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^{60}Fe and ^{182}Hf nucleosynthesis via double neutron capture

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The long-lived radionuclides Fe-60 ($t_{1/2}$=2.6 Myr) and Hf-182 ($t_{1/2}$=8.9 Myr) are sensitive monitors to the neutron environment under different stellar conditions. Production of both nuclides requires neutron fluxes high enough to compete with the decay of the shorter-lived nuclides Fe-59 ($t_{1/2}$=44 d) and Hf-181 ($t_{1/2}$=42 d) which separate Fe-60 and Hf-182 from stable isotopes Fe-58 and Hf-180. Such conditions are predicted for the s (slow neutron capture) process in massive stars only at their late burning phases, e.g., shortly before they end in a supernova, as well as in the r process (rapid neutron capture). The site and frequency of the r process is heavily debated and attributed either to some rare cases of supernovae or neutron star mergers.
On Earth, (n,α) reactions do not contribute to their natural production as the parent nuclides for both cases are not stable. Fission yields are also very low, consequently, both Fe-60 and Hf-182 are very rare on Earth. Accordingly, any presence of either nuclides on Earth may indicate signatures of interstellar influx with their nucleosynthesis within a time period of a few half-lives. Indeed, two distinct interstellar Fe-60 influxes had been found in terrestrial and lunar archives demonstrating recent (within 10 Myr) and 'nearby' supernova activity (<150 pc distance). No interstellar Hf-182 had been detected so far. This reflects either the expected low production yields of Hf-182 or a low interstellar influx into the solar system. However, more importantly, the difficulty to chemically extract and measure Hf-182 at the expected low concentrations in terrestrial archives makes detection of interstellar Hf-182 extremely challenging.
The production yields of both nuclides at astrophysical energies are not yet measured and predictions are highly uncertain. This is crucial not only for interpreting the supernova-produced Fe 60 data, but also for Hf-182, as both, s and r process may contribute to an interstellar signal, potentially still undetected in terrestrial or lunar archives.
In this contribution, we present new and precise data for both double neutron-capture reactions as well as give an outlook on Fe-60 production via 63Ni(n,α). Samples, highly enriched in Fe-58, Ni-62 and Hf-180, were irradiated at the nuclear reactor at the Institut Laue-Langevin (ILL), Grenoble, with a high, predominantly thermal, neutron flux. At the Atominstitut in Vienna, additional Fe-58 samples were exposed to a mix of thermal and epithermal neutrons extending the energy range to the astrophysical interesting keV-energies. The induced Fe-59 and Hf-181 activities were utilised as intrinsic monitors for the neutron fluence. After the decay of intermediate Fe-59, the produced Fe-60 was measured with AMS at the ANU. The number of Hf-182 nuclides, however –owing to the much higher capture cross sections –was high enough for a direct activity measurement of the irradiated sample without the need for AMS.
These new experimental data will provide important anchor points for a better understanding of heavy element nucleosynthesis in massive stars and explosive stellar environments.

Student Submission

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