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THE ^{58,60}NI(N,XALPHA) REACTIONS FROM THRESHOLD TO 50 MEV

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ABSTRACT

The ^{58,60}Ni(n,xalpha) reactions have been studied at the fast neutron spallation source at the Los Alamos Neutron Science Center (LANSCE) for neutron energies from threshold to 50 MeV. Alpha particles were observed at four angles by detectors consisting of low-pressure proportional counters and silicon surface-barrier detectors. Cross sections and emission spectra agree fairly well with data in the literature for experiments where alpha particles are detected. The cross sections for the ^{58}Ni(n,alpha) reaction are significantly lower than those determined by activation in the region from threshold to 10 MeV. The cross sections for both isotopes are lower than the ENDF/B-VI evaluations from threshold to 12 MeV. The data are interpreted in terms of the Hauser-Feshbach reaction model with precompound emission.

1 Introduction

Alpha-particle production by neutron interactions has importance in basic physics and applications. The cross sections and emission spectra can be used to test nuclear model calculations and, in particular, to shed light on input parameters of statistical model calculations. In regard to applications, these cross sections on nickel have been an important component of the International Atomic Energy Agency's Coordinated Research Programme on Improvement of Measurements, Theoretical Computations, and Evaluations of Neutron-Induced Helium Production Cross Sections. [1]

For the two most abundant isotopes of nickel, ^{58}Ni and ^{60}Ni, measurements of alpha-particle production have been reported for individual neutron energies below 14 MeV [2-5] and near 15 MeV [6-8]. Near threshold, many more neutron energies have been used to investigate possible structure in the excitation function [9] for ^{58}Ni . Helium production, determined by helium accumulation, has been measured at 10 and 15 MeV [10,11]. Activation data are available only for ^{58}Ni [12] since the product of ^{60}Ni(n,alpha)^{57}Fe is stable. In any case, activation approaches address the total helium production only for neutron energies below the (n,n'alpha) threshold (approximately 9.5 MeV for both ^{58}Ni and ^{60}Ni) since these reactions on both isotopes lead to stable residual products, ^{54}Fe and ^{56}Fe. In this report, we describe measurements on (n,xalpha) cross sections, emission spectra and angular distributions for incident neutron energies from threshold to 50 MeV made with a spallation neutron source. A brief discussion of the theoretical analysis is also given.

2 Experiment

The experimental approach has been described previously [13]. Neutrons from the pulsed, fast neutron spallation source at the Los Alamos Neutron Science Center [LANSCE] are incident on samples of isotopically enriched nickel, 10 cm in diameter, placed 9.1 meters from the source. The ^{58}Ni foil had a thickness of 3.38 mg/cm^2 and had an isotopic enrichment of 99.66%. The ^{60}Ni was 2.98 mg/cm^2 thick and was enriched to 99.79%. Charged particles are detected by an array of four counter telescopes each consisting of a low pressure gas proportional counter and a 500 micron silicon surface-barrier detector. For these measurements, particle identification was very clean and target-out backgrounds nearly negligible due to excellent collimation of the neutron beam. Emission angles of 30, 60, 90 and 135 degrees were investigated.

The data were binned according to neutron energies determined by time-of-flight. The bin widths were 0.5 MeV up to En=15 MeV, 1.0 MeV from En =15 to 20 MeV and 2.0 MeV above 20 MeV. To investigate the excitation function near threshold, the data were re-analyzed and binned into 0.1 MeV wide bins. The neutron energy resolution due to the finite time resolution was approximately 43 keV at En = 3 MeV, 92 keV at En = 5 MeV, and 151 keV at En = 7 MeV.

3 Results

Cross sections for alpha-particle production on ^{58}Ni and ^{60}Ni are shown in Fig. 1 for neutron energies up to 50 MeV. The errors bars on the data are statistical. In addition a systematic error of 8 % should be added for target non-uniformities and solid angle uncertainties. Another systematic error, due to the angle integration when data from only four angles were available, should also be added: it is estimated to be 8% below 20 MeV rising to 20% at 50 MeV. For all these isotopes, alpha-particle production increases monotonically over nearly all of the range, but appears to flatten at the upper end, above about 35 MeV.

Present results for ^{58}Ni and ^{60}Ni are compared with previous data up to 20 MeV and with the ENDF/B-VI [14,15] evaluation in Fig. 2 and 3 respectively. The activation data of Ref. 12 appear to be systematically higher than the present results. Data on the threshold behavior of the ^{58}Ni(n,alpha) reaction are compared in Fig. 4. Our data show some evidence for the structure reported Ref. 9 near 5 MeV. The overall normalization of the present data in this region is consistent between our results and those of Ref. 3. The normalization of the data of Ref. 9 appears to be somewhat low.

Comparisons of the ENDF/B-VI evaluations for ^{58}Ni and ^{60}Ni in Fig. 2 and 3 show significant disagreements. The evaluations were made over a decade ago and had only the experimental results near 14 MeV and the activation data of Ref. 12 to guide them. Although the evaluations reproduce the 14-MeV data well, they are nearly a factor of 2 high in the region 5-10 MeV. We believe this problem can be attributed to the level density used to describe the competing (n,n') reactions, that is the level densities in the region of 4-9 MeV in ^{58}Ni and ^{60}Ni . If those level densities were raised by a factor of 2 or so, then neutron emission would compete better against alpha-particle emission in this energy range.

