WPJET4 Gamma Spectrometer Upgrade (GSU)

D18	Manufacturing of DM2 including: scintillator, photomultiplier, magnetic shielding, voltage divider and high voltage power supply *Due date: 31 December 2015*

1. Introduction

On JET the α-particle diagnostic is based on the nuclear reaction $^{9}Be(\alpha,n\gamma)^{12}C$ between confined α-particles and beryllium impurity ions typically present in the plasma, *see GSU Project Management Plan* and references therein. The applicability of gamma-ray diagnostic is strongly dependent on the fulfilment of rather strict requirements for the definition and characterization of the neutron and gamma radiation fields (detector Field-of-View, radiation shielding and attenuation, parasitic gamma-ray sources). For operating this diagnostic at the high DT neutron fluxes expected in the future high-power DT campaign on JET, specific improvements are needed in order to provide good quality measurements in the D-T campaign, characterized by a more challenging radiation environment.

In order to enable the gamma-ray spectroscopy diagnostic for α-particle diagnostic during the DT campaigns the following goals should be achieved:

- Maximization of the signal-to-background ratio at the spectrometer detector; this ratio is defined by terms of the plasma-emitted gamma radiation and the gamma-ray background.
- Establishing high count rate signal processing and energy-resolved gamma-ray detection.

In the DT experiments the gamma-ray detector must fulfil requirements for high count rate measurements. The existent BGO-detector with a relatively long decay time, about 300 ns, should be replaced by a new detector module (DM2) based on $CeBr_3$ scintillator, with an associated digital data acquisition system. The $CeBr_3$ scintillator are characterized by short decay time (~20 ns) and a high light yield about 45 000 photons/MeV. The coupling of the scintillators with photomultiplier tubes in specially designed detector modules will permit the operation at count rates over 2 Mcps. The $CeBr_3$ scintillator is an alternative to already tested at JET detectors based on $LaBr_3$:Ce.

The $CeBr_3$ scintillator was found to fulfil low noise measurement conditions. It shows 30 times reduction in internal activity in comparison with $LaBr_3$:Ce, see below. The $CeBr_3$ scintillator has a similar energy resolution, sensitivity and decay time as the $LaBr_3$:Ce scintillator. Moreover, the $CeBr_3$ scintillator seems to be more resistant for gamma radiation than $LaBr_3$:Ce. A 1 kGy dose of gamma radiation deteriorates the yield of $LaBr_3$:Ce by ~10% and worsens its energy resolution from 3.0 to 3.8%, while is almost negligible for $CeBr_3$.
$CeBr_3$ may also be more resistant to neutron radiation because of lower neutron capture cross section in Ce (~12 mb) than in La (~100 mb) at E_n ~30 keV.

These features make $CeBr_3$ an interesting alternative for JET plasma applications in spite of the excellent spectroscopic performances of $LaBr_3$:Ce scintillator.

2. Detector module DM2

In Fig. 1 a technical drawing of a detector ordered at Scionix is shown together with a photo of an already delivered detector.

