SDC-93-425

SDC
SOLENOIDAL DETECTOR NOTES

SURVIVABILITY OF THE SDC SCINTILLATING-FIBER TRACKER

December 11, 1992

The Fiber Tracking Group (FTG)

Presented by S. Margulies
University of Illinois at Chicago

SURVIVABILITY OF THE SDC SCINTILLATING-FIBER TRACKER

S. MARGULIES
University of Illinois at Chicago

for the

FIBER TRACKING GROUP

PRESENTED AT THE SDC GROUP MEETING
11 DEC. 1992, SSC LABORATORY, DALLAS, TX

B. Abbott[j], D. Adams[i], T. Armstrong[g], M. Atac[a,b], A. Baumbaugh[b], B. Baumbaugh[a], M. Binkley[b], S. Bird,[b], J. Bishop[a], N. Biswas[a], A.D. Bross[b], C. Buchanan[a], N. Cason[a], R. Chaney[j], D. Chrisman[a], M. Chung[a], D. Cline[a], G. Collins [b], M. Corcoran[j], D. Davis[f], R. Davies[j], J. Elias[b], H. Fenker[b], E. Fenyves[j], D. Finley[b], G.W. Foster[b], H. Goldberg[a], H. Hammack[j], A. Hasan[g], S. Heppelmann[g], J. Jaques[a], R. Jesik[a], J. Kauffman[j], R. Kehoe[a], C. Kelley[d], M. Kelly[a], V. Kenney[a], R. Kephart[b], C. Kim[b], D. Kolick[j], J. Kolonko[a], J. Kubic[a], R.A. Lewis[g], J. LoSecco[a], B. Lowery[j], J. Marchant[a], R. McIlwain[j], S. Margulies[c], H. Mendez[a], H. Miettenen[j], R. Moore[g], R.J. Mountain[a], B. Oh[g], J. Orgeron[j], H. Park[b], J. Park[a], J. Passaneau[g], A. Pla-Dalmau[b], C. Rivetta[b], R. Ruchti[a], R. Scalise[g], J. Schmitz[j], W. Shephard,[a], E. Shibata[j], J. Skeens[j], G.A. Smith[g], J. Solomon[a], J. Thomas[h], S. Tkaczyk[b], W. Toothacker[g], F. Vaca[a], D. Vandergriff [f], R. Wagner[b], J. Warchol[a], M. Wayne[a], and J. Whitmore[g]

(a) University of California at Los Angeles
(b) Fermi National Accelerator Laboratory
(c) University of Illinois at Chicago
(d) Massachusetts College of Pharmacy and Allied Health Sciences
(e) University of Notre Dame
(f) Oak Ridge National Laboratory
(g) Pennsylvania State University
(h) Philadelphia College of Pharmacy and Science
(i) Purdue University
(j) Rice University
(k) Superconducting Super Collider Laboratory
(l) University of Texas at Dallas

1. INTRODUCTION

- **SURVIVABILITY ISSUES**

  i) Long-term stability of components;

  ii) Radiation damage.

Reminder:

Detection elements (scintillating fibers) are passive, generating no heat, requiring no electrical services, coolants, or flammable gases in the tracking volume. Only an inert atmosphere (N_2) may be required.

Tracking volume contains only scintillating fibers and a portion of the clear waveguide fibers. All photodetectors (VLPCs and associated cryogenics) and read-out and trigger electronics are located outside the calorimeter in a low radiation environment.

S. MARGULIES/UIC
14 DEC. 1992

LONG-TERM STABILTY

CERN fiber-tracking systems (UA2, L3) have been in operation for several years.

Candidate fibers for SDC tracker, stored in darkness, show no changes after 1yr.

RADIATION DAMAGE

Because of the design geometry, potential risk is limited to scintillating and waveguide fibers.

