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High performance detectors for upgraded gamma ray diagnostics for JET DT campaigns

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Abstract

In forthcoming deuterium-tritium (DT) experiments on JET a significant population of alpha-particles will be produced. For operating alpha-particle diagnostics at high DT neutron fluxes, specific improvements have to be made. Proposed new detectors for gamma-ray measurements will be based on $CeBr_3$ and $LaBr_3$:Ce scintillators. They are characterized by a good energy resolution, a relatively high detection efficiency for a few MeV gamma-rays and a fast response time. An overview of scintillator parameters is presented. A description of the properties of photodetectors is given to indicate optimal setups. Results of measurements, using gamma-ray sources with energies up to a few MeV, are discussed with relation to the DT campaign requirements.

Keywords: gamma-ray spectrometry, scintillators, MPPC, energy resolution, decay time, detection efficiency, tokamak

(Some figures may appear in colour only in the online journal)

1. Introduction

Plasma diagnostics aim to measure and control plasma parameters, including particle and radiation losses, plasma temperature and density. For low- and mid-temperature tokamak plasmas (up to an electron temperature of a few keV), mainly

[9] See the appendix of F Romanelli *et al* Proc. of the 25th IAEA Fusion Energy Conf. 2014, Saint Petersburg, Russia.

atomic processes, like ionization, excitation, recombination and charge exchange, govern the plasma performance [1–3], related to, e.g. plasma confinement, radiation power, energy loss and plasma transport. In high-temperature plasmas, nuclear reactions producing neutrons and charged fusion products become more important for plasma performance. Also, plasma heating with accelerated energetic ions leads to a variety of nuclear reactions occurring in plasma, which could be used for diagnostics. Gamma-ray diagnostics in magnetically confined plasmas provide crucial information on the behaviour of fast electrons, fusion reaction products and other fast ions [4–9]. Gamma-ray spectra from nuclear reactions between fast ions and the main plasma impurities, such as beryllium and carbon, provide information on the energy distributions of ions [10]. Time-resolved gamma-ray profile measurements provide spatial distributions of fast ions in plasmas by means of the reconstruction of measured 2D gamma-ray emission profiles [11]. Such diagnostics are already installed at tokamaks, e.g. the Joint European Torus (JET) and are planned for the ITER experimental device [12].

At JET an integrated program of diagnostic developments for the planned deuterium-tritium (DT) campaign and in preparation for ITER has been established. In order to take full benefit from the DT campaign a number of diagnostic upgrades are necessary for fusion alpha-particle measurements.

A short overview of gamma-ray diagnostics operating at JET will be presented, together with requirements for the forthcoming DT campaign, when high count rate measurements are expected. Measured scintillator parameters, energy resolution, decay time and full energy peak detection efficiency will be presented, together with results obtained in the investigations of photodetectors. Results of measurements, using gamma-ray sources with energies up to a few MeV, are discussed with relation to requirements for upgraded detectors.

2. Gamma-ray diagnostics at JET

At JET alpha-particle measurements are performed using gamma-ray emission spectrometry of the ^{9}Be(α,nγ)^{12}C nuclear reaction between alpha-particles and beryllium impurities present in the plasma [11, 13]. The gamma-ray spectrum measured in this reaction shows a full energy peak (FEP) at 4.44 MeV. A few MeV gamma-rays are absorbed in a detector mainly due to the e^+e^- pair production process. As a result, 0.511 MeV annihilation quanta are also produced inside the scintillator. Therefore in a recorded spectrum, beside the FEP, two additional peaks are present: a single escape peak (SEP) when only one annihilation photon leaves the detector without further interaction, and a double escape peak (DEP) if both annihilation photons escape without interaction [14]. SEP appears in the spectrum at an energy of 0.511 MeV below FEP, while DEP is located in the spectrum at an energy of 1.022 MeV below FEP. The spatial and energetic characteristics of the alpha-particles are investigated by two types of gamma-ray diagnostics systems: the gamma-ray camera and the gamma-ray spectrometer, respectively. The JET gamma-ray camera diagnostics system (KN3 neutron/gamma-ray profile monitor) has already provided valuable information on the fast ion evolution in JET plasmas [15]. The gamma-ray profile monitor (gamma-ray camera) is equipped with CsI:Tl scintillators, whereas the tangential gamma-ray spectrometer is equipped with BGO scintillators [4, 9, 10, 16–19].

The gamma-ray camera and the gamma-ray spectrometer will be upgraded with new detectors and digital electronics to sustain the expected high count rates, up to 1 MHz, during the forthcoming JET DT campaign. An energy range of interest for reactions occurring during a tritium discharge is above 1 MeV [4]. It is proposed to enhance the existing spectroscopic and count rate capability by replacing CsI:Tl and BGO scintillators in the gamma-ray camera and the gamma-ray spectrometer, respectively, with scintillators which are much faster and feature a better energy resolution, less than 5% at 1.1 MeV. Full width at half maximum (FWHM) equal to 5% at 1.1 MeV is enough to be sure that at higher energies, ~4 MeV, peaks differing in energies by 0.5 MeV will be sufficiently separated, because an energy resolution is better for gamma-rays with higher energy. As mentioned above, in case of detecting a few MeV gamma-rays it is necessary to resolve peaks separated by 0.5 MeV.

