Conf-921005--6

EFFECTS OF RADIATION ON SCINTILLATING FIBER PERFORMANCE*

M. L. Bauer, H. Cohn, Yu. Efremenko, A. Gordeev, Yu. Kamyshkov,
D. Onopienko, S. Savin, K. Shmakov, E. Tarkovsky, and K. G. Young

Oak Ridge National Laboratory,
P. O. Box 2008
Oak Ridge, TN 37831-6006
615-574-5603

CONF-921005--6

DE93 003620

R. Carey, M. Rothman, L. Sulak, and W. Worstell

Boston University
Boston, MA 02215

H. Parr

University of California - San Diego
La Jolla, Ca 92093-0319

Paper to be presented at the
IEEE 1992 Nuclear Science Symposium
Orlando, Florida
October 25-31, 1992

---

*Researchsponsored by the U. S. Department of Energy and performed at Oak Ridge National Laboratory, managed by Martin Marietta Energy Systems, Inc. for the U. S. Department of Energy under contract DE-AC05-84OR21400.

Effects of Radiation on Scintillating Fiber Performance*

M. L. Bauer, H. Cohn, Yu. Efremenko, A. Gordeev, Yu. Kamyshkov,
D. Onopienko, S. Savin, K. Shmakov, E. Tarkovsky, and K. G. Young

Oak Ridge National Laboratory, P.O. Box 2008
Oak Ridge, TN 37831-6006

R. Carey, M. Rothman, L. Sulak, and W. Worstell

Boston University
Boston, MA 02215

H. Paar

University of California - San Diego
La Jolla, CA 92093-0319

Abstract

Continued rapid improvements in formulations for scintillating fibers require the ability to parameterize and predict effects of radiation on detector performance. Experimental techniques necessary to obtain needed information and calculational procedures used in performing predications for hadron scintillating fiber calorimetry in the Superconducting Supercollider environment are described. The experimental techniques involve control of the testing environment, consideration of dose rate effects, and other factors. These calculations involve the behavior of particle showers in the detector, expected levels of radiation, and parameterization of the radiation effects. A summary of significant work is also presented.

I. INTRODUCTION

A scintillating fiber calorimeter for the SSC consists of fibers embedded in a matrix of high-Z material. The scintillating fiber is composed of a central core of doped base material such as polystyrene (typical diameter of 1 mm) surrounded by a lower refractive index cladding (polymethylmethacrylate is a standard choice) of several microns thickness.

The long-term stability of scintillating fibers is of critical importance in designing a calorimeter that will function under the conditions expected to exist in the environment of the SSC: radiation levels in excess of 1 Mrad/yr for a period of up to 10 years. A significant amount of data has been accumulated regarding radiation damage, extensive searches are underway for improved materials, and accelerated aging techniques are being enhanced.

II. RADIATION EFFECTS

Some of the factors that require consideration in the determination of fiber performance are: the effects of the environment (especially oxygen) on radiation damage and annealing of the fiber, energy resolution and compensation for the detector, fiber longevity under benign environments, and the amount and emission wavelength of the fluor.

In the presence of oxygen, radiation damage appears to be dependent on the rate of irradiation. However, under inert gas, radiation damage at different rates is equivalent. In the presence of oxygen, the rate of diffusion is the determining factor in the effect of oxygen. Oxygen increases the rate of radiation damage; it also increases the rate of annealing. In the absence of oxygen, annealing proceeds very slowly. However, heating will increase the rate of annealing. Bross found that after irradiating a 1 cm disk of polystyrene with 10 Mrads of ^{60}Co, the results of the first oxygen and heat anneals were similar; however, after the fourth cycle, the transmittance for the heat anneal (90°C) was 93% as compared with 86% for the oxygen anneal[1]

Radiation effects are strongly wavelength dependent. For example, the transmittance for a 1 cm disk of polystyrene irradiated to 10 Mrads in nitrogen was 0.42 at a wavelength of 420 nm, 0.82 at a radiation length of 520 nm, and 0.92 at a wavelength of 650 nm. Thus, radiation hardness is increased by using a fluor with a longer wavelength. As the amount of fluor is increased, the effect of radiation is decreased and then beyond a certain level, becomes constant. However, Zorn[2] found that the amount of fluor (3HF) could reduce the light output by as much a factor of 2 for a factor of 10 increase in the amount of fluor.

