PHENIX Note #255

A Comparison of Bicron BCF99-29A and BCF99-29AA WLS Fibers

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October 31, 1996

The light output, emission spectra, attenuation length, decay time, and radiation damage characteristics of the newly formulated 1mm diameter BCF-99 29AA wls fibers were compared with fibers of the earlier formulation BCF-99 29A

The BCF-99 29AA fibers measured were from Lot# 11052 T-1, Q12324 dated 10-1-96. The BCF-99 29A fibers used for comparison are from Lot# 9990 T-4, Q12324 dated 7-10-95. Unless otherwise stated, all of the fibers tested were 1.1m lengths. The fiber ends were prepared with 240 and then 600 grit sandpaper.

I. Light Output

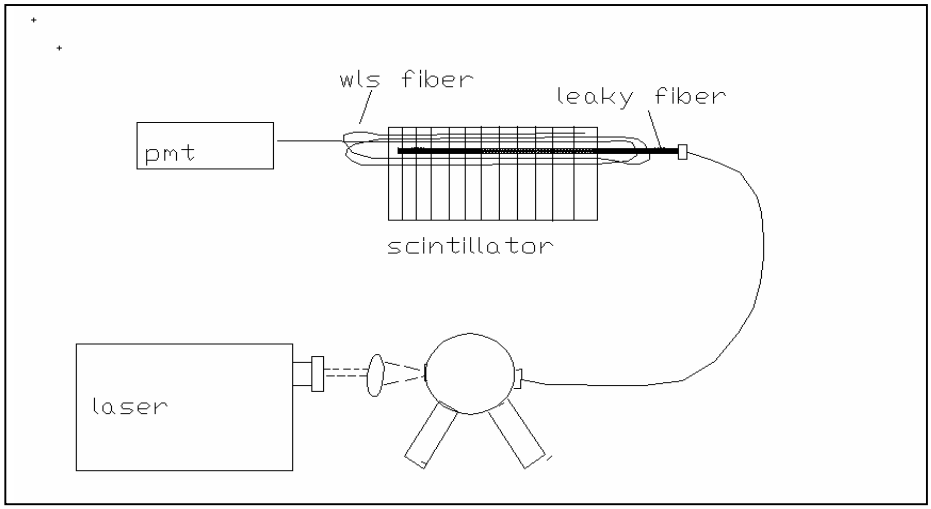
Six samples of each fiber type were individually threaded through a block of plastic scintillator tiles like those used in EMCal modules. Laser light (337nm) was injected, through a 2mm leaky fiber into the scintillator tiles. The light collected and transmitted by the wls fiber was read out with a photomultiplier tube placed in contact with a protruding end of the wls fiber. The results are summarized in the table below. The spread in the measurements within each type of fiber is the combination of the systematic error and the actual variation from fiber to fiber. Because threading the fiber through the scintillator was detrimental to the fiber, repeated measurements with the same fiber to separate the systematic error from the actual sample variation were not conclusive.

The results of these measurements are summarized in Table 1. While the new (29AA) wls had, on average, a slightly higher light output, the difference was within the measurement error. We conclude that there is no significant measurable difference between the light output of the 29AA and 29A fibers

Table 1. Summary of results of fiber light output measurements.

	new (29AA)	***old (29A)***
avg. output of 6 fibers:	716	698
sigma	54	60
sigma/avg.	7.5%	8.6%

Figure 1. Experimental set-up for measurement of wls fiber light output.



II. Emission Spectra.

The emission spectra of 3 of each type of fiber were measured. Four hundred nanometer light from a Xenon lamp and monochomator was focused into one end of each fiber. The other end of the 1.1m fiber was coupled to an Ocean Optics SD-1000 Fiber Spectrometer. Figure 2. shows a schematic drawing of the set-up. As an additional test, the emission spectrum of a 1.1m BCF-99 29AA fiber was measured. The same fiber was then cut in half, and a 55 cm was measured for comparison with the full length. The output spectra as a function of wavelength was overlain for comparison in Figures 3a and 3b.

The measurements indicate that the spectra of 29AA fibers are consistently shifted by 5-10nm toward shorter wavelengths, as shown in Figure 3a. The overall width of the emission peak seems consistent between the two fiber types, and no conclusions about the amplitude can be drawn from this measurement other than to say that there is no substantial difference.

When the emission spectra from two different lengths of the same fiber are compared (Figure 3b.), we see that the spectrum from the shorter length (55cm) is also blue shifted relative to the spectrum from the full length (1.1m) piece. The difference is ~3-4 nm when the amplitudes of the peaks are normalized. This suggests that the shorter wavelength light is more strongly attenuated in the fibers.