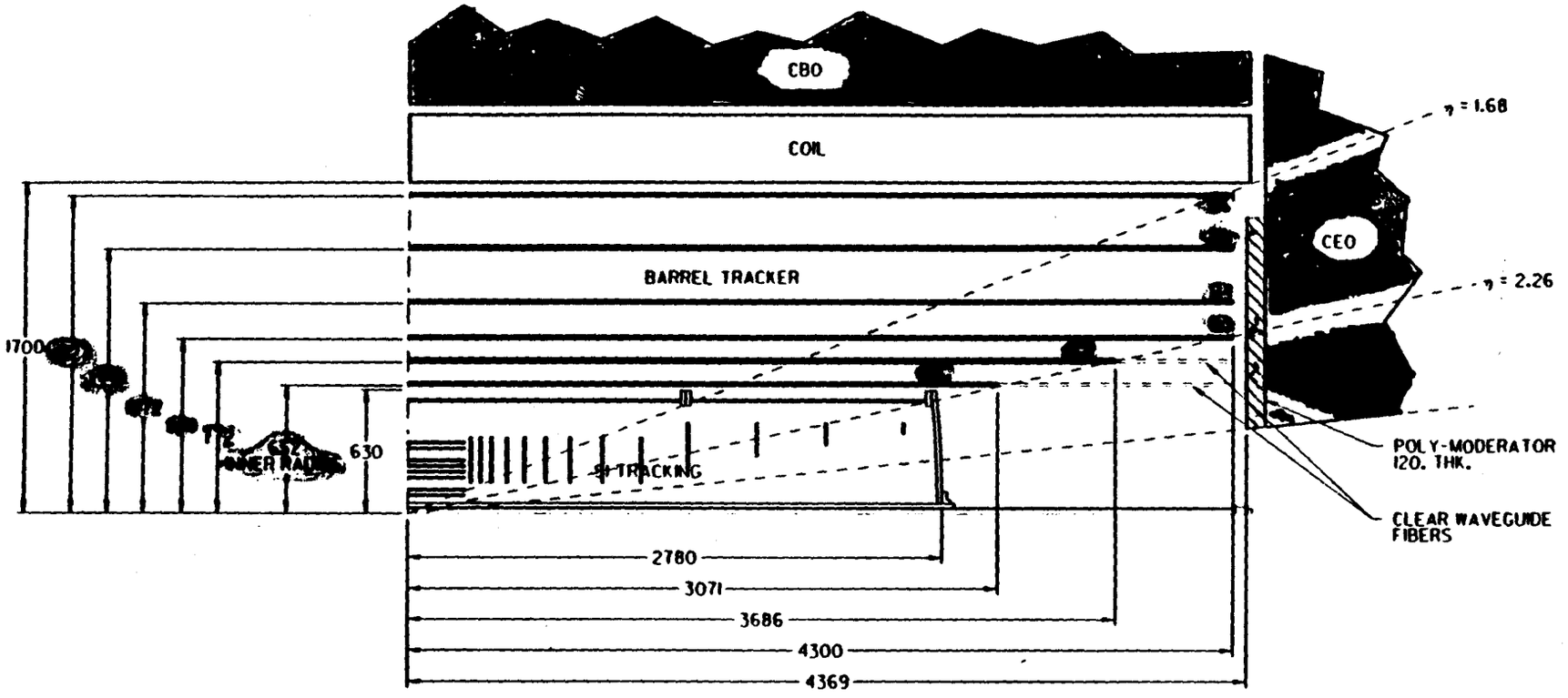
This talk will concentrate on

i) the SDC radiation environment, with estimates of doses, and

ii) effects of radiation on fibers, including experimental results.

Basic conclusion: while more work is required, radiation does not appear to pose a significant hazard, especially at $\mathcal{L} = 10^{33}\,cm^{-2}\,s^{-1}$.

S. MARGULIES/USC
11 DEC. 1992



DETECTOR GEOMETRY

Reference: SDC Detector Parameters, SDT-000010 (Rev. F), 14 Sept. 1992.

S. MARGULIES/UIC
11 DEC. 1992

DEFINITIONS

Time:

$$1 \text{ SSC yr} \equiv 10^7 \text{ s} = 2.8 \times 10^3 \text{ hrs};$$

$$1 \text{ SSC month} \equiv 1 \text{ SSC yr}/12 .$$

Radiation dose:

$$1 \text{ Gy} \equiv 1 \text{ J/kg};$$
$$1 \text{ rad} \equiv 100 \text{ ergs/g};$$
$$1 \text{ Gy} = 100 \text{ rad}.$$

2. SDC RADIATION ENVIRONMENT

INTRODUCTION

Radiation is produced by

i) directly ionizing particles resulting from collisions of beam particles, and including loopers, gammas, conversions, etc.;

ii) directly ionizing particles (mostly low-energy gammas and betas) from activation;

iii) indirectly ionizing particles, basically neutrons from the calorimeter albedo.

