Radiation Testing of Commercial off the Shelf 62.5/125/250 Micron Optical Fiber for Space Flight Environments

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Abstract

The 62.5/125/250 micron optical fiber manufactured by Lucent SFT was tested for gamma radiation resistance at the NASA Goddard Space Flight Center Cobalt^{60} chamber. The fiber was tested with 1300 nm light, at 20.7 rads/min and 5 rads/min at –25°C and at 32.3 rads/min and 5 rads/min at +25°C. Data was recorded during exposure until the attenuation reached levels below that of the optical detection data acquisition system. All gathered data is presented here along with extrapolation equations for other dose rates.

Background

In the past for space flight applications,100/140 micron optical fiber was used for optical communication purposes. This fiber has been characterized for space flight environments under various conditions.[1-2] For several years, there has more interest in usage of commercial optical fiber products because of the limited availability of 100/140 micron optical fiber. Over seven years ago, Corning ceased manufacturing the 100/140 fiber and since then Lucent SFT (formerly Spectran Specialty Fiber) has been the only manufacturer of this fiber. NASA has been asked to look into other options for purposes of providing alternatives to the 100/140 micron graded index fiber for space flight environments. Specifically, the question has been asked: how does 62.5/125 perform in a space radiation environment? The dopants used in the 62.5/125 micron optical fiber are different from those used in the radiation hardened 100/120/172 micron fiber being used currently. Therefore, it was expected that there would be a difference in the radiation performance but until now, answering the question about how much of a difference in performance there would be, was based on speculation with no data.

Experimental Set-up

The radiation exposure was conducted at Goddard Space Flight Center's Cobalt^{60} gamma radiation chamber. Four tests total were conducted to assess the performance of the 62.5/125 micron commercial fiber using two dose rate conditions for each thermal condition. In each case the fiber was tested until light could no longer be detected with the optical detection system used for in-situ monitoring throughout exposure. Table 1 summarizes the tests conducted.

Table 1: Summary of experiments conducted

Designation	Test Length	Temperature	Dose Rate	Total Dose*	Input Level
Spool A	100 m	-25°C	20.7 rads/min	33.12 Krads	.84 µwatt
Spool B	100 m	-25°C	5 rads/min	26.0 Krads	.84 µwatt
Spool C	100 m	+25°C	32.3 rads/min	45.22 Krads	.65 µwatt
Spool D	100 m	+25°C	5 rads/min	35.0 Krads	.65 µwatt

* Total dose is based on the last detectable transmission through each of the fiber spools.

In Table 1 the details of the experiments are shown with the designation for each spool under test. The last column is the input light level registered prior to the 100 m spool or the output of the lead in cables coupling the source to the spools themselves. The level used for monitoring the transmission of light through the fiber during exposure is required to be below 1 microwatt to limit photobleaching effects.[2] Two of the spools of 62.5/125 micron fiber were tested at –25°C and tested at two different dose rates; 20.7 rads/min for spool A and 5 rads/min for spool B. With typical germanium doped multimode fiber, this thermal environment represents a harsher scenario than room temperature since the lower temperatures inhibit thermal annealing of the radiation induced attenuation. At room temperature or +25°C, the other two spools were tested at 32.3 rads/min for spool C and 5 rads/min for spool D.

For all spools tested, data was recorded prior to testing and every minute during exposure. All spools were placed inside of lead boxes (to eliminate secondary low energy level reflections) and remained there through the duration of the test. Lead in and lead out cables were used to couple the source and detection equipment, through the chamber wall, to where the spools were located in the chamber. A thermal chamber (with enough room for one spool) was used in addition, to maintain a temperature of –25° C during and after the radiation exposure.

The RIFOCS 752L dual wavelength LED source was used at 1300 nm. The signal was attenuated with the JDS HA9 optical attenuator such that all incoming light to the spools was less than 1 microwatt of optical power. The HP8166 multichannel optical power meter was used for detection of the output signal from the spools.

