Nuclear Engineering and Technology 50 (2018) 519–525

Contents lists available at ScienceDirect

Nuclear Engineering and Technology

journal homepage: www.elsevier.com/locate/net

Technical Note

An innovative idea for developing a new gamma-ray dosimetry system based on optical colorimetry techniques

Mihail-Razvan Ioan

Horia Hulubei National Institute for R&D in Physics and Nuclear Engineering (IFIN-HH), 30 Reactorului Street, RO-077125, Bucharest-Magurele, Ilfov County, Romania

ARTICLE INFO

Article history:
Received 1 December 2016
Received in revised form
19 January 2017
Accepted 9 January 2018
Available online 3 February 2018

Keywords:
Absorbed Dose
Colorimetry
Color Standards
Gamma Rays
MATLAB
RGB

ABSTRACT

Obtaining knowledge of the absorbed dose up-taken by a certain material when it is exposed to a specific ionizing radiation field is a very important task. Even though there are a plenitude of methods for determining the absorbed dose, each one has its own strong points and also drawbacks. In this article, an innovative idea for the development of a new gamma-ray dosimetry system is proposed. The method described in this article is based on optical colorimetry techniques. A color standard is fixed to the back of a BK-7 glass plate and then placed in a point in space where the absorbed dose needs to be determined. Gamma-ray–induced defects (color centers) in the glass plate start occurring, leading to a degree of saturation of the standard color, which is proportional, on a certain interval, to the absorbed dose. After the exposure, a high-quality digital image of the sample is taken, which is then processed (MATLAB), and its equivalent I_{RGB} intensity value is determined. After a prior corroboration between various well-known absorbed dose values and their corresponding I_{RGB} values, a calibration function is obtained. By using this calibration function, an "unknown" up-taken dose value can be determined.

1. Introduction

The absorbed dose induced to a material by ionizing radiation is one of the main quantities used to describe the cumulative effects of such interaction. Whether we are talking about the effects induced by the ionizing radiation to nonliving matter or we are talking about effects induced on biological tissue, the absorbed dose, including the phenomena producing it, is the starting point. Obtaining precise knowledge of the absorbed dose magnitude in cases in which a certain material is exposed to a specific ionizing radiation field, in a certain point in space and for a certain period of time, is a very important task [1–3]. There are even a plenitude of methods for determining the absorbed dose, each one having its own strong points and also drawbacks. In this article, an innovative idea for a new gamma-ray dosimetry system is proposed. The method described in this article is based on optical colorimetry techniques, light being an ideal information-transporting vehicle that can be used to highlight and quantify some of the effects induced on matter by ionizing radiation [4].

Transparent optical materials are affected by their interactions with strong ionizing radiation fields via the occurrence of supplementary defects (color centers) into their structure, besides the preexisting ones due to the manufacturing processes. These color centers show associated absorption color bands, mainly in the ultraviolet–visible–infrared spectral region, due to redistributions of the dislocated valence electrons on more stable states. The color center–producing phenomenon is also known as “glass browning”. Color center occurrence leads to variations of the exposed glass samples’ colors and, implicitly, their absorption proprieties. These variations are proportional, on certain intervals, to the absorbed doses [5–7]. These intervals are strongly related to the glass types used and to the glass thickness. Using glass samples from the same manufacturer and from the same batch is highly recommended [8,9]. Color center production is also influenced by the environmental temperature. Eventually, a slow natural reversing process can be also seen. This reversing process can be accelerated by applying heat treatment (high temperatures) to the irradiated glass samples [10,11]. The main benefit of the reversing process it is economical nature, meaning that the used samples can be reused.

The innovative idea for developing a new gamma-ray dosimetry system proposed in this article is based on optical colorimetry techniques, making use of color standards. The color standards are

E-mail address: razvan.ioan@nipne.ro.

https://doi.org/10.1016/j.net.2018.01.007

officially recognized instruments, containing standardized colors (pure color and well-determined ratios of mixtures), used for comparison with other unknown tones of a specific color (determined in the same measuring conditions). A color standard is used to describe the colorimetric characteristics of a sample and also to assure a traceability chain.

First, a color standard is fixed to the back of a BK-7 glass plate; then, the sample is placed in a point in space where the absorbed dose needs to be determined. When the exposure time is over, a high-quality digital image of the sample is taken. After digitally processing the image (by using of a specific MATLAB-developed code), the individual I_R, I_G, and I_B and the equivalent (I_{RGB}) color intensities are determined. It is known that any digital color image is expressed by its red, green, and blue spectral components. Each pixel of the image is composed of these three components, with intensities in the 0–255 interval [12]. The RGB term comes from the three primary colors: red, green, and blue. In the RGB color space model, a color can be expressed by its equivalent intensity function (1) [13]:

$$I_{RGB}^2 = I_R^2 + I_G^2 + I_B^2 \quad (1)$$

The RGB color space model can be described as the color space interpreted and provided by a personal computer. Relation (1) is based on the Cartesian coordinates system, in which red, green, and blue colors are combined to obtain all the spectral colors. At the same time, the RGB model is the only additive color system that operates with the abstract values of an image, being unaffected by human eye limits. Basically, the relation (1) represents the Euclidean distance inside the RGB color space (RGB color space cube—Fig. 1), from the origin [(0, 0, 0) coordinates] to a certain point [(r, g, b) coordinates], and indicates the equivalent intensity associated with a certain color. In 8-bit–sized coordinates, a color space of 256*256*256 values, meaning more than 16 million color tones, can be obtained.

