# Electron Induced Scintillation Testing of Commercially Available Optical Fibers for Space Flight[1]

M. N. Ott
Swales Aerospace / Goddard Space Flight Center, Code 562, Greenbelt Maryland, 20771

## Abstract

A test to verify the performance of several commercial and military optical fibers available on the market today was conducted, via usage of an electron accelerator, to monitor radiation induced scintillation or luminescence. The test results showed that no significant effects could be detected with the PMT (Photomultiplier Tube) system used, above a noise floor of 50 photons/sec that were due to optical fiber scintillation. Although some data appeared to show events taking place, noise scan results have correlated these events to arcing inside the electron accelerator facility. This test was to simply characterize for space flight, which optical fiber candidates were the largest scintillators among the eighteen optical fiber candidates tested.

## I. INTRODUCTION

In the past many of the studies on radiation induced effects on fiber optics have dealt with the applications associated with communication systems where the signal to noise ratios are quite high. In these applications the greatest concern for passive optical fiber waveguides has been darkening as a result of radiation exposure. There was a need to investigate commercially available fibers for low signal to noise ratio applications where the concern was not of darkening but of false signals that could be caused from radiation induced scintillation or luminescence (scintillation, a charged particle converted to a photon, is a specific type of luminescence). In general, luminescence in a optical fiber can be caused by radiation induced excitons generated as a result of impurities, dopants, or structure variations in the silica. Although, these effects are of little concern to most communication systems, this was a concern to the aft optical system engineers for the Geoscience Laser Altimeter System, GLAS. Optical fibers rated for several different wavelengths will be used on GLAS with photon counters having a noise floor of 250 photons/sec. It was not expected that the optical fiber available on the market would jeopardize the mission, but due to lack of available data an experiment was necessary to verify the performance of optical fiber for very low signal to noise ratio applications such that a compensation plan could be implemented if necessary.

## II. EXPERIMENTAL DISCUSSION

### A. Environmental Parameters

The GLAS expected environmental spectrum analysis was conducted by Janet Barth of the Radiation Physics Office at Goddard Space Flight Center. That data was used to determine the average expected fluxes per electron energies over the mission duration that could lead to an overall increase in the noise floor In addition, the worst case expected fluxes (SEE flux) as a result of instantaneous increases in the electron intensity that could result in single event effects were determined at various energies based on the data. The actual test energies and fluxes were determined based on these levels as well as by the stability of electron accelerator. The environmental and actual tested energies and fluxes are in Table 1.

| Electron Energy MeV | Expected Ave Flux (e/cm$^2$/s) | Expected SEE Flux (e/cm$^2$/s) | Actual Accelerator Test Flux (e/cm$^2$/s) |
|---|---|---|---|
| 0.10 | $7.9*10^5$ | $7*10^6$ | $1*10^7$ |
| 0.50 | $6.4*10^4$ | $2*10^5$ | $2*10^5$ - $8*10^5$ |
| 1.00 | $1.6*10^4$ | $5*10^4$ | $2*10^5$ - $4*10^5$ |

Table 1: Environmental parameters for scintillation test

All of the optical fibers were tested at 1.0 and 0.5 MeV and some of the fibers based on their UV sensitivity were tested at 0.1 MeV. The reason selecting the more UV sensitive fibers for the lower energy test was due to the expectation of scintillation occurring around the 400-600 nm range. It was surmised that if the more UV sensitive fibers did not show signs of luminescence or scintillation than the others fibers under test, would not exhibit effects either. The electron accelerator facility was operated by Steve Brown of the Radiation Effects Group, at Goddard Space Flight Center.

### B. Experimental Set-up

For this experiment eighteen optical fibers were tested for radiation induced scintillation performance. The optical fiber samples tested are described in Table 2. For testing the multimode samples, a scan for a signal at all wavelengths or any wavelengths (within the range 185 nm to 900 nm) was performed and a scan at wavelengths ranging from 185 to 900 nm was conducted during radiation exposure. For testing the single mode fiber, the timed scan was set to monitor the wavelength of interest for that given single mode fiber. In

---

[1] Special thanks to Mark Flanegan, and Dr. Joe Marzouk from GLAS at GSFC for supporting this work; Acknowledgments to Harry Shaw and the Advanced Interconnect Program for funding some of this effort, Janet Barth, Pat Friedberg, Steve Brown, and Dr. Sumati Rajan, of GSFC for facilitating this task.

Table 2 the wavelength of interest is included next to the part number for the single mode samples.

