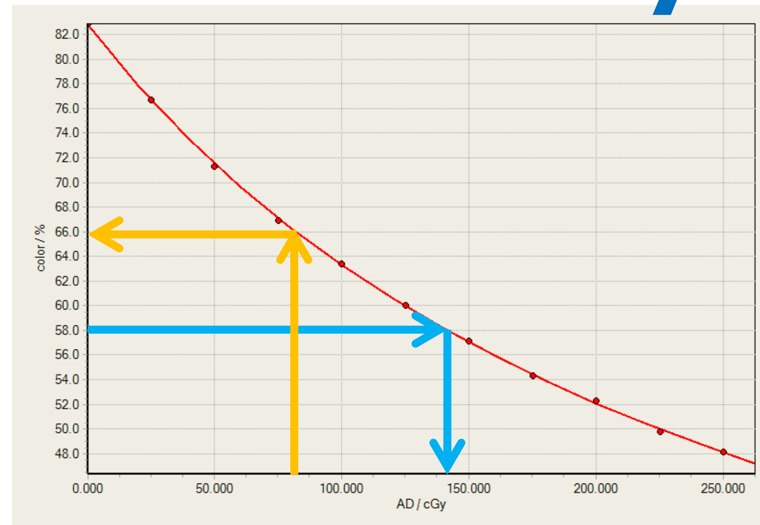
Multi-Channel Film Dosimetry

Micke A

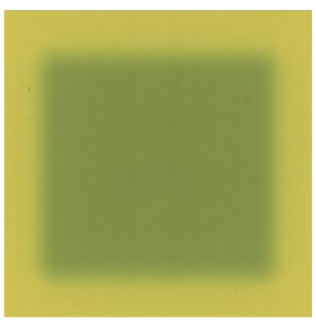
Ashland Inc. – Advanced Materials

Ashland proprietary technology, patents pending

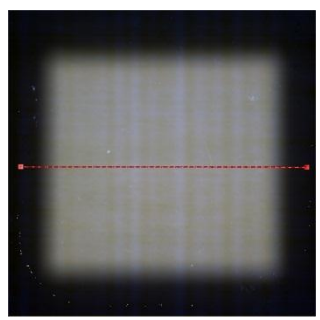
Single Channel Film Dosimetry

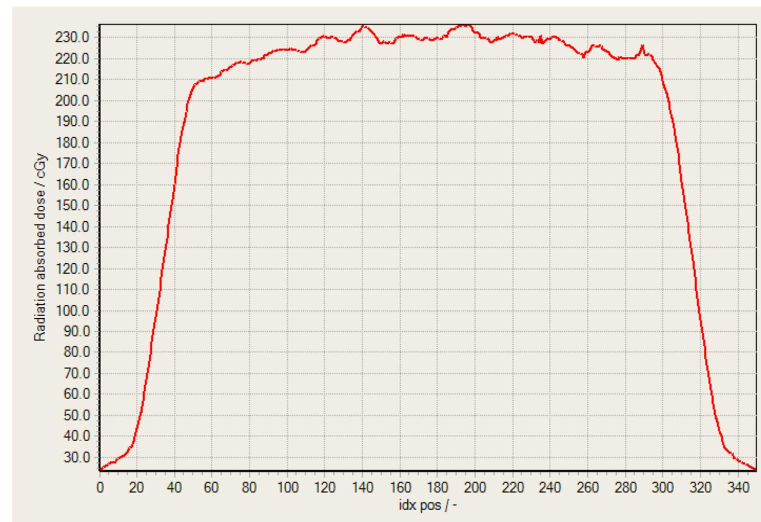


- Calibration Curve X=R
  $R_{ave} = R_{ave}(D) \leftrightarrow D_R = D_R(R_{ave})$
- Color channels X=RGB
  $D_X = D(X_{ave})$
  correlates average response of film-scanner system
- Robust method
  any X value delivers dose $D_X(X)$



