Fermi National Accelerator Laboratory

FERMILAB-Pub-85/67
2500.000

RADIATION DAMAGE TEST OF BARIUM FLUORIDE SCINTILLATOR*

Stan Majewski and David Anderson

May 1985

*Submitted to Nucl. Instrum. and Methods in Phys. Res. A

RADIATION DAMAGE TEST OF BARIUM FLUORIDE SCINTILLATOR

Stan Majewski

David Anderson

Particle Detector Group
Fermi National Accelerator Laboratory
Batavia, Illinois 60510

May, 1985

Abstract

Small samples of BaF_2 scintillator have been irradiated in a high-energy proton beam with doses of up to 1.3×10^7 rads. To the precision of our measurement there was no effect in the scintillation output and only a slight decrease in transmission was observed.

1) INTRODUCTION

There is a growing interest in radiation hardness of materials to be used as sensitive detecting media in presently constructed detectors, and for future machines such as LEP, SLC, HERA, SSC, etc. Recently, results of new studies on radiation damage of materials such as scintillating glass (1), silicon microstrip detectors(2), and bismuth germanate (BGO) (3-7), have appeared. Such studies are in progress on radiation resistant cerium oxide (Ce_2O_3) scintillating fibers (8) as well. There is also a continous, though uncorrelated, activity in understanding and solving radiation induced ageing effects in gaseous detectors.

Our interest in BaF_2 is due to its unique properties which have been studied over the last few years (9-11). It has two emission spectra. The slow component has a decay constant of 620ns and peaks at 310nm. The fast scintillation component has a decay constant of only 0.6 ns, peaking at 220 nm, which can be detected with a photosensitive wire chamber (12-16). Recently, there has been a successful operation of a test BaF_2 electromagnetic calorimeter (16) and a tentative proposal as a forward calorimeter for the SSC (17).

2) EVALUATION OF THE BaF_2 SAMPLES

Three disc-shaped BaF_2 crystals produced by Harshaw (17) were irradiated with 800 GeV/c protons in the Neutrino East beam line at Fermilab during June, 1984. Crystals numbers 1 and 2 were 38 mm in diameter and 4 mm thick. They accumulated radiation doses of 2.4×10^6 and 5.6×10^3 Rads, respectively. The third crystal, 22 mm in diameter and 6 mm thick, absorbed a local dose of 1.3×10^7 Rads.This was achieved by passing 1.7×10^{14} protons through a 4 mm x 6 mm spot. The total integrated beam intensity, and the position of the irradiated spot on the crystals, were monitored by means of induced radioactivity in copper activation foils, and by beam monitors. In the case of the third crystal, the beam-spot was of a slightly elongated shape, and off center by about 6 mm.

Because no traces of any color centers were seen in the crystal itself, and because of the primary importance of the localization of the irradiated region in the crystal, a scan of the induced radioactivity in the crystal was performed. The crystal was coupled to an RCA C31000M 2-inch photomultiplier. The coincidence rate between this scintillator and a second BaF_2 scintillator, coupled to an 1/2-inch Hamamatsu R2076 photomultiplier, was measured in the geometry of Fig. 1. By scanning the irradiated crystal through the 2.5 mm diameter collimator hole, the induced radioactivity could be monitored as a function of position. Figure 2 shows the result of the radioactivity scan along the axis marked with a line in the Fig.

1. This measurement confirmed the accuracy in the beam-spot localization by activation foils.

From a gamma spectrometry analysis using a Ge(Li) detector, it was found that after 4 weeks most of the radioactivity was due to Cs-136 and Ba-131 isotopes, at about 200 nanocuries each (19). Six months later, the main residual activity was due to Cs-134 (~5 nCi).

Two of the three irradiated crystals, numbers 2 and 3, were checked for radiation effects. The response of each crystal to the excitation by a collimated beam of 511 keV annihilation gamma rays (from Na-22 source) was studied. The same coincidence geometry of Fig. 1 was used. The fast component and total light output from the crystal were measured simultaneously. After splitting the photomultiplier signal in a linear fanout, two integrating CAMAC ADC's were used: a LeCroy 2249A and a LeCroy 2249W were used for the fast and total light output, respectively. The time gates to these ADC's were applied using the output of the second scintillator in coincidence with the irradiated crystal. In this way a cut against background (mainly due to the induced radioactivity in the crystal) was obtained. The gates were of 40 ns and 2.5 μs width, respectively, with the start of the short gate advanced by 30 ns so that only the fast component was included.

