Detection of $^{90}\text{Sr}$ with aerogel Cherenkov detector with low background

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Abstract—$^{90}\text{Sr}$ is a highly radiotoxic fission product, which may pollute the environment following an accident in a nuclear power plant. It is a pure $\beta$ emitter and thus difficult to detect by standard methods. Recent progress in silica aerogel production as well as the new large multichannel photomultiplier tubes offer possibilities for detection of $^{90}\text{Sr}$, based on Cherenkov radiation of $\beta$ particles emitted by its daughter $^{90}\text{Y}$. An appropriate choice of the aerogel refractive index (produced in the range between 1.005 to 1.06) determines the threshold for Cherenkov radiation and thus separates between higher and lower energy $\beta$ particles. Also multichannel PMT’s permit the counting of the Cherenkov photon yield, offering additional discrimination. An additional multiwire proportional chamber operating in a coincidence with the photon detector hits was used to lower the background and for timing. A prototype apparatus was constructed for detection of the relatively high energy $\beta$ particles emitted by $^{90}\text{Y}$ ($E_{\text{max}}=2.27$ MeV). The efficiency of the prototype detector and the photon yield as a function of the $\beta$ spectrum end-point energy is presented, as well as results of investigations of various backgrounds and the lower limit of activity required for quick and accurate measurements of samples extracted from animal bone, air filters or sediments.

Index Terms—Cherenkov detectors, silica aerogel radiators, multichannel photomultiplier tubes, Sr-90 radioactivity analysis

I. INTRODUCTION

STRONTIUM $^{90}\text{Sr}$ is a very radiotoxic isotope because it accumulates in bone tissue, has a rather long half-life of 28.2 years and its daughter $^{90}\text{Y}$ emits $\beta$ particles of 2.27 MeV end-point energy. It is a fission product, so it may pollute the environment either as a result of a nuclear power plant accident or of a nuclear weapon explosion, both of which have unfortunately happened in the previous century.

$^{90}\text{Sr}$ and its daughter $^{90}\text{Y}$ are pure beta emitters so they cannot be detected by standard and accurate methods of gamma ray spectroscopy. Other beta emitters in the sample, with overlapping spectra, will lead to erroneous results in total beta counting or would complicate matters in the usual $\beta$ spectroscopy. Cherenkov radiation offers the possibility of a well defined $\beta$-energy cutoff by choosing an appropriate refractive index of the Cherenkov radiator. In addition, it has been demonstrated ([1], [2]) that the counting efficiency rises steeply above threshold. Not very many isotopes have $\beta$ end-point energies above 2 MeV, so $^{90}\text{Y}$, the daughter of $^{90}\text{Sr}$, with $E_{\text{max}}=2.27$ MeV, seems well suited for detection through Cherenkov radiation.

Recent progress in production techniques has led to improved properties of aerogels ([3], [4]), most important of which is greater transparency for Cherenkov photons in the wavelength region of highest photomultiplier sensitivity. On the other hand, Hamamatsu has developed 64 channel, flat panel detectors of single photons with photosensitive area of $49 \times 49$ mm$^2$ [5], which allow counting of the number of Cherenkov photons for each incident $\beta$ particle. In the present paper we report on preliminary results obtained with such an improved detector.

II. THE APPARATUS

The apparatus (Fig. 1) is enclosed in a light tight box. It consists of the sample or source of $\beta$ particles, a thin (8 mg/cm$^2$) $2 \times 2$ cm$^2$ multi-wire proportional chamber (MWPC), a stack of two $5 \times 5$ cm$^2$ and 2.5 cm thick aerogel radiators with refractive index $n=1.047$ [6] and a photon detector. We were testing three different photon detector configuration Fig.2. In the first case we tested one 16 channel Hamamatsu photomultiplier R5900-M16 positioned centrally at the exit window of the aerogel radiator. In the second configuration we used an 2x2 array of the same photomultipliers and in the last configuration we tested Hamamatsu H8500 64 channel flat PMT with active area of $49 \times 49$ cm$^2$.

An additional scintillation counter positioned above the triggering MWPC provides veto pulses for background-contributing cosmic particles coming from above. The MWPC, with its high efficiency for charged particles ($\sim 99\%$) and low
efficiency for gamma rays (∼ 0.1%) signals an incoming β particle, distinguishing it from events where a gamma photon from the source generates an energetic electron in the aerogel Cherenkov radiator or in the PMT glass window. The electron kinetic energy threshold in the aerogel radiator (n= 1.047) is 1.21 MeV.

A coincidence-anticoincidence circuit triggers a time-to-digital converter for each channel in which the Cherenkov photons appear as peaks in the PMT-MWPC time difference (Fig. 3).

III. ANALYSIS AND RESULTS

To quantify the prototype one should determine the efficiency for detection of $^{90}$Sr and the minimum detectable activity of the apparatus. The efficiency of the particular channel is determined by counting the events where the photons have been detected in the coincidence time windows of ±3σ around the mean value of the distribution (Fig. 3). The background count rate is determined in the same way by removing the source.

An additional indication of the $^{90}$Sr in the sample is a distribution over number of the hit channels (Fig. 4). If the velocity of the incident particles is on average higher, this would show as a more flat distribution.

The efficiencies obtained with the three configurations of Fig. 2, are given in Fig. 5. The maximal efficiency for detecting $^{90}$Sr amounts to 0.058 for the configuration with a 2x2 array of R5900-M16 PMTs. It was calculated with respect to the MWPC trigger rate. Although the $^{137}$Cs β end point energy is below the Cherenkov threshold, some counts have been registered also for this isotope. That they are due to photons coming from the aerogel, has been verified by covering the aerogel photon exit window with black paper which resulted in a considerable reduction of the count rate. A possible explanation could be scintillations in the aerogel generated by the β particles.

I has been already been shown [8] that the efficiency is increased by covering the side walls of the aerogel tile. It is also clear that by covering the larger area the efficiency is increased. The increase in the efficiency when using only one and a 2x2 array of Hamamatsu R5900-M16 tubes is consistent...
with the Monte Carlo simulation. However we found out that by using the Hamamatsu H8500 photomultiplier the efficiency is lower than by using 2x2 array of Hamamatsu R5900-M16 photomultipliers, although its photosensitive area is larger. The lower efficiency may be attributed to the lower collection efficiency of the H8500 tube.

The minimal detectable activity [9]

\[ A_{\text{min}} = \frac{3 + 3.29\sqrt{N_b}}{\eta_a t} \]  

(1)
determined for measurement time \( t \), background rate \( N_b \) and an absolute efficiency \( \eta_a \approx 0.018 \) is rather high. For the case of realistic 3 hour measurement amounts to 0.1 Bq. It should be noted that the anticoincidence veto of the scintillator did not remove all the cosmic ray background. The background events also mainly appear as a peak in the time distribution. However the number of hits on the photon detector is on average higher in comparison to the \(^{90}\text{Sr}\) signal (Fig. 6). An explanation for this is the higher average energy of the cosmic rays which then radiate more Cherenkov photons in the aerogel tile.

To further remove the correlated background, a larger scintillator will be placed above the setup. We expect this final apparatus will be an efficient detector of low level \(^{90}\text{Sr}\) activity as required for environmental samples.