WPJET4 Gamma Spectrometer Upgrade (GSU)

D27	Report on the integration of DM2 with DAQ (NCBJ and IST). *Due date: December 2016*

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 most important difference between these two crystals is connected with the presence of the long-lived naturally occurring ^{138}La isotope in $LaBr_3$:Ce. Such an intrinsic activity poses a serious limit for application in low count rate experiments. More details about $LaBr_3$:Ce intrinsic background can be found in papers "Development of MPPC-based detectors for high count rate DT campaigns at JET", prepared for the SOFT-2016 conference and "High performance detectors for upgraded gamma ray diagnostics for JET DT campaigns", Phys. Scr. 91 (2016) 064003.

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

The detector module prepared for the upgraded Gamma-ray Spectrometer at JET comprises a 3”×3” cylindrical $CeBr_3$ scintillator, encapsulated in a 0.5 mm thick Al housing and coupled to a R6233-100 PMT. It is equipped with a SMA connector for tests with LED sources.

The specification of a detector module DM2 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.

Active voltage divider designed at NCBJ.

3. Measurements at JET with 3”×3” $CeBr_3$ scintillator

In October/November 2016 we performed measurements with the detector module DM2 at JET with both commercially available CAEN Desktop Digitizer DT5720 and the TRP-400 data acquisition system from IST. The DM2 detector module was equipped with an active voltage divider and we have checked three pieces of the divider. Obtained results do not depend which divider was used.

Results of measurements performed in laboratory conditions at NCBJ, among others with a ^{137}Cs source (400 MBq activity), can be found for example in a report “D04: Design of a gamma-ray Detector Module 2 included: scintillator, photomultiplier, magnetic shielding, voltage divider and (preliminary) high voltage power supply” or in a paper “$CeBr_3$ –based detector for Gamma-ray Spectrometer Upgrade at JET” prepared for the SOFT-2016 conference.

Measurements at JET were performed with ^{22}Na (33 kBq activity) and a mixed source No. AG-5430, see Table 1. In addition to measurements with radioactive sources, a background was also registered.

Table 1. Radioactive mixed source No. AG-5430.

nuclide	gamma-ray energy (keV)	activity (kBq)	emission rate $[10^3 s^{-1}]$
^{241}Am	60	3.42	1.23
^{109}Cd	88	15.90	0.582
^{57}Co	122	0.579	0.496
^{139}Ce	166	0.725	0.579
^{203}Hg	279	1.40	1.14
^{113}Sn	392	2.58	1.68
^{85}Sr	514	2.88	2.83
^{137}Cs	662	2.77	2.36
^{88}Y	898	5.11	4.80
^{57}Co	1173	3.36	3.36
^{60}Co	1333	3.36	3.36
88Y	1836	5.11	5.07

3.1. Measurements at JET with CAEN Desktop Digitizer DT5720 and TRP-400 IST digitizer

In Fig. 1 a spectrum measured with a mixed source No. AG-5430 and registered with the CAEN DT5720 digitizer is shown. The distance between a 3"×3" $CeBr_3$ scintillator and a mixed source was 5 cm and a measuring time was 60 minutes.

