PROCEEDINGS OF SCIENCE

NERO – The Neutron Emission Ratio Observer

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The Neutron Emission Ratio Observer (NERO), has been constructed for use at the National Superconducting Cyclotron Laboratory to work in conjunction with the NSCL Beta Counting System BCS [1] in order to detect β-delayed neutrons. The design of the detector provides high and flat efficiency for a wide range of neutron energies, as well as a low neutron background.

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1. Motivation

The r-process is a major mechanism for producing elements heavier than Fe. It occurs in an environment of large neutron flux, and it involves the progressive build up of heavier isotopes via neutron capture proceeding on neutron rich isotopes with interspersed β-decays. When the neutron flux diminishes, the exotic nuclei will decay to stability by β-decay and β-delayed neutron emission. In this context, the knowledge of the probability for the emission of n β-delayed neutrons (P_n value) is a critical input for r-process models affecting the final abundance pattern. As a consequence of delayed neutron emission, a fraction of the decay products moves to lower A, resulting in a smoothing of the calculated final r-process abundance pattern. This effect is illustrated in Figure 1 [2].

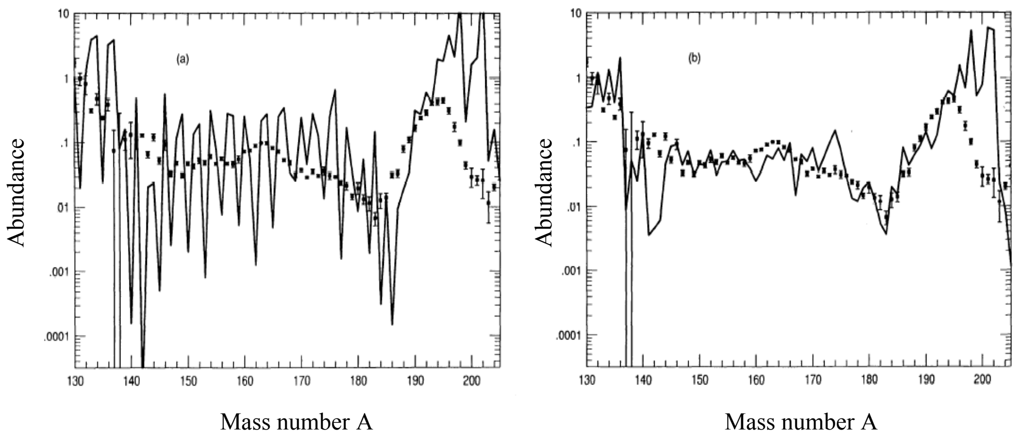

Figure 1: Smoothing effect of the delayed neutron emission on the r-process model calculation. Because the β-decays do not change A, the difference in the pattern of abundances before (left) and after (right) the freeze-out are due to the β-delayed neutron emission.

The NERO detector (Neutron Emission Ratio Observer) was designed and built at the NSCL for the main purpose of measuring neutron emission probabilities. Another possible application of NERO is the measurement of the efficiency of nuclear reactions that create neutrons in stars.

2. General features of the NERO design

There were several experimental criteria in determining the optimal configuration for NERO.

1. A high efficiency is required, since the laboratory production rates for very neutron rich isotopes are low.
2. The neutron efficiency curve as a function of energy must be as flat as possible over a range of reasonable neutron energy, since the energy of the neutron-rich nuclei of interest are generally not known.

3. The need to accommodate the existing NSCL Beta Counting System (BCS) [1] inside the neutron detector in order to measure β-delayed neutrons.

NERO consists of an axially symmetric set of proportional gas counters embedded in a moderating matrix. The main feature of the detector system is a large diameter hole to allow for the insertion of the implantation detector which stops the nuclei of interest and allows for β-delayed neutron decay to occur in the center of NERO, thus providing a solid angle of almost 4π.

