	61.1	92.2	33.2	95.7		
Se-89	1646	0.5	137	0.6	410(40)	7.8(25)
Se-90	724	0.6	141	1.1		
Se-91	39.3	0.2	37.6	1.3	270(50)	21(10)
Se-92	137	2.3	62.3	2.7		
Se-93	24.0	14.5	51.6	7.1		
Se-94	39.0	3.7	48.2	23.9		
Br-94	33.4.	14.2	113	56.6	70(20)	68(16)
Br-95	53.2	93.8	70.2	79.1		
Br-96	19.2	31.9	36.7	56.2		
Br-97	20.2	97.2	42.4	92.0		

Table 1. *QRPA calculations of β decay half-lives and β-delayed neutron emission ratios for spherical and deformed nuclei. Previously available experimental results are also shown. Ref [4].*

These isotopes are of interest because they lie in the r process path and away from closed neutron shells. To date, only a few dozen out of several hundred r process nuclei have been studied [5], [6]. These nuclei have been located at or near closed neutron shells, making them easier to produce and measure. This project has measured some of the first r process nuclei away from closed neutron shells, and will shed light on unknown areas of the process.

2. Experiment

This experiment was performed at the National Superconducting Cyclotron Laboratory (NSCL) at Michigan State University. This facility features two coupled cyclotrons and a fragment separator. The primary beam was ^{136}Xe at an energy of 120MeV/nucleon, and an intensity of 2 particle nA. This beam was focused on a 240mg/cm^2 Be target, and produced a variety of products via fragmentation reaction. These products were focused using the A1900 fragment separator. The purpose of the fragment separator was to transmit only desired products from the beam, using the magnetic rigidity of each species. This was extremely important, as the nuclei of interest were produced in very low quantities (10^{-2} - 10^{-4} / s) and would otherwise have been undetectable.

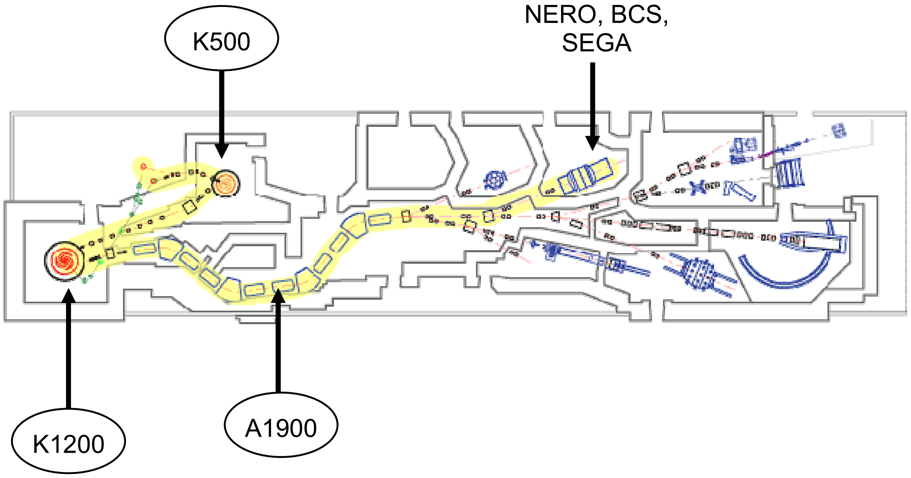

Fig 1. *Layout of the NSCL including coupled cyclotrons, A1900 fragment separator and location of detectors used.*

Particle identification was done using the delta-E time-of-flight technique. Two plastic scintillators, one located in the dispersive focal plane of the A1900 and the other located at the final focal plane, provided the time of flight measurement. The delta-E measurement was made using the first silicon PIN detector of the Beta Counting System.

In order to obtain a correct particle ID, at least one blob in the delta-E-time-of-flight spectrum must be uniquely identified using gamma rays. This was done using three SeGA (Segmented Germanium Array) detectors. Each detector was a 75% relative efficiency high-purity germanium detector with a resolution of 3.5keV (at 1.3MeV). One nucleus in the particle ID spectrum must have an isomer that lives long enough to be transmitted through the A1900 separator (approx. 150ns). The 7.6 μs isomer in ^{98}Y was used in this experiment. Fig. 3.

Detection of the beta decay half lives and neutron emission ratios involved several detector systems from MSU. These included the Neutron Emission Ratio Observer (NERO), the Beta Counting System (BCS), and the Segmented Germanium Array (SEGA). These detectors measured neutron emission ratio, beta decay half-lives, and gamma decay energies respectively.

