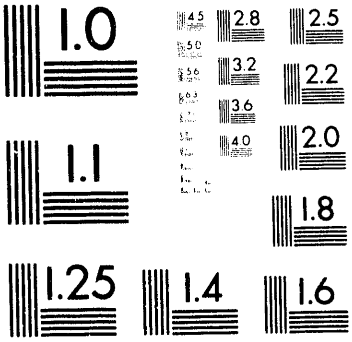
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REPORT ON RADIATION EXPOSURE OF LEAD-SCINTILLATOR STACK*

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Abstract

A stack of lead and scintillator was placed in a neutral beam obtained from targeting 800 GeV protons. Small pieces of film containing radiochromic dye were placed adjacent to the layers of scintillator for the purpose of measuring the radiation dose to the scintillator. Our motivation was to calibrate the radiation dose obtainable in this manner for future tests of scintillator for SSC experiments and to relate dose to flux to check absolute normalization for calculations. We also observed several other radiation effects which should be considered for both damage and compensation in a calorimeter.

Description of Experimental Setup

The lead-scintillator stack was constructed in a simplified manner due to limitations of space and materials. It consisted of SCSN81 CDF scintillator (5 mm thick) at 1/2 and 6 radiation lengths of lead, old scintillator from a

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prototype (5 mm thick) at 3 and 4.5 radiation lengths, Y7 waveshifter plate (3 mm) at 6 radiation lengths, and 1/2 radiation length of lead behind this. Dye film was placed at .5, 1.5, 3, 4.5, and 6 rl. At approximately 6.5 rl., the film was placed both between the lead and the 5 mm scintillator and after the scintillator before the 3 mm shifter plastic. From 5 to 10 pieces of dye film 1 cm square were used at each depth in the hope of seeing the beam profile or at least providing redundant measurements.

The stack was placed at the face of the neutral beam dump of the polarized beam at Fermilab. The neutral beam is from very forward production and consists mainly of photons and neutrons. The collimator acceptance in the sweeping magnet is approximately 0.7 mr polar angle. The flux of neutrons was less than about 1.66 E10 per 1. E12 primary beam as scaled from the broadband photon beam proposal. The neutron spectrum has a triangular shape peaking at 600 GeV. The constants in these analytic forms are for a primary energy of 800 GeV. The photon flux was calculated explicitly for our measurement using a production formula called FN-341 in the Turtle program (Fig. 1). The photon flux was about 0.64 E10 per 1. E12 primary. The neutral beam covered a spot about 7 to 8 cm diameter at the location of the test stack. Approximately 1.5 E12 primary beam was targeted per minute, on a 1 interaction length target, 30 cm Be, from July 26 to August 13, 1990 (18 days with about 30% down time). Approximately 2.5 E16 protons were targeted.

Dose Measurement

The radiation exposure was determined by measuring the optical density of the radiochromic dye films with a spectrophotometer at two wavelengths. Calibration curves provided by Far Western Technology[2] and traceable to NIST only covered .3 MRad to 2. MRad for 600 nm, and .5 to 5. MRad for 510 nm. Curves for up to 100 MRad are published in a survey article on dosimetry (Ref.

3). The curve turns over at 50 MRad. The film is sensitive to the UV from fluorescent room lights. A sample was visibly darkened by UV in the spectrophotometer before a 400 nm low pass filter was installed.

RESULTS

The dose was higher than anticipated and in a non-linear part of the response curve of the film. At .5 rl. we found 8. MRad in the center and 1 to 2 MRad at the edges due to the beam profile. At 6 rl. we found 40 MRad immediately after the lead before the scintillator and 20 MRad after the 5 mm hydrocarbon and before the waveshifter plate behind it. It is not certain that this effect is real and not a difficulty in the measurement. However, it is interesting to note that analytic formulas for E-M showers give 477 e^+e^- pairs above 1.5 MeV at shower maximum for showers in pure lead at 100 GeV and 150 e+e+ pairs at maximum for showers in carbon. Also, calculations show that one can reduce the number of delta rays emanating from lead by up to a factor of 2 by using low Z material. The 5 mm of scintillator would range out electrons below about 1.5 MeV/c. It appears to be messy to calculate the energy distributions below 2 MeV at each 1 mm in depth in a stack using EGS. Furthermore, it was observed that of the 3 thin layers of paper between the lead and the scintillator, the one nearest the lead was damaged the most. This question should be investigated, both experimentally and with calculation as it has implications for both damage and compensation.