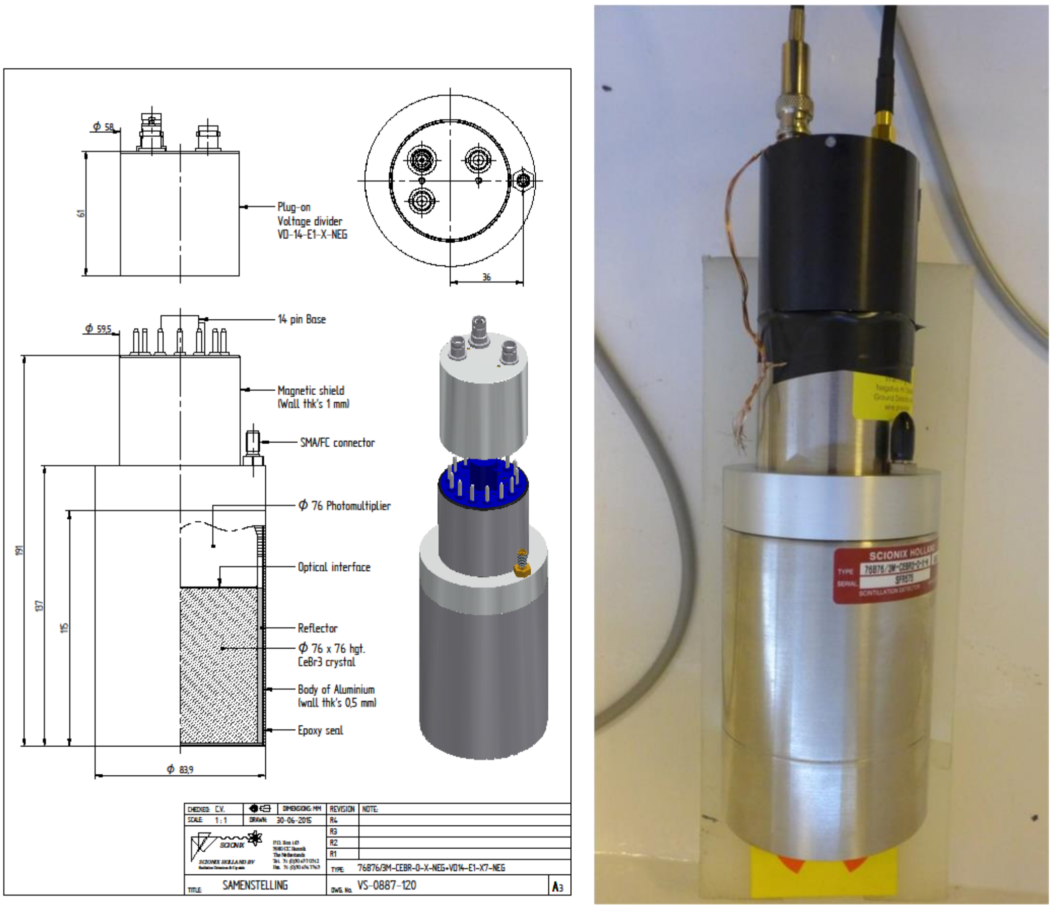


Fig. 1. 3”×3” $CeBr_3$ from Scionix: a technical drawing and a photo.

The specification of a detector based on $CeBr_3$:

- scintillator dimensions: 3”×3” (76 mm diameter, 76 mm high),
- low background,
- high resolution <4.3% FWHM at 662 keV scintillation crystal,
- 0.5 mm thick aluminium housing.

The photomultiplier R6233-100 PMT:

a 76 mm diameter PMT surrounded by an extra-long solid mu metal shield.

Additional features:

a fiber optics stabilization port with SMA connector.

Plug on voltage divider (Scionix model VD14-E1-X7-NEG):

- negative high voltage -700V,
- divider equipped with extra capacitors for high rate operation.

Active voltage divider designed at NCBJ:

A voltage divider (VD) has a significant influence on the performance of the PMT based detectors by interfering in its main characteristics, the gain control range and linearity. An active voltage divider ensures a constant gain. At NCBJ such a device was designed and produced. This fully active divider can be used up to 1.5 kV with a PMT 14 pin standard socket. It has easy removable components and has a direct output from both anode and last dynode.

3. Measurements at NCBJ with 3”×3”

We performed measurements on an energy resolution and a detection efficiency at our laboratory at NCBJ. Measurements were performed with both the Scionix voltage divider and the NCBJ dedicated active voltage divider.

For measurements we used standard γ-ray sources: ^{137}Cs (662 keV), ^{65}Zn (1115 keV) and ^{22}Na (1274 and 511 keV).

In Fig. 2 spectra registered with these standard sources are shown, as measured in the NCBJ laboratory.