The optical fiber samples were terminated on one end with an SMA connector with the exception of the 80 micron outer diameter 3M optical fiber (rated for 532 nm and coded as M4 for this testing) which was terminated with an ST connector and connected to the monochromater (Model 101 from Photon Technology International, PTI) with an ST/SMA adapter. The other end of the optical fiber samples were covered with black tape to keep all room light from entering the fiber and giving a false result in the 400-500 nm range. All samples were coiled into a one inch diameter target such that each by itself would fit well inside the electron beam diameter of two inches. The sample was placed in front of the electron beam, approximately two inches from the beam window, just behind where the dosimeter was lowered to measure the energy and flux of the beam (Figure 1). The majority of the fiber sample, which was approximately three meters in length, with the exception of the Polymicro fiber samples which were four meters long, was positioned centered within the electron beam. Less than 3 cm was used as a lead to connect the optical fiber sample to the monochromater. The monochromater was motorized and controlled via computer with software developed by the PMT system manufacturer, PTI. The output of the monochromater is mated to the input of the PMT (Model 814, with a Hamamatsu PMT model R928) housing. The output of the digital signal from the PMT was sent back through the SID-101 controller to the computer for data storage. To eliminate erroneous results or events, lead shielding was placed around the PMT to limit stray electrons and backscatter X-rays and the monochromater was sealed to be sure that no stray light was entering the sealed box holding the PMT/monochromater system.

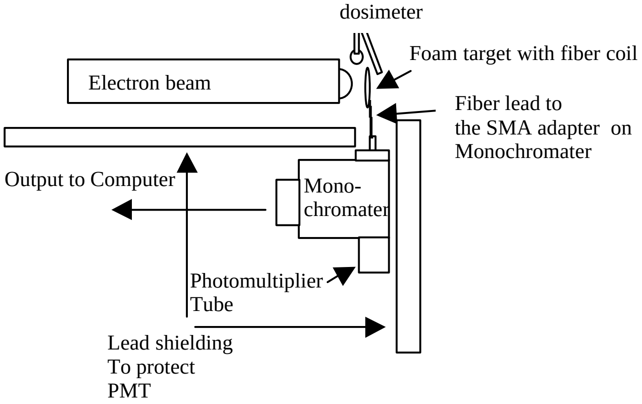

Figure 1: Experimental set-up for radiation induced scintillation testing

**Table 2: Summary of all optical fibers under test.**

| **Manufacturer** | **Part Number** | **Dimensions** | **Abbrev.** | **Coating** | **Profile** | **Test** | **Scan** |
|---|---|---|---|---|---|---|---|
| Polymicro | FVA200240320 | 200/240/320 | **PM1** | acrylate | step, high OH | B | 1,4 |
| Polymicro | FIP200220240 | 200/220/240 | **PM2** | polyimide | step, low OH | A | 1,4 |
| Polymicro | FVP200220240 | 200/220/240 | **PM3** | polyimide | step, high OH | A | 1,4 |
| Polymicro | FIA100140250 | 100/140/250 | **PM4** | acrylate | step, low OH | A | 1,4 |
| 3M | FS-SN-4224, 816 nm | 4.95/125/250 | **M3** | acrylate | step | A | 3 |
| 3M | FS-VS-2614, 532 nm | 3/80/200 | **M4** | acrylate | step | A | 2 |
| 3M | FS-SC-5624, 1064 nm | 5.95/125/250 | **M5** | acrylate | step | A | 1 |
| 3M | FG-200-UCR | 200/240/260/400 | **M1** | Tecs/acrylate | high OH | B | 1,4 |
| 3M | FG-200-LCR | 200/240/260/400 | **M2** | Tecs/acrylate | low OH | A | 1,4 |
| Spectran | SMCA0780, 816 nm | 4.9/125/250 | **SP1** | acrylate | step | A | 3 |
| Spectran | SMCA0515, 532 nm | 3/125/245 | **SP2** | acrylate | step | A | 2 |
| Spectran | SMCA0980D, 1064 nm | 6.2/125/250 | **SP3** | acrylate | step | B | 1 |
| Spectran | C1032XA BF05444 | 100/140/500 | **SP4** | acrylate/ hermetic | graded index | B* | 1,4 |
| CeramOptec | UV200/220/245P | 200/220/245 | **CO1** | polyimide | step, high OH | B | 1,4 |
| CeramOptec | WF200/220/245P | 200/220/245 | **CO2** | polyimide | step, low OH | A | 1,4 |
| CeramOptec | UV100/140/155P | 100/140 | **CO3** | polyimide | step, high OH | A | 1,4 |
| CeramOptec | WF100/140/155P | 100/140 | **CO4** | polyimide | step, low OH | A | 1,4 |
| Litespec |  | 100/140/900 | **LS1** | buffer | step index | A | 1,4 |

Test Index
A: Tested at energies 0.5 MeV and 1.0 MeV
B: Tested at energies 0.1 MeV, 0.5 MeV and 1.0 MeV
*: indicates fiber tested at 1.5 MeV

