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Research article

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Analysis of Single Mode Optical Fiber Cable Behavior Under Neutron Irradiation Effect: Practical Application

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Abstract

Analysis of neutron induced attenuation within fiber cables has received more attention in this article. Overcoming the attenuation of transmitted signals should be addressed. A single mode optical fiber with pure silica core is employed in experimental analysis. The total fiber length is 40 m. This experiment is done in the second Egyptian Training Research Reactor (ETRR-2). The Neutron Beam Facility (NBF) within ETRR-2 has a flux of 1.5 × 107 n/cm2sec and thermal power of approximately 18 MW. The experiment is done at room temperature. A 20 cm length of fiber cable is directly exposed to NBF for 4 hours. The measurements of attenuation are performed using two instruments. These instruments are power meter and laser source device. The experimental measurements are done at two different spectral wavelengths of 1310 nm and 1550 nm. The measurements are done before and after neutron irradiation. A comparison between obtained results is investigated. Before irradiation, a fixed attenuation is noted. Attenuation recovery of pair 1 is noted after 1 hour at 1310 nm. However, it is attained after 2 hours for pairs 2 at 1550 nm. The attenuation is incremented with time until 2 hours. Then, it is suddenly decreased. The experimental results show better attenuation recovery within fiber cables after littlies hours depending on operating wavelength and fiber length.

Keywords: Fiber cable; Single mode; Attenuation; Power meter; Light source and neutron irradiation

Introduction

The recent advancements in photonic technologies have provided new applications for optical fibers involving radiation environment, the nuclear industry shows an increasing interest in the fiber optic technology for both data communications and sensing applications in nuclear plants [1]. So it is necessary to study the effects of radiation on optical fiber links. This is because its advantages as compared to current methods [2]. Optical fiber signals are immune to Electro Magnetic Interference (EMI) and Radio Frequency Interference (RFI); optical fiber is secure and allows for privacy, smaller in size by Song [3], lighter in weight, easier installation and low signal loss enables longer transmission distances.

A limiting factor for usage of optical fibers is an uncertainty of their performance in the presence of radiation [4]. In order to know the performance of optical fiber in radiation fields an experimental study was carried out. According to the previous studies when radiation projects to optical fibers, some effects will produce [5-7]: Increase of optical fibers absorption loss, changes of optical fiber refractive index and development of optical fiber luminescence. Researchers showed that radiations generate, at the microscopic scale, point defects in the amorphous silica glass network through ionization or “knock-on” processes [8,9]. These point defects, or color centers, induce the appearance of new energy levels located inside the band gap of the dielectric. As a consequence, the defect-containing glass absorbs a more important part of the transmitted signal leading, at the macroscopic scale, to an increase of the attenuation of the fiber waveguide [10]. This absorption increase is called Radiation-Induced Attenuation (RIA) [11]. For neutrons in the energy range produced by nuclear reactors, energy deposition, and hence radiation damage, occurs in silica glass via three primary mechanisms [12,13]: Elastic scattering, inelastic scattering, and in the case of silicon atoms irradiative capture of thermal neutrons. The purpose of this research is to provide experimental data to evaluate system performance degradation of optical fibers under nuclear environments. In this research, an experiment is studied to show the effects of neutron-radiation on single mode optical fiber cable Birri [14], the attenuation is measured at different wavelengths and at different times. Radiation induced attenuation is varied in accordance with fiber wavelength; its composition; time of exposure and the applied radiation.

This paper is organized as follows; section (2) Includes the experimental procedure and system configuration. The attenuation measurements within optical fiber cable are declared in section (3). The experimental results and discussions are illustrated in section (4). Finally, section (5) is devoted for work conclusion.

Experiment Procedure and System Configuration

ETRR-2 is a multipurpose reactor, open pool type, 22 MW thermal power, with maximum core thermal flux of 2.37*1014 n/cm^2 sec, cooled and moderated by light water, and with Beryllium reflector. Various experimental devices and irradiation facilities are provided in it. One of our experiments has been done in front of one of these facilities, which is neutron beam facility at flux of 1.5*107 n/cm^2 sec, thermal neutron flux 8.6*107 n/cm^2 sec and dose rate intensity at beam outlet 3.3 Sv/hr at 13.3 MWatt thermal. It is a radial beam tube with proper shielding, in front of this beam, neutron radiography facility is mounted. The exposure of optical fiber to neutron radiation leads to various defects. Neutrons are interacted with cable material and produce multiple materials. An experiment is done to illustrate the possibility of cable transfer for measurements. This experiment has two samples of the fiber cable, one centimeter each. One of them is irradiated for short time (~120 s) at rabbit system in ETRR-2.