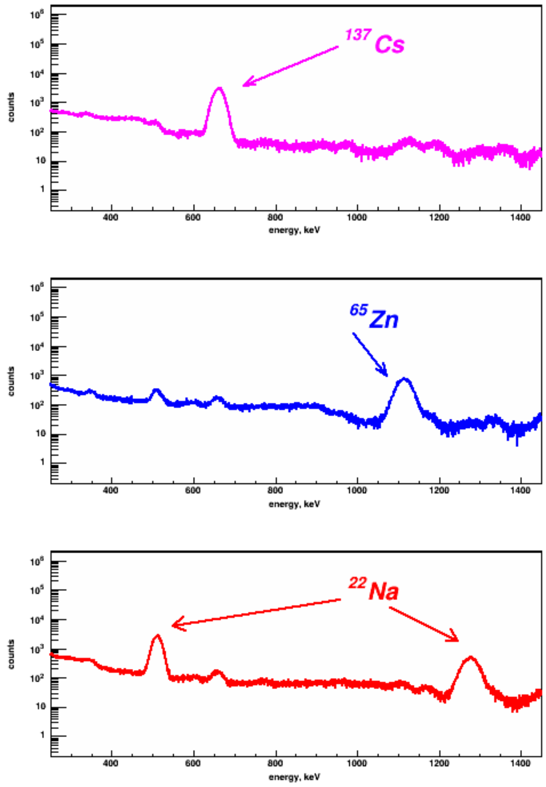


Fig. 2. Gamma-ray spectra measured with 3”×3” CeBr$_3$ scintillator and Scionix voltage divider. Upper: spectrum registered with for ^{137}Cs, center: with ^{65}Zn, lower with ^{22}Na source.

In Table 1 the results of measurements performed with the 3”×3” CeBr$_3$ scintillator equipped with the Scionix voltage divider are presented. The energy resolution is defined as a ratio of full width at half maximum (FWHM) divided by the energy of the recorded peak.

Full energy peak detection efficiency ε was calculated using the following equation:

$$\varepsilon = \frac{N}{A \times b \times t \times \omega}$$

where:
N – number of counts in full energy peak (background subtracted),
A – source activity,
t – live time of the measurement,
ω – solid angle of detection,
b – branching ratio of the reaction resulting in gamma-ray emission.

Table 1. Parameters of 3”×3” $CeBr_3$ scintillator equipped with Scionix voltage divider.

γ energy (keV)	γ-ray source	FWHM (%)	detection efficiency (%)
511	^{22}Na	4.8±0.1	56±2
662	^{137}Cs	4.2±0.1	51±2
1115	^{65}Zn	3.5±0.1	38±2
1173	^{60}Co	3.4±0.1	34±1
1275	^{22}Na	3.3±0.1	32±1
1332	^{60}Co	3.3±0.1	32±1

In Table 2 the results of measurements performed with the 3”×3” $CeBr_3$ scintillator equipped with the NCBJ dedicated active voltage divider are presented.

Table 2. Parameters of 3”×3” $CeBr_3$ scintillator equipped with NCBJ active divider.

γ energy (keV)	γ-ray source	FWHM (%)	detection efficiency (%)
511	^{22}Na	4.9±0.1	58±3
662	^{137}Cs	4.3±0.1	49±2
1115	^{65}Zn	3.5±0.1	37±2
1173	^{60}Co	3.3±0.1	34±1
1275	^{22}Na	3.3±0.1	33±2
1332	^{60}Co	3.3±0.1	33±1

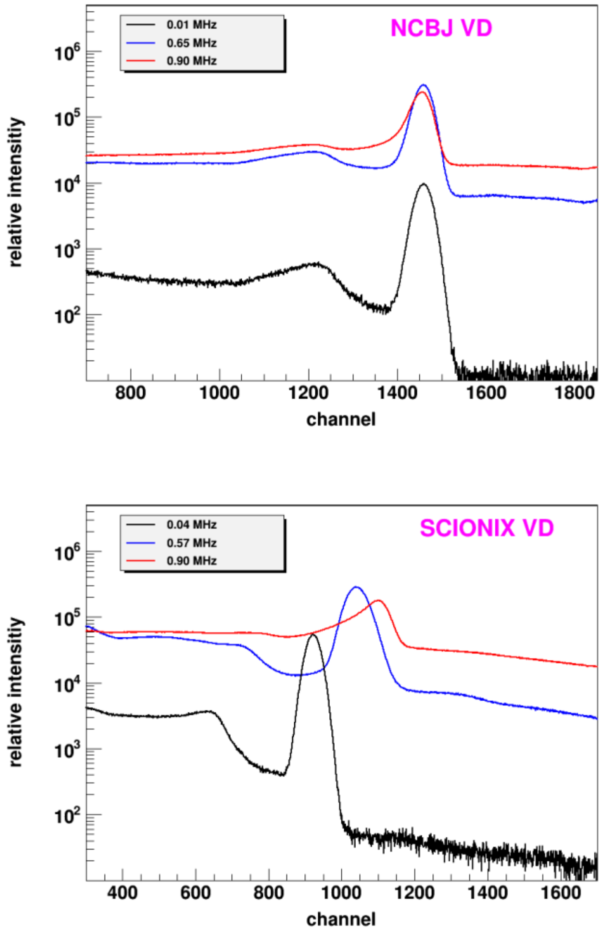
From obtained results from measurements with standard gamma-ray sources, we conclude that both FWHM and detection efficiency do not depend on a type of used voltage divider.

