Narodowe Centrum Badań Jądrowych
National Centre for Nuclear Research
Świerk

SCINTILLATORS FOR HIGH TEMPERATURE PLASMA DIAGNOSTICS

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Abstract

Gamma-ray measurements in fusion devices require detectors characterized by a good energy resolution, a relatively high detection efficiency for few MeV gamma-rays and a fast response time. Scintillators proposed for monitoring such gamma-rays observed in high temperature plasma fulfill most of requirements. In addition, they are rather resistant to neutron damage in comparison to, e.g. germanium detectors. Intense fast neutron yield expected during DT campaigns restricts considered materials to oxygen-free scintillators.

$CeBr_3$ scintillators were investigated with the aim to use them for gamma-ray diagnostics of high temperature fusion plasma. Basic scintillation properties like energy resolution and full energy peak detection efficiency were measured using spectrometry photomultipliers for light readout. The response of $CeBr_3$ scintillators was studied as a function of crystal volume between 0.5 cc and 350 cc. A comparison with well-known and used as reference halide scintillators is presented.

Measurements were performed at NCBJ using gamma-ray sources with energies up to few MeV, in particular PuBe and PuC. Analysis of background spectra, registered without an external radiation source, allowed one to evaluate an internal activity of the tested scintillators.

Experimental details

Tested scintillators were coupled to spectroscopy photomultiplier tubes (PMT) selected for optimal light collection, according to the size of invesigated samples.

The list of tested scintillators included:

- $CeBr_3$ (cuboid 10 x 10 x 5 mm^3)
- $CeBr_3$ (cylinder 1" diameter x 1" height)
- $CeBr_3$ (cylinder 3" diameter x 3" height), see Fig. 1
- $LaBr_3$ (cylinder 1" diameter x 1" height)
- $LaBr_3$ (cylinder 3" diameter x 3" height)
- NaI:Tl (cylinder 1" diameter x 1" height)
- CsI:Tl (cylinder 1" diameter x 1" height)

Analogue spectroscopy modules (preamplifier, shaping amplifier and multichannel analyzer) were used to record the spectra for γ-ray sources (^{137}Cs, ^{152}Eu, PuBe, PuC).

Fig. 1
$CeBr_3$ scintillator (3"x3") coupled to R6233 PMT.

$CeBr_3$ detection efficiency vs. size of the scintillator

- Full energy peak (FEP) detection efficiency was measured for three $CeBr_3$ samples in energy range between 122 keV and 6.13 MeV (see Fig. 2).
- The results for 4.44 MeV and 6.13 MeV γ-rays are not available for the smallest sample as interaction probability is too low to produce a FEP in this scintillator within acceptable acquisition time.

