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Radiation Hardness Tests of Tile/Fiber Calorimeter Structures for SDC

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The radiation hardness properties of a calorimeter with different structures or with different materials used for the tile/fiber have been studied. Five calorimeter modules were irradiated to a maximum dose of from 1 Mrad to 6 Mrad using the BEPC electron beam (~1 GeV). Radiation damage is quantified using a measurement of the light yield in various locations within the calorimeter modules. A narrow collimated source system was built for the accurate measurement of the light yield uniformity across a scintillator tile.

1. INTRODUCTION

As a result of data taken last year(1) with four scintillator tile/fiber modules for SDC calorimeter R&D, a definite conclusion was made. The scintillator tile/fiber technique can be used in the SDC barrel calorimeter. The maximum ionizing dose at EM shower maximum for the SSC operating at a design luminosity of 10^{33}/cm^2.sec varies from 2.7 Krad/year to 6 Krad/year in the barrel region(2). The maximum total dose for 100 years operation in the barrel region is only 0.6 Mrad.

However, the dose at the inner edge of the end-cap calorimeter is 570 Krad/year, and one must design assuming that the SSC will operate at a luminosity of 10^{34}/cm^2.sec. It is therefore necessary to study how to decrease the radiation damage by selecting suitable tile/fiber materials or by trying different structures. The goal of this study is to provide proof that tile/fiber calorimetry will work in the SDC endcap region. Progress has been made, but that goal has not yet been realized.

Two kinds of fiber grooves, a multifiber module, and different materials for the tile/fiber assembly were studied in this experiment. The test beam, experimental apparatus, and procedure are the same as described previously in Ref. 1. The main elements used in the test were:

Radiation Source: BEPC (Beijing Electron Positron Collider) 1.1 GeV to 1.3 GeV electron beam

Dose Monitoring: The BCT (Beam Current Transformer) measured the integrated electron flux. The conversion from incident electron flux to dose in Mrads at shower maximum is calculated to be, 1.0 rad = $3 * 10^6$ e/cm^2. That means we define 1.0 Mrad to be $3 * 10^{12}$ e/cm^2 at 1.1 or 1.3 GeV irradiating the front surface of the module.

The modules were mounted on a moveable table, which is motorized and capable of motion in both the horizontal and vertical directions in order to provide for uniform irradiation. The measurement of radiation damage was accomplished using a moving radioactive source. The source has a remotely actuated driver capable of pushing a fine wire carrying a radioactive source through any one of 26 fine tubes which pass through 6 longitudinal (L1:L6) and 20 transverse (T1:T20) direction of the test module. The signal output then measures the radiation damage in the vicinity of the source. Wires oriented along the beam axis of a module are called longitudinal (EL), while those oriented transverse to the beam are called transverse (ET).

It is impossible to accurately measure fine details in the uniformity across a tile surface with this source since it is not collimated (11mm spread). For the uniformity measurements, a narrow collimated source (size ~ 1.3 mm) was built. All five modules discussed in this paper were kept in air. Studies with different atmospheres were prevously made and reported in Ref. 1.

2. CALORIMETER MODULES

A "standard" module consists of 21 Pb plates of absorber, interspersed with 20 scintillator tiles.[(1)] The five modules herein reported have the following properties:

(1) The Wave Length Shifting (WLS) fibers used in Ref. 1 were 60" in total length BCF91 meanufactured by Bicron Co. without splicing to clear fibers. For this test the fibers are BCF91A, which is spliced to a high-transmittance clear fiber. Each WLS fiber used in Modules #1, #2 and #3 is 22" long, spliced to a Kuraray clear fiber of 20" in length.

(2) The fiber groove of tiles in Module #2 is a half keyhole shape (semi circle groove as shown in Fig. 1b) machined by Florida State University group[(3)]. They used a higher speed (a rotation speed of 20,000RPM and a feed rate of 6"/min) to achieve better surface quality. The fibers were loaded from the top of the tiles therefore applying less stress and avoiding the four 90 degree turns while being inserted to tiles. All others have a keyhole groove as shown in Fig.1a, machined at Fermilab with a rotation speed of 26,000 RPM coupled to a feed rate of 180"/min.

(3) Module #8 has 9 straight line fibers imbeded per tile and is called the multifiber module = MFM (see Fig.1(c)). Each BCF91A fiber is 6" long and spliced to a 15" long clear fiber. The other end of the WLS fiber is polished.

(4) The materials used in Module #3 are green emitting tiles (SCSN81 dopped with 100 ppm of Y7) and orange scintillating fiber (polystyrene dopped with 3HF and O2) spliced to clear fibers.

(5) The edges of tiles were painted with a reflective coating (BC620). The tiles were wrapped with aluminum foils.

The parameters of the five modules reported on here are listed in Table 1.

Table 1. Parameters of the Test Modules

MODULE	TILE	FIBER	PMT	Groove	DOSE Mrad	e BEAM (GeV)
Mod #1_Run2	SCSN81 (Blue)	BCF91A(Green)+Clear	XP-2081B (Extended	keyhole	1	1.3
Mod #2_Run2	SCSN81 (Blue)	BCF91A(Green)+Clear	Green)	half-keyhole	1	1.3
Mod #3_Run2	SCSN81+Y7(Green)	3HF/02(Orange)+Clear		keyhole	1	1.3
Mod #8_Run2	SCSN81 (Blue)	BCF91A(Green)+Clear (MFM)		keyhole	6	1.1
Mod #5_Run1	SCSN81 (Blue)	BCF91(Green)	XP-2020	keyhole	6	1.1

3. CALIBRATION AND DATA TAKING

(1) Absolute Calibration Technique

The current output of the PMT (Photomultiplier Tube) is taken as a measurement of the radiation damage at various positions within the module. This current was measured using the DSP2032 autoranging scanning DVM (Digital Volt Meter), which measured the voltage at the output resistor of the PMT during the motion of the source within the module.

The absolute output of the PMT was monitored using an ^{241}Am source covered by a small piece of BC408 scintillator, which was embedded in the "cookie" (Fig.2a). The ^{241}Am source is about 20 - 100 nCi. The function of this source is to monitor the stability of the PMT and the coupling of the cookie to the PMT . Thus, we can check the assumption used in measurements using the moving source. A typical oscilloscing trace of the ^{241}Am induced pulse is shown in Fig.2b.

(2) Relative Calibration -- first and second normalization

The longitudinal non-uniformity in a module due to the tile-to-tile light output variation and the length variation of clear fibers from front to back of the stack was not corrected. Therefore, before irradiation, a longitudinal scan of the 20 tiles in depth was made. This scan was used to normalize the damage data to preirradiation values for each tile (first normalization).

The second normalization refers to normalizing the current to the data of tile #20 and defining damage there to be negligible. This method is adopted although there is an absolute calibration because the absolute calibration with the ^{241}Am source is done simply by viewing a pulse on an oscilloscope which is not very accurate. It is also possible that the coupling of the small scintillator to the PMT is not really the same as the coupling of the fibers to the PMT. The second normalization also removes the effect of a possible damage to the transmitting fibers. According to a Monte Carlo calculation, tile #20 should get a negligible dose with 1.1 or 1.3 GeV electrons incident on the test module. As will be seen later, these two methods of first and second normalization agree at the 10% level, after annealing and recovery.

(3) Background and Irradiation

The PMT current "background" is defined to be the sum of the pedestal plus the dark current. This data was taken in a short run (200 samples per run) before and after every measurement of a module, when the source was in the "garage" (a shielded lead box). The average value of the 400 samples was defined to be the background. This background was subtracted from the source data for each source tube of a module.

The irradiating steps for Module #1, #2 and #3 were 0.1, 0.1 and then 0.2 Mrad per step. The accumulated dose was therefore 0, 0.1, 0.2, 0.4, 0.6, 0.8 and 1 Mrad. The data were taken more than 8 hours after irradiating. The background was observed to be stable. An exception occured during the measurement period of one module. In that case, background data taken during the data measurement period was used for the different source tubes of a module.

4. RESULTS AND DISCUSSION

(1) Comparison between Module #1 and Module #2 --- Study of the Fiber Groove

Since the optical coupling between the tile and the fiber is a crucial part of the calorimeter in defining performance, different groove shapes and surface qualitiy of grooves were tested.

