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Comparative calibration of IP scanning equipment

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ABSTRACT: Imaging Plates (IP) are diagnostic devices which contain a photostimulable phosphor layer that stores the incident radiation dose as a latent image. The image is read with a scanner which stimulates the decay of electrons, previously excited by the incident radiation, by exposition to a laser beam. This results in emitted light, which is detected by photomultiplier tubes; so the latent image is reconstructed. IPs have the interesting feature that can be reused many times, after erasing stored information. Algorithms to convert signals stored in the detector to Photostimulated luminescence (PSL) counts depend on the scanner and are not available on every model. A comparative cross-calibration of the IP scanner Dürr CR35 BIO, used in ABC laboratory, was performed, using the Fujifilm FLA 7000 scanner as a reference, to find the equivalence between grey-scale values given by the Dürr scanner to PSL counts. Using an IP and a ⁵⁵Fe β-source, we produced pairs of samples with the same exposition times, which were analysed by both scanners, placing particular attention to fading times of the image stored on IPs. Data analysis led us to determine a conversion formula which can be used to compare data of experiments obtained in different laboratories and to use IP calibrations available, till now, only for Fujifilm scanners.

KEYWORDS: X-ray detectors; Particle detectors; Detector alignment and calibration methods (lasers, sources, particle-beams); Data processing methods, Photostimulated luminescence.

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1. Introduction

Imaging Plates (IPs) are reusable diagnostic devices capable of detecting ionizing radiation and storing the information [1,2]. An IP-system consists of IP and related scanner, a device that retrieves electronically the image stored into the IP [3]. IPs are commonly used in medical application, but are very valuable for particle and electromagnetic radiation detection in research experiments. Moreover, their sensitivity, resolution and immunity to electromagnetic pulses (EMP) make them an excellent choice for detection of X-rays and particles produced in harsh environments, as in laser-plasma interaction [4]. Their adaptability makes them useful in various kinds of diagnostics, as X-ray imaging and X-ray and particle spectroscopy [3-7].

The unit employed to measure the accumulated dose on IP is mostly the number of Photostimulated luminescence (PSL) counts, but the scanning process usually gives as output a grey-scale image. The conversion from this grey-scale signal to PSL counts depends on the scanner and settings. In general this conversion is not automatically performed by the scanner software, and a conversion algorithm (to the author's knowledge) is given only in the case of Fujifilm scanners [8].

In comparison with the Fujifilm FLA 7000 scanner, the Dürr CR35 Bio scanner is more compact and lightweight, has a built-in eraser unit, higher resolution and higher portability. On the other hand it lacks a conversion algorithm to calculate the number of PSL counts.

In this work we describe the accurate scanner modeling and the experimental measurements we performed to determine the effective conversion relation and the parameters for the Dürr CR35 Bio IP scanner in use in ENEA Frascati laboratory using the Fujifilm FLA 7000 scanner in use at CELIA laboratory as a reference.

2. IPs Scanning

The typical IPs sensitive layer is a photostimulable phosphor based on an alkali-halide compound like BaF(Cl, Br, I):Eu²⁺[1,9]. The radiation energy is absorbed by the phosphor and transferred to Eu²⁺ ions, becoming Eu³⁺ after the emission of a photoelectron. These electrons are

then trapped in lattice defects inside the phosphor. These traps are metastable and effectively store the image on the IP [1].

To retrieve the image, IP is scanned with a narrow sized laser beam (usually with $\lambda \sim 630$ nm), which excites electrons, that decay and recombine with Eu^{3+} , emitting blue photons ($\lambda=400$ nm). A filter may be applied, and a photomultiplier then collects this light for each position, mapping the image with a resolution depending on the beam focal spot [3]. This process extracts only part of the information stored on the IP, and the amount depends on beam power. Complete erasing of IP can be later performed by exposition to intense light, step commonly performed for multiple reuses of the single detector.