Upgrading these two gamma-ray diagnostics is a challenging task because of existing constraints in terms of available space for detectors and shielding at JET.

$CeBr_3$ and $LaBr_3$:Ce scintillators are considered as candidates for replacing detectors now installed at JET [20]. These crystals are characterized by a good energy resolution, a relatively high detection efficiency in the MeV gamma-ray energy range of interest for JET and a fast response time, enabling spectrometry at high count rates [21, 22]. Such scintillators are rather resistant to neutron damage [23, 24] and they are oxygen-free to avoid reactions induced by neutrons.

3. Choice of scintillators for the JET gamma-ray diagnostics upgrade

The parameters of the CsI:Tl and BGO scintillators presently used in JET gamma-ray diagnostics as well as of the proposed $CeBr_3$ and $LaBr_3$:Ce crystals are shown in table 1. Details of measurements performed at the National Centre for Nuclear Research (NCBJ) are given in [25].

CsI:Tl crystals are characterized by a long decay time of ~780 ns measured for a fast component and an energy resolution equal to ~5% at 1.1 MeV. BGO scintillators are relatively slow with a decay time of about 300 ns and much worse energy resolution than CsI:Tl. Moreover, BGO comprises oxygen that becomes a source of unwanted high energy gamma-ray background when exposed to fast neutron flux, emitting gamma-rays with an energy of 6.1 MeV. Following the data included in table 1, CsI:Tl and BGO have been excluded from further studies at this point of analysis due to their worse basic scintillation properties, in comparison with

Table 1. Typical scintillator parameters important for gamma-ray measurements at JET.

		CsI:Tl	BGO	$CeBr_3$	$LaBr_3$:Ce
Manufacturer		Amcrys-H	Novosibirsk	Scionix	St-Gobain
density (g cm^{-3})		4.51	7.13	5.18	5.06
effective atomic number, Z_{eff}		54.0	71.5	45.9	45.2
decay time (ns)		780 ± 50 (46% fast component)	300[a]	19 ± 2	18 ± 2
energy resolution (FWHM, %) at 1.1 MeV		4.9 ± 0.1	8.8 ± 0.3	3.4 ± 0.1	2.4 ± 0.1
detection efficiency (%)at 1.1 MeV	1″ × 1″	6 ± 1	19 ± 1	6 ± 1	7 ± 1
	3″ × 3″	-[b]	40 ± 1	29 ± 2	27 ± 3

[a] see [14].
[b] not relevant for JET gamma-ray diagnostics.

$CeBr_3$ and $LaBr_3$:Ce, that would result in evidently inferior performance in the experimental conditions expected during JET campaigns.

Both $CeBr_3$ and $LaBr_3$:Ce have a short decay time (~20 ns) and an energy resolution better than 5% at the gamma-ray energy of 1.1 MeV. A detection efficiency at the gamma-ray energy of 1.1 MeV is similar for $CeBr_3$ and $LaBr_3$:Ce scintillators and is strongly dependent on crystal size [25].

4. Gamma-ray camera at JET

Spatial profiles of the gamma-ray emission are measured at JET using the gamma-ray camera (figure 1), which has ten horizontal and nine vertical collimated lines of sight. Each collimator corresponds to a poloidal-viewing extent at the centre of plasma of about 10 cm. The detector array is comprised of 19 CsI:Tl crystals coupled to photodiodes [26]. This system was initially intended for time, spatial and energy resolved measurements of bremsstrahlung that originated in the interaction of fast electrons with bulk plasma, gas puff or injected pellet. The gamma-ray camera has also been used in lower hybrid current drive experiments to characterize the fast electron driven tail [27]. The tomography of the measured gamma-ray emissions on the stage of runaway electrons (RE) plateau provides detailed data on the temporal evolution and spatial structure of RE beams during disruptions.

In addition, the gamma-ray camera is suitable for the detection of gamma-rays produced when fast ions react with either plasma fuel ions or plasma impurities such as beryllium, boron, carbon and oxygen. This diagnostic has already provided valuable information on the gamma-ray imaging of fast ions in JET plasmas [6, 11].

For operating the gamma-ray camera diagnostic at high neutron fluxes, expected in the next DT campaign at JET, specific improvements are needed. In particular, it is proposed to replace 19 CsI:Tl detectors with faster and better energy resolution detector modules, composed of a scintillator and silicon photomultiplier [28, 29].

