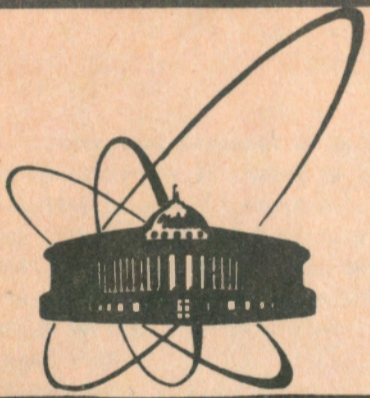

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E13-90-80

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# TEST OF LARGE VOLUME $BaF_2$ SCINTILLATORS

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1990

Increasing interest in $BaF_2$ crystals as scintillators for gamma-ray spectroscopy is caused by their attractive properties /1-3/: short radiation length ($X_0$=2.05 cm), high density ($\varrho$=4.88 g/cm$^3$) as well as high light output and detection efficiency. Because of its fast component ($\lambda$=220 nm, $\tau$=600 ps), the $BaF_2$ crystal offers time resolution several times better than NaI(Tl) at the expense of slightly worse energy resolution. The presence of the fast component allows very good timing characteristics comparable to those obtained with a fast plastic scintillator. A practical advantage of $BaF_2$ is its mechanical and chemical stability. The crystal is nonhygroscopic and resistant to radiation damage. For application in gamma-ray spectroscopy, it is also important that the mean neutron capture cross section of barium for low energy neutrons is more than 10 times lower than that of iodine.

Measurements of the UV light from the $BaF_2$ scintillator must be made with a quartz-window photomultiplier having a photocatode with a good response in the UV region /4/. Recently, the investigations of the barium fluoride crystals working with p-terphenyl wavelength shifter /5,6/ have shown that an efficient shifting of the UV light into the visible region, where conventional photomultipliers work, is possible. It has been also shown /7/ that p-p' diphenylstilbene evaporated on a one side of the $BaF_2$ crystal shifts the wavelength of the fast component to the region of visible light (fast emission wavelength component of $BaF_2$+diphenylstilbene was shown to be about 410 nm). Both the energy and time resolution were found to be only slightly poorer than those of the pure $BaF_2$ scintillator.

During the last few years the progress in growing large $BaF_2$ crystals has been made. It makes possible to use scintillators of this type in $4\pi$ "crystal ball" detection systems /3,8/ and to build the electromagnetic calorimeters with layers of the $BaF_2$ crystals coupled to multiwire proportional chambers /9/, as well. The performance of thick $BaF_2$ scintillators as detectors for gamma-rays and light charged particles have also been tested /10/: it has been shown that signals due to gamma-rays and different light particles with $BaF_2$ crystals of large volume can be electronically discriminated. It has been also reported on the first experience with large volume $BaF_2$ applications to in-beam gamma-ray spectroscopy /11/. Recently, we have reported on the application of the large volume $BaF_2$ scintillators to off-line gamma-ray spectroscopy. Using the scintillator of this type and conventional

electronics, we have measured the cross sections of the monitoring reactions $^{27}Al(particle,X)^{24}Na$ and $^{12}C(particle,X)^{11}C$ at relativistic energies via the induced $^{24}Na$ /12/ and $^{11}C$ /13/ activity in the irradiated aluminium and graphite targets, respectively.

Regarding the application of $BaF_2$ scintillators in the future experiments on high-energy physics at the Laboratory of High Energies, scintillation characteristics of JINR (produced in the U.S.S.R. and Czechoslovakia) large volume $BaF_2$ crystals have been carefully measured. A part of these measurements have been performed at the Delft University of Technology, the Netherlands.

First, the influence of $Pb^{2+}$ contamination has been studied. The $BaF_2$ crystals, with different dimensions, have been tested for their optical transformation between 180 and 400 nm. Samples were irradiated by X-rays from a 35 kV X-ray generator to measure their emission spectra. A dip in the emission spectrum situated at 250 nm (between the emission maxima at 195 and 220 nm) and an extra emission band centered at 260 nm is an indication of the presence of $Pb^{2+}$ ions in the crystal /14/. If this effect is large, it can affect the fast scintillation output of a crystal. In some crystals we found small concentrations of $Pb^{2+}$, being, however, of only a few ppm. As an example of $Pb^{2+}$ contamination in crystal of 18.5x3x3 $cm^3$, Fig.1 illustrates a typical scintillation emission spectrum containing $Pb^{2+}$ transition peak $^3P_1-^1S_0$.

