γ(TAGS)-n(He-3)- β Coincidence Spectrometer for β-Delayed Neutron Decay Study

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Abstract

It is proposed to measure the delayed neutron emission probability, obtain information about delayed neutron spectra and beta decay strength function simultaneously by β-n, γ-n and γ-n- β coincidence methods. The He-3 counters of special form and β-particle detector are placed inside the total absorption gamma-spectrometer (TAGS) well. This spectrometer (TAGS+He-3+β-particle detector) will be used for β-n, γ-n, β-γ, γ-n-β coincidence/anticoincidence spectra measurements. The delayed neutrons spectra may be restored from coincidence/anticoincidence data. Application of the He-3 counters of special forms in combination with β-detectors and TAGS make it possible to study the delayed neutron emission with more high efficiency and obtain new data about exotic neutron-rich nuclei.

1. Introduction

New experimental information about neutron-rich nuclei far from stability is very essential for the nuclear structure prediction testing near the neutron drip-line and for explaining important aspects in astrophysics. The β^- -delayed neutron emission provides a significant tool for studying nuclear properties at intermediate excitation energies in neutron-rich nuclei far off the stability line. Information about delayed neutron emission is essential for decay-heat calculations.

The β^- -decay half-life ($T_{1/2}$) and the delayed neutron-emission probability (P_n) are the important gross β^-decay properties for nuclei very far from stability produced in a low production yields [1]. They contain information about nuclear structure; the $T_{1/2}$ is sensitive to low-lying β^-strength and the P_n –value contain information on β^- strength in (Q_β –B_n) window, Q_β-total energy of β^- decay, B_n- neutron separation energy. Indication of nuclear structure changing associated with neutron excess may be obtained by comparing experimental data with theoretical predictions using the available nuclear models. Properties of nuclei on the expected astrophysical r-process path can be predicted by extrapolation on the basis of the systematics of experimental and theoretical data. Information about beta decay strength function (S_β) is very important for study week interaction in exotic nuclei, for nuclei structure and charge-exchange residual interaction study, for analysis of delayed neutrons spectra and for construction decay schemes of nuclear far from stability. Because the production cross sections of neutron-rich nuclei far from stability are low, spectrometers with high efficiency are needed.

When using TOF systems with liquid or plastic scintillator detectors, there is the problem with detection of low-energy neutrons (below ca. 500keV), the energy region where most fission products precursors have the main delayed neutron intensities. When using He-3 detectors for delayed neutrons spectra measurements, there are problems with low efficiency (ca. 10^{-4} to 10^{-5}) and acoustic noise sensitivity [2,3]. Furthermore, in most cases it will not be enough to just measure delayed neutron singles spectra. One has to determine the delayed neutrons feeding of excited states in the respective final nucleus by n-γ coincidence measurements in order to obtain reliable β-strength functions above the neutron binding energy. This later part could be done with our [4] high efficiency total absorption gamma ray spectrometer (TAGS) and He-3 counters of special forms placed inside the TAGS. Applications of the He-3 counters of special forms in combination with β-detectors and TAGS make it possible to study the delayed neutron emission with more high efficiency and to obtain new data about exotic neutron-rich nuclei. The key question is the selection of the optimal value of the n-γ coincidence time window τ_{coin}. To increase efficiency of He-3 detectors it is necessary some moderation of neutrons. When one increase τ_{coin} than the moderation time, efficiency of neutrons detection and coincidence background also increasing. After moderation one increase the efficiency of neutrons detection and loss information about neutrons energy. Information about neutrons energy may be restored from γ(TAGS)-n(He-3)- coincidence spectra. Using our TAGS spectrometer and τ_{coin} about few microseconds it is possible to obtain information about delayed neutrons spectra in the energy region below 300keV with the efficiency about few percent.

2. Spectrometer

The total absorption spectrometer (TAGS), two He-3 counters of special form and beta particle detector are used for beta decay and delayed neutrons emission study. He-3 counters and beta particle detector are placed inside the TAGS well (fig.1, fig.2).

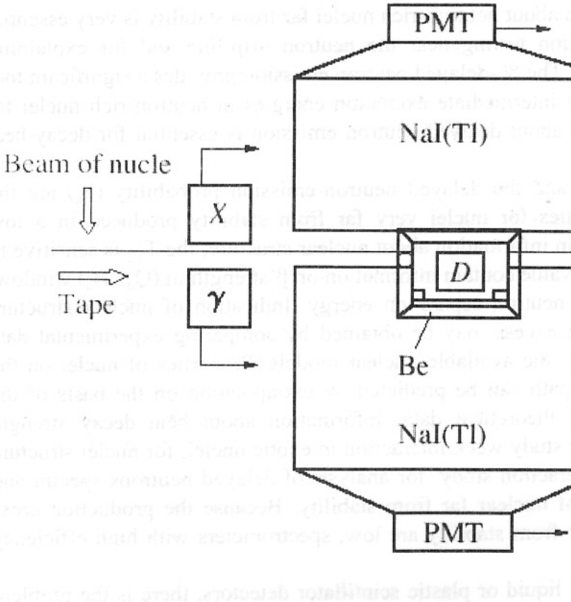

Fig.1. Total absorption γ-rays spectrometer. D- He-3 counters and beta particle detectors inside TAGS well . Si detectors are installed for β-particles detection, He-3 counters are installed for delayed neutrons counting, X-γ: HPGe detectors for contamination determination and decay schemes measurements.

