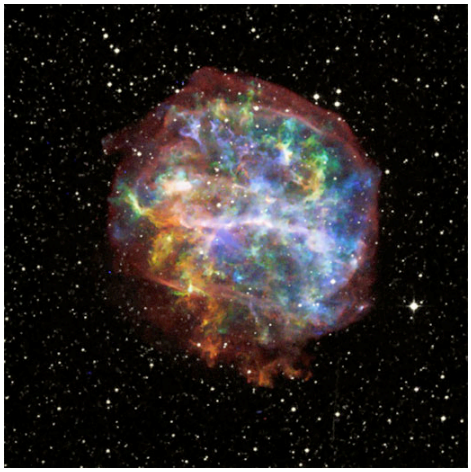
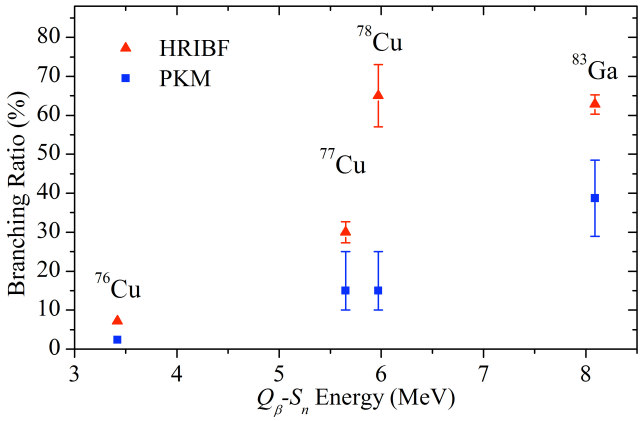
Understanding the ashes of supernovae - Beta-delayed neutron emission

The Holifield Radioactive Ion Beam Facility at Oak Ridge National Laboratory produces intense beams of neutron-rich radioactive nuclei. These beams are generated by bombarding a uranium-carbide target with protons resulting in uranium fission similar to that occurring in nuclear reactors. The fission products are ionized and formed into a beam that is used to study the decay properties of these nuclei. Armed with this information, we can begin to understand the processes which occur in a very neutron-rich environment. Such environments are found in nuclear reactors and in supernovae explosions.



In one of our first experiments we studied the nuclear decay properties of the very neutron-rich copper (Cu) and gallium (Ga) isotopes. These nuclei are more than 10 neutrons heavier than the nearest stable isotope. The beta decay of these extremely neutron-rich nuclei results in the emission of neutrons and thus, alters the normally expected decay sequence. This change of nuclear mass affects the isotopic abundances observed following the explosion of supernovae that are believed to be sites of the rapid-neutron capture process (r-process) that creates approximately half of the neutron-rich atomic nuclei that are heavier than iron. Thus, we can effectively study the ashes of the stellar cataclysmic events in the laboratory such as the one shown in the image above [Ref. 1]. This work also impacts the operations and the characterizations of radioactive waste from nuclear reactors by shedding light on the time profile of the energy released during the cooling down of the reactor and the isotopic mix remaining in the nuclear fuel.

Our data [Ref. 2], shown to the right, reveal beta-delayed neutron branching ratios that are 2-4 times higher than previously reported. In addition, the gamma-decay of two nuclei were observed for the very first time (^{79}Cu, ^{85}Ga). The precision of our data as well as the ability to study a sequence of isotopes also allowed us to explain changes in the structure of the neutron and proton systems that comprise these Cu isotopes. Our data support a change of ground-state configuration occurring at ^{75}Cu; all odd-mass (A) Cu isotopes below A=74 have ground state spin and parity of 3/2- while those above have 5/2-. This change is caused by the interaction between the unchanging number of protons (Z=29) and the ever larger number of neutrons (N=A-29). This puzzling data challenge nuclear theory and provide critical tests that result in improved calculations. In summary, the new data from HRIBF contribute to the core information that is used to estimate nuclear reactor shielding as well as the nuclear structure of the world around us.



References

[1] Composite image of G292.0+1.8 from the Chandra X-ray Observatory website; Image credit: X-ray: NASA/CXC/Penn State/S.Park et al.; Optical: Pal.Obs. DSS.

[2] J. A. Winger et al., submitted to Physical Review Letters.