$D=D_X$





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A. Micke, AAPM, August 2012

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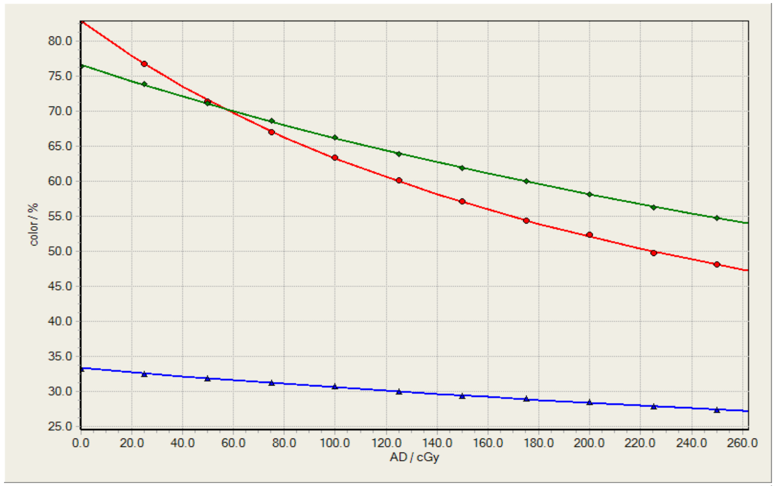
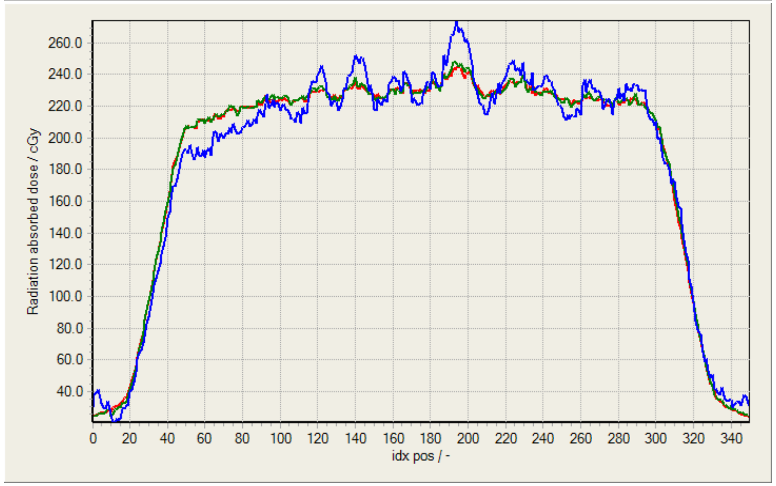
Single Channel Film Dosimetry

Problem:

Specific pixel does not behaves like average

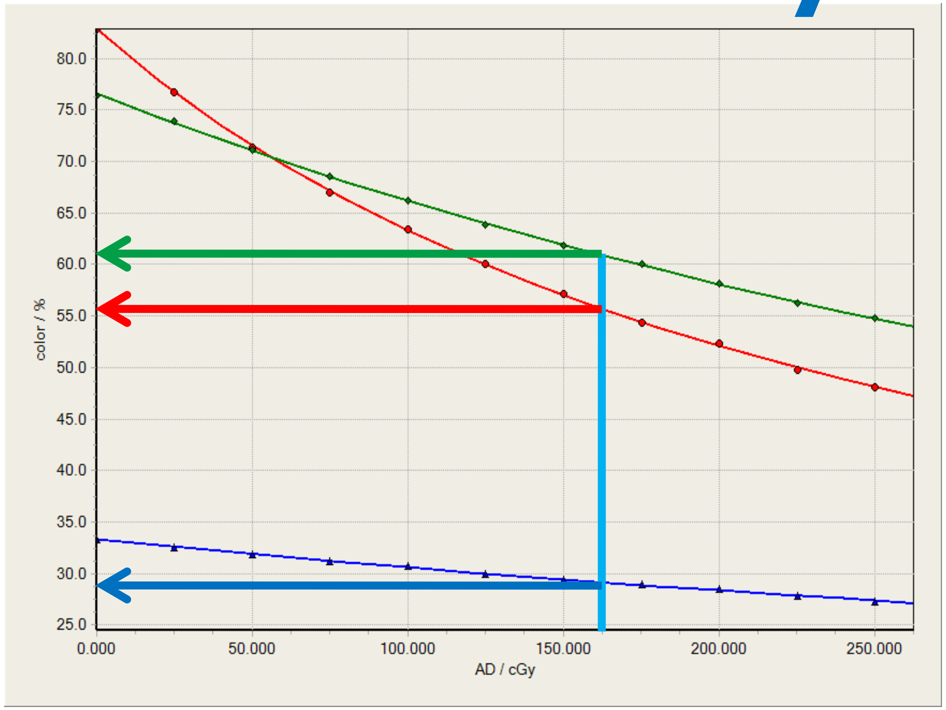
- Disturbance ΔX generates ΔD_X
  $X + \Delta X \leftrightarrow D(\ X\ ) + \Delta D_X$
  - Film uniformity variations
  - Scanner non-linearities
  - Newton rings, noise, finger prints curling, …
- Any X value delivers dose $D_X(X)$
  - Each channel specific ΔD_X
  - No indication of 'big' ΔD_X
  - What dose D_X is best?





