FILM DOSIMETRY

(LAB REPORT)

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1. Aim

- To evaluate the characteristics of radiochromic film images,
- To perform Quality Assurance tests of a Teletherapy unit.

2. Apparatus Required

- Radiochromic film (EBT3)
- Teletherapy unit
- Slab Phantom
- EPSON 12000 XL film scanner

3. Theory

Dosimetry in radiotherapy focuses on quantifying the energy deposited as absorbed dose to water. The ideal dosimeter possesses various physical and radiation-related features. It should exhibit fast kinetics for real-time data, stability, and predictability against environmental factors like temperature, pressure, and humidity. Additionally, it ought to be compact to offer high spatial resolution while causing minimal beam perturbations. Water equivalence is crucial for dose interpretation and artifact avoidance. Response to radiation should be energy and dose rate independent, ideally showing a linear relationship and sensitivity across a wide dose range. Furthermore, practical considerations include non-toxicity for in vivo use, affordability, reliability, and reproducibility.

Radiochromic dosimeters function as solid-state detectors, wherein the crystalline structure undergoes alteration upon radiation exposure. This transformation typically induces a color change through polymerization. These dosimeters come in diverse forms including liquids, gels, films, and pellets. Notably, radiochromic films (RCFs) have gained traction in radiotherapy centers for assessing 2D dose distributions. This adoption is attributed to both enhanced dose sensitivity in newer radiochromic films and the diminishing use of processor-based radiographic film.

Historical devlopment:

In the 1960s, researchers including McLaughlin developed colorless solid solutions of derivatives of the triphenyl methane molecule for radiochromic materials, primarily for high-dose applications like food irradiation and medical instrument sterilization.

- By the mid-1980s, GAFchromicTM film was introduced, which was more sensitive and suitable for mapping dose distributions above 5Gy. It was based on a first-order solid-state polymerization mechanism of the diacetylene monomer. GAFchromic film found applications in dosimetry of radioactive particles (e.g., 60-Co, 90-Sr/90-Y) and ophthalmic applicators, as well as in stereotactic radiosurgery fields and intra-vascular brachytherapy sources.
- Other radiochromic films for electron and proton beam dosimetry were also developed by the mid-1980s.
- By the mid-2000s, External Beam Therapy (EBT) film was released with an active layer made of the lithium salt of pentacosa-10,12-diyonic acid crystal. It had a more tissue-equivalent composition and increased sensitivity, covering a dose range of 0.01–8 Gy.

- EBT film utilized diacetylene monomers sensitive to doses as low as 1cGy and underwent 1,4-polymerization upon exposure to heat, UV, or ionizing radiation.

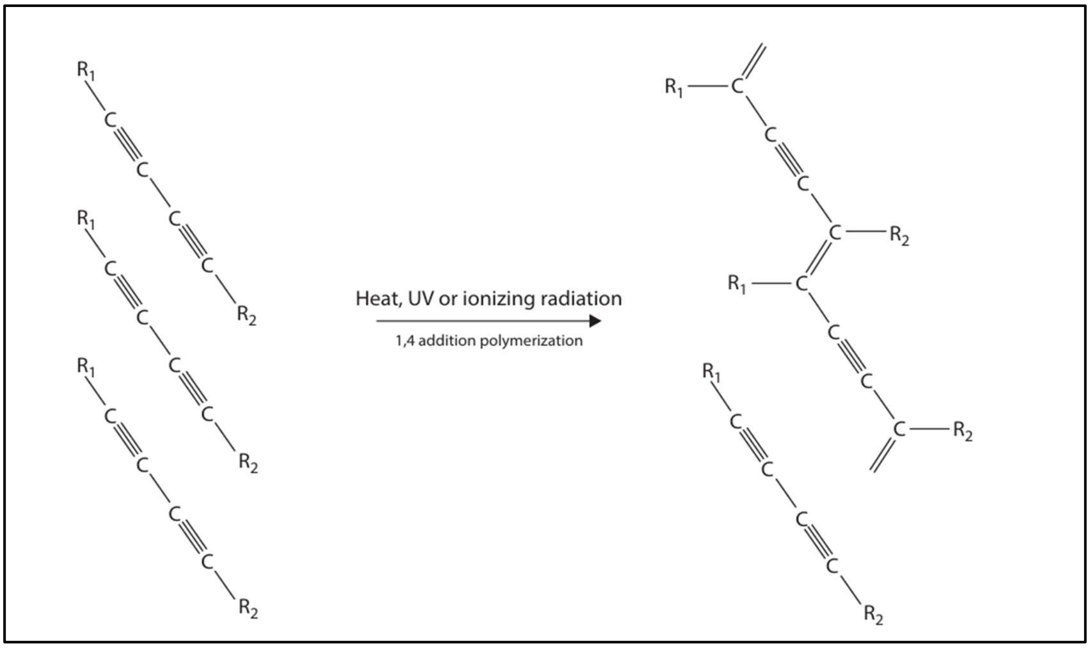


Figure 1: *Diacetylene monomers undergo a 1,4-polymerization upon exposure to heat, UV, or ionizing radiation.*

In 2009, the production of the EBT films was discontinued and replaced by the EBT2 films. The EBT2 film had the same active component as the EBT films but with a yellow dye added to the active layer and it was also constructed as a single layer instead of double. The film has a slightly narrower active layer than EBT and slightly different overall atomic composition (42.37% C, 40.85% H, 16.59% O, 0.01% N, 0.10% Li, 0.04% Cl, 0.01% K, 0.01% Br). The Z_{eff} of EBT2 is 6.84 compared with 6.98 for EBT, and close to Z_{eff} of water (7.3).