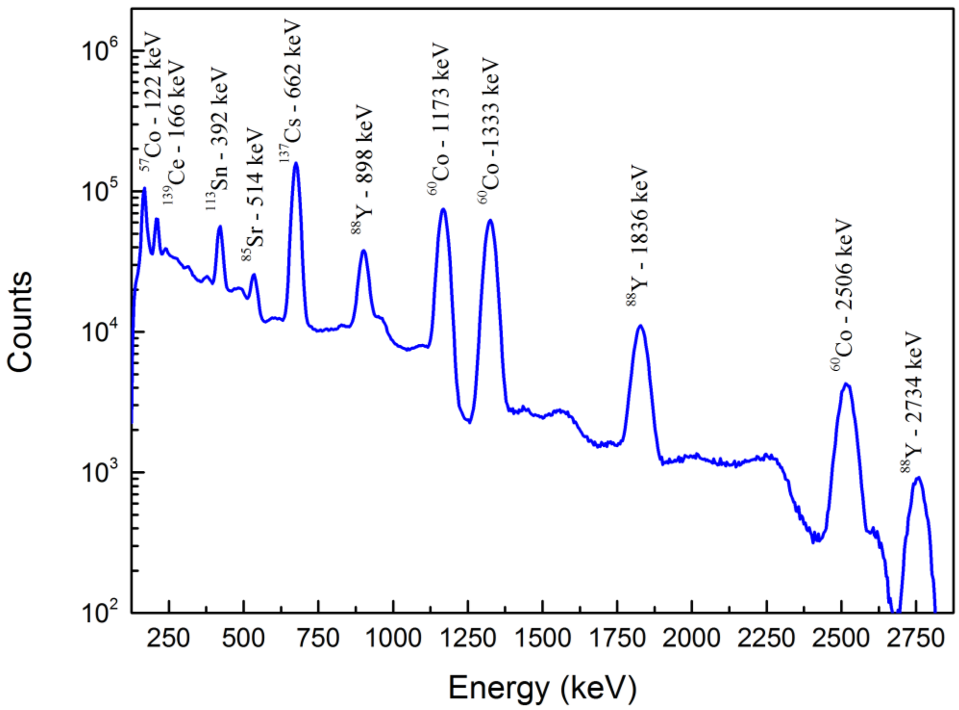

Fig. 1. Spectrum recorded with a 3"×3" $CeBr_3$ scintillator measured with a mixed source No. AG-5430 and registered with the CAEN digitizer.

In Fig. 2 a comparison of spectra measured with CAEN and with a Pulse Height Analysis (PHA) post-processing algorithm, identified as A1B1, applied to event based data acquired with the TRP-400 IST digitizer, recorded with the 3"×3" $CeBr_3$ scintillator. The measurements were performed under the same conditions: the distance between a detector and a mixed source was 5 cm, a measuring time was 60 minutes.

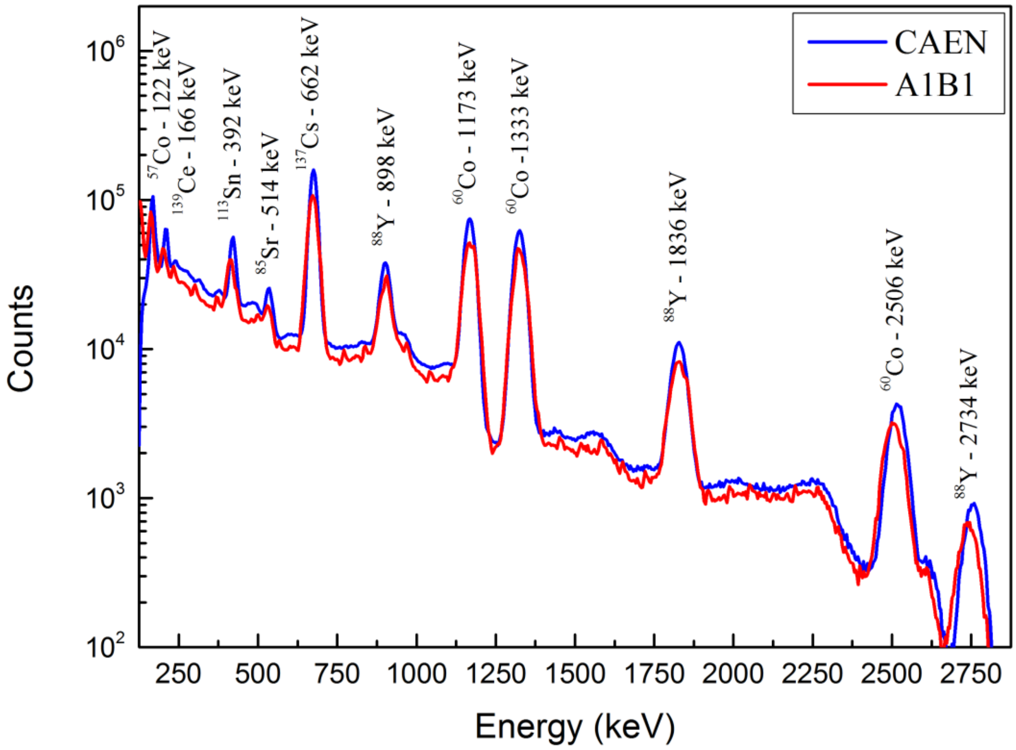

Fig. 2. Comparison of spectra registered with the 3"×3" $CeBr_3$ scintillator and both CAEN and TRP-400 (using a PHA post-processing algorithm (A1B1)), data acquisition systems. Measurements were performed with a mixed source in the energy range between 122 and 2734 keV.

We have determined an energy resolution defined as a full width at half maximum (FWHM).

In Table 2 and in Fig. 3 measured values of FWHM are presented as obtained with CAEN and with a PHA post-processing algorithm (A1B1) applied to data from TRP-400.

Table 2. Measured values of FWHM obtained with both data acquisition systems: CAEN and TRP-400 (A1B1 post-processing algorithm).

