


Glass plate irradiation and digital processing of electron beam images

A red arrow graphic pointing to the right, positioned to the left of the authors' names.

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This research explores the integration of glass plate irradiation and electron beam image digital processing to enhance the characterization of electron beam profiles and absorbed dose transverse distribution in materials and biological tissues irradiation experiments.

Image processing entails using computer algorithms to manipulate, analyze, and derive valuable information from digital images applying modern image enhancement, restoration, segmentation, feature extraction, and pattern recognition methods.

The advanced digital processing techniques offers the potential for high-resolution dose distribution mapping, ensuring precise and controlled irradiation for enhanced materials processing.



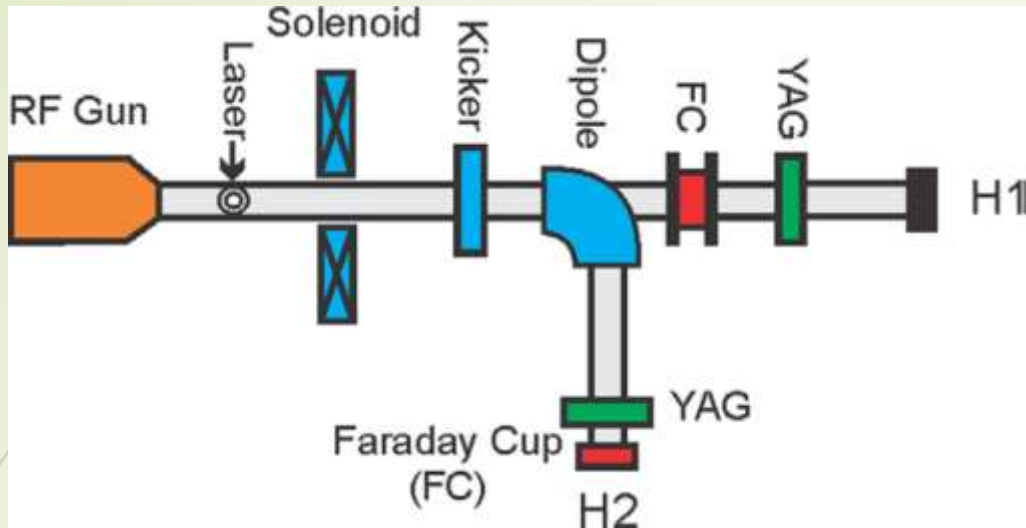
OUTLINE

1. AREAL beam transverse profile
2. Absorbed dose transverse distribution
3. Plate glass irradiation and acquisition of the beam image
4. The beam image digital processing
5. Response parameter
6. Image fading
7. Response linearity check
8. Calibration

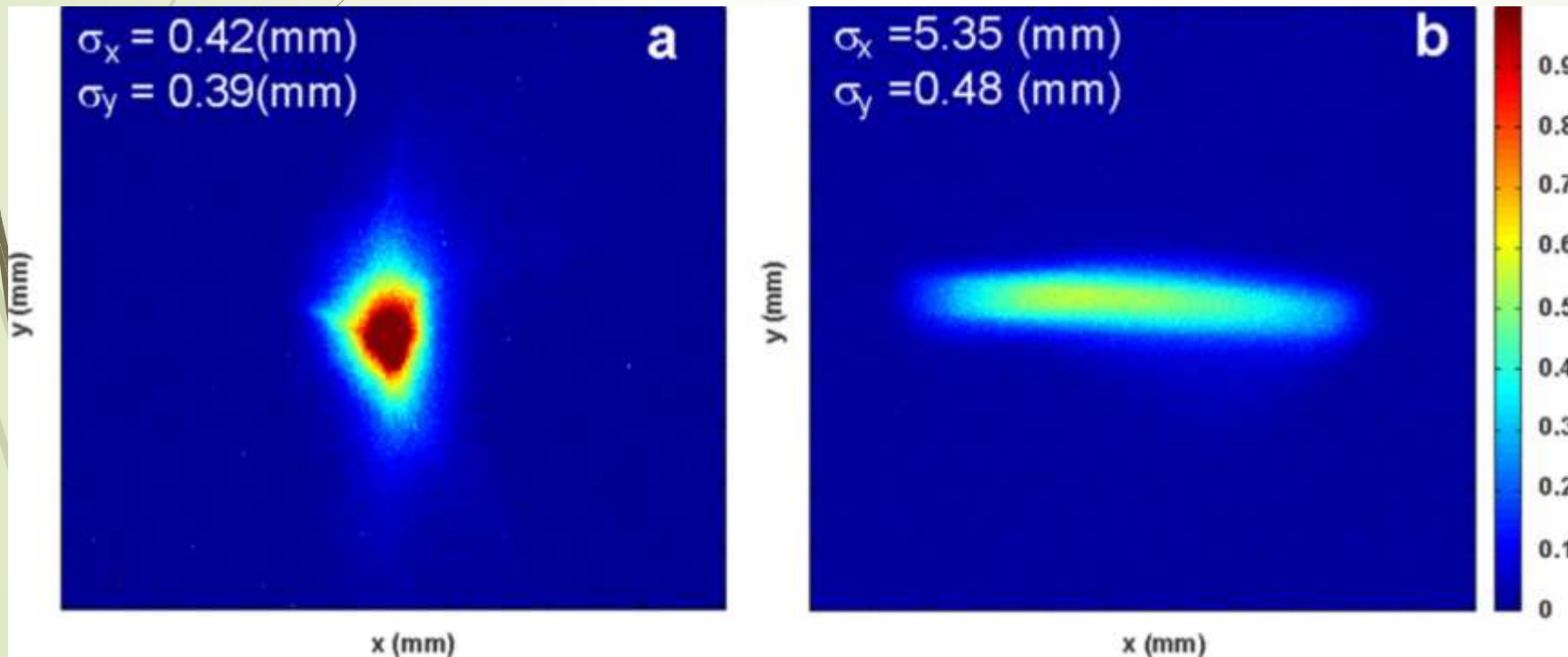


AREAL ELECTRON BEAM PARAMETERS

Energy	2–5 MeV
Pulse charge	30–250 pC
Pulse length	0.45 ps
Norm. emittance	≤ 0.5 mm-mrad
RMS energy spread	≤ 1.5 %
Pulse repetition rate	1-20 Hz
RF frequency	3 GHz