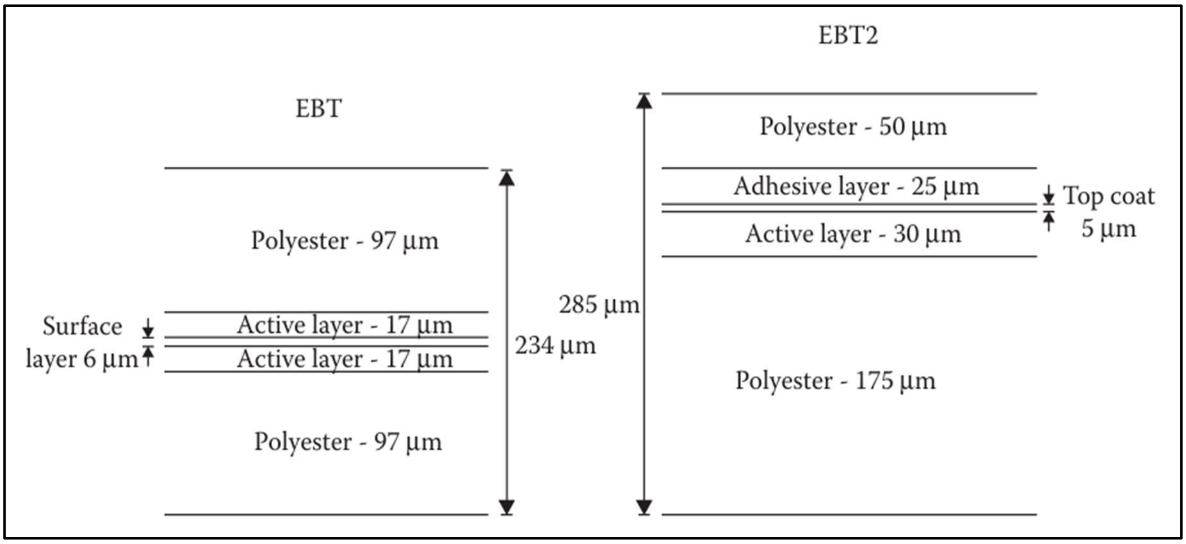


Figure 2: *Illustration of the physical construction of the EBT and EBT2 films. It is worth noting that EBT2 consists of only one active layer, while EBT films have two active layers.*

In 2010, it was discovered that EBT2 film's response varied depending on which side faced the light source during scanning. This led to a modification in the polyester layer configuration, resulting in the new EBT3 film. EBT3 features a 28 µm thick active layer of monomer and yellow dye, enclosed between two 125 µm thick polyester layers. Upon irradiation, charged particles in the active layer trigger di-acetylene monomer polymerization, causing a rapid color change to blue, primarily occurring within milliseconds. Although polymer growth continues within the matrix, its perceptibility decreases over time post-irradiation, prompting many protocols to recommend reading the film after 24 hours. The radiation-induced color change affects the entire visible light spectrum, peaking in red at 63 nm, making EBT3 highly sensitive to red scanning protocols. GAFChromic EBT-3 is specifically designed for measuring absorbed doses of ionizing radiation, optimized for high-energy photon applications with a dynamic range tailored for doses ranging from 0.2 to 10 Gy, making it suitable for various applications in IMRT, VMAT, and brachytherapy. The film is comprised of an active layer, nominally 28 µm thick, sandwiched between two 125 µm matte-polyester substrates. The active layer contains the active component, a marker dye, stabilizers, and other components giving the film its near energy-independent response. The thickness of the active layer will vary slightly between different production lots.

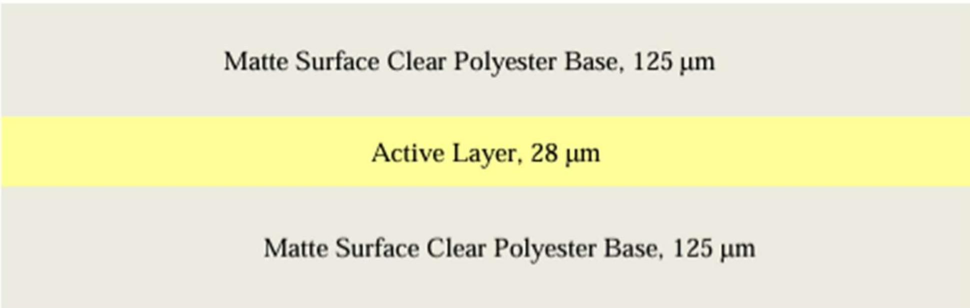


Figure 3: *Structure of GAFChromic EBT3 Dosimetry Film.*

Key technical features of GAFChromic EBT3 include:

- ➔ Dynamic dose range: 0.1 Gy to 20 Gy
- ➔ Optimum dose range: 0.2 Gy to 10 Gy, best suited for applications such as IMRT and VMAT
- ➔ Develops in real time without post-exposure treatment;
- ➔ Energy-dependence: minimal response difference from 100keV into the MV range;
- ➔ Near tissue equivalent;
- ➔ High spatial resolution – can resolve features down to 25µm, or less
- ➔ Proprietary new technology incorporating a marker dye in the active layer:
- ➔ Enables non-uniformity correction by using multi-channel dosimetry
- ➔ Decreases UV/visible light sensitivity;
- ➔ Stable at temperatures up to 60°C

Dose Response

To perform accurate dosimetry with RCF, the dose response must be characterized. As the film underwent irradiation, there was a change in the film's absorbance. The change in the film's absorbance can be quantified through the measurement of the optical density (OD), which is defined as

$$OD = \log_{10} (I_0 /I)$$

I_0 is the initial light intensity, and I is the transmitted light intensity.