The new detector modules will be based on fast $CeBr_3$ and $LaBr_3$:Ce scintillators coupled to photodetectors which are optimised for use at the JET gamma-ray camera and will comply with all the JET experiment requirements.

4.1. Photodetectors for the JET gamma-ray camera

Currently, the CsI:Tl scintillators are coupled to PIN photodiodes in the gamma-ray camera. PIN photodetectors are characterized by small dimensions, low operating voltage and immunity to a magnetic field. The main drawback of PIN diodes is a low gain coefficient of ~1, requiring the usage of a preamplifier for spectrometry measurements. This results in a relatively slow response time which is not suitable for measurements at high count rates. As an alternative, a multi-pixel photon counter (MPPC), interchangeably called a silicon photomultiplier, is considered for the gamma-ray diagnostics during the JET DT campaign [30, 31]. MPPC advantages are: fast response time, high gain coefficient, high photon detection efficiency resulting in good energy resolution and immunity to a magnetic field. Moreover, its small size and low bias voltage in comparison with photomultiplier tubes have to be pointed out too. The MPPC main drawbacks are connected with a gain sensitivity to temperature and voltage. Therefore a good quality voltage supply with a voltage ripple less than 3 mV is exploited to bias the MPPC. Such low voltage fluctuations do not affect the performance of the MPPC. To reduce the noise pick-up by the detector signal μ-shielded cables with additional electromagnetic shielding are used. A limited dynamic range and non-linearity of a signal response are also drawbacks when bright and fast scintillators are in use. The gain of the device will be monitored repeatedly using a gamma-ray source available both in the laboratory and inside the JET gamma-ray camera. A correction for nonlinear response will be applied off-line to record spectra based on the spectra library collected for every module during tests performed at the NCBJ laboratory.

The S12642-040 MPPC from Hamamatsu, used during tests, has 4×4 channels with a photosensitive area per channel equal to 3×3 mm^2. More details about MPPC research works performed at NCBJ can be found in [32–36].

In figure 2, a breakdown voltage as a function of MPPC temperature is shown. The 20 mm × 15 mm cylindrical $CeBr_3$ scintillator coupled to MPPC was used in these measurements.

Due to this very strong voltage-temperature dependence for MPPC-based detectors, a device for real-time temperature monitoring and MPPC gain stabilization was designed and produced at NCBJ. The MPPC temperature compensation