The detection of neutrons with proportional gas counters takes advantage of the fairly large neutron capture cross section of ^{3}He and ^{10}B at low neutron energy (less then 0.5 eV). The flat efficiency is achieved by the placement of rings of proportional counters at various distances from the center of the detector. Multiple rings also allow for the possibility of extracting some average energy of the emitted neutrons which may be desiderable since the energy information of an individual neutron is lost in moderation.

The beamline-hole requirement was a particular challenge. The larger the hole, the further away the tubes are from the center of the detector and therefore the lower solid angle that is covered with the same number of tubes.

3. NERO design

Based on the calculations that were performed using MCNP [3] to optimize the design of NERO, the final design of NERO [4] included a polyethylene moderating matrix 60 cm by 60 cm by 80 cm, being longer along the beam axis. The detector contains 60 proportional counters, 16 ^{3}He and 44 BF_3 tubes, arranged in three concentric rings. The inner ring has a radius of 13.6 cm and contains 16 ^{3}He tubes. The middle ring has a radius of 19.2 cm and contains 20 BF_3 tubes, and the outer ring has a radius of 24.8 cm with 24 BF_3 tubes. The rings are all concentric around the cylindrical beamline hole of radius 11.2 cm, running the length of the detector along the beamline direction.

Two models of ^{3}He proportional counters were used in NERO; their features are listed in Table 1. All of the BF_3 counters are 100% BF_3 gas enriched in ^{10}B to greater than 96%. The casing is 304 Stainless Steel.

Table 1: Proportional counter data

Detector	Active length (in)	Inactive Length (in)	Radious (in)	Nominal pressure (atm)
^{3}He mod. 1	9.84	10.24	0.5	5.73
^{3}He mod. 2	14	17	0.5	4
BF_3	20	22	1	1.18

The moderating polyethylene block was divided into two halves, upper and lower. In addition, each half was cut into 6 equal pieces so that the entire moderating block can be

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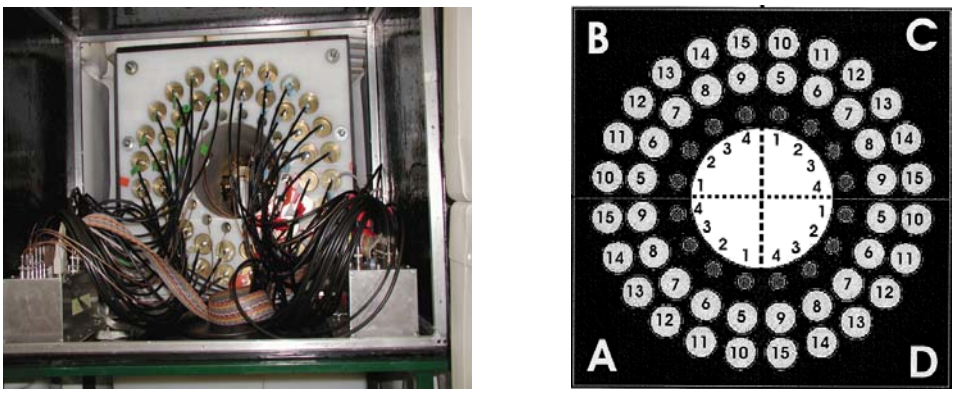
disassebled into 12 pieces for transportation. When assembled, the pieces are held together by 8 stainless steel bolts which run the length of NERO and were included in the simulations.

A boron carbide shield was added around NERO. The boron carbide shield was fabricated by mixing boron carbide powder in epoxy and pouring the mix into a frame. Inside the sheet, fiberglass ribbons provide added support. The final design can be seen in Figure 2.



(a) (b)

Figure 2: Views of NERO. (a) The tubes are inserted and high voltage cables come out of the proportional tubes to the preamp boxes. In the beamline hole, a special holder allows a source to be placed in the middle of NERO. (b) Cross section of NERO. For the purpose of electronics, NERO was divided into four quadrants, and the proportional counters were numbered by quadrant.