For EBT3 film, the OD increases (becomes optically less transparent) with increasing radiation dose as a result of the radiation-induced polymerization of diacetylene monomers. As a result, the dose-response of film can be determined for a particular source of radiation by delivering a range of known (absolute) doses and calculating the associated OD for each dose based on the measurement of initial and transmitted light intensity through the film. From this relationship, relative dose measurements can be performed within the measured dose range.

Applications

Radiochromic films play a crucial role in radiation dosimetry for various medical applications, notably in quality assurance for radiotherapy treatments such as intensity-modulated radiation therapy (IMRT) and stereotactic radiosurgery (SRS). By accurately measuring absorbed dose distributions, these films enable precise verification of treatment plans and delivery techniques, ensuring optimal patient outcomes and safety. Beyond medical settings, radiochromic films are also valuable in industrial dosimetry for radiation processing, including food irradiation and sterilization, where they offer reliable dose measurements. Moreover, they find applications in research, particularly in radiation physics and biology studies, serving as essential tools for characterizing radiation fields and evaluating biological responses to radiation exposure. The broad spectrum of uses underscores the significance of radiochromic films in radiation dosimetry across medical, industrial, and scientific contexts.

- **Quality Assurance of MV linear accelerator**

Quality-assurance programs are essential to the safety and accuracy of radiotherapy delivery. Task Group 142 provides recommendations on machine QA parameters, some of which can be performed using RCF. The QA items such as the coincidence of light field and radiation field, star shots for rotation axes, MLC tests for leaf characteristics, and soft wedge could be easily performed using RCF.

- **Coincidence of light and radiation field**

Ensuring that the light field is in coincidence with the radiation field is especially important for treatment cases in which the light field is used to clinically define or match the radiation field to be delivered. Such cases include electron–photon field matching, light-field entry points relative to tattoos or patient anatomy, and clinical electron setups. Errors in light field radiation field alignment may result from positioning errors in mirror or bulb positioning or beam steering. Field size is defined as the size of collimator opening at source–axis-distance (SAD) 100 cm.

- **Star-shot/ Spokeshot**

Star-shot analysis determines the coincidence of radiation isocenter and mechanical isocenter with respect to the rotation axes of gantry, collimator, and couch. Treatment room laser should be matched to the mechanical isocenter before performing star-shot irradiation. As an example, during gantry star-shot irradiation, the RCF is placed on the treatment couch and parallel to the beam axis in transverse (lateral–vertical) plane and is sandwiched between solid water phantoms. Then, slit beams made by the X-jaw at several gantry angles (e.g., 0°, 45°, 90°, and 135°) irradiate the RCF to create the star-shot pattern. As with the procedure of the coincidence of light field and radiation field, the vertical and lateral marks with respect to the treatment room laser are marked on the RCF by a marker pen. The radiation isocenter would be a center of gravity calculated from the slit fields. The coincidence of radiation isocenter to mechanical isocenter could be calculated by the displacement between the center of gravity from slit beams and the cross point of the four marks.

- **MLC tests**

MLC leaf evaluation using radio chromic film (RCF) is crucial for ensuring the accuracy of leaf-positioning and leaf transmission. These evaluations are essential before implementing MLC programs clinically and as routine quality control checks. The TG-142 report distinguishes between non-IMRT and IMRT procedures for MLC tests.

To verify field shape using MLC blocking, the planned field is compared with the radiation field by placing RCF perpendicular to the beam axis and sandwiched between solid water phantoms. Distance-to-agreement evaluation is useful for quantitative checks of planned versus irradiated dose distribution. For MLC leaf-transmission measurement, films are irradiated for both MLC banks, with a third film serving as a normalization scan to remove beam nonuniformity. Spatial registration is achieved by marking films, and the ratio of closed-field to open-field films represents transmission. MLC transmission films typically require more MUs for sufficient exposure due to leaf transmissions.

Alternatively, ionization chambers can be used, but they measure average leaf transmission due to their relatively large size compared to leaf width. Film dosimetry's high spatial resolution allows for distinguishing interleaf and interleaf transmissions necessary for MLC modeling in some Treatment Planning Systems (TPSs). the spatial resolution for film dosimetry is high, it is possible to distinguish these leaf transmissions that are necessary for MLC modeling in some TPSs.

- **Beam Profile**

Using radiochromic film beam profile data such as flatness, symmetry, field size and penumbra can be measured. Film is irradiated with particular monitor units (such as to get proper blackening of film i.e. 500 MUs) and before irradiation light field dimensions are marked over the film. Film is placed between slab phantom with about 10 cm base and 2 cm buildup with 6 MV beam, and SAD is fixed at 100 cm. After irradiation, film is scanned and analyzed with the software.

4. Observations

Following observations were made,

Epson Expression 12000XL flatbed scanner was used for scanning the films.

- **To evaluate the characteristics of radiochromic film images**

Films were irradiated with different doses ranging from 0.50 Gy to 3 Gy for calibration.

After 24 hours, the irradiated films were scanned using Reflective and transmission scans.