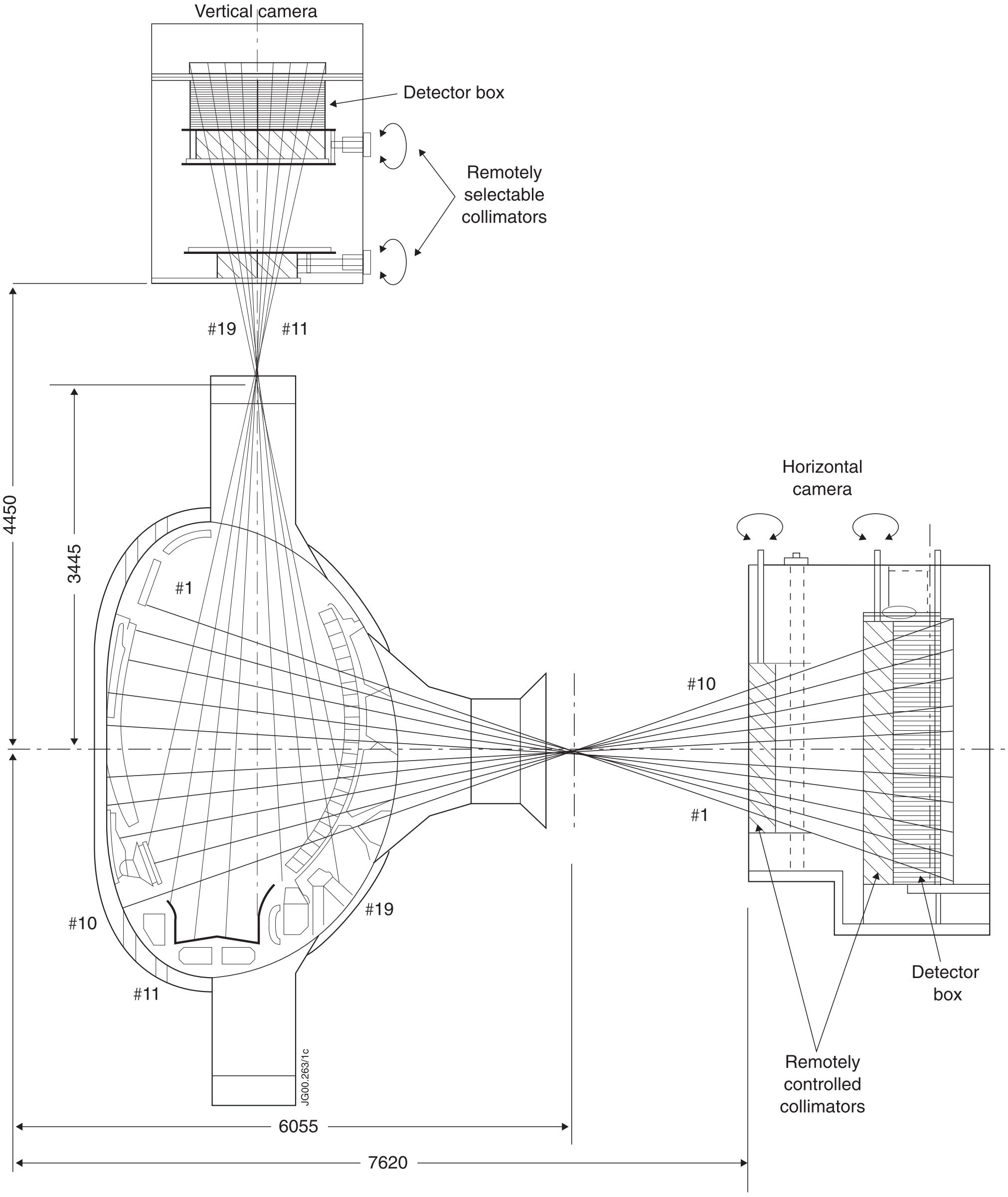

Figure 1. Schematic of the JET gamma-ray camera used for the spatial gamma-ray emissivity measurements.

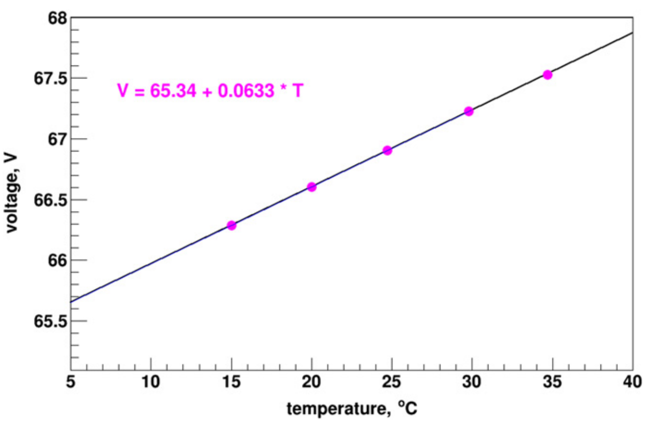

Figure 2. Breakdown voltage as a function of MPPC temperature.

device (MTCD@NCBJ) uses a measured dependence of a breakdown voltage on temperature to maintain a constant value of the MPPC gain [37]. MTCD@NCBJ provides a current limitation and filtering of the MPPC voltage and can supply an output voltage up to 80 V. All functions are controlled from a personal computer.

In figure 3 the spectrum measured with a ^{137}Cs source at a constant temperature T = 20 °C is shown for two MPPC voltages: 65.70 and 66.00 V. A change in the MPPC voltage equal to 0.30 V corresponds to a shift in a ^{137}Cs peak position, equal to 345 analog-to-digital converter (ADC) channels of the used data acquisition (DAQ) [38]. So, if the temperature difference is 1 °C, the change in the peak position is about 70 channels and a voltage change equal to 0.0633 V is necessary to maintain a constant value of the MPPC gain. Since the voltage supply accuracy is at the level of 10 mV, the peak position can be maintained within about 11 channels.

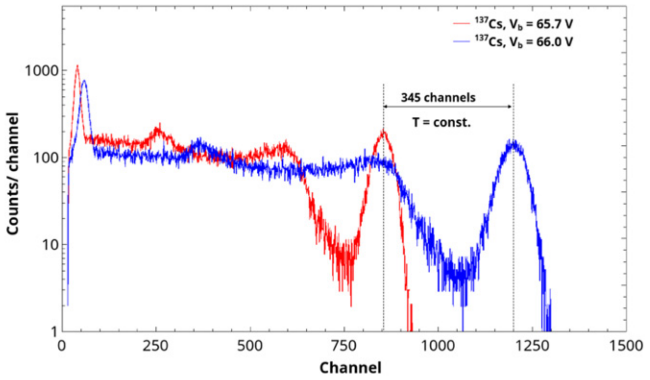

Figure 3. ^{137}Cs spectra measured for two MPPC voltages: 65.70 and 66.00 V.

