Production of a New ^{79}Se Standard for AMS

The long-lived isotope ^{79}Se plays an important role for the understanding of the nucleosynthesis of heavy elements. In collaboration with researchers from the Maier-Leibnitz-Laboratory (MLL) of the LMU and TU Munich, a new reference probe of the isotope ^{79}Se was produced at the PTB Ion Accelerator Facility (PIAF) to be used for accelerator mass spectrometry (AMS) in Munich.

The nucleosynthesis of elements heavier than iron can be almost completely ascribed to the *s*-process ("slow neutron capture process") and the *r*-process ("rapid neutron capture process"). The *s*-process can be further divided into a "weak" component (responsible for nuclei up to A~90) and a "main" component (for 90<A<209), which occur in different astrophysical scenarios at different temperatures and with different neutron exposures. Among the nuclei involved, the long-lived radioactive isotopes ^{63}Ni ($t_{1/2}$ = 100.1 yr), ^{79}Se ($t_{1/2}$~295000 yr), and ^{83}Kr ($t_{1/2}$ = 10.76 yr) assume key positions, because their β-decay rate becomes comparable to the neutron capture rate. The resulting competition leads to branchings in the *s*-process nucleosynthesis path.

These branching isotopes can be used either to determine the neutron density or the temperature in the star during the *s*-process. The strong temperature dependence of the β-decay rate of ^{79}Se [1] is due to thermal population of low-lying excited states and reduces the half-life from the terrestrial value of 295000 yr to only a few years at *s*-process temperatures of 5 MK. Due to this behavior ^{79}Se can be used as *s*-process thermometer and the increase in the abundance of the *s*-only isotope ^{80}Kr can be used to deduce the effective temperature. ^{63}Ni and ^{85}Kr do not show such a strong temperature dependence and are thus ideal neutron density monitors.

In the last years, the AMS group at the TU Munich used the GAMS setup at the MLL and determined the stellar (n,γ) cross sections of ^{62}Ni and ^{78}Se at kT = 25 keV. The detection of ^{79}Se is also of interest for nuclear technology because due to its long half-life it builds up in burnt reactor fuel elements. The large uncertainty of its half-life (presently favored value: 295000 yr) makes a determination of the ^{79}Se amount via its radioactivity very uncertain. AMS is one of the few possibilities for direct atom counting. But since the measurements are always carried out relative to a standard, the production of these standards is a critical point.

The previously used ^{79}Se standard was produced with thermal neutrons and had an uncertainty of 6 %, mainly due to the uncertainty in the thermal neutron capture cross section of 0.43 ± 0.02 b [2]. An alternative way to produce a ^{79}Se standard independent of the thermal cross section is the reaction chain ^{82}Se$(p,\alpha)^{79}$As$(\beta)^{79}$Se. This activation was carried out at the cyclotron of the PTB. The sample consisted of Al powder mixed with ^{82}Se (enrichment 99.93 %) in the stoichiometry of 8.5:1. Because no experimental information existed so far, the sample was irradiated with protons of $E_{c.m.}$=18.625 MeV (see Fig.1), close to the (theoretical) cross section maximum for the ^{82}Se$(p,\alpha)^{79}$As reaction in the Hauser-Feshbach code NON-SMOKER [3].

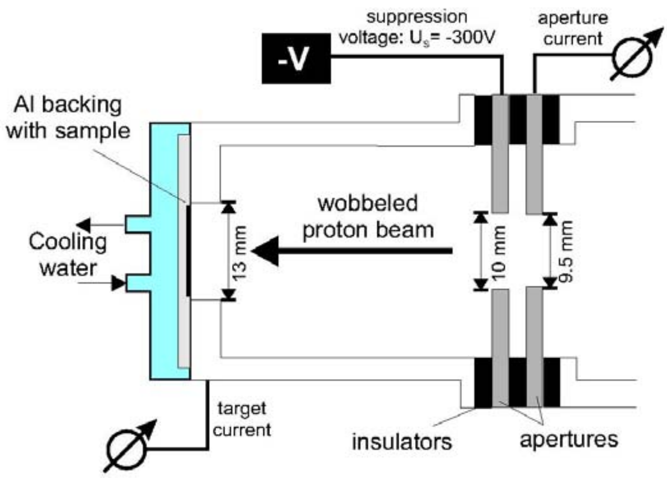

Fig.1: Target cup setup at the PTB.

