HYBRID-3HEN — NEW DETECTOR FOR GAMMAS AND NEUTRONS*

R. Grzywacz[a,b], K.P. Rykaczewski[b], C.J. Gross[b], M. Madurga[a]
K. Miernik[b,c], D.T. Miller[a], S.V. Paulauskas[a], S.W. Padgett[a]
C. Rasco[d], M. Wolińska-Cichocka[b,e,f], E.F. Zganjar[d]

[a]Dept. of Phys. and Astr., University of Tennessee, Knoxville, TN 37996, USA
[b]Phys. Div., Oak Ridge National Laboratory, Oak Ridge, TN 37830, USA
[c]Faculty of Physics, University of Warsaw, 00-681 Warszawa, Poland
[d]Dept. of Phys. and Astr., Louisiana State University
Baton Rouge, LA 70803, USA
[e]Oak Ridge Associated Universities, Oak Ridge, Tennessee 37831, USA
[f]Heavy Ion Laboratory, University of Warsaw, 02-093 Warszawa, Poland

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Recently, a unique detector system for beta-delayed neutron spectroscopy, Hybrid-3Hen, was constructed and used in an experiment. This detector is a modification of the neutron detector 3Hen array, which uses ^{3}He-filled tubes at 10 atm and high density polyethylene moderator. In Hybrid-3Hen the gamma-ray detection capability was implemented by adding two large HPGe clover-type detectors from the CLARION/CARDS array. This modification of 3Hen enabled efficient studies of beta-delayed neutron emission by using neutron–gamma coincidences. The system is equipped with full-digital readout for easy implementation of the slow and fast coincidences between various parts of the entire detection system. This new array was used in measurements at the Holifield Radioactive Ion Beam Facility and proven to be an essential tool to measure the large beta delayed two neutron emission branching ratio from the exotic isotope ^{86}Ga.

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1. Introduction

When departing from the stability line, beta decay energies increase and neutron separation energies decrease, and both effects lead to large beta delayed neutron emission probabilities. For sufficiently neutron-rich nuclei, this

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becomes a dominating decay mode, and as observed in the light nuclei [1], or predicted for heavier [2], large multi-neutron emission probabilities will occur. Large probability of beta delayed neutron emission, see Fig. 1, influences the experimental methods of decay spectroscopy very far from stability. A decay spectroscopy measurement has to take into account the fact, that significant or even most of the decay energy is carried away by the emitted neutron, thus, making a neutron detector an essential part of the decay station. Neutron counters, which are based on ^{3}He compressed gas ionization chambers embedded in a moderator have been traditionally used in beta delayed neutron emission experiments, for a recent example, see [3]. Their channel selection capability was exploited in lifetime and neutron branching ratio measurements [4] for beta delayed precursors. The attractive property of neutron counters is their potentially high neutron detection efficiency which is scalable with the amount of ^{3}He and amount of moderator. One disadvantage of the ^{3}He-based neutron counters is the necessity of neutron thermalization, which is relatively slow and may take tens of microseconds. This may have an impact the quality of coincidence measurements due to the increase of random correlations.

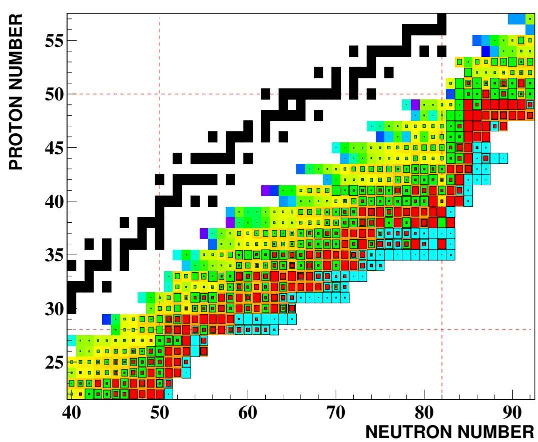

Fig. 1. Beta-delayed neutron emission predicted by Möller *et al.* [2]. The squares with solid borders indicate beta-delayed $\beta 1n$, $\beta 2n$ and $\beta 3n$ channels.