However, the second sample is irradiated for long time (~30 minutes) within core of the reactor. The composition of the cable due to interaction with neutron radiation is analyzed via specific radiation system. On other words, measurements of the irradiated samples were performed using a gamma-ray spectroscopy system. It consists of n-type HPGe (Hyper Pure Ge) detector (model comp-100250-S) with associated electronics and a computer-based multichannel analyzer, all provided by (EG and G ORTEC). Gamma vision (software) for gamma-ray detection, by analyzing you can determine each isotope.

The detector has a relative efficiency of 100% at 1332 keV, and FWHM of 2.1 keV at 1332 keV and of 0.875 keV at 122 keV. Both energy and efficiency calibrations were performed using certified sealed point sources of 60 Co, 133 Ba, 137 Cs and 152 Eu. The results of the interaction due to short time and longtime are shown in Table 1 and Table 2. Similarly, the compositions of the cables due to radiation influences are declared in Figure 1(a-b) and Figure 2(a-b) for short and long duration, respectively. In addition, each experiment is repeated in order to assure the obtained results. So, each figure is accounted for first count experiment and second count experiment.

Isotope	Half life time
Ti-51	5 minutes
Mn-56	2.5 hours
Mg-27	9.5minutes
Cu-66	5 minutes
Na-24	15 hours
V-52	3 minutes
Cl-38	37 minutes
Al-28	2 minutes
Ca-49	8.7 minutes

Table 1: Composition of fiber cable due to interaction with neutron radiation under short irradiation period (~120 seconds).

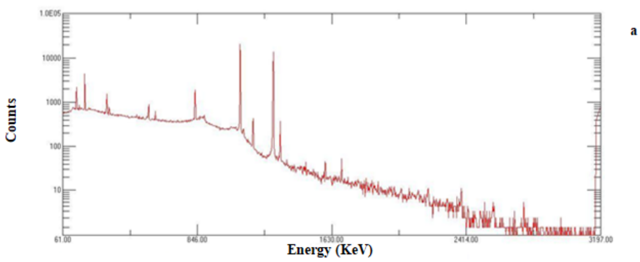

Figure 1(a): Obtained radioisotope materials due to interaction between fiber cable and neutron radiation and for short irradiation first count experiment.

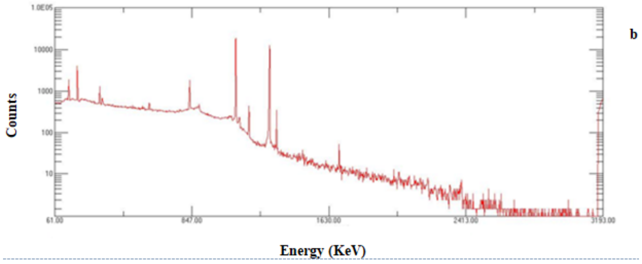

Figure 1(b): Obtained radioisotope materials due to interaction between fiber cable and neutron radiation and second count experiment.

Isotope	Half life time
As-76	1 day
Fe-59	44.5 days
Cr-51	27.5 days
Co-60	5 years
Sb-122	2.7 days
Sb-124	60 days

Table 2: Composition of fiber cable due to interaction with neutron radiation under long irradiation period (~30 minutes).

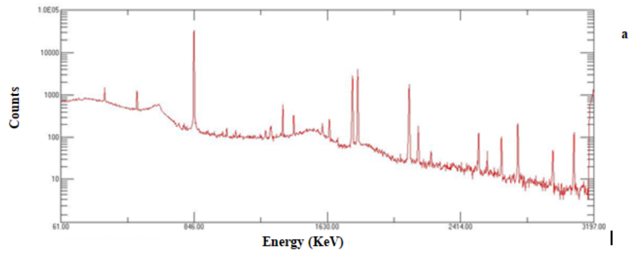

Figure 2(a): Obtained radioisotope materials due to interaction between fiber cable and neutron radiation for long irradiation first count experiment.

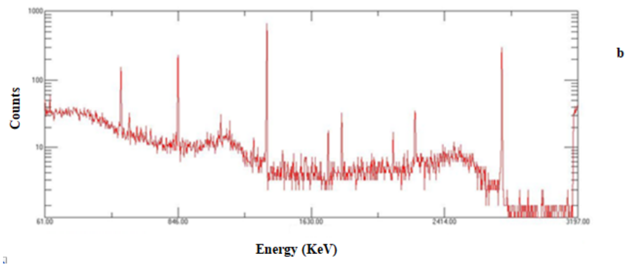

Figure 2(b): Obtained radioisotope materials due to interaction between fiber cable and neutron radiation second count experiment.