Shown in Fig.3 (a,c) and (b,d) are PMT currents when the source was scanned transversely across tile #2 (T2) and longitudinally along all tiles (L2) for Module #1 and #2 separately. The points shown in Fig.3 (a,c), where the output drops by 50% as compared to the value at the center, correspond to the positions of the edges of the tiles. The 20 peaks observed in Fig.3 (b,d) correspond to the 20 tiles of a module. In Fig.3 (b,d) the data before irradiation at 0 Mrad, immediately after irradiation at 1 Mrad and after a 6 day recovery period are shown.

Fig.4 shows the depth profile of damage (a,b) after irradiation at each dose step and (c,d) at 1.0 Mrad dose recovery as a function of time after irradiation. For Module #1, Fig.4 (a,c), data are normalized to preirradiation values while for Fig.4 (b,d) data are normalized to tile #20.

Fig.5 shows the 6 day recovery curves inferred from a transverse scan of the tiles of Module #2. In Fig.5 (a) data is normalized to preirradiation values, while in Fig.5 (b) data is normalized to tile #20. Clearly at tile 20 the two normalization methods differ by about 6%. Note that the clear fibers were not shielded. That may explain why tile #20 appears to be damaged by 6%.

For comparison, the results of longitudinal scans L1, L2, L5, L6[1] and a transverse scan at shower maximum for Module #1 and #2 are listed in Table 2. The relative outputs from the transverse scan are slightly less than the outputs of the longitudinal scan. A possible explanation is that the L scans couple better to the fiber than the T scans (see Fig.1) so that T scans probe scintillator attenuation more than L scans. The output of Module #2 is slightly larger than Module #1, but the results for Module #1 and #2 are clearly the same within errors. Even though the absolute light yield for Module #2 is slightly higher than that from Module #1, the two different kinds of fiber grooves in both shape and surface quality give indistinguishable performance under irradiation.

Table 2. The Damage and Recovery of Modules #1 and #2

MODULE #1

Dose (Mrad)	Normalized	L1	L2	L5	L6	T2
1	0Mrad	0.573	0.567	0.583	0.571	0.564
	T20	0.677	0.622	0.678	0.688	0.655
6 Day Recovery	0Mrad	0.652	0.648	0.658	0.650	0.640
	T20	0.712	0.694	0.709	0.704	0.685

MODULE #2

Dose (Mrad)	Normalized	L1	L2	L5	L6	T2
1	0Mrad	0.619	0.613	0.605	0.604	0.595
	T20	0.698	0.685	0.681	0.678	0.669
6 Day Recovery	0Mrad	0.700	0.694	0.689	0.678	0.666
	T20	0.734	0.730	0.727	0.716	0.707

(2) Comparison of Module #3 and #1 -- Longer Wavelengths

The difference between Module #3 and #1, shown in Table 1, is in the materials used in the tile/fiber assembly. The structure is exactly the same. The idea of constructing and testing Module #3 was to operate at longer wavelengths where radiation damage is known to be less[4].

Due to the rapidly falling QE curve of PMT (QE ~ 7 % at orange color), the output, the absolute current of the PMT, of Module #3 (see Fig.3) is much smaller than the output of Module #1. In order to make an accurate comparison of signal output, $\overline{T}$ is calculated as the average of the output values of the tile scans at the centers of tile #1, 2, 4, 6, 8, 10, 12, 15, 18 and tile #20 before irradiating. The $\overline{T}$ of Module #1 is 11.1 MA, while Module #3 has a $\overline{T}$ of 2.63 MA. The quantity $\overline{L}$ is the average of the 40 peak values from the L2 and L5 source scans. The $\overline{L}$ of Module #1 is 3.51 MA and Module #3 is 0.84 MA. The $\overline{T}$ / $\overline{L}$ ratio is 3.16 for both Module #1 and #3. The absolute calibration with an ^{241}Am source showed that the amplitudes of the ^{241}Am source signals were 324 mV and 326mV for Module #1 and #3 respectively. Therefore, we conclude that the absolute output of Module #3 is only 24% that of Module #1.

For comparison of damage, we used the relative output. Fig.6 shows the damage curves from the transverse scans of the tiles of Module #3, (a) normalized to preirradiation values (0 Mrad), (b) normalized to T20. Note that the discrepancy in the two normalizations seen in Fig.6 may indicate damage to the orange fibers. The relative outputs of Module #3 at shower maximum are listed in Table 3.

Table 3. The Relative Outputs at Shower Maximum for Module #3

MODULE #3

Dose (Mrad)	Normalized	L1	L2	L5	L6	T2
1	0Mrad	0.439	0.429	0.430	0.426	0.427
	T20	0.581	0.574	0.583	0.579	0.569
7.5 Day Recovery	0Mrad	0.554	0.541	0.542	0.528	0.528
	T20	0.668	0.643	0.645	0.628	0.631

In comparison with the values of Module #1 (Table 2), the relative outputs of Module #3 are somewhat less. Thus, Module #3 not only has much smaller absolute light yield but also has slightly larger damage. A comparison of Fig.6a and Fig.6b also leads to the suspicion that the scintillating fibers used in this test are more radiation soft. However there was a more positive result shown by Tsukuba group using tiles dopped with 3HF and read out by WLS fibers which contains only O2 dye[5]. Studies will continue with these and other candidates operating at longer wavelength.

(3) Module #8 (MFM) -- Study of Module Structure

First, the data at a total dose of 1 Mrad can be compared with that of Module #1, because both modules are built with the same materials. The difference between modules is only that the number of fibers per scintillator tile is much larger (Fig.1c). The idea behind building and testing this module is to reduce the optical path length at short wavelengths, i.e. in the tile. The relative outputs at shower maximum using T20 normalization for Module #1 are 0.665 (at the center of tile), 0.694 from the L2 scan and 0.707 after 6 days recovery. For Module #8, the relative outputs are 0.872 at the center of the tile and 0.877 for the L2 scan (no recovery data). Clearly, radiation hardness of Module #8 is better than that of Module #1. Encouraged by this result, Module #8 (MFM) was irradiated up to 6 Mrad. The data for Module #8 can be compared to data for Module #5 used in a previous test (Ref. 1). This module was kept in air during irradiation up to 6 Mrad. Fig.7 is the depth profile of the relative light yield of Module #8 (MFM).

The output of Module #5 normalized relative to preirradiation values, at shower maximum immediately after 6 Mrad, is only 0.065. By comparison for Module #8, it is 0.383, 5 times larger than Module #5. (See Appendix)

The relative output normalized to T20, at shower maximum for Module #5, is 0.207 after a 30 day recovery period. For Module #8, the output is 0.47 immediately after 6 Mrad irradiation. There appears to be little recovery of the MFM after 12 days.

(4) Data Fitting

We have attempted to find a simple parametrization of the data. The idea is to have a single parameter characterizing radiation hardness. The formula [6], relative output = 1 - damage = $e^{-D/Do}$ was used to fit the damage data. D is the accumulated dose, while Do is a quantity characterizing the radiation hardness of a calorimeter. The dose Do is the radiation dose when the damage at EM shower maximum is 63% or the relative output has dropped to 37%. Shower maximum is at tile #3 in our experiment. Fig.8 shows the damage data and the fit. The data comes from the respone of tile #3 to the L2 scan. The fit is excellent except at small dose. The characteristic doses Do, are 3.8 Mrad and 8.5 Mrad for Module #5 and Module #8 respectively.

(5) Transverse Uniformity of MFM Tiles

A narrow collimated source (^{90}Sr is a radioactive source 1.3 mm wide and 5 mm long with a narrow slot parallel to the fiber in the tile) is scanned across the tile in the vertical direction with uniform speed. This source is used to study the uniformity across a tile in more detail than is available with the physically larger and diffuse (γ) ^{137}Cs source used in previous scans. Shown in Fig.9 are the outputs at various positions (x) across tile #2 of Module #8, (a) at various doses with the normal ^{137}Cs source (11 mm) and (b) preirradiation data with the 1.3 mm source. The non-uniformity at the region near the 9 fibers is very clear. Clearly, more R&D is needed to optimally deploy the fibers or "mask" the tile to achieve more uniform light output as a function of transverse position.

5. SUMMARY

(1) Existing commercial scintillator (SCSN81) and fiber (BCF91A) are suitable for the SDC barrel calorimeter.

(2) The type of fiber groove or surface quality are not important.