Flux vs. Dose Calibration

We would like to relate measured dose to known photon flux. A crude attempt to do this is as follows: A calculated photon spectrum was used. It peaked at about 90 GeV. The number of charged (e+ or e-) was taken as 400 at 100 GeV and taken to scale linearly with energy, ignoring a logrithmic term. With 6.4 E9 gamma per 1. E12 proton, this gave 3.7 E12 charged per 1. E12 primary protons by numerical integration. We take the area illuminated by the beam uniformly to be 8 cm diameter at the front of the stack, and 10 cm diameter at shower maximum. The area is then 78. cm^2 and we need 2.73 E9 charged (e+ or e-) per Rad, (assuming 3.5 E9 charged over 2 MeV in carbon for 100 rad). We had about 2.5 E16 primary protons and so predict 34. MRad at shower maximum. We measured 40 MRad immediately after the lead plate and 20 MRad after 5 mm plastic near shower maximum, so the normalization is crudely right.

One possible problem with calibration of dose was possible exposure of the film to UV light from the scintillator excited by the particles in the electromagnetic shower. Possible light shields such as the garbage bag disintegrate. In fact, measurements between layers of lead with no scintillator were in reasonable agreement with measurements at the scintillator.

Radiation Damage to Materials, etc.

When the stack was removed from the beam, the induced radiation level in the lead at 6.5 rl. was about 700 mRem/hour on contact. The upstream side was about 200 mRem/hour. The radiation was mainly gamma rays and had a half life of about three days. We believe that the isotopes responsible for the radiation can be determined. We are in the process of arranging for measurement of the gamma spectrum. The gamma counting equipment must be modified due to the dead time effects of the high counting rate from the activated lead. Knowing the radiation history and the time constant, we could find the amount of induced radiation per primary proton, and using the radiochromic dye to measure exposure, we could find induced radiation vs. radiation exposure. The induced activity is probably due to the neutron beam, but the hadron to photon ratio may be typical for hadronic reactions such as colliding beams.

The steady state activity for constant rate exposure is obtained from a convolution integral and turns out to be simply the dose rate * ratio factor * decay time constant. A = int from -inf. to t0 of ratio*exp((t0-t)/tau))* dt. Crudely, if we take 40 MR in 18 days and a time constant of 2.5 days, and .8 Rad activity, the ratio factor is 1.6 E7. When the stack was disassembled after 2.3 days, the scintillator was found to have very little induced radiation (less than .005 of the lead).

When the stack was disassembled, there was radiation induced physical damage to the plastic materials and paper. A thin dark plastic garbage bag disintegrated into small flakes. The paper, which was in contact with the lead, on the CDF scintillator (the same paper used in the calorimeter) at 6 rl. turned to powder in the area of the beam. But the paper in contact with the scintillator was not as badly damaged. There was less obvious damage at 0.5 rl. Some white plastic foam used to cushion the older scintillator in compression with the lead disintegrated and stuck to the lead. The glue in stick-on paper labels used to attach the dye films became very hard and brittle. The CDF scintillator at 6 rl. was yellow-brown in a circle of the beam diameter but the others were transparent. A transmission spectrum of this scintillator taken a few days later showed attenuation at short wavelengths but essentially no change above 600 nm (Fig. 2). The protective paper on the Y7 waveshifter surface had not been removed and became a white powder which was stuck to the surface.

Conclusions

This experience may aid in the future to make comparative measurements of the optical properties of damaged and undamaged stacks with the configuration of calorimeters. We would like a more precise way to relate the dose to the photon and neutron flux. There are two other questions which are suggested already: 1) Is the dose really higher immediately behind the lead than behind a few mm of scintillator in the stack? 2) What level of gamma background from activation of the lead is tolerable? (This flux will presumably be on the order of 1. E6 of the photon flux from interactions.)

Acknowledgements

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Figure 1

A) Calculated gamma spectrum from production target without collimator.