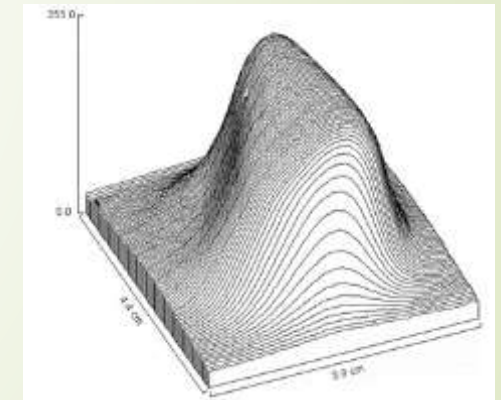
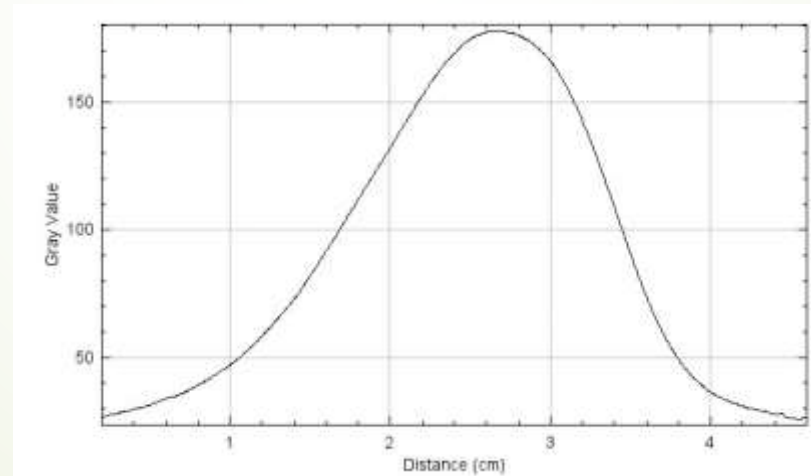
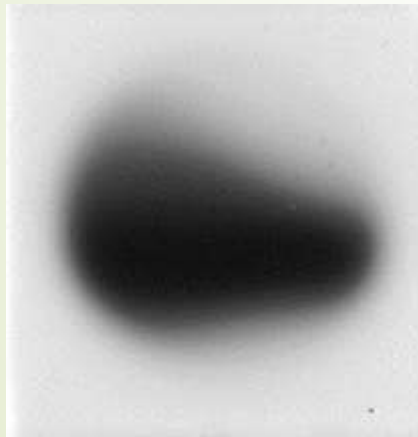
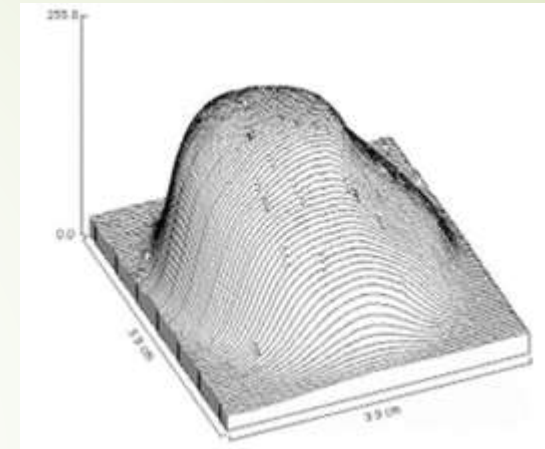
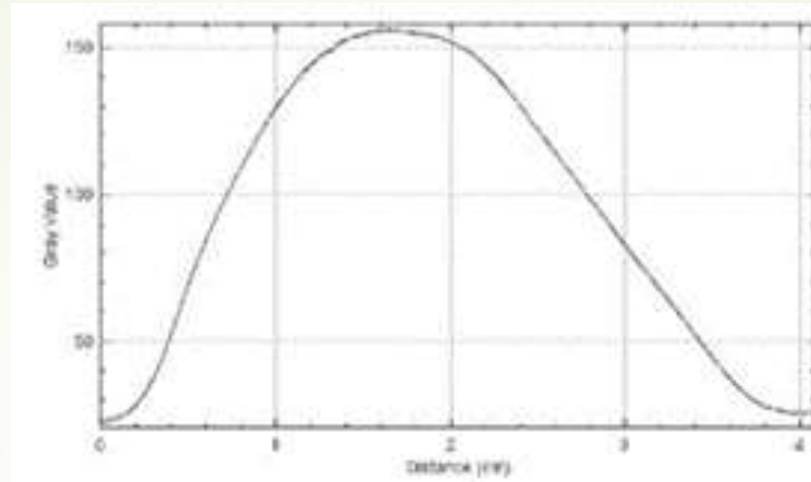
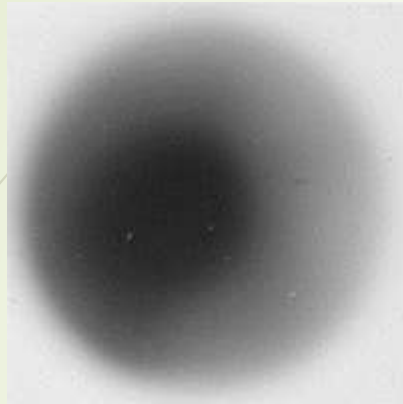


AREAL RF photogun linac layout with experimental stations H1 and H2.



Electron beam transverse profiles for the strait (a) and bent (b) beams on the YAG scintillation screen

AREAL ELECTRON BEAM TRANSVERSE PROFILES





Glass Plate

Plate thickness is greater than the range of (3.6 MeV) electrons. Its properties can be obtained in ESTAR online database of National Institute of Standards and Technology.

(M. J. Berger, J. S. Coursey, M. A. Zucker and J. Chang, “ESTAR, PSTAR, and ASTAR: Computer Programs for Calculating Stopping-Power and Range Tables for Electrons, Protons, and Helium Ions (version 1.2.3),” National Institute of Standards and Technology, Gaithersburg, 2005. <http://physics.nist.gov/PhysRefData/Star/Text/ESTAR.html>)

ESTAR provides Stopping Powers and Range Tables for Electrons



GLASS PLATE COMPOSITION:

Atomic number Fraction by weight

8 (O) 0.459800

11 (Na) 0.096441

14 (Si) 0.336553

20 (Ca) 0.107205

PLATE GLASS PROPERTIES

Kinetic Energy 3.1 MeV

Total stopping 1.636 MeV cm²/g

power

CSDA range 1.792 g/cm²

CSDA range 0.43 cm

Density 2.4 g/cm³

CSDA denotes Continuous Slowdown Approximation

Absorbed Dose from Charged Particle Beam

The absorbed dose is defined as the mean energy imparted by ionizing radiation to matter of mass m in a elementary volume V by:

$$D = \frac{d\bar{\epsilon}}{dm}$$

$$\dot{D} = \frac{\dot{\phi} A (-dE/dx) \Delta x}{\rho A \Delta x} = \dot{\phi} \left(-\frac{dE}{\rho dx} \right)$$

\dot{D} = dose rate
 $\dot{\phi}$ = fluence rate ($\text{cm}^{-2} \text{s}^{-1}$)
 ρ = density
 A = area

Mass stopping power

$$(S/\rho)_{\text{tot}} = \frac{1}{\rho} \frac{dE_K}{dx} \quad (\text{MeV} \cdot \text{cm}^2/\text{g})$$

$$(S/\rho)_{\text{tot}} = (S/\rho)_{\text{col}} + (S/\rho)_{\text{rad}}$$

$$D = \phi (S/\rho)_{\text{col}}$$

1. INTERNATIONAL COMMISSION ON RADIATION UNITS AND MEASUREMENTS, Stopping Powers for Electrons and Positrons, Rep. 37, ICRU, Bethesda, MD (1984).
2. Fundamental Quantities and Units for Ionizing Radiation, Rep. 60, ICRU, Bethesda, MD (1998).