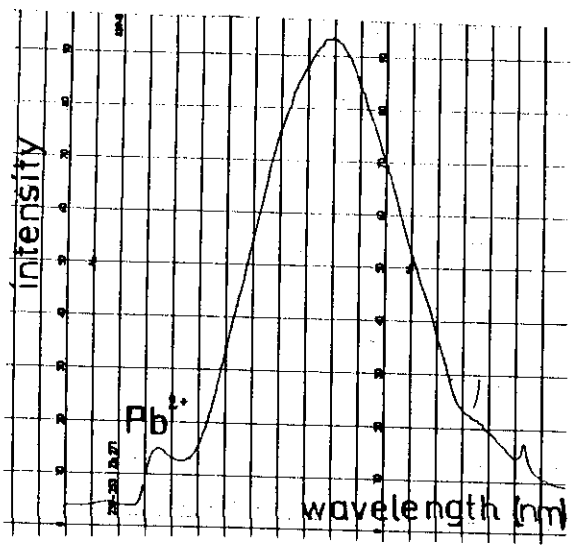


Fig.1. Scintillation emission spectrum of $BaF_2$ sample 18.5x3x3 $cm^3$ contamined with $Pb^{2+}$ ions.

Next, scintillation crystals were mounted on the window of a XP 2020 Q photomultiplier using optical coupling compound (Bayer Silicon Compound M 1.000.000). The sides of the crystals were wrapped with reflective teflon tape (0.1 mm thick). The photomultiplier was operated at -2 kV. The signal of the PMT was fed into a preamplifier (TU Delft) with a switchable signal attenuator of $10.55^{\pm}0.10$ . Subsequently the signal was amplified using a Canberra model 4013 main amplifier with a shaping time of 6 μs. The amplification factor could be changed from 10-32-100-300-1000-3000 (calibrated). "Oscilloscope image" of the signals (fast and slow, respectively) from 21.5x3x3 $cm^3$ $BaF_2$ crystal when irradiated with a $^{137}Cs$ gamma-ray source (662 keV) is displayed in Fig.2. The pulse height spectrum for 662 keV gamma-rays is given in Fig.3. The $^{137}Cs$ source (AMERSHAM,UK,set No 2071) was positioned 4 cm above the axis of the crystal. The resolution is 12.7%.

By measuring the signal photoelectron spectrum (photoelectrons thermally emitted by the cathode of the PMT) using a high amplification factor of the main amplifier (3000) without the attenuator, the photoelectron yield for a certain scintillator was determined /15/.

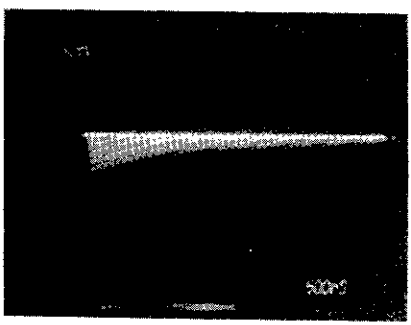

Fig.2a "Slow" signal from the 21.5x3x3 $cm^3$ $BaF_2$ crystal irradiated with 662 keV $^{137}Cs$ gamma-ray source.

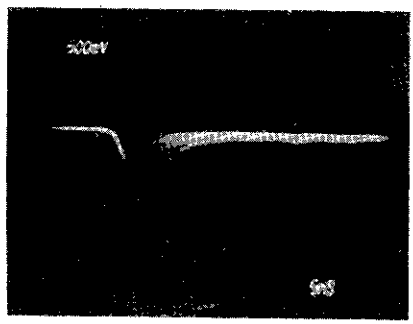

Fig.2b "Fast" signal from the same crystal.