S. MARGULIES/UZC
11 DEC. 1992

DIRECTLY IONIZING PARTICLES

Particles from beam collisions

Reference: D.E. Groom, "Radiation Levels in SSC Detectors", Nucl. Instr. & Meth. A279, 1 (1989).

The SSC annual dose at a distance $r_\perp$ (in cm) from the beam due to charged particles from beam collisions at $\mathcal{L} = 10^{33}\ cm^{-2}\ s^{-1}$ is taken to be

$$D_{beam} = f\left(\frac{4 \times 10^5}{r_\perp^2}\right) \quad Gy \quad .$$

To account for loopers, gammas, conversions, etc., we conservatively take $f = 2$.

This gives the following doses:

Tracker Layer	$r_\perp$ (cm)	SSC Annual Dose	
		(Gy)	(Krad)
B1	65	190	19
B2	77	135	14
B3	89	100	10
B4	107	70	7
B5	135	44	4
B6	163	30	3

S.MARCULIS/U3
11 DEC. 1992

Particles from endcap calorimeter activation

Reference: R.W. Kadel, "Radiation Dose Profiles and Activation of the Endcap Calorimeter", SDC-92-176, 17 Jan. 1992.

Dose-equivalent rates at the endcap calorimeter face are given for 30 days of operation plus 1-day cooldown at $\mathcal{L} = 10^{34}\,\mathrm{cm}^{-2}\,\mathrm{s}^{-1}$:

$$10\,\frac{\mathrm{mrem}}{\mathrm{hr}} \text{ at } \eta = 2 \lesssim \dot{H}_{30d}(\eta) \lesssim 160\,\frac{\mathrm{mrem}}{\mathrm{hr}} \text{ at } \eta = 3$$

This must be converted to total dose after 1 SSC yr at $\mathcal{L} = 10^{33}\,\mathrm{cm}^{-2}\,\mathrm{s}^{-1}$.

First, calculate applicable average dose-equivalent rates assuming

i) neglect of 1-day cooldown;

ii) linearity with $\mathcal{L}$ (reasonable);

iii) linearity with operating time (probably an overestimate because of simultaneous formation and decays of activated states).

S. MARGULIES/UIC
11 DEC. 1992

This gives

$$\langle \dot{H}'(\eta) \rangle = \dot{H}_{30d}(\eta) \times \underbrace{\frac{1}{10}}_{\text{luminosity}} \times \underbrace{\frac{1}{3.15}}_{\text{SSC time}} \times \underbrace{6}_{\text{av. operating months}} ,$$

$$= 0.19\, \dot{H}_{30d}(\eta) .$$

The dose-equivalent rate is related to the dose rate by

$$\dot{H} = Q\, \dot{D} ,$$

where $Q = 1$ rem/rad since the activation radiation is mostly gammas and soft betas.

The annual dose is then

$$D^{\text{end cap}}_{\text{activation}} = Q^{-1} \langle \dot{H}'(\eta) \rangle \Delta t ,$$

$$= 0.19\, Q^{-1}\, \dot{H}_{30d}(\eta)\, \Delta t ,$$

$$= \begin{cases} 85 \text{ rads at } \eta = 3 \\ 5 \text{ rads at } \eta = 2 . \end{cases}$$

- These contributions are negligible.

S. MARQUES/UIC
11 DEC. 1992

Particles from fiber tracker activation

Reference: R. Barrall, UIC (private communication).

Dose from activation depends on

i) fluence rates of activating particles;
ii) activation cross-sections;
iii) density and amount of material;
iv) lifetimes of activated states;
v) activation decay energy;
vi) time.

Tracker consists mostly of polystyrene fibers, $(CH)_n$, $\rho = 1\,g/cm^3$, total mass $\approx 1.4 \times 10^3$ kg.

Principal activation comes from

$$^{12}_{6}C(\gamma, n)\,^{11}_{6}C\,, \quad E_\gamma > 20\,MeV,$$

with $^{11}_{6}C$ de-exciting via β^+ decay ($\tau_{1/2} = 20$ min, $E_{\beta max} = 0.96$ MeV).

- A rough calculation assuming 200 γs per interaction gives

$$D^{tracker}_{activation} < 1\,rad,$$

which is negligible.

INDIRECTLY IONIZING PARTICLES

Neutron albedo

References: D.E. Groom, "Radiation Levels in SSC Detectors", Nucl. Instr. & Meth. A279, 1 (1989);
H.F.-W. Sadrozinski, "Neutron Fluence in the SDC Detector Cavity", SCIPP 91/01, Jan. 1991.

