AAPM 41st Annual Meeting Continuing Education Courses

Special Dosimetry Measurements-3

Two Dimensional Radiation Field Mapping Using Radiochromic Film

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7:30 AM - 8:30 AM

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Task Group 55 Recommendations

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Introduction

Two Dimensional Radiation Dosimeters

A. Silver halide radiographic films

- **Advantages:**
  - **High spatial resolution**
  - **Relative dose measurement**
- **Disadvantages:**
  - **Energy dependence**
  - **Room light sensitivity**
  - **Wet chemical processing**
  - **Not tissue equivalent**
  - **Not an absolute dosimeter**

Introduction (Cont.)

Two Dimensional Radiation Dosimeters

B. Radiochromic films

- **Advantages:**
  - **High spatial resolution**
  - **Energy dependence (??)**
  - **Tissue equivalent**
  - **Not sensitive to room light**
  - **No chemical processing**
- **Disadvantages:**
  - **Uniformity**
  - **Environmental factors**
  - **Not an absolute dosimeter**

Introduction (Cont.)

- **William McLaughlin, NIST**
  - **Since 1965: Organic free-radical imaging medium can combine photopolymerization with leuco dyes that produce color upon irradiation.**
- **Dave Lewis, International Specialty Products (ISP)**
  - **Since 1980s: Radiochromic films based on polydiacetylene has been introduced for medical applications**

Radiochromic Films

Radiochromic film consists of a single or double layer of thin nylon-base with a transparent coating of radiation-sensitive organic microcrystals monomers.

Radiochromic Films (Cont.)

- **HD-810 (Formerly: DM-1260)**
  - **20 cm x 25 cm x 0. 1 mm**
  - **ISP & Nucl. Assoc. (Model No. 37-040)**
  - **Dose Range: 50-2500 Gy**
- **MD-55-1**
  - **12.5 cm x 12.5 cm x 0.08 mm**
  - **ISP & Nucl. Assoc. (Model No. 37-041)**
  - **Dose Range: 10-100 Gy**
- **MD-55-2 (NMD-55)**
  - **12.5 cm x 12.5 cm x 0.25 mm**
  - **ISP & Nucl Assoc. (Model No. 37-041)**
  - **Dose Range: 3-100 Gy**

Radiochromic Films (Cont.)

Color of the radiochromic films turns to shade of blue upon irradiation.

Darkness of the film increases by increasing the absorbed dose.

Factors to be considered in Selecting 2D Radiation Dosimeters

Sensitivity
Uniformity
Dynamic Range
Spatial Resolution
Energy / LET Dependence
Tissue Equivalence
Dose Rate Dependence
Light Sensitivity
Signal Stability
Environmental Stability: Temp, Humidity, ...

RCF: Characteristics

- **Effective Z: 6.0 - 6.5**
- **Sensor material has similar electron stopping power as water & muscle**
- **Sensor material has similar mass-energy absorption coefficients as water and muscle for $h\nu$ > 100 keV**
- **For secondary electron 0.1 to 1.0 MeV and $h\nu$ 0.1 to 1.33 MeV : ~2% of water and muscle**

RCF: Absorption Spectra

- **Fig A shows the OA spectrum of MD-55-2 from 600 nm to 700 nm before and after 6Gy dose.**
  - **There is a small shift with dose:**
    - **675 (0 Gy) → 676 (6 Gy)**
  - **Some apparent absorption is due to reflection loss, not absorption**
- **Fig B shows the spectrum of an unirradiated MD-55-2**
  - **The interference fringes depend on the bandpass used: 0.25 nm vs 3.5 nm (diff ~ 0.2%)**

RCF: Color Stability

- At certain wavelengths of the main absorption band (~ 670 nm), absorption is stable the 1st four hrs.
- During the 1st 24 hrs after irradiation, absorption increases by up to 16%.
  - 4% thereafter for up to 2 wks
- Greatest increase in absorption occurs at higher temp: ~ 40ºC

RCF: Effect of Polarized Light

- Klassen et al studied polarity effect for MD-55-2:
  - Microcrystals in sensitive layers have a preferred orientation (i.e. flat)
  - Monomers in microcrystals have a preferred orientation in the same plane of the film
  - ∴ OD would vary with the plane of polarization of the analyzing light and would change with film orientation