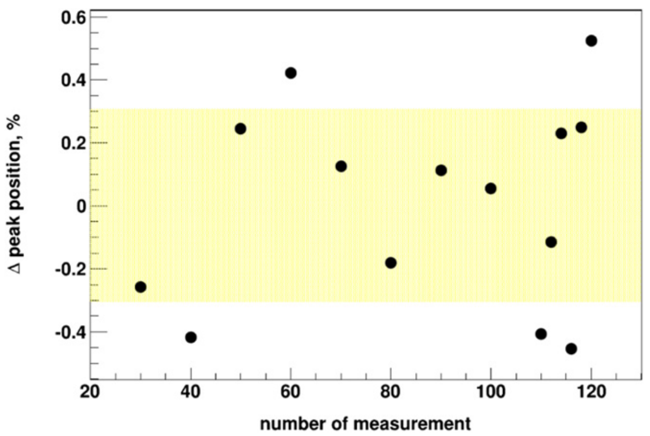

Figure 4. Registered peak position obtained for the 661.7 keV gamma-ray line measured with a $CeBr_3$ scintillator and MTCD@NCBJ. For simplicity, results from only 14 sessions are shown.

This means that in the case of the tested MPPC-based detector the gain fluctuations can be kept at the level of 1%.

The MTCD@NCBJ performance was checked during measurements lasting 17 h. Results from 14 sessions, each 500 s of live time, are shown in figure 4. The observed MPPC temperature change was about 2.5 °C and the change in peak position was below 1%, which is comparable with widely used photomultipliers (PMT).

In figure 5 the dependence of a peak position, expressed in ADC channel values, on a gamma-ray energy is shown, as measured at the MPPC voltage of 66.47 V and an MPPC temperature of 22 °C. Measurements were done for gamma-ray sources in the energy range from 0.6–5.1 MeV. As already mentioned, based on such measurements, a dedicated spectra library is under preparation and will allow for corrections applied to every module.

4.2. First measurements at the JET facility

First tests at JET have been done to compare the energy resolution for two detector setups, one using $CeBr_3$ scintillators and the other using CsI:Tl crystals. A ^{22}Na source placed permanently inside the JET gamma-ray camera was used for tests made during the JET shutdown in Summer 2015.

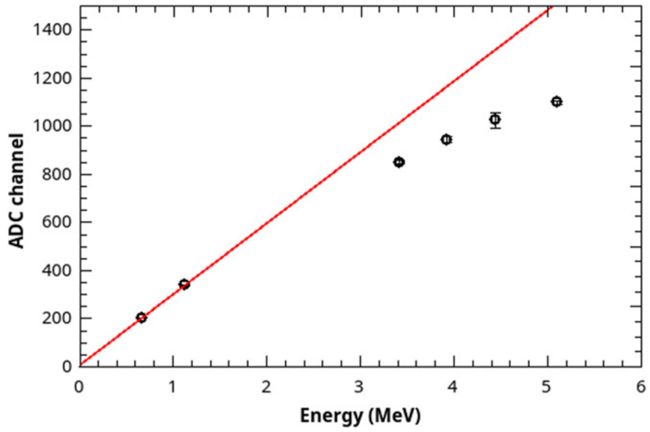

Figure 5. Peak position, expressed in ADC channels, as a function of the gamma-ray energy. The red line is drawn to show an ideal linear performance.

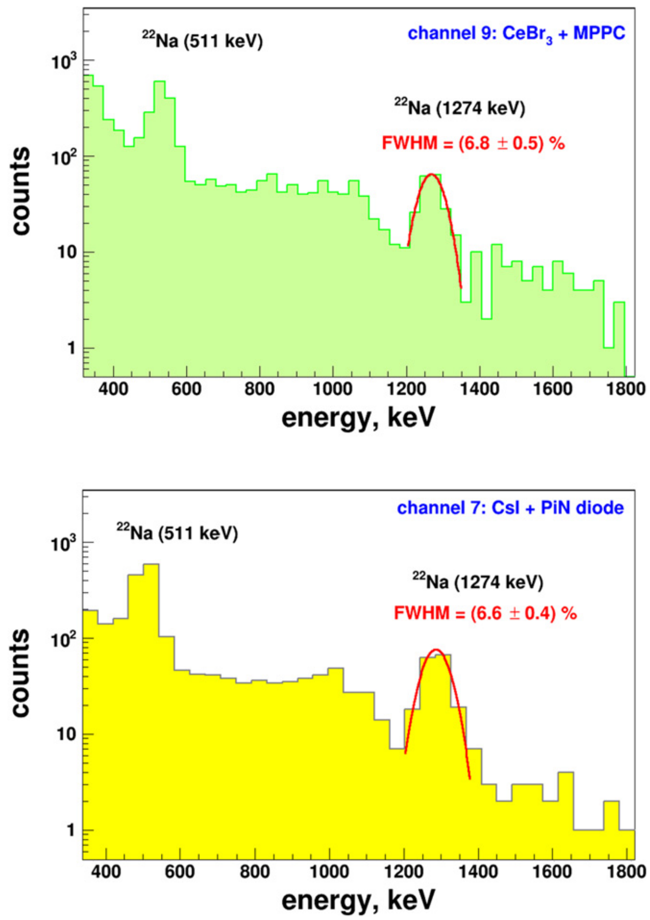

Figure 6. Upper part: ^{22}Na spectrum measured with $CeBr_3$ coupled to MPPC installed in channel 9 of the gamma-ray camera. Lower part: ^{22}Na spectrum measured with CsI:Tl coupled to a PIN diode installed in channel 7 of the gamma-ray camera. In both spectra, the red curve is a Gaussian fit used to determine the FWHM for the 1274 keV gamma line.

