New C_6D_6 detectors: reduced neutron sensitivity and improved safety

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1. INTRODUCTION AND MOTIVATION

During the 2011 data measurement campaign at n_TOF, the liquid scintillator detectors developed at FZK-Karlsruhe (hereafter named K_6D_6, [1]) and used with success along 10 years have shown ageing problems, mainly related to liquid leakage. The mould used to produce the carbon fiber structure, containing the liquid and the detection elements, was not available anymore and the technician involved in its construction was retired.

Once decided to proceed to the production of new detectors (L_6D_6 in the following) two major items have been identified:

- The detector setup must be able to work in the new class A experimental area (safety requirements advise to avoid the use of the old K_6D_6 in this area).

- If possible, it is useful to reduce the neutron sensitivity, with the aim to have a liquid scintillator detector with very low neutron sensitivity (improving the already high performing K_6D_6).

2. THE L_6D_6 DETECTORS

A huge optimization work was already done in the preparation of K_6D_6 detectors [1]; but in order to further on reduce the neutron sensitivity, a smaller photomultiplier tube (PMT) with a thinner window has been adopted. The need of long durability and safety of detector implies the use of thicker carbon fiber walls, which have been compensated by a reduction of material in the PMT. The use of a smaller PMT brings a lower efficiency in the light collection, so particular care has been devoted in improving the light collection efficiency at the photocathode. This has been studied both selecting appropriate materials for the inner part of the detector and by detailed simulations of the light collection with the GEANT4 code.

The new L6D6 detector is entirely made of carbon fiber. The active cell has a cylindrical part with a 45º conical shape at the end in order to better collect the produced light at the 2” PMT [2]. the size of this PMT is significantly smaller than the 5” ones used in both commercial Bicron detectors (B6D6 in the following) and the K_6D_6.

The conical part of the cell works both as a light guide and as active scintillation volume. The PMT is embedded in the carbon fiber cylinder and tight by a Viton o-ring for safety improvement: even though two windows are present (one 2 mm thick and another of 0,8+/-0,1 mm coming with the PMT), in case of accident the quartz window could undergo to a break, and the benzene could come in touch with a naked PMT which could be on with high voltage. In such rare situation the absence of air inside the tube prevents fire and explosion. The system is designed, if needed, to have a slow flowing argon gas inside the PMT can, in order to increase the safety in case of accident and avoiding any spilling of benzene in the surrounding area.

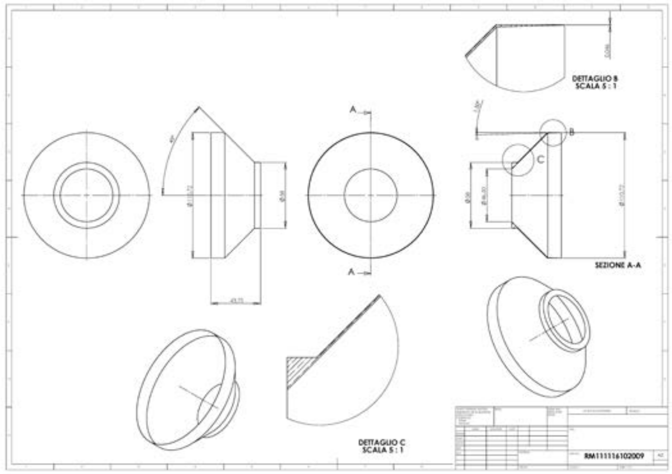

Figure 1: Technical sketch of the active volume of the detector

The active volume of the liquid is 1 liter (the same of K_6D_6 and about 30% more than B_6D_6).

The expansion volume has been designed to have a detector able to work in any position. Moreover, the bubble inside the expansion volume cannot enter in the scintillator cell, whatever will be the position of the detector.

The whole volume, including the cell and the expansion volume, is approx. 1.2 liters and the expansion volume is about 4% of the total volume.

All materials in touch with the C_6D_6 liquid, but the glue (Torr Seal, VARIAN, [3]) used for the quartz window, are certified to be benzene resistant.

The EJ520 (ELJEN Technology, [4]) has been used as reflective paint inside the detector volume.

Figures 2 report the conceptual design of the detector. Figure 3 shows the L6D6 prototype.