4. Detection efficiency

The NERO design resulted in a relatively constant calculated detection efficiency of about 45% from 1keV to 500keV, dropping off to around 26% at 5MeV. Figure 3 shows the NERO efficiency versus the neutron energy as calculated in the code MCNP. The plot includes the total NERO efficiency, as well as the efficiency of each one of the three rings of proportional counters.

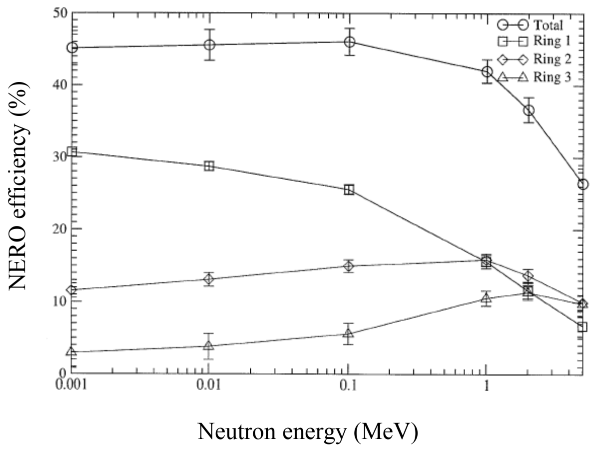


Figure 3: The calculated efficiency curve for NERO.

5. NERO electronics

All counters from a given quadrant (see Figure 2b) are connected via high-voltage cables to one preamplifier box which contains 16 individual preamp chips, leaving one spare channel per preamp box.

The signals from a given quadrant are sent out of the preamp box via a 34-conductor ribbon cable to a double-wide CAMAC 16-channel discriminator module designed by Pico Systems. The input signal is then split; one signal proceeds through the shaper and amplifiers, while the other is filtered by the discriminator. The shaper outputs feed a pair of VME CAEN V785 ADCs. The discriminator outputs are split into two other signals; one goes into a multi-hit TDC CAEN V767, which is used to count the number and arrival time of neutrons associated with a single event, while the other feeds a scaler. The shaper gains and discriminator thresholds can be controlled via software.

6. NERO background

Background simulations were counducted with various shielding configurations, and background measurement were taken with and without shielding. Neutron background can be induced by interaction of the incoming beam with matter, and from cosmic rays. Figure 4 shows a common NERO neutron background spectrum without beam. The background rate measured during a typical experiment is about 5 neutrons per second.

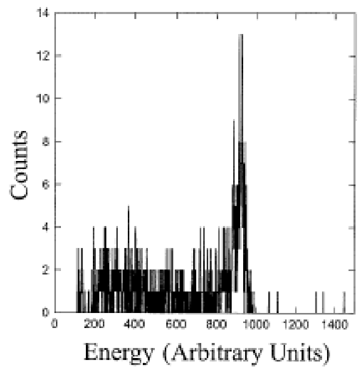


Figure 4: NERO background spectrum in a typical ^{3}He counter. The charateristic shape for neutron detection is clearly identifiable, showing that the background is due to ambient neutrons.

7. Test with 252Cf source

^{252}Cf, a spontaneus-fission neutron emitter with a half-life of 2.638 years, is a readily avaible neutron source that has often been used for calibration of neutron detectors. It has a neutron productin rate of 0.116 neutrons/s/Bq. The emitted neutrons cover a broad range of energy from 0 MeV to 7 MeV (see reference [5], pag. 20). The activity of our calibration source was 0.8 μCi. The current activity was calculated from the initial activity known with an uncertainty of 15%. This activity was multiplied by the neutrons/s/bq from ref [5] to obtain a calculated neutron rate. This was compared to the neutron rate measured by NERO with the source located at the target position. Their ratio, the average efficiency weighted by the source neuton energy spectra, was calculated to be 27 ± 4%. The response of the MCNP code for this quantity is 34.48 ± 0.06% and the nature of this discrepancy is still under discussion.

