Production of neutron-rich copper isotopes in 30-MeV proton-induced fission of ^{238}U

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The neutron-rich isotopes $^{70-76}$Cu have been produced in 30-MeV proton-induced fission of ^{238}U using the Ion Guide Laser Ion Source (IGLIS) at LISOL. The production rates of the copper isotopes, and of the nickel and cobalt isotopes that were measured earlier, are compared to cross section calculations. Based on these new results an estimate for the cross section of ^{78}Ni is given.

Key words: Cu Ni Co production; LISOL; IGLIS; fission

1 Introduction

Studies in the region of doubly magic ^{78}Ni provide an anchor point for testing nuclear theory. Although, it is expected that ^{78}Ni should exhibit its double magicity equally for neutrons and protons, it is not clear in what way this large neutron excess will affect the properties of the nucleus and to what extent the shell model, as we know it now, will still be valid [1,2].
Another motivation for research in this area is related to astrophysics and the

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r-process. It is believed that the r-process follows a path through the neutron-rich nuclides, while the properties of nuclei around ^{78}Ni are suspected to play a fundamental role in the definition of this path. If the predicted ^{78}Ni magicity weakens or disappears, it may profoundly affect our understanding of the stellar nucleosynthesis and the origin of the premordial nuclides.
Our ultimate goal is therefore to reach ^{78}Ni. This can be approached in different ways. Fission using relativistic ^{238}U beams [3], high-energy proton induced fission of ^{238}U [4] and low-energy proton induced fission [5]. At the LISOL (Leuven Isotope Separator On-Line) facility we followed the latter approach. So far production rates of $^{66-70}$Co and $^{68-74}$Ni [5,6] have been obtained. In this article the production of $^{70-76}$Cu isotopes is discussed.

2 The Isotope Production at LISOL and the Detection Setup

A 30 MeV proton beam from the cyclotron hits a 10 mg/cm^2 ^{238}U target, that is situated in a gas cell, inducing fission. The reaction products are stopped and thermalized in a Ar or He buffer gas at a pressure of 500 mbar.
A common problem associated with the Ion Separation On Line (ISOL) technique is isobaric contamination, especially when reaction products of interest are in minority. To overcome this problem the isotopes of interest are selectively ionized by a two step laser ionization process. The reaction products are evacuated from the gas cell along with the buffer gas via an exit hole. An RF sextupole ion-guide directs the ions forwards of the analyzing magnet of the mass separator.
After mass separation the nuclei are implanted on a movable tape in front of a detection setup. The tape allows removal of undesirable long lived accumulated activity. The detection setup consists of five ΔE detectors, and two high efficiency Ge detectors which are shielded by lead and boron. Data was written in list mode event by event by a VME based data acquisition, which allows event reconstruction for later analysis. The acceptance condition for an event is a β-γ or γ-γ coincidence.
The effect of laser ionization is shown in fig. 1. Two measurements at mass 73 were taken; lasers on and lasers off. The cyclotron beam was pulsed using a 50 ms on - 50 ms off cycle. During the cyclotron on period, the mass separated beam was electrostatically deflected to prevent any implantation in the tape system during this period. More details about the experimental setup can be found in [6]. The spectra shown in the fig. 1 are accumulated during 200 s. Without lasers no copper lines are present in the spectra, only background counts, while with lasers γ-lines of ^{73}Cu and of its daughter ^{73}Zn are seen in the spectrum.

3 Experimental Production Rates for the $^{70-76}$Cu Isotopes

Fig. 2 shows the obtained production rates for the $^{70-76}$Cu isotopes. The previously obtained data on the nickel and cobalt production rates [5,6] are included as well. The data are compared with two cross section calculations [7–10]. As the absolute ion-source efficiency is not known precisely enough, the production rates were multiplied by 0.01 mbarn μC/atoms. In this sense a cross section of 1 mbarn corresponds to production rate of 100 atoms/μC. The experimental production rate distributions were fitted with by a gaussian function and the centroids and widths are summarized in table 1.

While the cross section calculations of [7] reproduce the global trend of the production rates, the calculations of [9] are shifted further out of stability. As a consequence, the prediction of [9] for the cross section of ^{78}Ni (3.6 nbarn) appears to be too high. Extrapolation of our experimental data for ^{78}Ni and using the above mentioned normalization yields a production cross section for ^{78}Ni in the picobarn range. The difference between the two calculations deserves further investigation.

The measured production curve gives an estimate for the ^{77}Cu production of 0.2 atoms/μC. Although the predicted production of ^{77}Cu was comparable to that of ^{74}Ni previously seen at LISOL, no sign of β-delayed γ-rays from ^{77}Cu were observed. This effect, we believe, is due to a strong β-feeding to the ground or an isomeric state of ^{77}Zn.

4 Conclusion

The heavy copper isotopes, $^{70-76}$Cu, were produced by 30 MeV proton induced ^{238}U fission at the LISOL facility using resonant laser ionization. The production rates were compared with two cross section calculations. An extrapolation of the data towards ^{78}Ni yields a production cross section in the pbarn range for this doubly magic nucleus.

