Neutron capture on the s-process branch point nucleus ^{63}Ni

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The cosmic abundance distribution of elements and isotopes is related to the reaction rates of the different synthesis processes. It is important to know those rates under the different conditions found in the universe to explain the origin of this abundance pattern. Most of the elements heavier than iron have been and still are synthesized in neutron-induced reactions in stars of different stages. Nearly all of the observed abundances are either formed by the s- or the r-process in almost equal shares. Of special interest are branching point nuclei like ^{63}Ni, where the s-process path can take different ways. The neutron capture cross (CS) section of ^{63}Ni affects the abundances of other nuclei in this region. In order to determine the energy dependent neutron capture cross section in the astrophysical energy region ($kT_{astro} \approx 1 \dots 100$ keV), an experiment at the Los Alamos National Laboratory has been performed using the calorimetric 4π BaF$_2$ array DANCE. A preliminary result of the ^{63}Ni experiment is presented. The (n,γ) CS of ^{63}Ni has been determined relative to the known ^{62}Ni CS, which was also measured at Los Alamos [1]. Various possible ^{63}Ni resonances have been identified via the Q-value. The contribution of other isotopes in the sample could be identified.

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1. Introduction

One of the important questions in nuclear astrophysics is how the observed abundances of nuclei came to be. For this reason, it is important to know the rates of all relevant reactions under the different conditions found in the universe. Most of the elements heavier than iron have been and still are synthesized in neutron-induced reactions in stars of different stages. Nearly all of the observed abundances are either formed by the s- or the r-process in almost equal shares.

The precise s-process path depends on parameters like temperature, neutron density, cross sections (CS) and half-lifes in case of unstable isotopes. Some of those unstable isotopes on the s-process path play a special role. They act as branching points, creating different possible ways for the nucleosynthesis, neutron capture and β-decay compete. This branching affects the isotopic abundances of the heavier elements in the weak s-process component [3] [4]. Therefore it is important to know the capture CS for these isotopes. ^{63}Ni with $t_{1/2} \approx 100$ yrs is one of these branching points and there is no experimentel CS data so far. Figure 1 shows the current situation. Network calculations show a sensitivity on the ^{63}Ni CS for some nuclei in the vicinity of Nickel. A deviation from the theoretical predictions can affect the abundances of ^{64}Ni, the s-only nucleus ^{64}Zn, and the isotopic ratio of ^{63}Cu and ^{65}Cu.

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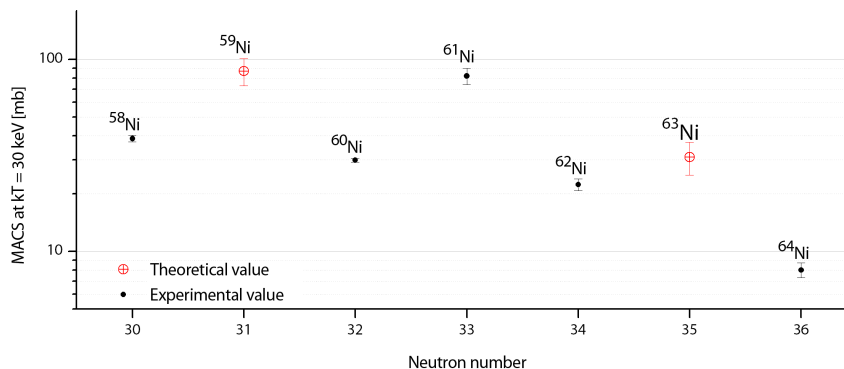

Figure 1: Experimental (black) and theoretical (red) MACS (30 keV) for the Nickel isotopes from the KADoNiS database. [2]
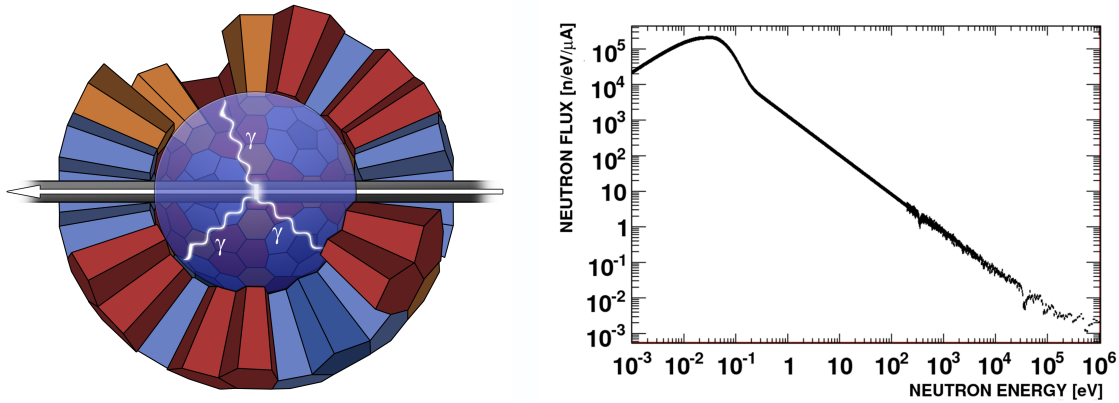
Figure 2: Left: Schematic drawing of the 4π BaF$_2$-detector geometry. The neutrons come from the right side; the sample position is in the center. The semi-transparent sphere depicts the LiH$_6$ neutron absorber. Right: The neutron flux energy spectrum at the DANCE experimental site.

