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#4-106 Mixed Neutron and Gamma radiation effects on Optical Fibers performed at CERN's n_TOF NEAR irradiation station

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Optical fibers provide significant benefits for use in radiation-rich environments. They are immune to electromagnetic interference, support signal multiplexing, and provide high bandwidth for substantial data transfer. Their distributed sensing capabilities can replace complex networks of individual sensors with a single optical fiber, reducing both weight and volume and making them ideal for low-intrusiveness instrumentation in radiation zones. Additionally, optical fibers with appropriate coatings can withstand extreme temperatures (ranging from a few K up to 1000 K), making them suitable for environments where both radiation and thermal constraints apply. These advantages make optical fibers invaluable across numerous applications such as the nuclear and space industries, high energy physics facility monitoring, and radioactive waste storage monitoring. The ability of optical fibers to support reliable measurements in harsh environments, relies not only on the intrinsic radiation tolerance of the fiber glass (enabling proper signal transmission) but also on the tolerance of their coatings to high temperature and radiation doses. Coatings, used as protective layers, are often polymer-based materials made of acrylate or polyimide, depending on the specific application. While traditional acrylate coating degrades above a temperature of 80 ℃, polyimide coatings can withstand higher temperatures up to 300 ℃. However, polyimide is known to be sensitive to ambient humidity inducing radial strain on the sensing fiber. New types of acrylate coatings have been developed to enhance their temperature tolerance up to 150 ℃ (high-temperature acrylate). Other coatings such as aluminum or carbon (or a combination of both) have been proposed for their mechanical properties to prevent H2-gas diffusion into the fiber core, which could alter the fiber's optical response and compromise its function as a sensor, plus their high temperature tolerance (up to 400 ℃). Radiation tolerance constraints continuously evolve, becoming harsher and more complex, as progress is made in the development of devices operating under extreme conditions and as radiation fields grow increasingly challenging. Accordingly, experimental studies are continuously needed to characterize the optical fiber response to different irradiation conditions for various and new applications. So far, optical fiber coatings have not been extensively tested under intense mixed neutron and gamma fields, despite the relevance of these characterizations for many applications. In this context, the mixed neutron and gamma radiation fields available at the NEAR irradiation test station of the n_TOF facility at CERN offer a unique opportunity to assess radiation effects in material and to compare the response to different fields (such as more conventional 60Co gamma sources and X-rays) already assessed in previous works. In particular, it is of interest to deliver a mixed neutron and gamma dose in the MGy range to the selected material. This study reports the mechanical and functional structural response of polyimide, three types of acrylate coatings, and a carbon layer, irradiated in mixed neutron (with a fluence ranging from 3.14×〖10〗^17 n/cm2 to 1.10×〖10〗^17 n/cm2) and gamma radiation fields at NEAR. Optical fiber samples have been passively irradiated at NEAR during a period of one operational year of the facility. Similar samples have also been irradiated up to 250 kGy and 1 MGy gamma-cumulated dose at the 60Co-irradiation IRMA facility from IRSN (CEA France). Post-mortem experiments have been performed to assess and quantify radiation-induced degradations on silica-based polyimide-, acrylate- and carbon-coated optical fibers. Cut-back measurements have been performed to measure the radiation induced attenuation spectra in the near infrared range, in combination with Optical Time Domain Reflectometry-based loss measurements at 1310 nm, 1550 nm and 1625 nm. Macroscopic coating physical degradation will be reported: optical microscopy images for both irradiated and pristine samples show large physical degradations of the tested high-temperature acrylate. High-temperature

acrylate showed melted sections from the irradiation exposure whereas other acrylate formulations presented no specific degradation other than a coloration darkening. Polyimide coatings showed no measurable degradation. Optical Frequency Domain Reflectometry trace measurements have been performed on both irradiated and pristine samples, showing a significant radiation-induced increase in the Rayleigh gain, suggesting a measurable Radiation-Induced Refractive Index Change caused by the compaction of the fused silica under high neutron fluences, as already reported after reactor neutron field exposures. This result will be confirmed and quantified by Refractive Index Profile measurements on both pristine and irradiated samples. A comparison between samples irradiated at NEAR and at IRMA, currently ongoing, will deepen the understanding of the neutron contribution to the refractive index change compared to a gamma MGy dose. In addition, we already reported that the carbon coating layer can get slightly damaged by gamma irradiation up to 1 MGy. Through hydrogen-loading experiments, the integrity of the physical barrier blocking H2-diffusion will be quantified for pristine, gamma and NEAR irradiated samples. Hydrogen diffusion-induced temperature monitoring error for samples irradiated at 1 MGy of gamma dose and hydrogenated at 80 °C under a 100 bar H2-atmosphere has previously been quantified at +0.2 °C. We expect higher degradation for carbon-coated samples irradiated in mixed neutron and gamma field. This study opens to further scientific studies to better understand those phenomena and, possibly, to develop a structured approach in the selection of optimal fibre coatings. We believe that these results will allow meaningful advancements to be made in the selection of optimal optical fiber coatings for emerging fiber-based technologies that are pivotal in present and future harsh environments, where intense mixed radiation fields are present, such as the nuclear and space industries and particle accelerators facilities.

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