(3) Initial attempts to go from tile/fiber = blue/green to green/orange have not been successful due to large damage in scintillating fibers. This test will be repeated using 3HF tiles and O2 WLS fibers.

(4) The MFM structure increases the radiation hardness of a module. This structure is thus a candidate for part of the SDC end-cap calorimeter.

(5) The transverse uniformity of the MFM tiles needs to be improved. Further research is in progress.

REFERENCES

1. L. Hu et al.
Radiation Damage of Tile/Fiber Scintillator Modules for the SDC Calorimeter
SDC-91-119 or Fermilab-TM-1769 (1991)

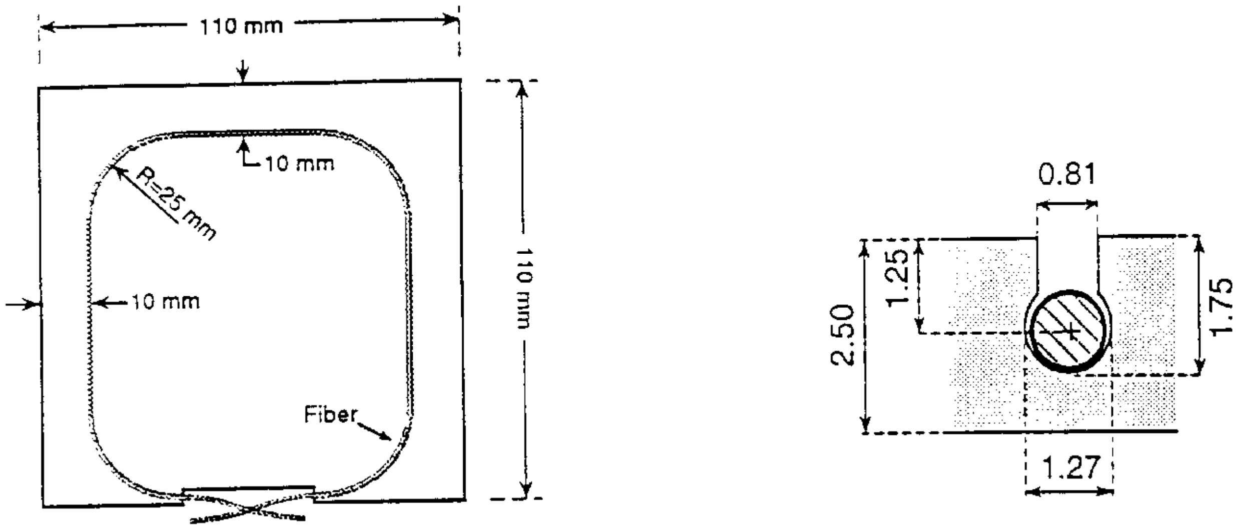
2. Letter of Intent by SDC (Nov. 30, 1990)
SDC-90-00151, Page 7

3. M. Bertoldi et al.
Machining of Scintillator tiles for the SDC Calorimeter
SDC-92-289

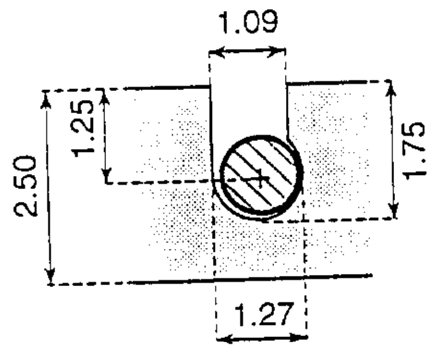
4. A. Bross and A. Pla
Radiation induced hidden absorption effects in polystyrene based plastic scintillator
Fermilab-Pub-90/224

5. K. Hara et al.
Radiation hardness study of scintillating tile/fibers
SDC-92- 186

6. D. Green and A. Para
Radiation Damage, Calibration and Depth Segmentation in Calorimeters
FN-565 (1991)



(a)



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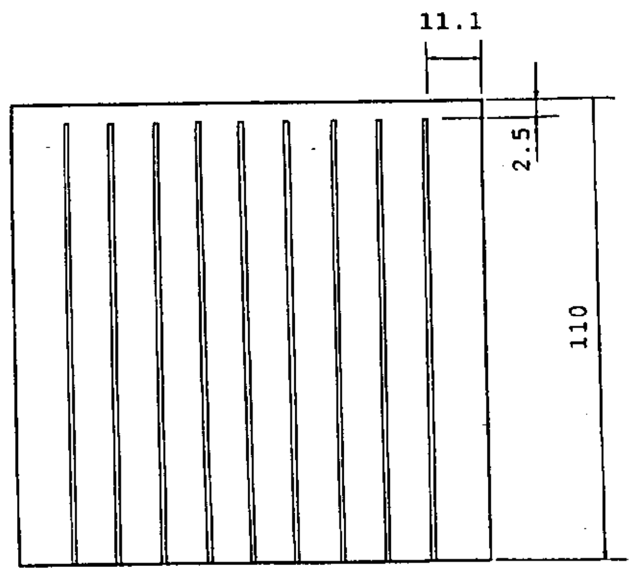
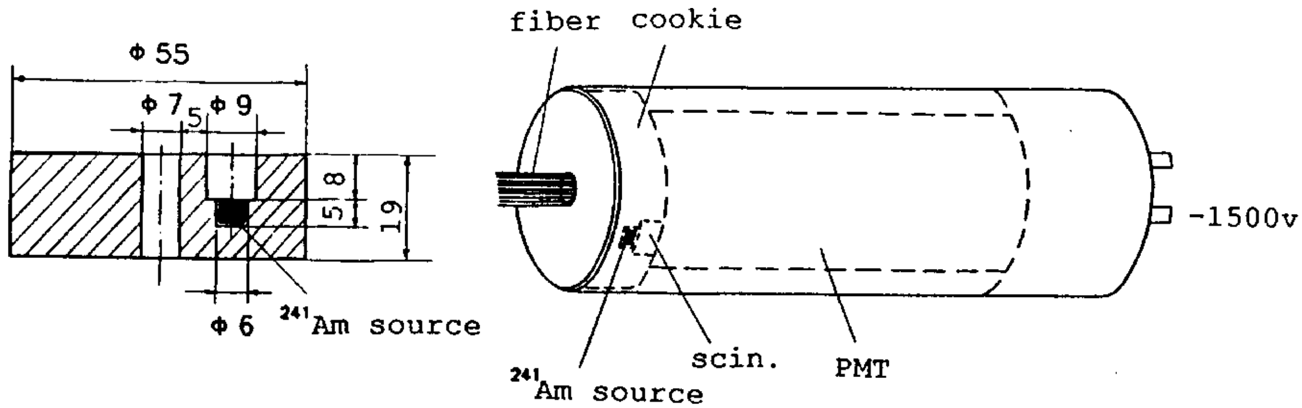
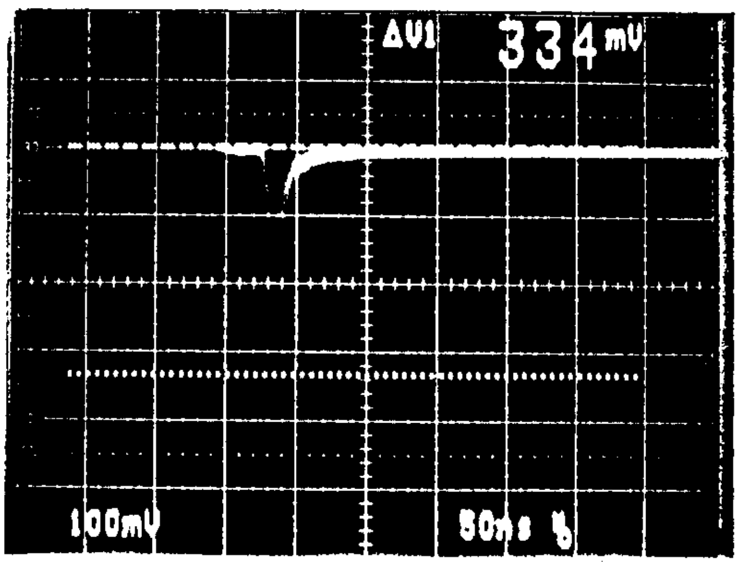


(c)