2. The DANCE array

At the Los Alamos Neutron Science CEnter (LANSCE) prompt γ-rays from ^{63}Ni(n,γ) capture events have been observed with the Detector for Advanced Neutron Capture Experiments (DANCE). DANCE is a 4π BaF$_2$-detector, which consists of 160 spherically arranged BaF$_2$-crystals (Figure 2). The inner radius of the sphere is 34 cm. The space between the beam pipe and the crystals is filled with a LiH$_6$ spherical shell, in order to reduce background from scattered neutrons. This is very important, since capture CS are usually smaller than for scattering. DANCE is a high efficiency detector for γ-cascades able to run in a calorimetric mode. The data aquisition is running with an readout rate of 500 MHz. The system delivers several information:

- Total γ energy radiated after capture (E_{tot}).

- Angular distribution.

- Multiplicity (M).

- Neutron energy via time-of-flight (TOF) methode; the flight path length is 20 m.

3. The sample

The sample, a metallic foil of 10.5 cm in diameter, was produced more than 20 years ago by neutron irradiation of an enriched ^{62}Ni sample. The irradiation resulted in about 11% of ^{63}Ni. The total mass of the sample is 347 mg. Since much time passed, one could expect a considerable amount of the decay product ^{63}Cu. Follow-up investigations at PSI in Switzerland showed that the sample contained about 5.94 mg of ^{63}Cu. Additionally ^{59}Ni was produced during the irradiation as well.
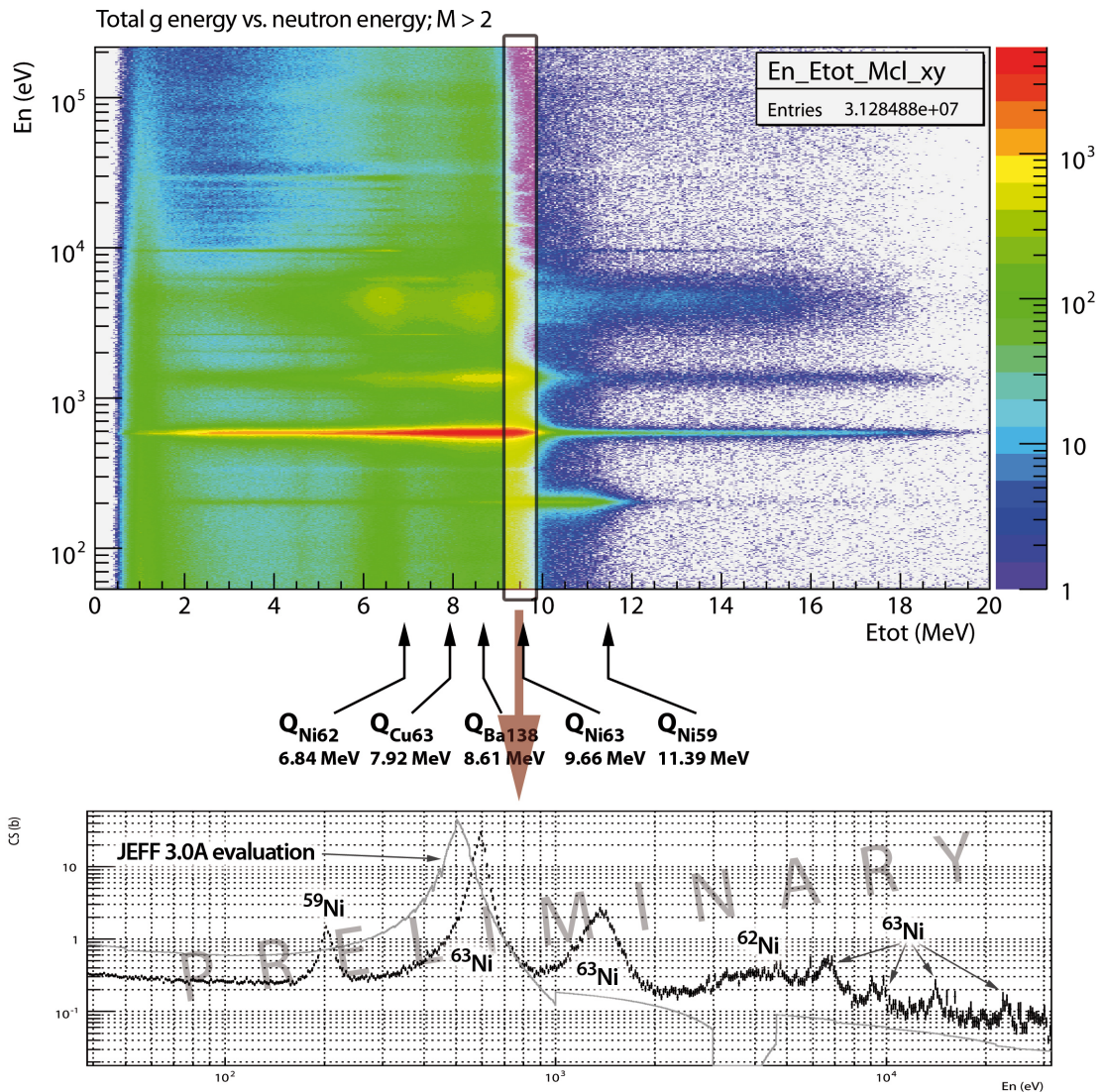
Figure 3: Top: 2D plot of E_{tot} vs. neutron energy, with multiplicity greater than 2, showing the used data cut in order to get a clean as possible ^{63}Ni CS. Bottom: Preliminary CS vs. the only available data at JEFF 3.0A.