In order to facilitate a precise measurement of the changes in the output of the fast component, the 511 keV photopeak events of the pulse-height spectrum were selected. This was achieved by accepting only the fast component signals that correspond to the photopeak events from the total light output. The result of this procedure is shown in Fig. 3. The measured pulse-height spectra of the total light output and of just the fast component are presented in figures 3A and 3C, respectively. Figure 3D shows the spectrum of fast component events which correspond to events in the 511 keV photopeak in the total light spectrum (Fig. 3B). There was only a small effect found on the width of the fast component photopeak spectrum when changing the width of the energy window on the total light output.

The light output was optimized by taping the crystals with teflon tape and then by using an optical coupling fluid (General Electric Viscosil 600,000 silicon fluid). Teflon tape alone increased the amount of collected light for the fast (total) component by a factor of 2.4 (1.9). The final improvement factor was 4.0 (3.2) with the addition of optical coupling, as compared to the "bare" crystal situation.

After this optimization, the mean number of photoelectrons in the fast component was measured to be about 75 in the 511 keV photopeak. This result is in agreement with the estimate of 80 photoelectrons obtained by Wong, et al (10), and is consistent with

the energy resolution of 24-25 % FWHM measured by us (Fig. 3D). Laval, et al (9) obtained about 200 electrons/511 keV in the fast component, but they used precisely polished crystals of high purity, coated with Al_2O_3 reflecting powder. On the other hand, we found that the photoelectron yield of the fast component is equal to about 20% of the total light yield in agreement with Laval, et al, while Wong, et al measured a value of about 10%. One should point out here that it is not only the quantum efficiency of the photomultiplier used that is important, but also a collection efficiency of the fast photoelectrons originated from UV photons, that plays an important role. Moszynski, et al (11) have found strong differences, of up to a factor of 3, in the collection efficiency of fast photoelectrons for two types of photomultipliers. (High collection efficiency was obtained with the Phillips XP2020Q photomultiplier).

The crucial check performed on the crystal number 3 (with the highest dose), was to compare the response to the 511 keV gammas from irradiated and non-irradiated parts of the crystal. The first position was in the middle of the irradiated spot (ie 6.3 mm off the center) and the second, symmetrically on the other side of the crystal (Fig. 1). To correct for asymmetry effects in the photomultiplier response (of the order of 2-5%) measurements were repeated with the crystal rotated by 180 degrees. The first measurements were made 7-8 weeks after the irradiation with no evidence of radiation damage found in either the fast or slow components of the light output. This is with a 1% measurement

precision.

Measurements on radiation hardness of BaF_2 used as UV transmitting windows were done some time ago (20). After irradiation with 1 and 2 MeV electrons to doses of up to $2x10^3$ Rads, only a very small change in transmission properties of BaF_2 windows were observed. It should be pointed out here that in the case of scintillators radiation effects are first seen in the transmission properties of the material and not in the scintillation process itself. For example, in the above mentioned cases of BGO (3) and Ce_2O_3 glass (8), a shift in the short wavelength transmission edge towards longer wavelengths was mainly observed. An apparent decrease in the scintillation yield results, due to increased self-absorption of the scintillation light.

Recently we have obtained a spectrophotometer and have thus been able to do transmission tests of the BaF_2 samples. Results obtained six months after the irradiation, are shown in Fig. 4. Transmission curves were measured in the irradiated spot of crystal 3 and in the symmetrically placed nonirradiated region. The monochromator beam was collimated to 2.8 mm in diameter. We observed a small difference in transmission, of about 0.5%, in the region from 240 nm and up. This could be attributed to systematic measurement errors, though it is consistent with the results of the above mentioned study(20).

3) SUMMARY

From our "one experimental point" measurement it appears that BaF_2 is the most radiation hard scintillator in the literature. But as in the case of BGO crystals, studies performed with the large-size long crystals (5-7) have found that they are much more sensitive to accumulated radiation doses than previously expected from measurements done with small samples (3). Thus the results presented here, obtained with small crystals of BaF_2, should be considered only as a serious indication of the radiation hardness of this material. Also our measurements were made some time after irradiation and thus we were insensitive to damage with a short recovery time.

