CONF-9606248--2

Measurements of ^{142,144}Nd(n,γ) cross sections at ORELA for astrophysical s–process studies

K.H. Guber,[a*] R.R.Spencer[a], P.E. Koehler [a †] and R.R. Winters[b]

[a]Oak Ridge National Laboratory, MS-6354, Oak Ridge, TN 37831

[b]Department of Physics and Astronomy, Denison University, Granville, OH 43023

We have completed measurements of the ^{142,144}Nd(n,γ) cross sections from approximately 20 eV to 200 keV at the Oak Ridge Electron Linear Accelerator (ORELA) using a recently improved C_6D_6 detector apparatus. ^{142}Nd is an s-only isotope, i.e. it is only formed during the s–process. It has a closed neutron shell and therefore defines a step in the $< \sigma >N_s$ curve from which the mean s–process neutron exposure can be calculated. In addition, ^{144}Nd is the normalization point for the neodymium abundances. Also accurate (n,γ) cross sections would help to determine the r– and p–process residuals of these isotopes and will impact the interpretation of the recently discovered isotopic anomalies in silicon carbide grains from the Murchison meteorite. Our new (n,γ) cross sections also show that reaction rate extrapolations for nuclei near closed neutron shells from measured values at 30 keV down to 8 keV can be inaccurate.

1. Introduction

The identification of the s–process site in low mass red giant stars on the asymptotic branch (AGB stars) has increased the interest in and need for improved neutron capture cross sections at lower temperature [1–3]. Abundances calculated using the most recent stellar models have come reasonably close to the observed abundances. The major difference in these newer stellar s–process models is that the temperature of the site of nucleosynthesis is significantly lower, kT = 6 - 12 keV, than the canonical kT = 30 keV assumed in the classical s–process calculations. To provide input data for and to test the new stellar models of s–process nucleosynthesis, Maxwellian-averaged neutron capture cross sections derived from measurements to considerably lower incident neutron energy than previously available are required. Most of the previous measurements were restricted to energies above 3 - 5 keV (see for example [4]). We are particularly concerned about the use of simple cross section models, e.g. a $\frac{1}{\sqrt{E}}$ energy dependence, to extrapolate existing measurements at higher energies down to $\approx$8 keV.

*The JIHIR has as member institutions the University of Tennessee, Vanderbilt University, and the Oak Ridge National Laboratory; it is supported by the members and by the Department of Energy through Contract Number DE-FG05-87ER40361 with the University of Tennessee.

†Research sponsored by the Oak Ridge National Laboratory, managed by Lockheed Martin Energy Research Corporation for the U.S. Dept. of Energy under contract number DE-AC05-960R22464

DISCLAIMER

The present interest in the (n,γ) cross sections of ^{142}Nd and ^{144}Nd is motivated by the following considerations : (i) ^{142}Nd is an s–only isotope, i.e. it is shielded against contribution from the r–process β decay by its stable isobar ^{142}Ce. (ii) With a closed neutron shell at the magic Neutron Number N= 82, ^{142}Nd is located at a step in the $< \sigma > N_s$ curve. Therefore this isotope along with ^{124}Te and ^{150}Sm serves as the third normalization point [5] for the mean neutron exposure of the main component in the classical s–process. (iii) Recently discovered anomalies for the Neodymium isotopes are currently interpreted in terms of a pure s–process origin [6]. With the previously extant data sets of ^{142,144}Nd (n,γ) cross sections, this interpretation could not be confirmed [11]. (iv) Given that the half-life of ^{141}Ce is 32 days, a small branching in the s–process path is expected. In Ref. [7] an estimated 5% of the s–process current bypasses ^{142}Nd. With more precise cross sections the branching could be further investigated. (v) Because of the increasing sophistication of the current stellar models of s–process nucleosynthesis, the possibility of contributions from other process can no longer be neglected. More reliable measured capture cross sections will help to improve the derived r– and p–process abundances in this mass region.

