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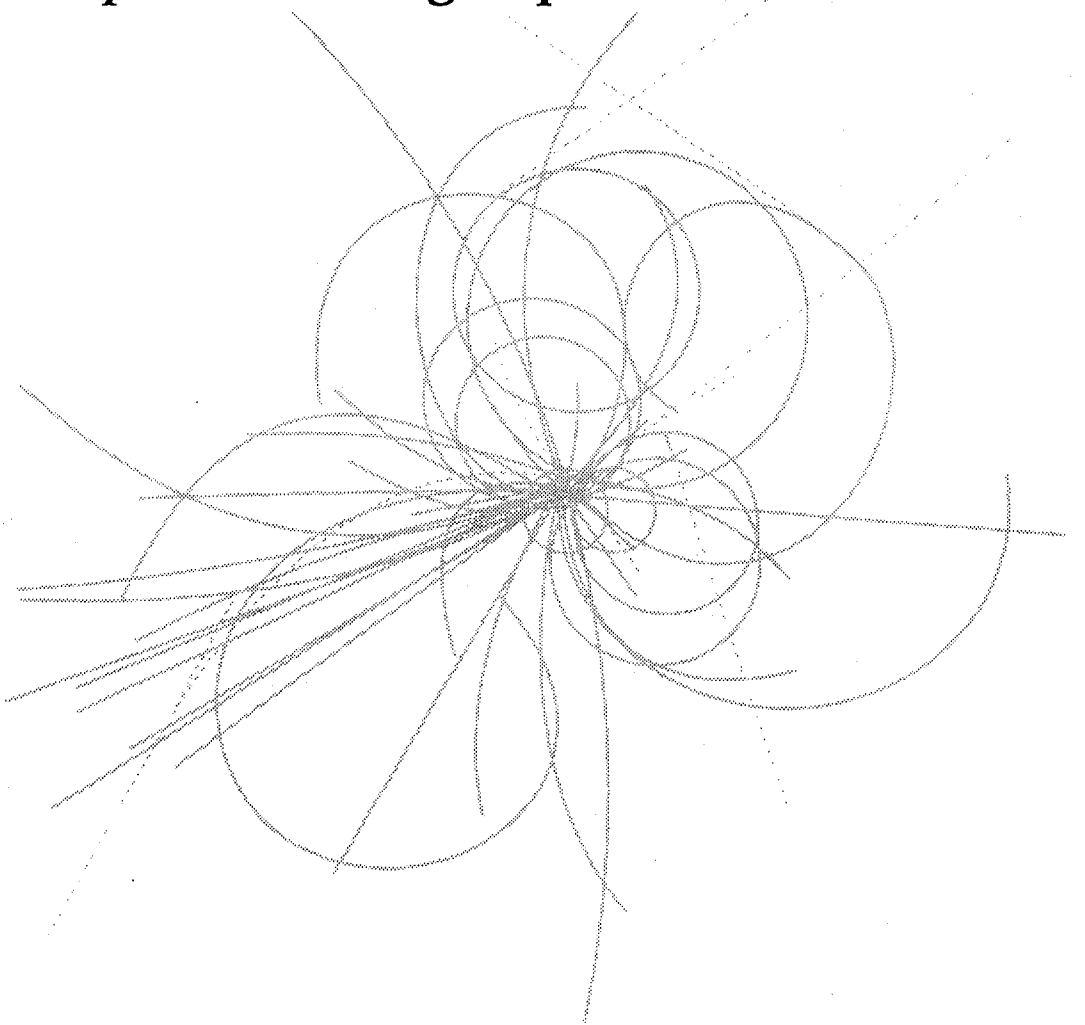

Problems in the Use of Plastic Scintillators in Intense Radiation Fields

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PROBLEMS IN THE USE OF PLASTIC SCINTILLATORS IN INTENSE RADIATION FIELDS

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ABSTRACT

Annual doses in the SDC End Cap Calorimeter, and possible design decisions in the use of radiation resistant scintillators are discussed. Some candidates for base radiation tolerant scintillators and wave length shifters are discussed. Absorption and emission spectra of one of them are represented.