To further study radiation hardness of BaF_2 we are presently preparing a series of tests in collaboration with Idaho National Engineering Laboratory. The samples of BaF_2 crystals of different sizes will be irradiated in gamma and neutron beams.

ACKNOWLEDGEMENTS

We would like to thank Brian Kross of our group for his skillfull technical help in the preparation of the measurements and Rich Allen from Radiation Physics Section for the measurements of the induced radioactivity in the irradiated samples. We also thank Gordon Koizumi of the Beams Group for providing us with the necessary beam information.

REFERENCES

1. D.E. Wagoner et al, IEEE Trans.Nucl.Sci.NS-31(1984)53.

2. T.Kondo,M.Nakamura,K.Niwa and Y. Tomita, Radiation damage test of silicon microstrip detectors, Contributed Paper to the 1984 Summer Study on the Design and Utilization of the Superconducting Super Collider, Snowmass,Colorado,June 23-July 12,1984.

3. M.Kobayashi et al , Nucl.Instrum. Methods 206(1983)107.

4. S.L.Wen and C.F.He, Nucl.Instrum.Methods in Phys.Research 219(1984)333.

5. G.J.Bobbink, A.Engler, R.W.Kraemer, J.Nash and R.B.Sutton, Nucl.Instrum.Methods in Phys.Research 227(1984)470.

6. Ch.Bieler, D.Burkart, J.Marks, M.Riebesell, H.Spitzer, K.Wittenburg and G.G.Winter, Nucl. Instrum. Methods in Phys. Research A234 (1985)435.

7. G.J.Bobbink,A.Engler,R.W.Kraemer,J.Nash,R.B.Sutton,R.A.Gearhart, F.L.Linde and J.C.Sens, Performance of BGO in a high radiation enviroment, Invited Paper presented at the 3rd Int.Conf. on Instrumentation for Colliding Beam Physics,Novosibirsk,USSR, March 15-21,1984, preprint SLAC-PUB-3339,May 1984.

8. R.Ruchti et al ,IEEE Trans.Nucl.Sci. NS-32(1985)590.

9. M.Laval, M.Moszynski, R.Allemand, E.Carmoreche, P.Guinet, R.Odru and J.Vacher, Nuclear Instrum.Methods 206(1983)169.

10. Wai-Hoi Wong,Nizar A.Mullani, Gary Wardworth, Ross K.Hartz, David Bristow, IEEE Trans.Nucl.Sci.NS-31(1984)381.

11. M.Moszynski, R.Allemand, E.Cormoreche, M.Laval, R.Odru and J.Vacher, Nucl.Instrum.Methods in Phys. Research 226(1984)534.

12. D.F.Anderson, IEEE Trans.Nucl.Sci.NS-28(1981)842.

13. D.F.Anderson,Phys.Lett.118B(1982)230.

14. D.F.Anderson, R.Bouclier, G.Charpak and S. Majewski, Nucl. Instrum. Methods 217(1983) 217.

15. D.F.Anderson,G.Charpak,Ch.von Gagern and S.Majewski,Nucl.Instrum. Methods 225(1984)8.

16. D.F.Anderson,G.Charpak,W.Kusmierz,P.Pavlopoulos and M.Suffert, Nucl. Instrum. Methods in Phys. Research 228 (1984)33.

17. D.F.Anderson and S.Majewski, A very high rate calorimeter,in Summary Report of the PSSC Discussion Group Meeting, Fermilab,June 1984.

18. Harshaw/Filtrol Partnership, Solon,Ohio.

19. Checked for us by Rich Allen,Radiation Physics Section,Fermilab.

20. D.F.Heath and P.A.Sacher,Applied Optics 5(1966)937.

FIGURE CAPTIONS

Figure 1. Experimental arrangement to test the irradiated crystals in the gamma-gamma coincidence geometry with a second BaF_2 detector.

Figure 2. Result of the radioactivity scan in the crystal number 3 as measured in the geometry of Fig. 1.

Figure 3. Crystal #3 pulse-height spectra for 511keV photons. The photons were collimated in the center of the irradiated spot:

A) Total light output,

B) Photopeak only;

C) Fast component, and

D) Fast component photopeak only. The energy resolution for the photopeak in the fast component is 25% FWHM.