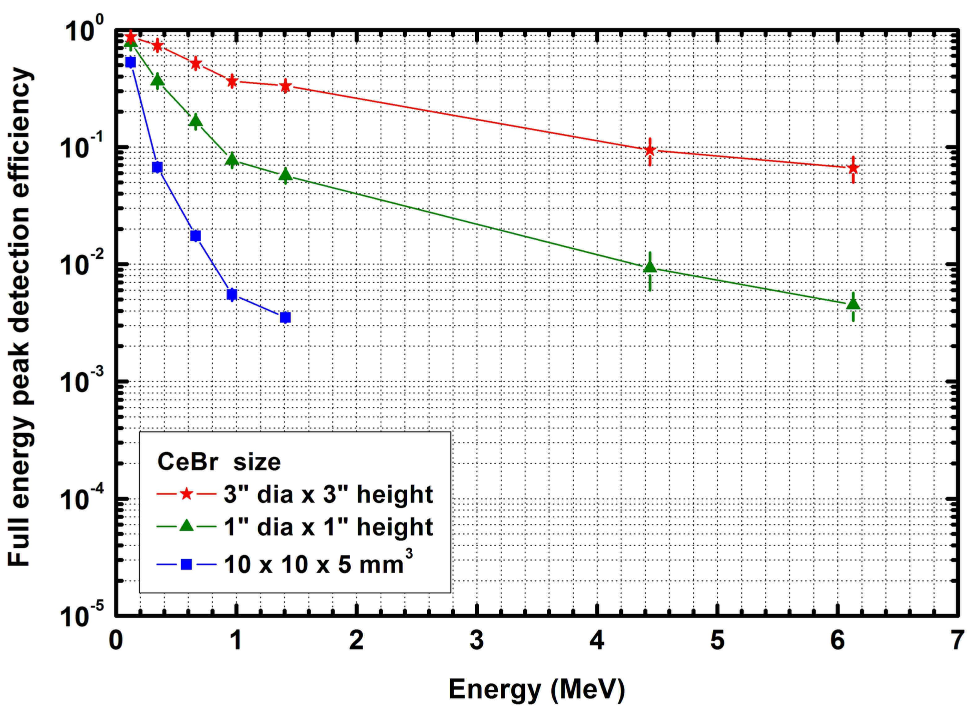

Fig. 2
FEP detection efficiency of $CeBr_3$ crystals of different size.

- Energy spectra recorded by 1"x1" and 3"x3" $CeBr_3$ cylindrical scintillators irradiated with PuBe source are presented in Fig. 3.
- High energy γ-rays are detected via e^+e^- pair production in the crystals.
- Beside FEP at 4.44 MeV, single escape peak (SEP) and double escape peak (DEP) are observed at 3.93 MeV and 3.42 MeV, respectively.
- The difference in intensities between FEP, SEP and DEP is caused by different escape probabilities of 511 keV γ-rays produced during absorption of high energy γ-ray.

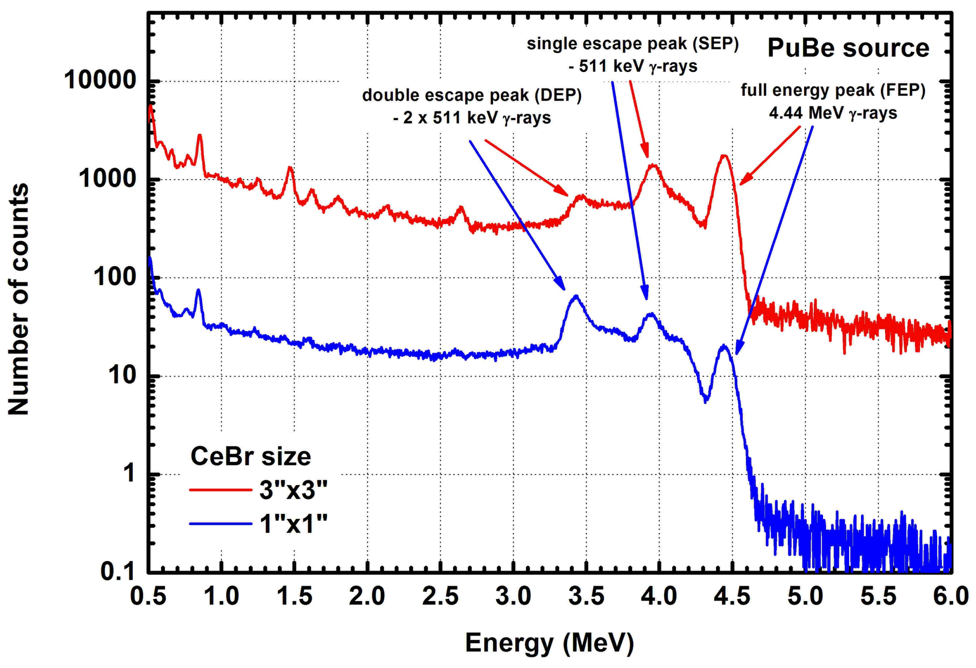

Fig. 3
Response of different size $CeBr_3$ scintillators to PuBe source emitting 4.44 MeV γ-rays.
Single and double 511 keV escape peaks are also observed along with full energy peaks.
Spectra were normalized according to acquisition time and γ-ray flux at the detector surface.

Background and intrinsic activity in $CeBr_3$ and $LaBr_3$

- Both $CeBr_3$ and $LaBr_3$ are contaminated with α-radioactive isotopes from actinides that manifest their presence in energy spectrum between 1.5 MeV and 2.5 MeV.
- $LaBr_3$ is contaminated also with naturally occurring ^{138}La that decays by EC or β^-, giving rise to a peak at about 1470 keV (1436 keV γ-ray + X-ray cascade) and a continuum above 789 keV (789 keV γ-ray + e^-).

