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The Effects of Radiation and Low Temperatures on Optical Fibers

Nnadozie Tassie
Southern Methodist University, ntassie@mail.smu.edu

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THE EFFECTS OF RADIATION AND LOW TEMPERATURES ON OPTICAL FIBERS

Nnadozie Tassie
Department of Physics
Southern Methodist University
3215 Daniel Avenue, Dallas TX, 75275 USA
Faculty Advisors: Drs. Andy Liu and Jingbo Ye

ABSTRACT:

My research seeks to identify optical fibers capable of operating in an environment with radiation and low temperatures. This study is for an international detector R&D project which is for the high luminosity upgrade of the Large Hadron Collider (LHC) at CERN, Switzerland. In high energy particle physics experiments, silicon pixel detectors, often called inner trackers, are used to precisely measure the trajectories of charged particles. The Inner Trackers for both the ATLAS and the CMS, two of the four large experiments at the LHC, operate in high radiation environment and in an ambient temperature of -20 to -30^{o}C to reduce thermo noise for the silicon sensors. These Inner Trackers will need to be upgraded when the Hadron collider is upgraded for high luminosity (intensity), which will mean high radiation levels for the silicon sensors and readout electronics in which fiber optics are used. To identify fibers that are suitable for these readout systems, we irradiate them and measure the radiation induced attenuation as a function of total dose delivered to the fibers. In this R&D project, I am constructing a test setup that will be used to irradiate optical fibers using a Co-60 source at the Brookhaven National Lab next February. During that irradiation test, we will study radiation induced optical attenuation. My responsibility in this research work is to construct the temperature controlled chamber and to monitor the temperature using the PT100 resistance-thermometers that are known to be radiation resistant. My work about calibrating the PT100 sensors, the design and construction of the chamber, and the final irradiation tests on the fibers and the experimental results will be presented. My research contributes to collaboration with the Fermi National Laboratory (USA), Oxford University (UK) and CERN (Switzerland), and my experience of working in such an international collaborative environment will also be discussed.

Keywords: Radiation, Temperature, Fibers

1. INTRODUCTION

Optical fibers are long, thin strands of very pure glass about the diameter of a human hair. Fibers are arranged in bundles called optical cables and used to transmit light signals over long distances. The bundles are protected by the cable's outer covering, called a jacket. An optical fiber consists of the following parts

- Core - Thin glass center of the fiber where the light travels
- Cladding - Outer optical material surrounding the core that reflects the light back into the core
- Buffer coating - Plastic coating that protects the fiber from damage and moisture

There are two types of optical fibers: Single-mode fibers (SMF) and Multi-mode fibers (MMF)

Single-mode fibers have small cores (about 9 micrometers in diameter) and transmit infrared laser light (wavelength = 1,300 or 1,550 nm). Multi-mode fibers have larger cores (about 50 or 62.5 micrometers in diameter) and transmit infrared light (wavelength = 850 or 1,300 nm) from light-emitting diodes (LEDs) or laser diodes. The light in a fiber-optic cable travels through the core by constantly bouncing from the cladding (mirror-lined walls), a principle called total internal reflection. Because the cladding does not absorb any light from the core, the light wave can travel great distances. However, some of the light signal degrades within the fiber, mostly due to impurities in the glass. The extent that the signal degrades depends on the purity of the glass and the wavelength of the transmitted light.

ATLAS and CMS are competing particle physics experiments at the Large Hadron Collider at CERN (European Organization for Nuclear Research), Geneva Switzerland. They are both searching for new discoveries in the head-on collisions of protons of extraordinarily high energy. ATLAS and CMS will learn about the basic forces that have shaped our universe since the beginning of time and will determine its fate. Among the possible unknowns are the origin of mass, the Higgs boson, extra dimensions of space, unification of fundamental forces, and evidence for dark matter candidates in the universe.