Figure 4. Transmission curves measured in the center of the irradiated spot and in the nonirradiated region of the crystal #3.

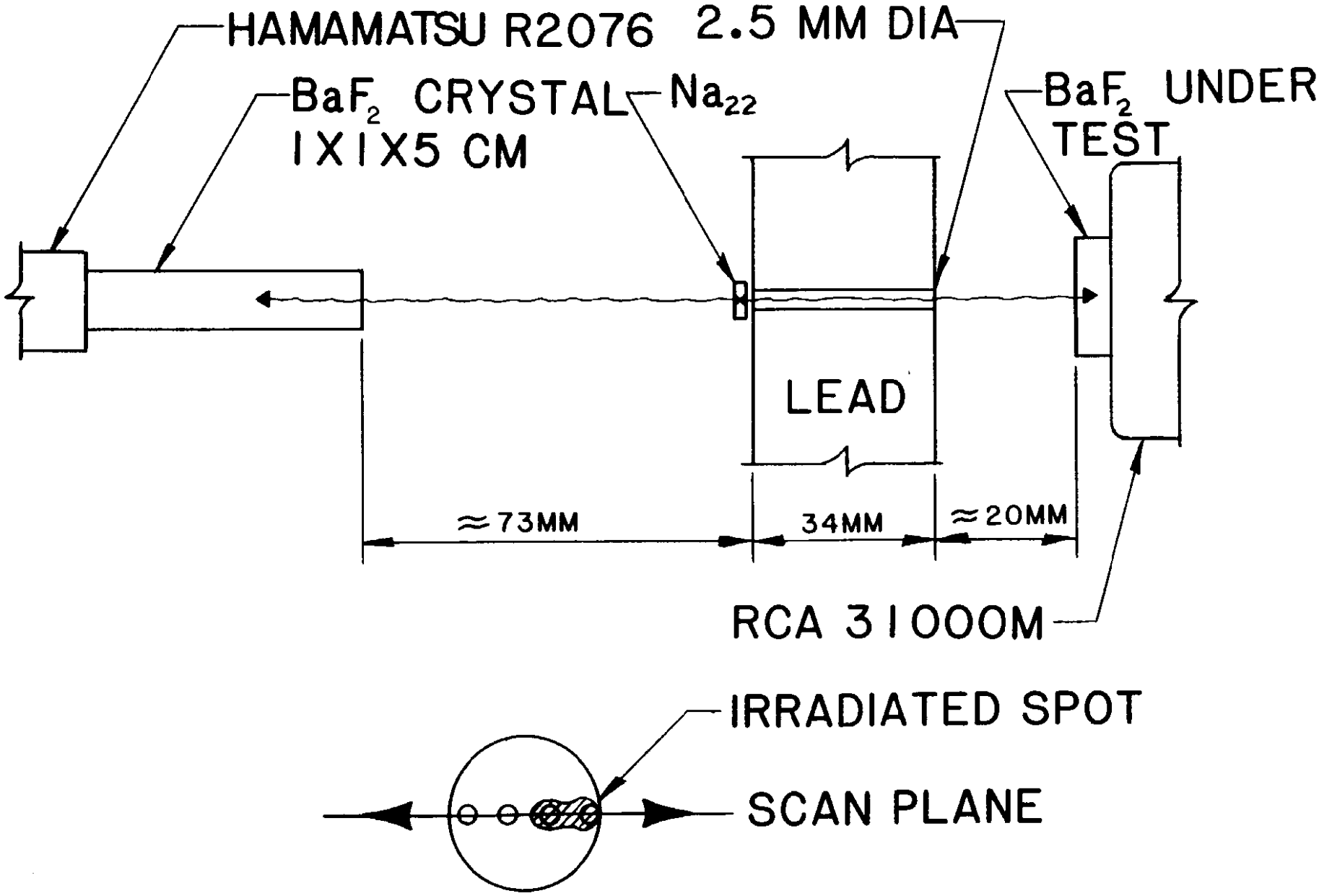
HAMAMATSU R2076
2.5 MM DIA
BaF2 CRYSTAL
1X1X5 CM
Na22
BaF2 UNDER
TEST
LEAD
≈73MM
34MM
≈20MM
RCA 31000M
IRRADIATED SPOT
SCAN PLANE