2. Hybrid-3Hen

Recently, a large neutron array 3Hen was developed at the Oak Ridge National Laboratory [5]. This detector is characterized by high detection efficiency, which is flat for a wide range of neutron energies. It uses sixteen 1-inch and fifty eight 2-inch diameter tubes. Both types are 28 inch long, embedded in high density polyethylene (HDPE) moderator in octagonal shape.

In order to augment this detector system with efficient gamma detection capability, its variant called Hybrid-3Hen was constructed and is shown in Fig. 2. In the new configuration, the HDPE of the 3Hen was modified in order to accommodate two large volume "clover" germanium detectors. Different from the set-up used by Hoff *et al.* [6] constructed for the same goal of measuring neutron–gamma coincidences, the Hybrid-3Hen is optimized for high detection efficiency of both gammas and neutrons, and is more suitable for conditions, where the production rates are low.

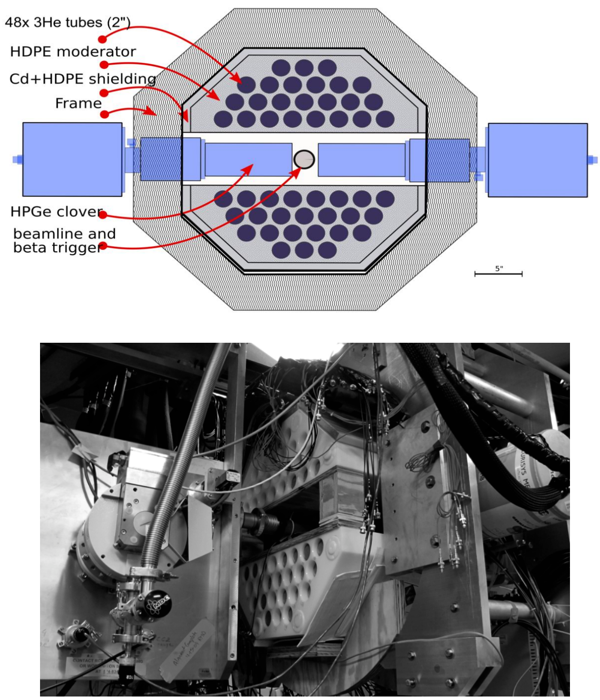

Fig. 2. Neutron detector Hybrid-3Hen at LeRIBSS.

The new moderator design resulting in a separated octagonal structure uses the same frame system as the original 3Hen and was able to accommodate forty eight of the 2-inch diameter tubes. Each half of the moderator is constructed out of seven 4-inch thick segments, which are stacked together. The 2-inch holes are precisely aligned in order to accommodate the 3Hen tubes. The half-octagons are 9 inches tall, and 24 inches wide, and the full length is 28 inches. The two halves of the moderator are separated by a 6-inch wide gap and that causes some loss of efficiency compared to full 3Hen. The detection efficiency was modelled with the Geant4 code for the Hybrid-3Hen system, see figure 3. The detection efficiency is flat up to about

1 MeV and drops down quickly for neutrons of higher energy. Additional essential elements of the detection system are the beta trigger detectors and tape transport system (MTC) used at previous experiments at LeRIBSS [9].

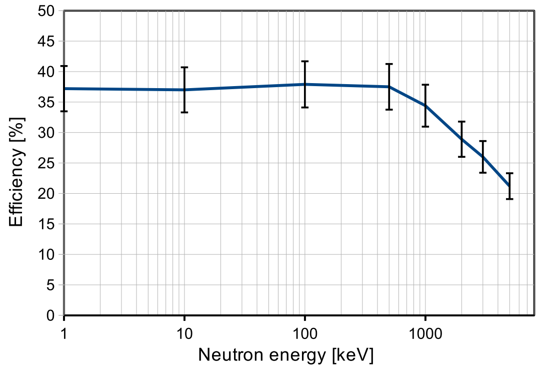

Fig. 3. Neutron detection efficiency for Hybrid-3Hen as modelled by Geant4. The 10% relative error bars are estimated due to Geant4 model uncertainties. Line is to guide the eye.