B) Calculated gamma spectrum with 1.3 cm diameter collimator at 9.1 meters.

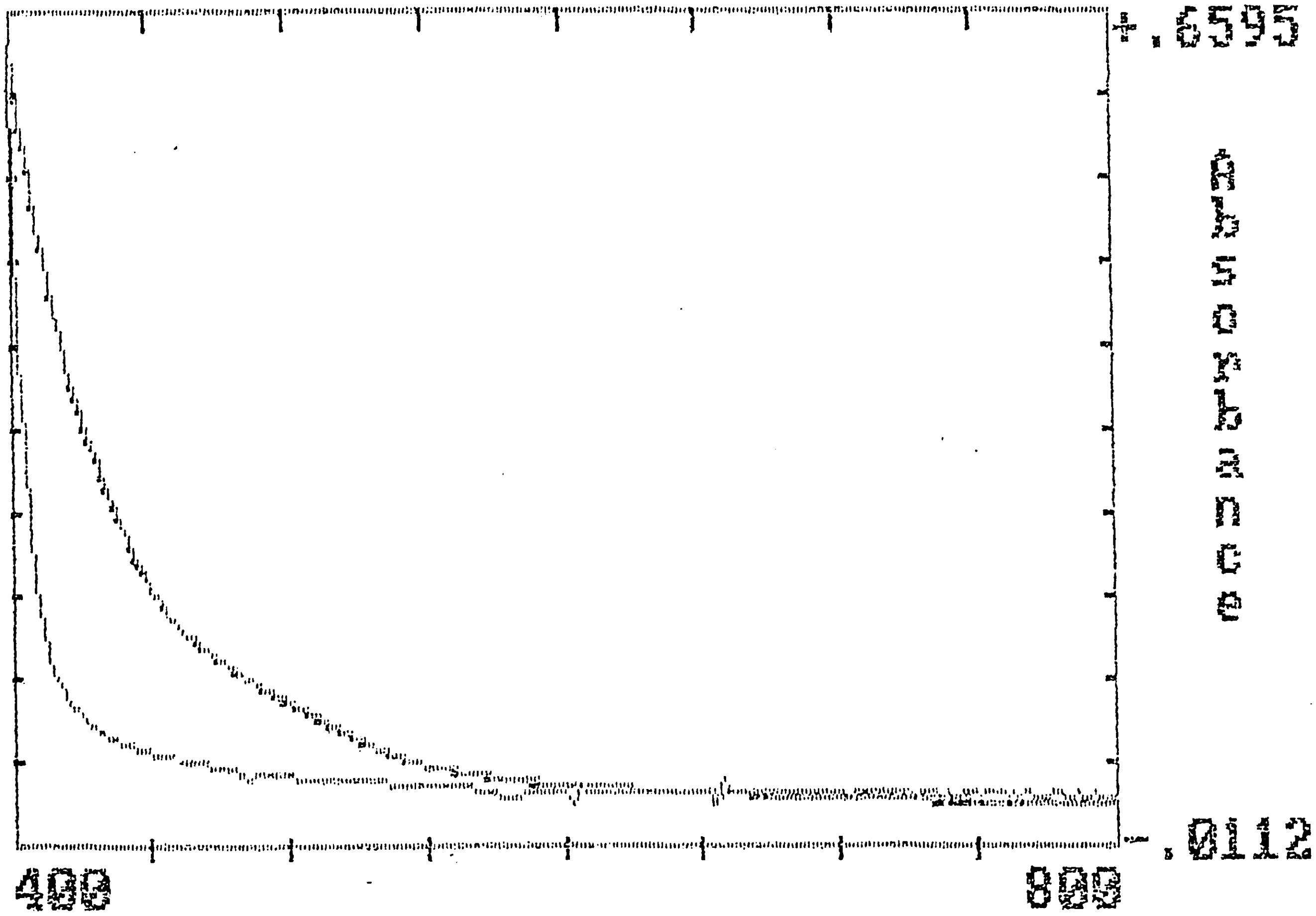

Figure 2

Absorbence (Log_{10} scale) of damaged and undamaged SCSN81 scintillator.

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