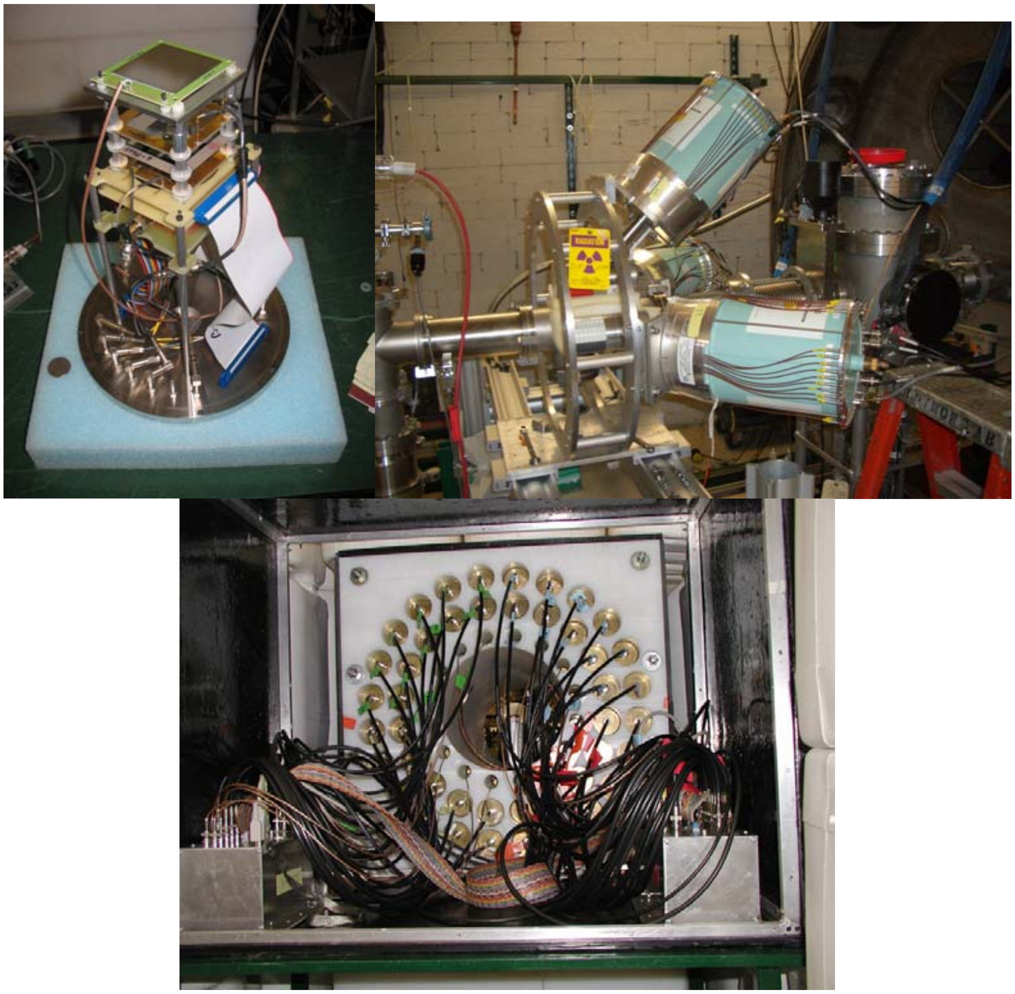

Fig 2. *Pictures of BCS (top left), SeGA (top right), and NERO (bottom) detectors*

Nuclei passed through four silicon PIN detectors and were implanted into a 979 micron thick DSSD. This detector was segmented into 40 horizontal and 40 vertical strips for a total of 1600 pixels. The time in which a nucleus was implanted into a pixel of this detector was recorded. Later, the time of a decay (high gain) signal from this same pixel was recorded; the time between the implant and decay signals was taken as the decay time. A decay curve was constructed from the decay times of each particular species. Fig 4.

After each decay was observed in the DSSD, the NERO detector received a 200 μs gate for beta-delayed neutrons. NERO is comprised of one ring of sixteen ^{3}He detectors surrounded by two rings of BF_3 detectors. These are seated in a polyethylene moderator, which thermalizes the neutrons. Energy information about the neutron was lost by this moderation, but because only a simple count of the number of emitted neutrons was required this loss of energy information was not important.