STOPPING POWER

The Bethe theory is used to calculate stopping powers for electrons and positrons. The complete mass collisional stopping power for electrons and positrons, according to ICRU Report No. 37, is:

$$\frac{S_{\text{col}}}{\rho} = \frac{N_A Z}{A} \frac{\pi r_0^2 2m_e c^2}{\beta^2} [\ln(E_K/I)^2 + \ln(1 + \tau/2) + F^\pm(\tau) - \delta]$$

for electrons

$$F^-(\tau) = (1 - \beta^2)[1 + \tau^2/8 - (2\tau + 1) \ln 2]$$

for positrons

$$F^+(\tau) = 2 \ln 2 - (\beta^2/12)[23 + 14/(\tau + 2) + 10/(\tau + 2)^2 + 4/(\tau + 2)^3]$$

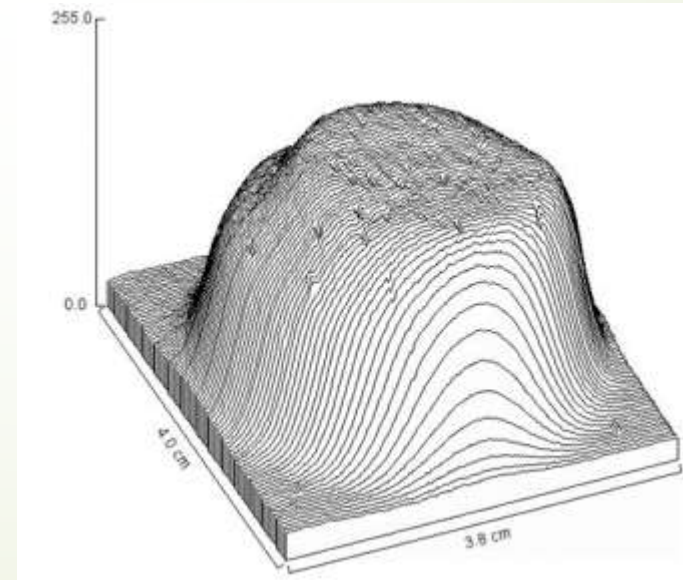
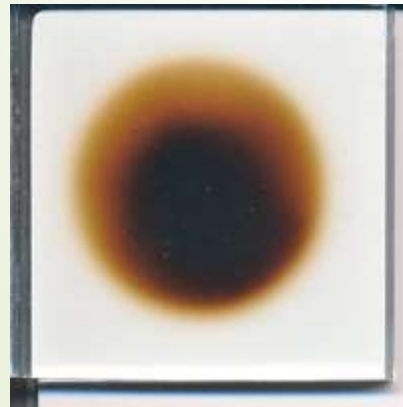
$$\tau = E_K/m_e c^2 \text{ and } \beta = v/c.$$

The Bethe–Heitler theory leads to the following formula for the mass radiative stopping power:

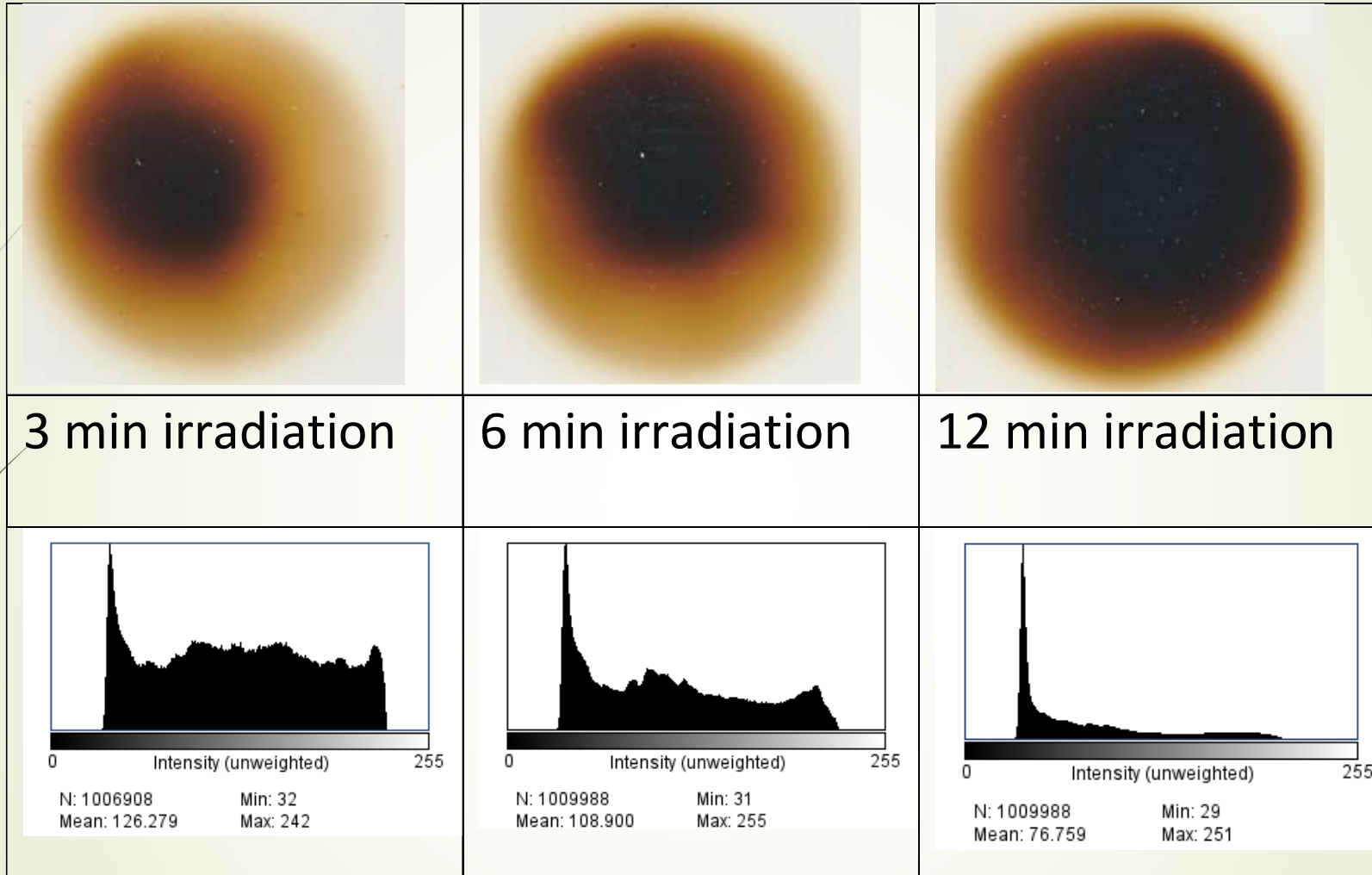
$$\frac{S_{\text{rad}}}{\rho} = \sigma_0 \frac{N_A Z^2}{A} (E_K + m_e c^2) \bar{B}_r$$

Image obtained by glass plate irradiations has been converted into digital format using camera or office scanner Canonscan 5600F in 800 Dpi mode. Digital image processing is performed applying ImageJ.

ImageJ is free and open source software.(Rasband, W.S., ImageJ, U. S. National Institutes of Health, Bethesda, Maryland, USA, <https://imagej.nih.gov/ij/>, 1997-2018.).