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Table 1

Element	Centroid	Full Width at Half Maximum
Co (Z=27)	66.64 ± 0.06	1.4 (*fixed*)
Ni (Z=28)	69.45 ± 0.07	1.42 ± 0.04
Cu (Z=29)	72.32 ± 0.10	1.41 ± 0.09

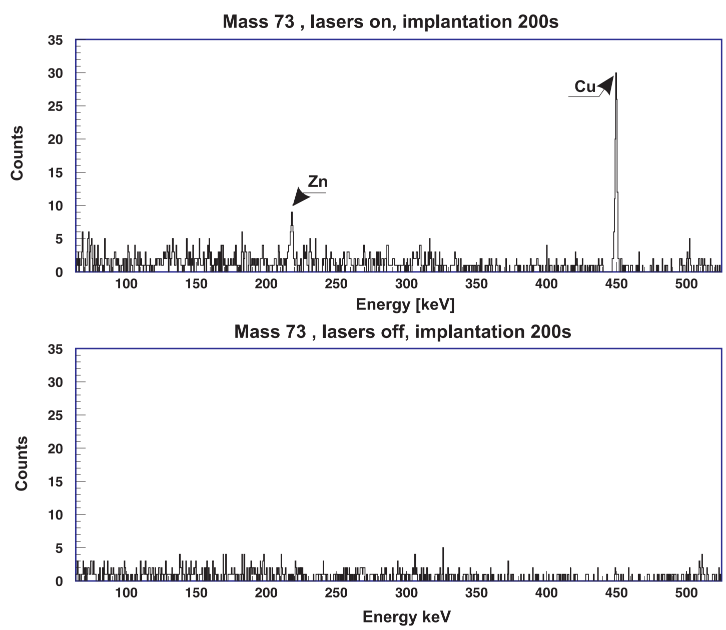

Fig. 1. Singles gamma-ray spectra recorded for 200 s at mass number A=73. The effect of the laser ionization is shown. When the lasers are tuned on copper ionization, γ-lines of ^{73}Cu and its daughter ^{73}Zn are seen.

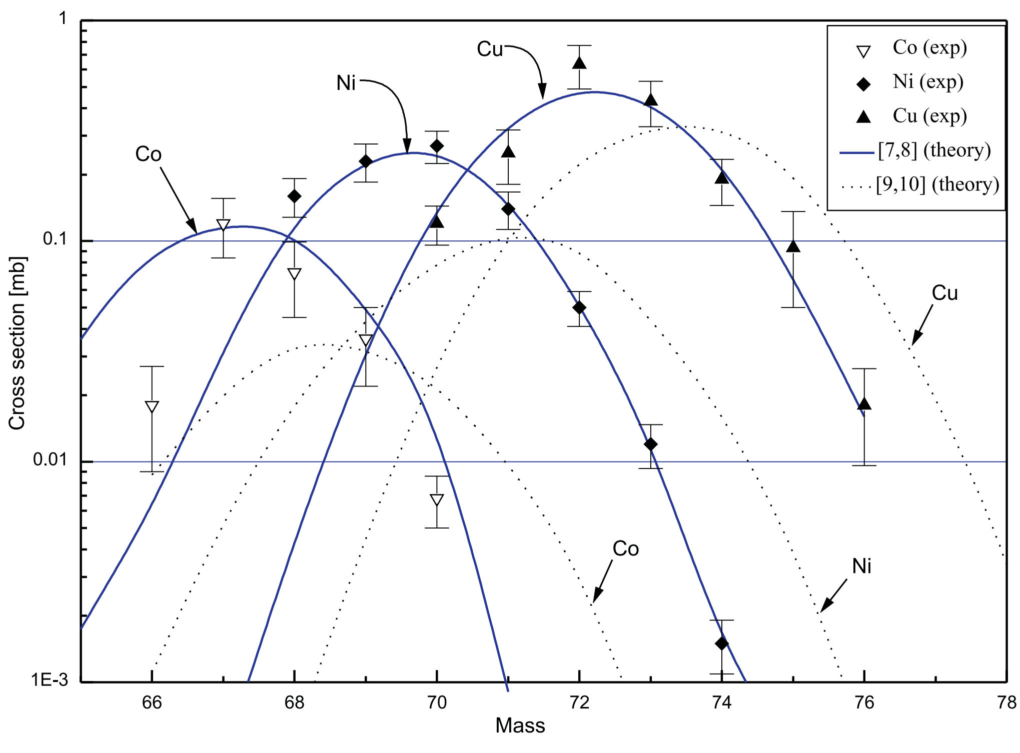

Fig. 2. The cross section calculations of K.-H. Schmidt [7,8] and V. Rubchenya [9,10] are shown together with the experimental production rates obtained. The experimental production rates were multiplied by 0.01 mbarn μC/atoms.