Design of Beta Coincidence Spectroscopy

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1. Introduction

A beta coincidence spectroscopy has been studied for both objectives: (1) to measure beta spectrum of ^{238}U in order to more accurately determine anti-neutrino spectrum emitted from ^{238}U beta decay [1] and (2) to more precisely measure positron production rate in order to develop positron annihilation spectroscopy [2]. The important technique is to remove efficiently gamma-ray background interfering beta-ray signal. In this study the beta coincidence spectroscopy has been designed based on N. Haag, et. al.'s research which used beta-gamma coincidence counting method [1].

2. Method and Design

Beta particles are free electrons or positrons emitted by certain fission fragments and produced by beta decay (weak interaction): $n \rightarrow p + \bar{\nu}_e + e^+$. The beta decay is energetically correlated with the anti-neutrino. In this study neutrons provided by a beam tube are used to induce (n, γ) interaction in a target and then beta particles and gamma-ray particles are emitted as shown in Fig. 1 where it is a schematic diagram of positron production considered as a part of positron annihilation spectroscopy. Positron annihilation spectroscopy is nowadays well recognized as a powerful tool of microstructure investigations of condensed matter.

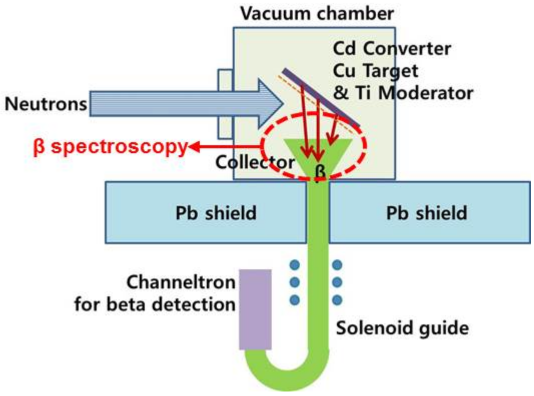

Fig. 1. Schematic diagram of positron beam production equipment. Beta coincidence spectroscopy will be applied in this equipment.

2.1. Design of Beta Coincidence Spectroscopy

The plastic scintillator is sensitive to any ionizing radiation occurred in the decay chain of the considered isotopes by the neutron beam. To distinguish electrons from electrically neutral particles, a gas detector such as a multi-wire chamber was introduced to response only charged particles. However, the direction and the energy of the electrons should be influenced as little as possible. Electrons produce a measurable signal with minimum energy deposition in low gas densities, while neutrons and photons traverse the gas volume mostly without interaction.

To measure the energy spectrum of the electrons emitted from the target, the three main subdetectors of this system are:

- A multi-wire chamber
- A plastic scintillator
- A photomultiplier

Fig. 3 shows the design of beta coincidence spectroscopy where the energy spectrum of all beta particle-emitting processes is recorded by means of a plastic scintillator, whereby a background suppression of gamma through a leading multi-wire chamber in coincidence is guaranteed.

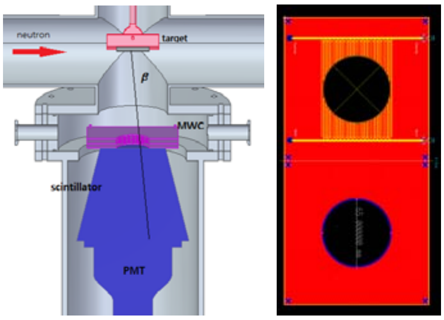

Fig. 2. Design of Beta Coincidence Spectroscopy (left) and Multi-wire circuit boards (Anode & cathode) (right)