Scan Index

1. Indicates testing for a minute duration monitoring all wavelengths simultaneously.
2. Indicates testing for a minute duration monitoring a single wavelength scan at 532 nm.
3. Indicates testing for a minute duration monitoring a single wavelength scan at 816 nm.
4. Indicates testing over several minutes (less than 3 minutes) to capture data from a full scan of wavelengths from 185 nm to 900 nm

The Van der Graaf electron accelerator used was the AEC-1000, from High Voltage Engineering Corp. with a 2 MeV maximum energy. All tests were performed with the setup external to the accelerator chamber and in ambient conditions. As soon as the dosimeter indicated the desired energy and flux had been attained which took approximately less than five minutes, the scans were recorded as quickly as possible, to avoid exposing the fiber too long to radiation and causing darkening which would inhibit any guidance of scintillation or luminescence. The entire test per fiber sample was about 10 minutes or less in duration. A single sample of fiber of each part type was used for all testing.

After the first day of testing, the PMT parameters were adjusted to limit the noise floor to 50 photons/s by varying the PMT voltage such that the system was sensitive enough to detect light (verified with room light scans and measurements taken using an 850 nm source) but such that the noise floor was limited as much as possible. The integration time was then set to the maximum possible setting of .1 sec. The assumption was that radiation induced scintillation would be detected above the noise floor but by setting the PMT to its specified parameters, the noise floor would have to be large. When no scintillation or luminescence was detected after testing several of the multimode optical fiber samples, the noise floor was lowered to much less than that of the actual GLAS requirement of 250 photons/s. The PMT was set to values not in specification but the noise floor was lowered to 50 photons/sec.

## C. Collected Data

During testing it was apparent that some type of event was occurring only during wavelength scans of test 4. However these events were less likely to occur during test 1. The same type of event scans were observed with the accelerator on, and the large events above 70 photons/sec could be directly correlated with the events that were occurring in the accelerator as shown on the accelerator energy monitors. Several times during testing, when test 4 showed significant results while test 1 scans did not, noise scans to correlate the events to arcing events inside the accelerator were conducted with the results being that random events at various wavelengths were occurring due to these arcing events. The arcing events inside the accelerator were created from the discharging between the casing and the high voltage terminals (corona points) and as a result, short spikes of RF current could travel to area equipment through grounding to result in erroneous results. In cases where the energy levels were low enough to limit the arcing, other minor events as a result of impurities in the beamline and the capacitor plates discharging along the path of the electron beam was causing instantaneous errors. It is therefore, difficult to state whether any of the optical fibers tested actually showed scintillation effects as a result of electron bombardment. Since the arcing inside the accelerator seemed to be dominating the events and distinction between scintillation in the optical fiber and arcing were impossible to separate.

## D. Discussion

The largest event recorded (within the energy and flux requirements for GLAS) was at 250 photons/sec at a wavelength of 461 nm, for the CO4 fiber at 1.0 MeV and a flux of $3.6*10^5$ e/cm$^2$/s. The GLAS noise requirement is that no radiation induced effects can add to the noise floor such that the noise floor is greater than 1000 photons/sec over the duration of the mission. The noise floor of the PMTs are 250 photons/sec without an radiation induced effects. If we were to assume that some of the events detected were from optical fiber scintillation, it is safe to say that at the electron energies and fluxes that the GLAS instrument will be exposed to, there would be no events larger than the proposed noise floor of the instrument photon counters (without radiation induced effects) in that are stated to be 250 photons/sec. It was also the case that there was no fiber scintillation detected at the GLAS specified wavelengths of 532 nm or 816 nm.

Fibers SP4, PM1, PM2, PM3, PM4, M1, and M2 were tested prior to lowering the noise floor of the PMT system. No effects were detected above this noise floor. Once the noise floor was lowered to 50 photons/sec maximum, the high OH content candidates that were previously tested at 0.5 and 1.0 MeV were retested. Candidate M1 was supposed to be retested and was not due to oversight but was tested at the .1 MeV along with the other high OH, UV sensitive optical fibers. Once the noise floor was lowered all single mode fiber candidates were tested at 0.5 and 1.0 MeV at the expected SEE flux or larger for each energy. The high OH content multimode candidates that were previously tested with the higher noise floor: PM1 and PM3, where retested and in addition SP4 was retested since it was the only graded index multimode candidate. The reason for choosing to retest only the UV sensitive optical fibers was due to the expectation that if scintillation were to occur, it would occur in the near UV or low visible regions. These high OH fibers, due to their lower attenuation and guidance at these wavelengths would be the first to exhibit the effects. It was assumed that if these fibers did not show effects that the other optical fibers would not as well. The same deduction was used to test at the lower energy of 0.1 MeV. Again, it was assumed that if the UV or near UV sensitive optical fibers that now included single mode as well, were not exhibiting scintillation effects at this energy, none of the other fiber candidates would either. Theses optical fibers included: SP3, PM1, PM3, M1, CO1, CO3. The candidate CO3 was not tested at 0.1 MeV. Due to its brittleness and breakage during handling, this candidate was considered an unlikely candidate as a final choice and was eliminated from the testing at this time. The candidate SP4, once again was tested since it was the only graded index fiber of the eighteen fibers tested.

