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Microarticle

Direct comparison between solid state Silicon+^{6}LiF and ^{3}He gas tube neutron detectors

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ABSTRACT

During the last decade the worldwide lack of ^{3}He for neutron detection has triggered research and development on alternative technologies and methods. One of the promising techniques consists of assembling sandwiches of fully depleted double sided Silicon detectors between thin layers of ^{6}LiF neutron converter material. In this paper we show the very promising result of a comparative test of such a detector with respect to an elliptical section ^{3}He filled proportional counter for application at spallation neutron source facilities.

The Silicon+^{6}LiF technique (SiLiF) for thermal neutron detection, whose possible implementation is long since known [1], was recently brought to the attention of the scientific community with applications involving large area double sided Silicon detectors and independent ^{6}LiF layers deposited on different substrates [2–4].

Several characterizations of such detectors have been performed with neutron sources and beams, but so far no direct comparison with ^{3}He tubes had been done at a spallation neutron beam facility. This is why we tested two SiLiF detectors at the ISIS facility at the Rutherford Appleton Laboratory in UK, placing them immediately beneath the detection plane of the INES diffractometer consisting of 144 elliptical cross section (12.5 mm × 2.5 mm) ^{3}He tubes 10 cm long operated at a nominal pressure of 20 atm [5],[6],[7]. The two SiLiF detectors were a SiLiF8 (meaning that a single layer of ^{6}LiF 8 μm thick, deposited onto a carbon fiber plate, was placed in close contact with a 3 cm × 3 cm Silicon detector 300 μm thick), and a SiLiF64 sandwich (two double sided Silicon pads, 3 cm × 3 cm × 300 μm, each facing two layers of ^{6}LiF 16 μm thick for a total effective converter thickness of 64 μm). The two Silicon pads included in the SiLiF64 were handled as a single detector. Fig. 1 shows the SiLiF64 before and after packing it into a light-tight thin aluminum box.

In Fig. 2 we show a sketch of the experimental setup with the details of the main geometrical features. In a first piggy-back run we tested the SiLiF8 detector (the SiLiF64 was not yet available). The neutron beam, nominally thermal, was scattered off a Copper target. In Fig. 3 we show the resulting yield as measured by the SiLiF8 and by the ^{3}He tube situated at the corresponding angle (both detectors were placed at 35° with respect to the incident beam), with the characteristic peaks detected by both detectors. We remark that the worse resolution of the peaks as measured by SiLiF8 is only apparent, as it is due to its larger angular coverage (3 cm versus 1.25 cm). This was also verified by comparing the SiLiF8 data with the sum of adjacent ^{3}He tubes, and the test also allowed us to compare SiLiF8 with several other ^{3}He tubes.

In a second parasitic run we tested the SiLiF64 detector with the neutron beam scattered off a Vanadium target. Vanadium is known to produce no peaks, giving rise to a rather flat isotropic distribution (generally used to verify the response uniformity of the diffractometer). The expected efficiency increase from SiLiF8 to SiLiF64 was at least a factor 5, depending on the threshold setting needed to suppress the background [2]; the actual value we obtained in our test was 4.7 ± 0.5 (syst.). In Fig. 4 we show the resulting yield as measured by the SiLiF64 and the ^{3}He tube situated at the corresponding angle. One can immediately see that SiLiF64 has a slightly better detection efficiency than the ^{3}He tube, and that the overall behavior of the two detectors is quite similar.

In Fig. 5 we show the energy distribution of the (nominally) thermal neutron beam scattered by the Vanadium target, in linear scale and in a low energy range, as measured by SiLiF64 and by the corresponding ^{3}He tube. The energy values were calculated from the measured time-of-flight, and the counts were rebinned in 10 meV bins. Both curves show a thermal behavior, peaked at 25 meV that corresponds to the ambient temperature, with the SiLiF64 exhibiting a higher efficiency.

As the detection efficiency of SiLiF detectors can be calculated analytically ([1],[2]), we knew that under the test conditions it should be around 14%. This immediately implies that all of the

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Fig. 1. The tested SiLiF64 detector, consisting of a multi-sandwich of 6 elements: ^{6}LiF, Silicon, ^{6}LiF, ^{6}LiF, Silicon, ^{6}LiF. The ^{6}LiF layers are 16 μm thick and deposited onto carbon fiber plates 650 μm thick. The Silicon detectors, double sided and operated in full depletion, are 300 μm thick.

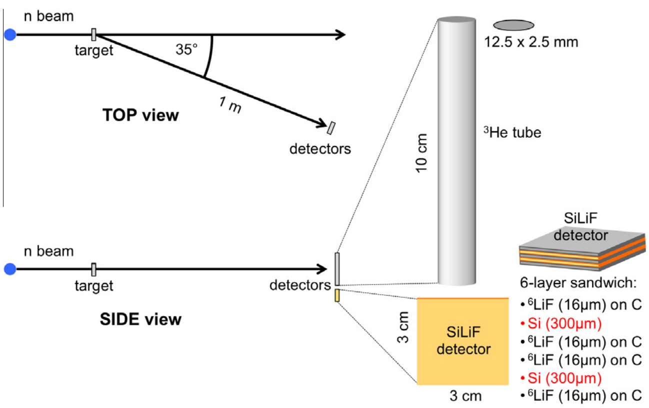

Fig. 2. The experimental setup for the test measurement of the SiLiF64 detector versus the ^{3}He tube.