Multi-Channel Film Dosimetry

- RGB Calibration Curves
  - Dose induced color C
    C(D) = {R(D),G(D),B(D)}
- Dose exposure generates only ‘certain’ colors C
  - Not all C deliver dose value



- Observed color C_{scan} is superposed with disturbance ΔC
  - $C_{scan} = C(D) + \Delta C$
- Solution: Optimize dose D value, *i.e.* minimize ΔC
  - $| C_{scan} - C(D) | \rightarrow \min_D$

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Triple Channel Film Dosimetry

- Model:
  Scanned optical density $d_{X,scan}$
  - $\mathbf{d_{X,scan}(D) = d_{X,D}(D) * \Delta d}$

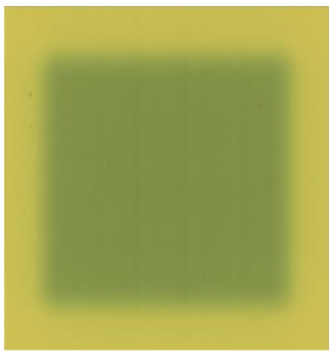
    $d_X = -\log(X)$ for $X = RGB$
  - $d_{X,D}$ is calibration function (average behavior)
  - ! disturbance Δd independent of dose + X (wave length) !

    but $\Delta d = \Delta d(\text{thickness, scanner, noise, artifacts})$
- Solution:
  - Minimized function ϕ *vs.* disturbance Δd:

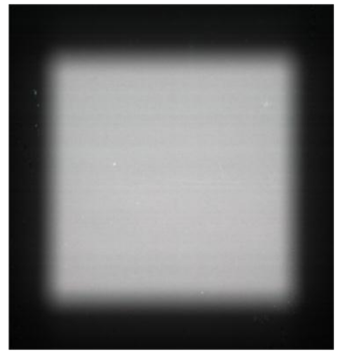
    $$\phi(\Delta d) = (D_R - D_B)^2 + (D_B - D_G)^2 + (D_G - D_R)^2 \rightarrow \min_{\Delta d}$$

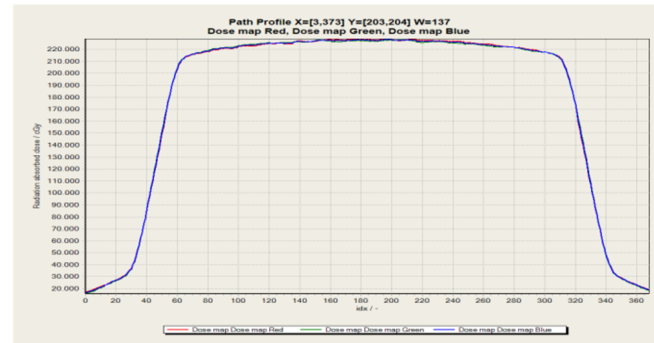
Triple Channel Film Dosimetry Example

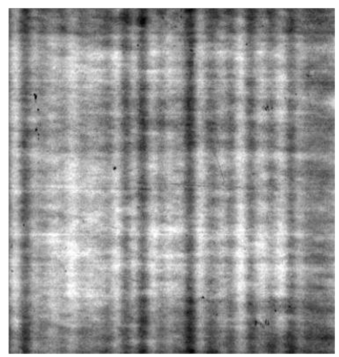
- Signal split into *dose dependent* and *dose independent* part