As mentioned previously, many of the events seen and recorded were correlated to arcing and discharges inside the electron accelerator chamber. This being the case it is impossible to separate what could have been scintillation from the accelerator events. In addition, many of events detected were falling below the threshold of the R928 nm PMT which is rated for no lower than 185 nm. This added to the theory that most of the events were due to the accelerator arcing.

If it is possible that some of the recorded events were due to actual scintillation during this testing, it has been verified that none of the wavelengths where these events occurred were within 6 nm of the GLAS wavelengths of 532 or 816 nm. The only exception is CO4 which had an event occur during the 0.5 MeV test during the wavelength scan at 821 nm, which when converted by the calibration constant (determined prior to testing) becomes 818 nm. This was the only event that was close to the GLAS wavelengths of interest of 532 nm or 816 nm. Beyond that, any of the other events that occurred did not occur at rates larger than 250 photons/sec.

The losses incurred from bending the fiber into a diameter of 1 inch are expected to be less than 1 dB. For PM4, a step index 100/140/155, the loss from coiling the fiber into a 1 inch diameter as compared to an uncoiled fiber is -.3dB at 1310 nm for 4 meters of fiber. For 3 meters of 100/140/500 graded index, SP4, at 850, the loss as a result of coiling is -.07 dB and at 1310 nm is -.44 dB. Therefore, the result of losses as a result of bending do not greatly impact the outcome of this testing at the (shorter than 1310 nm) wavelengths of interest.

## III. CONCLUSIONS

The intention of the experiment was to characterize commercially available fiber for radiation induced scintillation effects. The experimental set up used was limited to a noise floor of 50 photons/s. This was adequate to provide information to the GLAS mission since the noise floor requirement due to radiation induced effects is 1000 photons/sec or less and the noise floor of the PMT system used on GLAS is 250 photons/sec before any radiation induced effects. The GLAS mission wavelengths of interest were 532 nm, 816 nm, and 1064 nm. Our PMT system was limited to 900 nm so no data at 1064 nm could be gathered, however it was expected that any scintillation occurring would be largest at the wavelengths between 400-550 nm based on prior scintillation experiments.[3]

Although it was not expected that any of the optical fiber candidates would scintillate a great deal due to the lack of impurities in current commercially available products, the lack of any scintillation above the noise floor of 250 photons/sec (for the GLAS PMTs) was a pleasant surprise. In most cases, it appears that the optical fiber candidates performed approximately the same in terms of radiation induced scintillation or luminescence. It appears that most of the events occurring during testing were not related to radiation induced scintillation but to discharging inside of the electron radiation accelerator. If we are to assume that the events directly correlated to the discharging events inside of the accelerator, are conclusive evidence that allows us to assume that none of the events occurring during the experiment were due to fiber scintillation, than we can state that no events occurred above the experimental PMT noise floor of 50 photons/sec. Regardless of the actual source of the events, no events recorded at the expected environmental radiation energy and flux levels for GLAS were above the noise floor of 250 photons/sec expected for GLAS' photon counters for any of the wavelengths monitored during testing (185 nm to 900 nm). Given the criteria that no fiber should scintillate such that the noise floor goes above 1000 photons/sec (as a result of the inherent PMT noise floor plus any additional noise from radiation induced effects) at the wavelengths of 532 nm, 816 nm or 1064 nm, it is expected that all fiber candidates should perform adequately for the GLAS application. In conclusion, it appears that the choice of optical fiber for use at these given wavelengths is not limited by the radiation induced scintillation or luminescence.

## IV. REFERENCES

1) A. S. Beddar, T. R. Mackie, F. H. Attrix, "Cerenkov light generated in optical fibers and other light pipes irradiated by electron beams," Physics in Medicine and Biology, 1992, Vol. 37, No.4, 925 - 935.

2) P.L. Mattern, L. M. Watkins, C. D. Skoog, J. R. Brandon, E. H. Barsis, "The Effects of Radiation on the Absorption and Luminescence of Fiber Optic Waveguides and Materials," IEEE Transactions of Nuclear Science, Vol. NS-21 December 1974.

3) M. R. Khanlary, P. D. Townsend, J. E. Townsend, "Luminescence spectra of germanosilicate optical fibres. I: radioluminescence and catholuminescence," Journal of Physics D-Applied Physics, Vol. 26 No. 4, March 4, 1993, 371-378.

4) Janet Barth, Radiation Physics Office, Goddard Space Flight Center, Radiation Environmental Data for the GLAS Mission.