KEYWORDS

Scintillator; Radiation Damage; Calorimeter; Spectrum; Polyetherimide

PROBLEMS IN THE USE OF PLASTIC SCINTILLATORS

Radiation damage will be a serious problem at the Superconducting Super Collider (SSC) and LHC. The scintillators that are used in scintillator counters, hodoscopes, fast beam loss monitors and calorimeters will work at high levels of irradiation. The development of new radiation-resistant scintillators will be necessary for use in scintillator calorimeters for future experiments where many scintillator plates are required.

It is useful to consider some calorimeter parameters that can be changed after irradiation. The sandwich module of the scintillator calorimeter is shown in Fig. 1. The module consists of absorbers made of Iron, either Lead or Uranium, and scintillator plates. The wave length shifter (WLS) is put in the scintillator plates. The photomultiplier detects the light. The modules are installed in the calorimeter in Fig. 2.

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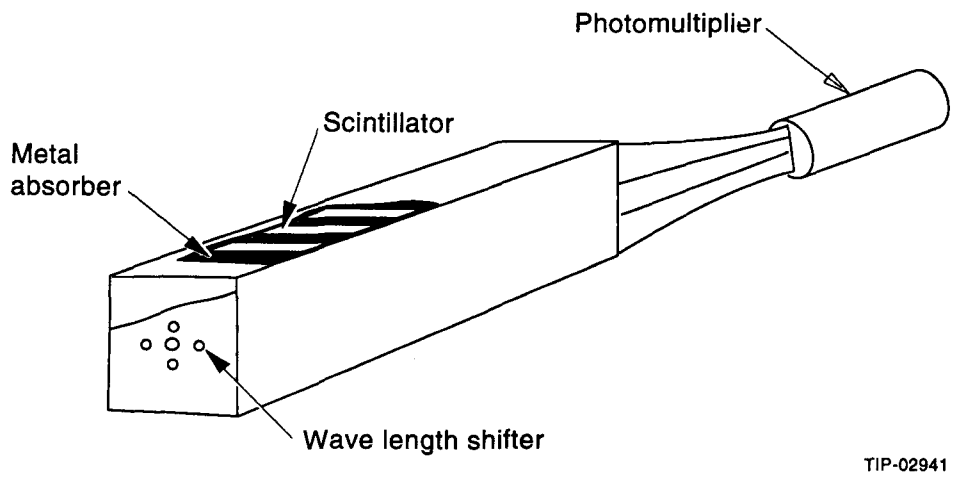

Fig. 1. The module of scintillator calorimeter.

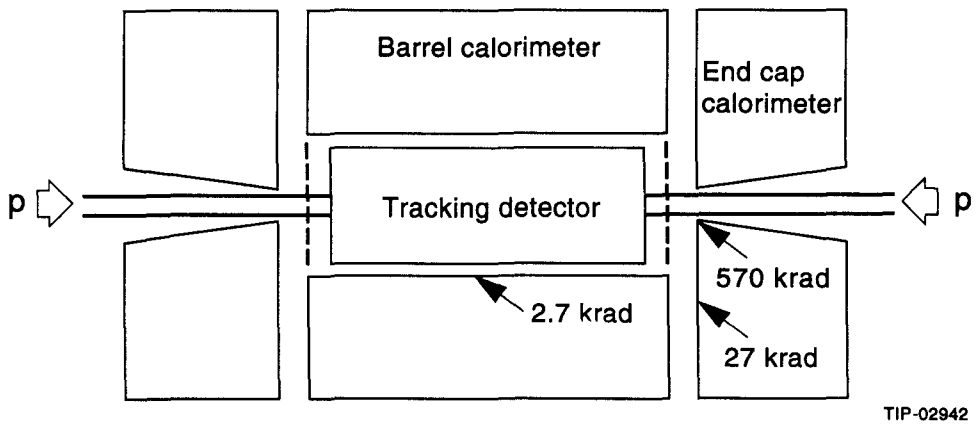

Fig. 2. Layout of calorimeter and annual doses of irradiation.

Some properties of the scintillator calorimeter are:

1. Fast response of about 15–30 ns
2. High level electrical output signal after the photomultiplier
3. Good energy resolution *e.g.*, $35\%/\sqrt{E}$ for hadrons and $18\%/\sqrt{E}$ for electrons—ZEUS, HERA (Behrens, 1990).

