Radioactivity of Very Neutron-rich Cu and Ga Isotopes Using a Ranging-out Technique

At the HRIBF, we developed a technique using accelerated radioactive beams (RIBs) to obtain beams with enhanced purity for studies of radioactivity. Typically, RIBs contain more than one nuclear isotope and that makes the study of very neutron-rich nuclei difficult. These nuclei are critical to our understanding of the astrophysical rapid neutron capture process (r-process) that is a building block of heavy nuclear isotopes. Our experiments constrain theory near ^{78}Ni, a special "magic" nucleus due to its number of neutrons (50) and protons (28).

In this technique, we accelerate the beam with our 25 million-volt Tandem electrostatic accelerator and pass it through a gas (ion) counter before depositing it onto a moving tape collector (MTC) which uses 35-mm film. Using the ion counter to identify the isotopes in the beam, a high-resolution magnet can be fine tuned to provide optimal beam purity. In addition, the gas pressure can be raised so that only the isotope with the lowest atomic number is transmitted. Our radioactivity studies identify γ-rays and β-particles and determine those isotopes that emit neutrons immediately following the β decay (βn). These mass-changing decays alter decay sequence and affect the r-process path. Half-lives of $^{76\text{-}79}$Cu and $^{83\text{-}85}$Ga range from 0.65-0.08 seconds (^{85}Ga is unknown and expected to be less than 0.08 s); the shortest-lived nuclei yet accelerated at HRIBF.

Copper-79 has one proton more than ^{78}Ni and we were able to observe for the first time the 730-keV transition in ^{78}Zn fed by the βn-branch. However, no γ-rays could be assigned to the β branch. This implies a very large βn branch for this r-process nuclide and a path out of the mass 79 decay chain. Radioactive decay of ^{83,84}Ga is dominated by γ-rays fed through the βn-branch. In Fig. 1, a γ-ray is observed in both experiments at 248 keV that we assign as the transition between the first excited state and the ground state in ^{83}Ga. The ^{84}Ga decay also reveals a γ-ray at 623 keV which we tentatively assign as the $2_1^+ \rightarrow 0_1^+$ transition in ^{84}Ge. Both γ-rays are at lower than expected energies suggesting ^{78}Ni might not be as "magic" as thought.

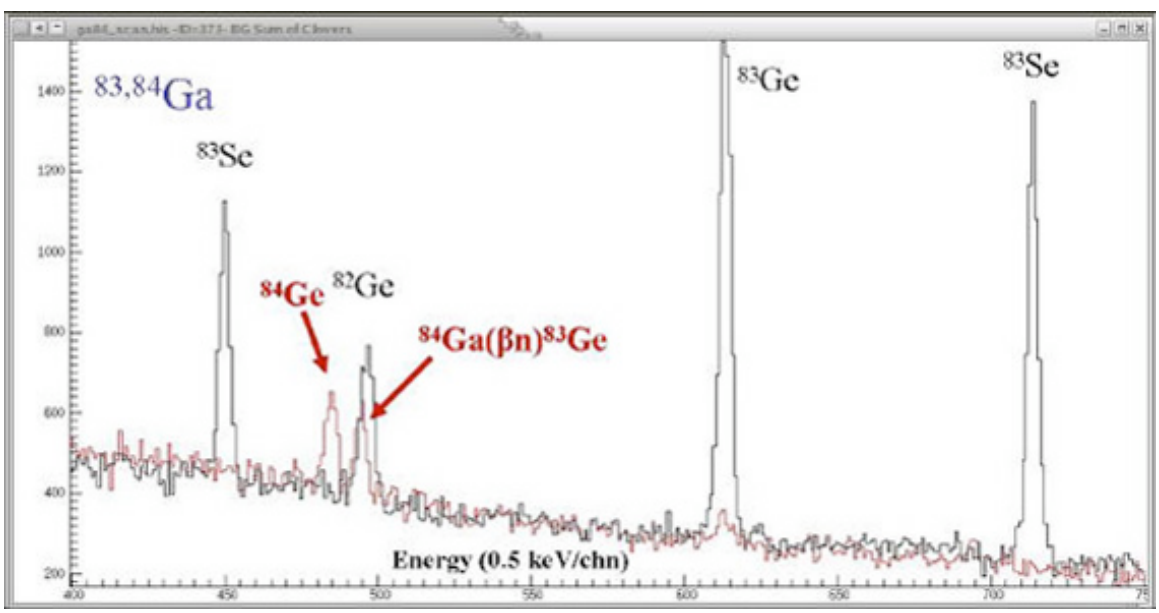

Fig 1 - Gamma-ray spectra from β decay of ^{83}Ga and ^{84}Ga. The presence of isotopes with different masses from the beam is indicative of beta-delayed neutron emission. The arrows indicate the ^{84}Ga radioactivity products and confirm the energy of the first excited state in ^{83}Ge and hence, the energy separation of the $s_{1/2}$ and $d_{5/2}$ neutron orbitals in ^{83}Ge.