γ energy (keV)	γ-ray source	**FWHM (%) CAEN**	**FWHM (%) ~~A1B1~~ TRP-400 PHA**
662	^{137}Cs	**4.62±0.02**	**4.15±0.02**
1173	^{60}Co	**3.45±0.02**	**3.46±0.02**
1333	^{60}Co	**3.29±0.02**	**3.36±0.02**
1836	^{88}Y	**2.71±0.04**	**3.08±0.04**
2734	^{88}Y	**2.23±0.26**	**2.48±0.47**

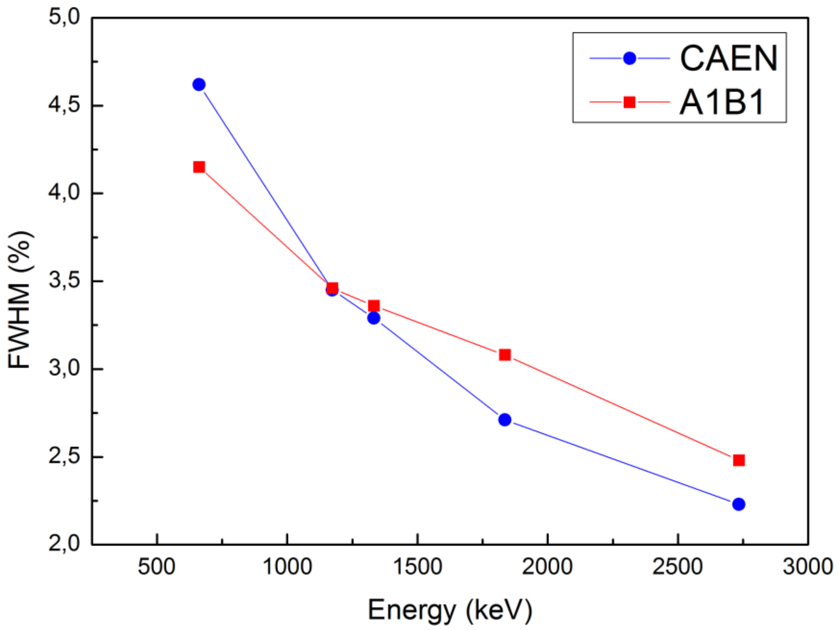

Fig. 3. Comparison of measured values of FWHM obtained with both data acquisition systems: CAEN and TRP-400.

In Fig. 4 a comparison of background spectra measured with CAEN and TRP-400 data acquisition systems is shown. In case of CAEN, time of measurement was 180 minutes, in case of TRP-400: 60 minutes. The CAEN-spectrum was normalized to the TRP400 spectrum due to its lower statistics.

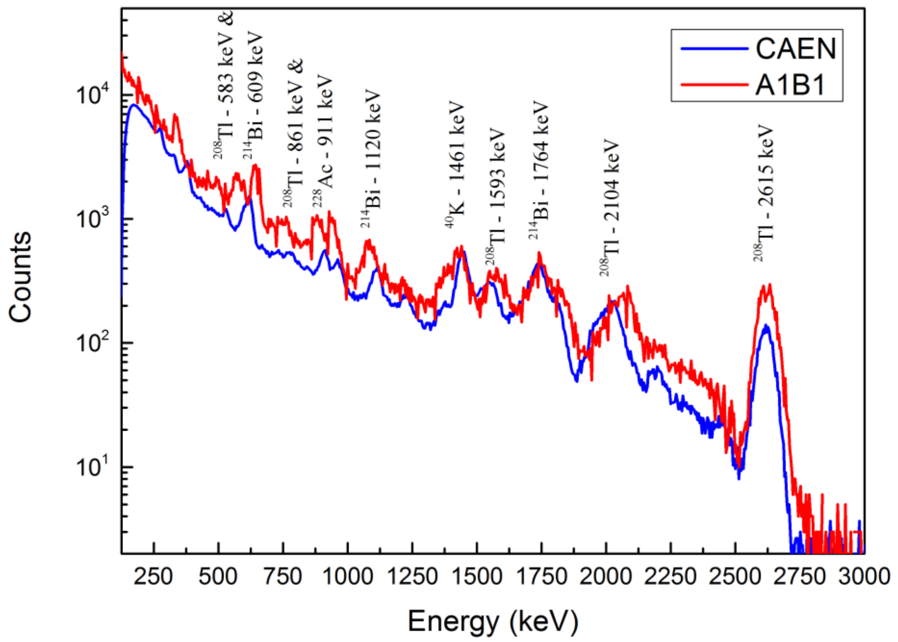

Fig. 4. Comparison background spectra measured with two data acquisition systems: CAEN and TRP-400 (PHA post processing method – A1B1).

3.2. Post processing algorithms for TRP-400 event based data

As detailed in D08 (Report on the DAQ hardware Installation), the TRP-400 data acquisition allow two different operating modes, the continuous mode, where all data is stored, and the event based mode where the detected events are stored with the corresponding time occurrence.