The signal of the photomultiplier is amplified and then stored as a grey-scale image file.

Thus the stored signal depends on various parameters of the scanning, such as laser beam power and focusing, filtering, photomultiplier, amplifier and data sampling.

2.1 The Dürr CR35 Bio Scanner

The Dürr CR35 Bio scanner is a high resolution device. The reading process starts with a narrow laser beam, with nominal power from 1 mW up to 8 mW, triggering the photostimulated emission on IP. A filter, opaque to red light and with high transparency to blue light, is used to block stray light from the laser. Then the filtered radiation is detected by a photomultiplier (PMT), whose voltage biasing can be set from 350 V up to 1200 V. The signal from the photomultiplier is digitized by a computer equipped with Dürr dedicated software, which integrates an automatic oversampling to improve the signal to noise ratio. The process is outlined in figure 1 [10,11]

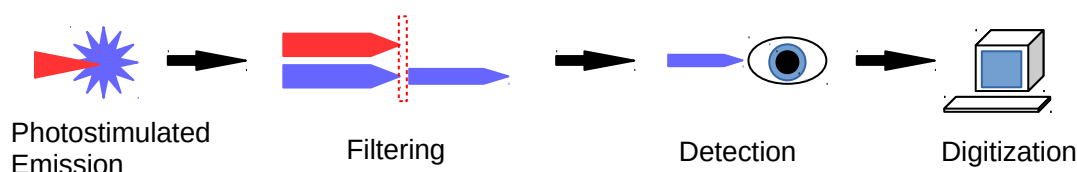


Figure 1. Block Diagram of the scanning process for Dürr CR35 Bio Scanner. Photostimulated Emission: the red laser beam triggers the blue emission of the IP. Filtering: a filter blocks red stray light. Detection: a PMT detects the blue light emitted by IP. Digitization: signal from PMT is digitized and processed by Dürr application.

According to the data given by the manufacturer, in the operating point all blocks should have a linear behaviour, thus leading to a relation of conversion:

$$PSL(GL) = \mu \times GL + \kappa \quad (1)$$

where $PSL(GL)$ is expected number of PSL counts, found as a function of GL ; GL is the grey-scale value (or grey-level) given by the scanner; the constants μ and κ are unknown, and to determine them we carried out a proper calibration experiment including the Fujifilm FLA 7000 scanner used in reference [12].

3. Experiment

We produced pairs of IP samples with the same exposition to a radiation coming from ^{55}Fe radioactive beta source and for each pair we analysed one element with the Dürr scanner, and the other with the Fujifilm one. In particular the BAS-TR (Bio-imaging Analyzer System - Tritium) IP, whose characteristics are summarized in table 1 [12-15], was chosen because it is the most sensitive to low energy radiation, due to the lack of a protective Mylar layer in front of the sensitive phosphor. Two pieces of IP were produced from the same batch and used in the experiment. To check their homogeneity we exposed them to the same radiation dose from our ^{55}Fe radioactive beta source, and controlled the consistency of the number of PSL counts measured in both samples.

Table 1: BAS-TR Imaging Plate Structure.

Layer	Thickness	Composition
Protective Layer	Not present	
Phosphor Layer	50 μm	$\text{BaFBr}_{0.85}\text{I}_{0.15}\cdot\text{Eu}^{2+}$
Support Layer	250 μm	$\text{C}_2\text{H}_2\text{O}$
Magnetic Layer	160 μm	$\text{ZnMn}_2\text{Fe}_5\text{NO}_{40}\text{H}_{15}\text{C}_{10}$

The used ^{55}Fe β -source has an activity of ~ 14 kBq, an average electron energy ~ 6 keV and a 2 cm diameter.

We placed one IP in direct contact with the source for a given time and then we analysed it with the Fujifilm scanner. We repeated the procedure for the same time with the second IP, this time analysed with the Dürr scanner. After erasing these IPs, the procedure was iterated, both for the same and for different exposure times, and a dataset was produced. The interval between the end of the exposition and the begin of the scanning was less than 15 s, to ensure the effect from fading to be negligible [13,16,17].