Figure 1

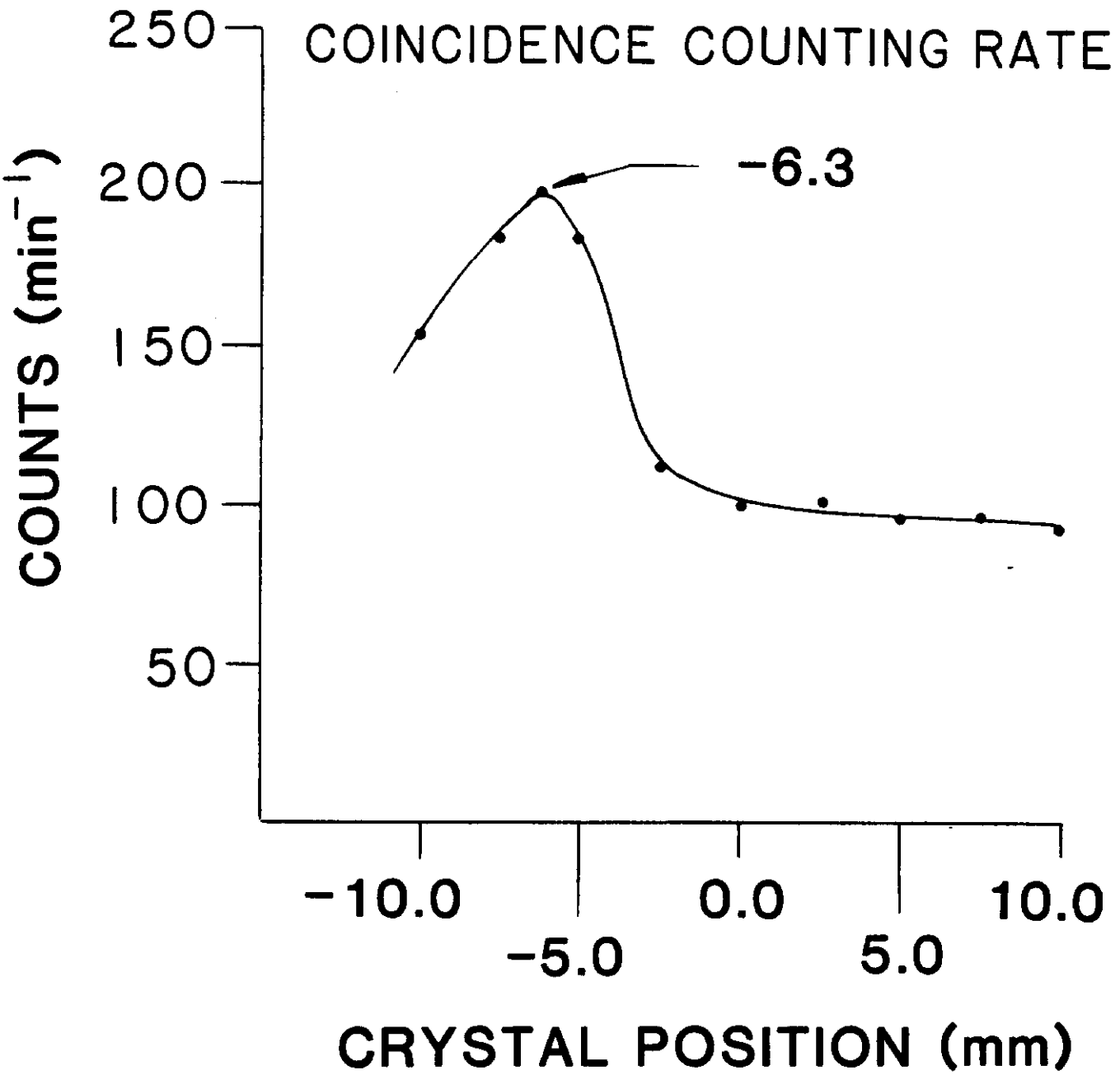
COINCIDENCE COUNTING RATE
-6.3
250
200
150
100
50
COUNTS (min⁻¹)
-10.0
-5.0
0.0
5.0
10.0
CRYSTAL POSITION (mm)