During the integration tests of DM2 with TRP-400, data was acquired using the segmented operating mode. When a pulse exceeds the pre-set threshold, a segment of 128 samples width was stored. The first 16 points contain samplings of the baseline level before the trigger condition occurs. The remaining 112 points are devoted to the pulse itself. The time stamp associated to each segment might be used for time resolved analysis of the collected data.

The event based data, from the DM2 detector, was offline processed by 2 different algorithms developed in MATLAB (8.3.0.532 (R2014a)) code, the Pulse Height analysis (PHA) and the trapezoidal based filter. The PHA is considered the fastest method to obtain results during prototype testing (e.g. detectors installation during shutdown), while DTS provides improved resolution for sharp peaks, being the selected option for DT experiments.

As described in D22 (Report on the DAQ system testing), these algorithms were selected according with its performance based on: i) peak detection as function of the event rate; ii) Pile-Up Rejection (PUR) efficiency; and iii) peak resolution.

The PHA method was used to compare the TRP-400 acquired data with results from CAEN, as presented in in section 3.1 (A1B1 data in figure 1-4 and table 2). In figure 5 is depicted a similar spectra obtained with DTS post-processing method, from data acquired with TRP-400 in presence of the mixed source No. AG-5430 (table 1).

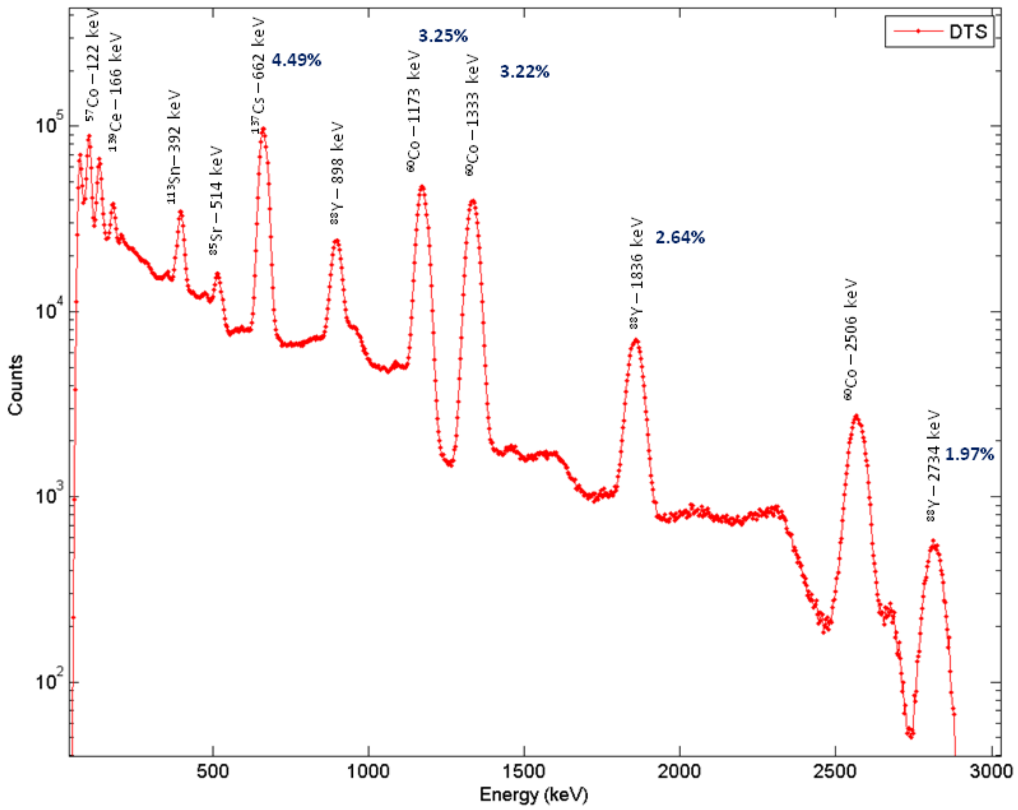

Fig. 5. Spectra obtained with DTS post-processing method, from data acquired with TRP-400 in presence of the mixed source No. AG-5430. Measurements were performed with a mixed source in the energy range between 122 and 2734 keV. Event rate of 2 kHz.

4. Conclusions

1. The measurements have been performed with the Detector Module 2, based on a 3”×3” $CeBr_3$ scintillator, purchased at Scionix.
2. The DM2 module was integrated with the TRP-400 IST data acquisition system prepared for experiments at JET.
3. In addition, the performance of the DM2 module was tested with the commercially available CAEN Desktop Digitizer DT5720 used at NCBJ for all measurements.
4. Two different offline processing algorithms, DTS and PHA, developed in MATLAB, were used to produce suitable spectra with event based data from TRP-400.

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