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TECHNICAL REPORT

Optical fibres – Guidance for nuclear radiation tests

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OPTICAL FIBRES – GUIDANCE FOR NUCLEAR RADIATION TESTS

FOREWORD

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IEC 62283, which is a technical report, has been prepared by subcommittee 86A: Fibres and cables, of IEC technical committee 86: Fibre optics.

This second edition cancels and replaces the first edition of IEC/TR 62283 published in 2003 and constitutes a technical revision.

The main changes with respect to the previous edition are listed below:

- Clause 5 now also covers Industrial environment.
- a new Clause 9 has been added to deal with "Measurement techniques and quality assurance of attenuation measurements".

The text of this technical report is based on the following documents:

Enquiry draft	Report on voting
86A/1312/DTR	86A/1327/RVC

Full information on the voting for the approval of this technical report can be found in the report on voting indicated in the above table.

This publication has been drafted in accordance with the ISO/IEC Directives, Part 2.

The committee has decided that the contents of this publication will remain unchanged until the stability date indicated on the IEC web site under "http://webstore.iec.ch" in the data related to the specific publication. At this date, the publication will be

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

A bilingual version of this publication may be issued at a later date.

INTRODUCTION

In order to restrict the test method of IEC 60793-1-54, *Optical fibres – Part 1-54: Measurement methods and test procedures – Gamma irradiation* to a clear, concise listing of instructions, the background knowledge that is necessary to perform correct, relevant and expressive irradiation tests as well as to limit measurement uncertainty is presented here separately as a "guidance document".

OPTICAL FIBRES –
GUIDANCE FOR NUCLEAR RADIATION TESTS

1 Scope

This technical report gives a short summary of the radiation exposure in certain environments and applications and the different radiation effects on fibres. It also describes the most important radiation effect, i.e. the increase of transmission loss, and its strong dependence on a variety of fibre properties and test conditions. These dependencies need to be known in order to perform appropriate tests for each specific application as well as to understand, compare and qualify the test results obtained at different laboratories when performed according to IEC 60793-1-54, *Optical fibres – Part 1-54: Measurement methods and test procedures – Gamma irradiation.*

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60793-1-40, *Optical fibres – Part 1- 40: Measurement methods and test procedures – Attenuation*

IEC 60793-1-46, *Optical fibres – Part 1-46: Measurement methods and test procedures – Monitoring of changes in optical transmittance*

IEC 60793-1-54, *Optical fibres – Part 1-54: Measurement methods and test procedures – Gamma irradiation*

3 Radiation units, dose calculation

The interaction of radiation with matter depends on charge, mass and energy in the case of particle radiation (for example, electrons, protons, neutrons, alphas and heavy ions) and on energy in the case of electromagnetic radiation such as X-rays or gamma quanta. The interaction causes an energy transfer to the respective matter. This leads to ionization and warming up. Additionally structural damage in the material may occur at higher doses, leading to other effects such as changes of refractive index or mechanical properties.

The higher the radiation's energy, the stronger its penetrability and the longer its range. The energy unit is the electron Volt (eV). Usual radiation energies in natural or technical environments range from tens of keV (medical X-rays) to several MeV (fission or fusion reactors and nuclear weapons). Current energies at high-energy physics accelerators vary depending on the type of colliding particles. The highest energy for electron-positron collisions is 100 GeV per beam. For proton-proton collisions the energy per beam is 1 TeV. The new "Large Hadron Collider" (LHC) at CERN uses beams with an energy of 7 TeV. In addition, there are quite a number of other accelerators which operate between these limits.

Note that these energies refer to the colliding particles. The secondary particles, i.e. the ones likely to affect fibres, have much lower energies.

The energy deposited by ionizing radiation in matter is called "energy dose" (or absorbed dose). The old unit is rad, (rd or rad); 1 rad = 100 erg/g (1 erg = 10^{-7} J) but should not be used anymore. The SI unit is the Gray [Gy]; 1 Gy = 1 J/kg = 100 rad.