Fig. 1 Structure of Modules
(a) Normal Fiber Arrangement and Key Hole Fiber Groove
(b) Half Key Hole Fiber Groove
(c) Groove pattern of a tile in a Multifiber Module (Mod #8), (MFM)



(a)



(b)

Fig. 2 (a) Coupling the Fibers and the ^{241}Am Source to the PMT through the "Cookie"
(b) Absolute Calibration Data using ^{241}Am Pulses

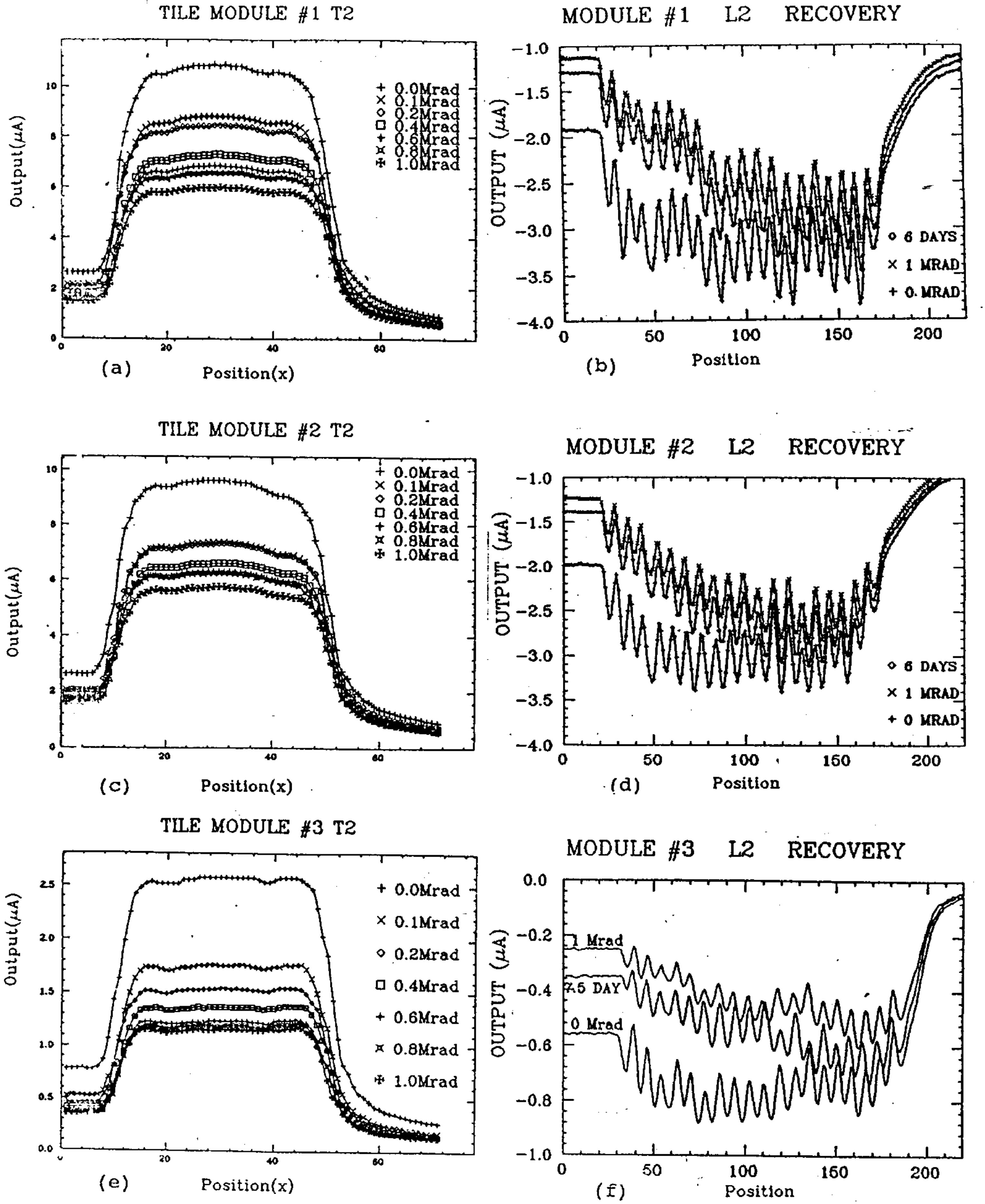


Fig. 3 Outputs at various positions (x) across Tile #2 (a,c,e), T2 Scan. Longitudinal Scan (y) along 20 layers of scintillator (b,d,f), L Scan, for Modules #1, #2 and #3

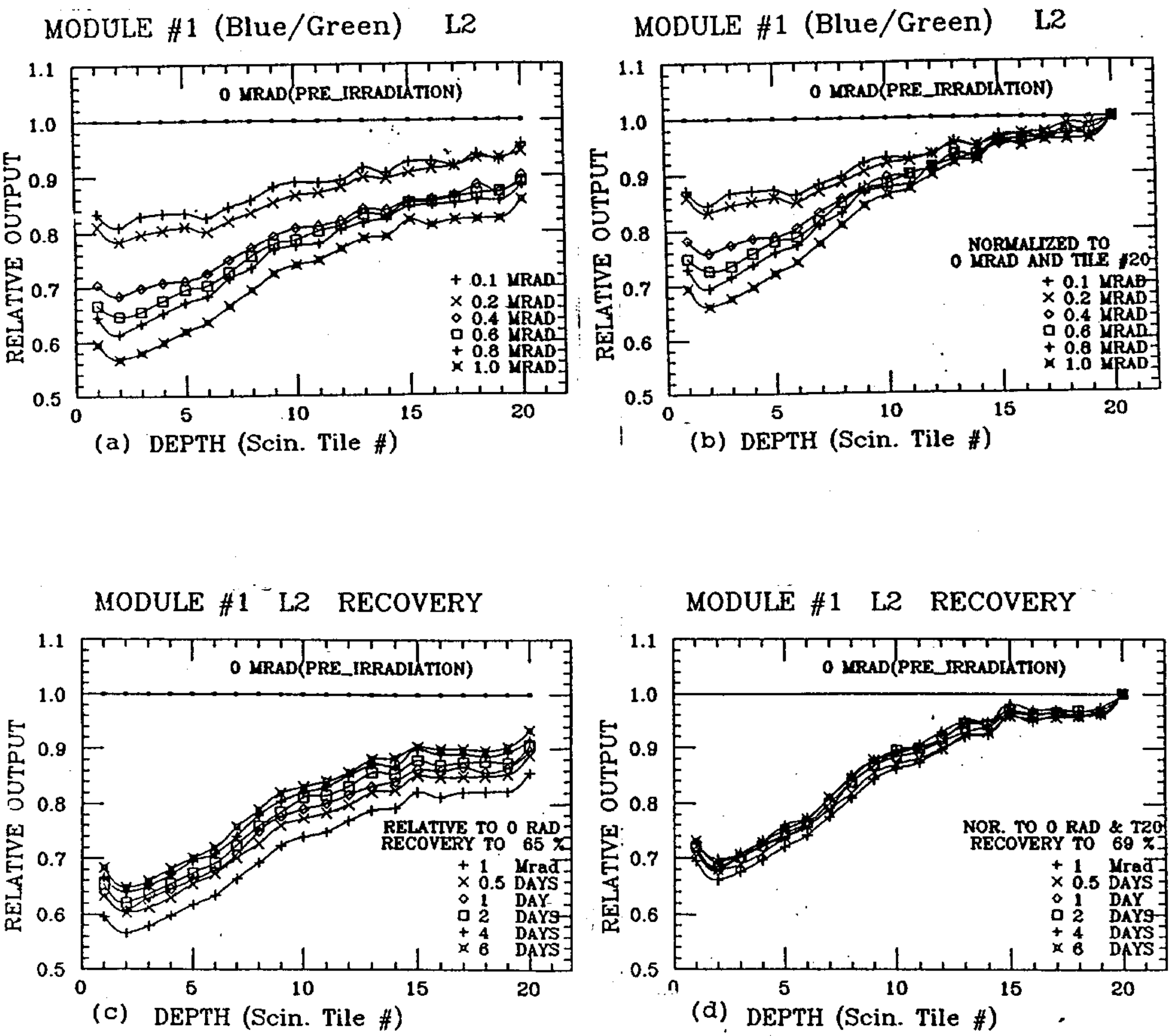
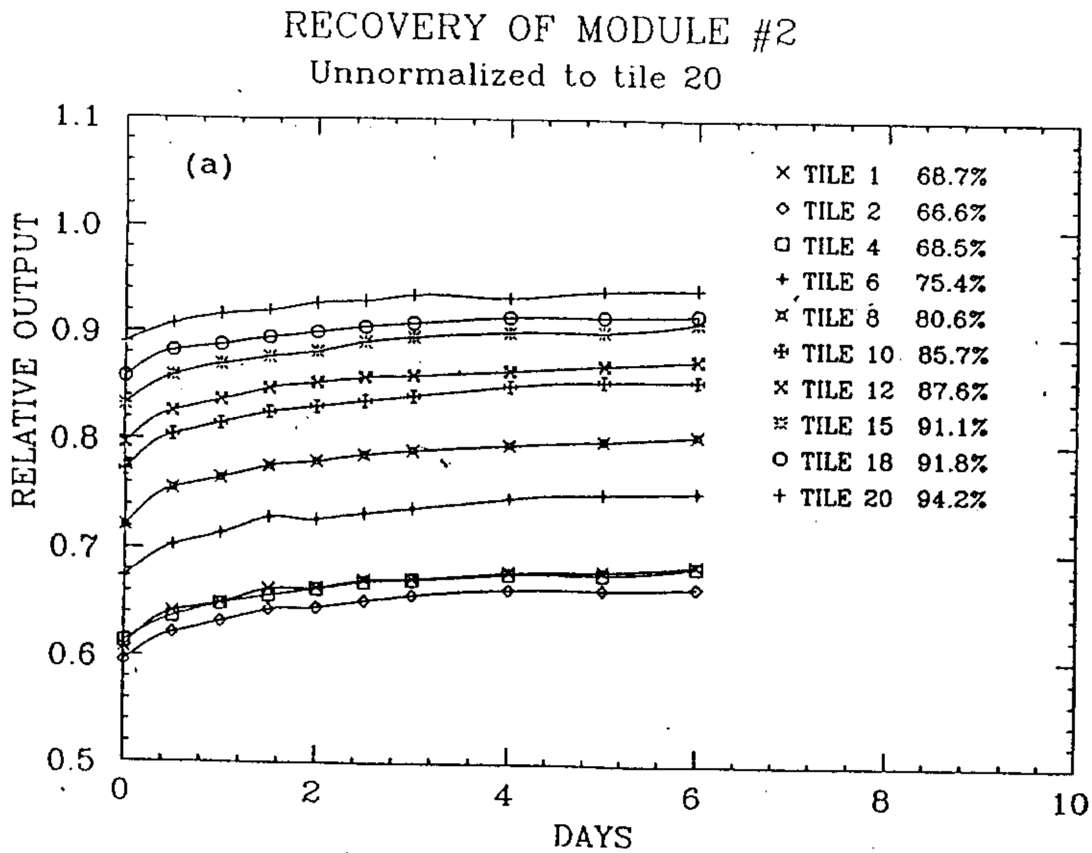