Experimental Results

Two exposure sessions were conducted to collect data for the two thermal and dose rate condition combinations, since the thermal chamber could only be used to test one spool at a time. The results of all testing conducted are graphed in Figure 1.

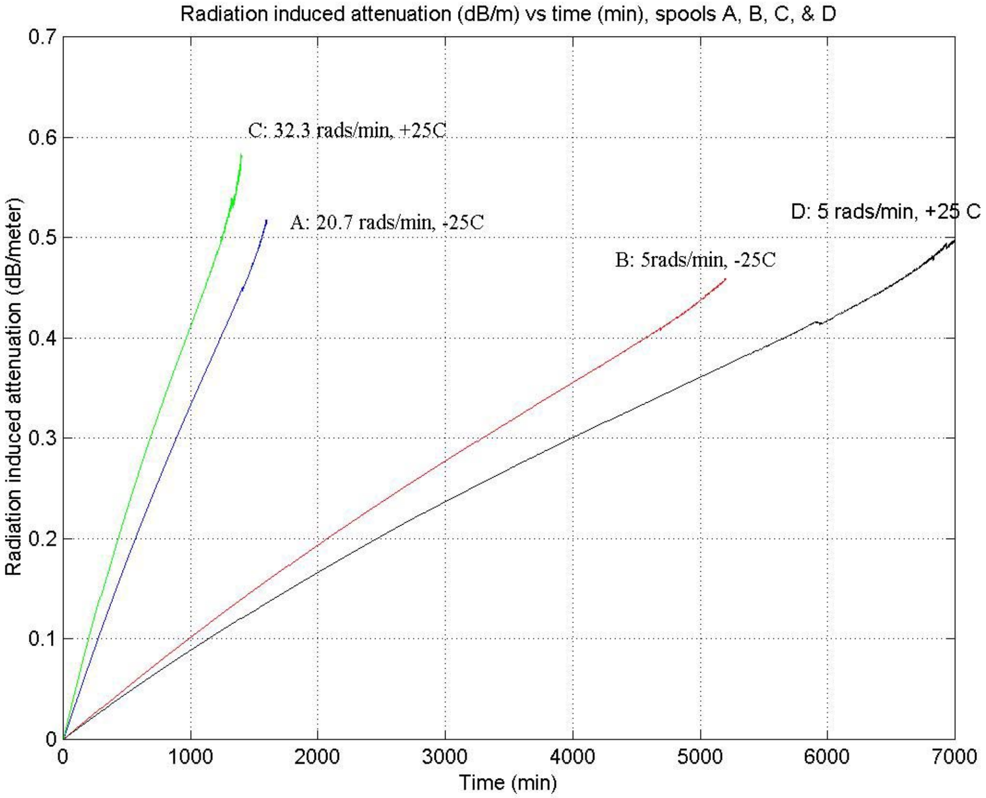

Figure 1: Complete data set of radiation induced attenuation recorded for each spool in units of dB/m vs. time .

It is evident by Figure 1 that all the spools experienced large radiation induced attenuation. The data has been scaled such that it is represented in dB/m units. Typical space flight applications will use 3 to 10 m of fiber when connecting instruments on a spacecraft for communication purposes. This would result in 1.5 to 5 dB for the short cables at the largest total dose registered here of ~ 25-40 Krads. However, the dose rates used for this testing are not exactly the dose rates expected for space flight. They may represent some periods of time but it is not usually the case that high dose rates such as these are maintained for any long duration over a few hours. The exposure at high dose rate in this testing was maintained for 3.5 to 4.5 days depending on the dose rate. The purpose of this was to collect enough data to formulate an extrapolation equation for other dose rates.

In Figure 1, it is evident that when held at the same dose rate but at different temperatures, the fiber performs as expected for germanium doped multimode where the colder thermal environment represents a harsher case for a fiber during radiation exposure. Spool B and spool D are both exposed at 5 rads/min but spool B experiences more induced attenuation since the temperature is much colder at –25°C.