For determining the cross section, six short-time activations between 60 and 150 s have been carried out. The decay of the ^{79}As can then be measured by γ-spectroscopy (see Fig.2). The transitions at 365 keV, 432 keV, and 879 keV were used for analysis. The cross sections determined via the single transitions exhibit an uncertainty of only ~1 %, each. However, there seem to be systematic deviations between the single transitions which are of the order of 10 %.

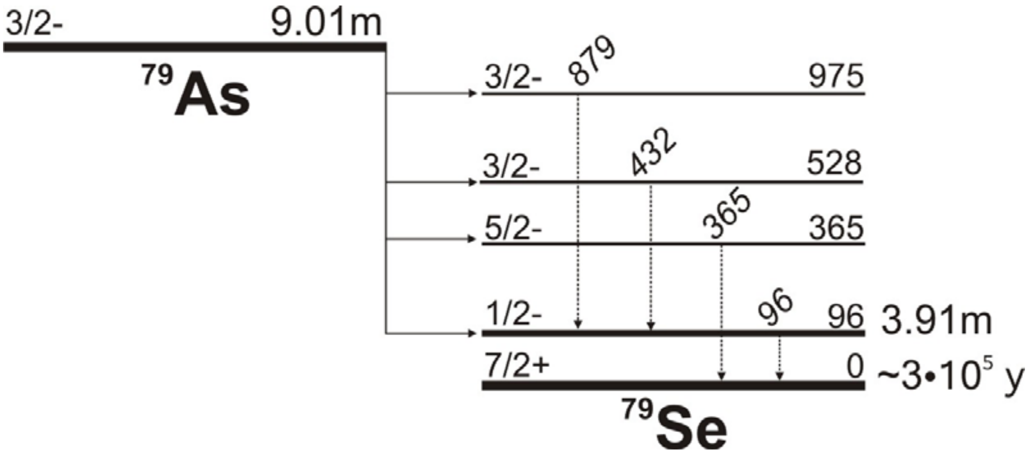

Fig.2: Decay scheme of ^{79}As

The preliminary results (including only statistical errors) are 9.8(1) mb, 11.7(1) mb and 10.8(1) mb for the 365 keV, 432 keV, and 879 keV transitions, respectively. The origin of these deviations might be due to the uncertainties in the γ-intensities, which were deduced with relative uncertainties of 5 % more than 40 years ago. Taking the weighted average, we obtained a preliminary production cross section of 10.6(7) mb. Together with a total proton fluence of 1.2 x 10^{18} p, this converts to a production of 2.3 x 10^{12} atoms of ^{79}Se, and a ^{79}Se/^{82}Se ratio of 1.3 x 10^{-8}.

References

1) K. Takahashi, K. Yokoi, At. Data Nucl. Data Tabl. 36 (1987) 375.
2) S.F. Mughabghab, Atlas of Neutron Resonances- Resonance Parameters and Thermal Cross Sections *Z* = 1-100, 5th Edition, Elsevier (2006), ISBN 0444 52035X.
3) T. Rauscher and F.-K. Thielemann, At. Data Nucl. Data Tables **75**, (2000) 1.

Contact:

U. Giesen, Fachbereich 6.4, Arbeitsgruppe 6.41, E-Mail: ulrich.giesen@ptb.de
I. Dillmann, Physik-Department E12, TU München, E-Mail: iris.dillmann@ph.tum.de