Evidence for "alpha-particle trapping" is seen in the calculations and, to some degree, in the data in Fig. 5. This effect is expected to occur under certain binding energy considerations, and is similar to "proton-trapping" which was observed many years ago [6]. It is discussed further in another contribution to this Conference. [16]

4 Calculations

Model calculations of neutron reactions on nickel isotopes were performed with the GNASH code, using Hauser-Feshbach theory for equilibrium decay, and Kalbach's exciton model for nucleon and cluster preequilibrium decay. A successful analysis of alpha emission, which represents a small fraction of the total reaction cross section, depends on the use of accurate level densities and optical potentials. The Gilbert-Cameron level density formalism was used. The level density parameters (a and Delta) were adjusted to fit D-0 values at the neutron binding energy, where available, and total level densities at 11 MeV from level density studies by Fisher et al. [17] Space limitations prohibit a more detailed description of all the parameters used, but this information will be supplied in a more extensive account of this work.

5 Conclusion

Alpha-particle production by neutrons on ^{58}Ni and ^{60}Ni has been measured from threshold to 50 MeV. The data constitute the first comprehensive study over the full energy range, and they are in good general agreement with other measurements using particle detection techniques. There is however a disagreement in normalization with the one activation study. Finally, our data show evidence for alpha-particle trapping in the emission spectra for the 60Ni sample.

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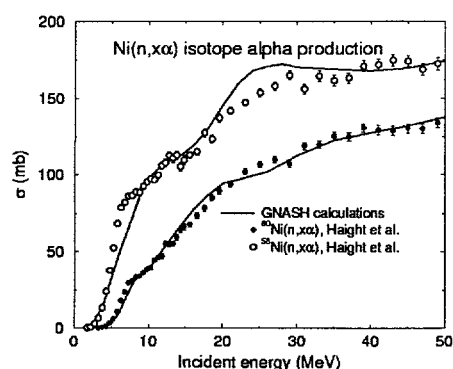17. R. Fischer, G. Traxler, M. Uhl, H. Vonach, and P. Maier-Komor, Phys. Rev. **C34**, 460 (1986).

Figure 1 - Experimental data and FKK GNASH calculations

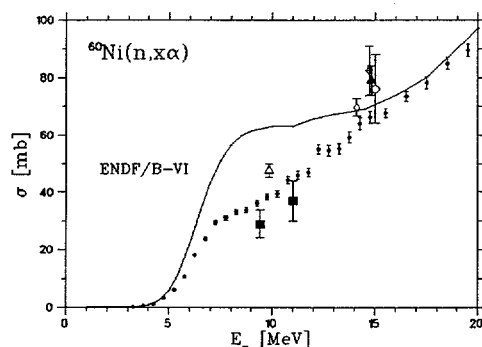Figure 2 - [58]Ni data compared with data from Refs. [2-8,10-12]

Figure 3 - [60]Ni data compared with Refs. [2,6-8,10,11].

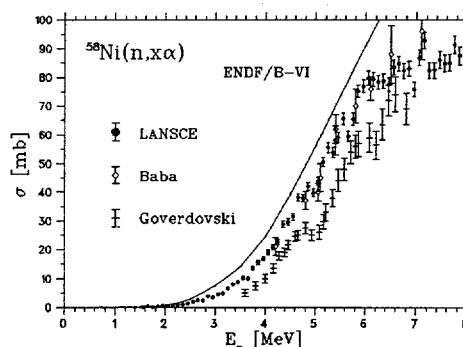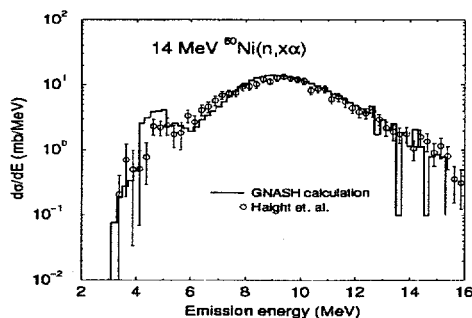Figure 4 – Threshold dependence for [58]Ni compared with Refs [3,9].

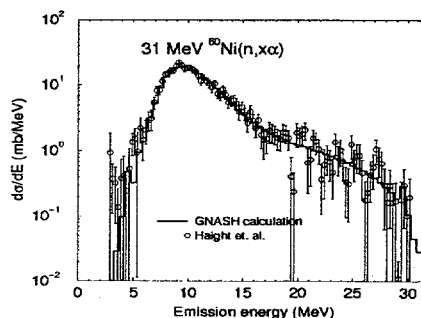Figure 5 - FKK GNASH calculation of the 14-MeV spectrum from [60]Ni.

Figure 6 - FKK GNASH calculation of the 31-MeV spectrum from [60]Ni.