Groom considers a uranium/scintillator calorimeter with a spherical cavity of 2 m radius down to $|\eta| = 3$ (6°) of the beam axis. At luminosity $\mathcal{L} = 10^{33}\,cm^{-2}s^{-1}$, the SSC annual fluence is

$$\Phi = 1.2 \times 10^{12} (1 + \text{no. reflections}) \quad (cm^{-2}).$$

The neutrons form a roughly uniform gas, whose kinetic energy distribution is approximately Gaussian in the log of the energy, with the peak at 1.3 MeV.

Using no. reflections = 1 and a correction factor of 1/2 for a lead/scintillator calorimeter gives

$$\Phi = 1.2 \times 10^{12} \quad cm^{-2}.$$

Sadrozinski corrects for the shape, using an 8.4-m-long × 2.05-m-radius cylinder having beam holes at 6°. He calculates fluences with and without a 10-cm-thick end-cap polyethelene liner (SDC liner is 12 cm).

Based on this work, we assume SSC annual fluences

$$\Phi = \begin{cases} 8 \times 10^{11}\ \mathrm{cm}^{-2} & \text{(no liner)}; \\ 4 \times 10^{11}\ \mathrm{cm}^{-2} & \text{(liner)}. \end{cases}$$

<u>Question</u>: How to convert radiation damage by neutrons to an equivalent charged-particle dose?

Naively, this is tabulated in handbooks:

- At 1 MeV: 1 neutron/cm^2 $\leftrightarrow$ 1.9×10^{-9} rad.

("Measurement of Absorbed Dose of Neutrons, and of Mixtures of Neutrons and Gamma Rays", NCRP Report No. 25, NBS Handbook 75, 3 Feb. 1961.)

S. MARAULIES/UIC
11 DEC. 1992

However, little data exist on the specific damage done by neutrons to plastic scintillator. Preliminary results from a new study indicate essentially no effect below $\sim 10^{13}$ cm^{-2}; damage above this fluence seems to vary with fiber type and manufacturer. (W.L. Dunn, et al., "Neutron/Photon Damage Assessment of Commercial Plastic Scintillating Fibers", to appear in the Proceedings of RADDAM 92, Tallahasee, FL.)

For the present, we use the handbook value which gives

$$D_{neutrons} = \begin{cases} 1.5 \text{ krad} & \text{(no liner)}; \\ 0.8 \text{ Krad} & \text{(liner)}. \end{cases}$$

This dose is independent of position.

TOTAL ANNUAL DOSES

Combining the previous results,

$$D_{Total} = D_{beam} + D^{end\,cap}_{activation} + D^{tracker}_{activation} + D_{neutrons}$$

$$\approx D_{beam} + D_{neutrons}.$$

S. MARGULIES/UCC
11 DEC. 1992

Tabulation of annual doses

Tracker Layer	$r_\perp$ (cm)	D_{beam} (Gy)	$D_{neutrons}$		D_{total}			
			Without	Liner	Without liner		Liner	
			(Gy)	(Gy)	(Gy)	(krad)	(Gy)	(krad)
B1	65	190	15	8	205	20.5	198	19.8
B2	77	135	15	8	150	15.0	143	14.3
B3	89	100	15	8	115	11.5	108	10.8
B4	107	70	15	8	85	8.5	78	7.8
B5	135	44	15	8	59	5.9	52	5.2
B6	163	30	15	8	45	4.5	38	3.8

Notes:
1. Generous factor of 2 for loopers, gammas, conversions, etc. included in D_{beam}.
2. Uniform neutron fluences of 8×10^{11} cm^{-2} (no liner) and 4×10^{11} cm^{-2} (liner) used.
3. Handbook conversion factor, 1 neutron/cm^2 $= 1.9 \times 10^{-9}$ rad, used.

S. MARCULIES/UCC
11 DEC. 1990

3. EFFECTS OF RADIATION ON FIBER

INTRODUCTION

Fibers used:

i) clear waveguide fibers
(polystyrene core, acrylic cladding)

ii) scintillating fibers
(same as clear fibers, but including waveshifters — currently p-terphenyl plus 3-hydroxyflavone; light output peaks near 530nm)

Justification:

Very little transmission loss beyond 500nm for polystyrene irradiated to more than 10 Mrad (500SSC yrs) after recovery in O_2.

pT+3HF are efficient waveshifters at these wavelengths.