For analysis the data was categorized into two segments by thermal condition and an extrapolation equation for each condition was formulated to make predictions for losses using other dose rates and total doses.[3]

Results of radiation exposure at –25ºC:

Data set one is the radiation induced attenuation gathered at –25°C for spools A and B. The data for spool A and spool B is shown in Figure 2.

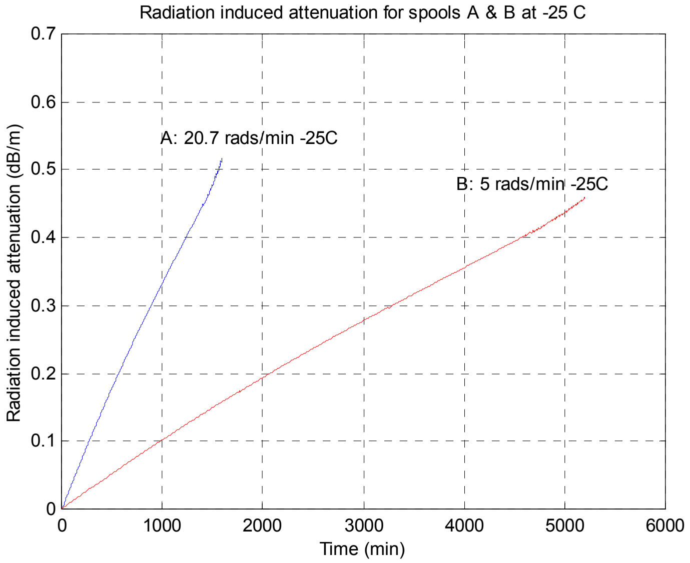

Figure 2: Radiation induced attenuation of spools A & B at –25°C.

With curve fitting, an equation to describe the induced attenuation can provide more information on how the attenuation would proceed if the test were continued with greater sensitivity of detection equipment. Figure 3 is a graph of the data from spool A and the corresponding model to fit the data.

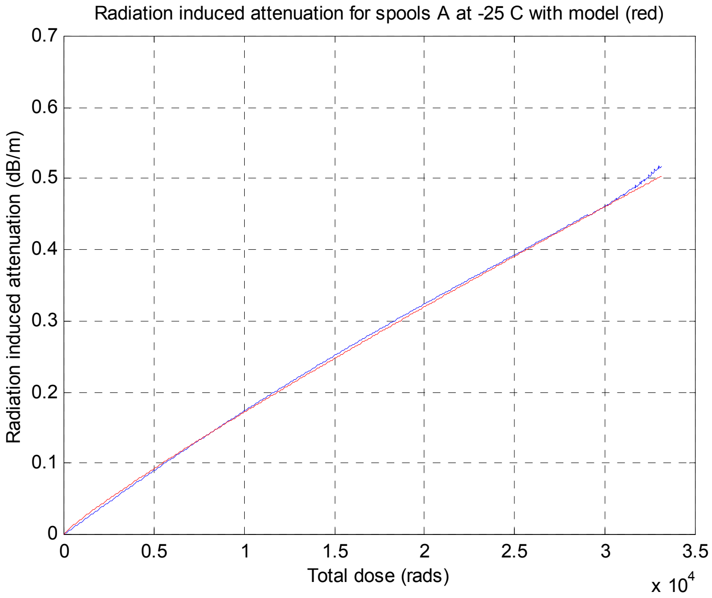

Figure 3: Radiation induced attenuation (dB/m) vs. Total dose (rads) for spool A (blue) at 20.7 rads/min and the curve fit equation (red).

The equation that fits the data, for spool A (shown in red in Figure 3) is:

$$A(D) = .43 * 10^{-4} D^{.90} \text{ (dB/m)} \quad (1)$$

where A(D) is radiation induced attenuation and D is the total dose.

The same analysis was performed on the data set for spool B and is shown in Figure 4.

