Determination of Absorbed Dose Using a Dosimetric Film

F. Scarlat, A. Scarisoreanu, M. Oane, E. Mitru, E. Badita
National Institute for Laser, Plasma and Radiation Physics - INFLPR,
Bucharest - Magurele, Romania
scarlat.f@gmail.com

ABSTRACT

This paper presents the absorbed dose measurements by means of the irradiated dosimetric reference films. The dose distributions were made by MULTIDATA film densitometer using RTD-4 software, in INFLPR Linear Accelerator Department.

Key Words: *Film Dosimetry/Optical Density/Radiation Dose/Photographic Dosimetry.*

INTRODUCTION

Model 9721 Film Densitometer employed in the process is an accurate Dosimetry Systemperipheral device for the measurement of relative density/dose information, captured by a
standard size x ray film exposed to ionizing radiation. As light source, the system utilizes special highly efficient light emitting diodes and color compensated solid state detectors in a balanced ratiometric circuit, making the device insensitive to ambient light. The light source/detector assembly is driven in finite incremental steps with a 1/16 millimeter resolution over the entire scanning area to ensure precise positioning with a high degree of repeatability.

This paper presents the optical density notion, some MULTIDATA film densitometer technical specifications, the methode of the absorbed dose determination by means of the dosimetric film irradiation and the results of dosimetric measurements performed in the NILPRP Electron Accelerator Laboratory.

PHOTOGRAPHIC FILM DOSIMETRY METHOD

The photographic film was one of the first was used in radiation natural detection, traceable effect produced on photografic film - Bequerel (1896). Radiation – sensitive photographic emulsion is a convenient environment for dosimetric measurements since its characteristics, sensibility in particular, may be controlled by composition and its preparation process wide-limits and it also can be adapted to different type radiation measuring. It is known that ionizing radiation effect is the blackening of photographic emulsion, meaning afilm dose radiation measuring. The emulsion sensitive component is a silver halide, the used one being AgBr.

The emulsion consists of silver halide crystals whose dimensions vary about the average of 0.5 to few *ìm* in diameter, embdded in gelatine, coated on both sides by transparent plastic sheet, called the film base. The dimension of crystals is important for the emulsion sensivity. The photographic measurement method employed in radiation dosimetry show the following

advantages: permanent measurements record, simultaneous record of different radiations types, repeated reading of the same film, large area dosimetry especially for electron beams, linearity of dose (over a short dose range, OD can be treated linearity with the dose for most films), dose rate independence permanent record, good spatial distribution of dose or energy permitting realization of little detectors.
A film densitometer is defined by the "response curve" - the Optical Density (OD) versus dose curve for an x-ray exposed film. The film densitometer characteristic curve is the relation between the measured values and optical film density. The Optical Density (1) is defined as:

$$OD = log_{10}(I_o/I) \quad \text{or,} \quad OD = log_{10}(1/T) \qquad (1)$$

where I and I_0 are the light intensities in the densitometer with and without the film and T is the transmittance. The transmittance is related by the second equation:

$$T = e_{an} \qquad (2)$$

where *a* is the average aria / grain, n is the number of developed grains/cm_2 and N is the grains number / cm^2.
Knowing that *n/N = a\Ö*, where *Ö* is the electron fluence, the second equation becomes:

$$OD = an\, log_{10}^{e} = 0.4343\, an = 0.4343\, a^2N\Phi \qquad (3)$$

Therefore**,** Optical Density is given by electron fluence *Φ*, number of grains *N*, and the grain average aria *a*.

FILM DENSITOMETER

The film densitometer (Fig. 1) is a simple to use peripheral device for the measurement of the blackening density film exposed to ionizing radiation. Since x-ray image on the film is a black & white image with various blackening densities, the unit may be used as a basis for a printer/plotter or similar output device. The densitometer accepts standard x-ray films.

Fig. 1 - The model 9721 Film Densitometer.

The film can be of any desired shape, since it is supported on a stationary film table unobstructed by the scanning head. The light source/detector assembly is driven in finite incremental steps with a high degree of repeatability.