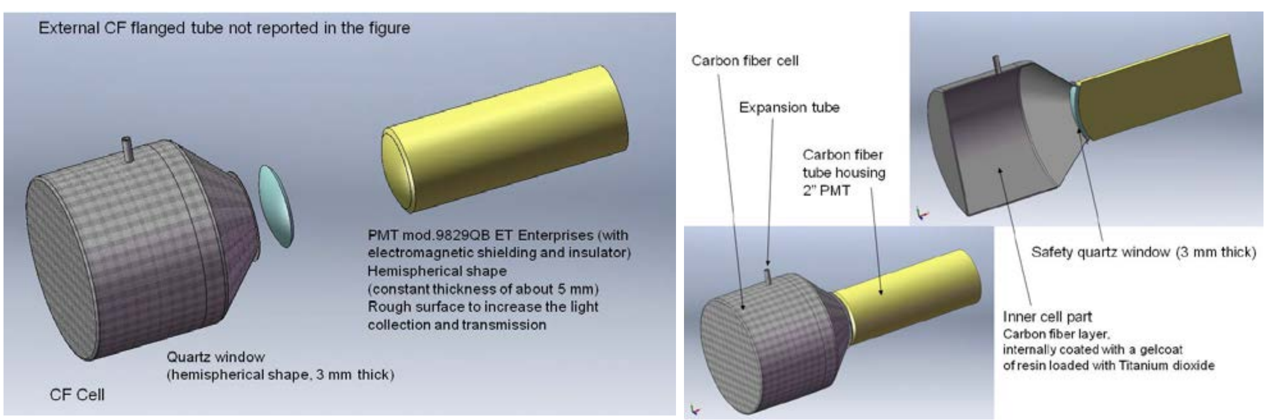

Figure 2: Sketch of the L6D6 detector

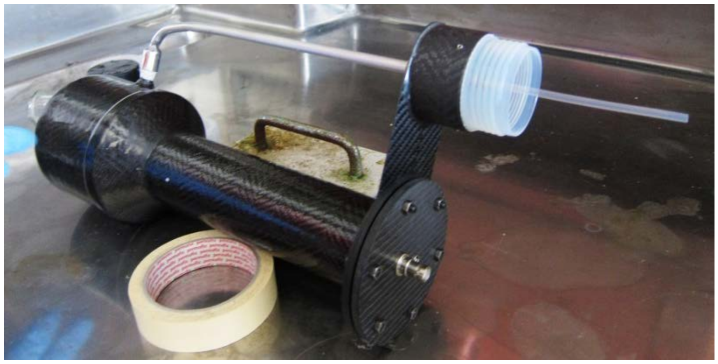

Figure 3: L6D6 prototype.

3. DETECTOR TEST AT CERN

At the end of July 2012 two L_6D_6 detectors have been delivered to CERN and tested with standard γ-ray sources and the neutron beam. Their performances in terms of signal shape, resolution and response to the γ-flash were compared to K_6D_6 and B_6D_6 detectors.

In Table 1 properties and dimensions of the used liquid scintillator detectors are reported [1].

Type	Walls (mm)	Bottom (mm)	Material	Volume (ml)	PMT window thickness (mm)	Photomultiplier
B_6D_6	0.4	1.0	Al	612	Unknown	XP1208
K_6D_6	0.4	0.5	Carbon fiber	1000	3mm at center and a radius of 175 mm	EMI9823QKA
L_6D_6	2.0	1.1	Carbon Fiber	1000	0.8 mm+2 mm (constant thickness)	9829QB ET Enterprises

Table 1: characteristics of tested detectors.

Figure 4 shows the L_6D_6 detector during the C_6D_6 liquid filling operation. Particular care has been devoted to this procedure in order to have a quick filling and avoiding the trap of bubble air inside the active cell. This goal has been achieved using only one hole in the cell where two coaxial tubes for filling and expelling the air pass trough.

Figure 4: L_6D_6 filling operation.

Figure 5 shows the L_6D_6, K_6D_6 and B_6D_6 detectors installed in the experimental hall.

Since the neutron sensitivity also depends on the size of the detector and on the dimensions of the quartz window, an important reduction (a factor 6 is estimated) is expected from the L_6D_6 detectors with respect to the K_6D_6. However, a dedicated experiment on the neutron sensitivity will be performed at GELINA.

