



Fermi National Accelerator Laboratory

TM-1602

**Technical Memo on
PbF₂ as a Cherenkov Radiator for
EM Calorimetry**

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P.O. Box 500, Batavia, Illinois

June 26, 1989



Operated by Universities Research Association, Inc., under contract with the United States Department of Energy

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It is apparent that the ever increasing rates and radiation levels found in high-energy physics are excluding more and more instrumental techniques. Those techniques that are remaining are often pushed to their theoretical limits. This situation reaches an extreme at the proposed luminosity of the SSC. Also, it is fair to say that at the SSC, after the accelerator itself, calorimetry will be the next most important physics tool. Therefore, we should be ever alert to new calorimetry techniques which may operate in this demanding environment. The material lead fluoride, PbF₂, has a real potential of yielding a very compact, high-resolution electromagnetic calorimeter that is both fast and radiation hard.

PbF₂ is not a scintillator but a Cherenkov radiator like lead glass, but with a radiation length even shorter than that of BGO. For comparison, tables of properties of PbF₂ and some scintillators and lead glasses are included at the end of this proposal. PbF₂ has a density of 7.66 g/cm³ and a radiation length of <1 cm. Although it has the same Moliere radius as BGO, its "apparent" Moliere radius is about 20% smaller. This is because, as a Cherenkov radiator, one does not see the soft particles at the outside of the shower. Thus, PbF₂ is the most compact non-sampling material for electromagnetic calorimetry. Also, since it is a Cherenkov radiator, if one can get the light out quickly, it is one of the fastest techniques available.

Figure 1 shows the transmission of a sample of PbF₂ obtained from Engelhard Corp. (used to be Harshaw) along with the cutoffs of a glass PMT and of a "typical" lead glass. The relative intensity of Cherenkov radiation (marked $1/\lambda^2$) and the spectral response of a bialkali photocathode are also included. The first point to note is that PbF₂ transmits much farther into the blue than lead glass and thus more Cherenkov photons will be produced per unit particle track length. This is also in a spectral region where the PMT has its highest quantum efficiency. Also, from the table one can see that its index of refraction is also very favorable for good light production. An additional point to be taken from figure 1 is that a glass PMT cuts off the blue edge of the PbF₂ transmission. This is very desirable since it removes the bluest light which is the most sensitive to the opacity of the material. Often in lead glass this is accomplished with a filter on the PMT which improves the energy resolution but reduces the detected light by a factor of 2.

Twenty years ago Hofstadter also looked at it and published two short papers [1,2]. With a crystal 5.25 inch diameter by 5 inch long (13.8 Xo ϕ x 13 Xo) he obtained an energy resolution of about $6.4\%/\sqrt{E}$. Craig Woody has placed a poor quality PbF₂ crystal in a BNL electron test beam for us. This crystal was 134 mm long and 44 mm in diameter (4.6 Xo ϕ x 14 Xo). Although the material was yellow and we estimate that the light output was down by at least a factor of 4, 1000 photoelectrons were detected per GeV. This would imply that with a good crystal, the contribution of photon statistics to the resolution would be about 1.5%. Figure 2 shows the signals for 3 GeV electrons and for minimum ionizing particles. Without any effort to optimize the optical coupling or reduce the signal reflection (20 ns) the signal is still down to about 20% of its peak value 20 ns after its beginning. With a little work, PbF₂ should easily work at SSC rates.

Radiation hardness is also an important question for any material considered for use at the SSC. Two samples cut from the sample given us by Engelhard Corp. have been irradiated in the research reactor at the University of Michigan. There was some degradation in the transmission of the samples but there was a remarkable recovery after exposing the samples to a UV light for 10 minutes. Figure 3 shows the transmission a sample exposed to 3×10^5 rad of gamma rays and 1×10^5 rad of neutrons, followed by a 10 minutes exposure to a UV light. Figure 4 shows the transmission a sample exposed to 3×10^6 rad of gamma rays and 1×10^6 rad of neutrons, again followed by a 10 minutes exposure to a UV light. The sample receiving the higher dose shows some permanent damage. Although the PbF₂ had a good transmission, we cannot be certain of its purity. In the case of BaF₂ it has been shown that the radiation hardness is very dependent upon the purity of the material. In general the fluorides are among the most radiation hard materials and there is hope that PbF₂ will also share that characteristic. All that can be said is that PbF₂ does not appear to be radiation soft.