Fig. 4 Depth profile of damage (a,b) and recovery (c,d) for Module #1
(a) (c) Normalized to Pre-irradiation
(b) (d) Normalized to Pre-irradiation and T20



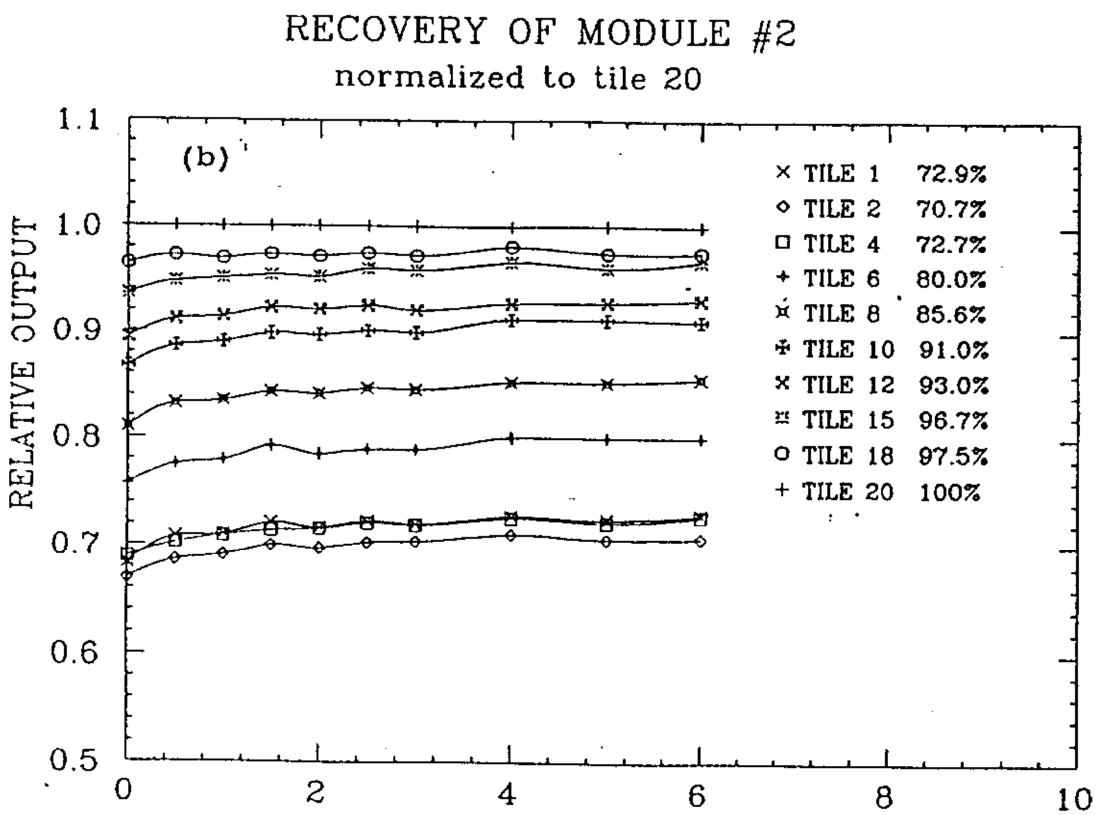


Fig. 5 Recovery Curve from Transverse Scan of Module #2
(a) Normalized to 0 Mrad
(b) Normalized to 0 Mrad and T20