It is observed that the compositions of cable at short interaction are characterized with short half life time isotopes. However, the interaction leads to long half-life radioisotopes within core construction at longer exposure time to neutron radiation. The deduced results confirm the difficulty of cable transfer for further analysis in external laboratories.

So after the analysis of the cable composition when exposed to neutron irradiation, we do our main experiment. In this experimental work, a sample of single mode optical fiber cable with pure silica core was used 40 m length of fiber cable is used but approximately 20 cm length is used for irradiation, this cable is (Telecom Egypt 2016-4G. 6520-Po No 231/2016/18-ZTT) as shown in Figure 3.

The connectors are FC/PC connectors that environmentally stable and reliable, these connectors are spliced to the cable through two pair patch cords by direct core monitoring fusion splicer, TYPE-71C-01 SUMITOMO ELECTRIC. The splicing machine is shown in Figure 4. This fusion splicer offers the idle combination of versatility, accuracy and speed. It is designed to provide consistent low-loss splices, of all types of fiber, utilizing the latest generation of proven PAS core-alignment technology.

Figure 3: Telecom Egypt fiber cable within spliced connectors.

Figure 4: Direct core monitoring fusion splicer of fc/pc connectors.

Approximately 20 cm of the cable is irradiated at different period of times; the total period is about 4 hours. The attenuation is measured *in-situ* after 0.25 hour, 1 hour, 2 hours, 3 hours and 4 hours. Figure 5 shows the mounted part of the cable in front of the beam.

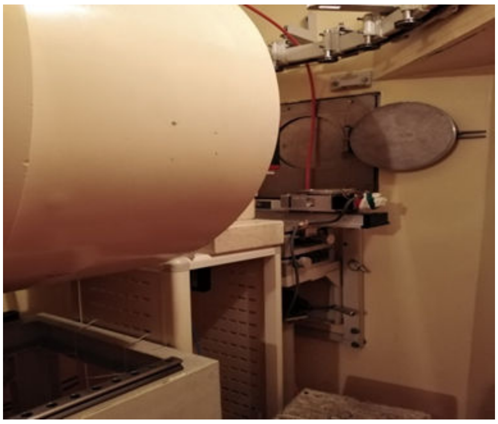

Figure 5: 20 cm fiber cable in front of the neutron beam.

The experimental measurements for fiber attenuation are done *in-situ* in front of the beam at ETRR-2. The used instruments are power meter and laser source. The utilized practical wavelengths are of 1310 nm, 1550 nm. These instruments are illustrated in Figure 6.

Figure 6: Laser source and power meter used in attenuation measurements.

Attenuation Measurements with in Optical Fiber Cables

The block diagram of the system by which the power losses of fiber samples were measured is shown in Figure 7. One end of the fiber was connected to the light source and the other end to the power meter. The light source sends a wavelength of light down the fiber. However, the power meter at the other end of the cable reads that light. This meter determines the amount of signal loss. This loss is computed by:

Power loss=Reference power (source)-Tested power (received)

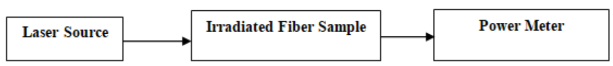

Figure 7: Attenuation measurements within optical fiber cables by power meter.

The irradiated part of the cable is exposed to neutron irradiation at flux of $1.5^{*}107$ n/cm2 sec, for total time about four hours. The attenuation is measured every an hour at wavelengths of 1550 nm and 1310 nm by power meter and laser source, this is shown in Figure 8. The power losses of fiber cable sample were measured before neutron-radiation using the same experimental components (power meter and light source) at the same place, the FC connectors did not expose to irradiation in this experimental work. This short time of irradiation is due to the increasing of dose in the place in which the measurements was done, this increasing is because of the opened neutron beam. These values of power losses are shown in the next subsection. It is concluded that losses are varied according to the period of time at which this sample of cable was exposed to radiation, also on the applied wavelength and fiber composition as shown in Figure 8.

Figure 8: Measurement of power losses.

Experimental Results and Discussion

Here, the single mode fiber cable (pure silica core) is irradiated with neutron radiation. The cable has double pairs. It is exposed to neutron beam facility in ETRR-2 at wavelengths of 1310 nm and 1550 nm. The attenuation measurements are executed at different time periods. These time periods are 0.5 H, 1 H, 2 H, 3 H and 4 H. The irradiated optical fiber cable has length of 20 cm. However, total length of cable is approximated to 40 m. A reference power of 0 dB is used in two central situations. These are before and after irradiation to neutron beam.