Figure 4: ***(a)*** *Reflective scan of films irradiated with known doses.*
(b) *Transmission scan of films irradiated with known doses. (150 dpi scans)*

Calibration was done by using the films irradiated with known doses. And mean errors observed in calibration are 5.2 cGy and 4.4 cGy with Reflective and transmission scans, respectively.

Figure 5: *Calibration result of* ***(a)*** *reflective scans with 150 dpi and*
(b) *transmission scan with 150 dpi.*

Now, the films irradiated with unknown doses were scanned.

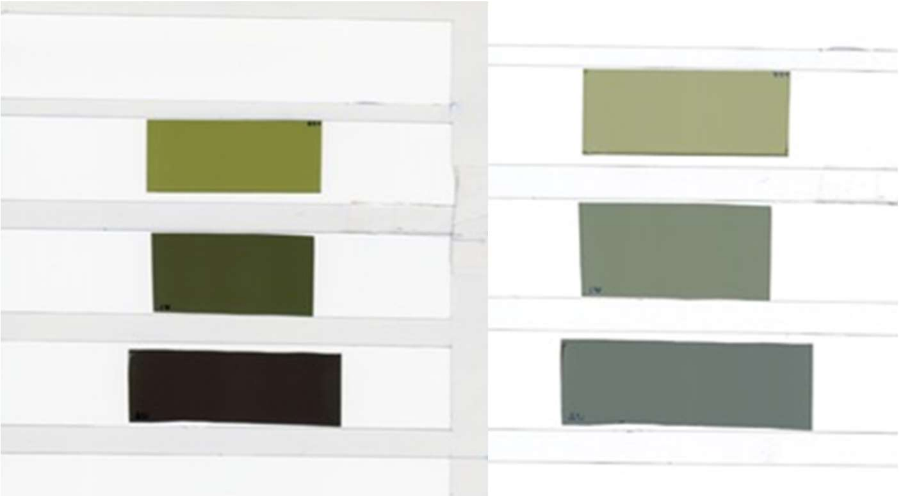


Figure 6: (a) Reflective scan of films irradiated with unknown doses. **(b)** Transmission scan of films irradiated with unknown doses. (150 dpi scans, the first film is unirradiated and used for reference as 0 Gy)

Dosimetry was done with the obtained calibration with reflective and transmission scans.

<u>Dosimetry with reflective scan:</u>

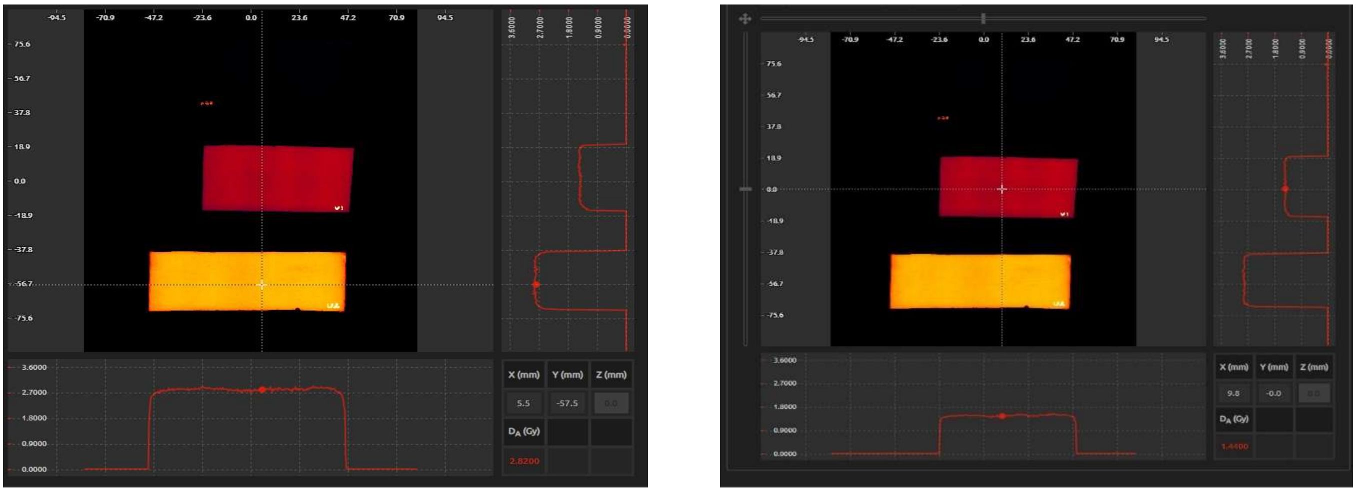


Figure 7: *Dosimetry with reflective scans of films irradiated with unknown doses. The values of unknown doses obtained with dosimetry using the calibration are are **(a)** 0 Gy, **(b)** 1.44 Gy & **(c)** 2.82 Gy*

Dosimetry with transmission scan:

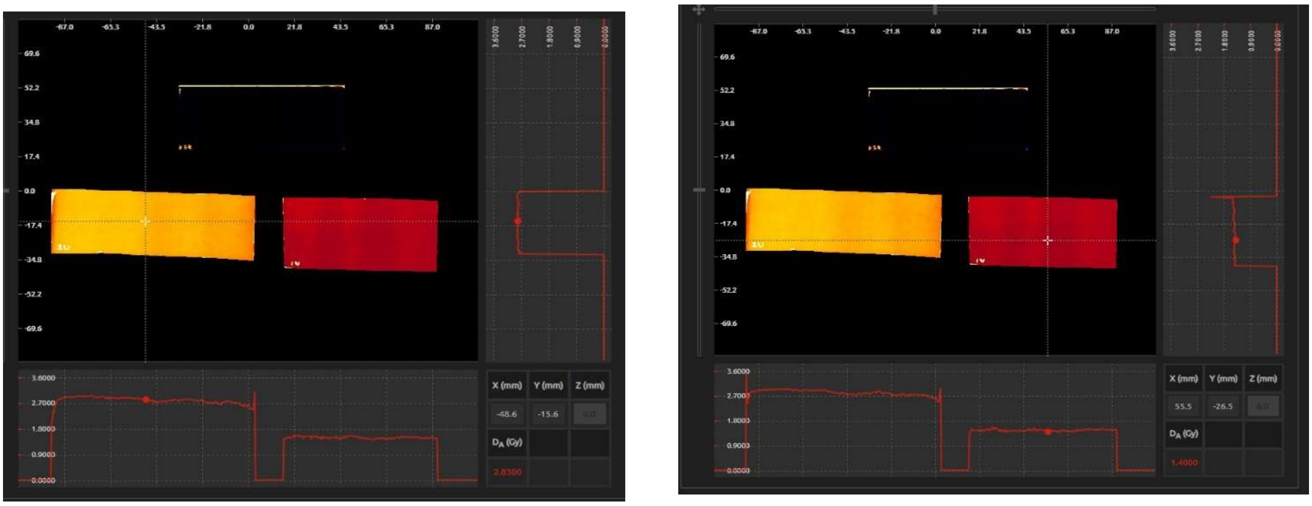


Figure 8: Dosimetry with transmission scans of films irradiated with unknown doses. The values of unknown doses obtained with dosimetry using the calibration are **(a)** 0 Gy, **(b)** 1.40 Gy & **(c)** 2.83 Gy.

- **To perform Quality Assurance tests of a Teletherapy unit**

Following Quality assurance tests were performed with the high-energy linear accelerator,

- **Light field and radiation field coincidence**

Two films were irradiated with field sizes of 5 x 5 cm^2 and 10 x 10 cm^2. Markings on the film were done for the light field, and the irradiated films were scanned using reflective scans at 200 and 150 dpi

For 10 x 10 cm^2 field size:

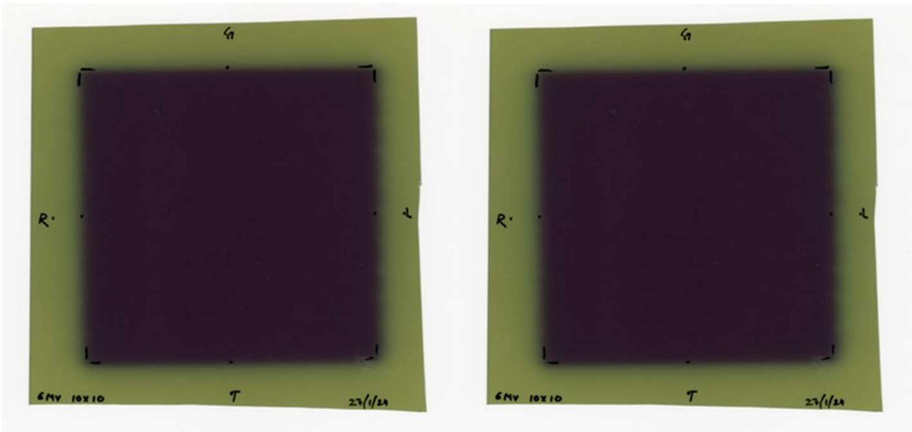
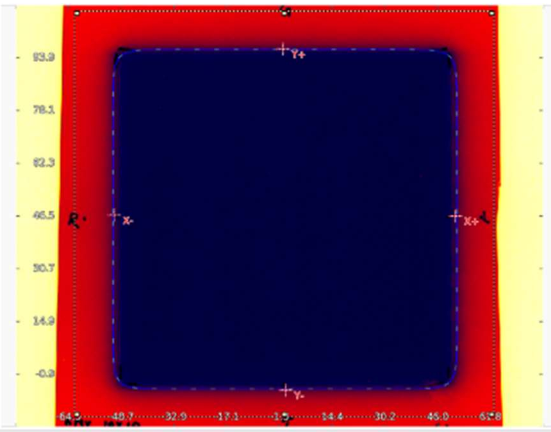


Figure 9: *FIlms irradiated using 6MV photon beam and 10 x 10 cm^2 field size and scanned using reflective scan at (a) 200 Dpi and (b) 150 Dpi.*

After analyzing the scanned images following outputs were observed:



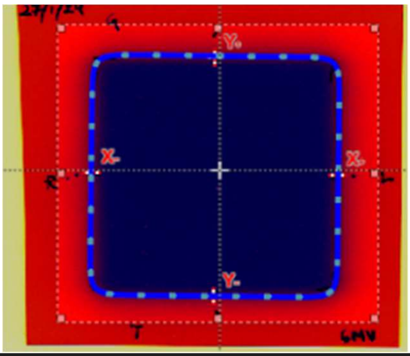
Output

Light-radiation angle	
Angle (°)	0.4

Light-radiation displacement		Light-radiation displacement		Light-radiation displacement		Light-radiation displacement	
X_- (mm)	0.4	Y_- (mm)	-0.3	X_+ (mm)	0.5	Y_+ (mm)	-0.2
Crosshair-light distance		**Crosshair-light distance**		**Crosshair-light distance**		**Crosshair-light distance**	
X_- (mm)	50.9	Y_- (mm)	52.3	X_+ (mm)	51.2	Y_+ (mm)	49.9