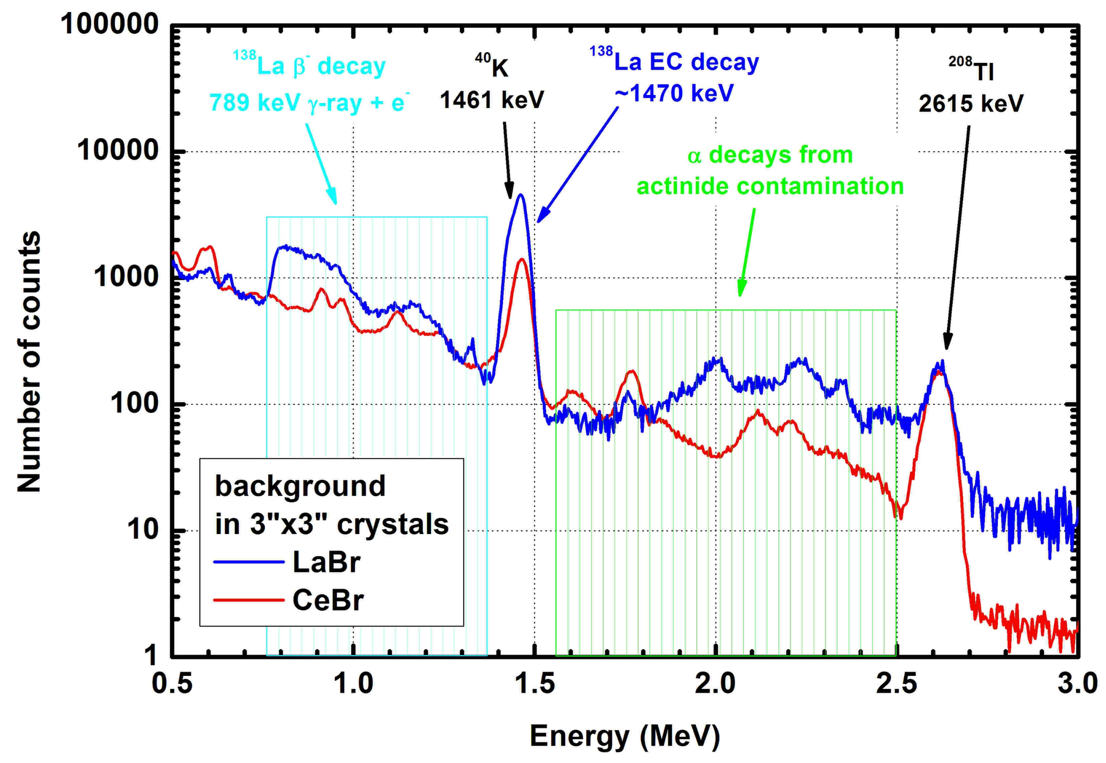

Fig. 4
Response of different size $CeBr_3$ scintillators to background.

Comparison of $CeBr_3$ and $LaBr_3$ with alkali halide scintillators

- FEP detection efficiency is presented in Fig. 5 for $CeBr_3$, $LaBr_3$, CsI:Tl and NaI:Tl samples in energy range between 122 keV and 6.13 MeV. Due to close atomic number and density $CeBr_3$, $LaBr_3$ and CsI:Tl show very similar values of detection efficiency.
- NaI:Tl is a factor of 2-3 less efficient for gamma ray detection at high energy range.
- Energy resolution was measured for all tested samples in energy range between 122 keV and 6.13 MeV (see Fig. 6). $LaBr_3$ shows superior energy resolution, however at high energies the difference is not large.
- The energy resolution measured at 4.44 MeV does not follow the trend for all scintillators due to Doppler broadening of γ-rays emitted from PuBe source.