Finally, there is the issue of the expected cost of PbF₂. With the exception of the one piece of material that we have from Harshaw, all of my material has come from Optovac, Inc. (North Brookfield, Mass; contact: Rob Sparrow, 508/867-6444). They have grown some 1 kg pieces for me and their best guess for the cost of PbF₂ in large quantities is $< \$3/\text{cm}^3$. This is using the best starting material available. The price could come down by as much as $\$1/\text{cm}^3$ if cheaper material can be used. To put that in perspective, BGO and BaF₂ cost about $\$15/\text{cc}$ and $\$8/\text{cc}$, respectively. In terms more appropriate for computing the price of a calorimeter PbF₂, BGO, and BaF₂ cost about $\$3$, $\$16$, and $\$17$ per $\text{cm}^2\text{-Xo}$. Even at $\$3/\text{cm}^3$ it is quite competitive as a calorimeter technique.

References

- 1) E.B. Dally and R. Hofstadter, IEEE Trans. Nucl. Sci. NS-15 #3 (1968) 76.
- 2) E.B. Dally and R. Hofstadter, Rev. Sci. Instr., 39 #5 (1968) 658.

Physical Properties of PbF₂ and Some Scintillators

	PbF₂	BGO	BaF₂	CsI
Density	7.66	7.13	4.87	4.51
Radiation length (cm)	0.95	1.1	2.1	1.9
Moliere radius (cm)	2.22	2.24	3.45	4.35
	(1.8) _{apparent}			

Physical Properties of PbF₂ and Some Lead Glasses

	PbF₂	F-2	SF-5	SF-6
Density	7.66	3.61	4.08	5.20
Pb (% by wt)	85	42	51	66
Radiation Length (cm)	0.95	3.22	2.54	1.69
Critical Energy (cm)	8.96	17.3	15.8	12.6
Index of Refraction	1.86	1.62	1.67	1.81