In the upper part of figure 6 a ^{22}Na spectrum measured by a prototype detector based on $CeBr_3$ coupled to MPPC is

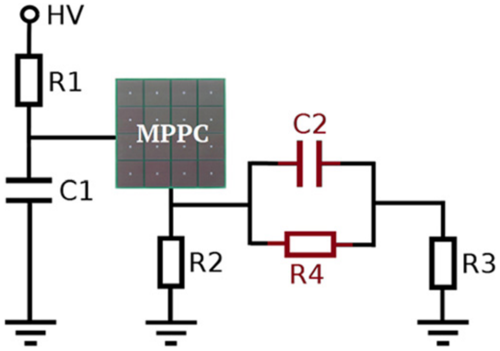

Figure 7. CR differentiator with a pole-zero cancellation applied for an MPPC-based detector.

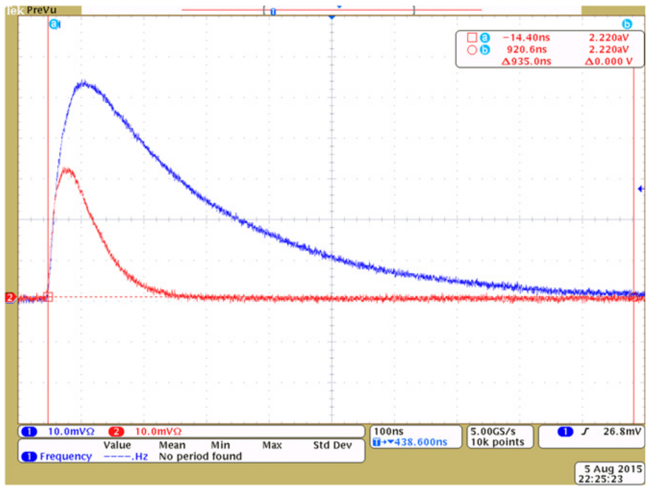

Figure 8. Signals measured with (red line) and without (blue line) a CR differentiator with a pole-zero cancellation. The count rate is ~0.3 MHz.

shown. This new detector was installed in channel 9 of the gamma-ray camera in May 2015, see figure 1. DAQ available at JET allowed us to acquire data at 200 mega samples per second (MSPS) and the correspondent spectrum was built with a fast non-optimized algorithm for pulse height analysis. The measured FWHM for 1274 keV gamma-ray energy is equal to (6.8 ± 0.5)%.

For comparison, a ^{22}Na spectrum was registered with a CsI:Tl coupled to a PIN diode detector currently installed in channel 7 of the JET gamma-ray camera; see the lower part of figure 6. In this measurement, lower sampling of 2.5 MSPS was enough to register signals. The spectrum was built with an optimized algorithm for Cs:Tl pulses [39]. Measured FWHM for 1274 keV gamma-ray energy is equal to (6.6 ± 0.4)%.

We conclude that the new experimental setup system based on a $CeBr_3$ scintillator coupled to MPPC and used at the 200 MSPS DAQ system does not worsen the energy resolution in comparison with the currently installed CsI:Tl detectors at the JET gamma-ray camera. We note the advantage of using a $CeBr_3$ + MPPC configuration that allows for high count rate spectrometry in contrast to a CsI + PIN detector.

4.3. CR differentiator with a pole zero cancellation for signal shortening

Detectors used in experiments with high count rates should have a short pulse duration. The pulse shape is described by a rise and fall time: the rise and fall times are here defined as the interval between the times at which the pulse reaches 10% and 90% of its maximum amplitude on the leading and falling edge, respectively.

Figure 7 illustrates a so-called 'CR differentiator with a pole-zero cancellation' circuit used for signal shortening in the detector system based on MPPC.

Output pulses from a ^{137}Cs source registered with the MPPC-based detector system are shown in figure 8. The blue line corresponds to a signal before the installation of a CR differentiator with a pole-zero cancellation circuit, whereas the red one corresponds to a signal after installing this circuit. The measurements were performed for the count rate ~0.3 MHz. The MPPC voltage was set at 66.50 V.

The signal registered with the detector system based on the MPPC and $CeBr_3$ scintillator, before shortening, has a total length of ~1 μs. The rise time is ~35 ns and the fall time is ~750 ns. The amplitude is ~54 mV for the FEP at 661.7 keV.