CAX		CAX		CAX	
Coordinate X (mm)	0.3	Coordinate Y (mm)	45.5	Distance to crosshair (mm)	1.1

Figure 10: *Output of Light and Radiation field coincidence check for 6 MV photon beam, 10 x 10 cm^2 field size scanned at 150 Dpi and reflective scan.*



Light and radiation field coincidence: Output

Light-radiation angle	
Angle (°)	0.4

Light-radiation displacement		Light-radiation displacement		Light-radiation displacement		Light-radiation displacement	
X_- (mm)	0.2	Y_- (mm)	-0.0	X_+ (mm)	0.2	Y_+ (mm)	0.4
Crosshair-light distance		Crosshair-light distance		Crosshair-light distance		Crosshair-light distance	
X_- (mm)	25.9	Y_- (mm)	26.1	X_+ (mm)	26.2	Y_+ (mm)	24.7
CAX		CAX		CAX			
Coordinate X (mm)	-3.7	Coordinate Y (mm)	-76.8	Distance to crosshair (mm)	0.4		

Figure 11: *Output of Light and Radiation field coincidence check for 6 MV photon beam, 5 x 5 cm^2 field size scanned at 150 Dpi and reflective scan.*

For 5 x 5 cm^2 field size:

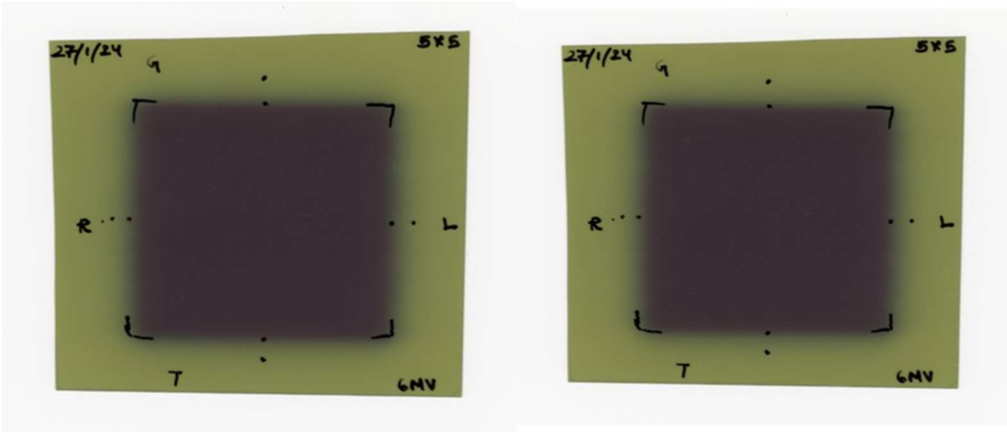
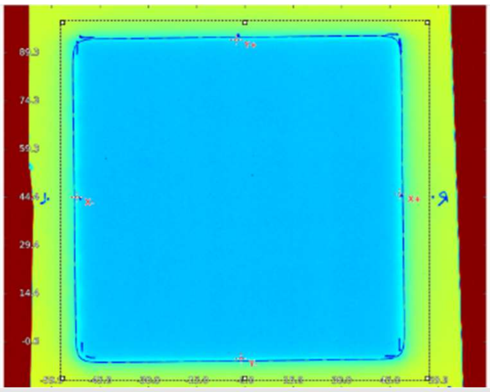


Figure 12: *FIlms irradiated using 6MV photon beam and 5 x 5 cm^2 field size and scanned using reflective scan at (a) 200 Dpi and (b) 150 Dpi.*

After analyzing the scanned images following outputs were observed:



Output

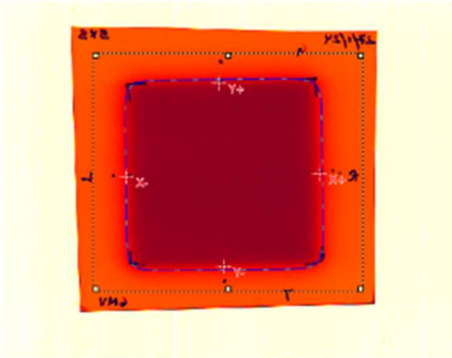
Light-radiation angle	
Angle (°)	0.2

Light-radiation displacement		Light-radiation displacement		Light-radiation displacement		Light-radiation displacement	
X_- (mm)	0.8	Y_- (mm)	0.7	X_+ (mm)	0.9	Y_+ (mm)	0.8

Crosshair-light distance		Crosshair-light distance		Crosshair-light distance		Crosshair-light distance	
X_- (mm)	50.2	Y_- (mm)	50.8	X_+ (mm)	50.0	Y_+ (mm)	48.4

CAX		CAX		CAX	
Coordinate X (mm)	-2.0	Coordinate Y (mm)	43.8	Distance to crosshair (mm)	1.1

Figure 13: *Output of Light and Radiation field coincidence check for 6 MV photon beam, 5 x 5 cm^2 field size scanned at 150 Dpi and transmitted can.*



Output

Light-radiation angle	
Angle (°)	1.0

Light-radiation displacement		Light-radiation displacement		Light-radiation displacement		Light-radiation displacement	
X- (mm)	0.0	Y- (mm)	1.0	X+ (mm)	0.8	Y+ (mm)	0.9

Cro:	CAX		CAX		CAX		tance
X- (n	Coordinate X (mm)	7.1	Coordinate Y (mm)	7.0	Distance to crosshair (mm)	0.8	24.8

Figure 14: *Output of Light and Radiation field coincidence check for 6 MV photon beam, 5 x 5 cm^2 field size scanned at 150 Dpi and transmitted can.*

- **Mechanical and radiation isocenter coincidence check (MLC)**

A film was irradiated by 6 MV photon beam with 0.6 x 40 cm^2 field size and at 0°, 45°, 90° & 135° collimator angles. After irradiation film was scanned via reflective scan mode at 100 and 200 dpi.