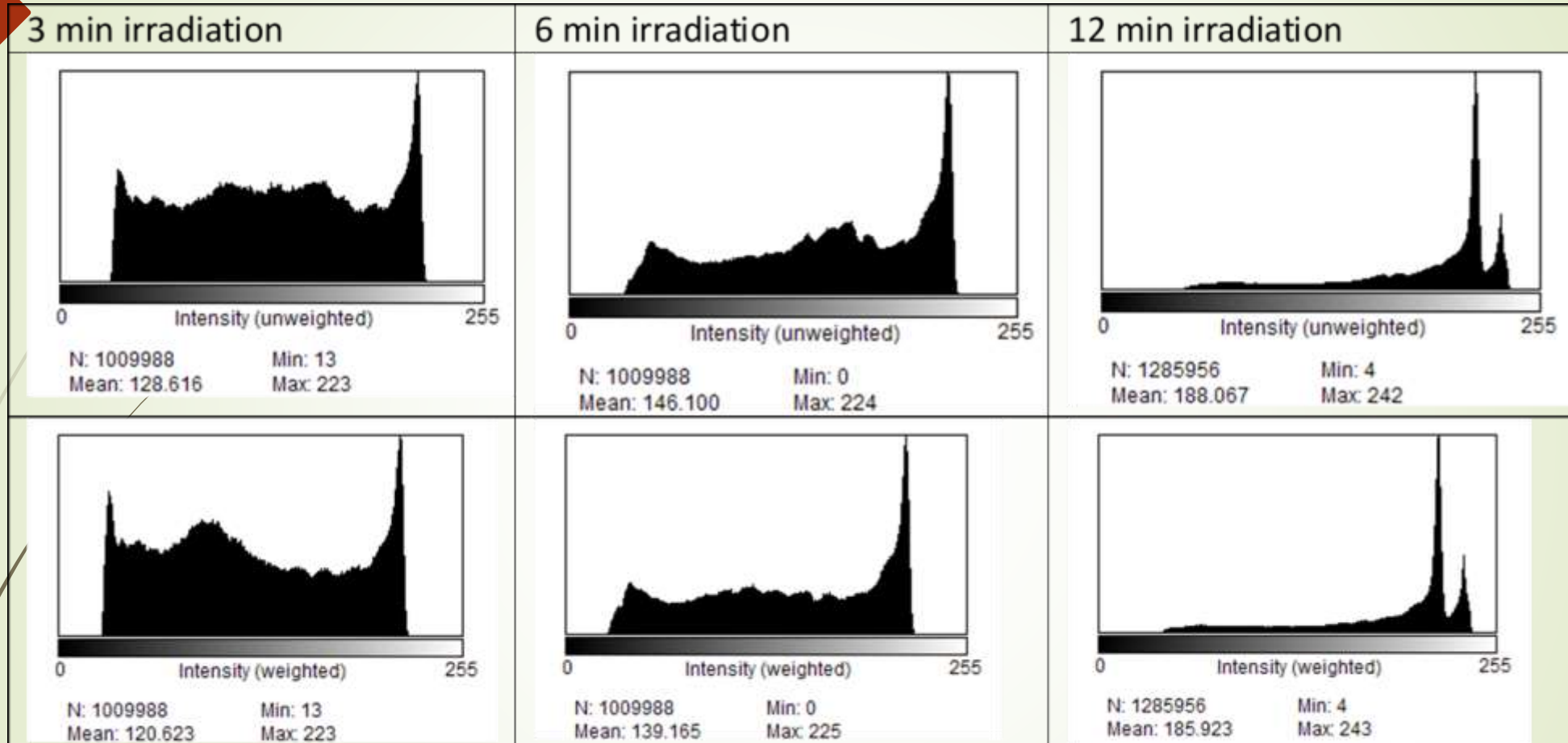


Beam image on the glass plate and color histograms



unweighted gray = (red + green + blue) / 3 ;

Inverted color histograms

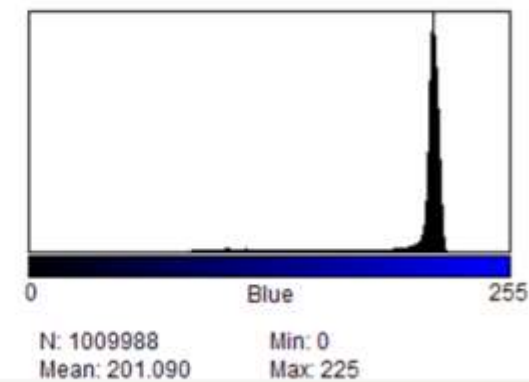
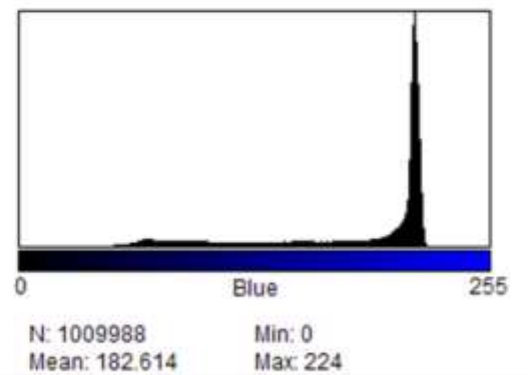
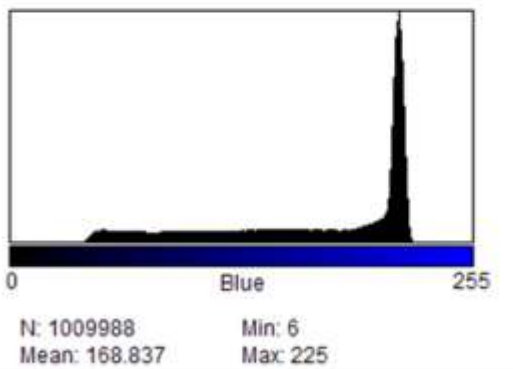
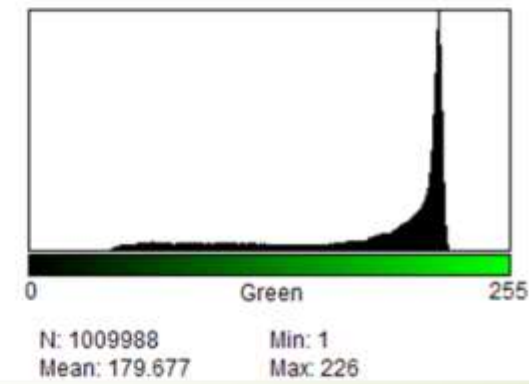
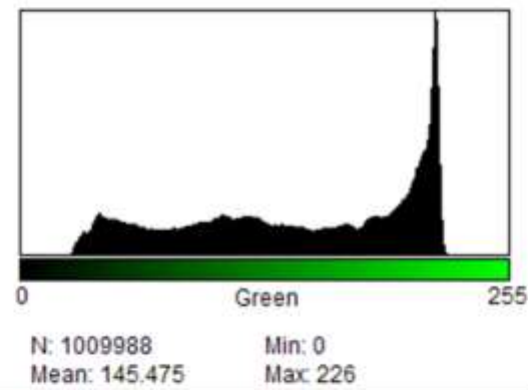
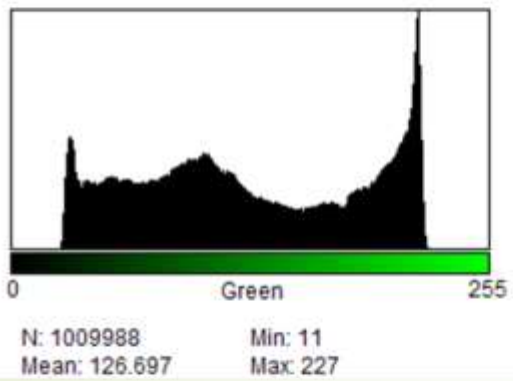
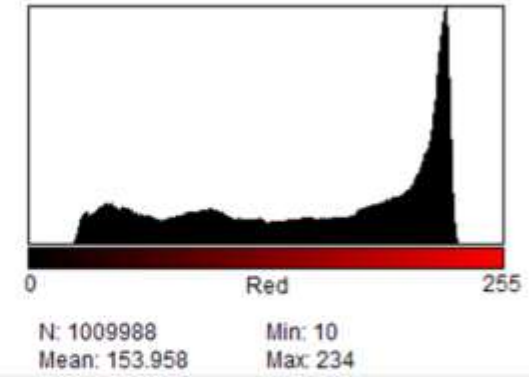
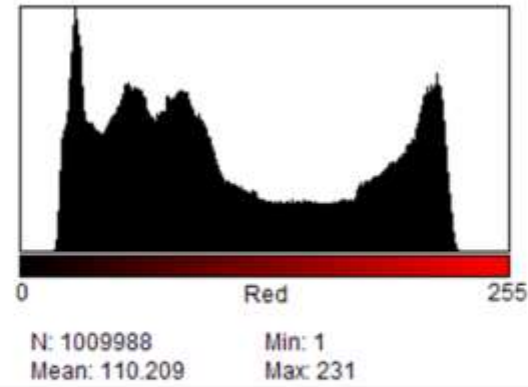
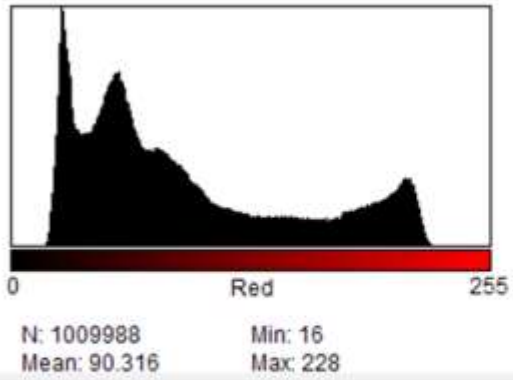