Figure 2. Experimental set-up for measurement of fiber emission spectra.

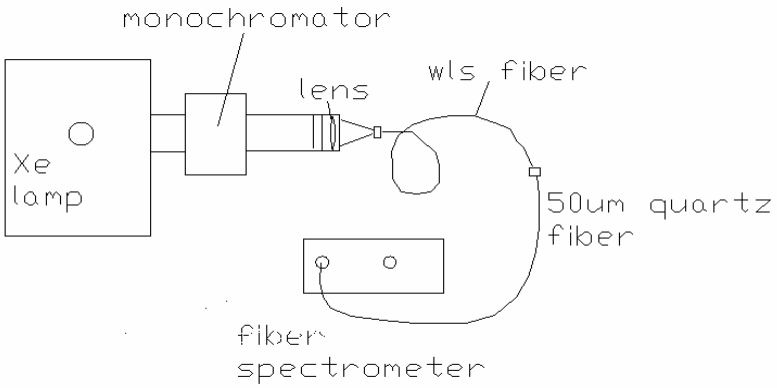
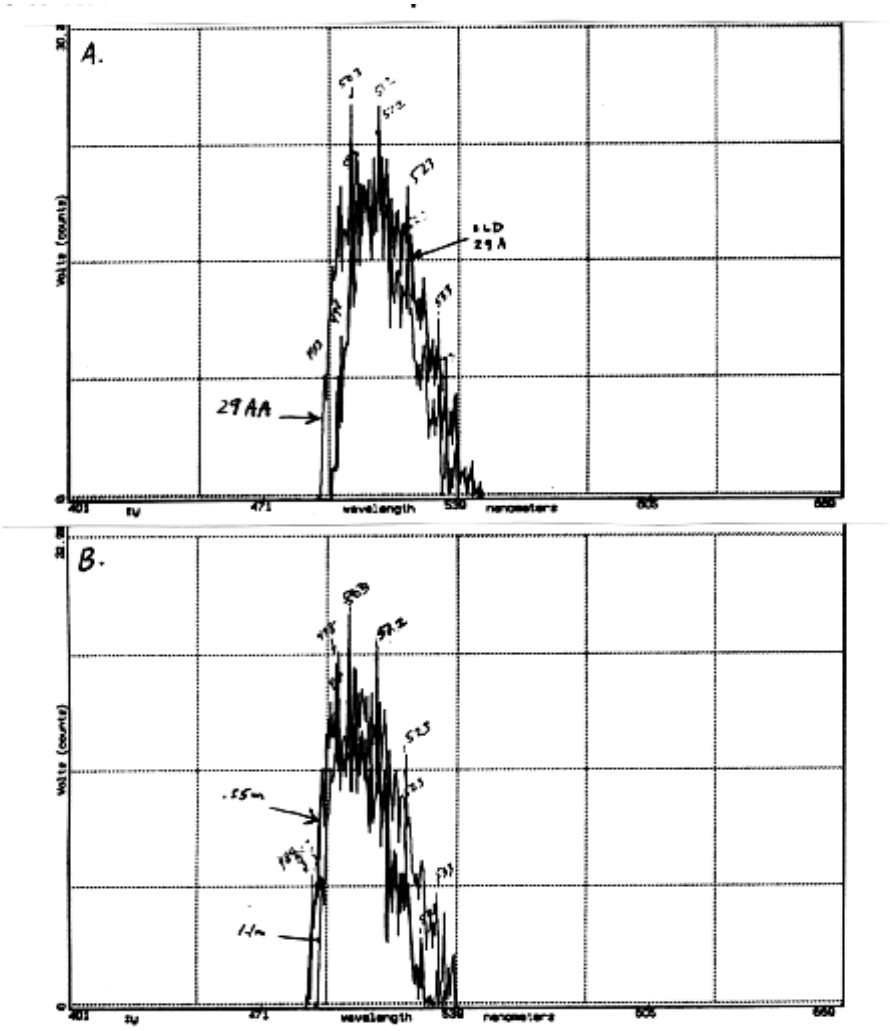


Figure 3. Results of fiber emission spectra measurements.