RCF: Dose Response

- HD-810 is insensitive to light at $\lambda > 300$ nm
  - But sensitive to UV at lower λ
- DM-1260 needed ≥ 50 Gy for ± 2% precision
- MD-55-2 needs ≥ 3 GY for ± 2% precision
- Films should be stored in the dark, at temp < 25ºC and relative humidity < 50% to optimize the useful life of the film
- Dependence of the absorption spectrum with dose has been documented
- Fractionated and unfractionated resp. ~ 1%

RFC: Energy Response

- Muench et al have studied the energy response of HD-810 as compared with LiF for $h\nu$ (20 to 1710 keV)
  - Response ↓ by ~ 30% as $h\nu$↓
  - Similar but in opposite direction as of TLD
  - Silver halide film response ↑ by ~ 980%
- Chiu-Tsao et al studied the energy response of MD-55-1 using brachytherapy sources
  - Sensitivity is ~ 40% lower for I-125 than Co-60

RCF: Energy Response (Cont.)

- McLaughlin et al studied MD-55-2
  - Response is ~ 40% lowe for $h\nu$ 20 to 40 keV than with Cs-137 and Co-60
- Sayeg et al suggest that the lower response of RCF for $h\nu$ < 100 keV is due to the larger carbon content relative to soft tissue

RCF: Dose Rate Response

- Saylor et al show that for MD-55-1:
  - There is no dose rate response within an uncertainty of ~ 5% (± one SD)
- MCLaughlin et al studied MD-55-2 for:
  - Dose = 20, 40, 60 Gy
  - Dose rate = 0.08 to 80 Gy/min
  - No dose rate response within an uncertainty of ~ 5% (± one SD)
  - But at 60 Gy there is ~ 10% higher response at lower dose rate

RCF: Environmental Factors

- **Humidity (HD-810) effect for 6 to 94% < ± 2%**
- **Temperature effect (MD-55-1 & MD-55-2) for 10 to 50°C:**
  - **Response varies with dose as well as λ of analysis**
  - **At ~ 50°C there is an erratic variation in response**
  - **At > 60°C the blue dye changes to red and may cause significant change in sensitivity**
- **UV exposure with λ > 300 nm(sunlight or continuous white fluorescent lights) colors the film**
  - **Needs to be stored in opaque container**
- **Shipping and handling may cause damaged locations**
  - **Color of the film turns from clear to milky white**
  - **Need to be ~ 1.5 mm away from cut edge**

RCF: Uniformity

- **Non-uniformity due to *local* fluctuations (spikes):**
  - **Small scale: film grain size, spatial and signal resolution of scanner, pixel size, electronic noise, …**
  - **Relative response is compared with the mean response in the ROI**
- **Non-uniformity due to *regional* variations:**
  - **Large scale: non-uniformity in film emulsion layer(s), systematic scanner problem(s)**
  - **Difference (or ratios) of max-min response in ROI**

RCF: Uniformity (Cont.)

- **Acceptable tolerances for film uniformity varies with application**
- **Meigooni et al studied *regional* variation for MD-55-1 & MD-55-2 along two central orthogonal directions:**
  - **Longitudinal (|| to coating application): ~ 4%**
  - **Transverse (⊥ to coating application): ~ 15%**
- **5 institution studies of *local* fluctuations:**
  - **Dose > 20 Gy: ~ ± 3%**
  - **Dose < 10 Gy: ~ ± 5%**

RCF: Double-Exposure Technique

Zhu et al suggest using a matrix of correction factors from relative film response

$$OD_{net}(i,j) = [OD_2(i,j) - OD_1(i,j)] / f(i,j)$$

$$f(i,j) = OD_1(i,j) / \langle OD_1(i,j) \rangle$$

RCF: Calibration & Sensitivity

- **Calibration:**
  - **Large well-characterized uniform radiation field**
    - **suggest: 40 x 40 cm, d ≥ 5 cm**
- **Calibration curve:**
  - **Relation between dose and response**
- **Sensitivity:**
  - **Average change in response per unit dose**
    - **calculate over most linear portion of the calibration curve**
  - **Depends on: λ used for readout, scanner, film batch, beam quality, readout time, T, H, ...**