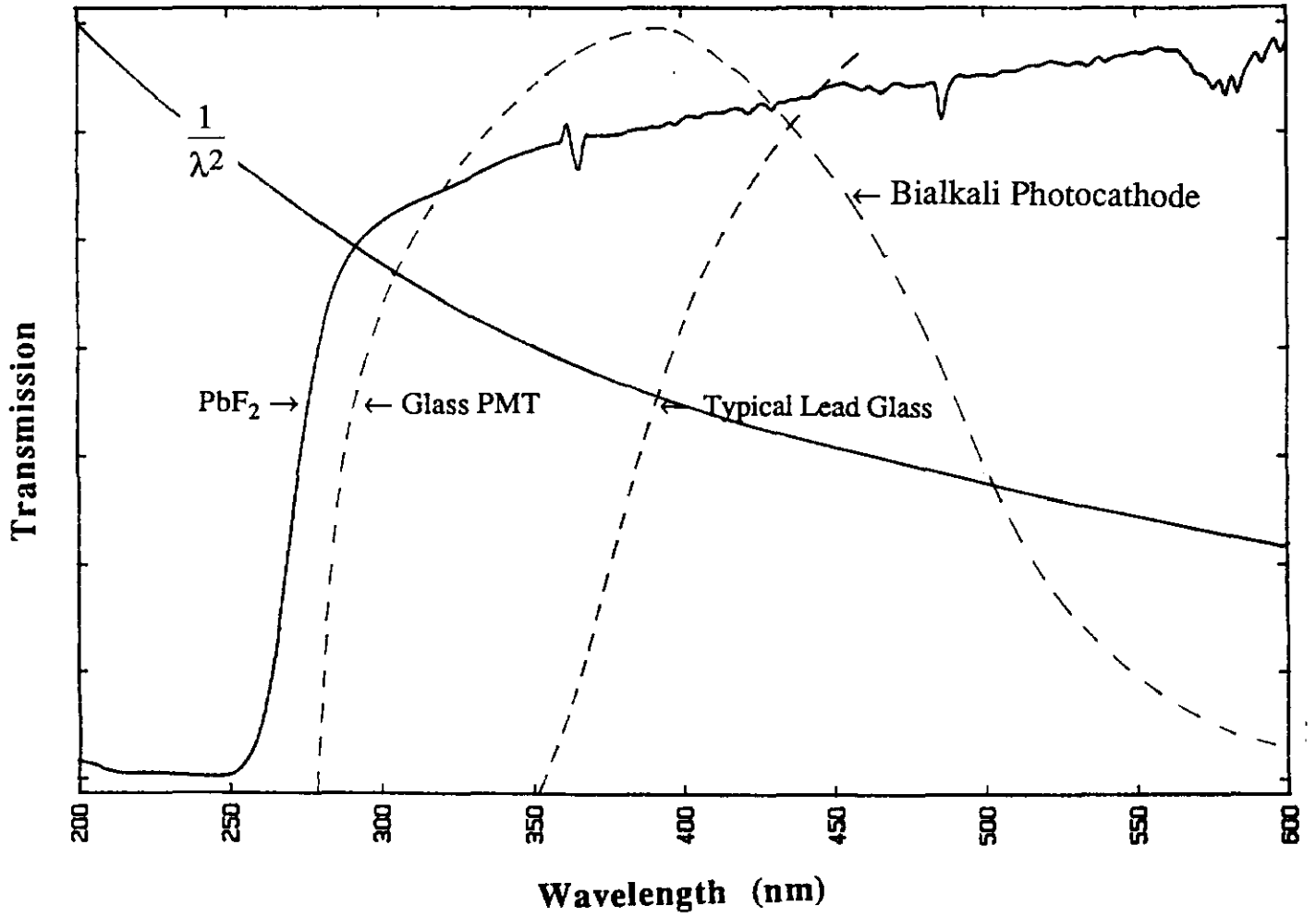
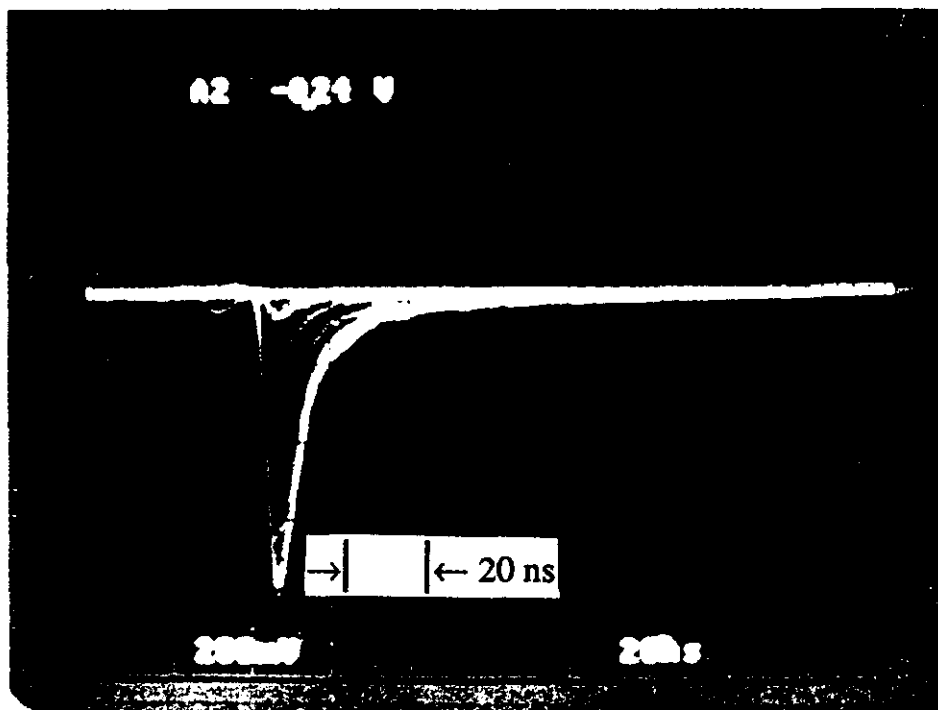