III. Attenuation Length

The attenuation lengths of several samples of each fiber type were measured by illuminating the fiber at 3 points along its length (x=10cm, 55cm, 100cm) and then measuring the intensity of the light output with a photomultiplier tube (at x=0). The fiber was illuminated with scintillator tiles, which were excited with 337nm laser light and moved along the length of the wls fiber. The light measured at the phototube is normalized to correct for pulse-to-pulse fluctuations in the laser output. The attenuation length of each fiber was measured once, and then again with the fiber reversed. The average of the two measurements was parameterized with a double exponential of the form:

$$y = A*e^{(-x/L1)} + B*e^{(-x/L2)}$$

to find the attenuation length for each fiber. The first attenuation length (L1) is the shorter of the two and results from light trapped in the fiber cladding. The second attenuation length (L2) results from absorption in the fiber and is more relevant for our application. We will mainly use L2 to compare the fiber types in this study.

The normalized results of the measurements are summarized in Table 2 and plotted in Figure 5. We found the 29AA fibers had a slightly longer attenuation length "L2" than the 29A fibers (~ 9%).

Table 2. Summary of fiber attenuation length measurements.

fiber type	*L1*	*L2*
average (2) 29A	15 cm	149 cm
average (3) 29AA	16 cm	162 cm

Figure 4. Experimental set-up for measurement of fiber attenuation length.

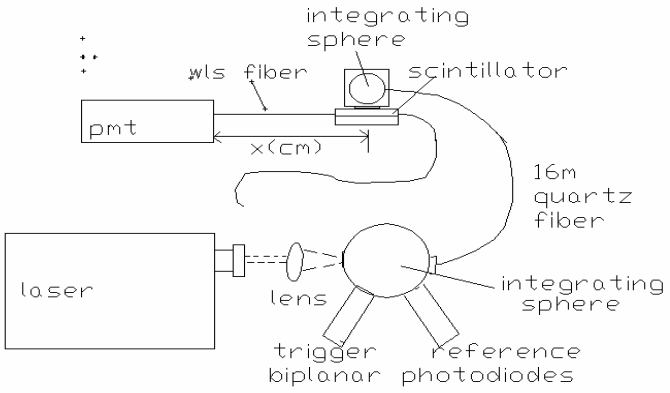
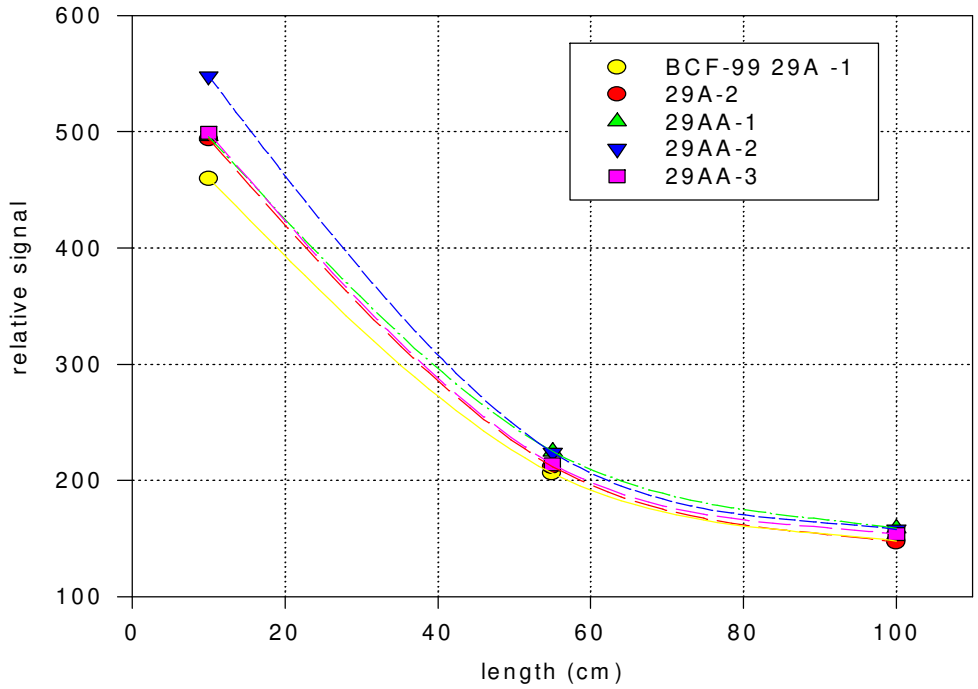


Figure 5. Results of fiber attenuation length measurements.