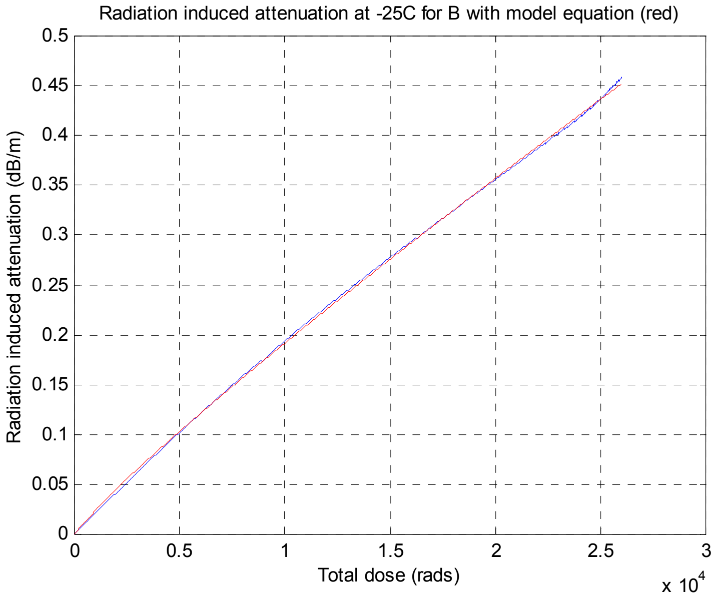

Figure 4: Radiation induced attenuation (dB/m) vs. Total dose (rads) for spool B (blue) at 5 rads/min and the curve fit equation (red).

The equation that fits the data, for spool B (shown in red in Figure 4) is:

$$A(D) = .48 * 10^{-4} D^{.90} \text{ (dB/m)} \quad (2)$$

Equation 1 and 2 appear to be very similar which is typical of germanium doped fiber and allows for an extrapolation equation to be determined. Using the results of both equations, the general model at –25°C for radiation induced attenuation of this fiber can be expressed as:

$$A(D) = 3.64 * 10^{-5} \phi^{.1} D^{.90} \text{ (dB/m)} \quad (3)$$

where A(D) is radiation induced attenuation, ϕ is the dose rate of exposure, D is the total dose of exposure, and the constant $Co = 3.64 * 10^{-5}$.[3] There is some error involved in predicting the exact numerical value of attenuation using equation 3 due to the slight difference in the constants generated from equations 2 and 1. The error for equation 3 can be represented by $Co = 3.64 * 10^{-5} +/- 0.45 * 10^{-5}$. Figure 5 is the extrapolation equation 3 plotted for 1 rad/min, .1 rads/min and .01 rads/min dose rates. Figure 5 represents more realistic background radiation dose rates that can are expected for typical space flight environments.