Figure 2 shows an example of the source image stored on the IP after 10 minutes of exposition, obtained with Dürr CR35 Bio in grey-scale values and displayed in inverted shades of grey (darker tones are for higher values) and with Fujifilm FLA 7000 in PSL and displayed in shades of grey (lighter tones are for higher values).

The user settings for the Dürr scanner were: Resolution 40 μm , photomultiplier voltage 800 V, Threshold 65535, Laser 8, Beam deflector speed 3000 RPM.

For the Fujifilm scanner the user settings were: Resolution 50 μm , Latitude 5, Sensitivity 4000, Gradation 16 bit.

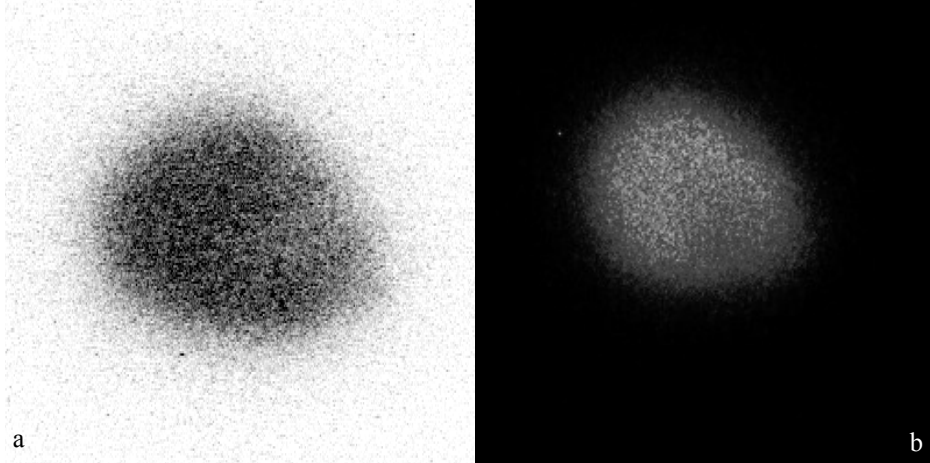


Figure 2. Image stored on the IP after 10 minutes of exposition to ^{55}Fe source. a) Grey-scale with Dürre CR35 Bio scanner; b) PSL with Fujifilm FLA 7000 scanner.

4. Data Analysis

To extract data from images we used ImageJ program [18]. For each image we integrated the values of GL (for the data from Dürre CR35 Bio) or PSL (for the data from Fujifilm FLA 7000) over a surface of $2\text{ cm} \times 2\text{ cm}$ covering the whole source image and then normalized the value with respect to this surface. To take into account the background radiation and its fluctuations, the process just described was repeated several times for each image, moving the centre of the sample surface while maintaining the whole source image covered. Then we calculated a mean value of these readings, using it as the image measure value (χ_n , where n is the image number), and an image measure error value (ζ_n).

χ_n corresponding to the same exposure time were compared, calculating their mean value (equal to GL_t or PSL_t , where t is exposition time) and the standard deviation σ_t . The overall errors on obtained PSL_t and GL_t (ε_{PSL_t} and ε_{GL_t} respectively) were estimated as the root sum squared (RSS) of the highest of the ζ_n associated with the specific exposure time and the σ_t .

The values for GL and PSL for the same exposure time were paired, creating thus a set of data (table 2) complete of errors on which was performed a linear regression.