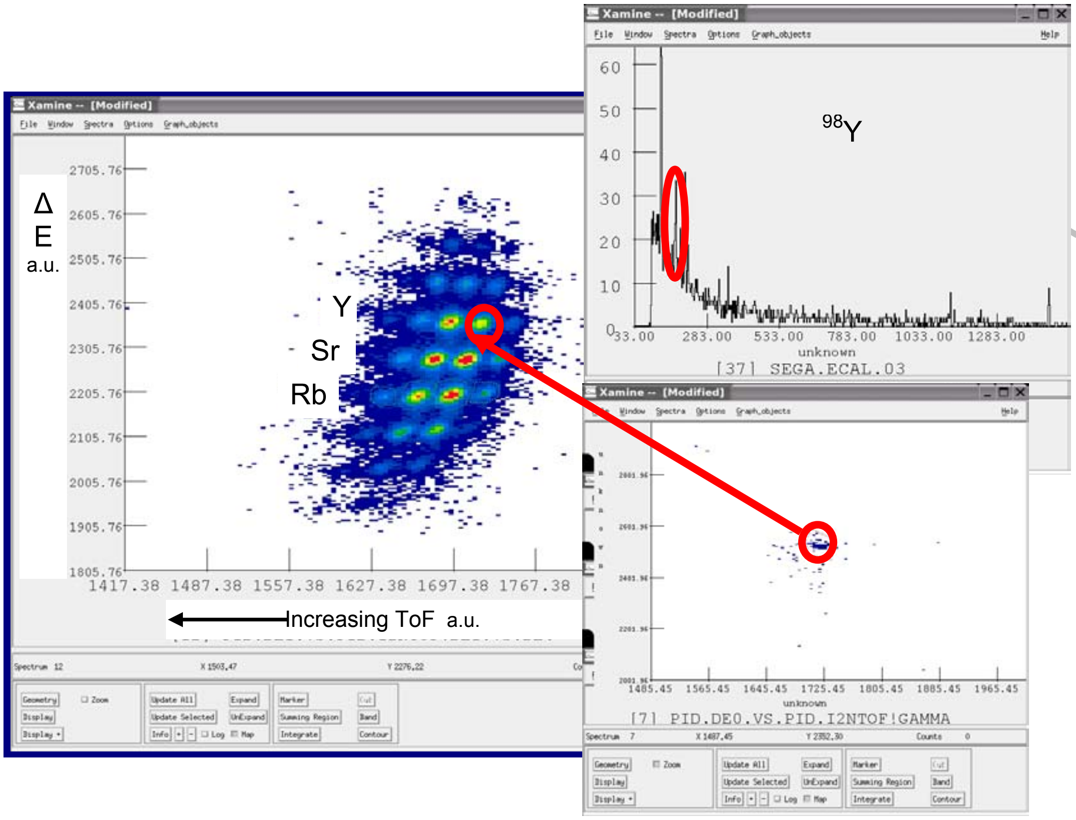

Fig 3. *Particle ID spectrum (left).* ^{98}*Y isomer line from SeGA spectrum (upper right). Particle ID spectrum gated on 98Y isomer line (lower right).*

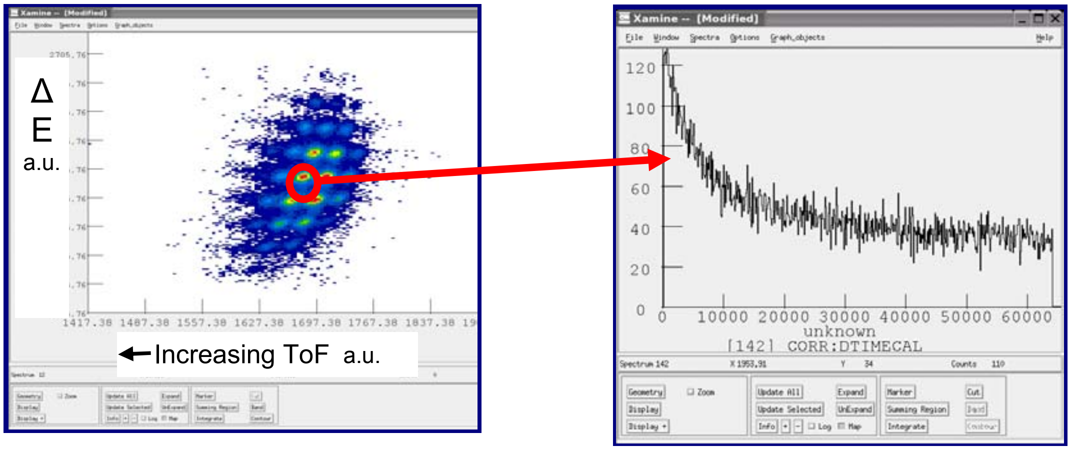

Fig 4. *Beta decay curve generated by gating on one isotope in particle ID spectrum*

3. Conclusion

The r process is responsible for the creation of almost half of the elements heavier than iron. The site of the r process is currently unknown, but several locations have been proposed [7], [8]. The location of the r process path on the chart of the nuclides depends on several nuclear physics parameters. Among these are: the nuclear mass, which determines the waiting points of the process (i.e. where the process waits until beta decay), the beta decay half-lives, which determine the time scale for the process in addition to shaping the overall abundance pattern, and the beta delayed neutron emission ratio, which can change the final mass abundances.

The beta-decay half lives and beta-delayed neutron emission ratios for several neutron rich isotopes in the Ge-Br region have been measured recently at the NSCL. This includes the r-process waiting point nucleus ^{90}Se. In addition to providing direct inputs for r-process models, these nuclei will also provide information about the onset of deformation between the N=56 subshell and N= 60 shell closures in the region just below Z = 40.

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