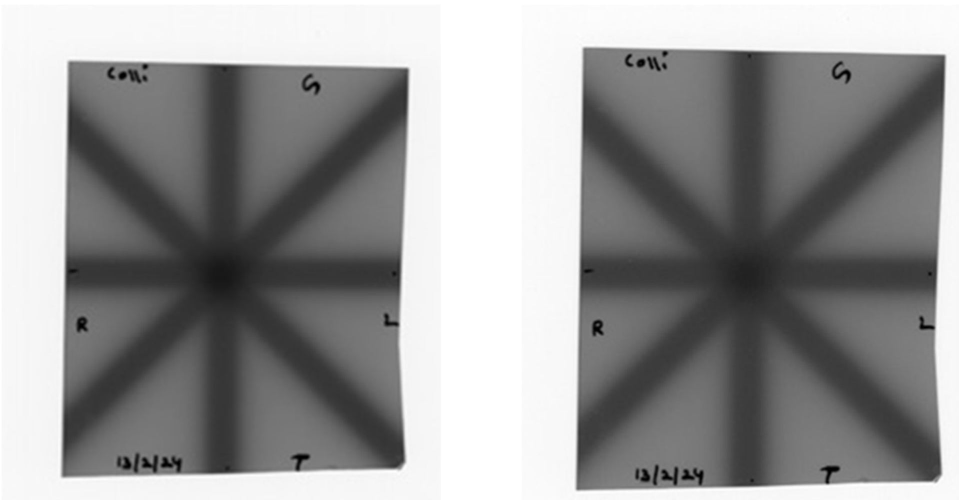
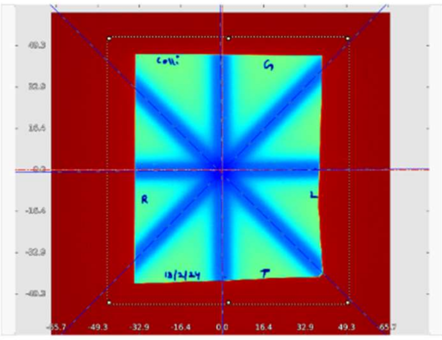


Figure 15: *Scanned images of spokeshot test* ***(a)*** *200 Dpi &* ***(b)*** *100 Dpi.*

After scanning, films were analyzed, and the following output was observed:

After scanning, films were analyzed, and the following output was observed:

Starshot



Study	pushpa&raka
Item	starshot_ref
Date	02 Apr 2024, 06:05 UTC
Detected beams	4
Fiducial X	0.0 mm
Fiducial Y	0.0 mm
Isocenter X	-0.6 mm
Isocenter Y	-0.6 mm
Isocenter Radius	0.34 mm
Distance (Fiducial - Isoc.)	0.8 mm

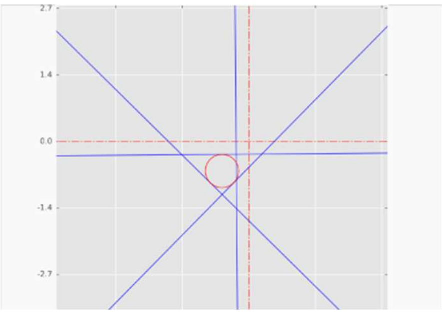
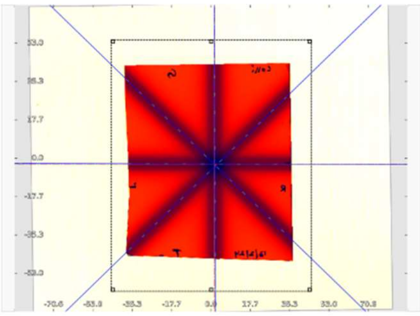


Figure 16: *Output of spoke-shot/star-shot test with 150 Dpi, reflective scan image analysis.*

Starshot



Study	pushpa&raka
Item	scan_starshot_trans
Date	02 Apr 2024, 07:11 UTC
Detected beams	4
Fiducial X	1.5 mm
Fiducial Y	-2.6 mm
Isocenter X	2.1 mm
Isocenter Y	-3.0 mm
Isocenter Radius	0.35 mm
Distance (Fiducial - Isoc.)	0.7 mm