The general specifications for this system are (4): scanning aria films is up to 37 x 45,5 cminclusively; scanning speed slowing rate is 5 cm/sec maximum on each axis; sampling resolution has a mechanical 0.25 mm (1/4 mm) increment and an electronic one 0.0625 mm (1/16 mm) over the entire scanning area to ensure precise positioning with a high degree of repeatability; detector driving mechanism consist of pulse driven stepping motors with the power transmission via a stainless steel cable over driving pulleys; absolute positioning repeatability is 0.5 mm, on long term and after warming up it is 0.1mm or better; Optical Density Units (maximum) and output signal is 2.5 Volts/Optical Density units; sensitivity ranges come from Software controlled range selection from 0 to 4 and 0 to 2 OD, corresponding to a full scale output of 10 Volts; densitometer interconnection is realized by a single 15-pin connector standard "D". A single USB cable between the film densitometer and the computer make possible the connection between the electronic compartment and computer.

The film densitometer is connected to the RTD-4 software computer. The interface makespossible the collection and drawing of the investigated film dose distributions. The outputsignal is presented as a relative density or as a dose voltage representing a percentage (usually 0% to 200%) of some user is selected maximum. Multidata's Realtime Dosimetry Software provides radiation response correction using table look-up to convert optical density measurements to absolute or relative doses.

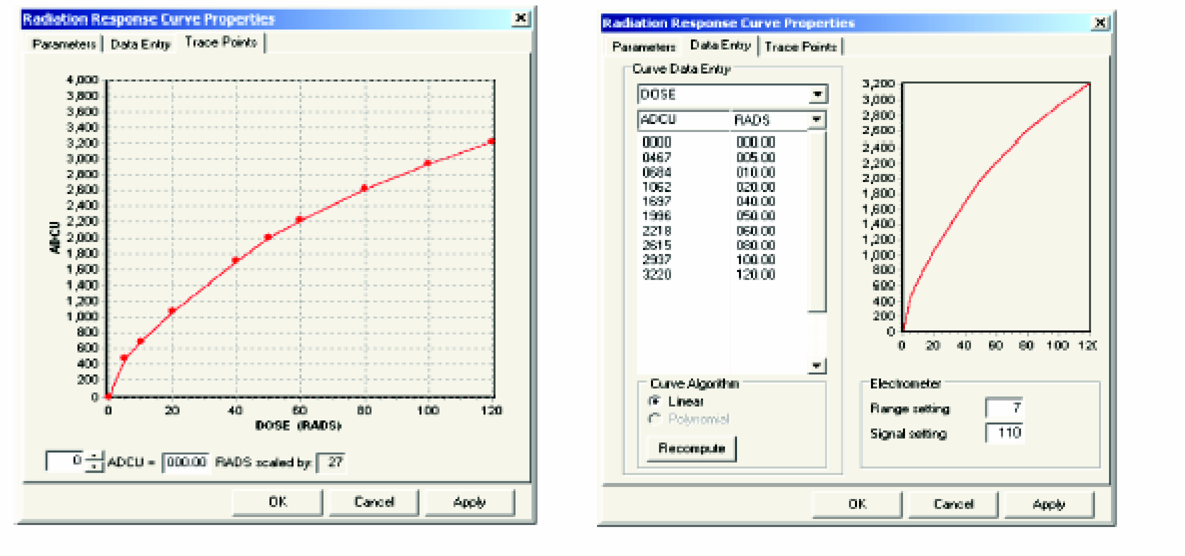


Fig. 2 – The radiation response curve properties in MULTIDATA densitometer program.

The MULTIDATA densitometer program (Fig. 2) correlates the ADCU values with the optical density of the step etalon film to obtain the radiation response curve.

THE ABSORBED DOSE DETERMINATION METHOD USING A FILM

In the appropriate scientific literature, the degree of the film blackening is measured by determining the optical density by a densitometer. The instrument consists of a light source, a tiny aperture through which the light is directed and a light detector (photocell) to measure the light intensity transmitted to the film.

The optical density is defined in equation (1), where I_0 is the signal corresponding to the amount of light collected without the film and *I*, the signal corresponding to the amount of light transmitted through the film; the immediate reading of a densitometer is called "measured optical density". In dosimetry, the quantity of interest is usually the "net optical density" (net OD), which is obtained by subtracting the "fog" reading (the OD of unexposed, but processed film) from the measured optical density.