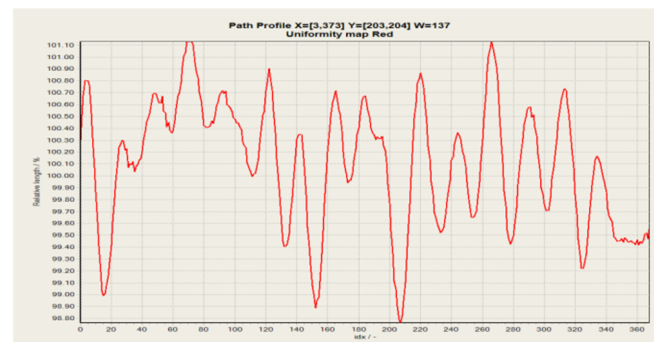


$D_{RGB} + \Delta d$







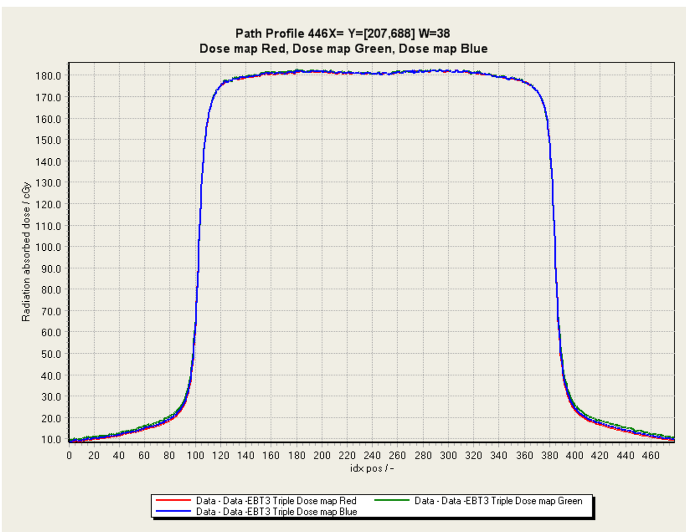


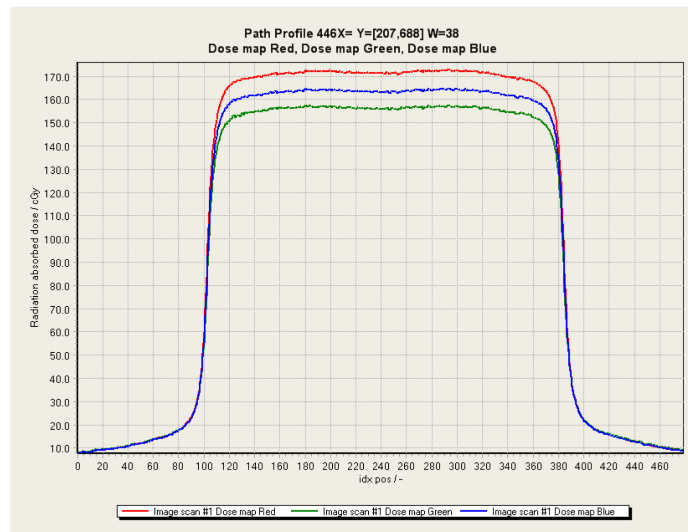
- Dose map (D dependent part)
- Disturbance Δd map (D independent part) includes film uniformity variations, noise etc.

Triple Channel Dosimetry
Film Consistency

Film consistent with Calibration Patches

- Film has same dose response for X=RGB
  i.e. same dose values D_X are calculable
- Offset between D_X measures calibration consistency

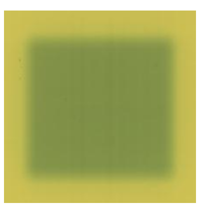




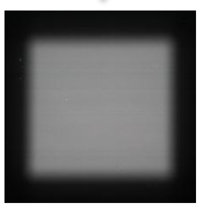
Example: Profiles original calibration patch and 90° rotated scan

Triple Channel Dosimetry Consistency Map

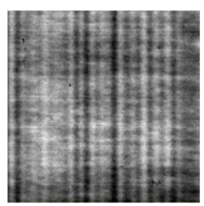
- Dose map
  – measurement result
- Disturbance map
  – removed error
- Consistency map
  – remaining error
  ideal case: noise only