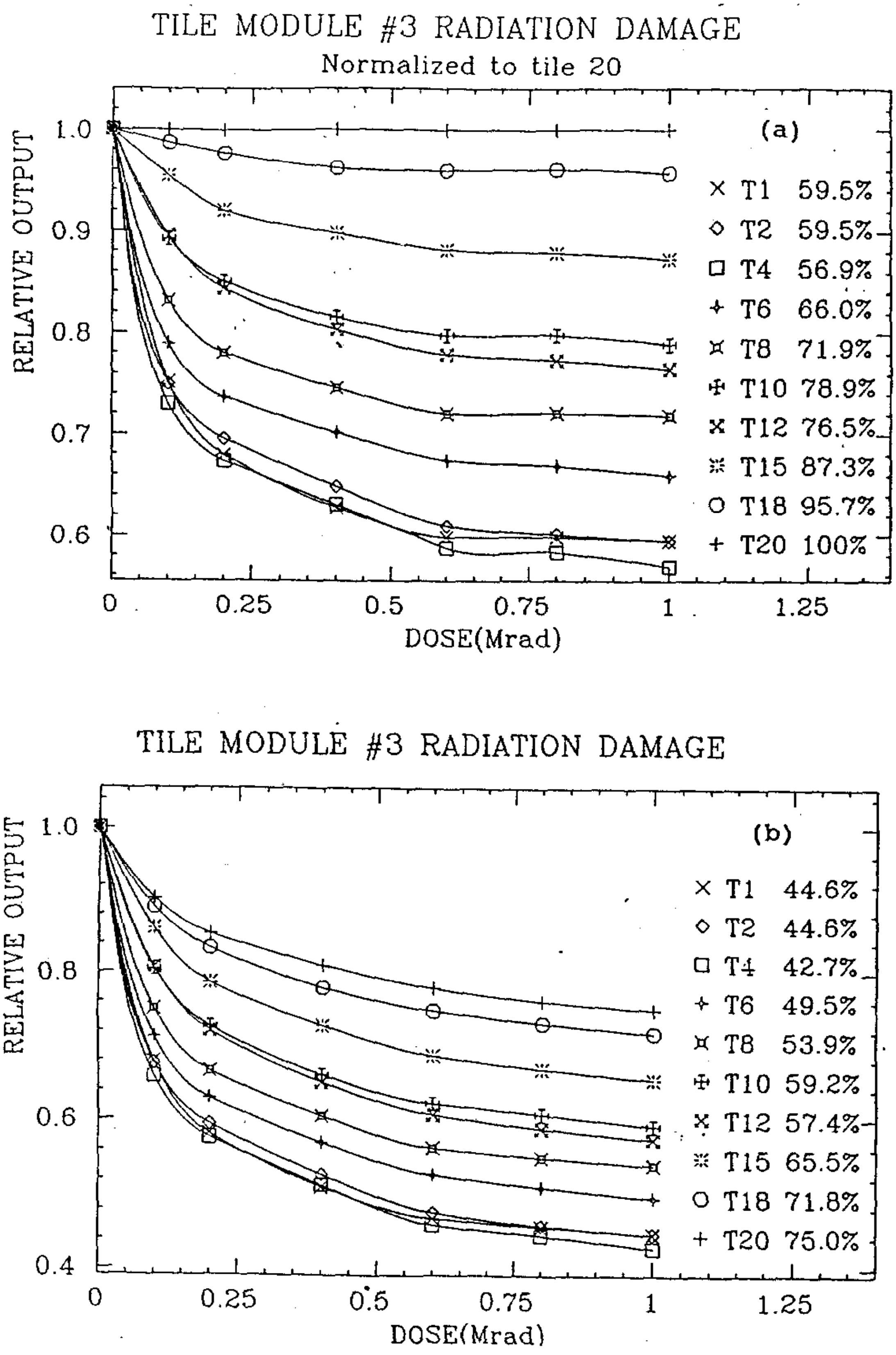


Fig. 6 Damage Curve from Transverse Scan of Module #3
(a) Normalized to 0 Mrad
(b) Normalized to 0 Mrad and T20

