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Limits of Scintillation Materials For Future Experiments at High Luminosity LHC and FCC

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Content

This report gives of a review the last results of the radiation damage effects in scintillation materials used in high energy physics experiments, that are caused by γ-quanta and high energy hadrons, and neutrons the three main causes of irradiation in the High Luminosity LHC and future FCC. The creation and recovery of color centers, induced radioactivity and harmful radio-luminescence in organic and inorganic materials under hadron irradiation are described. An approach to select scintillation materials suitable to operate in the different parts of the detectors, particularly in the forward part of calorimeters will be proposed. Report also considers approaches to construct detection modules capable to survive during the full operation period of the High Luminosity LHC.

Summary

Further physic programs at the LHC accelerator will require an increase of the luminosity up to 300 fb-1 per year from 2025 with an integrated luminosity of 3000 fb-1 by 2025 to 2035 [1]. At such luminosities, charged hadrons and neutrons with fluence higher than 1014 p/cm2 per year in a large pseudo-rapidity region of the detectors will have a non-negligible influence on the radiation damage of materials. Even stronger damage effects are expected at Future Circular Collider (FCC) experimental facilities [2]. Moreover, with the increasing activation of the experimental setups, it will become more difficult to periodically replace and maintain the detector elements for radioprotection issues for the personnel. Therefore for the selection of the materials for new detectors in such high radiation environment, a more reliable assessment of the risks of detector failures due to high radiation environment is required. Such assessment can be made through the consideration of the radiation damage effects occurred in the chosen components of the detector. The systematic study of the radiation hardness of inorganic scintillation materials began with the development of the new colliders. In the mid 80s of the past century, extensive investigation on the development of new scintillation materials have been performed under the Superconducting Super Collider program (SSC, USA), and Research and Development Project (RD18, Crystal Clear Collaboration) was initiated at CERN in frame of DRDC with the participation of experts from 15 countries. A comprehensive study of a variety of inorganic, organic and composite scintillators was carrying out. Similar research was performed in KEK (Japan) and under the UNK program (Protvino, Russia). Since last six years Crystal Clear Collaboration performs a systematic study of the damage effects under high-energy protons [3-19]. The unique possibility to irradiate the crystal samples with 24GeV protons of the PS accelerator at CERN with the 109 p/cm2s flux with fluence more than 1014 p/cm2 contributed to the progress in this research. Recently, it has been established that the damage effects at 150MeV protons [20] is similar to the effects measured after the irradiation with 24GeV protons. It is well known [21] that the cross-section σf of the heavy nucleus fission under protons strongly depends on the energy of the incident particle. For instance, for a 208Pb nucleus, a fast growth from 10-7 to 0.1b in the incident particle energy range from 20 to 90MeV followed by an increase up to 1bn at the energy of 1GeV. Smooth behavior of the σf energy dependence in the range above 100MeV allows extrapolating this behavior to the range of a few tens of GeV. Thus, the effect of the irradiation under 150MeV protons will be the same than 24GeV for the same order of fluence but smaller in magnitude because σf(150MeV)$<$ σf(24GeV). The studies of the effects of hadron damage is considerably simplified by the possibility to investigate damage under low energy protons. Several accelerating facilities, having relatively cheap proton machines with energy in the range 150-200MeV are available and became suitable for routine measurements of the damage effects. Up to now, the consideration of the deterioration of scintillating materials by ionizing radiation has been described by a simple interpretation, because only the main physics performance requirement was taken into account, i.e. the capability of electromagnetic calorimeters to maintain a high energy resolution throughout the full life of the detector operation. Because the deterioration of energy resolution is directly linked to the decrease of light collection of the crystals, generally only the effect of the radiation on the transmission is considered. However, the interaction of ionizing radiation with the crystals gives rise to several other effects with same importance than the transmission degradation. These effects were considered in [13]. Change in the optical transmission due to the formation of color centers under ionizing radiation represents only a portion of the effects, one should take in to account the effects of interaction between the active material and the radioisotopes generated in the detectors through nuclear reactions. The combination of these effects can lead to a large degradation of the detector performance, resulting in the worsening of the statistic term and the constant term in the energy resolution, the increase of the nonlinearity in the detector response. A review of the last results of the radiation damage effects in scintillation materials used in high energy physics experiments, that are caused by gamma and high energy hadrons, the two main causes of irradiation in the environment in the experimental facilities of the High Luminosity LHC and future FCC will be presented. The creation and recovery of color centers, induced radioactivity and harmful radio-luminescence in organic and inorganic materials under hadron irradiation will be described. An approach to select scintillation materials able to operate in different parts of the detectors, particularly in the forward part of calorimeters will be proposed. Report also considers approaches to construct detection modules capable to survive during the full operation period of the High Luminosity LHC.

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