Contribution ID: **108** Type: **Invited Review**

Direct neutron capture experiments on stable and unstable isotopes

Thursday 12 June 2025 16:10 (30 minutes)

Neutron-capture reactions drive the formation of elements heavier than iron, occurring through both the slow (s-) process in low-mass AGB and massive stars, and the rapid (r-) process in explosive stellar environments. Recently, the more exotic i-process, which involves higher neutron densities and more exotic nuclei than the s-process, is also gaining great interest.
For stable nuclei heavier than iron almost all neutrons capture cross sections at s-process temperatures have been determined. However, for cases such as the s-process bottlenecks, located at neutron shell closures, the neutron capture cross sections should be measured with improved accuracies since they directly impact the width and height of the abundance peak at these mass numbers. On the other hand, unstable isotopes acting as branching points of the s-process, offer crucial information about the physical conditions of stellar nucleosynthesis. Neutron-capture measurements on radioactive isotopes, in combination with stellar spectroscopy and isotopic analyses of primitive meteorites, can help to better understand the role of stellar mass, rotation or metallicity and to refine further our understanding of galactic chemical evolution.
One of the best suited methods to measure neutron capture (n,γ) cross sections over the full stellar range of interest is the time-of-flight (TOF) technique. However, TOF neutron capture measurements on unstable isotopes are still very challenging due to the limited mass (~mg) available and the high experimental background arising from the sample activity. The situation has improved in recent years with the combination of facilities with high instantaneous flux, such as the n_TOF-EAR2 facility, with detection systems with an enhanced detection sensitivity and high counting rate capabilities. In this context, this
contribution will present an overview of key s-process isotopes measured at the CERN neutron Time-of-Flight (n_TOF) facility over the years and their astrophysical significance and will show how recent improvements on the neutron-beam facility and state-of-the-art detector developments have led to significant advances on the measurement of radioactive nuclei.
Despite the significant breakthroughs, the TOF technique still presents limitations concerning unstable isotopes with short half-lives (smaller than a few years), restricted neutron energy ranges (beyond a few keV), and attainable accuracy. In this context, complementing the TOF technique with activation measurements in a quasi-stellar beam, when feasible, may deliver complementary and more accurate information on a specific cross section. Moreover, the unsurpassed sensitivity of activation measurement opens the door to first-time measurements on much smaller sample quantities. Following this logic, n_TOF has recently deployed the new high-flux n_TOF-NEAR activation station. In this line, the contribution will review some of the recent advances and ambitious future projects for direct neutron capture measurements at CERN and in other facilities which will help to push the boundaries of neutron-capture measurements, overcoming current limitations and helping to unlock new frontiers in our understanding of stellar nucleosynthesis.

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