RCF: Medical Applications

- **Ophthalmic Applicator Dosimetry**
  - **Sayeg et al used Sr-90 eye applicator**
    - **He-Ne scanning laser densitometer**
  - **NIST extrapolation ionization chamber (Agreement ~ 6%)**
  - **Soares mapped surface dose**
    - **LKB scanning laser densitometer**
  - **Physikalisch-Technische Bundesanstalt (PTB) (Good Agreement)**
  - **Soares found response to e same as to Co-60 (±5% at 95% confidence level)**

RCF: Medical Applications (Cont.)

- **Muench et al studied brachytherapy sources**
  - **Ir-192 (370 Gbq)**
  - **Compared with TLDs**
  - **Kodak X-Omat films**
- **Farahani et al studied tissue-metal interfaces**
- **Bjarngard et al and McLaughlin et al studied small fields for stereotactic**

  (Agreement with calculation ~ ± 2%)
- **Galvin et al studied penumbra region**

  (Good agreement with silver halide film)

RCF: Medical Applications (Cont.)

- **Soares et al studied hot particles in nuclear reactor**
- **Van Hoek et al studied inactivation of proteins using hundreds of kGy doses**

  (Agreement with Fricke dosimeter ~ 1%)
- **Duggan et al studied P-32 coated stents for intravascular application**
- **Vatnitsky et al studied proton beams**
  - **Linear response (10 - 100 Gy) for hν, e, p (except at Bragg peak region: 5-10% ↓ in response)**

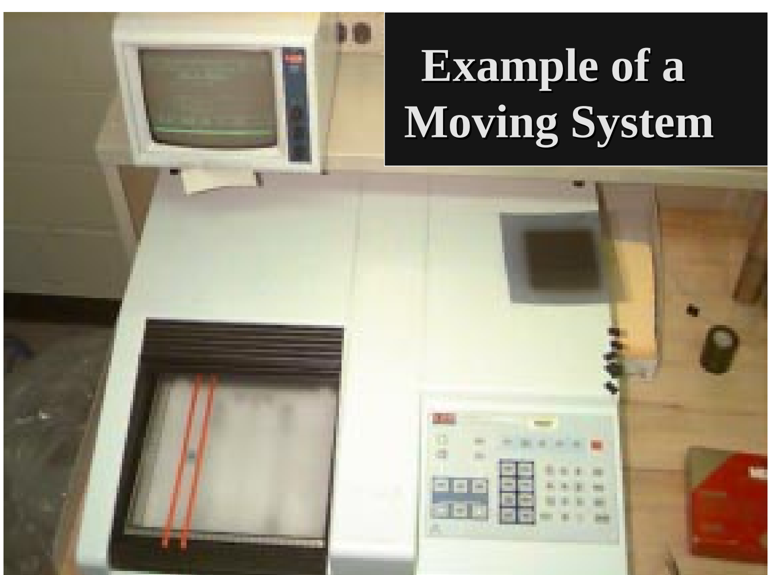
Densitometer Parameters

- light source
- light detection
- response linearity
- response accuracy
- response reproducibility
- response stability
- spatial resolution
- positional accuracy
- bed geometry
- acquisition time
- control software
- environmental factors

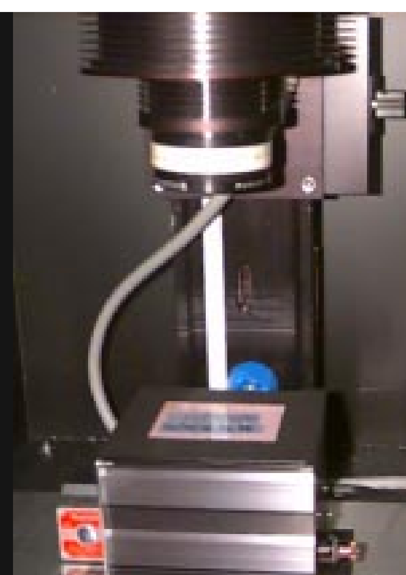
Types of Densitometers

- Moving:
- *single light source*
- *single detector*
- *sample and/or light source-detector moved*
- Imaging:
- *uniform backlit bed*
- *imaging device*
- *no movement*
- Hybrids:
- *combination of the above*