Figure 2

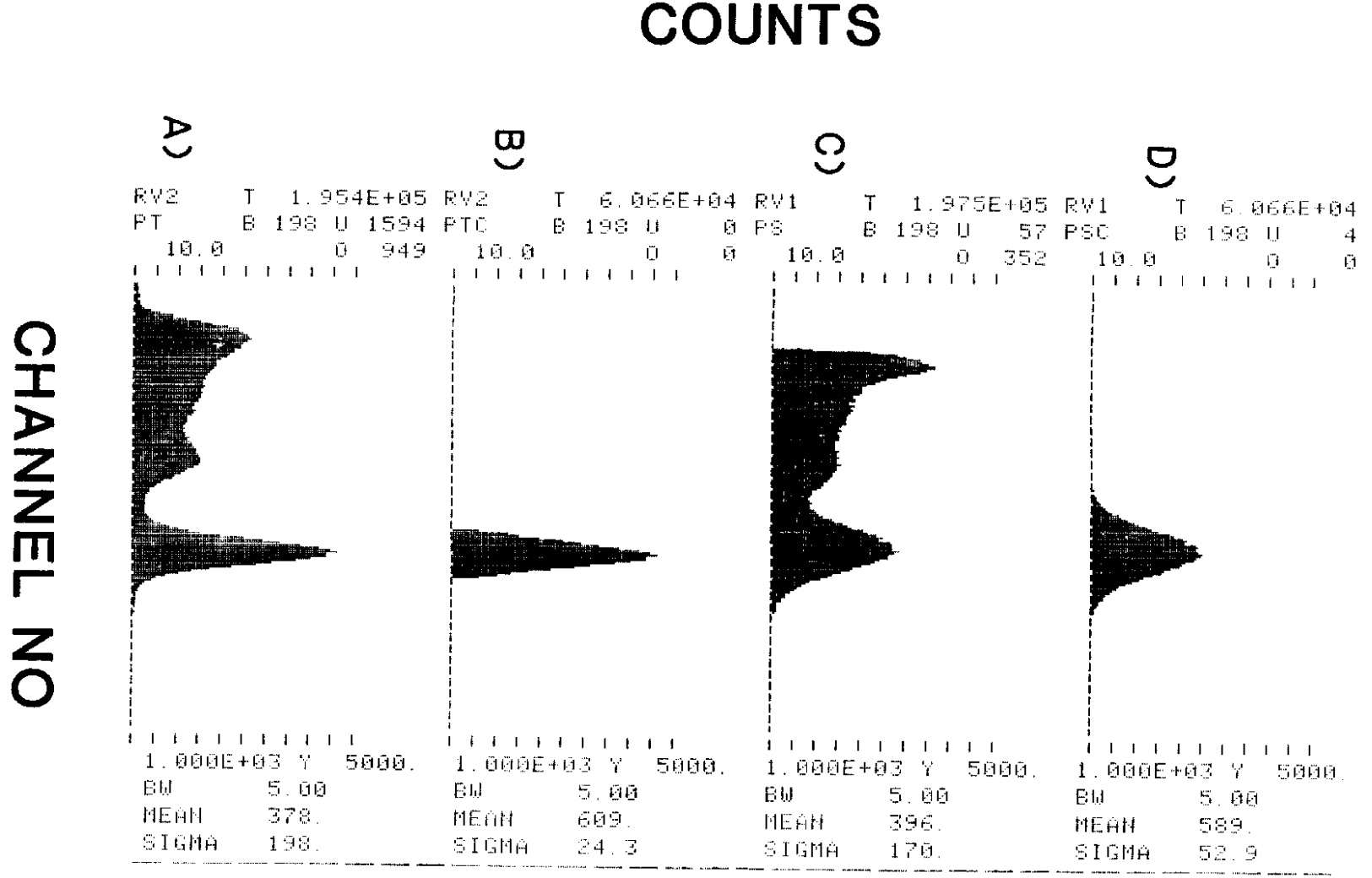
COUNTS
CHANNEL NO
A)
B)
C)
D)
RV2 T 1.954E+05 RV2 T 6.066E+04 RV1 T 1.975E+05 RV1 T 6.066E+04
PT B 198 U 1594 PTC B 198 U 0 PS B 198 U 57 PSC B 198 U 4
10.0 0 949 10.0 0 0 10.0 0 352 10.0 0 0
1.000E+03 Y 5000. 1.000E+03 Y 5000. 1.000E+03 Y 5000. 1.000E+03 Y 5000.
BW 5.00 BW 5.00 BW 5.00 BW 5.00
MEAN 378. MEAN 609. MEAN 396. MEAN 589.
SIGMA 198. SIGMA 24.3 SIGMA 170. SIGMA 52.9