On RGB images, each pixel grayscale value is obtained by the formula:
unweighted gray = $(\text{red} + \text{green} + \text{blue}) / 3$;
weighted gray = $0.299 \times \text{red} + 0.587 \times \text{green} + 0.114 \times \text{blue}$

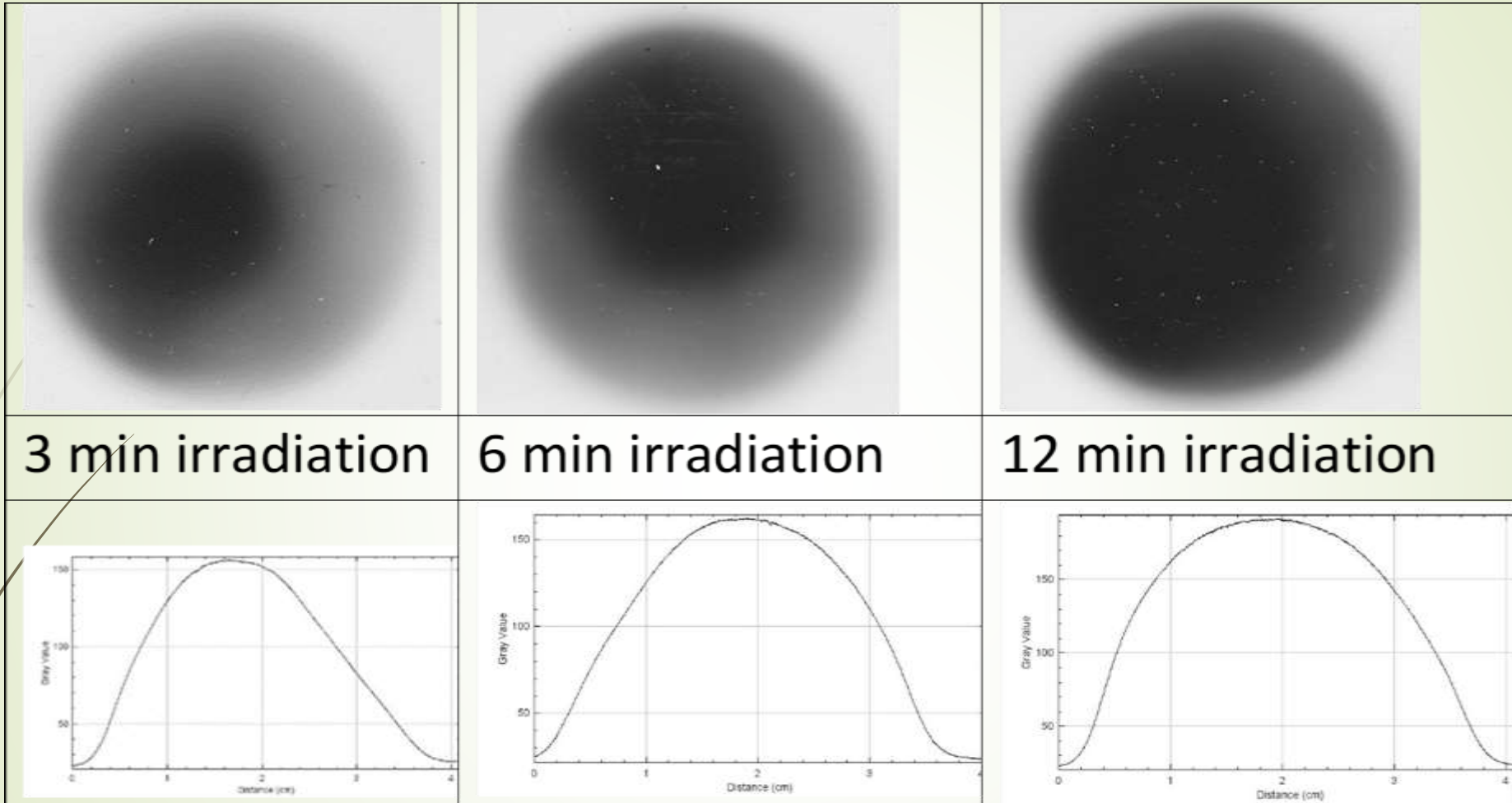
3 min irradiation

6 min irradiation