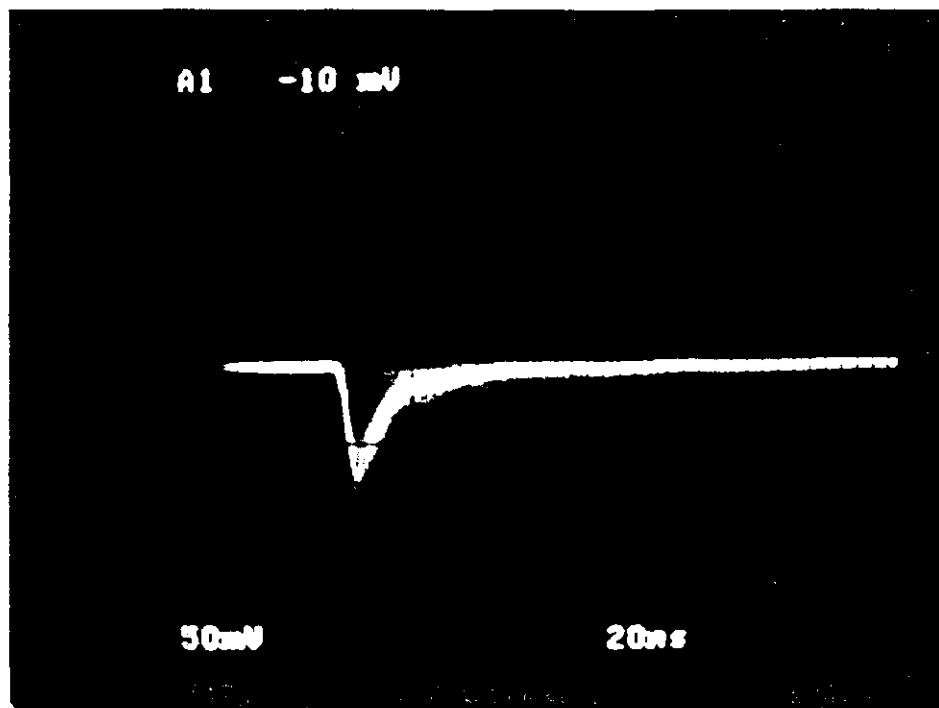