A plot of the net OD as a function of radiation exposure or dose is termed the *sensitometric curve*, or H-D curve, which we call "response curve" (2). Films, having a steep blackening curve, are also called "fast films" and those with a smaller slope are called "slow films".Ideally for film dosimetry, the net optical density versus exposure graph is a straight line passing through the origin (Fig. 2). The curve significantly departs from linearity only when the exposure becomes so great that appreciable energy is wasted on grains that have already been made developable. For commercially available fine-grain x-ray films, the density versus dose curve may be essentially linear up to densities of 2 or even higher.

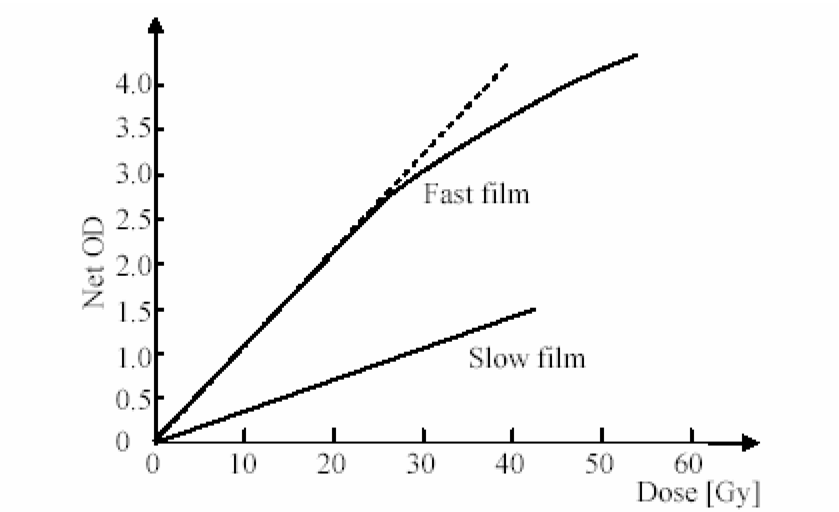


Fig. 3 – Typical response curve, i.e. net optical density versus dose curves of radiographic films for direct x-ray exposure (Kodak 1999).

The fairly straight-line relation between dose and net optical density is of considerable use for the photographic monitoring of radiation, permitting savings of time in the interpretation of densities observed on dosimetric films, and for clinical dosimetry.

The MULTIDATA etalon film (3), number Al-04-0001, model 10197211, is used in the model 9721 film densitometer system, a step blackening film, from 0 to 4 OD. Heeding of optical density definition, material which is perfectly transparent (incident intensity equals the transmitted intensity) has an OD = 0, (Log (1) = 0), likewise, a material with OD = 4 allows only 0.0001 or 0.01% of its incident light to pass through. The device which will measure optical density requires comparison of light transmitted by a substance with the light transmitted by a vacuum of the same dimensions. To do the comparison and gate the output to be the negative logarithm of the transmittance, the film densitometer uses sensitive color compensated photo sensors in a ratio circuit. One reference photo sensor monitors the intensity of a light source (and residual ambient light) before it passes through the film I_0, while the signal photo sensor registers the light that has passed through the film of interest I.

The output of the reference sensor is added to the inverted output signal photo sensor through
the use of a differential amplifier. The two signals are compared and the voltage thus obtained is directly proportional to the optical density, i.e. “net optical density”.

Experimentally films from radioprotection boxes that usually are used in radiologique risk unities for personal radioprotection were used. These four reference films exposed to ionizing radiations doses of 0.3, 1, 3 and 5 Gy (mSv) and after beeing developed they were investigated with the film densitometer. The curves, presented a proportional variation with the dose exposed films.

RESULTS

The first measurements in the lab consisted in drowing the blackening curve corresponding to MULTIDATA etalon film, model 10197211 (3), characterized by 21 blackening steps (Fig.3) delivered with the film densitometer.