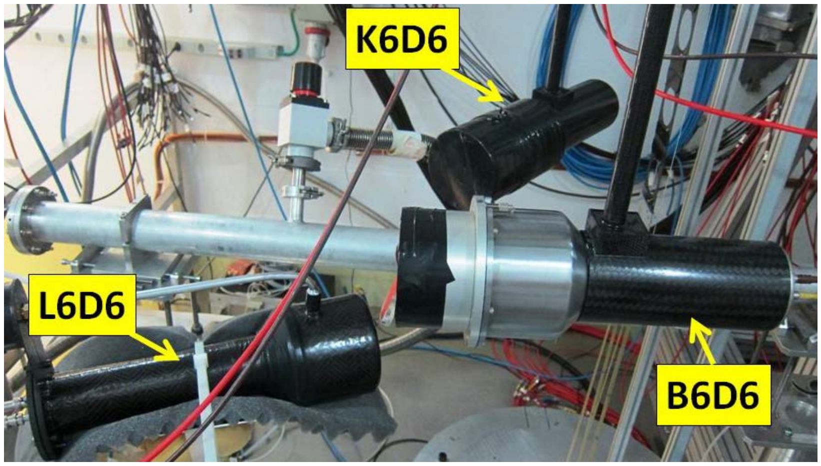

Figure 5: Detectors at the measurement point

Voltages used during the test of the three detectors are reported in Table 2.

Type	Power supply (V)
B_6D_6	950
K_6D_6	2400
L_6D_6	1550

Table 2: Voltages used during the detectors test

The detectors have been tested exposing them to a standard γ-ray source ^{88}Y (E_γ=898 and 1836 keV) in order to compare their energy resolution; moreover, the response to the γ-flash, which limits strongly the energy range of time-of-flight measurements, was studied using the n_TOF beam.

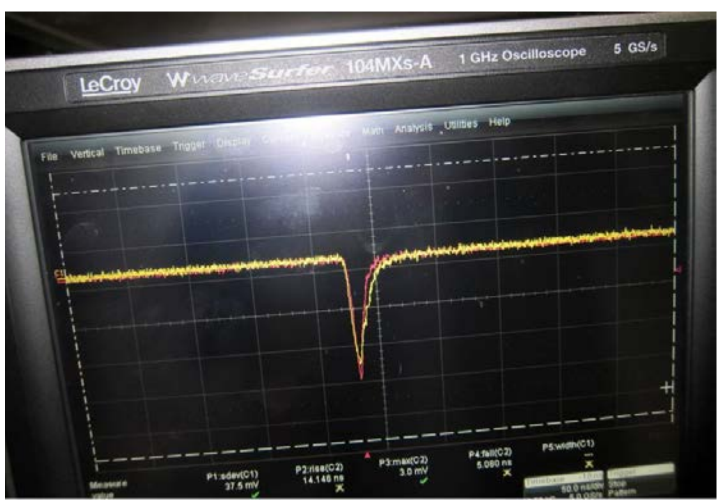

Figure 6: Signals collected by the L_6D_6 detector (red line) and B_6D_6 detector (yellow line).

Figure 6 shows the signals coming from L_6D_6 (red line) and B_6D_6 (yellow line). The scale has been adjusted (200 mV full scale for both detectors) in order to have the same height of the pulses and only pulses in coincidence are reported. The shape of the signals is very similar (rise time, width). Signals from the K_6D_6 are not reported because were strongly distorted, probably due to some problems in the voltage divider and to a deterioration of the internal reflecting part of the cell.

The energy resolution of the three detectors has been investigated by means of a ^{88}Y source. Figure 7 shows the obtained results.

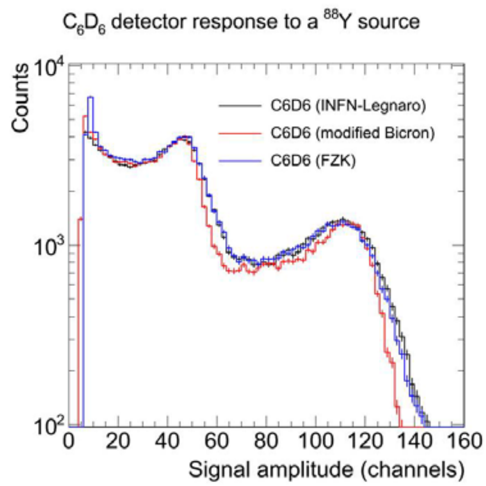

Figure 8: Energy yield of the three detectors after exposition to 88Y γ-ray source

Energy resolutions are very similar; the slight better result comes from the B_6D_6 one. However, it must be considered that this could be an effect of a smaller active volume of this detector (600 ml vs. 1 liter of K_6D_6 and L_6D_6).