Example of a Moving System



Example of an Imaging System



Light Sources

- wavelength
- FWHM
- intensity
- size
- uniformity
- match to light detector
- match to film being read

- *Examples:*
- HeNe laser, 633 nm, nearly 0 FWHM
- 1 mW, 50μm diameter spot
- Filtered white light
- LED light bed

Light Detectors

sensitivity

spectral efficiency

linearity

signal resolution

Types:

PMT

CCD

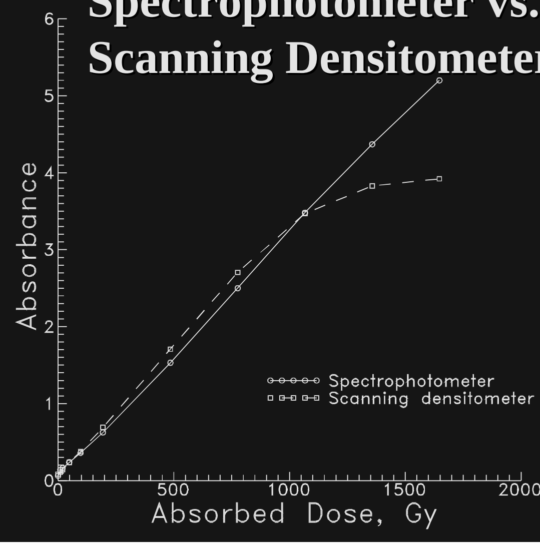
Response Linearity

calibration curve using film

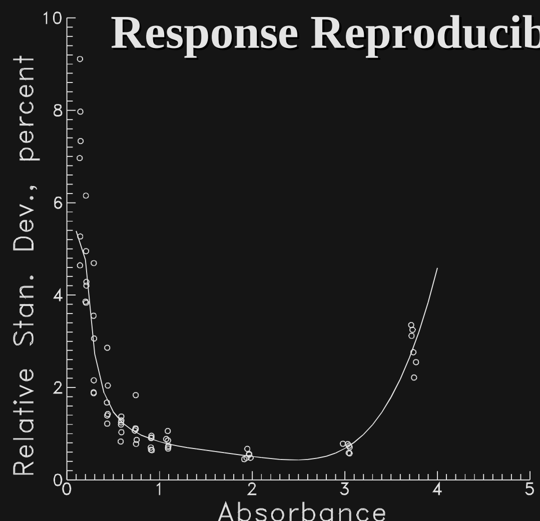
calibrated neutral density filters

comparison with spectrophotometer