At high radiation levels the drawback of a scintillator calorimeter is the need for signal calibration in the system (scintillator, wave length shifter, and photomultiplier) that is caused by radiation damage in these components. The radiation levels, when the light output begins to degrade are: (1) for polystyrene based scintillators—several units of Mrad, and (2) for wave length shifters—as a rule less than 1 Mrad.

One can analyze the distribution of annual doses (Groom, 1990) and possible design decision for the SDC End Cap Calorimeter, see Fig. 2, where the radiation problems should be taken into account. Radiation resistance is required only in the limited domain around the beam line, where the annual calculated doses at SSC design luminosity are about 0.5 Mrad. (However a possible tenfold luminosity increase is being discussed). There are smaller levels of irradiation at further distances from the beam line. Thus, one can use the standard inexpensive scintillator in the larger part of the volume. Modules

with more expensive scintillators and wave length shifters that have a higher level of radiation resistance are needed only in the zone of intensive irradiation . We determine the threshold of the radiation resistance as 50% of the reduction of light yield for the scintillator or the same reduction of the attenuation length for the wave length shifter.

To estimate degradation of light yield in the scintillator one takes into account that the scintillator has the ability to recover its light yield when irradiation is absent (Marini *et al.*, 1985 and Zorn, 1990). There are data that this recovery time may be about 150–200 days for some cases (Marini *et al.*, 1985). Therefore one can expect that if the scintillator module is irradiated by doses that equal or exceed its threshold (for six months run per year) the light output would be reduced to 10–20% of the initial magnitude after 5–7 years. Another problem is that calibration methods used at the collider detectors are developed only for the calibration of wave length shifters and photodetectors. One can calibrate with a radioactive source implanted in the scintillator plates, but it is very difficult having several thousand plates. There are preliminary proposals to apply, for the calibration, the natural activity of uranium plates with the uranium 235 content of about 0.2%.

As an illustration, one can show the changes in optical performance of the scintillator and WLS after irradiation for one calorimeter (Semenov, 1990). The deterioration of the energy resolution in this detector was calculated using data (Pischalnikov, 1986; Britvich *et. al.*, 1991; and Schonbacher, 1987) and shown in Fig. 3.

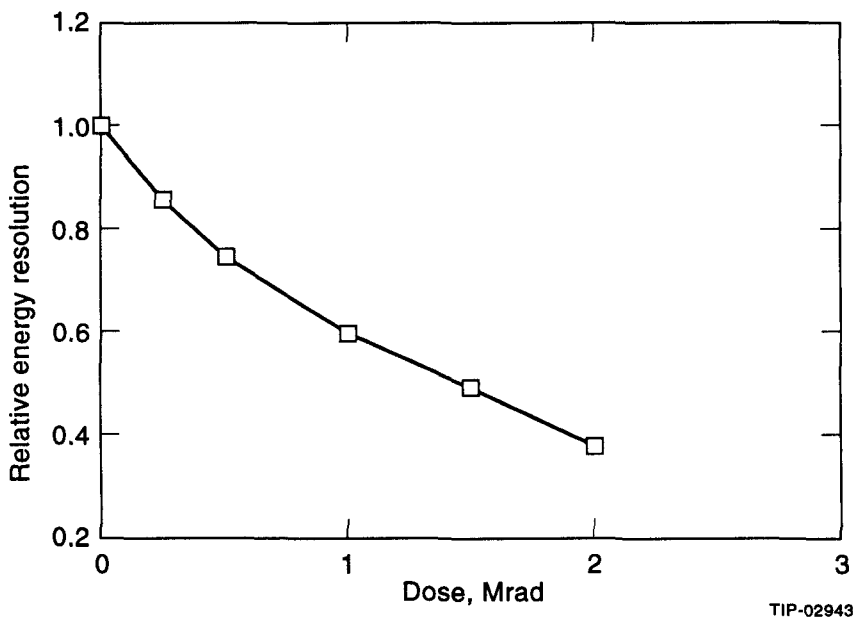

Fig. 3. Alteration of energy resolution of the calorimeter versus doses of irradiation for E = 10 GeV.

To solve the preceding problems one needs to search and develop new polymeric systems for WLS and scintillators that will be tolerant to intensive irradiation, as *e.g.*, polysiloxane-based scintillators (Feygelman, *et al.*, 1990), where the threshold of radiation resistance was increased over 16 Mrad . We think that the use of new polymeric systems will be expedient if their threshold exceeds the level of 20–25 Mrad.