Light output determined by

i) Light yield, I_0;

ii) Attenuation length, λ;

$$I(x) = I_0 e^{-x/\lambda}.$$

Radiation-damage possibilities

damage to: core
waveshifters
core-cladding interface

Possible variables (interrelated):

i) total dose (essentially no damage below ~200 Krad (10 SSC yrs));

ii) dose rate (especially in the presence of O_2, accelerated rates (>100 Krad/hr) may cause less damage than the same dose accumulated at actual detector rate; rate effect not present for irradiation in inert atmospheres, e.g., N_2);

iii) particle type (probably no difference, except possibly for neutrons — very little data);

iv) atmosphere, related to ii);

v) scintillator geometry, which affects gas diffusion;

vi) recovery after irradiation, related to iv) and v).

S. MARCULIES/UCC
11 DEC. 1992

EXPERIMENTAL RESULTS

Considerable work has been done, but more is still required.

Experiments irradiate either:

- bulk samples (generally cylinders 1 in. dia x 1 cm thick);
- actual fibers (~1 mm dia. x several m long).

Some results from bulk samples

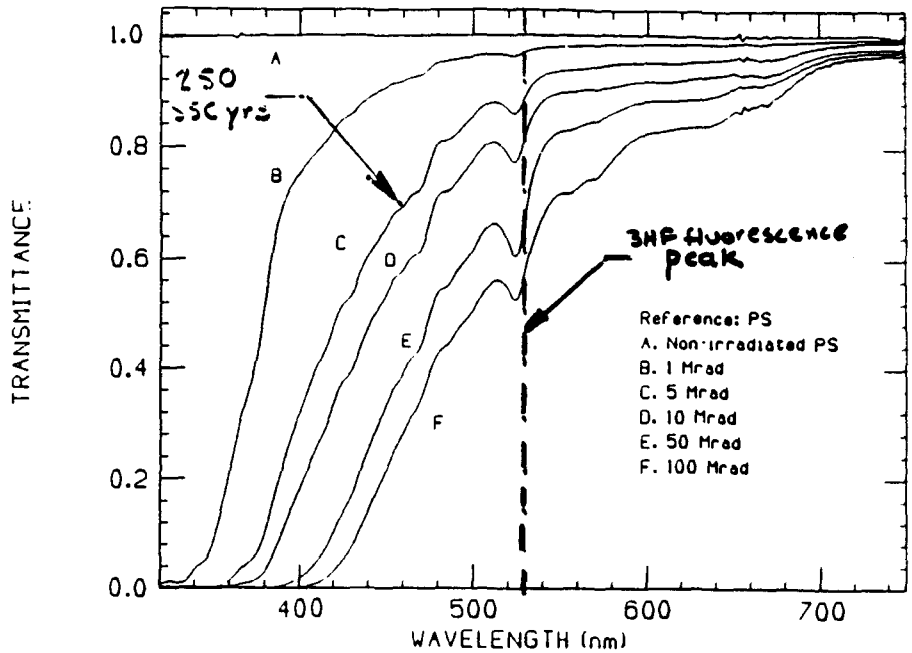
References:

A.D. Bross and A. Pla-Dalmau, "Radiatio Induced Hidden Absorption Effects in Polystyrene Based Plastic Scintillator," Am. Chem. Soc. Symposium Series, Oct. 1990.