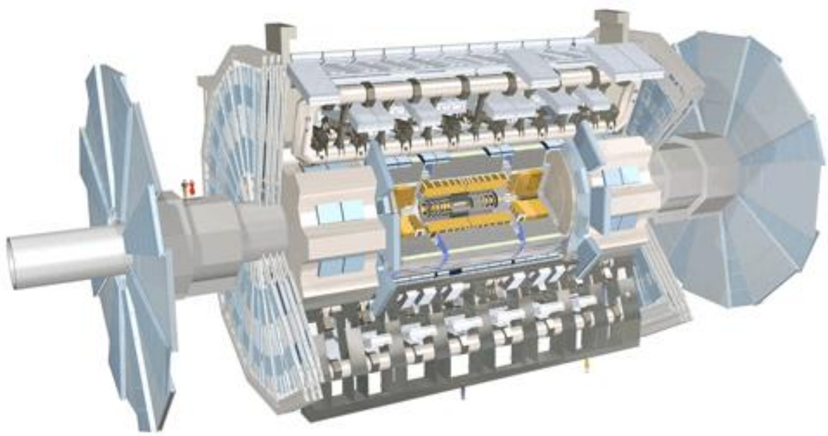


Figure 1: ATLAS Detector

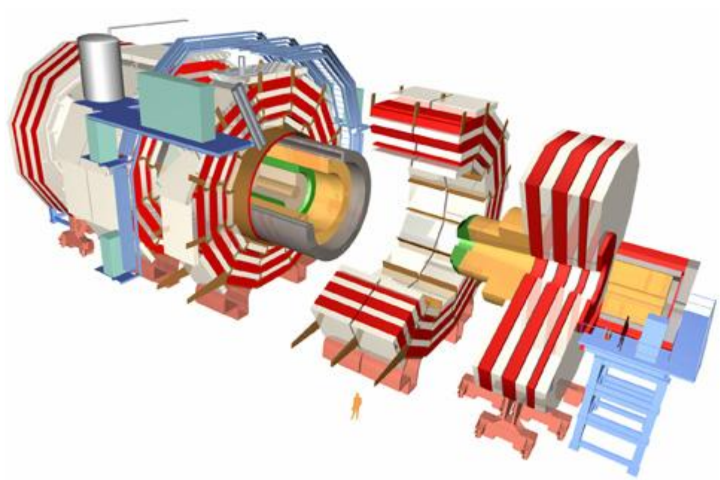


Figure 2: CMS Detector

Optical fibers are used widely in ATLAS and CMS to transmit information between front end readout electronics and the back-end computers, and will be used for detector upgrades. These fibers will be required to withstand high radiation as well as temperatures near -25^{o}C simultaneously. In order to achieve this, high quality optical fibers must be used in the project to prevent much radiation damage and possible loss of data while running experiments. Also, the optical fibers are expected to work at speeds between 5-10Gbits/s over distances of up to 150m.

Optical fibers are damaged when the glass core is defected by ionizing radiation. These increase relevant wavelength absorption as a result of new energy levels that have been introduced. At lower wavelengths, these energy levels attain their zenith, thus single-mode optical fibers tend to be more resistant to radiation than multi-mode fibers. This is because the single-mode fibers are optimized at wavelengths between 1300-1550nm while multi-mode fibers are optimized at about 850nm. Generally, resistance of an optical fiber to radiation mostly depends of the level and type of impurities present in the glass core, the operating wavelength, and the conditions during present during the manufacturing process of the fiber. What is not necessarily known about optical fibers is the type (SM or MM) that is more radiation tolerant. However, previous results from similar experiment conducted by the researchers from the Physics department at Oxford University show that single-mode optical fibers are more radiation resistant than multi-mode fibers.