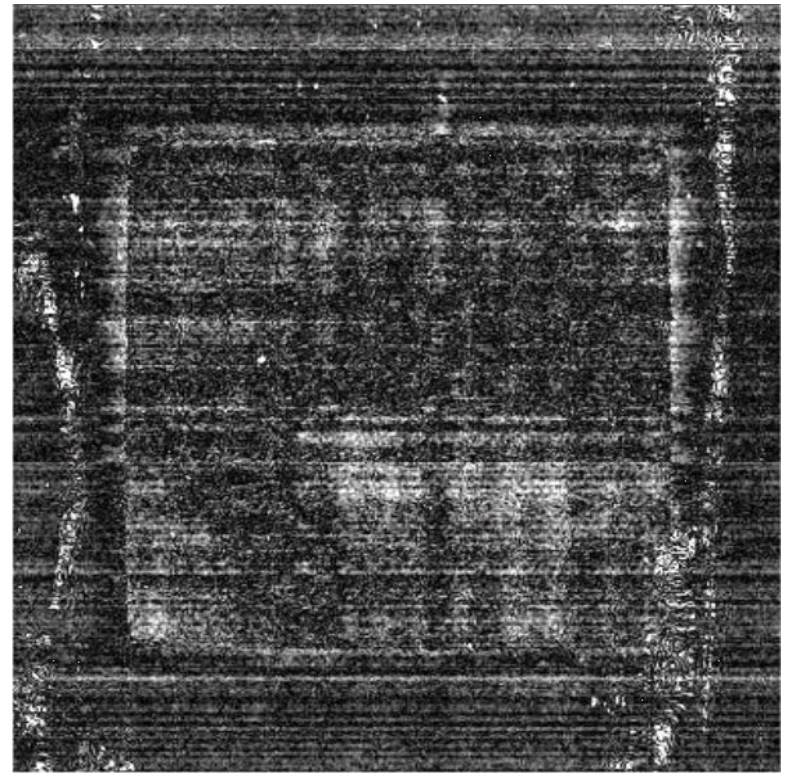
Film



Dose Map



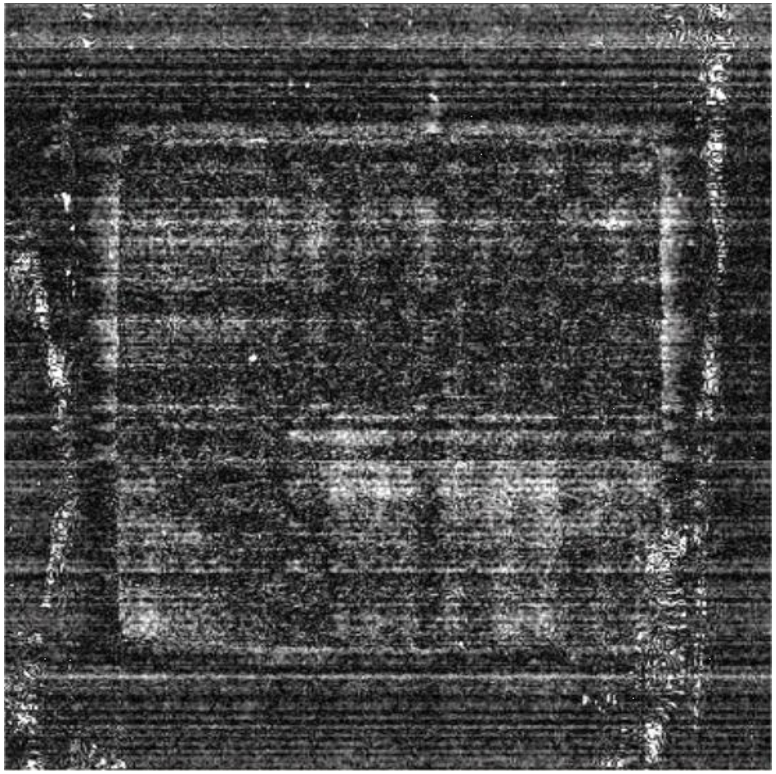
Disturbance Map



Consistency Map
(dark = +, light = -, contrast maximized)
Example: dominated by scanner cogging