12 min irradiation



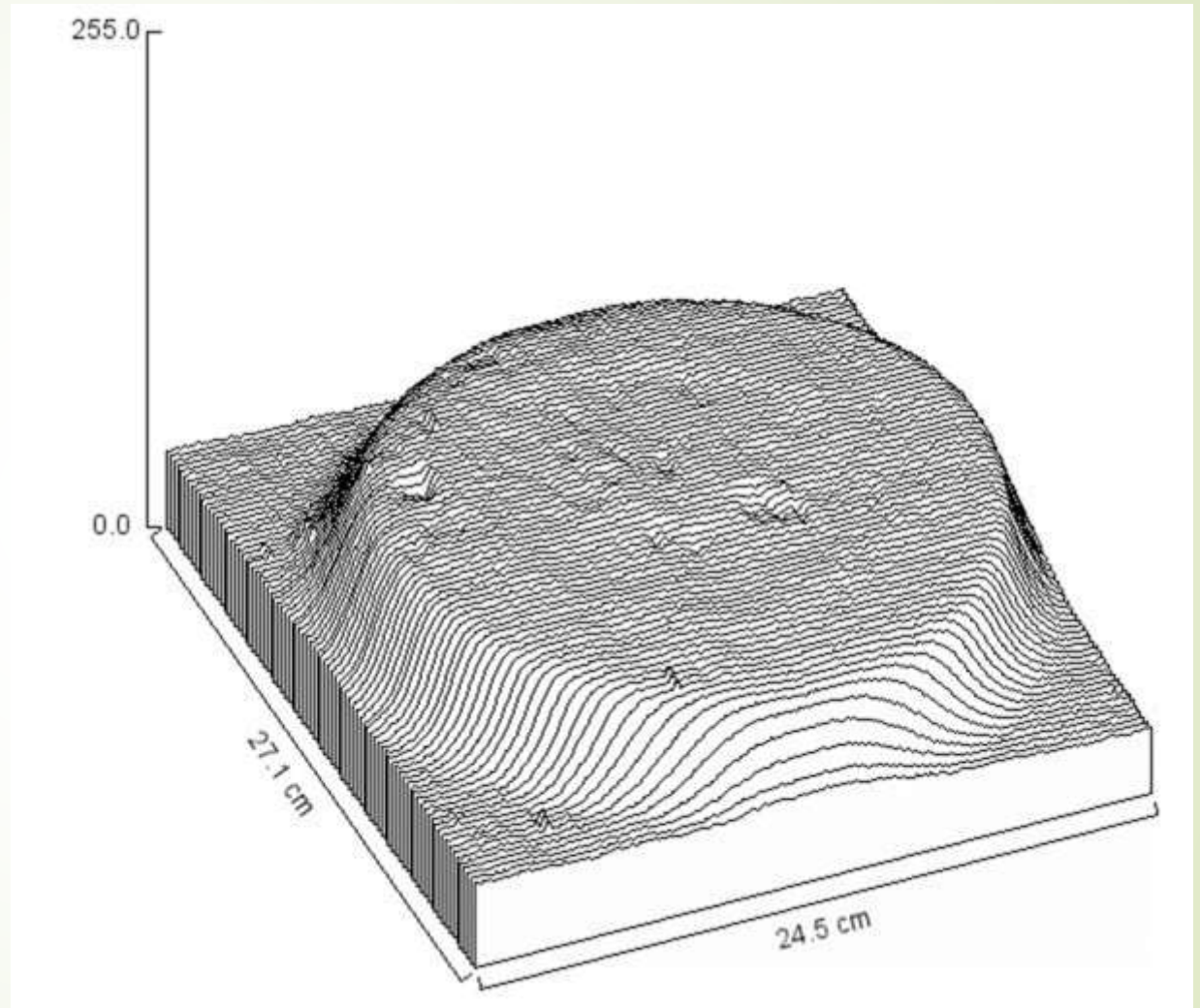
Beam image profile plots



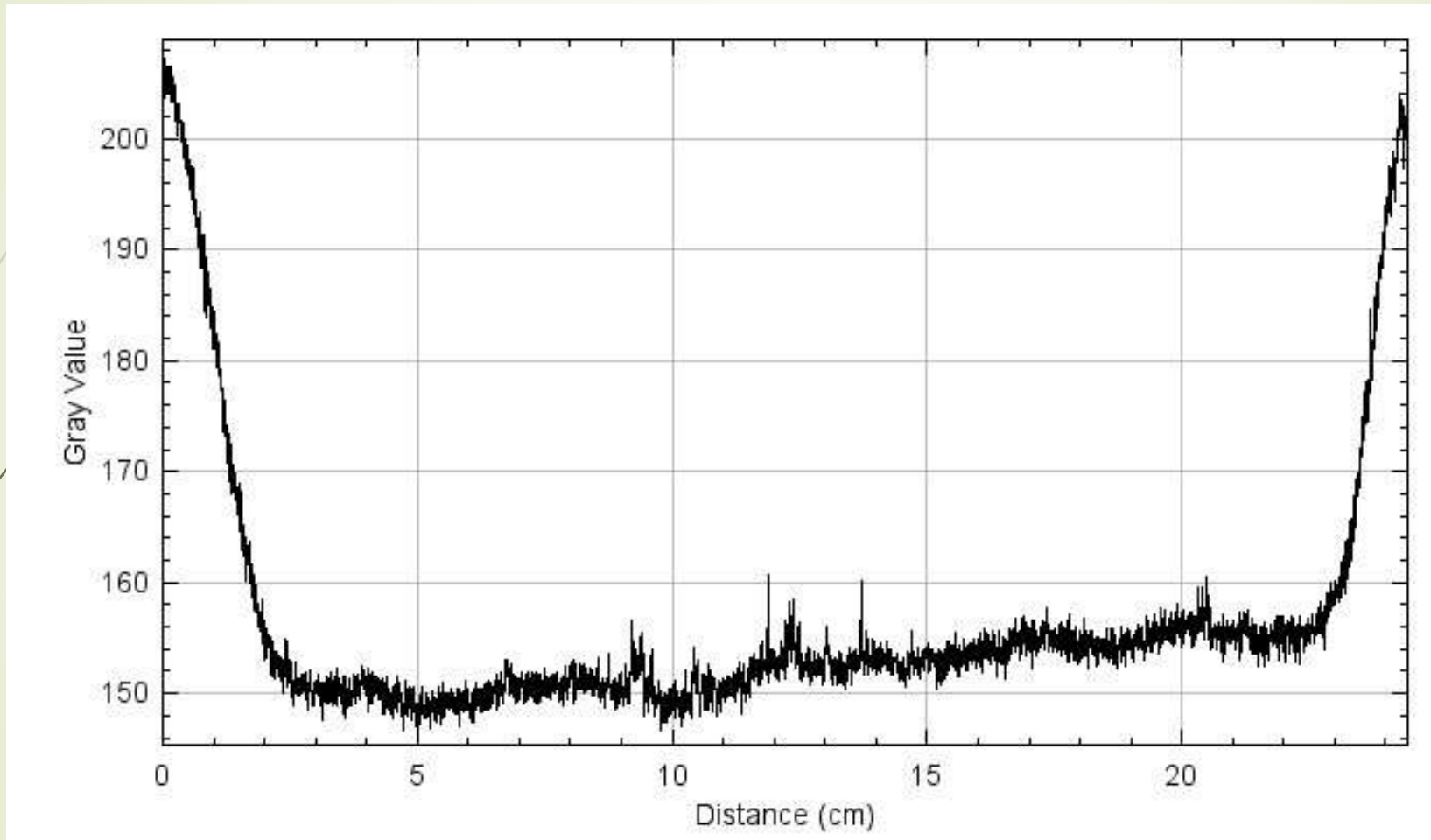
X -RAY IMAGES



The image on the glass plate has been obtained applying X-ray 225 keV beam



X-RAY IMAGES



The image on the glass plate obtained applying X-ray 225 keV beam is not perfectly uniform.