The Versatile Link Project was founded in April 2008. One of its goals is to find suitable optical fibers to upgrade the LHC's fiber optic links at the ATLAS and CMS detectors. The purpose of this experiment is to evaluate and determine the appropriate optical fibers for use in the LHC detector upgrades. In the past, several optical fibers were selected and tested under high radiation at room temperature and at -25^{o}C. However, some sub-detectors such as the ATLAS tracker operate at temperatures as low as -25^{o}C, and other parts may not attain such high radiation. Therefore this experiment was aimed at determining the RIA of certain specific fibers subjected to a relatively low radiation dose rate at low temperatures

The 6 fibers to be tested (all tight buffered) were rolled and put into a chest freezer (Model 19502 produced by Kenmore) to simulate the low temperature environment in the LHC. This freezer was then placed in front of a Cobalt-60 gamma radiation source at Brookhaven National Laboratory. Ten platinum resistance thermometers (PT100) were located at various positions around and inside the fiber rolls, and these were used to measure the temperature of the fibers

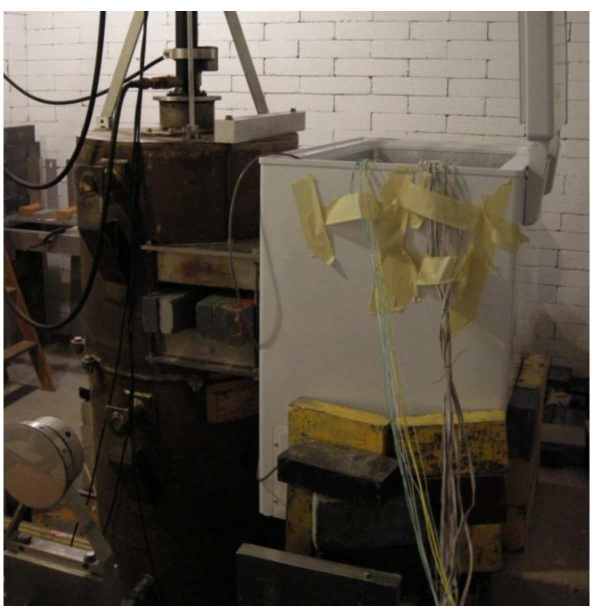
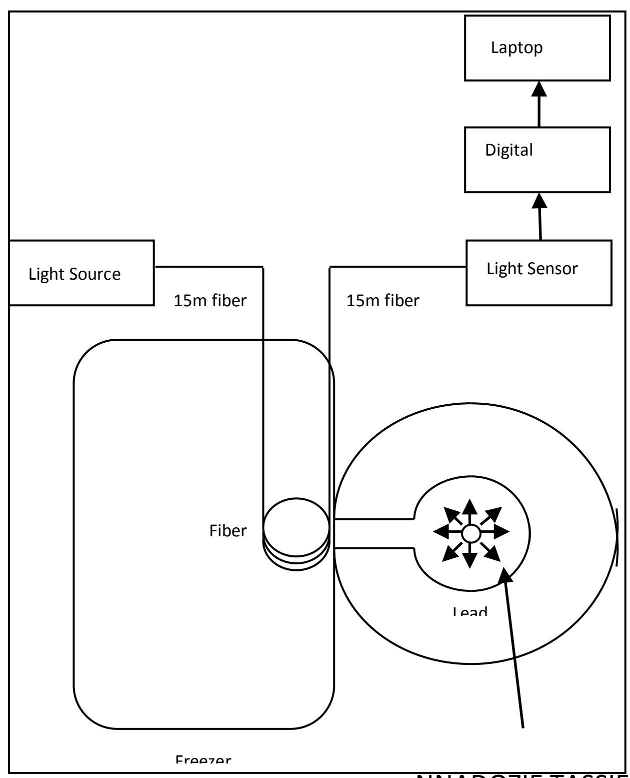


Figure 3. Experiment setup



Co 60 radiation source

The DAQ system consisted of the temperature control system, and the light source/power measurement system. Before these resistors could be used, they had to be connected to a computer through a digital multimeter and calibrated using a LabVIEW program. From the technical sheet provided by the manufacturers, a function of temperature with respect to resistance was derived. Higher order functions were then obtained from the primary (first order) function in order to determine the appropriate function to implement in LabVIEW. The function which yielded the residue with the least range was the third order function, and this was eventually used in the calibration process. The resistors, the digital multimeter, the LabVIEW program and the computer made up the temperature measurement.