A two-year study of the stability of fibers under normal conditions led to an upper limit of 5% degradation with a 95% confidence level[3].

---

*Research sponsored by the U. S. Department of Energy. The Oak Ridge National Laboratory is managed by Martin Marietta Energy Systems, Inc. for the U. S. Department of Energy under Contract No. DE-AC05-84OR21400

Effects of radiation damage on energy resolution were studied by Acosta et. al[4] and also by the RD1 group[5]. Acosta et. al. found that if they defined a contribution of .8% to the constant term of the electromagnetic energy resolution due to radiation damage as an acceptable performance degradation, then with the best fibers that are presently commercially available, an acceptable dose limit would be 7 Mrads for a Pb/scintillating fiber calorimeter. The RD1 group irradiated a Pb/scintillating fiber calorimeter with a 1 GeV electron beam. After 6 Mrads, they found 20% loss in light output and little change in the energy resolution.

Compensation, which is the equality of calorimeter response for hadrons and electrons, is an important consideration in the design of a calorimeter in which the electrons and hadrons are not distinguishable. Simulations[6] were performed using a generic slab of 4 mm Pb and 1 mm plastic with 10 GeV electrons and negative pions from 20 TeV p-p collisions. Electron and hadron depth profiles were calculated; the electron signal was appreciably degraded (especially in the first 15 cm) while the pion signal was hardly affected. With 1% signal degradation per Mrad per year for a dose of 5 Mrads the results show that e/h has decreased from 1.05 to.98 in 2 years, and to 0.76 for 10 years.

The decay constant for 3HF scintillating fibers is 5.69 ns, and this is not affected by radiation damage[7]. Timing is important in particle identification and in generating triggers for on-line data selection.

III. RESEARCH AND DEVELOPMENT FOR GEM HADRON CALORIMETRY

The GEM hybrid calorimeter consists of liquid krypton electromagnetic and Cu/scintillating fiber hadronic calorimeter. Dose shapes (Fig. 1) calculated[8] for the hybrid option with the BaF_2 em calorimeter show increasing doses as eta is increased. At the front of the calorimeter, at eta = 2.5, the dose would be 0.11 Mrad/yr for luminosity of 10^{33} per year. The shower shapes shown in Fig. 2 indicate that for higher energies the showers develop later in the calorimeter where the dose is lower.

Copper was chosen as the matrix for the calorimeter since it is relatively compact and easy to machine. However, Cu may be activated by neutrons to form isotopes with 12.9h and 5.1 m half-lives. While this may not pose a long-term health and safety problem, it will create a varying background during the experiment. Iron does not have this problem, since capture of neutrons by ^{56}Fe results in ^{57}Fe which is stable.

The latest 3HF + PTP Bicron fibers were evaluated for radiation hardness. The tests consisted of placing 2 meters of coiled (20cm diameter) 1.35 mm diameter fiber in the ^{60}Co irradiation facility at Brookhaven National Laboratory (BNL). During the irradiation, a constant flow of nitrogen gas over the fibers was maintained. Fibers were irradiated at 24 Mrads/h (Fig. 3) and at 16 Mrads/h (Fig. 4) to a total dose of 3.6 Mrads. Before and after irradiation the attenuation length of the fibers was measured using a 239 μCi ^{106}Ru source and a Keithley picoammeter. Measurements made immediately after the fibers were removed from the irradiation facility indicated a high background or baseline possibly due to luminescence. This baseline disappeared, rapidly at first, and then gradually, over a period of 24 hours. The progress of annealing is shown in Fig. 4. After a one day anneal the attenuation length is 15% of the original, and after 11 days has recovered to close to 60%. The data from the fiber irradiated at 24 Mrads is similar to the one at 16 Mrads.