Spectrophotometer vs. Scanning Densitometer



Response Reproducibility



Spatial Resolution

<u>Moving Systems:</u>

light source size

space between readings

<u>Imaging Systems:</u>

pixel size

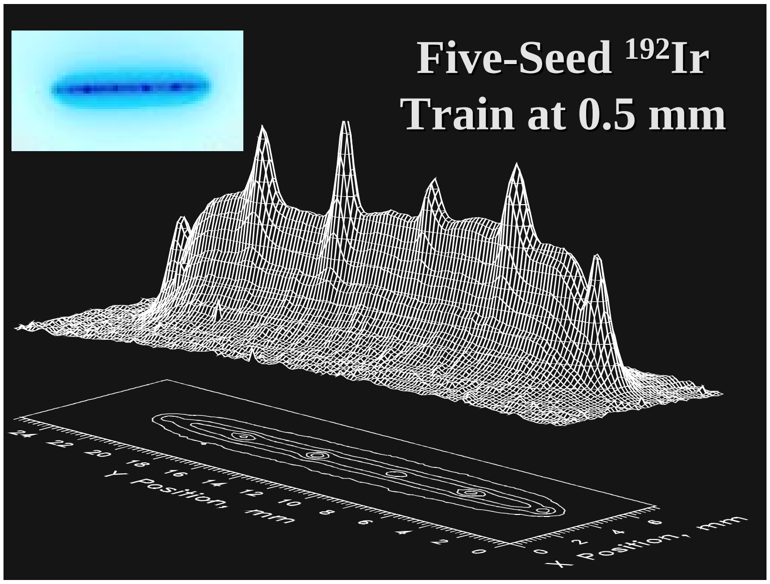
dead area

<u>Both:</u>

light diffusion in sample

stray light

Five-Seed ^{192}Ir Train at 0.5 mm

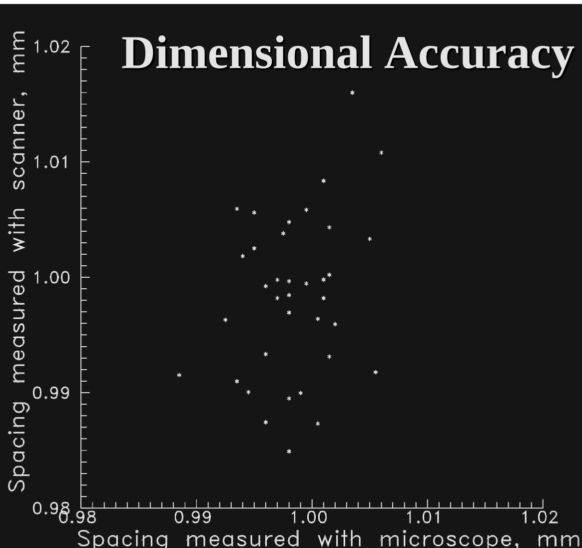


Positional Accuracy

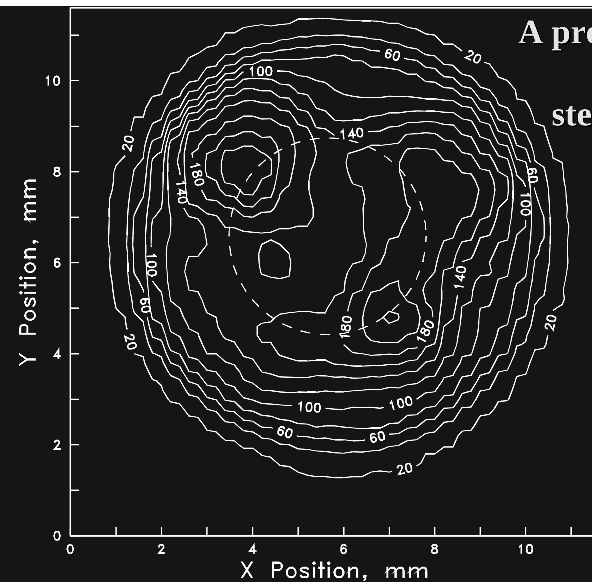
<u>Moving Systems:</u>
stepping accuracy
bi-directional motion

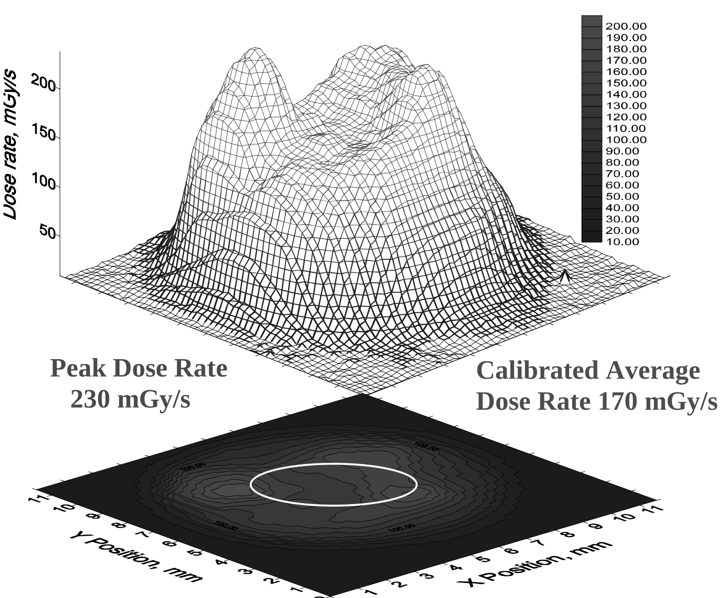
<u>Imaging Systems:</u>
regularity of imaging grid