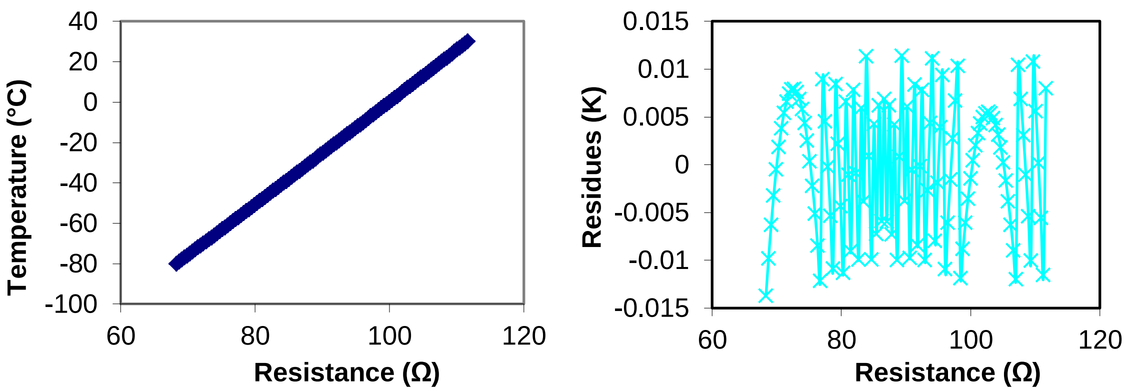


Figure 4: Graphs showing Temperature vs. Resistance for the third order function and its associated Residues

For light sources, four Vertical Cavity Surface Emitting Laser diodes (VCSELs) were used to generate 850nm lasers for the multi-mode fibers, while two Fabry-Perot laser diodes were used to generate 1310nm lasers for the single-mode fibers. Monolithic photodiodes with on-chip trans-impedance amplifiers (Part #OPT101 from Texas Instruments) were then used to convert the light into voltage during the experiment. From the voltage, the attenuation for the fiber was calculated while the fiber was under radiation in the freezer. The optical power of each fiber before the start of the experiment served as a reference point. The laser diodes, photodiodes, digital multimeter, LabVIEW program and the laptop made up the light source/power measurement system

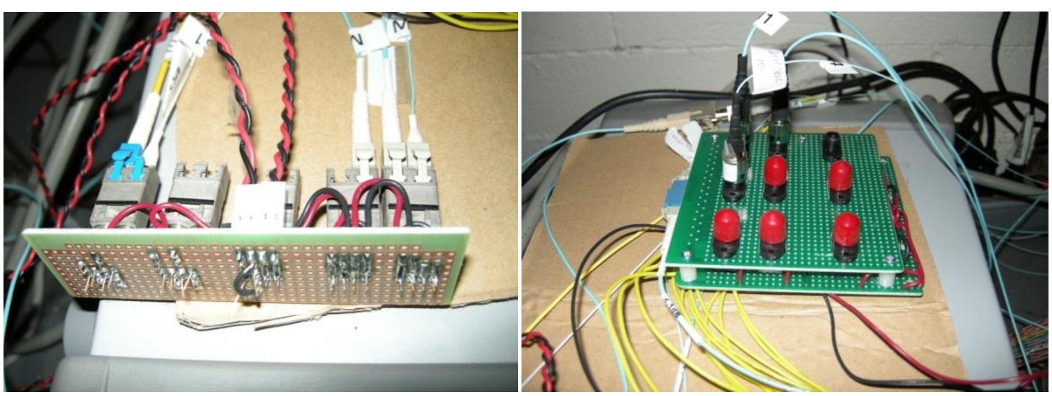


Figure 5: Pictures showing laser diodes used to generate lasers for fibers

2. RESULTS AND DISCUSSION

Everything went as planned during the actual experiment at BNL. The only problem was a loss of data due to a glitch in one of the humidity sensors (as seen in figure 7 below). This was probably as a result of radiation damage. For this experiment, six different fibers were tested – 4 MM and 2 SM. The dose rate and total dose varied for each fiber because fibers positioned closer to the source received a higher does and vice versa. Figure 7 below also shows that the temperature was maintained close to -25°C.