2.2.1. Multi-wire chamber (MWC) [3].

The multi-wire chamber is composed of three individual boards, which are located by four guide rods in the gas-filled main chamber as shown in Fig. 2. The wire board has wire track joints as well as the active area of the multi-wire detector. Over a hole with 65 mm diameter, 17 sense wires and 18 potential wires are stretched and then applied by 2460V and 660V voltage in the experiment. Both types are gold-plated tungsten wires 10 μm diameter. Since a position resolution is not necessary, the tracks of each wire are merged and supplied with voltage together. The wires were tensioned with a tension equivalent to a mass of about 25g to hold them in place despite the repulsive coulombs of the neighbors. This wire board is centered between two grounded cathode boards. The surface of the cathode board is coated with copper and the hole of it is covered with aluminized Mylar foil with a thickness of 6 μm. An electron (positron) that passes through the gas in the multi-wire chamber generates a multitude of primary electrons on its way through ionization of the gas molecules and the free electrons drift in the direction of the positively charged sense wires [4]. Thus, a charge avalanche develops, generating electrical signals of measurable amplitude at these amplifying wires. The electron passing through the chamber also hits the scintillator.

2.2.2. Plastic scintillator & photomultiplier (PMT)

A scintillator is used to convert kinetic energy of the incident particles into photons of a spectral range detectable for the photomultiplier. The detection efficiency of different radiations - directly linked with ionization rate and luminous efficacy - varies with the type of scintillator material. Solid-state scintillators offer the most cost-effective option at the same time easy handling and sufficient dissolving power. Organic scintillators such as BC404 are considered in this study. The main advantage of inorganic materials lies in the small band gap, whereby a light output can be achieved, which is about a factor 3 higher than that in organic detectors. This affects positively the resolution of the system, which is thus by factor 3 improved. In addition, a higher density, e.g. of NaI (Tl) of 3.67 g/cm^3 compared to the BC404 with 1.03 g/cm^3 reduces the size of the detector module, but due to the high atomic number of the components the detection probability for gamma radiation increases. A cylindrical detector would have some oblique electrons leave through the sides of the scintillator and thus it occurs energy loss of the beta spectrum. For this reason the scintillator was made as a truncated cone (see Fig. 3.). It includes the case for all electrons coming from the edges of the target. Particles that do not pass through the upper surface of the detector miss the active area of the multi-wire chamber and are discarded by the coincidence circuit. In addition this geometry increases the bundle of the scintillation light down into the photomultiplier. The scintillator is coupled by the diameter 130 mm wide photomultiplier. The materials of entrance window (borosilicate glass) and photocathode (Bialkali) are tuned for the wavelength of the emitted light to reach the highest detection probability.

2.2.3. Monte Carlo simulation.

A GEANT4 Monte Carlo simulation [5] was used to simulate to interpret the measured beta spectra and backgrounds by this beta coincidence spectroscopy. In this simulation all targets and the holder are implemented identically and the plastic scintillator is also implemented with an identical geometry to reality (see Fig. 3.). The thin cathode foils and all circuit boards of the multi-wire chamber will be implemented. The electric field inside the MWC is assumed not to have an influence on the energy of the electrons. Electrons passing through the inner hole of the MWC are marked as coincidence candidates. The deposited energy in the scintillator for all events is recorded. If the event in the scintillator has the MWC tag within relevant time interval in, then the signal is saved as coincident otherwise, as non-coincident event.

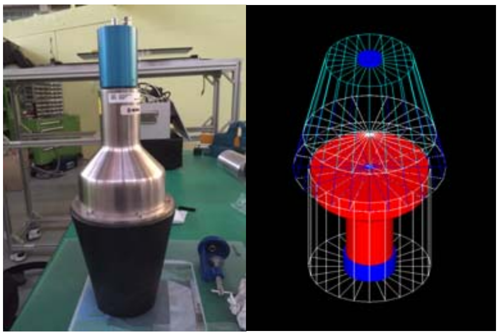

Fig. 3. Plastic scintillator & PMT detector (left) and GEANT4 simulation of scintillator detector (right)

3. Summary

Currently, the beta coincidence spectroscopy has been designed and installed to efficiently remove neutral particle backgrounds. The plastic scintillator and PMT detector was installed and the multi-wire chamber is in progress. In further study the performance of MWC will be tested and optimized and the background reduction rate of this beta coincidence spectroscopy will be demonstrated using beta-ray sources. In addition MC simulation of all detectors will be carried out to improve understanding of the measurement results.

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