Dimensional Accuracy



A problem with stepping





Reader Bed Parameters

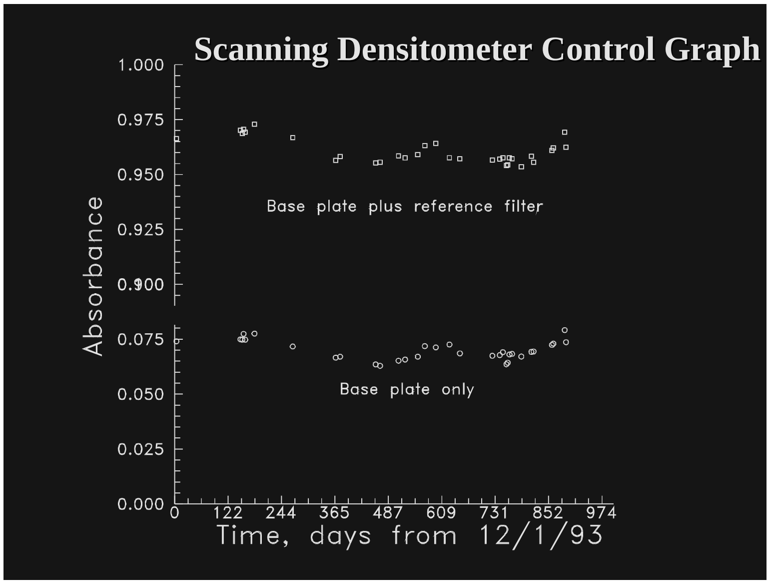
<u>Moving Systems:</u>
maximum pixel size

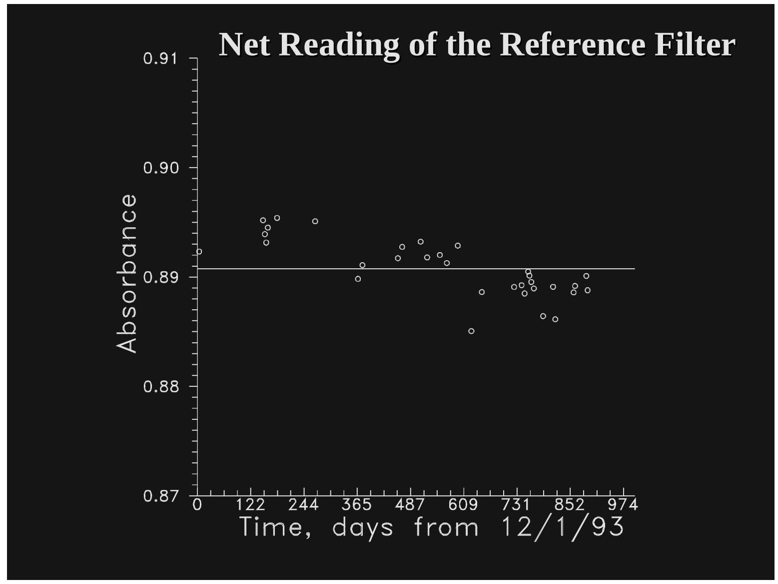
<u>Imaging Systems:</u>
light source uniformity

transmission uniformity

<u>Both:</u>
film positioning

size





Data Acquisition Time

Moving Systems:

time to step between positions

Both:

time to make measurement

data transfer time to host computer

Software

flexibility

access to data

color images

iso-density contour plots

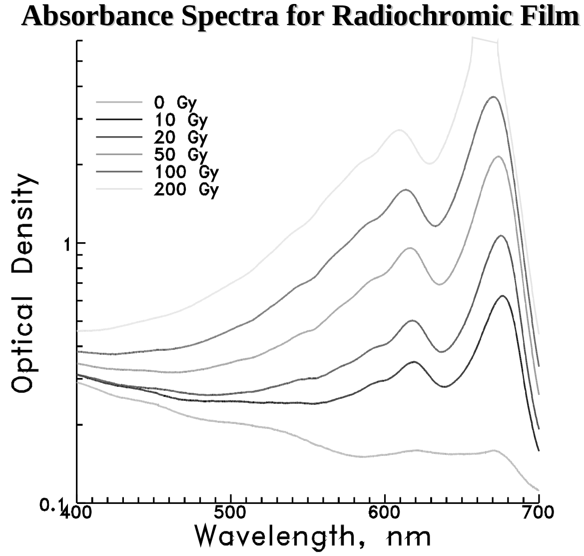
conversion to dose via stored calibration