Some dosimeter types measure the charge released in a gas (for example, ionization chambers). This was used to define another type of dose, the "ion dose". The ion dose unit is the röntgen (non-SI unit), [R]; 1 R = 2,58 × 10^{-4} C/kg, with C = charge unit (coulomb). Conversion of ion dose, D', to energy dose, D, can be performed for ^{60}Co gamma rays (about 1,2 MeV) by

$$D = 0{,}879 \frac{\text{Gy(air)}}{\text{R}} D' \tag{1}$$

If this unit is used, the values of relevant quantities shall be given in terms of SI units first followed by these non-SI units in parentheses.

The energy transfer of gammas and X-rays to matter depends on their energy as well as on the irradiated material. Therefore, the material has to be added to the dose unit (for example [Gy(Si)], [rad(SiO_2)], [Gy(air)] etc.), and the dose D(d) measured with a dosimeter material d (for example, air) can differ significantly from the dose D(m) deposited in the investigated material m (for example, Si, SiO_2, InGaAs etc.).

The dose ratio between both materials D(m) is given by the ratio of their "photon mass energy absorption coefficient" μ_{en}/ρ:

$$D(m) = \frac{(\mu_{en}/\rho)_m}{(\mu_{en}/\rho)_d} D(d) \tag{2}$$

The μ_{en}/ρ-values can differ significantly, especially for materials of high and low atomic number at energies < 300 keV. They are tabulated for various elements and compounds in reference [1][1].

The dose rate, i.e. the dose exposition per time, should be given in units of Gy/h, kGy/h, or Gy/s.

The intensity of particle radiation is usually characterized by the fluence Φ. The unit is particles/cm^2 or only cm^{-2}. The dose of charged particles (in a certain material depth) can be calculated from their fluence and their (energy-dependent) energy loss per unit of length, dE/dx (= stopping power):

$$D = \frac{\Phi}{\rho} \cdot \frac{dE}{dx} \tag{3}$$

with ρ = material density. The stopping power can be calculated with the software package "SRIM"[2], see [2]. The particle fluence per time unit is called flux or flux density. The unit is $cm^{-2}\ s^{-1}$.

The neutron dose D_n can be calculated from its fluence Φ_n and the energy and material dependent "fluence dose conversion factor" or "kerma factor" k(E_n,Mat.):

$$D_n = \Phi_n \cdot k(E_n, Mat.) \tag{4}$$

The kerma-factors are tabulated for a variety of elements and compounds in [3].

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[1] Numbers in square brackets refer to the bibliography.

[2] SRIM is the trade name of a product supplied by IBM. This information is given for the convenience of users of this Technical Report and does not constitute an endorsement by IEC of the product named. Equivalent products may be used if they can be shown to lead to the same results.

4 Radiation shielding

Shielding of optical fibres against (especially gamma) radiation is in most cases not reasonably achievable since, for example, gamma rays of 1 MeV are attenuated to 1/10 of their initial intensity only by 5 cm of lead.

However, buried fibre cables that are layed in at least 1 m depth are shielded against 1 MeV gamma rays by about a factor of 10^4.

5 Radiation environments and exposure

5.1 Natural radioactivity

The predominant radiation type is gamma rays. Typical annual dose value for earth cables or undersea cables is <0,004 Gy. The total dose during an expected cable lifetime of 25 years would thus be <0,1 Gy. Distinctly higher values are possible, for example, above uranium or thorium ore deposits. The dose and dose rates are typical and may vary depending on the specific application.

5.2 Nuclear reactors (fission)

Optical fibres can be exposed to gamma rays as well as to thermal and fast neutrons. Dose and fluence values depend strongly on the place within the reactor building and the operating conditions of the reactor (for example the power delivery, normal operation or accident).

Within the containment area, exposure levels range from 0,001 Gy/h to 0,03 Gy/h up to about 1 Gy/h near the primary coolant lines. The dose rate around the fuel rods is of the order of 10^3 Gy/h. In the early stage of an accident, dose rates as high as 10^4 Gy/h will occur within the containment [4].

The neutron flux (= fluence Φ per unit of time) within the containment can range from about 10 $\mathrm{cm}^{-2}\mathrm{s}^{-1}$ up to about 10^{12} $\mathrm{cm}^{-2}\mathrm{s}^{-1}$ near the fuel rods.

The dose, dose rates and neutron fluence are typical and may vary depending on the specific application.