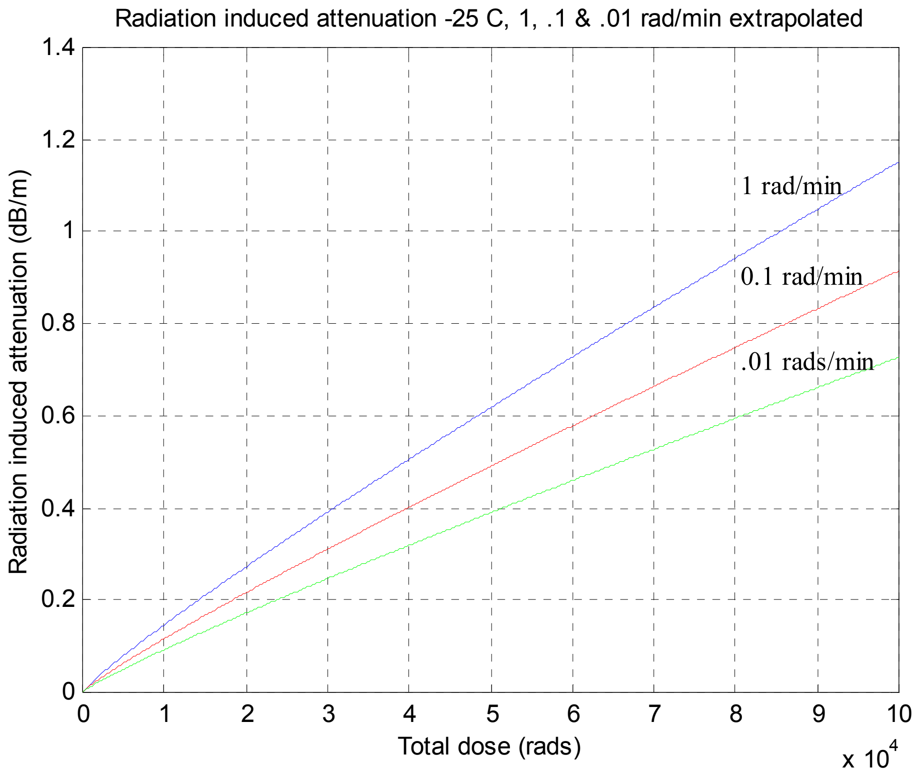

Figure 5: Radiation induced attenuation for –25°C extrapolated for 1 rad/min (blue), .1 rad/min (red) and .01 rads/min (green) to a total dose of 100 Krads.

In Table 2 the induced attenuation values at –25°C are summarized for the actual and extrapolated dose rate values.

Table 2: Summary of radiation induced attenuation for various dose rates and total doses both from actual data and extrapolated predictions at –25 °C.

Dose Rate	Total Dose	Attenuation (dB/m)	Attenuation (dB/3m)	Attenuation (dB/10m)	Comment
20.7 rads/min	35.65 Krads	.517	1.55	5.17	Actual Data
20.7 rads/min	100 Krads	1.55	4.65	15.5	Extrapolated
20.7 rads/min	10 Krads	.173	.519	1.73	Actual Data
5.0 rads/min	29.0 Krads	.459	1.38	4.59	Actual Data
5.0 rads/min	100 Krads	1.35	4.05	13.5	Extrapolated
5.0 rads/min	10 Krads	.193	.579	1.93	Actual Data
1.0 rad/min	100 Krads	1.15	3.45	11.5	Extrapolated
1.0 rad/min	10 Krads	.145	.435	1.45	Extrapolated
0.1 rad/min	100 Krads	.914	2.74	9.14	Extrapolated
0.1 rad/min	10 Krads	.115	.345	1.15	Extrapolated
0.01 rad/min	100 Krads	.726	2.18	7.26	Extrapolated
0.01 rad/min	10 Krads	.091	.278	.910	Extrapolated

In Table 2, the numerical values for radiation induced attenuation at –25°C are listed for lower dose rates that represent more realistic values for background radiation dose rates in typical space flight environments. The attenuation is listed for total doses of both 10 Krads and 100 Krads, again, typical total dose requirements for space flight fiber optics. The lengths used for calculation of these attenuation values are also typical space flight cable lengths of 3 m or 10 m. Space Station uses lengths of 30 m or more and because of these long lengths the radiation induced losses are too high for this fiber to be considered without making other efforts to compensate for the huge transmission losses. Space Station also has a –125°C requirement and a point where the dose rate would be as high as 42 rads/min for two hours. This would further increase the predicted losses. However, for other missions where the background radiation is close to .1 rad/min maximum with a 100 Krad requirement and lengths of fiber usage at 3 m, the extrapolated attenuation is 2.74 dB. This value is high in comparison to radiation hardened fiber but could still be tolerated with some compensation depending on the power budget requirements of the mission for optical transmission

Results of radiation exposure at +25°C:

Data set two is the radiation induced attenuation gathered at +25°C for spools C and D. The data for spool C and spool D is shown in Figure 6. Spool C was exposed to 32.3 rads/min and spool D was exposed to 5 rads/min radiation at room temperature.