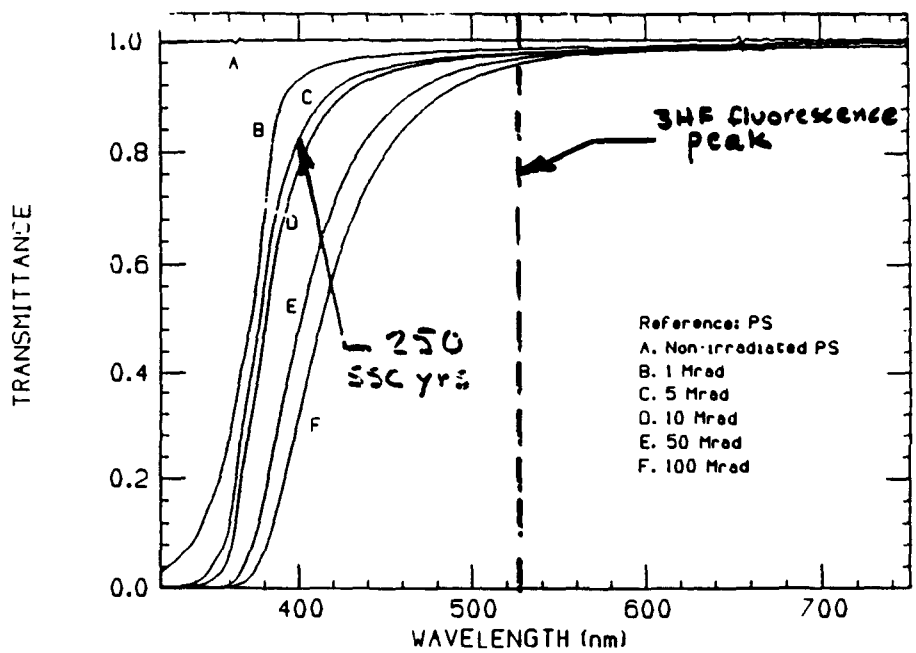
A. D. Bross and A. Pla-Dalmau, "Radiatio Effects in Intrinsic 3HF Scintillator," FERMILAB-PUB-92/247, 16 Sept. 1992.

WAVEGUIDES

Transmission through 1-cm-thick polystyrene irradiated in N_2.



Immediately after irradiation (gammas from ^{60}Co).

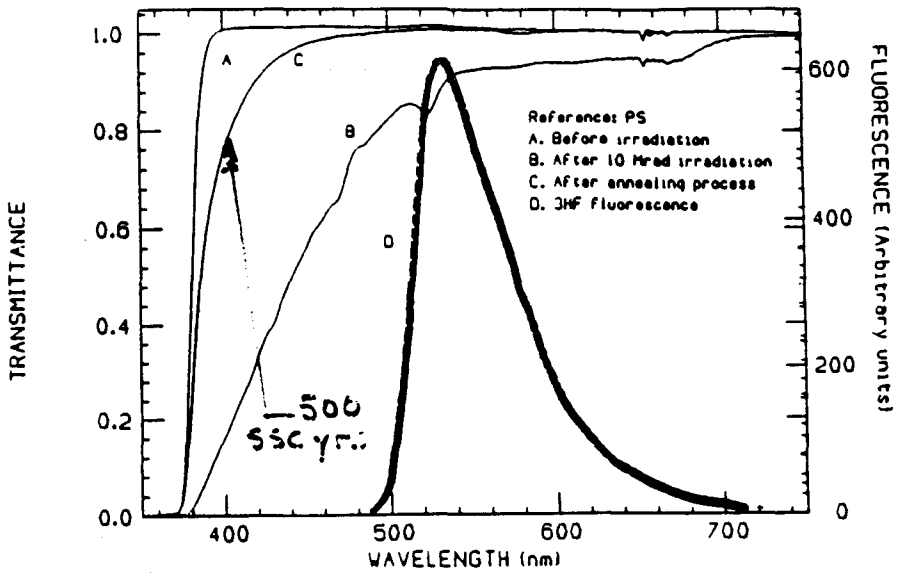


After 2 weeks in O_2.

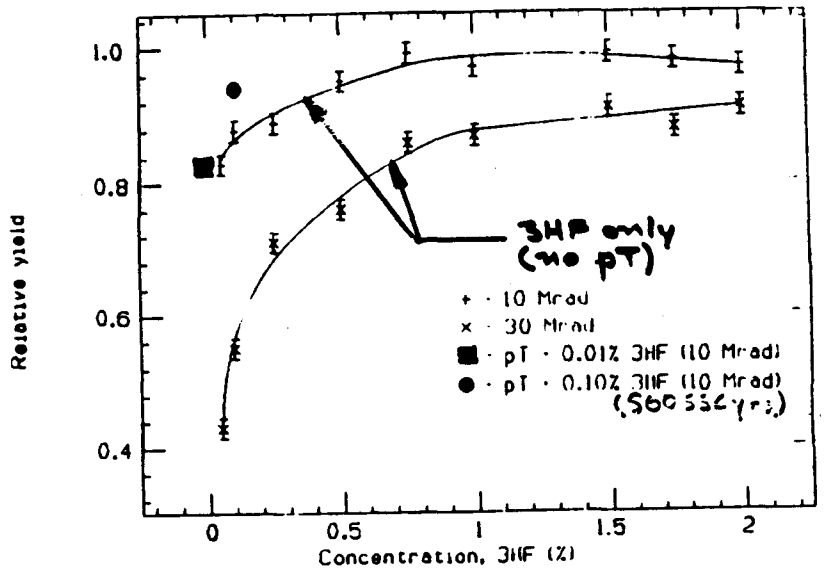
Conclusion: no problems with clear waveguide fibers anticipated.