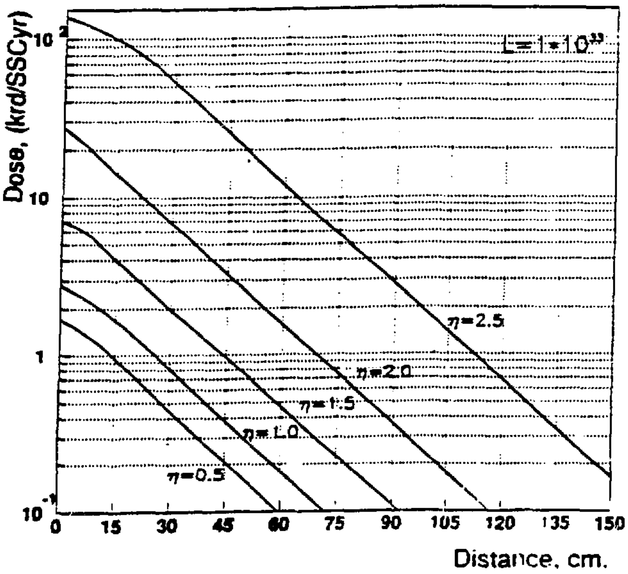

Fig. 1 Dose shape in hadron calorimetry

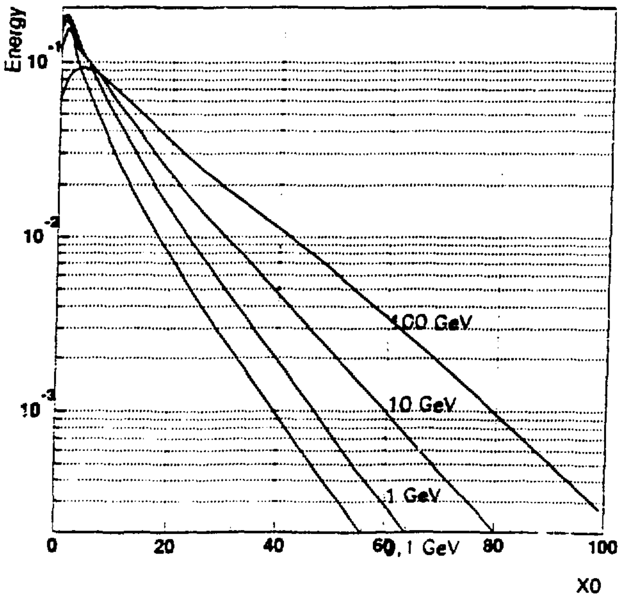

Fig. 2 Longitudinal hadron shower shape in copper

Calculations performed with a simple parameterization[9, 10] show that light output has dropped 2% from eta =0 to eta = 2.5 while it has dropped 5% from eta=2.5 to eta=2.9 (Fig. 5). The resolution changes very little. These trends agree with the RD1 data in that the predominant change is in the light output.