IV. Decay Time

The decay time of each type of fiber was measured by illuminating the fiber with laser-pulsed scintillating tiles, and measuring the time required for the coupled scintillation light to die away. A Bollinger-Thomas type trigger was set up, taking a “start” pulse from a photodiode looking at the partially reflected laser pulses. A “stop” pulse was generated by a single-photon counting pmt, placed at the far end of the wls fiber. The transmitted light travels ~90cm along the length of the wls fiber.

This arrangement measures the combined decay time of the scintillator tiles and the wls fibers. We measured decay times of ~3.9 ns for both types of fibers, and conclude that there is no obvious difference in the decay times of the two fiber types.

Figure 6. Experimental set-up for measurement of fiber emission decay-time spectra.

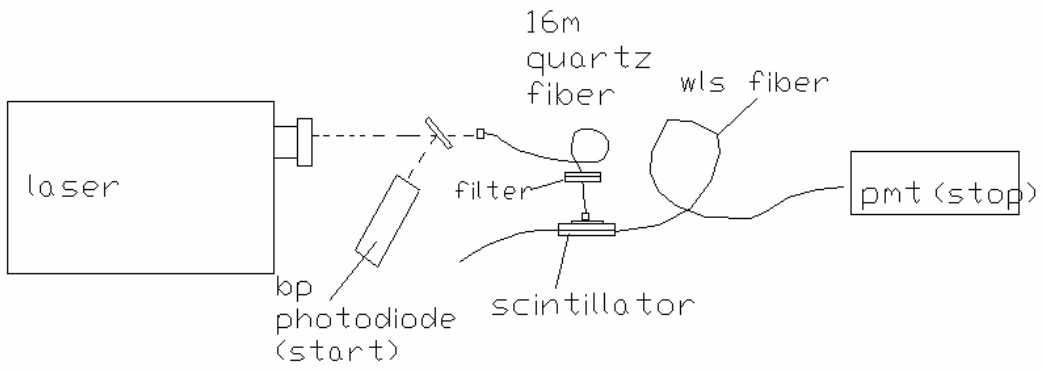
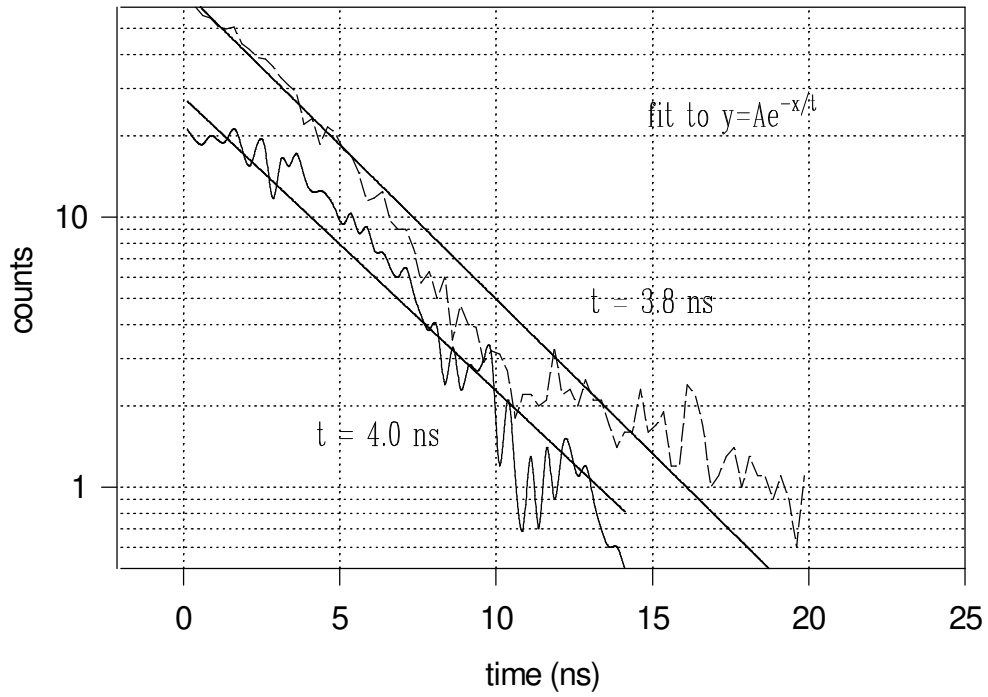