The single photoelectron spectrum is presented in Fig.4. As a reference crystal we considered a Harshaw $BaF_2$ scintillation crystal with a diameter of 30 mm and a thickness of 8 mm. The total number of photoelectrons per MeV (fast+slow) was 2160, which is in good agreement with literature. The total number of phe/MeV for a large scintillation crystal (21.5x3x3 $cm^3$) was found to be 850, which compared to the 8 mm thick reference crystal is equivalent to a decrease in the total light

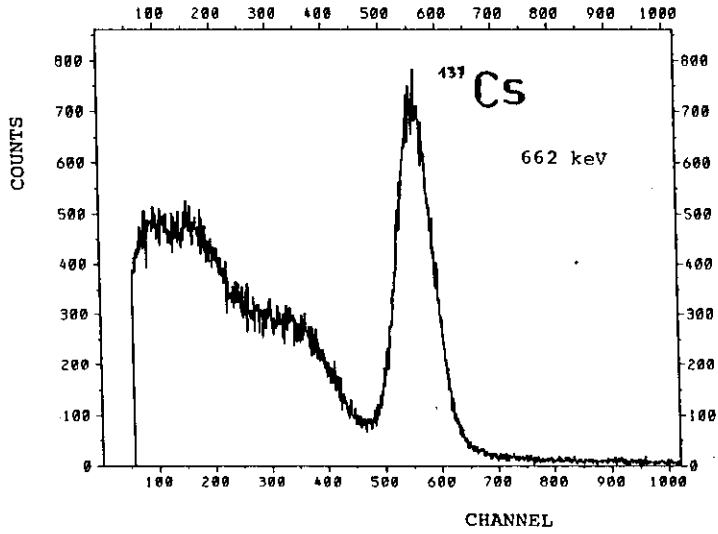


Fig.3. Pulse-height spectrum of the 21.5x3x3 $cm^3$ $BaF_2$ crystal irradiated with 662 keV $^{137}Cs$ gamma-ray source.

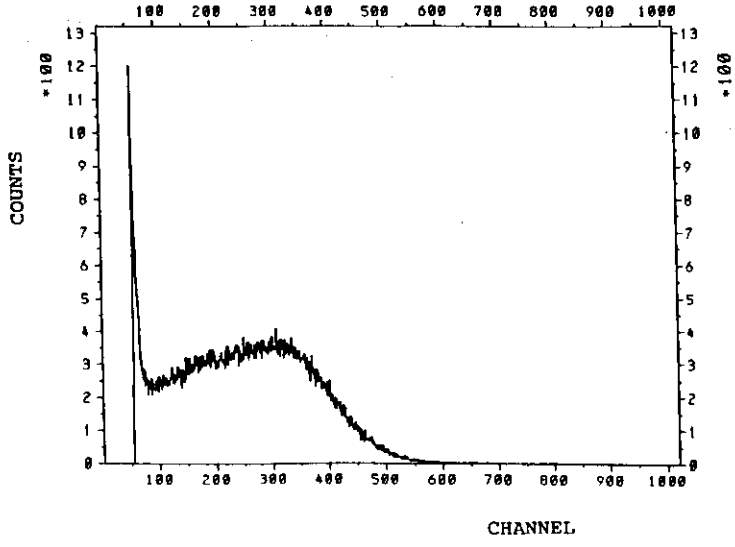


Fig.4. Single photoelectron spectrum.

Table 1 Energy resolution for a 21.5x3x3 $cm^3$ $BaF_2$ scintillator

| Gamma-ray source | Energy /keV/ | Energy resolution /%/ |
|---|---|---|
| $^{137}Cs$ | 662 | 12.9 |
| $^{88}Y$ | 898 | 11.1 |
| $^{60}Co$ | 1173 | 9.7 |
| $^{60}Co$ | 1334 | 9.2 |
| $^{88}Y$ | 1836 | 8.0 |
| $^{228}Th$ | 2614 | 6.5 |
| $^{241}Am+Be$ | 4440 | 5.5 |

Table 2 Energy resolution for a 9.6x2.8x2.8 $cm^3$ $BaF_2$ crystal measured at crystal temperatures for 243 and 293 K

| Energy /keV/ | Temperature /K/ | Energy resolution /%/ |
|---|---|---|
| 662 | 293 | 13.5 |
| 662 | 243 | 11.0 |
| 4440 | 293 | 6.5 |
| 4440 | 243 | 4.0 |

Table 3 Absorption coefficients of $BaF_2$ crystals

| Wavelength $\lambda$ /nm/ | Absorption coefficient $K_\lambda$ /$cm^{-1}$/ | Reflection correction $d_\lambda$ |
|---|---|---|
| 220 | 0.17 | 0.040 |
| 300 | 0.05 | 0.035 |
| 400 | 0.04 | 0.034 |
| 700 | 0.02 | 0.032 |

Table 4 Refraction index of $BaF_2$ crystals

| Wavelength $\lambda$ /nm/ | Refraction index $n_\lambda$ |
|---|---|
| 265.2 | 1.51217 |
| 325.64 | 1.49521 |

output of a factor 2.54 . It must be realized that 98% of 662 keV gamma-rays is absorbed in 10 cm $BaF_2$ material /16/. Assuming that the intensity of the signal on the fast oscilloscope is representative for the fast scintillation intensity, we can estimate the fast scintillation intensity of the 21.5 cm thick $BaF_2$ crystal as 90 phe/MeV gamma-rays. This yield holds only for gamma-rays entering the crystal through the long axis of the crystal: due to the larger penetration of higher energy gamma-rays, the yield will probably increase with increasing gamma-ray energy.