The point having (0, 0, 0) coordinates represents pure black color; the one having the (256, 256, 256) coordinates represents pure white color. The diagonal of the RGB color space cube (equal R, G, B intensities values) represents the gray tones. To numerically describe a certain color, it is sufficient to assign 8 bits to each of its three primary colors. This way, 256 intensity levels can be codified, starting from (00000000) (pure black—zero intensity) to (11111111) (pure white—maximum intensity).

In this article, using relation (1), a specific MATLAB code was developed to decompose the captured digital images and to obtain their corresponding equivalent RGB intensities (I_{RGB}).

In relation (1), the I_R, I_G, and I_B components associated with the images of the color standards, taken through BK-7 glass samples exposed to ionizing radiation, are influenced by the doses up-taken in the glass's volume. An increased absorbed dose leads to increased absorption of light in the glass volume (wavelength dependent).

After corroboration using various well-known absorbed dose values and their corresponding I_{RGB} values, a calibration function is obtained. Using this calibration function and determining the I_{RGB} value corresponding to the image of an arbitrary-exposed sample, its "unknown" up-taken dose value can be determined. Comparison of the I_{RGB} values obtained for the irradiated samples with the standard values (nonirradiated glass) was done for each pure color and also for the other tones (well-known ratios of mixtures between pure color and white/black).

The proposed method is a relative one, its precision resulting mainly from its calibration procedures. Therefore, in the calibration protocol, it is very important that all the parameters contributing to the resulted I_{RGB} values be taken into account. To obtain high-quality calibration curves, it is important to take into account all the phenomena involved in the interaction between the ionizing radiation and the chosen glass samples. In the calibration process, it is very important to use a gamma-ray source that provides a precisely known energy distribution and dose rate because these two parameters involve the specific response of the exposed glass samples. Different dose rates can lead to different color center occurrence rates. The effects of different gamma-ray energies on an exposed glass sample consist of different probabilities of occurrence of the involved interaction mechanisms: photoelectric effect, Compton effect, and electron–positron pair creation. In the calibration process, as many as possible absorbed dose points must be assured by using high-quality reference dosimeters. It is very important to perform precise measurements and calculations in the calibration procedure.

An important benefit of the proposed colorimetric method is the ease of obtaining different shapes and sizes of glass samples, mandatory conditions in some nuclear physics experiments and applications. The possibility of analyzing the exposed samples at the pixel level also allows mapping of the dose distributions in field homogeneity studies.

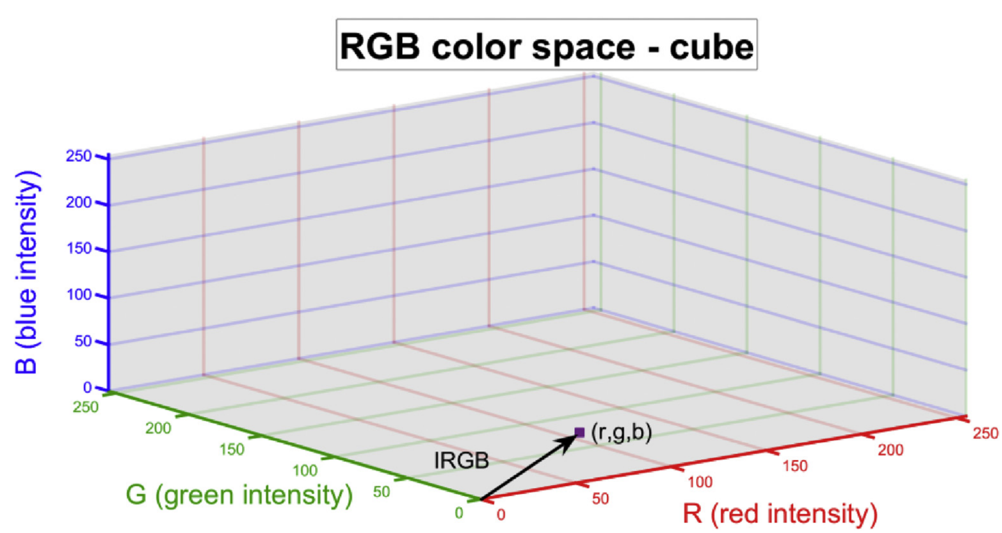

Fig. 1. Theoretical representation of RGB color space—cube.