Environmental Factors

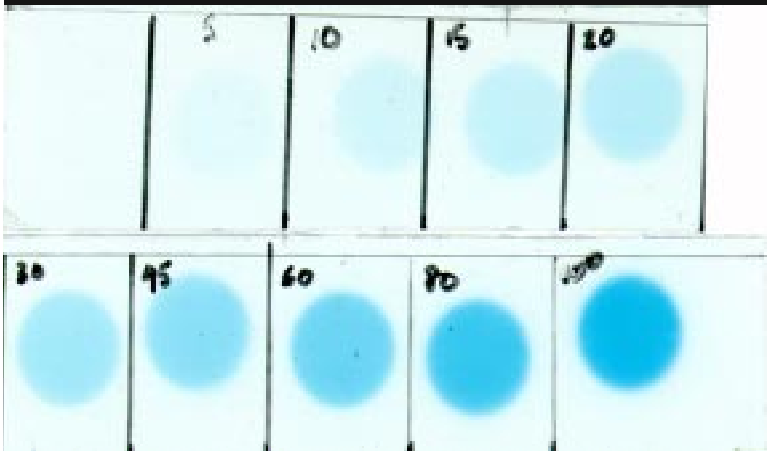
temperature during readout

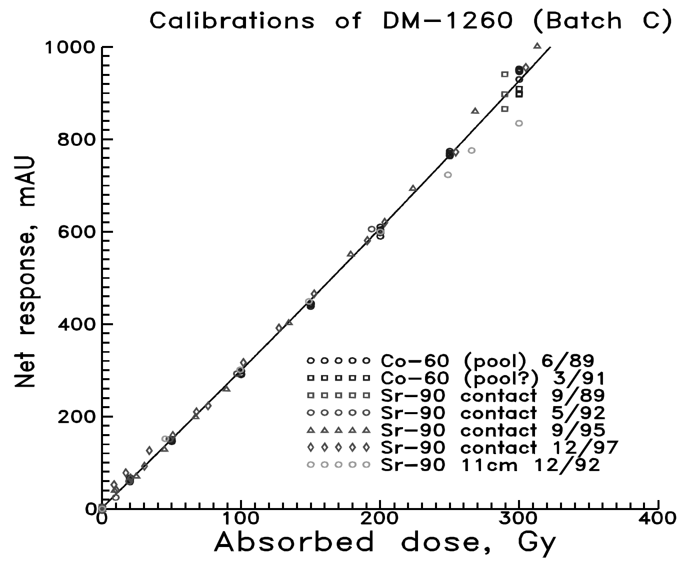
setup/interior lighting

Absorbance Spectra for Radiochromic Film



Radiochromic Film Calibration Exposures





Summary of Recommended Procedures: Film Handling

- visually inspect films prior to use
- handle films with care, avoiding dust, fingerprints or over bending
- store film in dry, dark environment
- avoid prolonged exposure to UV light

Summary of Recommended Procedures: Film Use

- note model and lot numbers
- note film orientation and allignment
- note emulsion side (check by wetting corner)
- control time between irradiation & readout (at least 24 h)
- check film uniformity

Summary of Recommended Procedures: Readers

- select densitometer with sufficient signal resolution
- determine maximum measurable OD
- measure OD at red wavelengths for maximum sensitivity

Summary of Recommended Procedures: Calibration

- use a large well-characterized field, ideally of the same quality as unknown field
- obtain response vs. dose over range of interest (extrapolation is dangerous)

Future Directions

- greater sensitivity
- greater uniformity
- better reading software
- better photon energy dependence
- 3D imaging with gels