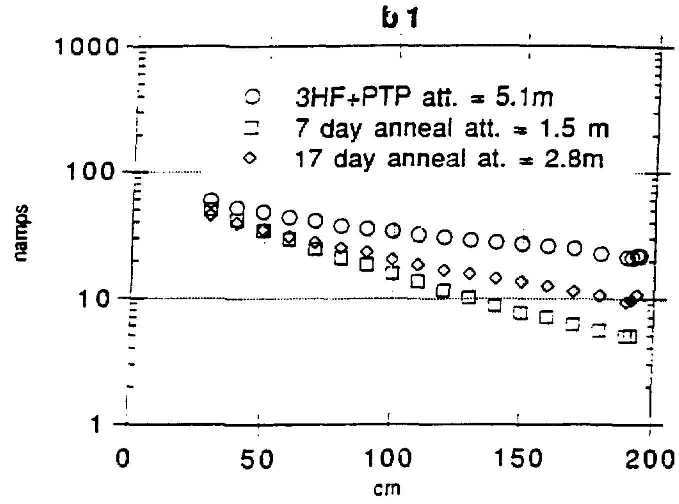

Fig. 3 Attenuation measurements

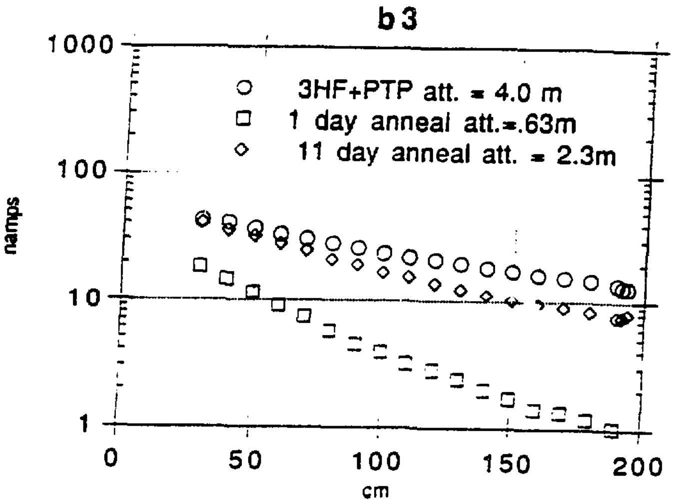

Fig. 4 Attenuation measurements

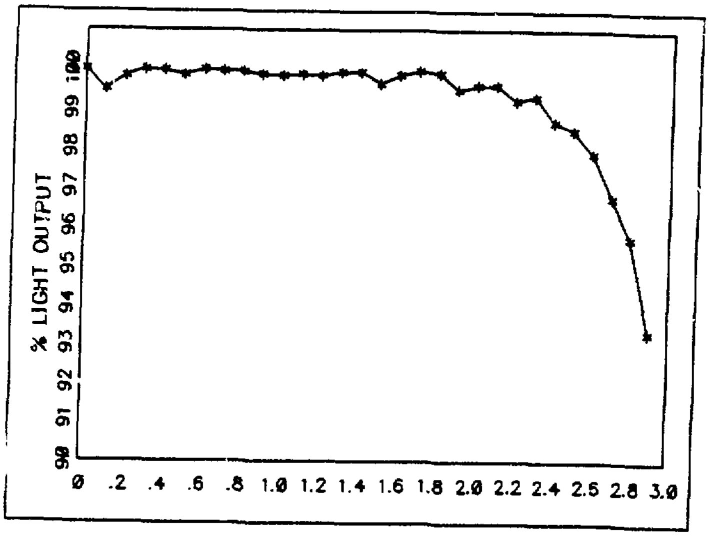

Fig. 5 Light output

IV. CONCLUSIONS

Future work is needed to obtain more information regarding slow radiation rates in realistic environments (i.e. use of prototype modules). Further work could be done to determine how simulations could reproduce the RD1 radiation results.

In conclusion, it appears that a small fraction of the fibers are in an area where radiation damage be of significance. Possible solutions to this situation are: a) improve the radiation hardness of the fibers, b) replace a small fraction of these fibers after several years and c) place a more rad hard technology at places where significant damage may occur. A combination of these approaches may be appropriate - such as replacing damaged fibers with more radiation resistant fibers of the future.

VII. REFERENCES

[1] A. D. Bross and A. Pla-Dalmau, "Radiation Damage of Plastic Scintillators," submitted to *IEEE TNS* 1991.

[2] C. Zorn, et al., "Progress in the Design of a Radiation-Hard Plastic Scintillator," *IEEE TNS*, April 1991 v. 38, No. 2, pp. 194.

[3] H. Blumenfield et al., "Ageing of Scintillating Fibers, Natural and Otherwise," *NIM* A279 (1989) pp. 281.

[4] D. Acosta, et. al., "Effects of radiation damage on scintillating fibre calorimetry," *NIM* B62, (1991) pp. 116.

[5] M. Livan, III International Conference on Calorimetry in High Energy Physics, September 29, 1992, to be published.

[6] T. A. Gabriel and T. Handler, "Radiation Damage Effects on Calorimeter Compensation," *Proceedings of the Workshop on Radiation Hardness of Plastic Scintillator,* March 19-21, 1990, FSU, Tallahassee, ed. K. F. Johnson

[7] J. M. Flournoy, *Journal of the Physics and Chemistry of Radiation,* to be published.

[8] F. Barreiro, et al., "Measurements of Longitudinal and Transverse Profiles for Hadron Showers in the Range 10-100 GeV and Comparisons with Monte Carlo Simulations," *NIM* A292 (1990) pp. 259.

[9] M. Rothman, "The Effects of Radiation Damage on the GEM Copper Scintillating Fiber Hadron Calorimeter," B.A. Thesis, Boston University, Boston MA, May 14, 1992.

[10] R. K. Bock et. al., "Parametrization of the Longitudinal Development of Hadronic Showers in Sampling Calorimeters," *NIM* 186 (1981) pp. 533.