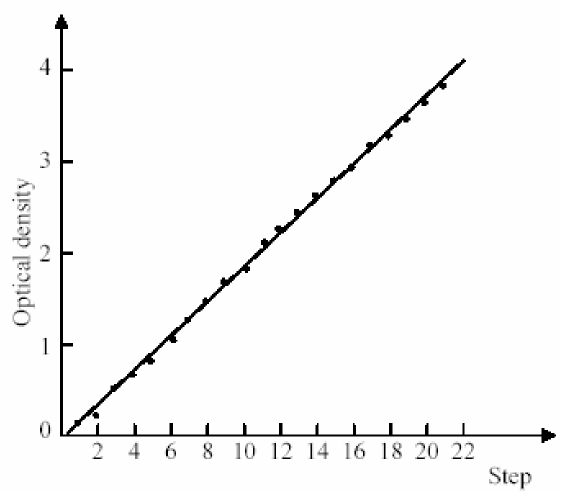
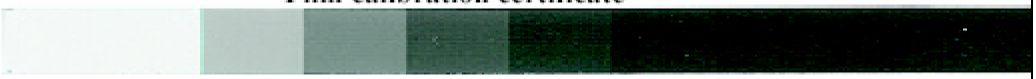


Fig. 4 - Optical density and the 21 steps for Multidata delivered film with calibration certificate.

Table 1 presents the 21 blackening film and optical density values (3).

Table 1.

Film calibration certificate



Step	1	2	3	4	5	6	7	8	9	10
Optical Density	0.05	0.28	0.51	0.70	0.90	1.10	1.29	1.48	1.68	1.88

Film calibration certificate

Step	11	12	13	14	15	16	17	18	19	20	21
Optical Density	2.05	2.26	2.45	2.64	2.81	2.98	3.18	3.35	3.55	3.69	3.84

Fig. 5, shows the model 0197211 film coresponding graph made by the MULTIDATA densitometer (4). From left to right it was sensitive to the 21 blackening steps optical density increasing.

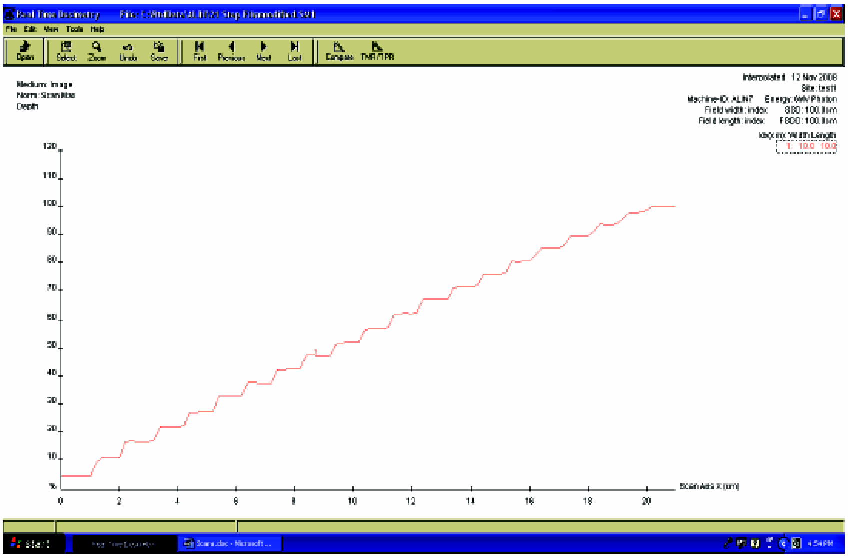


Fig. 5 – The reference film blackening curve.

Fig. 6 is presents the design of the photodosimetric box used by persons exposed to radiological risk in nuclear units, for radioprotection monitoring. Evidencing the locations where the plates made of Al (1 mm), Pb (0.4 mm), Cu (d_1 = 1mm), Cu (d_2 = 0.1 mm), CU (d_3 = 0.5 mm) and plastic are housed in the boxes.

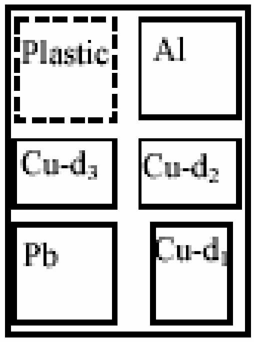


Fig. 6 – Part view of photodosimetric box schematic designe.