The power losses for double pairs of optical fiber at λ=1550 nm are depicted in Table 3. Also, this table compares the attenuation before and after neutron irradiation. The peak attenuation is attained after irradiation to neutron radiation for both pairs. It is observed that a constant attenuation is realized before attenuation for both pairs. The measured values are noted to be of -0.74 dB and -0.18 dB for pair 1 and pair 2, respectively. For pair 1, the utmost attenuation is recorded at lower explosion time. Then, it is suddenly reduced during 1 hour. It remains fixed until 2 hours. A bit increase of attenuation is noticed with exposure time at 3 H and 4 H. These results are matched with results in Figure 9(a). For pair 2, the attenuation is peaked and decayed around exposure time at 2 hours. The attenuation takes bell shape around this time. On other words, attenuation recovery is achieved around this time period. These results are specified in Figure 9(b).

Power loss (dB) at λ=1550 nm, reference power=0 dB				
Time (hours)	Pair#1		Pair#2	
	Before irradiation	After irradiation	Before irradiation	After irradiation
0.25	-0.74	-0.05	-0.18	0.43
1	-0.74	-0.58	-0.18	0.83
2	-0.74	-0.59	-0.18	2.51
3	-0.74	-0.47	-0.18	0.78
4	-0.74	-0.4	-0.18	0.57

Table 3: Power losses for optical fiber (telecom Egypt) pairs (1 and 2) using reference power of (0dB) at 1550 nm.

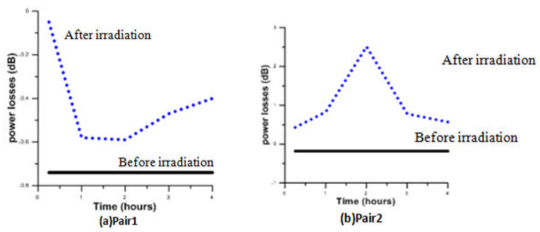

Figure 9: The variation of power losses under influence of neutron irradiation with operating wavelength of 1550 nm, reference power of (0 dB) and cable length of 20 cm measured *in-situ* at MPR.

However, the measured attenuation for the double pairs at λ=1310 nm is declared in Table 4. For pair 1, it is noticed that the power losses are increased for the first hour of irradiation. At second hour, the attenuation is decreased. It becomes approximated to the attenuation before irradiation. Then, it is saturated at 3rd and 4th hour of irradiation. These measurements are indicated in Figure 10(a). For pair 2, the power losses are increased with exposure time. Then, it is saturated after 3rd hours. The measured attenuation results are presented in Figure 10(b).

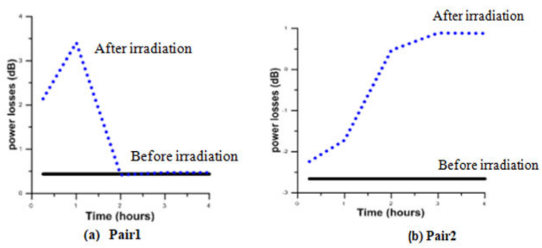

Figure 10: The variation of power losses under influence of neutron irradiation with operating wavelength of 1310 nm, reference power of (0 dB) and cable length of 20 cm measured *in-situ* at MPR.

It is seen that pure silica core fiber is generally more radiation hard than doped fiber this fiber exhibits unique behaviors, such as enhanced recovery due to photo bleaching (light-activated recovery) and hence diverse measured incremental losses.

Conclusion

The paper discusses the effects of incident neutron radiation on optical fiber cables. The composition of fiber cable materials exposed to neutron radiation is determined by gamma spectrometry system. These measurements are done for both long and short duration interactions and indicate that, we cannot transfer the cable for measurements. So measurements are done *in-situ* in the reactor. Attenuation degradation is raised due to exposing single mode optical fiber to neutron radiation in ETRR-2. These neutrons has a flux of 1.5 × 107 n/(cm^2 sec) at room temperature and thermal power of approximately 18 MW. The length of the fiber cable is 20 cm. Experimental measurement for the attenuation is carried out using power meter and laser source. The exposure of fiber cable to neutron irradiation remains for 4 hours. The measure of power losses is done every 1 hour. Additionally, the fiber cables are measured at operational wavelength of 1550 nm and 1310 nm. Comparable results for attenuation at the two wavelengths are attained. The experimental results confirm that random attenuation inside optical fiber cables is resulted that in turn degrades the performance of transmitted wave. In addition, the unexpected attenuation results are variants. It is due to recovery process in which the optical properties improve again. It is based on reconstructing bonds that damaged during irradiation. A reduction of optical defects occur leading to a decrease of attenuation. This is happened automatically with time. Even though, the attenuation issue in optical fiber can be handled through recovery process.

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