Figure 1



3 GeV electrons



Minimum Ionizing Particles

Figure 2

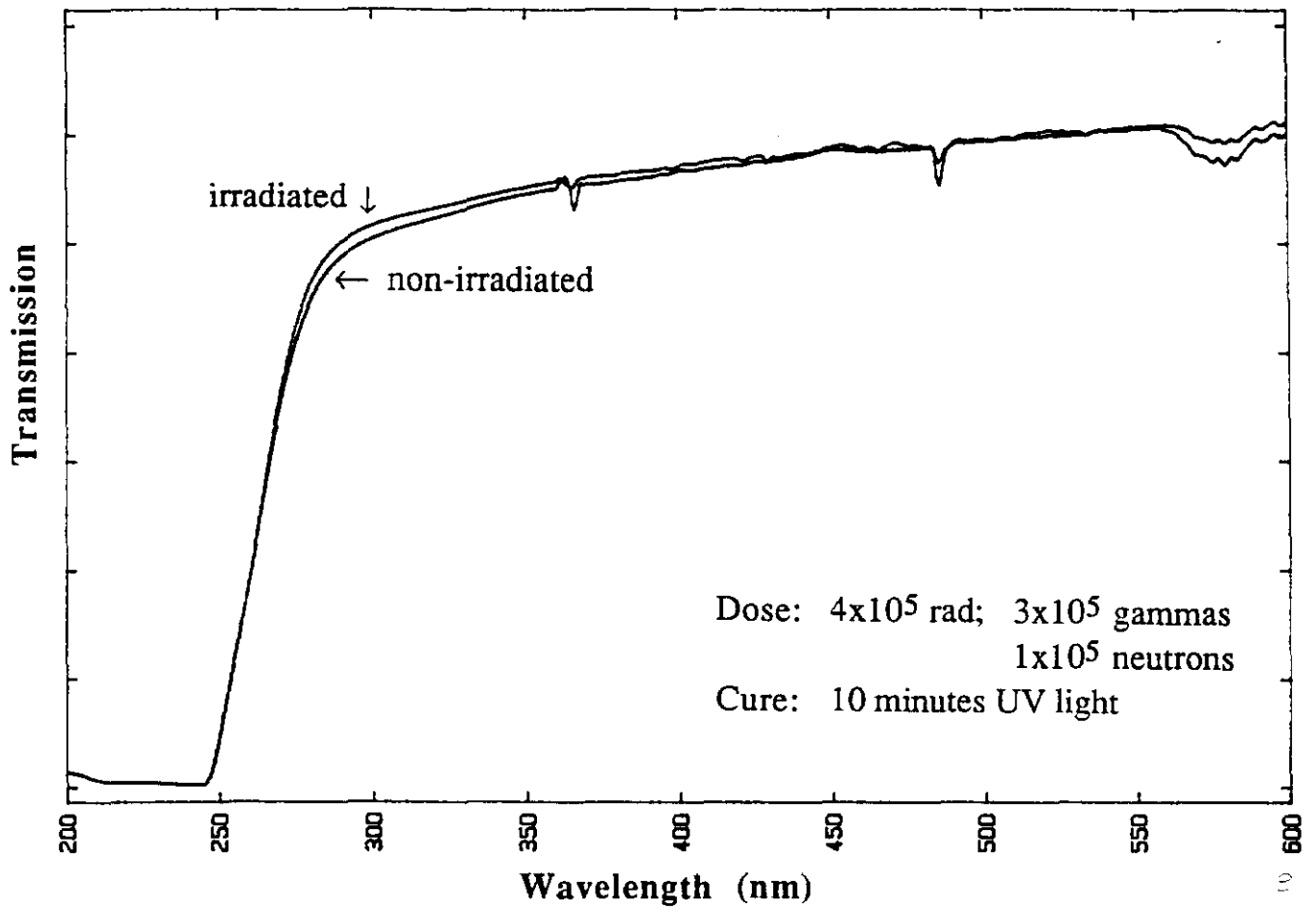


Figure 3

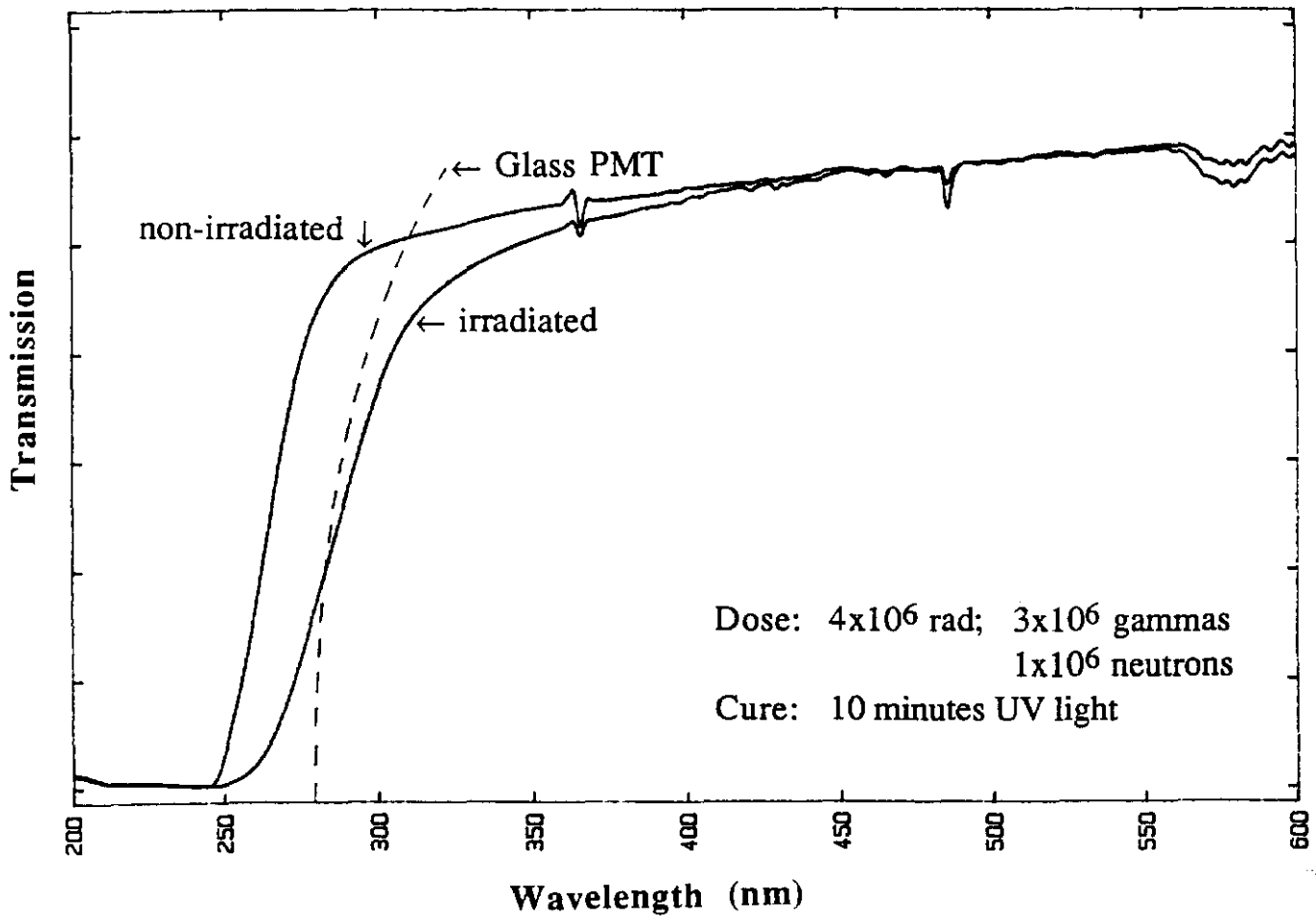


Figure 4