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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
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.)

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

Darkness of the film increases by
increasing the absorbed dose.

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

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 6 Gy
  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: ~ 40°C

**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 $\lambda$
- DM-1260 needed $\geq 50$ Gy for ± 2% precision
- MD-55-2 needs $\geq 3$ Gy for ± 2% precision
- Films should be stored in the dark, at temp < 25°C 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% lower 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

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

\[
f(i,j) = \frac{OD_1(i,j)}{<OD_1(i,j)>}
\]

**RCF: Calibration & Sensitivity**

- **Calibration:**
  - Large well-characterized uniform radiation field
    *suggest: 40 x 40 cm, d ≥ 5 cm
  - 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 be 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
- Bjarnagard 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 backlight 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

Absorbance vs. Absorbed Dose, Gy

Response Reproducibility

Spatial Resolution

Moving Systems:
- light source size
- space between readings

Imaging Systems:
- pixel size
- dead area

Both:
- light diffusion in sample
- stray light
Two Dimensional Radiation Field Mapping Using Radiochromic Film

Wednesday, July 28, 1999

Azam Niroomand-Rad and Christopher Soares

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

Positional Accuracy

Moving Systems:
- stepping accuracy
- bi-directional motion

Imaging Systems:
- regularity of imaging grid

Dimensional Accuracy

A problem with stepping

Reader Bed Parameters

Moving Systems:
- maximum pixel size

Imaging Systems:
- light source uniformity
- transmission uniformity

Both:
- film positioning
- size

Peak Dose Rate
230 mGy/s

Calibrated Average
Dose Rate 170 mGy/s

AAPM Annual Meeting, Nashville, TN

Azam Niroomand-Rad and Christopher Soares
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
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 alignment
- 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