Fig. 7, 8, 9 and 10, present the measurements for reference films exposed to ionizing radiations doses of, 0.3, 1, 3 and 5 Gy (mSv) investigated with the film densitometer. The curves show a proportional variation with the dose exposed films. Measurements were performed two times for each film area: one for plastic, Cu-d3, Pb and the other for Al, Cu-d2 and Cu-d1.

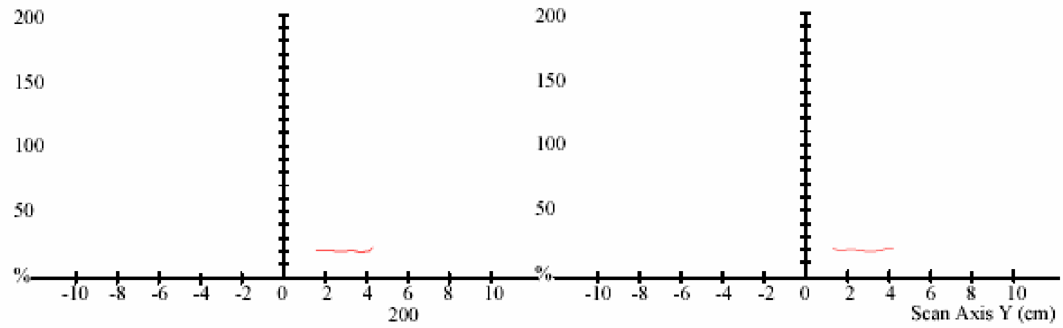


Fig. 7 - Reference film 1, exposed to 0.3 mSv.

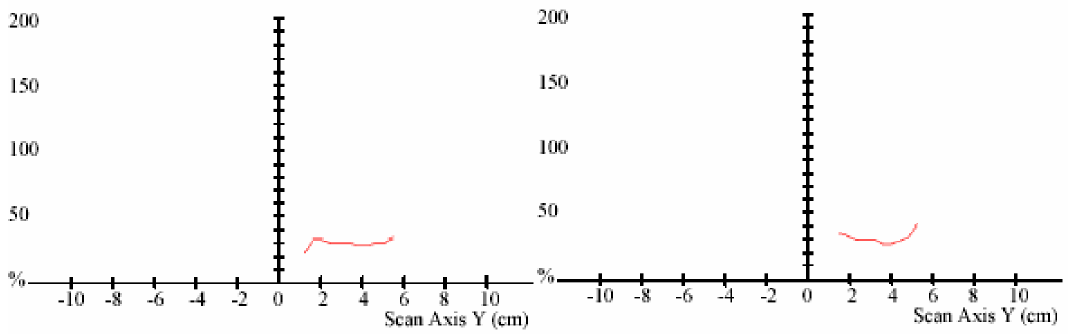


Fig. 8 - Reference film 2, exposed to 1 mSv.

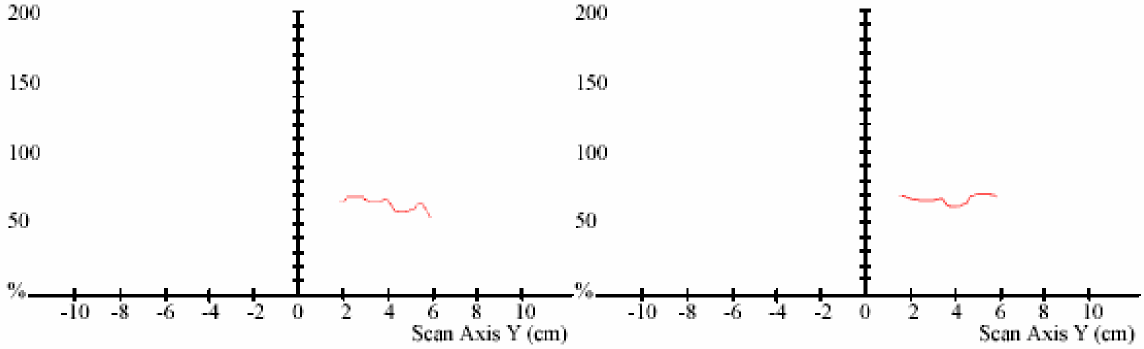


Fig. 9 - Reference film 3, exposed to 3 mSv.