The tests performed at the JINR have been made with FEU-140 photomultiplier tube using the same optical coupling compared as given above. The FEU-140 PMT was operated at -1.95 kV.

The energy resolution has been determined in the energy range between 662 keV and 4.44 MeV. The results for the 21.5x3x3 $cm^3$ $BaF_2$ sample are compiled in Table 1. It has been also verified that the energy resolution of $BaF_2$ scintillation detectors can be improved by cooling the crystal. The results of temperature dependence for a 9.6x x2.8x2.8 $cm^3$ $BaF_2$ sample are summarized in Table 2. Finally, the measured optical properties of a 12x3x3 $cm^3$ $BaF_2$ sample are displayed in Tables 3 and 4, respectively. It has been also verified that the radiation stability of crystals under study is very good ($10^9$ rad). Results of this investigation as well as measurements of the efficiencies for gamma-rays and various particles will be published elsewhere.

Concluding, we can say that large volume $BaF_2$ crystals from JINR are of good quality. It should be noted that the energy resolution can be improved by using a selected photomultiplier with a higher quantum efficiency than XP 2020 Q or FEU-140. Tested $BaF_2$ scintillators have been found to be very perspective tools for high-energy physics experiments planned in the near future at JINR, particularly with those connected with $\Delta E$-E particle identification, $4\pi$ crystal ball and calorimeter techniques, as well.

The authors would like to thank Academician A.M.Baldin and Professor C.W.E.van Eijk for their support. We would also like to thank Dr.G.Stam of Engelhard Corp. for helpful discussions. One of the authors (P.K.) thanks for kindness hospitality at the Delft University of Technology.

References

1. M.Leval et al., Nucl.Instr. and Meth., 1983, vol. 206, p.169.
2. K.Wisshak, F.Kappeler, H.Müller, Nucl.Instr. and Meth., 1986, vol.A 251, p.101.

3. L.Woody, C.I.Petridon, G.C.Smith, IEEE Trans.Nucl.Sci. NS-33, 1986, p.136; and references cited therein.
4. H.Kobayashi et al., Nucl.Instr. and Meth., 1988, vol.A 270, p.106.
5. E.Dafny, Nucl.Instr. and Meth., 1987, vol.A 254, p.54.
6. W.Klamre et al., Nucl.Instr. and Meth., 1988, vol.A 265, p.485.
7. V.Yanovsky, P.Kozma, Nucl.Instr. and Meth., 1989, vol.A 275, p.659; P.Kozma, V.Yanovsky, Nucl.Instr. and Meth., 1989, vol.A 281, p.346;
8. F.A.Beck, in Instrumentation for Heavy Ion Nuclear Research, Nucl. Sci.Research Conference Series, vol.7, Harwood Academic Publishers, New York, 1985.
9. R.Boudier et al., Nucl.Instr. and Meth., 1988, vol.A 267, p.69.
10. C.Agodi et al., Nucl.Instr. and Meth., 1988, vol. A 269, p.595.
11. W.Karle, M.Knopp, K.H.Speidel, Nucl.Instr. and Meth., 1988, vol. A 271, p.507.
12. P.Kozma, V.Yanovsky, Czech.J.Phys. B 40, in print;
13. P.Kozma, K.D.Tolstov, V.Yanovsky, Nucl.Instr. and Meth., in print; and JINR Report E1-89-745, Dubna, 1989.
14. P.Schotanus, C.W.E.van Eijk, R.V.Hollander, Nucl.Instr. and Meth., 1988, vol. A 272, p.917.
15. P.Schotanus, PhD thesis, Delft University of Technology, Delft, 1988.
16. R.V.Hollander, V.Bom, Delft University of Technology Report TU 83-1, Delft, 1983.

Received by Publishing Department
on February 7, 1990.