Neutron flux normalization with the $^{51}V(p,n)^{51}Cr$ reaction for the calibration of PICO bubble chambers

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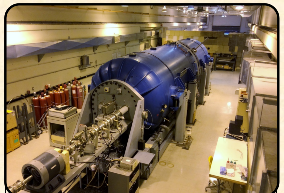
Introduction

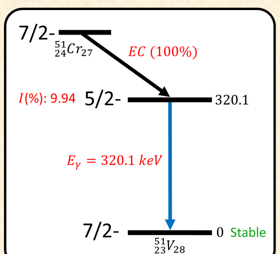
The PICO experiment uses bubble chambers to search for dark matter. Two C_3F_8 loaded detectors, PICO 2L and PICO 60, are currently operated in SNOLAB. The small PICO 0.1 test chamber is used for neutron calibration at the accelerator facility at the Université de Montréal. A 1.6 MeV proton beam is used to generate mono-energetic neutrons via the $^{51}V(p,n)^{51}Cr$ reaction. Neutron flux normalization is done with two ^{3}He neutron counters. An independent absolute neutron flux measurement was needed to relate the ^{3}He counter rates to the neutron flux.



6 MV Tandem Van de Graaff

Method

The absolute flux measurement was done by Proton Activation Analysis (PAA). 9.94% of ^{51}Cr produced in the ^{51}V target by the nuclear reaction are in a metastable state, emitting a 320 keV photon when reverting back to ^{51}V by electron capture. Measuring the gamma emission after activation allows for the determination the quantity of ^{51}Cr produced, and thus the total amount of neutrons emitted. A HPGe detector was used to measure the target activity after a 56h activation period at the 50 keV resonance. (Fig. 1, peak VII)



^{51}Cr decay scheme

Results

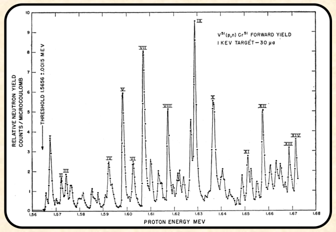


Fig. 1: $^{51}V(p,n)^{51}Cr$ reaction spectrum. From: J. H. Gibbons, R. L. Macklin, et H. W. Schmitt, Phys. Rev. **100**, 167 (1955).

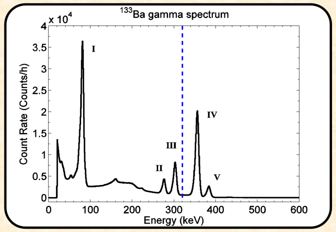


Fig. 2: ^{133}Ba calibration source spectrum. The HPGe detector was first calibrated with a 1 μCi ^{133}Ba source standard. ^{133}Ba was chosen for its four peaks located around the 320 keV region, shown as the blue dotted line.

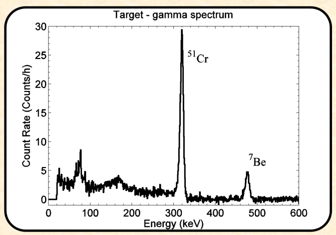


Fig. 3: Gamma spectrum of the activated target. The main peak is ^{51}Cr and the second, smaller peak was identified as ^{7}Be. Note the much lower count rate than that of the calibration source.

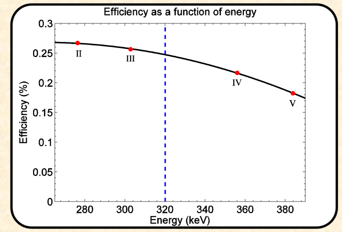


Fig. 4: Relative efficiency fit of the HPGe detector. The calibration source was put at 10 cm. The efficiency at 320 keV (blue dotted line) is $\varepsilon_\gamma = (0.247 \pm 0.007)\%$.

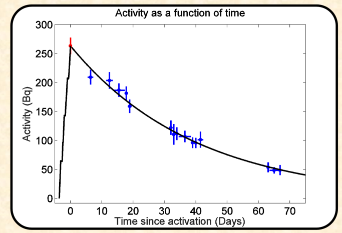


Fig. 5: Activity of the target calculated from the HPGe detector data. Fitting a decay function with the half-life of ^{51}Cr $(27.7010 \pm 0.0011\ days)$ allowed for the determination of the target activity at t = 0 as being 263.3 ± 14.4 Bq.

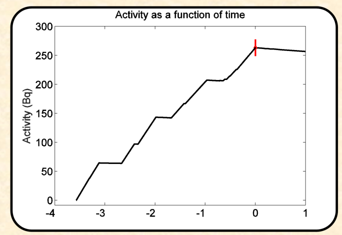
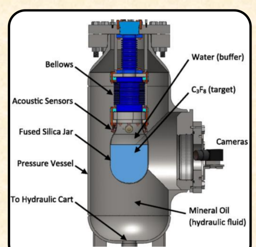


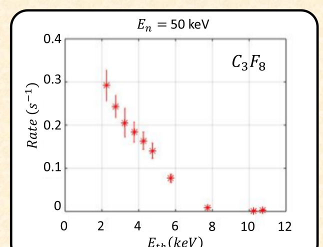
Fig. 6: Activity of the target during the activation. The total amount of neutrons produced is $N_n = (9.52 \pm 0.52) \cdot 10^8$ neutrons. This value is compared to the ^{3}He counts recorded during the activation period to infer the efficiency $\varepsilon_{He} = \frac{N_{He}}{N_n}$.

Conclusion

The PICO collaboration uses test beam data to determine the detection efficiency and the energy threshold as a function of the operating parameters, pressure and temperature. These measurements were able to improve the detailed understanding of the detection technique. Next steps are to extend the beam measurements to other promising detector liquids.



PICO 2L scheme



Calibration curve of PICO 0.1

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