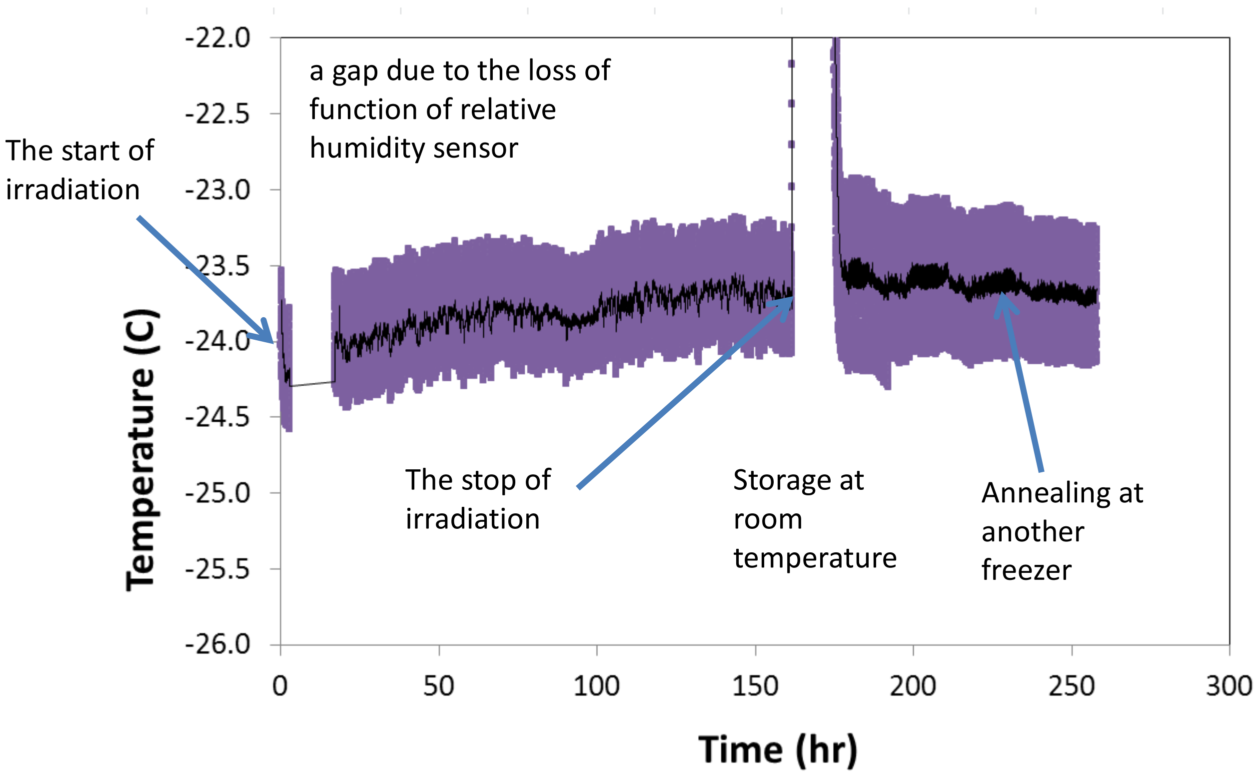


Figure 7: Graph showing temperature during the experiment

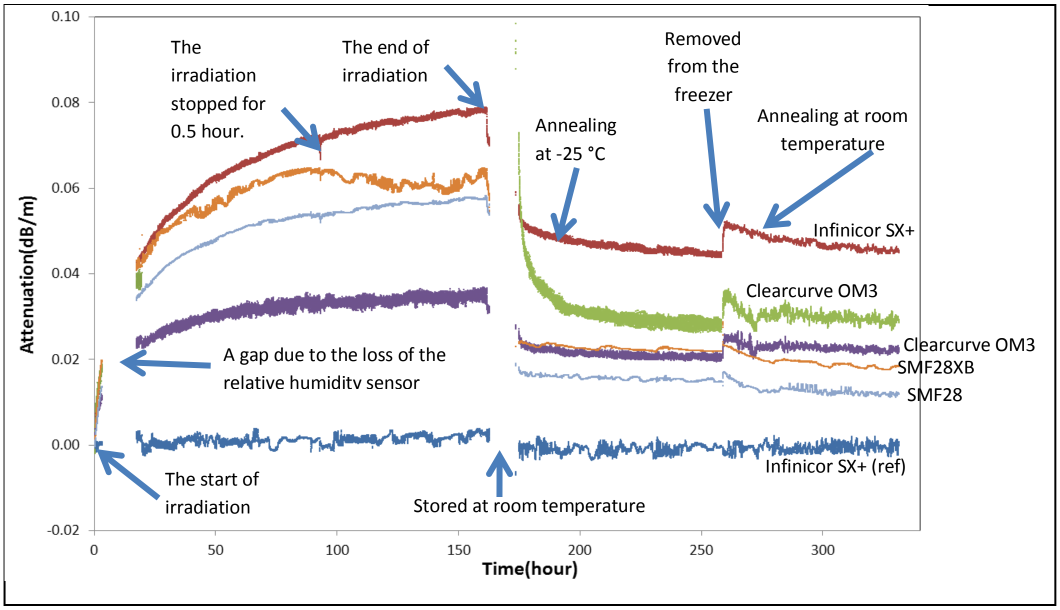


Figure 8: Graph of RIA vs. time

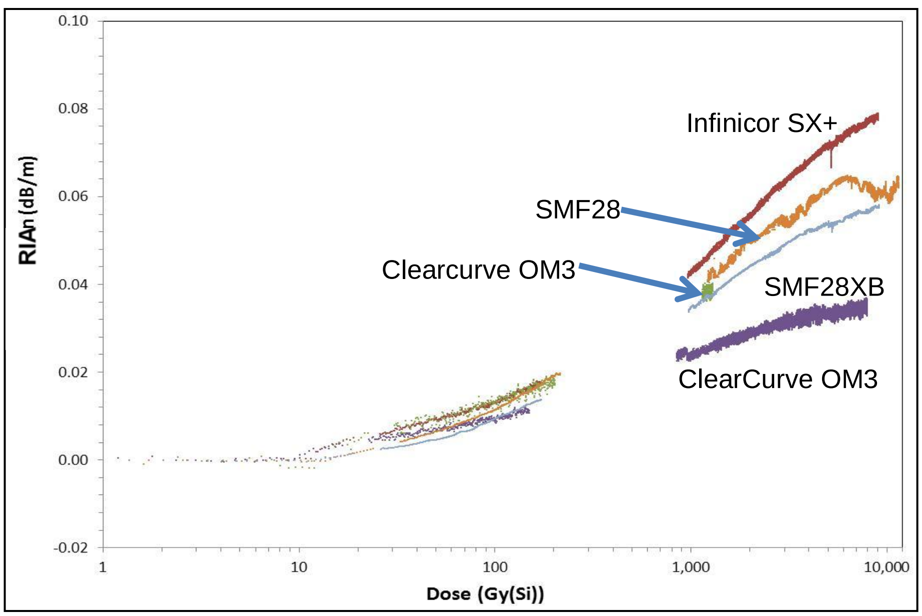


Figure 9: Graph of RIA vs. total dose

Figure 8 shows that RIA for each fiber greatly increased at first but then it slowly approached a certain value (about 0.08db/m) as time increased before the irradiation was finally stopped. The gap in the graph shows the time when the fibers were stored at room temperature while in transit from research facility. Once the fibers were returned to Southern Methodist University, they were placed in another freezer to check for annealing. As seen in Figure 8, all the fibers showed sharp annealing initially, but this slowly reduced as time went. It is worth noting that the RIA of the fibers never returned to 0 (the RIA of the fiber used as control).

Figure 9 shows the graph gotten when RIA is plotted against total dose. Although the difference was small, the SM fibers showed a lower RIA than the MM fibers tested. The ClearCurve OM3 had the lowest RIA value while the Infinicor SX+ had the highest.

$$RIA = 10 * \log[P(t_0)/P(t)]; \quad (1)$$

Where $P(t_0)$ is the optical power at the beginning of the experiment and $P(t)$ is the optical power as a function of time.