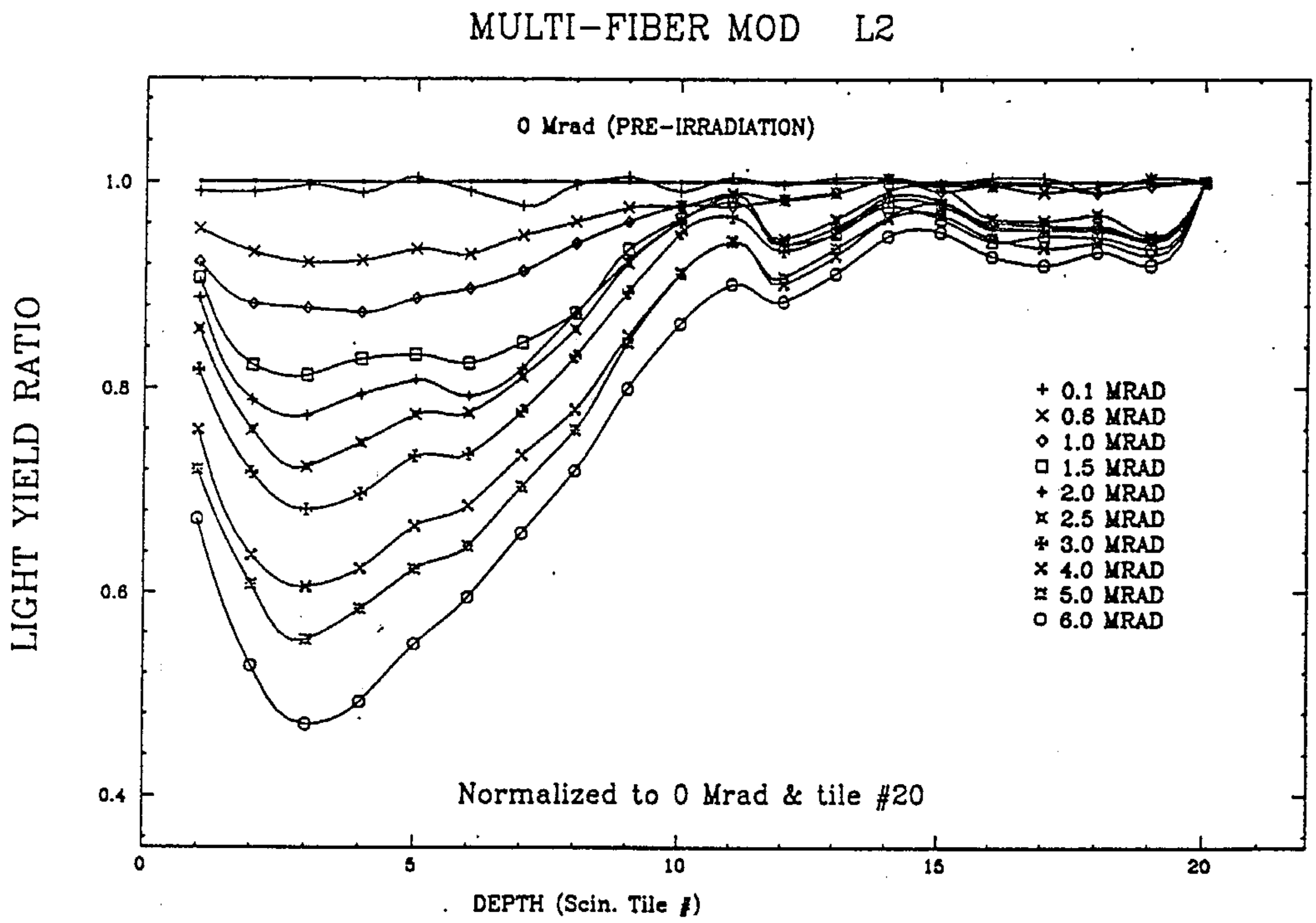


Fig. 7 Depth Profile of Damage for MFM (Mod #8) Normalized to T20

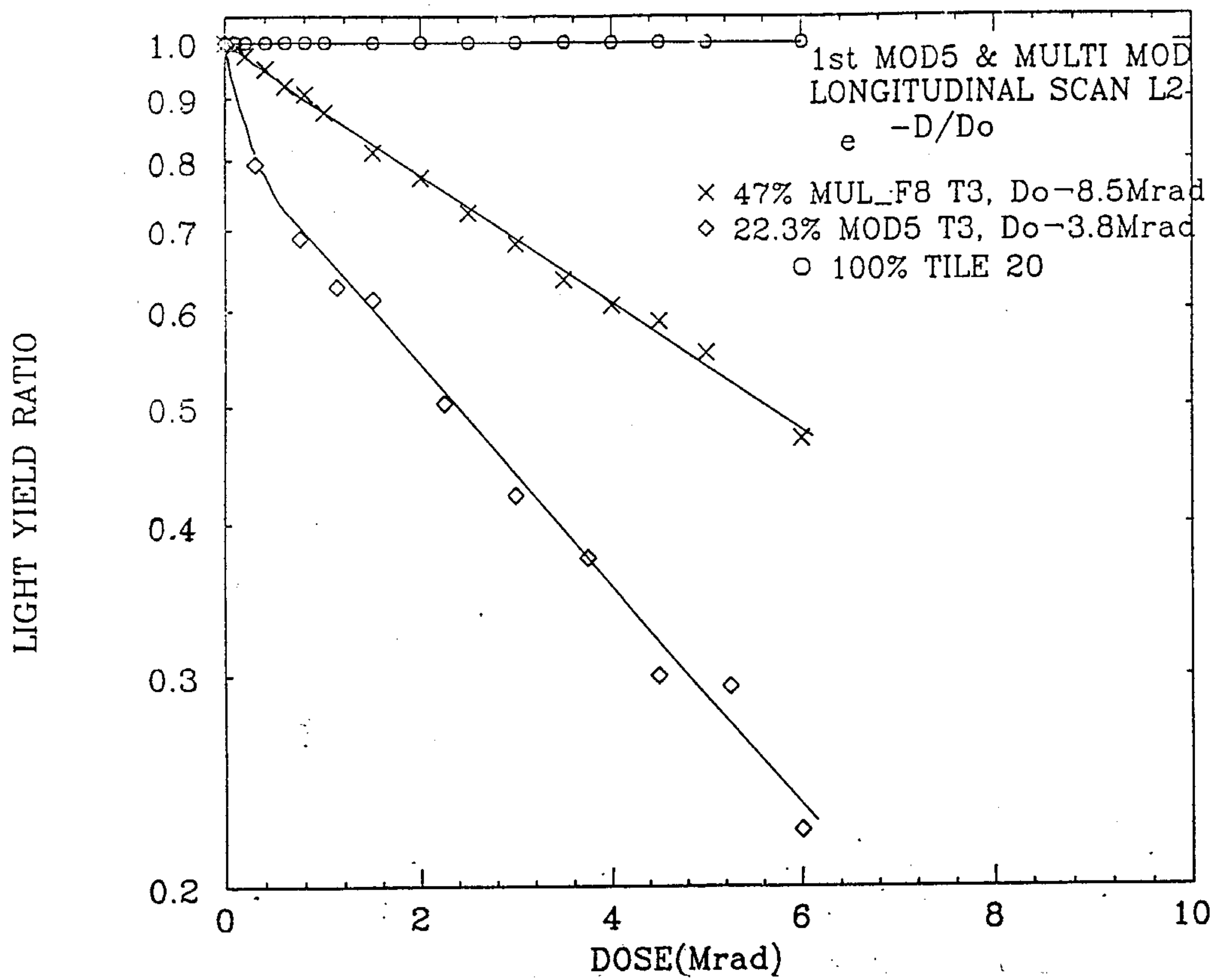
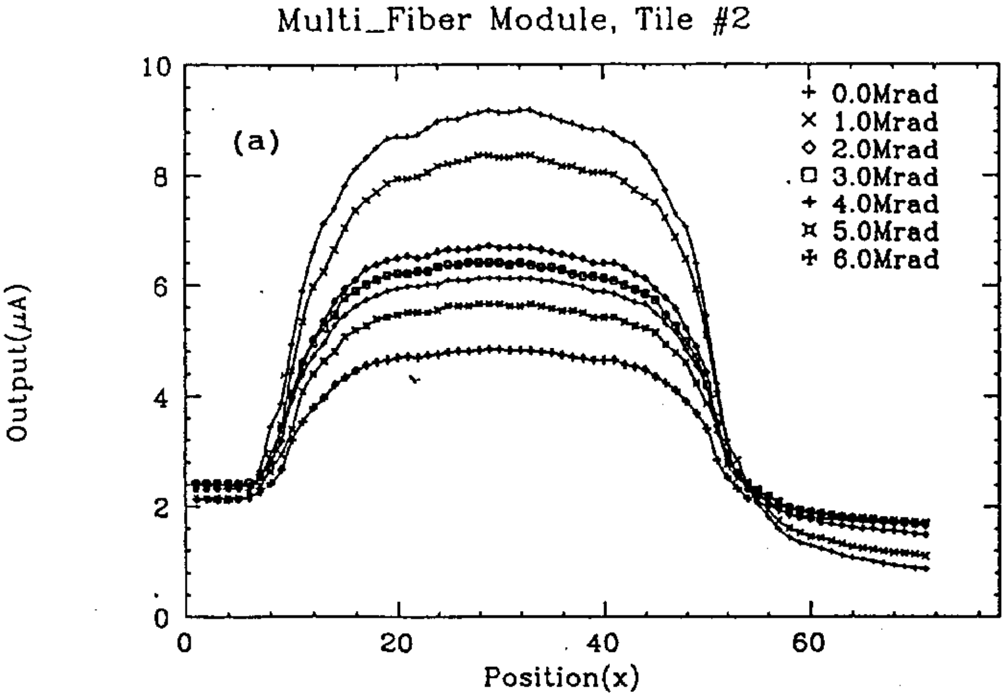


Fig. 8 Damage Data as a Function of Dose at Shower Maximum for Mod #8 (MFM) and Mod #5. The Curves are Best Fit Values



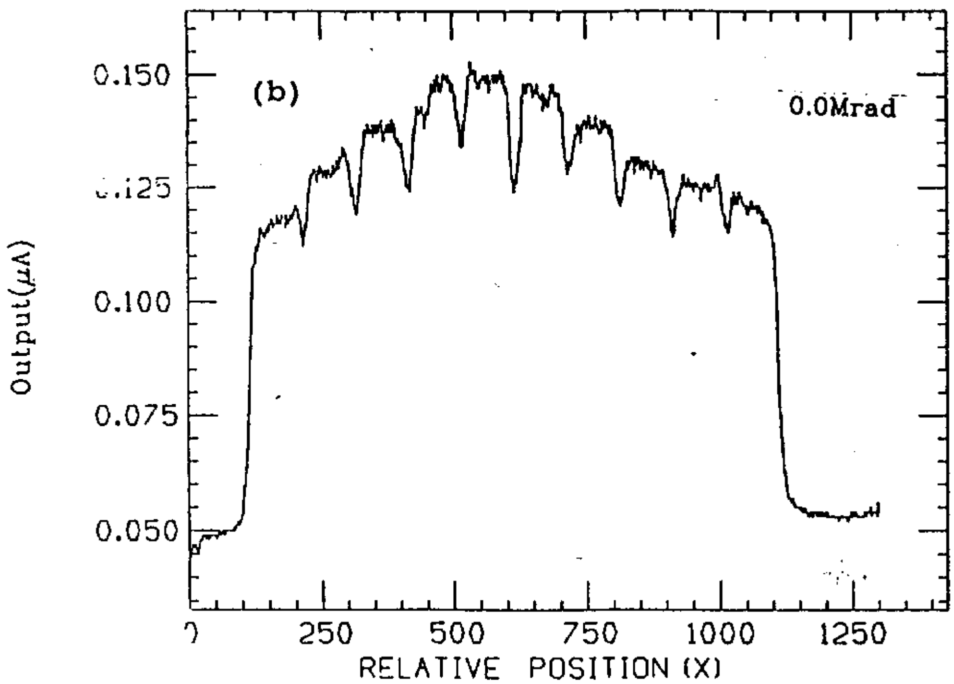


Fig. 9 Outputs at Various Transverse Positions (x) Across Tile #2 of Mod #8 (MFM) using

(a) Normal Photon Source ^{137}Cs (11 mm)

(b) Electron Source ^{90}Sr (1.3mm)

MULTI FIBER MODULE (SCSN 81 / BCF 91A and CLEAR)

APPENDIX

TRANSVERSE SCAN DATA

1. NORMALIZED TO OMrad and TILE #20

Data at the Center of Wide Peak

DOSE(Mrad)	TILE 2	TILE 4	TILE 18	TILE 20
0	1.000	1.000	1.000	1.0
0.1	0.977	0.980	0.995	1.0
0.2	0.976	0.977	1.007	1.0
0.4	0.938	0.926	0.982	1.0
0.6	0.930	0.918	1.004	1.0
0.8	0.899	0.887	0.997	1.0
1.0	0.886	0.872	0.995	1.0
1.5	0.830	0.825	0.931	1.0
2.0	0.735	0.741	0.932	1.0
2.5	0.785	0.759	0.973	1.0
3.0	0.688	0.662	0.939	1.0
3.5	0.649	0.619	0.930	1.0
4.0	0.659	0.623	0.936	1.0
4.5	0.624	0.591	0.924	1.0
5.0	0.608	0.572	0.936	1.0
6.0	0.489	0.437	0.934	1.0

2. DATA FROM THE AVERAGE BETWEEN 50%(left) and 50%(right) OF TRANSVERSE SCAN WIDE-PEAK

FROM TRANSVERSE SCAN DATA
****

NORMALIZED TO O Mrad and Tile #20				NORMALIZED TO OMrad (Not Tile 20)		
DOSE(Mrad)	TILE 2	TILE4	TILE 20	TILE 2	TILE 4	TILE 20
0	1.0	1.0	1.0	1.0	1.0	1.0
0.1	0.9786	0.9800	1.0	0.9980	0.9995	1.0199
0.2	0.9593	0.9613	1.0	0.9784	0.9805	1.0199
0.4	0.9445	0.9436	1.0	0.9853	0.9843	1.0431
0.6	0.9160	0.9120	1.0	0.9582	0.9540	1.0460
0.8	0.8976	0.8946	1.0	0.9343	0.9312	1.0409
1.0	0.8788	0.8738	1.0	0.9115	0.9064	1.0372
1.5	0.8559	0.8632	1.0	0.7665	0.7729	0.8955
2.0	0.7738	0.7987	1.0	0.7389	0.7628	0.9550
2.5	0.7971	0.7934	1.0	0.7490	0.7455	0.9396
3.0	0.7319	0.7244	1.0	0.7093	0.7020	0.9690
3.5	0.6977	0.6929	1.0	0.6806	0.6759	0.9755
4.0	0.7069	0.6960	1.0	0.6797	0.6691	0.9614
4.5	0.6830	0.6783	1.0	0.6327	0.6284	0.9264
5.0	0.6710	0.6633	1.0	0.6283	0.6211	0.9364
6.0	0.5666	0.5454	1.0	0.5375	0.5174	0.9487