With a signal shortening system, the total length of a signal is ~120 ns, with a rise time of ~17 ns and a fall time of ~90 ns. As expected, a lower amplitude of ~36 mV was measured with this system at the gamma-ray energy of 661.7 keV.

A transimpedance amplifier is an alternative to the CR differentiator with a pole-zero cancellation for measurements with high count rates. Such a device is already designed and under test at NCBJ.

The final decision about a solution for the JET gamma-ray camera upgrade will be taken in the first half of 2016.

5. Upgrade of tangential gamma-ray spectrometer at JET

The JET tangential gamma-ray spectrometer uses, in its present configuration, a calibrated BGO scintillation detector with a diameter of 3″ and a height of 3″ [13]. BGO has a decay time equal to 300 ns, an energy resolution (FWHM) at 1.1 MeV equal to 8.8% and a detection efficiency at 1.1 MeV equal to 34%. It is located in a shielded bunker, which views the plasma quasi-tangentially. In order to reduce the neutron flux and the gamma-ray background, the front collimator is filled to a depth of 500 mm with polythene. Behind the scintillation detector, there is an additional 500 mm long dump of polythene and a 1000 mm long steel plug. The detector line of sight lies in a horizontal plane about 30 cm below the plasma magnetic axis. The gamma-ray spectra are continuously recorded in all JET discharges over the energy range 1–28 MeV, with an energy resolution of about 4% at 10 MeV [4].

In order to prepare the forthcoming JET DT campaign the tangential gamma-ray spectrometer is undergoing a full upgrade [40]. The upgraded spectrometer will be equipped with both $CeBr_3$ and $LaBr_3$:Ce scintillators, the two detectors being planned to be used alternatively. The scintillator crystals will be coupled to a photomultiplier which will provide a fast signal. An additional extra-long solid μ-metal housing around the PMT assures a proper operation in a varying magnetic environment.

The main drawback of the $LaBr_3$:Ce scintillator is its performance in low noise measurements due to a high intrinsic background, caused by the 0.09% natural abundance of radioactive ^{138}La isotope with a half-life of $\sim 10^{11}$ years [41]. The radioactive decay of the ^{138}La via beta-decay or electron capture leads to an emission of gamma-rays at ~0.8 MeV or ~1.4 MeV energies and low energy x-rays. Absorption of emitted radiation causes an internal activity of $LaBr_3$:Ce up to ~1.5 counts/s/cm^3. In the case of $CeBr_3$, only activity related to contamination by alpha-radioactive isotopes from actinides is seen. This radiation is also observed at a similar level in $LaBr_3$:Ce crystals, being at least an order of magnitude less than the activity originating from ^{138}La [41]. The $CeBr_3$ scintillator was found to fulfill low noise measurement conditions—it shows about a 30 times reduction in internal activity in comparison with $LaBr_3$:Ce [42]. Moreover, the $CeBr_3$ scintillator seems to be more resistant to 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 at 662 keV from 3.0 to 3.8%, while this is almost negligible for $CeBr_3$ [43]. $CeBr_3$ should also be more resistant to neutron radiation than $LaBr_3$:Ce because of the much lower neutron capture cross section in Ce than in La (at a neutron energy below 10 keV). These features make $CeBr_3$ an interesting alternative for JET plasma applications in spite of the excellent spectroscopic performances of the $LaBr_3$:Ce scintillator. Therefore, besides ensuring an already tested component, the project also attempts to provide enhanced performance by including a detector based on a $CeBr_3$ scintillator.

5.1. Intrinsic activity of $CeBr_3$ crystal

The intrinsic activity of a 3″ × 3″ $CeBr_3$ scintillator, foreseen for the tangential gamma-ray spectrometer, was measured. The crystal available in the NCBJ laboratory was especially produced by Scionix featuring a low background. The PMT used in this detector setup is surrounded by a 1 mm thick wall made of a μ-metal. The response of the $CeBr_3$ crystal to natural background radiation, measured at NCBJ, is presented in figure 9. Peaks originating from gamma transitions observed in the NCBJ laboratory natural background (1.461 MeV from ^{40}K and 2.615 MeV from ^{208}Tl) are clearly seen. In the measured distribution, peaks between 1.5 and 2.5 MeV related to contamination by alpha-radioactive isotopes from actinides, are also identified with relatively low intensities.