4. First results

The ^{63}Ni(n,γ) reaction has a Q-value of $Q_{^{63}Ni} = 9.658$ MeV. Background from other species in the sample can also be identified via Q-value using the total gamma energy information. Most of the observed background is the result of the main material of the sample, ^{62}Ni, and the result of the ^{59}Ni and ^{63}Cu contaminations. Neutron captures on ^{62}Ni and ^{63}Cu have lower Q-values than on ^{63}Ni ($Q_{^{62}Ni} = 6.838$ MeV and $Q_{^{63}Cu} = 7.916$ MeV respectively) and can be discriminated by a cut on the total gamma energy. ^{59}Ni(n,γ), unfortunaly, has Q-value of $Q_{^{59}Ni} = 11.388$ MeV. But
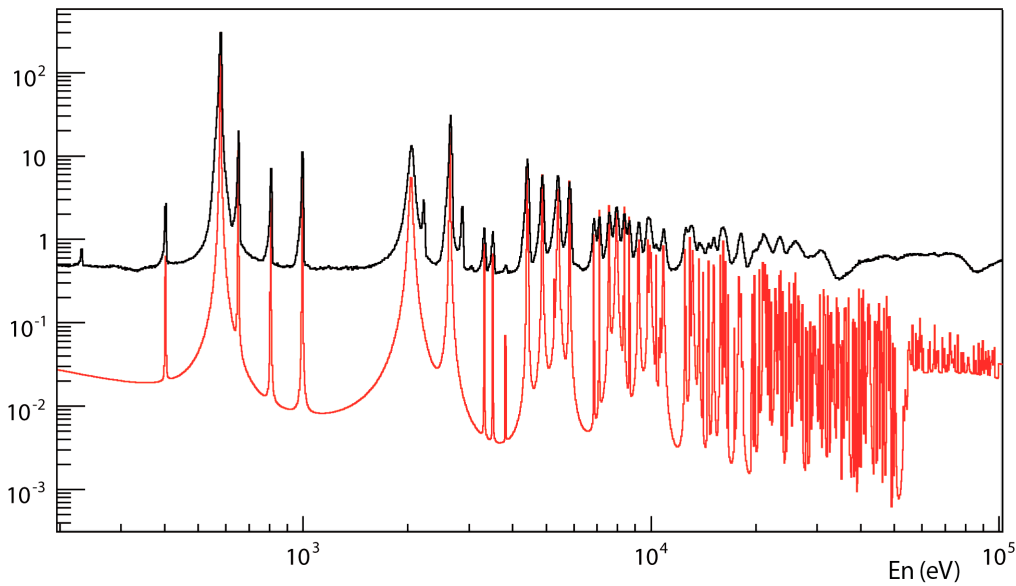
Figure 4: A preliminary, not normalized plot of the ^{63}Cu measurement (black) and JEFF 3.0A data for comparison (red) [8].

the data show, that there is only a significant contribution in the area of the strongest resonance at about 200 eV.

Additionally, neutron scattering on ^{62}Ni produces a significant background, which appears at the Q-value of ^{137}Ba(n,γ) at 8.612 MeV due to capture events in the crystals. This background can also be discriminated via E_{tot} cut. Figure 3 top shows a 2D plot with a rough sketch of the cut. The bottom part shows the current state of the analysis with a preliminary differential cross section.
One major challenge of this analysis is the determination of the efficiency for the used data cut. First, the DICEBOX code was used to create artificial gamma cascades [6]. Second, in order to calculate the fraction of the used data, GEANT3 simulations of the complete detector geometry and with the created cascades were performed [7]. The preliminary result is an efficiency of 6.53% for the used energy window of 9.2 to 9.7 MeV and multiplicities from 3 to 10.
Two strong and several smaller peaks could be identified as resonances from ^{63}Ni(n,γ). They are marked in figure 3 bottom.

5. Further analysis

The analysis of the ^{63}Ni experiment will be finished soon. Simulation studies with GEANT3, concerning the efficiency of the used data cuts are in the final stages. Additionally the CS will also be determined relative to the Gold standard to verify the results. Follow-up measurements from February 2012 with a 99% ^{63}Cu sample will provide additional CS data for the Ni-Cu-Zn region. A preliminary plot of the data is shown in figure 4.

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