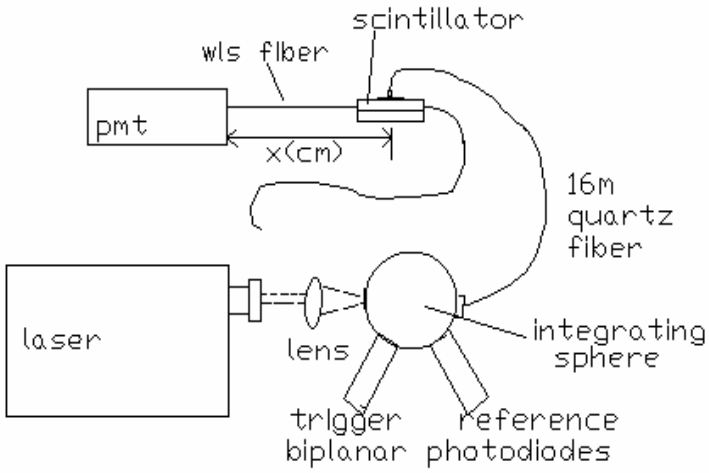
Figure 7. Results of fiber decay time measurements



V. Radiation Damage

The attenuation lengths of three 29AA and two 29A fibers were measured before and after exposure to ~50 krad of ^{60}Co gamma rays at a dose rate of ~3.5 x 10^4 rad/hr. One 29A fiber that was not irradiated, was measured before and after irradiation as a control. The measurement set-up (as shown in Figure 8) was the same as that used for the attenuation length measurements except that the second, smaller integrating sphere was removed. The fibers were measured within 3hrs of the irradiation. One fiber (type 29AA) was measured again after ~20hrs to check for recovery of the light output. The fibers were kept in the dark during irradiation, measurement, and at all other times.

Figure 8. Experimental set-up for measurement of radiation damage in wls fibers.



The results of these measurements are displayed in Figure 9. The initial curves are plotted with green symbols and the post-irradiation results are plotted with red symbols. All fibers showed a decline in light output and a decreased attenuation length (increased attenuation). The 29A fibers on average, were more strongly effected than the 29AA fibers. The average attenuation length of the two 29A fibers dropped by 76% while the average a.l. of the three 29AA fibers dropped by 65%.

One BCF-99 29AA fiber was measured initially, ~3 hrs after irradiation, and ~20 hrs. after irradiation. This fiber showed a drop in the light output after the irradiation but then partially recovered after ~20 hrs. The attenuation length first dropped to 45% of its initial value, but then recovered to 63% of the initial value. Data from this measurement are summarized in Table 3 and are plotted in Figure 10.

Table 3. Summary of results of radiation damage and recovery measurements.

fiber	*initial att. lngth (cm)*		*att. lngth. after 50 krad (cm)*		*att. lngth 20h after 50 krad*	
	L1	*L2*	*L1*	*L2*	*L1*	*L2*
29AA-1	10	200	9	54		
29AA-2	9	127	10	57	11	80
29AA-3	10	165	9	64		
average 29AA	**10**	**164**	**9**	**58**		
29A-1	8	114	10	36		
29A-2	10	127	9	21		
average 29A	**9**	**121**	**10**	**29**		
29A-3 (control)	9	90	13	103		

Figure 9. Results of radiation damage measurements.