The response of detectors to the γ-flash has been also tested. Detectors were positioned close to the beam line. Typical flash-ADC plots are presented in Figure 8.

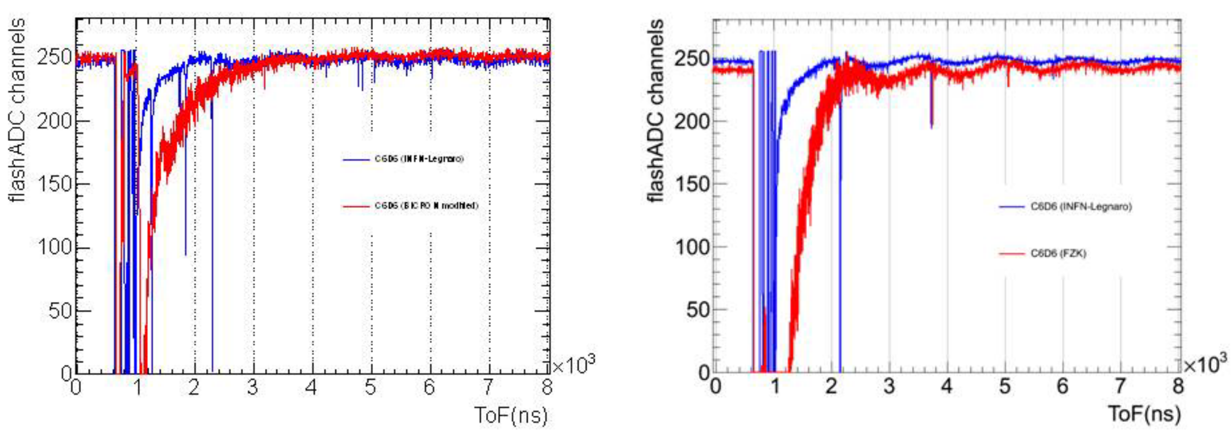

Figure 8: The effect of γ-flash on the detectors

The L_6D_6 response to the flash resulted in a narrower signal (i.e. smaller width) than the ones produced in the B_6D_6 and K_6D_6 detectors. Moreover, one has to consider that the recovering time could be further reduced using a lower voltage and accepting smaller amplitude signals. In addition, the signal oscillations in the baseline have lower amplitudes as well than the ones found for the B_6D_6 and K_6D_6. It is expected that such a behavior will allow to operate the L_6D_6 detector in the same neutron energy range than the B_6D_6 and K_6D_6 detectors, if not larger. The detailed response of the L_6D_6 to the flash will be characterized during the commissioning of the detector with real beam conditions and a reference cross section like the $^{197}Au(n,\gamma)$.

Even if such performance is not mandatory when using C_6D_6 in capture measurements at experimental area 1 (the capture cross sections above 1 MeV are extremely small), a faster recovery time after the flash might be a great advantage for the operation of the detectors at the second experimental area (EAR-2), where the time of flight will be ten times shorter for the same neutron energies.

4. CONCLUSIONS

Two detectors have been delivered to the n_TOF collaboration. The prototype has been filled in January 2012 and until now doesn't show any leak of benzene. We strongly recommend keeping the prototype detector filled and inspected from time to time, in order to verify the tightness of the container over long periods of time. All parts of the detector but the quartz window have been constructed using materials certified as benzene-resistant. A particular care has to be devoted to verify the tightness of the window area.

The measured performance shows that the L_6D_6 detectors have an energy resolution comparable with the K6D6 and slightly worse than the B6D6. The recovery time after γ-flash is significantly faster for L_6D_6 than K_6D_6 or B_6D_6, although further tests in real experimental conditions at EAR-1 and EAR-2 will be necessary for establishing the upper neutron energy limits in (n,γ) measurements. The neutron sensitivity will be measured in a series of dedicated experiments, planned in 2013 at the GELINA and LNL-INFN facilities. The very small amount of mass and a careful choice of the materials, in particular de quartz window of the PMT, allows to be confident on a significant reduction of the neutron sensitivity.

Last, but not least, The L_6D_6 detectors have been designed and built taking into account the strict safety requirements at EAR-1 and EAR-2 Class A experimental areas.

References

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