MULTI FIBER MODULE (SCSN 81 / BCF 91A and CLEAR)

LONGITUDINAL SCAN DATA L2

1. NORMALIZED TO 0 Mrad and TILE #20 (PLOTS)
****

DOSE(Mrad)	TILE 2	TILE 3	TILE 4	TILE 19	TILE 20
0	1.0	1.0	1.0	1.0	1.0
0.1	0.9900	0.9967	0.9899	1.004	1.0
0.2	0.9775	0.9760	0.9697	0.9997	1.0
0.4	0.9607	0.9520	0.9460	0.9897	1.0
0.6	0.9316	0.9218	0.9241	1.0035	1.0
0.8	0.9117	0.9078	0.9034	0.9996	1.0
1.0	0.8814	0.8773	0.8735	0.9967	1.0
1.5	0.8225	0.8126	0.8286	0.9348	1.0
2.0	0.7884	0.7738	0.7942	0.9418	1.0
2.5	0.7594	0.7231	0.7470	0.9472	1.0
3.0	0.7177	0.6813	0.6968	0.9444	1.0
3.5	0.6743	0.6359	0.6617	0.9357	1.0
4.0	0.6368	0.6056	0.6237	0.9283	1.0
4.5	0.6288	0.5874	0.6066	0.9393	1.0
5.0	0.6078	0.5534	0.5840	0.9440	1.0
6.0	0.5278	0.4700	0.4918	0.9194	1.0

2. ONLY NORMALIZED TO 0 Mrad (NOT TO TILE #20)

DOSE(Mrad)	TILE 2	TILE 3	TILE 4	TILE 19	TILE 20
0	1.0	1.0	1.0	1.0	1.0
0.1	0.9860	0.9928	0.9859	1.0004	0.9960
0.2	0.9608	0.9593	0.9531	0.9826	0.9829
0.4	0.9604	0.9517	0.9457	0.9894	0.9997
0.6	0.9321	0.9223	0.9246	1.0040	1.0005
0.8	0.8964	0.8926	0.8883	0.9829	0.9832
1.0	0.8803	0.8762	0.8724	0.9954	0.9988
1.5	0.6800	0.6719	0.6850	0.7729	0.8268
2.0	0.6598	0.6475	0.6647	0.7882	0.8369
2.5	0.6087	0.5796	0.5988	0.7593	0.8016
3.0	0.5889	0.5591	0.5718	0.7750	0.8206
3.5	0.5536	0.5221	0.5433	0.7682	0.8210
4.0	0.5169	0.4916	0.5063	0.7536	0.8118
4.5	0.5018	0.4688	0.4841	0.7496	0.7981
5.0	0.4684	0.4264	0.4500	0.7275	0.7707
6.0	0.4306	0.3834	0.4012	0.7500	0.8157

****
* RECOVERY *
****

MULTI FIBER MODULE (SCSN 81 / BCF 91A and CLEAR)

LONGITUDINAL SCAN DATA L2

1. NORMALIZED TO 0 Mrad and TILE # 20 (PLOTS)
****

RECOVERY(Day)	TILE 2	TILE 3	TILE 4	TILE 19	TILE 20
6 Mrad(0Day)	0.5278	0.4700	0.4918	0.9194	1.0
0.3 Day	0.5440	0.4930	0.5202	0.9322	1.0
1	0.5379	0.5078	0.5198	0.9190	1.0
2	0.5361	0.5032	0.5168	0.9382	1.0
3	0.5338	0.5011	0.5193	0.9378	1.0
4	0.5297	0.4993	0.5110	0.9098	1.0
5	0.5224	0.4939	0.5078	0.9294	1.0
7.5	0.5259	0.4991	0.5109	0.9359	1.0
9.5	0.5197	0.4951	0.5098	0.9298	1.0
12 Day	0.5190	0.4911	0.5075	0.9341	1.0

2. NORMALIZED TO 0 Mrad (NOT TO TILE #20)

RECOVERY(Day)	TILE 2	TILE 3	TILE 4	TILE 19	TILE 20
6 Mrad(0Day)	0.4306	0.3834	0.4012	0.7500	0.8157
0.3 Day	0.4276	0.3876	0.4090	0.7329	0.7861
1	0.4405	0.4158	0.4256	0.7525	0.8188
2	0.4170	0.3914	0.4019	0.7404	0.7296
3	0.4177	0.3921	0.4064	0.7339	0.7826
4	0.5103	0.4809	0.4922	0.8764	0.9633
5	0.4063	0.3841	0.3949	0.7229	0.7777
7.5	0.4015	0.3811	0.3901	0.7146	0.7636
9.5	0.4184	0.3986	0.4104	0.7486	0.8051
12 Day	0.4890	0.4627	0.4782	0.8800	0.9421

**FIRST ROUND MODULE #5 (SCSN 81 / BCF91)* *

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LONGITUDINAL SCAN L2

1. NORMALIZED TO 0 Mrad and TILE #20 (as PLOTS)

DOSE(Mrad)	TILE 2	TILE 3	TILE 4	TILE 19	TILE 20
0	1.0	1.0	1.0	1.0	1.0
0.3	0.746	0.794	0.760	0.985	1.0
0.75	0.661	0.689	0.645	1.003	1.0
1.13	0.639	0.628	0.571	1.121	1.0
1.5	0.580	0.613	0.588	1.125	1.0
2.25	0.523	0.503	0.468	1.147	1.0
3.0	0.437	0.422	0.428	1.098	1.0
3.75	0.381	0.375	0.381	1.103	1.0
4.5	0.341	0.300	0.305	1.099	1.0
5.25	0.334	0.294	0.298	1.107	1.0
6.0	0.253	0.223	0.278	1.124	1.0

2. if ONLY NORMALIZED TO 0 Mrad

DOSE(Mrad)	TILE 2	TILE 3	TILE 4	TILE 19	TILE 20
0	1.0	1.0	1.0	1.0	1.0
0.3	0.489	0.521	0.498	0.646	0.656
0.75	0.369	0.384	0.360	0.560	0.558
1.13	0.289	0.285	0.259	0.508	0.453
1.5	0.254	0.269	0.258	0.493	0.438
2.25	0.186	0.179	0.167	0.408	0.356
3.0	0.176	0.170	0.172	0.442	0.402
3.75	0.143	0.141	0.143	0.415	0.376
4.5	0.135	0.119	0.121	0.436	0.397
5.25	0.119	0.105	0.106	0.395	0.356
6.0	0.074	0.065	0.082	0.329	0.293

3. NORMALIZED TO OMrad and TILE #19

DOSE(Mrad)	TILE 2	TILE 3	TILE 4	TILE 19	TILE 20
0	1.0	1.0	1.0	1.0	1.0
0.3	0.757	0.806	0.771	1.0	1.015
0.75	0.659	0.687	0.643	1.0	0.997
1.13	0.570	0.560	0.509	1.0	0.892
1.5	0.516	0.545	0.523	1.0	0.889
2.25	0.456	0.438	0.408	1.0	0.872
3.0	0.398	0.384	0.390	1.0	0.911
3.75	0.345	0.340	0.345	1.0	0.907
4.5	0.310	0.273	0.277	1.0	0.910
5.25	0.301	0.265	0.270	1.0	0.903
6.0	0.225	0.199	0.248	1.0	0.889
RECOVERY					
* 2 days	0.251	0.164	0.225	1.0	1.052 *
* 13 day	0.216	0.217	0.221	1.0	1.047
* 30 day	0.235	0.207	0.210	1.0	1.044 * *