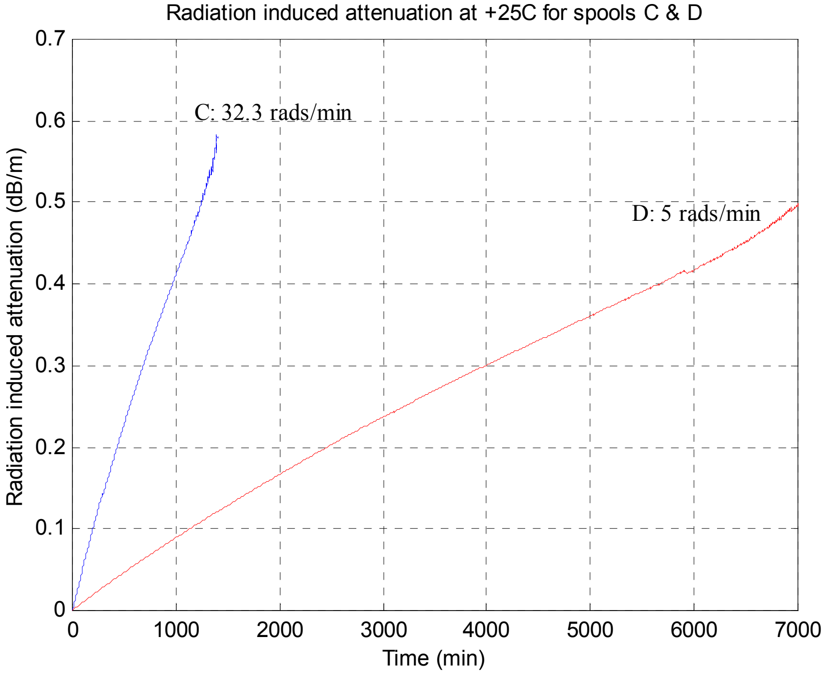

Figure 6: Radiation induced attenuation at +25°C for spools C (blue) and D (red).

Figure 7 shows the curve fitting equation graphed along with the actual data for spool C.

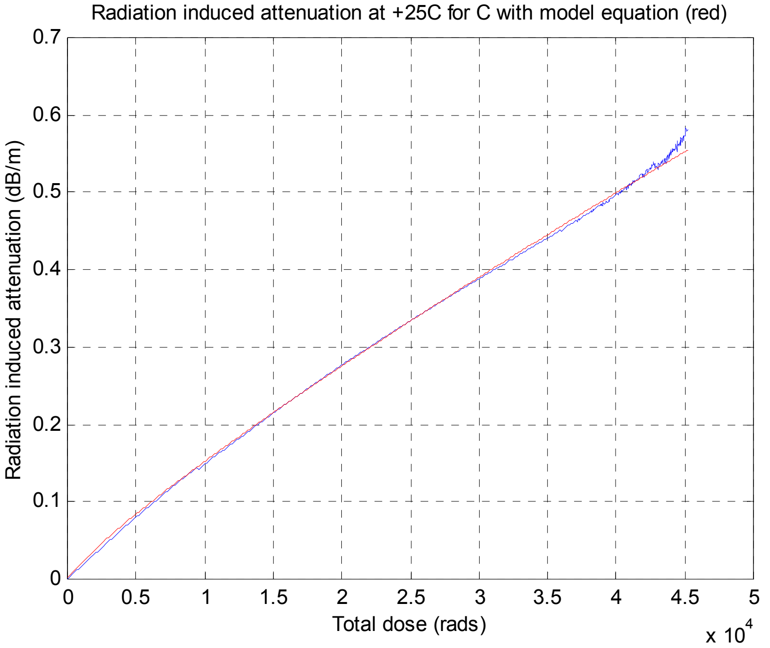

Figure 7: Radiation induced attenuation (dB/m) vs. Total dose (rads) for spool C (blue) at 32.3 rads/min and the curve fit equation (red).

The equation represented in Figure 7 in red, for radiation induced attenuation on spool C is:

$$A(D) = .55*10^{-4}\, D^{.86} \text{ (dB/m)} \tag{4}$$

where A(D) is again radiation induced attenuation given a total dose of D.
The same analysis was performed on the data for spool D and the results are in Figure 8.