We performed measurements with a strong ^{137}Cs source with an activity of ~400 MBq, in order to increase the rate of events. Due to a lack of a safe setup we could not make measurements at count rates higher than 0.90 MHz.

In Fig. 3 ^{137}Cs spectra registered with both Scionix and NCBJ voltage dividers are shown for different count rates.

Results of measurements with the NCBJ dedicated active voltage divider are shown in Fig. 3, upper part. Spectra were recorded at count rates of 0.01, 0.65 and 0.90 MHz. The relative difference in a ^{137}Cs peak position is less than 0.5%. This result confirms a very good linearity of the NCBJ dedicated active voltage divider.

In the lower part in Fig. 3 spectra obtained with a Scionix voltage divider are shown for count rates of 0.04, 0.57 and 0.90 MHz. For this case, a strong correlation between peak position and increasing count rate is observed.



<u>**Fig. 3.**</u> ^{137}Cs gamma-ray spectra measured with 3”×3” CeBr$_3$ scintillator: *upper part*: NCBJ dedicated active voltage divide, *lower part*: Scionix voltage divider.

4. Comparison of 3”×3” CeBr$_3$ and 3”×3” LaBr$_3$:Ce scintillators

We performed measurements of a detection efficiency and full width at half maximum (FWHM) for both CeBr$_3$ and LaBr$_3$:Ce scintillators of the same size equal to 3”×3”, see tables 3 and 4 as well as figures 4 and 5.

Table 3. Detection efficiency of 3”×3” CeBr$_3$ (with Scionix VD) and 3”×3” LaBr$_3$:Ce scintillators.

γ-ray energy (keV)	γ-ray source	detection efficiency (%)	
		CeBr$_3$	LaBr$_3$:Ce
511	^{22}Na	56±2	59±3
662	^{137}Cs	51±2	54±3
1115	^{65}Zn	38±2	37±3
1173	^{60}Co	34±1	37±3
1274	^{22}Na	32±1	33±3
1332	^{60}Co	32±1	34±3

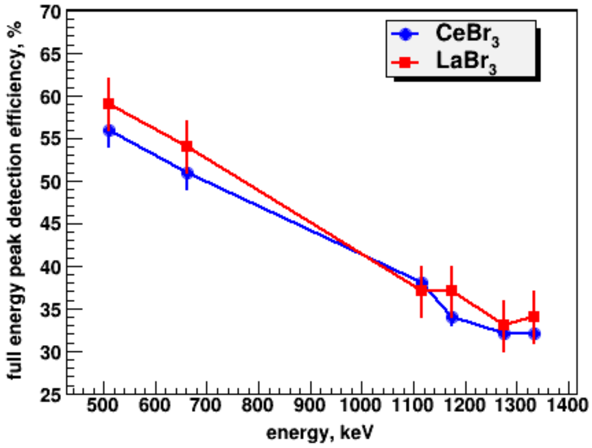


Fig. 4. Full energy peak detection efficiency measured with 3”×3” CeBr$_3$ (blue) and for LaBr$_3$:Ce (red) scintillators for γ-ray energies in the range between 0.5 and 1.3 MeV.

Table 4. FWHM of 3”×3” CeBr$_3$ (with Scionix VD) and 3”×3” LaBr$_3$:Ce scintillators.