2. Experimental Technique and Measurements

These measurements were performed at the 40 m flight station of the white neutron source ORELA. The experimental arrangement used for the neutron capture measurements is described elsewhere [8]. While the detector system at the 40 m flight station has been used for over 25 years, significant modifications have been made in the past few years. These changes resulted in a much lower neutron sensitivity of the whole system, i.e. the (n,γ) background from sample scattered neutrons which were captured by the surrounding material has been significantly reduced. In addition the method of the pulse-height weighting function was improved by acquiring both pulse-height and TOF. The absolute neutron capture yield calibration was done by the saturated resonance technique [9] using the 4.906 eV resonance in the ^{197}Au (n,γ) cross section.

The samples were produced from highly isotopically enriched Nd_2O_3 powder and pressed into 2.54 cm diameter disks. Neodymium oxide is, as are all other oxides, very hygroscopic and has therefore to be treated in a special way [4].

3. Data Analysis and Results

To fit the capture data obtained by our experiment we used the multilevel R-matrix code SAMMY [10]. By comparing our results with previous experimental data [12] we found several new resonances and some misassignments which will be discussed in an upcoming paper. Because we had very pure and highly enriched samples we could exclude any visible resonance effects from the isotopic impurities, except for the very strong low energy resonances of ^{143}Nd in the ^{142}Nd sample. From the resonance parameters together with the data from the unresolved region we obtained the astrophysical reactivity data (compare Fig. 1). We want to point out again that the (n,γ) cross section measurement to lower energies are very important, because the extrapolation of the data to lower temperatures could be wrong due to missing resonance parameters. i.e. previous measurements had energy threshold at 3-5 keV. The stellar model calculations [7] underestimates the s–

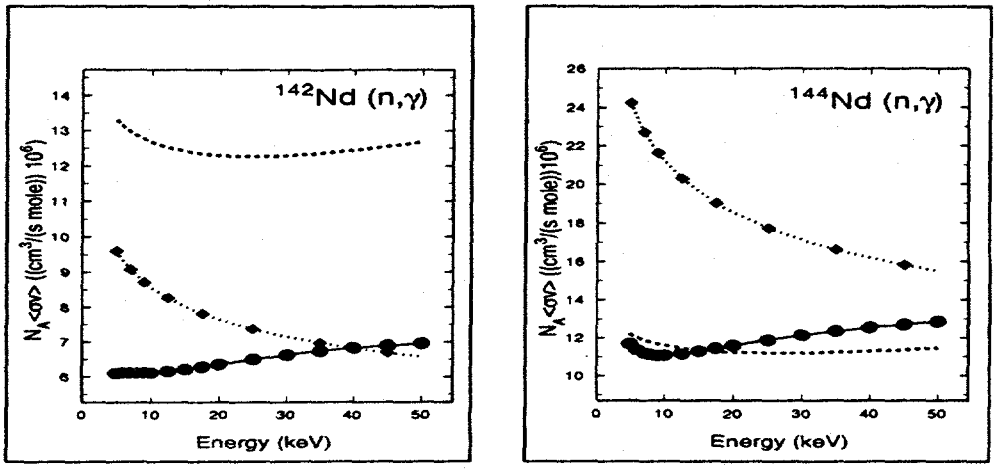

Figure 1. Astrophysical reactivities, $N_A < \sigma v >$, for ^{142}Nd and ^{144}Nd. ○ represent the ORELA data with an overall uncertainty of less than 6% for ^{142}Nd and 3.5% for ^{144}Nd respectively. ◇ are the experimental data from ref. 16, the dashed curve is the theoretical fit from ref. 17

process abundance for ^{142}Nd with the old cross section set for the Neodymium isotopes from ref. [15] Compared to the old resonance data [12] we found an enhancement of the cross section at 5 keV of 20 % for ^{142}Nd and 40 % for ^{144}Nd. We also want to point out that the Maxwellian cross section at 10 keV has 20 % contribution from resonances below 5 keV for ^{142}Nd and 25 % for ^{144}Nd respectively. Our new measurements yield a Maxwellian cross section of 45.8±1.7 mb for ^{142}Nd at 30 keV and 83.9±2.5 mb for ^{144}Nd respectively. This is lower by 6% than the previous measurements [16] for ^{142}Nd and 30% for ^{144}Nd. At 10 keV the difference is even more dramatic, we measure 73.2±2.5 mb for ^{142}Nd which is 30% lower than ref [16] and 132.6±4.2 mb for ^{144}Nd which is 50% lower.