We have studied other candidates for polymer "bases" in scintillators and WLS besides the already known polydimethylsiloxane. These are:

1. Polycarbonate
2. Polysulfone
3. Epoxypolymer
4. Polyetherimide

Preliminary results for the first three will be presented in a companion paper in this volume (Barashkov, 1992). The fourth plastic has never been considered before as a candidate base material. Figure 4 shows the absorption and emission spectra of pure polyetherimide samples (Kazakova and Yuzakov, 1992) that had a thickness about 15 mkm. This plastic has an emission spectrum peak with $\lambda = 470$ nm. Using a solvent doped with primary and secondary fluors one can expect to shift the final fluorescence to the red.

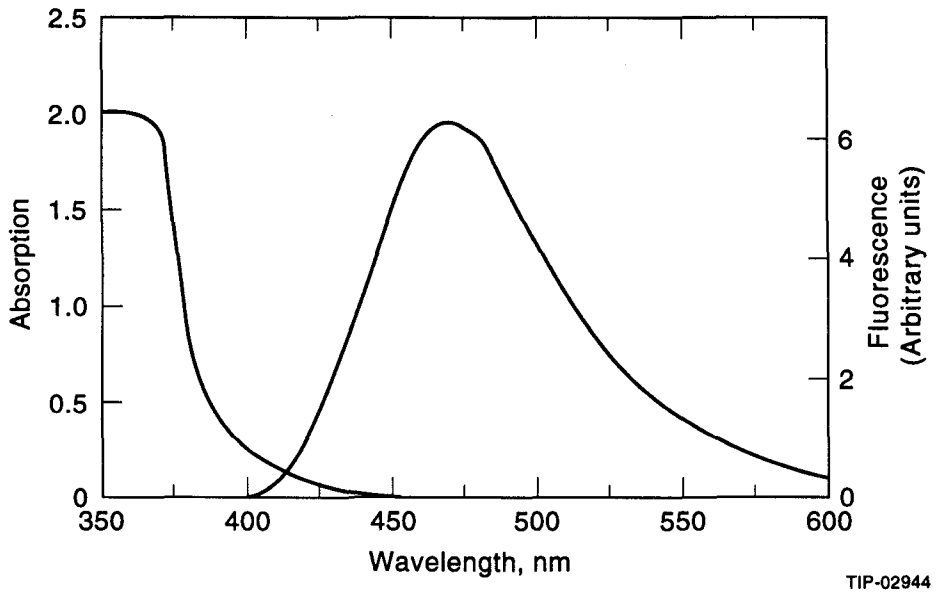

Fig. 4. The absorption and emission spectra of pure polyetherimide.

In this case, one can use semiconductor photodiodes as the detector; for example, the avalanche photodiode (Fenker *et al.*, 1991; Jeanney *et al.*, 1991; and Bruckner *et al.*, 1991), PIN photodiode (Suffert, 1991) and the hybrid photodiode tube (DeSalvo *et al.*, 1991) which are sensitive to the red part of spectra. The smaller sensitivity of photodiodes, compared to photomultipliers, will not be problematic as the amplitude of signals in the calorimeter tower is sufficient. The application of a semiconductor photodiode has several advantages. The diodes have small sizes, a high linearity of a output performance and the ability to work in high magnetic fields.

Some conclusions are:

1. The SDC scintillator calorimeter will have some radiation damage of the wave length shifters and the scintillators in the end cap calorimeter.
2. High yearly doses in the end cap calorimeter require new solutions. One of them is the use of scintillators and WLS made of new materials. The replacement of the scintillator module can be more expensive than the development of the new scintillators.
3. The use of new plastics will be expedient if their threshold of the radiation resistance is over 20–25 Mrad.
4. In addition to polydimethylsiloxane, such plastics as polycarbonate, polysulfone, polyetherimide have high threshold of radiation resistance and are candidates for the base in new scintillators and WLSs.
5. The scintillator calorimeter may be improved if the photodetector uses semiconductor photodiodes.
6. The results of the investigations in the development of new radiation resistant scintillators can be used for other types of scintillator detectors such as intensity counters, hodoscopes, beam loss monitors and others.

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