SCINTILLATOR

Transmission through 1-cm-thick polystyrene + 1.25% pT + 0.01% 3HF scintillator:



Light yields, after recovery of 10 days in O_2 at 40 psig, for polystyrene-based scintillators with different waveshifter concentrations:



Sample with 1% pT + 0.1% 3HF shows only 6% light loss after 10 Mrad.

S. MARGULIES/UIC

Interpretation by authors:

i) No damage to waveshifters (even with 3HF crystals irradiated to 100 Mrad!).

ii) Light-yield loss due to "hidden" absorption in irradiated polystyrene, which interferes with $pT \rightarrow 3HF$ energy transfer.

iii) Transmission losses following irradiation due to absorption in damaged polystyrene. Much of this damage is cured in O_2 atmosphere (especially above 500 nm).

- Conclusion: no problems with scintillating fibers anticipated.

Some results from fiber samples

a. Low dose-rate studies

Reference:

B. Abbott, et al., "Effects of a Hadron Irradiation on Scintillating Fibers", submitted to IEEE Trans. Nucl. Sci.

S. MARGULIES/LZC
11 DEC. 1992

Experiment:

Fibers: 10 different fiber types from Bicron (polystyrene core, 830 μm O.D., 15-μm-thick acrylic cladding, 4 m long).

Fiber Type	Color	Dopants
BI-1	blue	pT + BBOT
BI-2	green	pT + BBQ
BI-3	green	0.6% 3HF
BI-4	green	pT + 3HF
BI-5	green	pT + BBQ
BI-6	green	pT + 3HF
BI-7	blue	pT + BBOT
BI-8	green	BPBD + BBQ
BCF-9905	green	pT + 3HF
BCF-10	blue	pT + DMPOPOP

Table I. Bicron fibers irradiated in this test. Abbreviations used: pT = p-terphenyl; BBOT = thiophene derivative; 3HF = 3-hydroxyflavone; BBQ = isoquinoline derivative; BPBD = oxadiazole derivative; DMPOPOP = phenyloxazol derivative.

Atmospheres: ambient air (atmospheric pressure)

dry air, dry N_2, argon } (15 psig)

vacuum (~ 0.2 torr).

Irradiating particles: hadrons from injection losses and aborts in Fermilab Tevatron CØ region.

Exposure: 49 days; doses to ~60 Krad (3 SSC yrs) at ~50 rad/hr.

Measurements: relative light yields; attenuation lengths.

S. MARGULIES/UIC
11 DEC. 1992

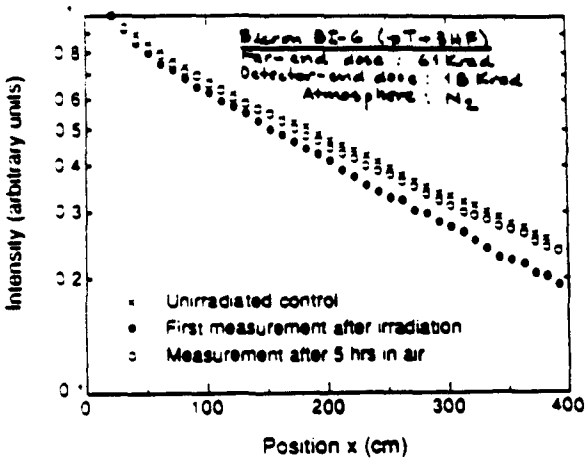
Results for pT+3HF fibers:

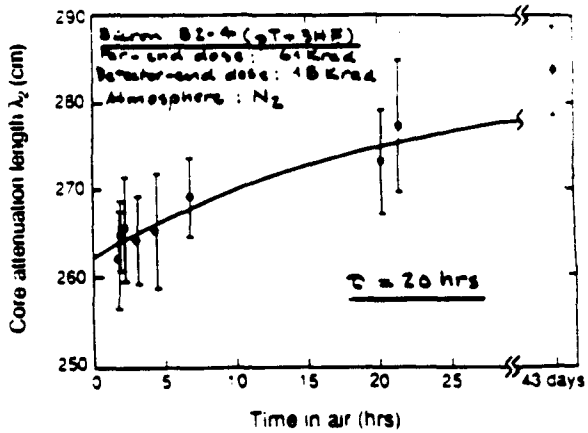
i) Light yield loss immediately after irradiation is smaller than measurement uncertainty of ~ ± 15%.

ii) Decrease of attenuation length immediately after irradiation is ~ 10%.

iii) Attenuation lengths recover fully after a few days in air.

iv) No change in properties of control fibers after 1 yr.





