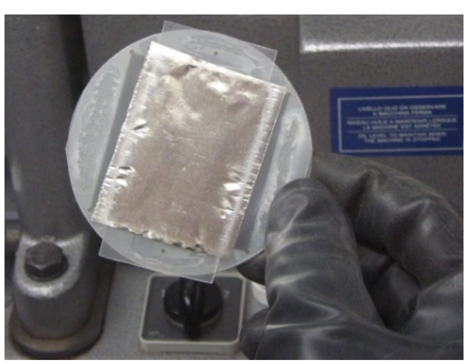
Nuclear Reactions in Supernova Explosions

To understand how massive stars detonate as supernovae, scientists need to map the nuclear reactions that take place just prior to the explosion. So-called "electron-capture" reactions play an important role. In these reactions, nuclei capture electrons that are also present in the stellar plasma. The nuclei that undergo electron capture have their number of protons reduced by one, while their number of neutrons increases by one. It is difficult to measure such reactions directly on earth, partially because the electron-capture reaction rates are low and partially because the relevant nuclei are unstable. As an alternative to a direct measurement, charge-exchange reactions are used, in which a proton in a target nucleus is exchanged for a neutron in a projectile. Such reactions are closely related to electron-capture reactions and have a much higher reaction rate. To study charge-exchange reactions on unstable nuclei, the experiments must be performed in inverse kinematics, in which the short-lived isotope of interest is bombarded onto a target that supplies the neutron. This severely complicates the experiments and it required researchers at the National Superconducting Cyclotron Laboratory (NSCL) at Michigan State University (MSU) to combine various experimental techniques to succeed in measuring charge-exchange reactions with rare isotopes.

In the experiment, a beam of unstable Phosphorous-34 nuclei (which have 15 protons and 19 neutrons) was bombarded onto a thin foil containing Lithium-7 nuclei (which have 3 protons and 4 neutrons). In the charge-exchange reaction, Silicon-34 (14 protons and 20 neutrons) and Berrylium-7 (4 protons and 3 neutrons) are produced. With a certain probability, Berrylium-7 is produced in an excited state which decays by emitting a gamma ray. By measuring this gamma-ray (using a detector array consisting of Germanium detectors, the Segmented Germanium Array SeGA) the charge-exchange reaction was distinguished from other, more prevalent reactions. At the same time, the energy of the Silicon-34 reaction production was determined with very high resolution in a magnetic spectrometer called the S800, which allowed for the extraction of the necessary information about the nuclear reactions that are similar to those taking place inside a massive star.

Although most of the nuclei that undergo electron-capture inside stars prior to detonation are slightly heavier than Phosphorous-34, researchers at the NSCL will apply the new technique it to the study of other rare isotopes, including those most abundant inside massive stars prior to their demise as supernovae. This work was published in Physical Review Letters 104, 212504 (2010) and supported by the National Science Foundation (grants: PHY-0606007, PHY-0822648 (JINA) and PHY-0758099).



Photograph of a pure lithium metal target prepared for this work. The metal reacts rapidly with air or moisture and must be prepared and handled with great care in an inert atmosphere.