2.1. Digital electronics

The 3Hen detector was designed to use digital electronics, which was consistently used in all decay spectroscopy experiments carried out at HRIBF for more than a decade [7]. Here, the main benefit of using a digital system is the versatility, which enables the same type of electronics to be used with different detector kinds constituting Hybrid-3Hen array. The high resolution time-stamping feature allows for variable correlation times between detector signals to be selected. This is of particular importance with the moderator based detector, where the neutron thermalization time is variable and can be as slow as 100 μs. Such long and unpredictable correlation times make the design of a triggering system based on conventional electronics cumbersome. Digital system can operate without a master trigger, so that all signals are recorded enabling flexible software based correlations. In this particular implementation of Hybrid-3Hen, the Pixie 16 revision F system was used [8]. The electronics board utilized digitization scheme based on a 250 MHz clock and 12-bit ADC. In order to accommodate the slow risetime of the signals from the ^{3}He-filled proportional counters, the trapezoidal trigger and pulse shape processing system had to have a relatively long energy filter time constant of 5 μs (integration time) and 11.4 μs (gap time), and a trigger filter set to 0.5 μs (integration) and 0.1 μs (gap) respectively. The choice of filtering scheme resulted in clear identification of the signals at 0.76 MeV from the energy released in the neutron capture reaction on ^{3}He.

2.2. Detector performance

The detector system was utilized in an experiment at HRIBF with high purity gallium beams obtained using the combination of laser resonance ionization and electromagnetic separation [10]. These studies included decays of ^{83}Ga,^{85}Ga and ^{86}Ga [11]. These nuclei are characterized by relatively large beta delayed neutron decay energy windows Q_β–S_n as well as large beta delayed neutron branching ratios, which made them an ideal case for the demonstration experiment. The main purpose of using the neutron detector in these studies was to select gamma rays emitted after beta-delayed neutron emission. Figure 4 shows the selectivity of the neutron tagging on the gamma-ray spectrum. The results for the beta-tagging on the gamma-ray spectrum have been shown previously for ^{83,85}Ga [10, 11]. For the neutrons emitted from this isotope, we observe the average neutron detection efficiency of about 10(2)%. An experimental problem in triggering method was found later and the nominal detector efficiency should be about 30(6)% in agreement with the Geant4 prediction. This does not change conclusions on the branching ratios published in [11].

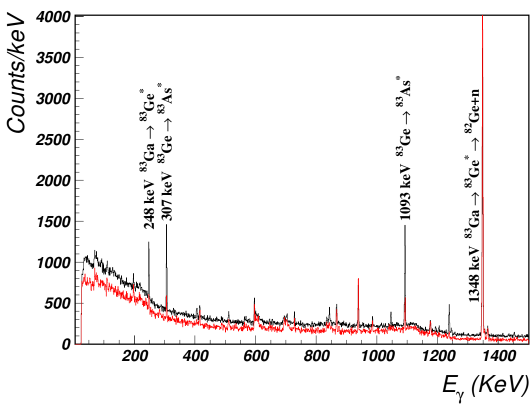

Fig. 4. Beta–gamma (black) and beta–neutron–gamma (grey/red) spectra for decays of $A = 83$ isobars.

The performance of the system was demonstrated by the discovery of the decay of ^{86}Ga [11]. The surprisingly large $\beta 2n$ branching ratio of $20 \pm 10\%$ is the first evidence of this decay mode in this mass region and validates theoretical predictions.

The Hybrid-3Hen detector achieved high detection efficiency both for neutrons and gammas. Its simple design and modularity enables applications in future experiments at ISOL and fragmentation based facilities. With the large Q_β–S_n neutron emission common far from stability and low production rates, such a detector system is essential in complete decay spectroscopy studies.

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