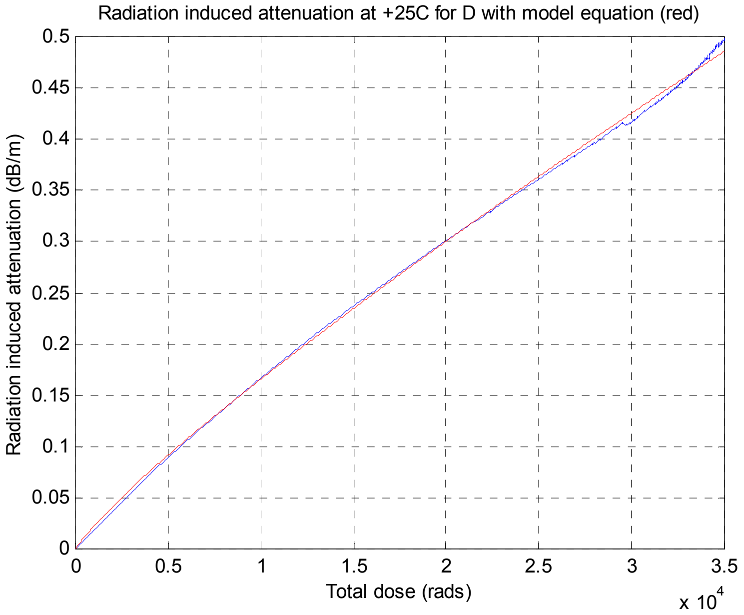

Figure 8: Radiation induced attenuation at +25°C for spool D at 5 rads/min with curve fit (red).

In Figure 8 the equation for the curve fit can be expressed as

$$A(D) = .60*10^{-4} D^{.86} \text{ (dB/m)} \tag{5}$$

Both equations 4 and 5 are similar as expected. Using both equations and their respective data to generate the extrapolation model for radiation induced attenuation at room temperature the resulting expression is:

$$A(D) = 4.10*10^{-5} \phi^{.14} D^{.86} \text{ (dB/m)} \tag{6}$$

Where ϕ is any dose rate, D is total dose and A(D) is radiation induced attenuation. This is the extrapolation equation for +25°C gamma exposure. The uncertainty associated with the constant in equation 6 is $C_o = 4.1*10^{-5} \pm .71*10^{-5}$. Equation 6 is graphed in Figure 9 for three different dose rates, 1 rad/min, 0.1 rad/min, & .01 rad/min.

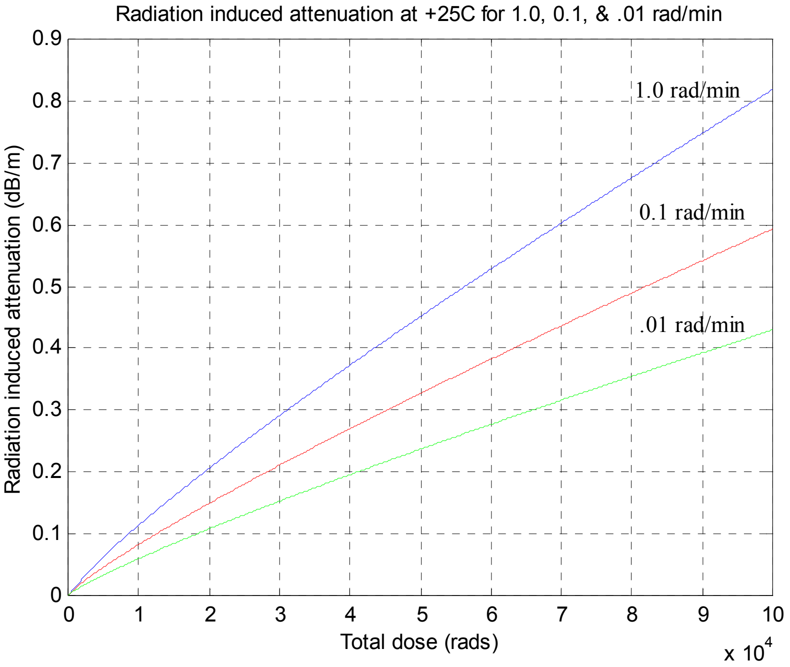

Figure 9: Radiation induced attenuation in dB/m using the extrapolation equation 6, +25°C exposure for 1.0 rad/min, 0.1 rad/min, & .01 rad/min vs. total ionizing dose.