Ch ID	Manufacturer	Part #	Mode	Length Exposed to Radiation (m)	Dose Rate (Gy/hr)	Total Dose (kGy)	RIA (dB/m)
S1	Corning	SMF28XB	SM	166.56	56.19	9.14	0.057
S2		SMF28		74.11	70.59	11.48	0.063
M1		Infinicor SX+	MM	0.00	0.00	0.00	0.000
M2				170.45	55.75	7.00	0.076
M3		ClearCurve OM3		69.55	66.13	10.75	N/A
M4				118.96	48.91	7.95	0.034

Table 1: Showing experimental results. M1 was used as control while M3 was removed for other purposes.

Comparing these results with previous results gotten from similar experiments in the past, it has been confirmed that there is a positive correlation between RIA and total dose/dose rate of applied radiation. The same can also be said about temperature. Though this may not always be the case, figure 8 below shows that fibers subjected to radiation at room temperature experienced a lower RIA than those at -25 ℃. However, dose rate is the largest contributing factor to attenuation

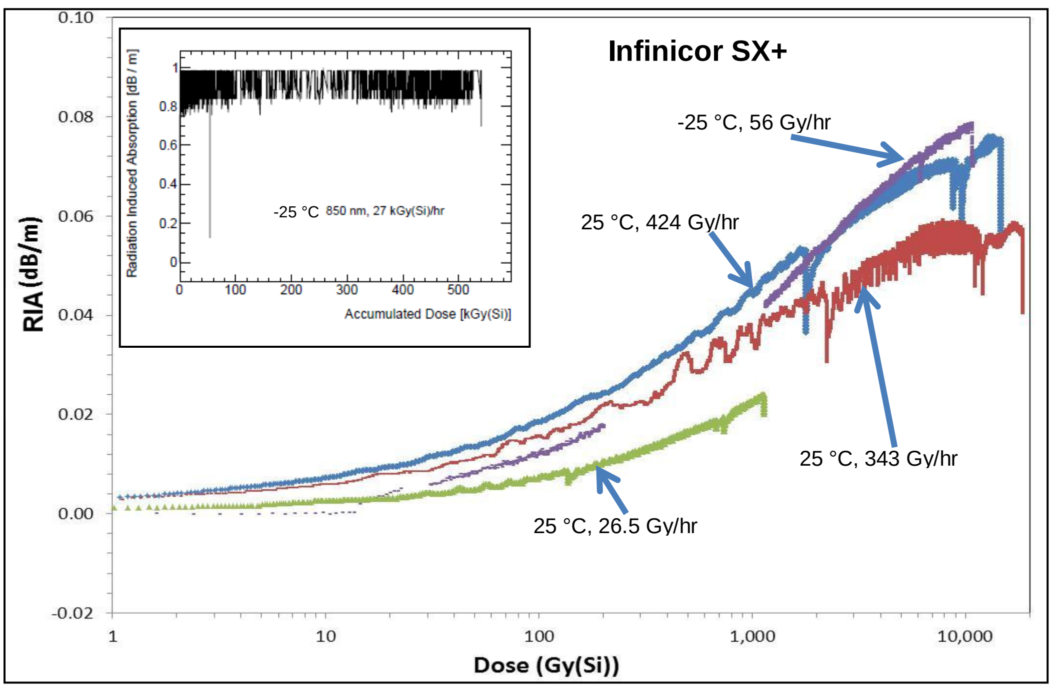


Figure 10: Comparison of previous results

3. CONCLUSION

As expected, the newer optical fibers, the ClearCurve OM3 and SMF28, performed better than their older counterparts, experiencing a lower RIA. All of the fibers tested are viable candidates for use in the proposed LHC and SLHC upgrades, although still more tests are needed to qualify them. Future versatile Link Experiments will utilize radiation doses closer to the conditions likely to be found in the LHC.

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