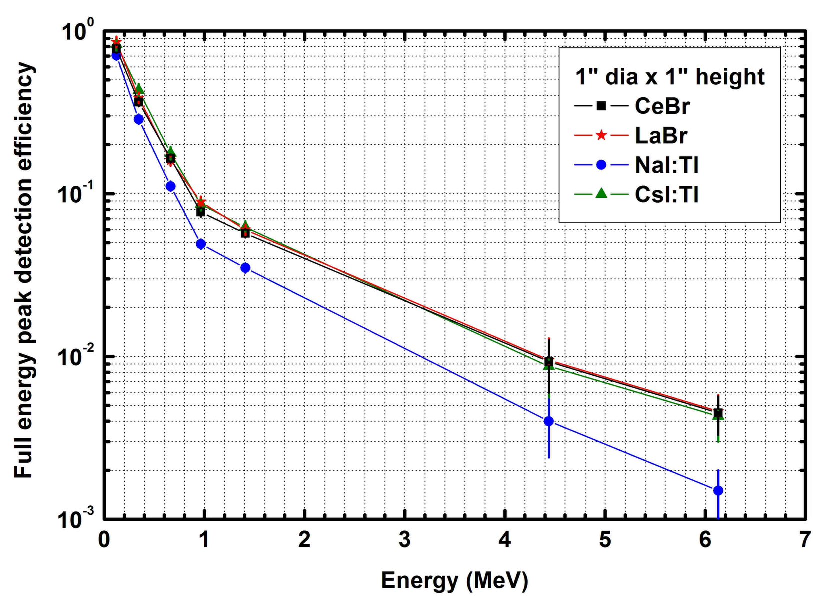

Fig. 5
FEP detection efficiency measured between 122 keV and 6.1 MeV for 1" diameter and 1" height cylindrical shape $CeBr_3$, $LaBr_3$, NaI:Tl and CsI:Tl scintillators.

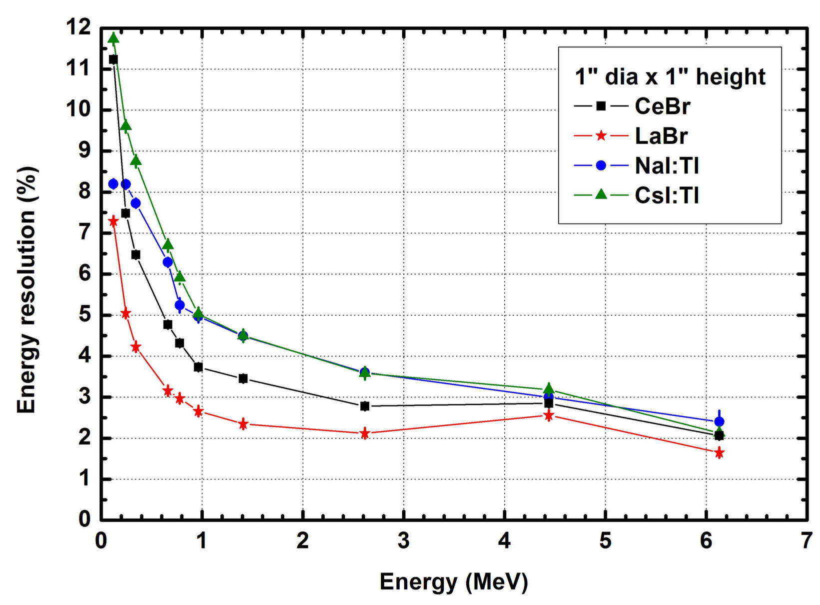

Fig. 6
Energy resolution measured between 122 keV and 6.1 MeV for 1" diameter and 1" height cylindrical shape $CeBr_3$, $LaBr_3$, NaI:Tl and CsI:Tl scintillators.

Conclusions

- High full energy peak detection efficiency of $CeBr_3$ and $LaBr_3$ and good energy resolution makes those scintillators good candidates for detection of high energy γ-rays, especially comparing with the standard low density scintillator like NaI:Tl.
- High detection efficiency combined with fast response (scintillation decay times ~15-25 ns) makes $CeBr_3$ and $LaBr_3$ well suited for measurements where high counting rates are expected. In contrast, CsI:Tl demonstrates much longer decay time (~1 μs) that excludes this material from measurements in intense flux of radiation.
- $CeBr_3$ has advantage over $LaBr_3$ exhibiting substantially lower internal radioactivity below 1.5 MeV due to lack of radioactive ^{138}La.
- Detection of high energy γ-rays is possible with sufficently large samples. For example, 1"x1" $CeBr_3$ scintillator has full energy peak detection efficiency for 4.44 MeV γ-rays at the level of 10^{-2}. However, single and double escape peaks may also be used as fingerprints for detection of high energy γ-rays.

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