Recovery of attenuation length after exposure to air.

S. MARGULIES/UIC

b. High dose-rate studies

Reference: A. D. Bross, private communication.

Experiment:

Fibers: various green and blue fibers (polystyrene core, 830 μm O.D., acrylic cladding, 5 m long).

Atmosphere: N_2.

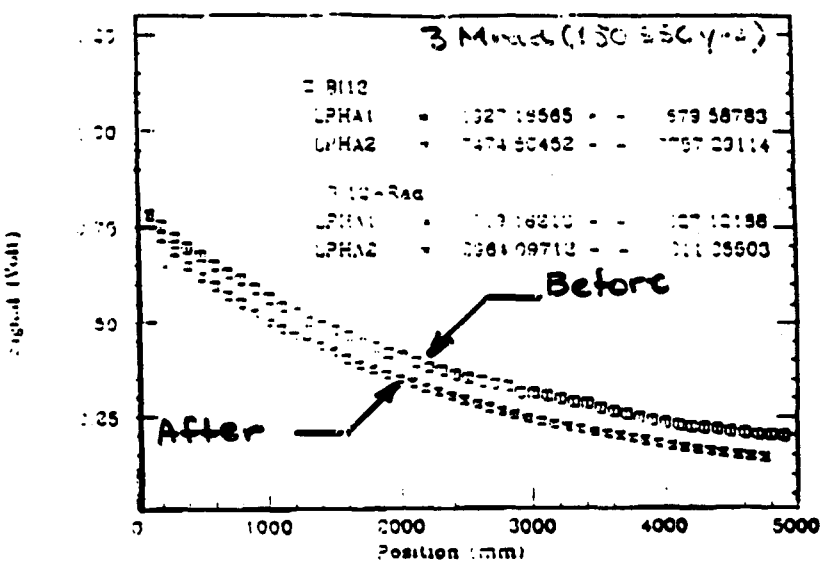
Irradiating particles: gammas from ^{60}Co.

Exposure: 3 Mrad (150 SSC yrs) over a few days.

Measurements: attenuation lengths after 2 weeks in O_2 at 20 psig.

Analysis is still in progress.

Measurement for a BI-12 (pT + 0.01% 3HF) fiber:



- Preliminary result: Attenuation length at $x = 5$ m has decreased by ~25%. For $\lambda = 6$ m, this corresponds to a relati light loss of 20% for light produced at 4 m.

S. MARGULIES/UIC
11 DEC. 1992

4. SUMMARY

- Worst-case annual radiation dose is ~ 20 Krad/SSC yr at $\mathcal{L} = 10^{33}\,cm^{-2}s^{-1}$.
  This is a relatively small dose for polystyrene + pT + 3HF fibers which seem to show no unrecoverable damage below ~ 200 Krad (10 SSC yrs).
- Clear polystyrene, after recovery in O_2, shows very little loss of transmission above 500 nm for doses up to at least 5 Mrad (250 SSC yrs). Thus, no problems with clear waveguides anticipated.
- Low dose-rate irradiation of scintillating fibers shows essentially no effects, after a few days recovery in air, for doses up to at least 60 Krad (3 SSC yrs).
- High-dose-rate irradiation of bulk samples of scintillator shows an unrecoverable intrinsic light yield loss of only 6% after 10 Mrad (500 SSC yrs).

S. MARGULIES/UIC
11 DEC. 1992

- Preliminary results from a high-dose-rate irradiation of scintillating fibers show ~25% decrease in attenuation length after 3 Mrad (150 SSC yrs).

  A similar experiment, using 6 MeV x-rays and doses to ~ 1 Mrad, will begin soon (UIC).

- Basic conclusion: SDC detector radiation levels do not appear to pose a significant hazard.

S. MARGULIES/UIC
11 DEC 1992