Figure 3

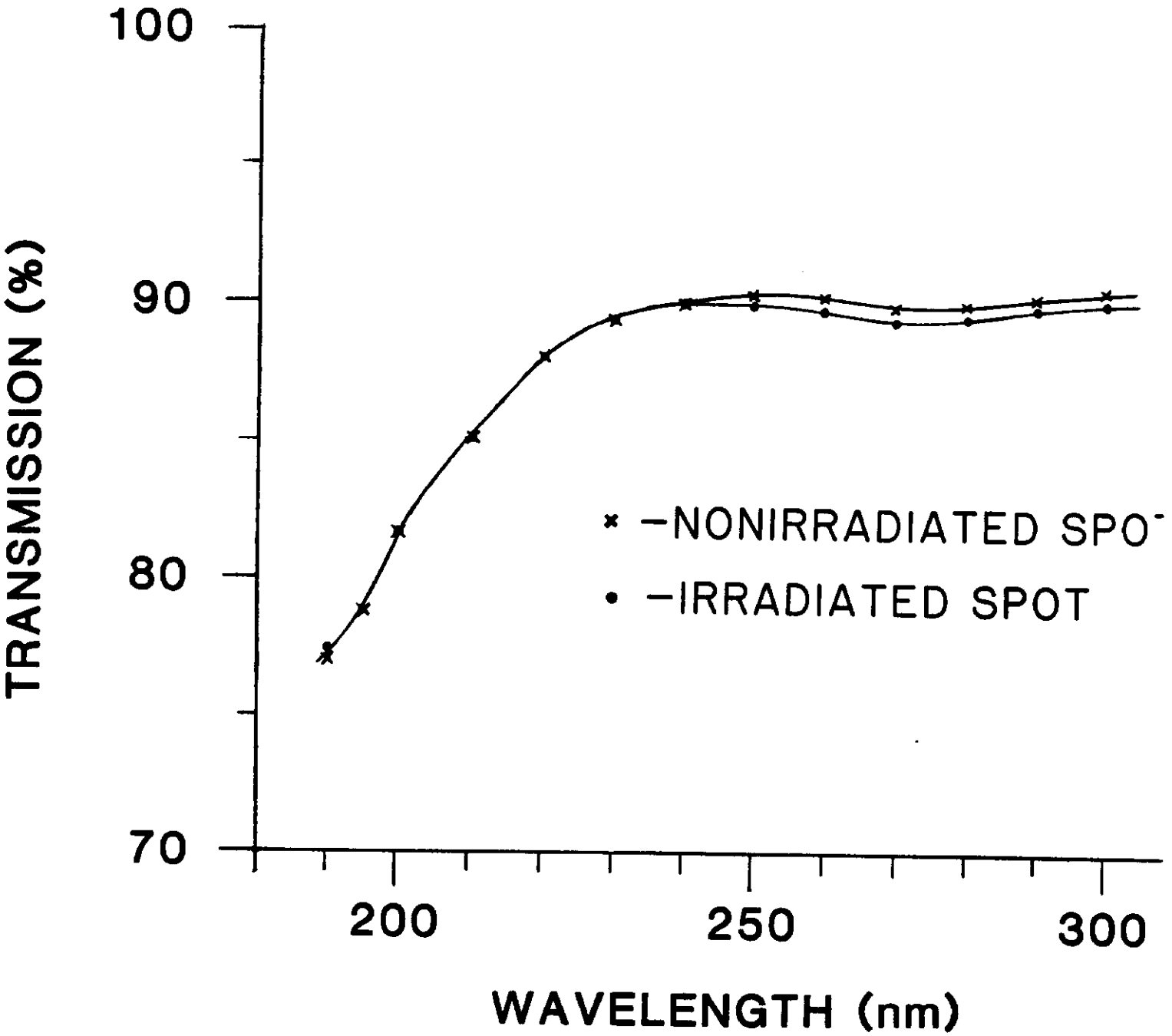
100
90
80
70
TRANSMISSION (%)
200
250
300
WAVELENGTH (nm)
× —NONIRRADIATED SPOT
• —IRRADIATED SPOT

Figure 4