In our experiments we use the total absorption γ-rays spectrometer (fig.1) which consists of the two NaI(Tl) crystals Ø200mm by 110mm and Ø200mm by 140mm. The larger crystal has a Ø70mm by 80mm well into which the nuclei under investigation are supplied and where a Si detector is install for β-particles detection. Isolating total absorption peaks in the TAS spectrum, one can find the occupancy of the levels *I(E)* and the beta decay strength function $S_\beta(E)$. Compare TAS spectra without coincidence/anticoincidence and β-n, γ(TAS)-n, β-γ(TAS), γ(TAS)-n-β coincidence/anticoincidence spectra one may obtain information about beta decay strength function, delayed neutrons spectra and P_n value simultaneously.

The TAS spectrum and $S_\beta(E)$ may be calculated from decay scheme data. Compare the TAGS spectroscopy data (TAS spectrum and $S_\beta(E)$) with the data obtained from decay schemes one may estimate the degree of the decay scheme completeness and determine the energies regions where decay scheme is not enough complete [5].

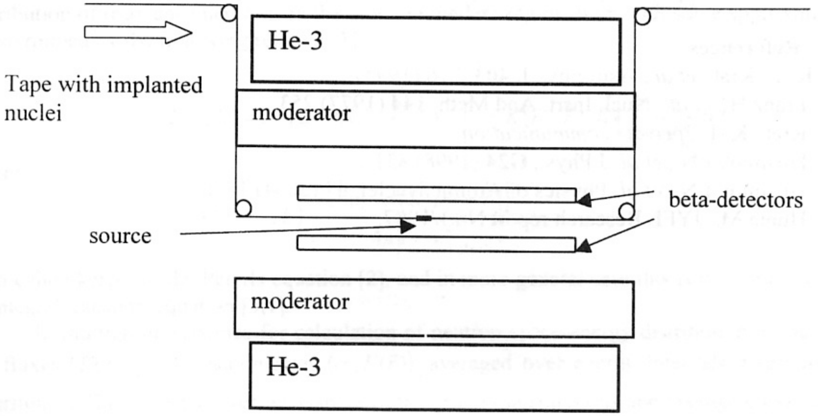

Fig.2. He-3 counters and beta particle detectors inside the TAGS well.

Delayed neutrons emission scheme is shown in fig.3. Using the γ(TAGS) spectra in coincidence/anticoincidence mode with n(He-3) one may restore the position of delayed neutrons in decay scheme, i.e. restore the delayed neutrons spectra.

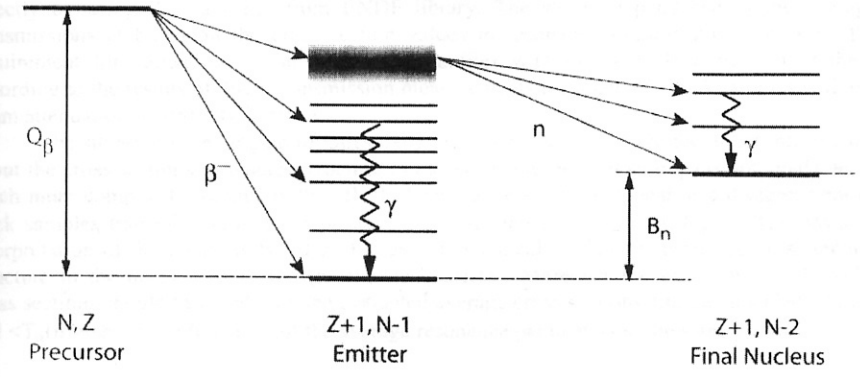

Fig.3. Delayed neutron emission process.

Efficiency of delayed neutrons detection in coincidence mode depends on the coincidence time window and neutrons energy. Optimal value for coincidence time is about 1-3 microseconds. Efficiency of the 200keV delayed neutrons detection will be about 1-2% (MCNP calculations).

The optimal counting rate for TAGS [4] is not more than 1000 decay/s. We may study 50-1000decay/s in coincidence mode with coincidence time window about 1-3 microseconds. For example the yield for fission products at IGISOL [6] is about 2700 ions/s per mb. So the nuclei under study in γ(TAGS)-n(He-3)-coincidence/anticoincidence mode must have the cross section not less than 0.02 mb.

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