γ-ray energy (keV)	γ-ray source	FWHM	
		CeBr$_3$	LaBr$_3$:Ce
511	^{22}Na	4.8±0.1	3.4±0.1
662	^{137}Cs	4.2±0.1	3.0±0.1
1115	^{65}Zn	3.5±0.1	2.4±0.1
1173	^{60}Co	3.4±0.1	2.4±0.1
1274	^{22}Na	3.3±0.1	2.4±0.1
1332	^{60}Co	3.3±0.1	2.2±0.1

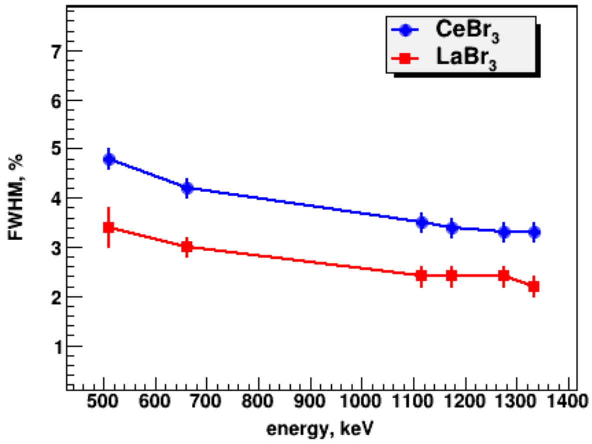


Fig. 5. Energy resolution measured with 3”×3” CeBr$_3$ (blue) and for LaBr$_3$:Ce (red) scintillators for γ-ray energies in the range between 0.5 and 1.3 MeV.

In addition, we compared intrinsic activity of both crystals. It is necessary to mention that CeBr$_3$ was produced by Scionix as a “low background” scintillator, whereas LaBr$_3$:Ce available at NCBJ is a “standard” crystal from St Gobain. It would be interesting to compare CeBr$_3$@NCBJ with a LaBr$_3$:Ce purchased for the GSU project by the Milan team.

The response of the 3”×3” CeBr$_3$ and LaBr$_3$:Ce crystals to natural background radiation is presented in Fig. 4. Peaks originating from gamma transitions observed in natural background (1.461 MeV from ^{40}K and 2.615 MeV from ^{208}Tl) are clearly seen. Both scintillators show peaks between 1.5 MeV and 2.5 MeV related to contamination by α-radioactive isotopes from actinides. LaBr$_3$:Ce is contaminated also with ^{138}La decaying by electron capture (EC) or β$^-$. EC is followed by emission of 1.436 MeV γ-ray and X-ray cascade, giving contribution to a peak at about 1.470 MeV. In addition, β$^-$ decay produces a continuum above 0.789 MeV.

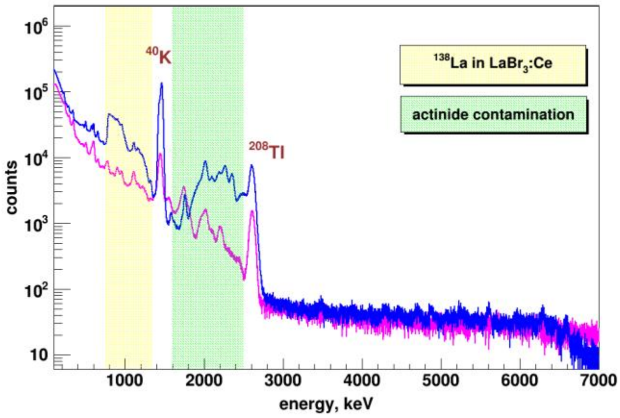


Fig. 4. Response of 3”×3” CeBr$_3$ and LaBr$_3$:Ce to natural background radiation.

5. Conclusions

1. The full energy peak detection efficiency is similar for both $CeBr_3$ and $LaBr_3$ scintillator.
2. 3”×3” $CeBr_3$ scintillator, purchased at Scionix, has a full width at half maximum equal to 3.3% at gamma-ray energy of 1.1 MeV.
3. In average, lower energy resolution by ~40% for $CeBr_3$ in comparison with $LaBr_3$ was observed.
4. Much lower intrinsic activity of the $CeBr_3$ scintillator is measured in comparison with a standard $LaBr_3$:Ce crystal.

References

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