Table 3 contains the summary and some extrapolated values given dose rate and total dose for room temperature exposure or exposure at +25°C.

Table 3: Summary of radiation induced attenuation for various dose rates and total doses both from actual data and extrapolated predictions for +25 °C.

Dose Rate	Total Dose	Attenuation (dB/m)	Attenuation (dB/3m)	Attenuation (dB/10m)	Comment
32.3 rads/min	46.8 Krads	.581	1.74	5.81	Actual Data
32.3 rads/min	100 Krads	1.33	3.99	13.3	Extrapolated
32.3 rads/min	10 Krads	.148	.444	1.48	Actual Data
5.0 rads/min	37.1 Krads	.498	1.49	4.98	Actual Data
5.0 rads/min	100 Krads	1.02	3.06	10.2	Extrapolated
5.0 rads/min	10 Krads	.166	.498	1.66	Actual Data
1.0 rad/min	100 Krads	.818	2.45	8.18	Extrapolated
1.0 rad/min	10 Krads	.113	.339	1.13	Extrapolated
0.1 rad/min	100 Krads	.593	1.78	5.93	Extrapolated
0.1 rad/min	10 Krads	.082	.246	.820	Extrapolated
0.01 rad/min	100 Krads	.429	1.29	4.29	Extrapolated
0.01 rad/min	10 Krads	.059	.177	.590	Extrapolated

Even at room temperature exposure, the losses are still very high for a low dose rate environment such as .1 rad/min. At 10 Krads the losses for a 3 m length of fiber is .246, but at 100 Krads the losses increase to 1.78 dB. To make a comparison to the performance at -25°C, this attenuation is about 1 dB lower.

Conclusions:

In previous papers the results of testing 100/140 micron optical fiber were presented.[1-2] The Spectran 100/140/500 micron acrylate coated fiber was tested at +25°C and resulted in losses less than .007 dB/m when tested at a dose rate of 34 rads/min to a total dose of 100 Krads. Testing the Lucent SFT radiation hardened 100/140/172 fiber at –125°C to a total dose of 5 Krads with a dose rate of 28.3 rads/min the losses were approximately .15 dB/m and would have been .21 dB/m if the test were continued to 10 Krad. These facts are mentioned to make a comparison to the results presented here. The performance of a radiation hardened fiber under very severe thermal and radiation environments performed similarly to how the 62.5/125 micron optical fiber would in a moderately benign space environment of 1 rad/min for 10 Krads at –25°C (attenuation was .113 dB/m).

Answering the question as to whether the Lucent SFT 62.5/125/250 micron acrylate coated commercial off the shelf product would be suitable for a space flight environment depends on how much attenuation can be tolerated over short lengths. It is obvious from the data presented that for lengths greater than 10 m this fiber is not the best choice for applications that rely on high performance. However, at low dose rates, total doses and short lengths this fiber can perform with less than 1 dB of losses. For .1 rad/min at 10 Krads the losses at –25°C for 3 meters of fiber (typical length used) is less than .5 dB and at +25°C the losses with these same conditions is less than .3 dB. So in benign radiation environments the commercial 62.5/125 micron fiber can provide a suitable solution in lengths less than 10 m.

References:

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3. E. J. Friebele, M.E. Gingerich, D. L. Griscom, “Extrapolating Radiation-Induced Loss Measurements in Optical Fibers from the Laboratory to Real World Environments”, 4th Biennial Department of Defense Fiber Optics and Photonics Conference, March 22-24, 1994.