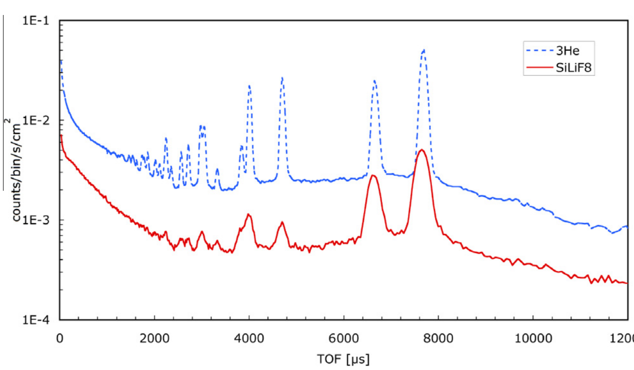

Fig. 3. Yield as a function of the time-of-flight for the SiLiF8 and the ^{3}He tube, when a Copper rod target was used to produce well known resonance peaks. The apparently worse resolution of the SiLiF8 is a geometrical artifact due to its wider horizontal size (3 cm versus 1.25 cm).

^{3}He tubes must have lost pressure, we estimated their real pressure around 4–5 atm. The time resolution can easily achieve down to 0.5 ns, and even lower if choosing suitable preamplifiers. As the test was performed off-beam, the detectors did not see any appreciable gamma flash. However, the SiLiF detectors employed as neutron beam monitors at the n_TOF spallation facility have shown that a fast recovery after 1–2 μs is feasible [4]. Such detectors have also proved rather stable and reliable, and feature a good reproducibility. As for their duration, it mainly depends on the typical radiation damage produced by fast neutrons (when present), even though their operational life can be increased by raising the bias voltage. In such a case the noise level will increase but still staying below the operational threshold.

The described tests show that the SiLiF technique can be a viable alternative to ^{3}He tubes, at least in several small and medium sized

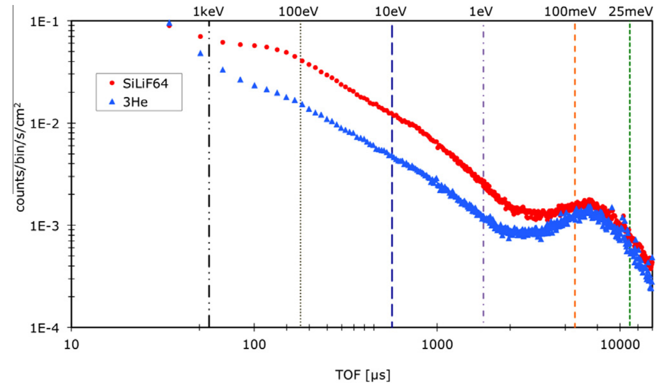

Fig. 4. Yield as a function of the time-of-flight for the SiLiF64 and the ^{3}He tube, when a Vanadium rod target was used. The Vanadium target produces a well known almost flat isotropic distribution (no peaks). The SiLiF64, as expected, has a five times larger efficiency than SiLiF8, and also surpasses the tested ^{3}He tube.

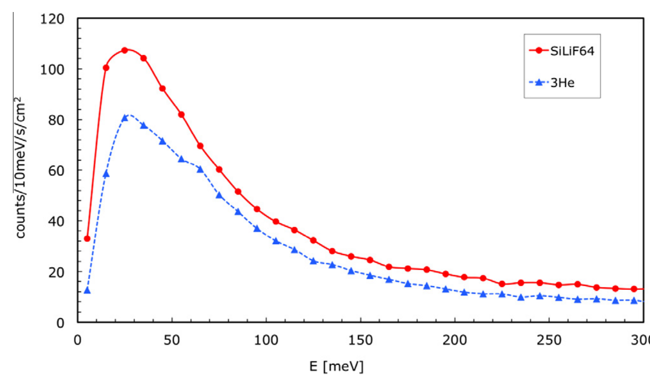

Fig. 5. Energy distribution of the detected neutrons, scattered from the Vanadium target, as measured by the SiLiF64 and by the ^{3}He tube. The bin size is 10 meV, the maximum, as expected from the nominally thermal beam, is around 25 meV which corresponds to the ambient temperature.

detectors where tiling the needed area/volume with many Silicon pads can still be cost competitive with long tubes filled with ^{3}He. We are currently planning a beam test with Copper target of a SiLiF featuring a 5 cm × 5 cm Silicon pad divided into 16 vertical strips, in order to prove that a plot of the same (or better) quality of Fig. 3 can be achieved. Such a detector was already successfully tested, unfortunately only with the Vanadium target. Meanwhile we are going for the construction of a few prototypes of SiLiF64 covering the same geometrical area of the INES ^{3}He tubes, in order to make a head-to-head comparison with the same geometry.

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