Remeasurement of the Stellar ^{58}Ni$(n,\gamma)^{59}$Ni Cross Section

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Iron-group nuclei in the mass region A=50-65 can be produced in different astrophysical scenarios [1]. A large fraction originates from Supernovae of type Ia (a binary system where a White Dwarf accumulates material from its accompanying Red Giant until it reaches the "Chandrasekhar Limit"), as well as advanced hydrostatic and explosive burning stages in massive stars (including the weak s-process during core He and shell C burning). The solar system abundances [2] show that the most abundant iron-group nuclei are ^{56}Fe (produced via its radioactive isobar ^{56}Ni), ^{54}Fe, and ^{58}Ni. These nuclei are the seed for the nucleosynthesis of heavier elements with the slow (s) and rapid (r) neutron capture processes.

Stellar modeling of the s process requires "reliable" (accurate and precise) neutron capture cross sections at s-process energies between 100 eV and 200 keV. This reliability is of utmost importance for the weak s-process up to $A\approx90$ because the neutron density here is not high enough to reach the so-called local equilibrium, and changes in single cross sections can have large propagation effects on the abundances of heavier nuclei.

Unfortunately, for most iron-group nuclei only measurements with the time-of-flight technique were performed, and the deduced uncertainty at a Maxwellian energy of kT=30 keV is in the order of 13%. At the key nuclei ^{56}Fe, ^{54}Fe, and ^{58}Ni an uncertainty of 4.3%, 5.4%, and 4.9% was achieved, still too high compared to the 2-3% uncertainty required to reveal model-dependent uncertainties. However, not only the precision of a measurement is important, also the accuracy has to be checked. An independent method to the time-of-flight method is the neutron activation technique with offline detection of the produced radioactivity with HPGe detectors or the produced (long-lived) radionuclides via accelerator mass spectrometry (AMS).

In the last 8 years all possible cross sections of iron-group nuclei have been remeasured with the activation technique, including the (n,γ) cross sections of ^{54}Fe and ^{58,62}Ni with the help of AMS, decreasing the average uncertainty slightly to 10%, but at the same time strongly increasing the reliability of these cross sections. One exception is the cross section of ^{58}Ni where a discrepancy between previous time-of-flight measurements [3,4] and a recent AMS measurement [5] was discovered.

Thus we decided to repeat this measurement with another independent irradiation at the now closed 3.7 MV Van de Graaff accelerator at Forschungszentrum Karlsruhe using the ^{7}Li$(p,n)^7$Be source for simulating a Maxwellian neutron distribution of kT=25 keV. The present sample consisted of natural Ni powder with 68.077% ^{58}Ni and was activated with Φ_{tot}=9.95×10^{14} neutrons over 5 days. The following AMS measurement yielded a ^{59}Ni/^{58}Ni ratio of (2.84±0.34)×10^{-11} (using the ^{59}Ni standard with a corrected isotope ratio of ^{59}Ni/^{58}Ni=(9.1±0.4)×10^{-11} [6]). The experimental cross section can be deduced from the relation $\sigma_{\rm exp} = \frac{^{59}\rm Ni}{^{58}\rm Ni} \cdot \frac{1}{\Phi_{\rm tot}}$=28.6±3.4 mbarn. The sample from the AMS measurements in 2006 was also remeasured, yielding $\sigma_{\rm exp}$=26.8±3.5 mbarn (weighted average over 5 AMS runs between 2005 and 2008). From these experimental values true Maxwellian average cross sections can be deduced, see Table 1. The error weighted average of our two AMS measurements thus yields $\langle\sigma\rangle_{25keV}$=30.6±3.8 mbarn, significantly lower than the previous TOF values from Wisshak *et al.* [3] and *Perey et al.* [4]. The astrophysical consequence of this reduction in the neutron capture cross section is a slower full depletion of ^{58}Ni during the s process.

	$\langle\sigma\rangle_{25keV}$ [mbarn]
AMS (2008)	31.6 (38)
AMS (2006)	29.7 (39)
Wisshak [3]	39.0 (25)
Perey [4]	42.7 (64)

Table 1: Comparison of Maxwellian averaged cross sections at kT=25 keV from previous experiments with our AMS results.

This discrepancy in the cross sections between activation and TOF measurements will hopefully be solved soon with the CERN/n_TOF measuring campaign in summer 2009 under the title "The s-process efficiency in massive stars". It is planned to remeasure all stable Fe and Ni neutron capture cross sections in the astrophysical energy range between E$_n$=100 eV and 1 MeV with the time-of-flight method with an uncertainty of <3%. The neutrons at n_TOF are produced by a pulsed 20 GeV proton beam impinging on a water-cooled lead spallation target. After a flight path of 183 m and a collimator with 1.9 cm diameter a neutron flux of ≈1.4×10^5 n/cm^2 per pulse reaches the experimental area with several detector setups for neutron capture and neutron-induced fission measurements. The neutron-to-proton ratio is 300 and thus one of the highest ratios worldwide. The Excellence Cluster Universe/TU München will participate in these astrophysical experiments with special focus on the ^{58}Ni$(n,\gamma)^{59}$Ni cross section.

References

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