4. Astrophysical Implication

The uncertainties of the (n,γ) cross section have been reduced by more than a factor of two compared to ref. [16]. Thus error of the calculated *s*–process abundances were reduced. From the new (n,γ) cross section for ^{142}Nd and ^{144}Nd and the calculation performed with the most recent parameters [7,11] we draw the following conclusions:

- With the now approximately 30% lower cross section for ^{144}Nd at 30 keV we find an *s*–process pattern of the isotopic ratios ^{142}Nd/^{143}Nd/^{144}Nd/^{145}Nd/^{146}Nd/^{148}Nd for the classical model as follows:

$$1.84\pm0.13/0.36\pm0.02/1/0.17\pm0.036/0.92\pm0.053/0.04\pm0.003$$

compared to the value obtained from the Murchison meteorite [6] which is

$$2.13 \pm 0.08/0.293 \pm 0.006/1/0.161 \pm 0.005/0.775 \pm 0.009/0.0281 \pm 0.0058$$

Our network calculations at 12 keV using the code NETZ [13] yields 1.83/0.345/1/ 0.1675/0.762/0.027. This is in good agreement for the observed isotopic anomalies except for ^{142}Nd whereas the classical model results differ from the observations for both ^{142}Nd and ^{144}Nd. This remaining difference for ^{142}Nd shows that there might still be a problem for the stellar model or that the meteorite abundances do not arise from pure *s*–process material. These results show that there might be still a problem with the isotopic abundances or the anomaly might be a hint that the ^{142}Nd is not a pure *s*–process isotope.

- Network calculations at 12 keV with our new cross sections yields a *p*–process contribution to ^{142}Nd of only 7% which is in good agreements with the model calculations [3]. Whereas the classical model still obtains an 18% *p*–process contribution which is much more than any *p*–process model predicts.
- Due to the much lower ^{144}Nd cross section, the calculated *r*–process abundance is smaller and fits much better in a smooth *r*–process pattern obtained from the classical model [5].

REFERENCES

1. O. Straniero *et al.*, Ap. J. 440 (1995) L85.
2. R. Gallino, C.M. Raiteri, and M. Busso, Ap. J. 410 (1993) 400
3. F. Käppeler *et al.*, Ap. J. 354 (1990) 630.
4. K. Wisshak, K. Guber, F. Voss, F. Käppeler, and G. Reffo, Phys. Rev. C 48 (1993) 1401.
5. F. Käppeler, H. Beer, and K. Wisshak, Rep. Prog. Phys. 52 (1989) 945.
6. S. Richter, U. Ott, and F. Begemann, in *Nuclei in the Cosmos '92*, edited by F. Käppeler and K. Wisshak (Institute of Physics, Bristol, 1993) p. 127.
7. F. Käppeler *et al.*, Phys. Rev. C. 53 (1996) 945.
8. R.L. Macklin *et al.*, NIM 91 (1971) 565.
9. R.L. Macklin *et al.*, NIM 164 (1979) 213.
10. N. Larson, Technical Report No. ORNL/TM-9179/R2, Oak Ridge National Laboratory, 1989.
11. K. Toukan, K. Debus, F. Käppeler, and G. Reffo, Phys. Rev. C 51 (1995) 1540.
12. J. Mughabghab, M. Divadeenam, and N. Holden, in *Neutron Cross Sections, Vol. 1, Part A* (Academic Press, New York, 1981).
13. S. Jaag, Diplom thesis, University of Karlsruhe,Germany, 1990.
14. Z.Y. Bao and F. Käppeler, Atomic Data Nucl. Data Tables 36 (1987) 411.
15. H.Beer, F. Voss, R.R. Winters Ap. J. Supl. 80 (1992) 403.
16. G.J. Mathews, F. Käppeler, Ap. J. 286 (1984) 810.
17. J. A. Holmes *et al.*, Atomic Data and Nucl. Data Tables 18 (1976) 305.