5.3 Fusion reactors

The primary radiation emitted after the fusion of deuterium (D) and tritium (T) nuclei are 14 MeV neutrons and ^{4}He nuclei (energy about 3,5 MeV). The ^{4}He ions are very short-ranged and will not reach optical fibres that might be used as sensors or to transfer data, whereas the fast neutrons are very penetrating and will also activate the structural materials around the reaction chamber. These materials then emit high gamma ray intensities also after reactor turn-off.

Again, the total dose and neutron fluence values depend strongly on location and operation conditions.

For the future test facility ITER (International Thermonuclear Experimental Reactor), gamma dose rates at the first wall of about 2×10^2 Gy/s and life dose values of 10^7 Gy to 10^9 Gy are expected. The neutron fluence there could reach values up to 10^{20} cm^{-2}.

At inertial confinement fusion (ICF) facilities such as "Laser Megajoule" (France) or "National Ignition Facility" (USA) diagnostic equipment, comprising also optical fibres, is exposed to pulsed radiation of up to 10^3 Gy at dose rates up to 10^{10} Gy/s.

The dose and dose rates are typical and may vary depending on the specific application.

5.4 High-energy physics experiments

Usually, in high-energy physics, electrons or protons with energies as high as several 100 GeV (protons) are used to study elementary particles. In order to increase the reaction energy it is common that two beams collide within a reaction zone which is surrounded by huge detectors analyzing the reaction products. The accelerator tube and the inner parts of the detectors will become highly radioactive, especially if protons collide.

The secondary radiation that threatens the accelerator control instruments and the detector read-out equipment mainly consists of pions (mean energy several 100 MeV), gamma rays and, at radii >50 cm, of neutrons with maximum energies up to more than 100 MeV, but a mean energy of only about 1 MeV to 2 MeV. The radiation intensities strongly depend on the operating conditions (particle energy, beam current), the distance from the beam line, and the emission angle (maximum in beam direction). Particularly in the beam cleaning sections, high radiation levels may occur.

The annual total dose can be of the order of 10^5 Gy to 10^6 Gy and the neutron fluence can reach values from 10^{13} cm^{-2} to 10^{15} cm^{-2}. The dose and dose rates are typical and may vary, depending on the specific application.

5.5 Space environments

Close to the earth the dominating radiations are solar protons, trapped protons and trapped electrons. "Trapped" means trapped by the magnetic field of the earth, within the Van Allen Belts.

The electrons are concentrated in an inner zone (ending at about 2,4 earth radii) and an outer zone (between about 2,8 earth radii and 12 earth radii). Their maximum energy is about 7 MeV. They can be stopped, for example, by about 10 mm Al. During the slowing down process in matter, they produce penetrating X-rays (Bremsstrahlung).

The proton flux decreases with increasing distance from earth. The maximum energy is several 100 MeV. For example, the range of 300 MeV protons in Al is about 24 cm. More than 90 % of the protons have energies below 100 MeV.

In a geostationary orbit (for example, 15° east) the total annual dose behind 3 mm Al is nearly 600 Gy, of which about 550 Gy is caused by trapped electrons and about 50 Gy by solar protons. In a low earth orbit (LEO), height 1 000 km and 70° inclination, the total annual dose of about 823 Gy (behind 3 mm Al) is composed of about 400 Gy trapped electron contribution, about 420 Gy trapped proton contribution and 3 Gy solar proton contribution.

Additionally to the above-mentioned radiation types, cosmic rays are an additional type of space radiation. The "primary" cosmic rays are a low flux of high energetic particles (about 85 % protons, 14 % alpha particles and about 1 % heavier nuclei). Their contribution to the total dose, however, is negligible.

Particle fluences for certain orbits and dose values can be calculated, for example, with the "SPENVIS" system [5]. The dose and dose rates are typical and may vary depending on the specific application.

5.6 Medicine

For radiography purposes (diagnostics) X-rays with energies <100 keV are used. With modern image intensifier techniques dose values $<10^{-3}$ Gy are sufficient to take a series of expressive pictures.

Irradiation of tumours is made with ^{60}Co gamma rays, high energy electrons (20 MeV to 30 MeV), high energy protons (60 MeV to 300 MeV) or heavy ions (for example ^{12}C, 2 GeV to 4 GeV), and thermal or fast neutrons. Dose values within the tumour can reach several Gy per