The ^{252}Cf source was also used to locate the axial position within the beamline hole which has the maximal neutron efficiecy. During experiments, this should be considered the target position. By design, the target position should be at the midpoint of the beamline hole. This assumption was validated by the ^{252}Cf study. It can also be seen in Figure 5 that the efficiency function along the axial direction is fairly symmetric for small displacements around the target position.

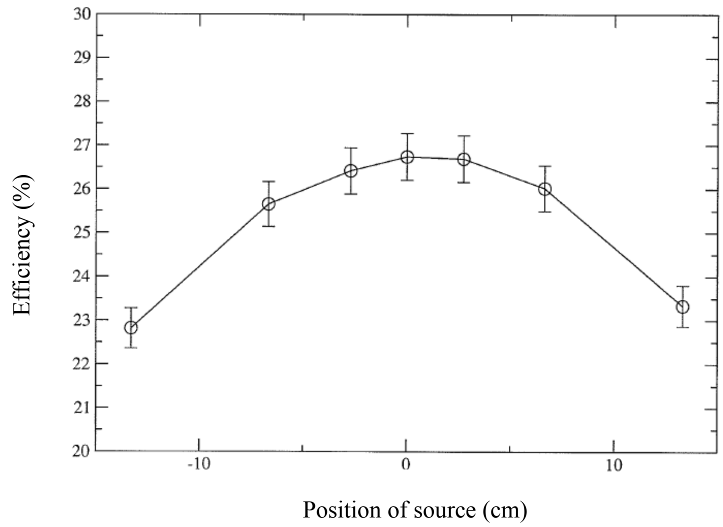


Figure 5: Variation of NERO efficiency in the beamline hole as a function of position along the beamline axis. Zero is the NERO target position. Larger negative numbers are upward the beam direction.

8. NERO moderation time measurements

The NERO neutron moderation time was also studied with the 252Cf source [4]. In the fission of 252Cf, gamma rays are emitted in coincidence with neutrons. A 252Cf source was placed on the bottom surface of the NERO beamline hole near the up-stream of the detector. A BaF2 gamma detector was inserted in the NERO beamline hole three inches from the end. The detection of a gamma ray by the BaF2 was used to start a clock and the detection of a neutron by NERO served as a stop. The results of this test is the moderation time spectrum in Figure 6. Almost all of the detected neutrons were moderated within about 200μsec.

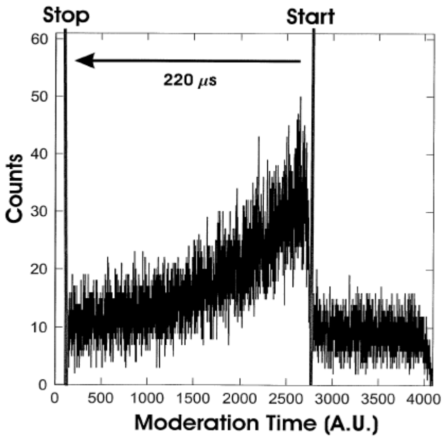


Figure 6: BaF_2 moderation-timimg measurement with 252Cf source. The start and stop for the TAC were inverted.

9. Summary

The Neutron Emission Ratio Observer (NERO) has been developed at the NSCL to determine β-delayed neutron emission branching ratios. Its special geometry allows operation with the BCS in order to measure neutrons correlated with β-decays. Monte Carlo simulations indicate that the detector can achieve efficiencies of approximately 45% for neutrons between 1 and 500keV dropping to 26% at 5MeV. Results from tests demonstrated the optimum performance of NERO: high and flat efficiency for a wide range of neutron energy and low neutron background [4].

P_n values of nuclei relevant to the r-process have been measured for the first time in recent experiments at the NSCL [4], [6-8] and new r-process experiments are planned to make use of the capability of NERO.

References

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