The results of the performed measurements do not pose any concern for the application of $CeBr_3$ scintillators in

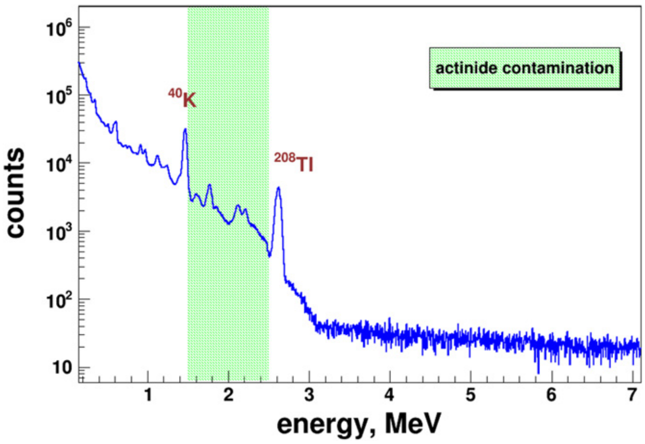

Figure 9. Response of 3″ × 3″ $CeBr_3$ scintillator to natural background radiation and intrinsic activity.

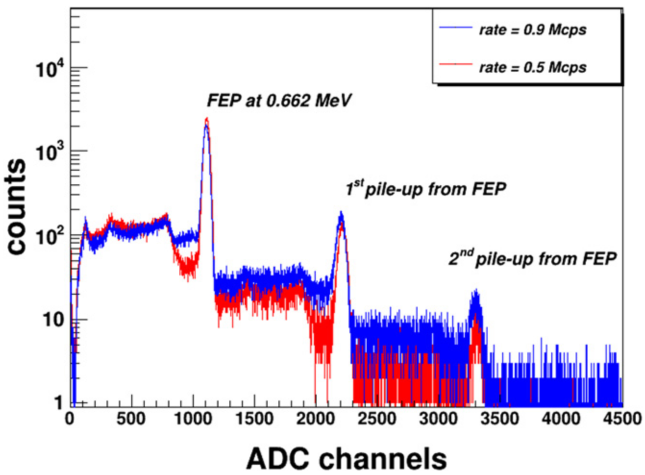

Figure 10. Energy spectrum of ^{137}Cs measured with a 3″ × 3″ $CeBr_3$ scintillator for two count rates: 0.5 Mcps (red curve) and 0.9 Mcps (blue curve) (*preliminary*). The NCBJ active voltage divider was used in both cases. Due to ~400 MBq source activity a pile-up structure is clearly observed.

plasma diagnostics in which interesting gamma-ray lines have an energy above 3 MeV. However, the lower background is of course important to maximize the signal-to-background ratio at the detector.

5.2. Dedicated active voltage divider for high count rates

A voltage divider has a significant influence on the performance of the PMT-based detectors by interfering, in its main characteristics, a gain stability and an energy resolution. To ensure the best performance, an active voltage divider was designed and produced at NCBJ. This fully active divider can be used up to 1.5 kV with a PMT 14 pin standard socket. It has easily removable components and has a direct output from both the anode and last dynode.

Figure 10 depicts the energy spectra of ^{137}Cs for a count rate equal to 0.5 and 0.9 MHz, collected in laboratory conditions with a source activity of ~400 MBq. Measurements were performed with a 3″ × 3″ $CeBr_3$ scintillator, a detector foreseen for the tangential gamma-ray spectrometer at JET. Due to the high detection efficiency and high activity of the source, pile-ups are observed in addition to FEP at 0.662 MeV. The most pronounced peaks are located at an energy of ~1.324 MeV = 2 × FEP (1st pile-up) and ~1.986 MeV = 3 × FEP (2nd pile-up) for ^{137}Cs. Spectra at both count rates were collected for the same number of counts in a whole registered spectrum. A dedicated pulse pile-up correction algorithm is under preparation to recover an energy of each individual pulse present in a pile-up tail.

From preliminary analysis, we obtained that the gain change for FEP is below 0.5% and the energy resolution worsens by about 1%. The obtained results ensure that the new active voltage divider is suitable for use at the upgraded gamma-ray spectrometer.

6. Summary and outlook

The study has shown that $CeBr_3$ and $LaBr_3$:Ce scintillators are suitable for gamma-ray diagnostics proposed for the next DT campaign at JET when high count rates are expected for both gamma-ray detection systems, the gamma-ray camera and the gamma-ray spectrometer. These crystals are characterized by a short decay time of ~20 ns and an energy resolution of about 3% at the gamma-ray energy of 1.1 MeV. The detection efficiency for the 1″ × 1″ scintillator is about 7% and for the 3″ × 3″ scintillator is about 28% at 1.1 MeV. $CeBr_3$ crystals better fulfill low noise measurement conditions due to a smaller intrinsic activity.

It was shown that an MPPC is a good solution for small size detectors installed at the JET gamma-ray camera.

Detectors based on MPPC and $CeBr_3$ scintillators were already tested at the JET gamma-ray camera in Summer 2015 and the obtained results will be used to design a final detector setup for the forthcoming JET DT campaign.

The new 3″ × 3″ $CeBr_3$ scintillator based detector, consisting of a PMT and fully active voltage divider, was checked in laboratory conditions for use in the tangential gamma-ray spectrometer. Results of measurements ensure that such a detector is suitable for the forthcoming DT campaign at JET.

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