RESPONSE PARAMETERS

- 1 - 3 min irradiation
- 2 - 6 min irradiation
- 3 - 12 min irradiation

	Area	Mean	Min	Max	IntDen
1	10.181	126.384	32	242	1286.753
2	10.181	108.887	31	255	1108.56
3	10.181	76.759	29	251	781.504

Mean - mean gray value
IntDen - integrated density

Reference dosimeter



Dose1 Dose Meter



NACP-02 ionization chamber

DOSE-1 electrometer with the NACP-02 Ion chamber sensor

“DOSE-1” is a portable, single-channel, high-precision reference class electrometer for measurements of absorbed dose with beam currents up to 1 mA. Dose, dose rate, average dose rate, charge, current, and dose per monitor unit are all measured and displayed simultaneously. NACP-02 Ion chamber sensor is designed according to recommendations of the Nordic Association of Clinical (Medical) Physicists – NACP. The typical sensitivity is 6 nC/Gy.





The parallel plate ionization chamber NACP-02 is designed for absolute and relative electron beam dosimetry between 2 and 50 MeV in the quantity of absorbed dose to water. It can be used for proton beam absolute and relative dosimetry and for photon beam depth-dose measurements as well.

Sensitive volume (nominal): 0.16 cm³;

Entrance window (polarizing electrode) diameter: 20 mm;

Typical sensitivity: 6 nC/Gy;

Minimum dose rate: 0.01 Gy/min;

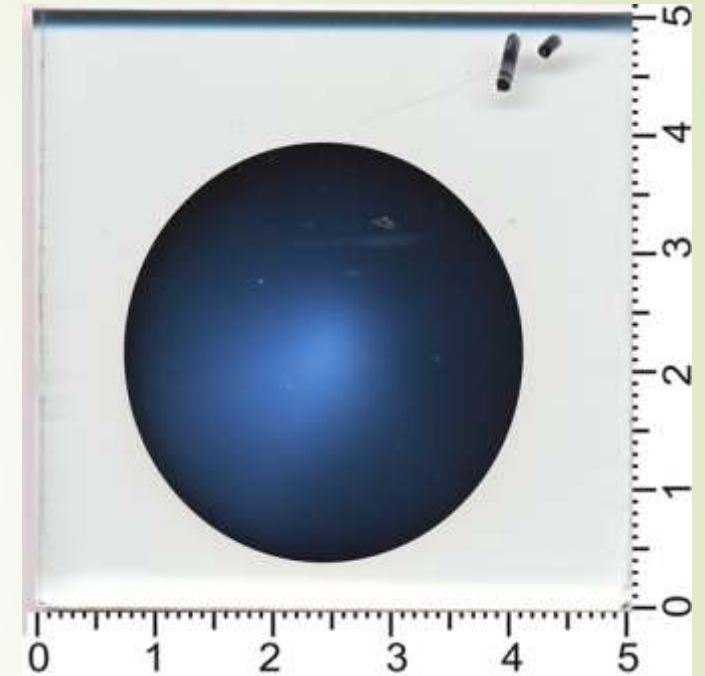
Maximum dose rate: 600 Gy/min;

Range for electrons: 2 to 50 MeV.

IMAGE FADING

The fading process of the beam image on the glass plate obtained after 1 min irradiation

Time [hours]	Mean	StdDev	XM	YM
1	74.83	41.28	2.45	2.54
2	74.49	40.18	2.49	2.47
3	74.77	39.23	2.43	2.53
4	74.9	38.43	2.4	2.61
24	66.81	33.77	2.41	2.59
45	65.17	31.05	2.41	2.57
117	61.49	27.1	2.44	2.63



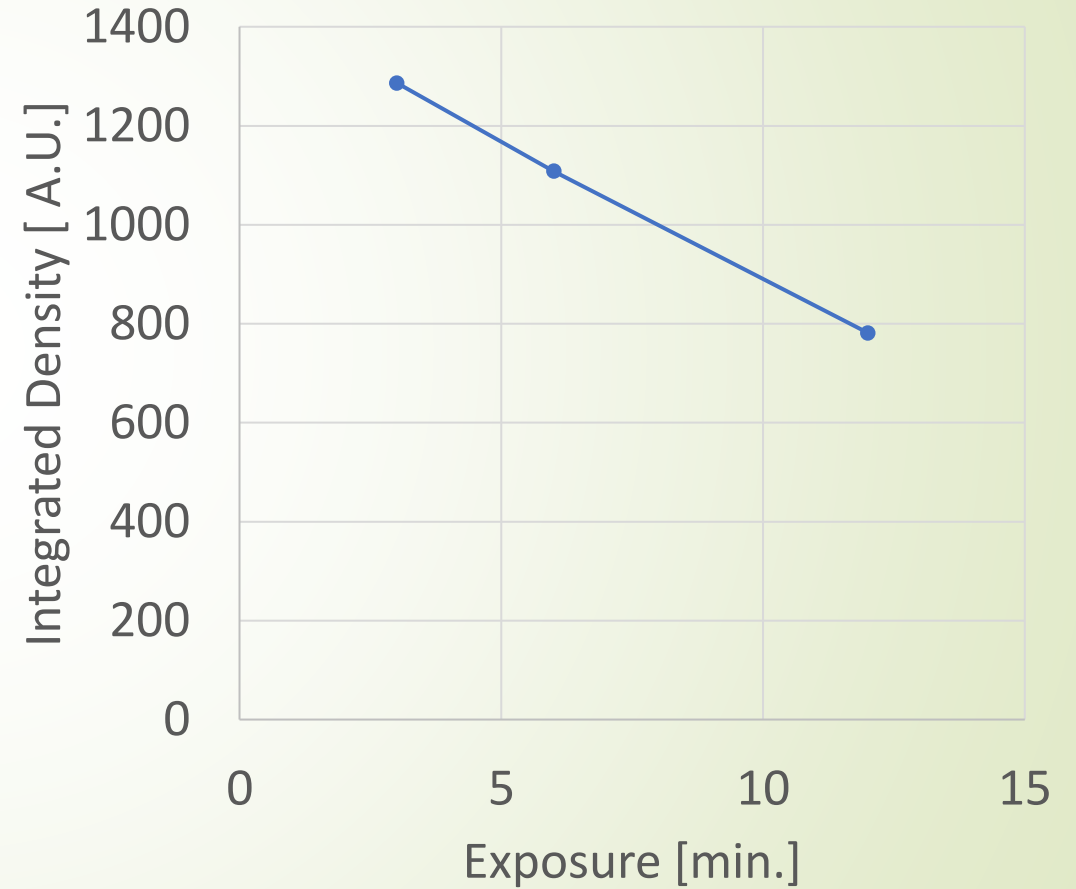
No significant fading can be observed after 4 hours of irradiation

Response Linearity

	Area	Mean	Exp [min]	IntDen
1	10.181	126.384	3	1286.753
2	10.181	108.887	6	1108.56
3	10.181	76.759	12	781.504

Integrated density The sum of the values of the pixels in the image or selection.

Mean gray value The sum of the gray values of all the pixels in the selection divided by the number of pixels.