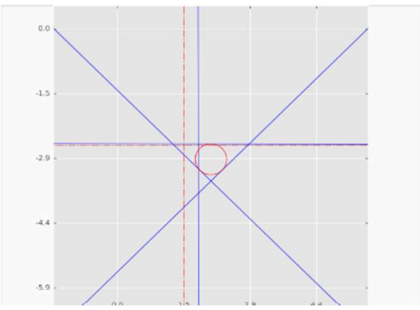
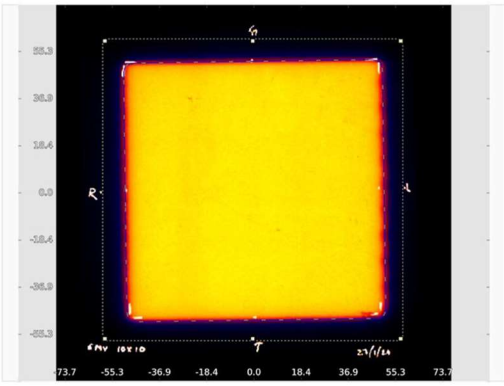


Figure 17: *Output of spoke-shot/star-shot test with 150 Dpi, transmitted scan image analysis.*

- **Beam Profile**

Reflective scan of film irradiated with 6 MV photon beam with 10 x 10 cm^2 field size open was analyzed using beam profile mode and the following output was observed.

Radiation field



Output

Radiation field center		Radiation field center					
Coordinate X (mm)	0.3	Coordinate Y (mm)	0.9				

Radiation field size		Radiation field size		Radiation field rotation	
X (mm)	101.1	Y (mm)	101.2	Angle (°)	0.8

Central dose statistics		Central dose statistics		Central dose statistics		Central dose statistics	
Measuring points	28	Mean (Gy)	3.13	Median (Gy)	3.13	Standard deviation (Gy)	0.02

Penumbra		Penumbra		Penumbra		Penumbra	
X_- (mm)	4.8	Y_- (mm)	3.5	X_+ (mm)	4.8	Y_+ (mm)	3.5

Flatness (%)	Symmetry (%)	Maximum dose (%)
103.5	101.9	100.6

Figure 18: *Output of beam profile analysis which contains results for beam flatness, symmetry, field size, penumbra.*

5. Results

Following results were obtained

- **To evaluate the characteristics of radiochromic film images**

- With a reflective scan the values of unknown doses observed are, 1.41 ± 0.052 Gy and 2.84 ± 0.052 Gy.
- With the transmission scan the values of unknown doses observed are, 1.46 ± 0.044 Gy and 2.86 ± 0.044 Gy.

- **To perform Quality Assurance tests of a Teletherapy unit**

- <u>Light field and radiation field coincidence</u>

Field size (cm^2)	Scanning Mode (Dpi)	Light-Radiation Displacement				Tolerence
		X_- (mm)	Y_- (mm)	X_+ (mm)	Y_+ (mm)	
10 x 10	150	0.4	-0.3	0.5	-0.2	2 mm or 1% on a side
5 x 5	150	0.2	0	0.2	0.4	

Table 1: *Tabulated result for light and radiation field coincidence for 10 x 10 cm² & 5 x 5 cm² field size and 150 Dpi reflected scanning mode.*

From the table it can be seen that deviation of radiation field from light at all the edges is within the tolerance.

Field size (cm^2)	Scanning Mode (Dpi)	Light-Radiation Displacement				Tolerence
		X_- (mm)	Y_- (mm)	X_+ (mm)	Y_+ (mm)	
10 x 10	150	0.8	0.7	0.9	0.8	2 mm or 1% on a side
5 x 5	150	0	1	0.8	0.9	

Table 2: *Tabulated result for light and radiation field coincidence for 10 x 10 cm^2 & 5 x 5 cm^2 field size and 150 Dpi transmitted scanning mode.*

As from the table it can be seen that deviation of radiation field from light at all the edges is within the tolerance.

- Mechanical and Radiation isocenter coincidence check (Using MLC rotation)

Scanning mode (Ref and Trans)	Isocenter Radius (mm)	Distance (Fiducial - Isocenter) (mm)
150 Dpi (Trans)	0.35	0.7
150 Dpi (Ref)	0.36	0.3
Tolerance	±1 mm from baseline	±2 mm from baseline

Table 3: *Tabulated result for mechanical and radiation isocenter coincidence check at different scanning modes.*

From the table it can be seen that obtained isocenter radius and distance of optical & radiation isocenter is within the tolerance.

- Beam Profile

➔ Radation field size : 101.1 mm in X direction and 101.2 mm in Y direction
➔ Flatness : 103.5 % (Tolerance : 106% for field size ⩽ 30 x 30 cm^2 and 110% for field size > 30 x 30 cm^2)
➔ Symmetry : 101.9 % (Tolerance : 103 %)
➔ Penumbra : $X_- = 4.8$ mm, $X_+ = 4.8$ mm, $Y_- = 3.5$ mm & $Y_+ = 3.5$ mm (Tolerance: 10 mm)

6. Conclusion

In conclusion, the experiments conducted to evaluate the characteristics of radiochromic film images and to perform Quality Assurance tests of the Teletherapy unit have provided valuable insights into the performance and reliability of the equipment. The analysis of the radiochromic film images has allowed for a comprehensive understanding of the dose distribution and beam characteristics, while the Quality Assurance tests have ensured the accuracy and consistency of the Teletherapy unit's output. These findings underscore the importance of regular quality assurance procedures in maintaining the efficacy and safety of radiation therapy treatments.

7. Precautions

- Handle the radiochromic films with care to prevent any physical damage or scratches, as these can affect the accuracy of the results.
- Radiochromic films are sensitive to light, so they should be handled and stored in a darkroom or light-tight container to prevent unintended exposure.

- Maintain appropriate temperature and humidity conditions according to the manufacturer's recommendations to avoid any adverse effects on the film's properties.

8. References

- Radiochromic
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