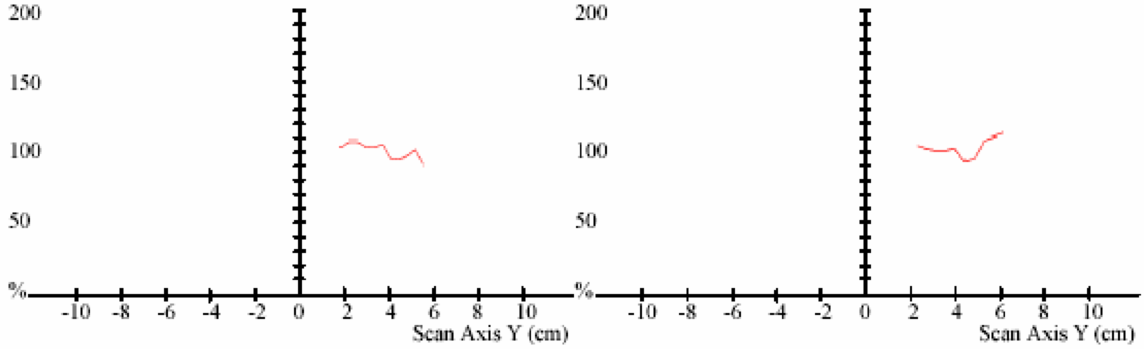


Fig. 10 - Reference film 4, exposed to 5 mSv.

Table 2

The reference film Nr.	Film dose (mSv)	Left side blackening density (%)			Right side blackening density (%)		
		Plastic	$Cu\text{-}d_3$	Pb	Al	$Cu\text{-}d_2$	$Cu\text{-}d_1$
1	0.3	21	21	21	20	20	20
2	1	33	30	32	29	30	32
3	3	65	62	70	68	68	65
4	5	109	95	102	90	100	102

Analyzing the measured values (Table 2) and curve graphs, it is obvious that the averrage of blackening densities are: 20, 30, 68 and 100, for the reference films 1, 2, 3 respectively 4.

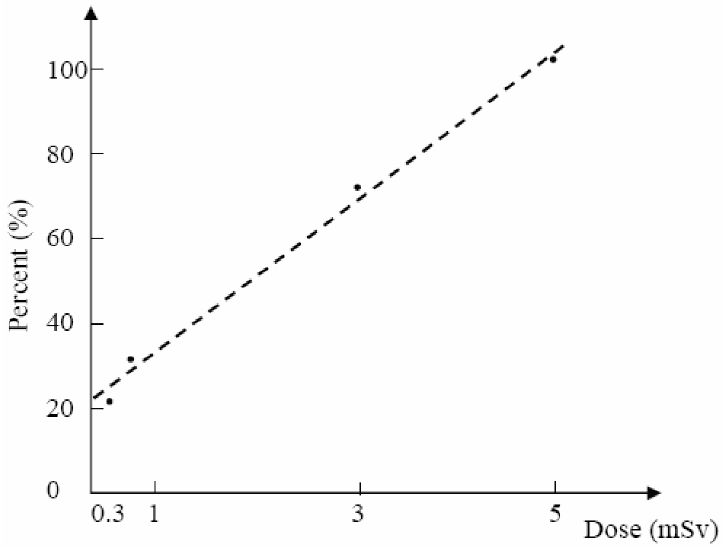


Fig. 11 - Blackening density versus dose for exposed reference films.

Fig. 11 presents the reference exposed film blackening density variation versus the absorbed dose or more fairly versus equivalent absorbed dose in the film area. With the dose range, used in the experiments, the density versus dose curve is essentially linear.

CONCLUSIONS

Considering the above one may conclude:

1. Dosimetric measurements were performed by MULTIDATA Densitometer, a precision Dosimetry System, used as peripheral device for the measurement of relative density/dose information.
2. The RTD-4 software densitometer employed, permit reading & storage values and automatic blackening curve plotting.
3. Knowing the exposed film doses, for the same film one can plot the absorbed dose calibration curve versus the blackening density.

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