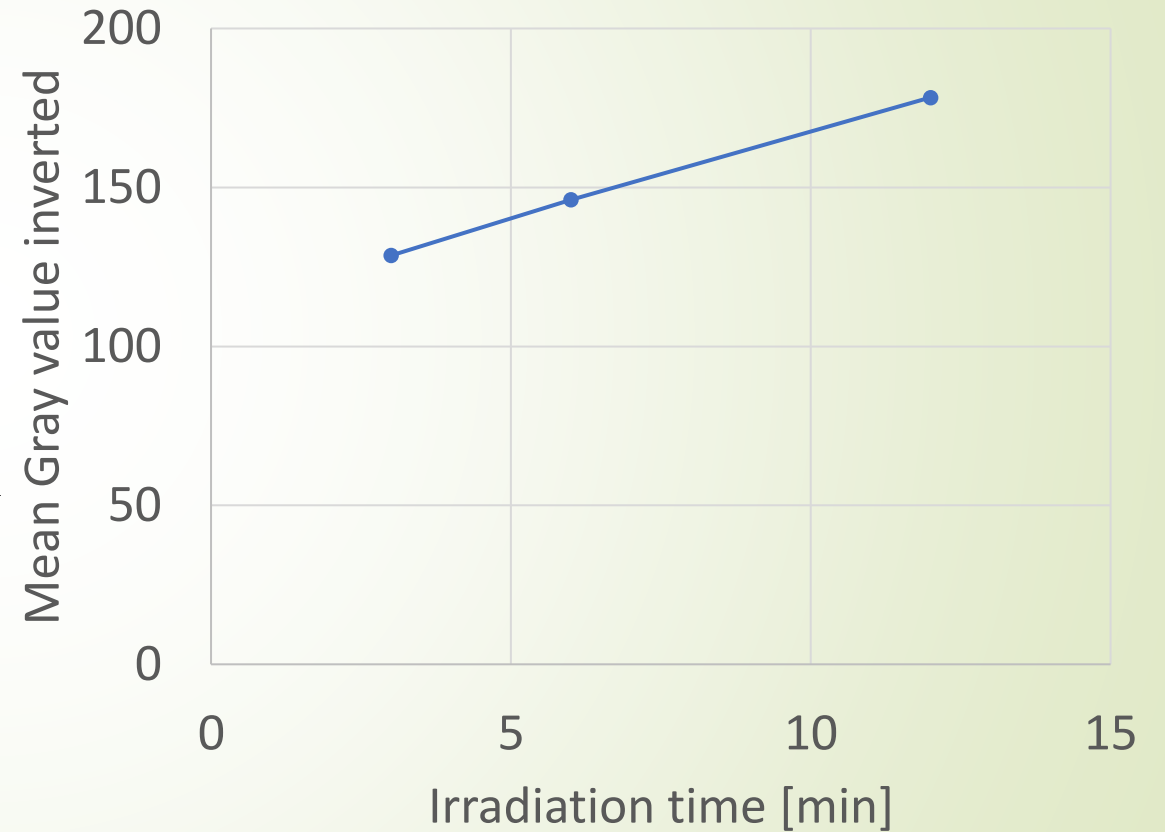


Response Linearity

	Irrad	Mean	IntDen
1	3	128.616	1309.482
2	6	146.1	1487.487
3	12	178.252	1814.749

Integrated density The sum of the values of the pixels in the image or selection.

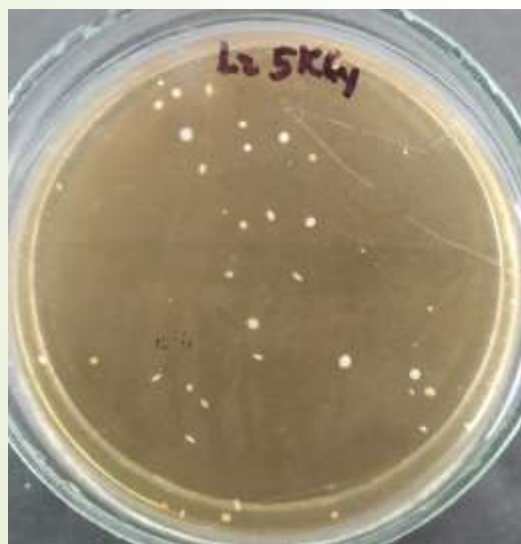
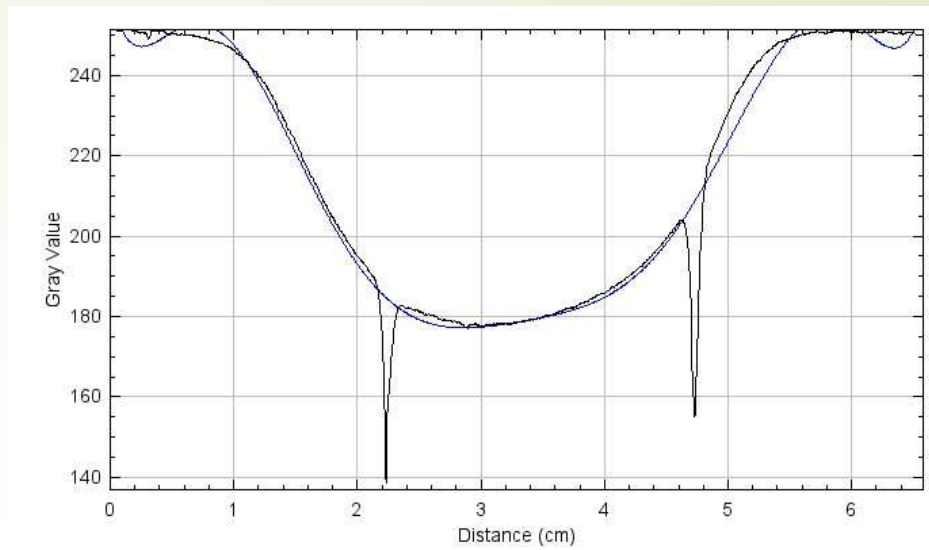
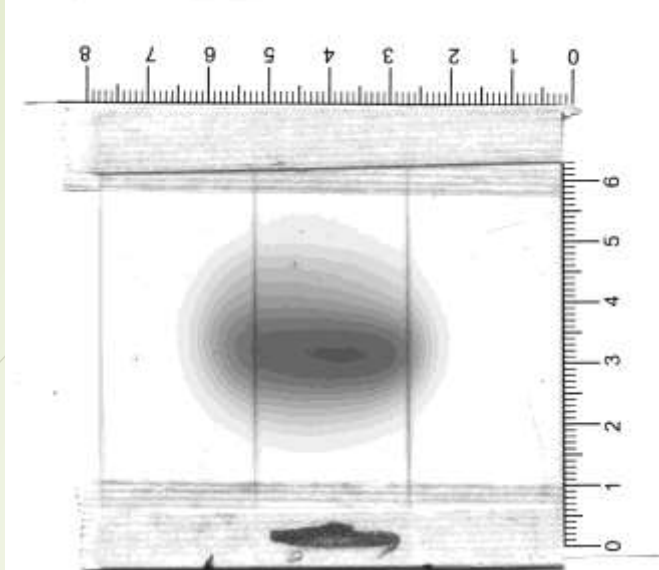
Mean gray value The sum of the gray values of all the pixels in the selection divided by the number of pixels.





Response Linearity Region

Mean	IntDen	Qd[muC]	muC/cm ²	Ne/cm ² /s
128.616	1309.482	4.788	1.524841	9.53E+12
146.1	1487.487	9.576	3.049682	1.906E+13
178.252	1814.749	19.152	6.099363	3.812E+13



D'Av [Gy/s]	D[Gy]	Qdm[C]	t(s)
4.127	412.7	2.58E-06	100
0.04	3.988	2.50E-08	100
0.018	5.254	3.29E-08	300
4.615	461.6	2.89E-06	100
0.000091	0.0091	5.7E-11	100