Table 2. Measured values of GL from Dürre CR35 Bio and PSL from Fujifilm FLA7000 for different exposure times.

t (exposition time in min)	$GL_t \pm \varepsilon_{GL_t}$	$PSL_t \pm \varepsilon_{PSL_t}$
1	25.0 ± 6.0	0.008 ± 0.001
2	46.5 ± 10.6	0.015 ± 0.003
3	78.0 ± 13.0	0.030 ± 0.005
5	103.5 ± 17.0	0.040 ± 0.006
7	168.0 ± 31.3	0.058 ± 0.009
10	197.0 ± 22.0	0.081 ± 0.009

The fit to the measured data is described by the equation:

$$PSL (GL) = 0.0004 \times GL - 0.0024 \quad (2)$$

Figure 3 shows the experimental data (black dots) with error bars and the fitted curve (solid line)

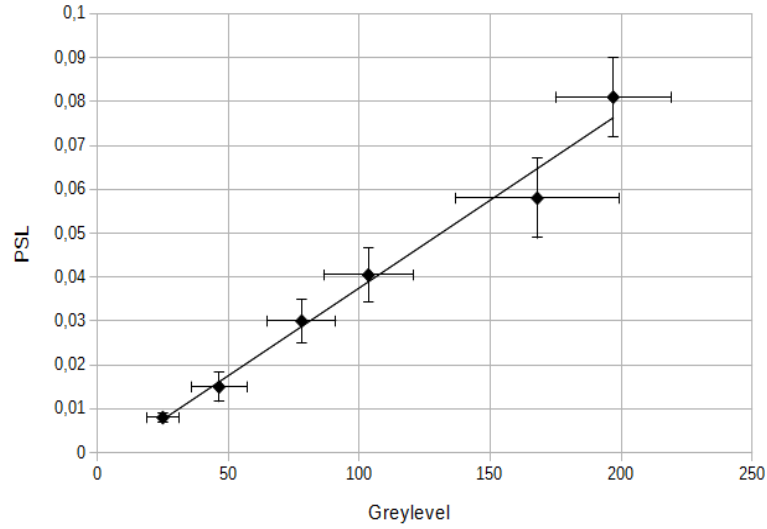


Figure 3. The relationship between GL from Dürr CR35 Bio and PSL from Fujifilm FLA7000. Experimental data (dots with error bars) and fit (solid line).

To have an estimation of the fitting reliability of equation (2), we calculated the residuals $\rho_t = PSL(GL_t) - PSL_t$ (being $PSL(GL_t)$ given by equation (2)) and we normalized it to $PSL(GL_t)$ expected value.

As it is shown in table 3, the maximum difference between the $PSL(GL_t)$ and the PSL_t is $\sim 10\%$ of the expected value.

Table 3. The differences between $PSL(GL_t)$ and PSL_t and the relative confidence of eq. (2) on the measured data.

Exposition time (min)	GL	PSL_t	$PSL(GL_t)$	ρ_t	$ \rho_t / PSL(GL_t) $
1	25	0.008	0.0076	-0.0004	0.0526
2	46.5	0.015	0.0162	0.0012	0.0741
3	78	0.030	0.0288	-0.0012	0.0417
5	103.5	0.040	0.0390	-0.0015	0.0385
7	168	0.058	0.0648	0.0068	0.1049
10	197	0.081	0.0764	-0.0046	0.0602

Moreover, the root mean square (RMS) of the $|\rho_t / PSL(GL_t)|$ values is ~ 0.0660 , a good result considering the usual tolerances of available PSL calibrations, as shown in [12].

5. Conclusions

We calibrated the Dürr CR35 Bio scanner by using the Fujifilm FLA7000 scanner as a reference. As a result we found a formula to convert GL values to PSL values for given operating user conditions.

This accomplishment permits to compare data achieved by examining IPs with different scanners. This makes the existing calibrations of IPs to particles and X-rays available also for Dürr scanner[12,19]. Moreover, it extends IP calibrations made with Dürr [20] to other scanners.

We are currently working on describing the effect of the user parameters of the Dürr scanner on the conversion formula, to extend the calibration to other working points to find a user setting dependent formula as the one available for Fujifilm FLA 7000 [8].

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