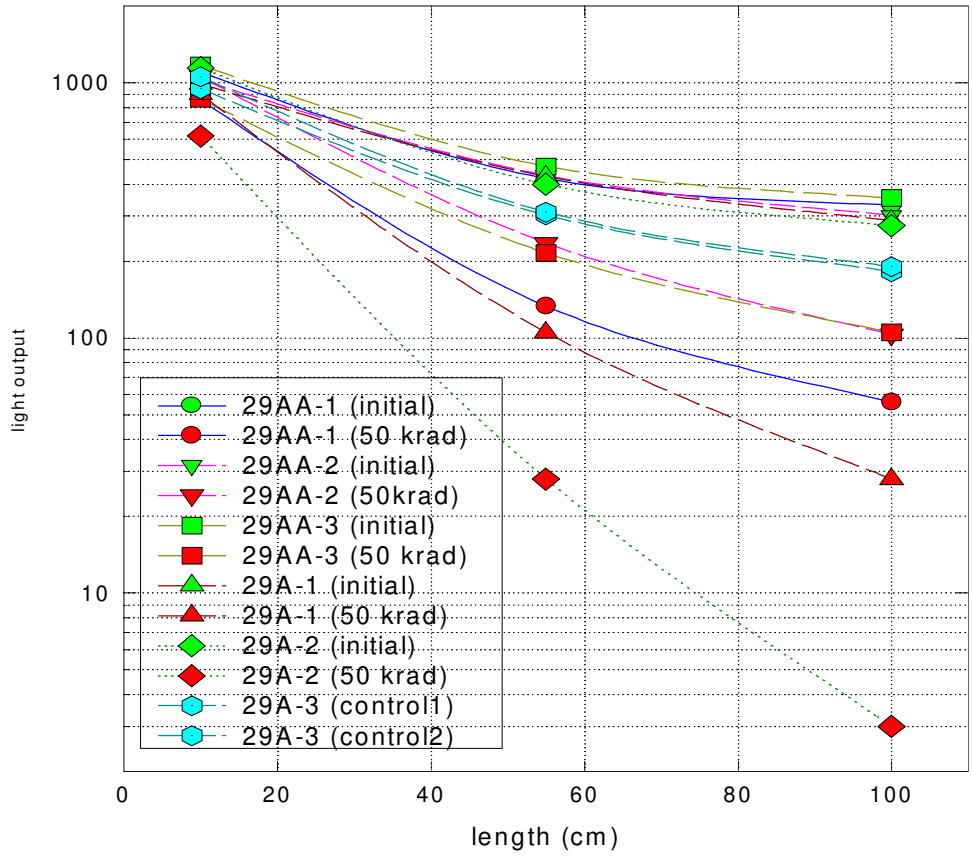
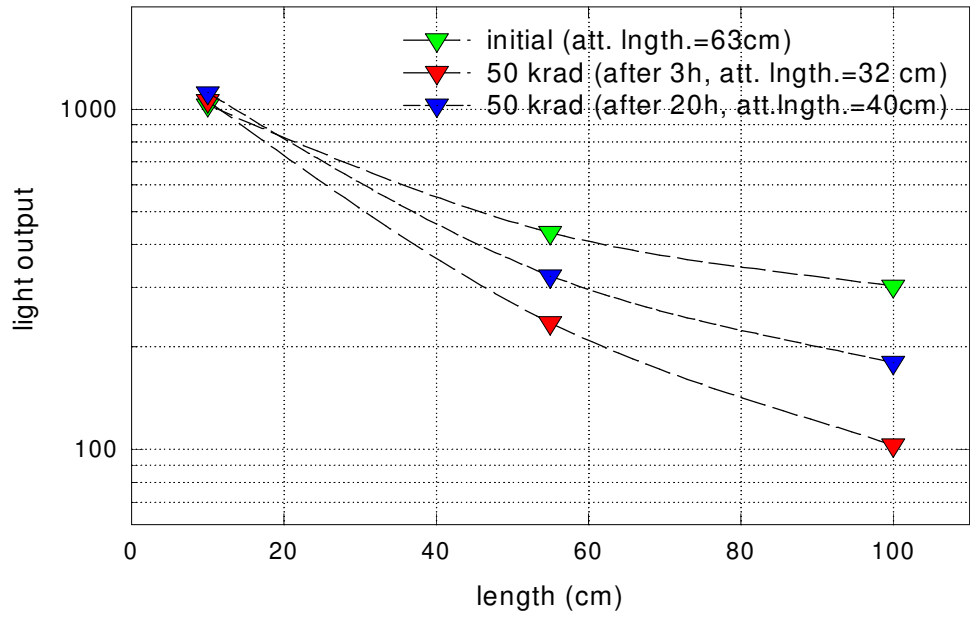


Figure 10. Radiation damage and recovery measurements of a BCF-99 29AA fiber, measured initially, ~3h after 50krad, and ~20h after 50krad.



VI. Conclusions

Overall, we observed some slight differences between the new (29AA) fibers and the earlier batch (29A). When there were differences, such as the attenuation lengths and radiation hardnesses, the 29AA fibers performed better than the 29A fibers.

- The 29AA fibers had a slightly higher light output than the 29A fibers.
- The emission spectrum of the 29AA fibers is blue-shifted by ~5-10 nm relative to the 29A fibers.
- The attenuation lengths of the 29AA fibers were slightly longer than those of the 29A fibers. When all of the fibers measured in the study were considered, the attenuation lengths (L2) were found to be 135 cm for the 29A fibers and 163 cm for the 29AA fibers. The "cladding effect" attenuation (L1) was ~12cm for both fiber types. This conclusion includes fibers measured in the Radiation Damage section of the paper. The 29A fibers measured in that section had shorter attenuation lengths than those measured in the Attenuation Length section of the paper, and therefore reduced the average attenuation length for 29A fibers.
- We measured no significant difference between the decay times of the two fiber types (~4ns).
- The 29AA fibers were less susceptible to radiation damage than the 29A fibers.