Multi Channel Calibration

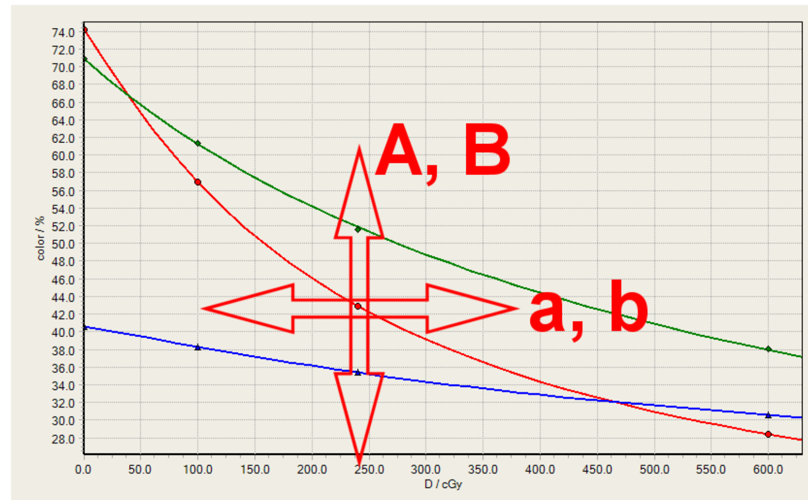
- **Optimize Calibration**
  - Lower consistency = better calibration
  - Offset in calibration points is **not** a quality criterion
- **Calibration goal**
  - Correlate calibration parameter for best (perfect) consistency
  - Calibration function
    C(D) = { R(D), G(D), B(D) }
    matches film dose spectrum

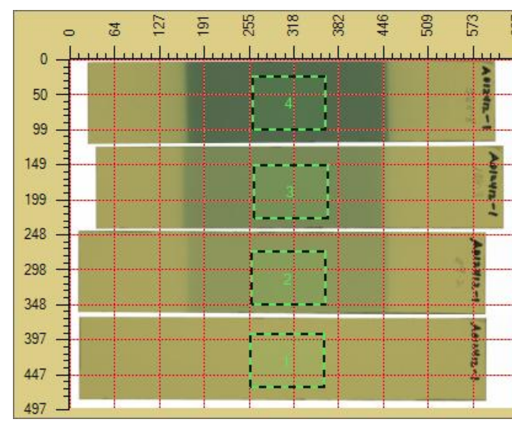


Perfect consistency ≡ 0

Multi Channel Calibration

- **Single channel calibration**
  average system response
  - **$x = x(D)$**
    x = RGB
    each channel fitted separately
- **Multi-channel calibration**
  - **$X(D) = A + B\,x(a + b\,D)$**
    X = RGB
    rescales calibration x
    a,b dose scaling, A, B color scaling
  - Correlation $D_R(R_{ref}) = D_G(G_{ref}) = D_B(B_{ref})$
    enforces perfect consistency at reference
  - Compensates calibration patch distortions
    if multi channel dose is used to rescale dose

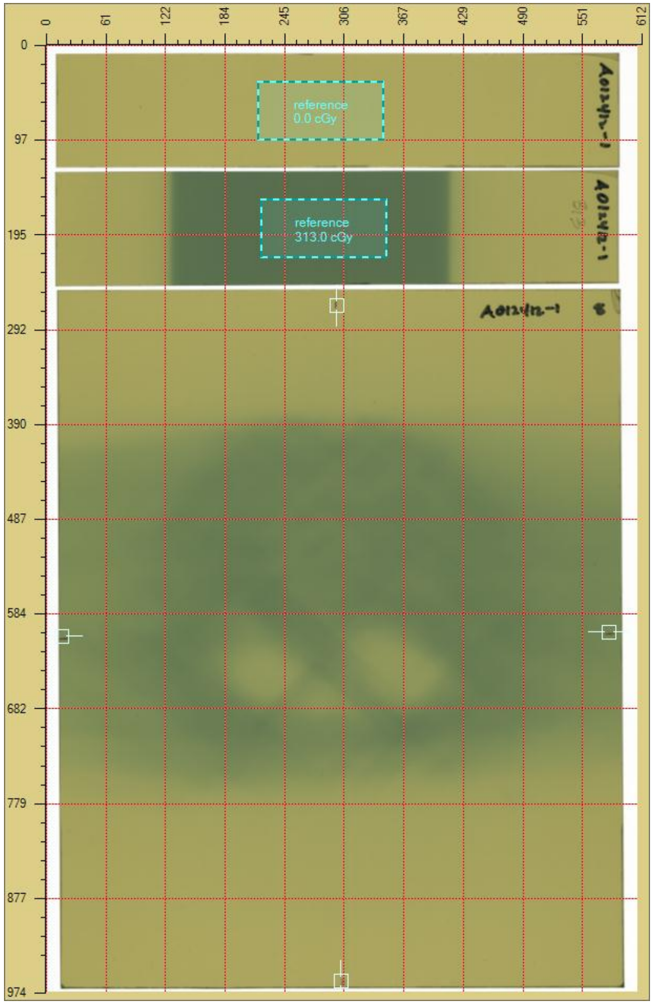




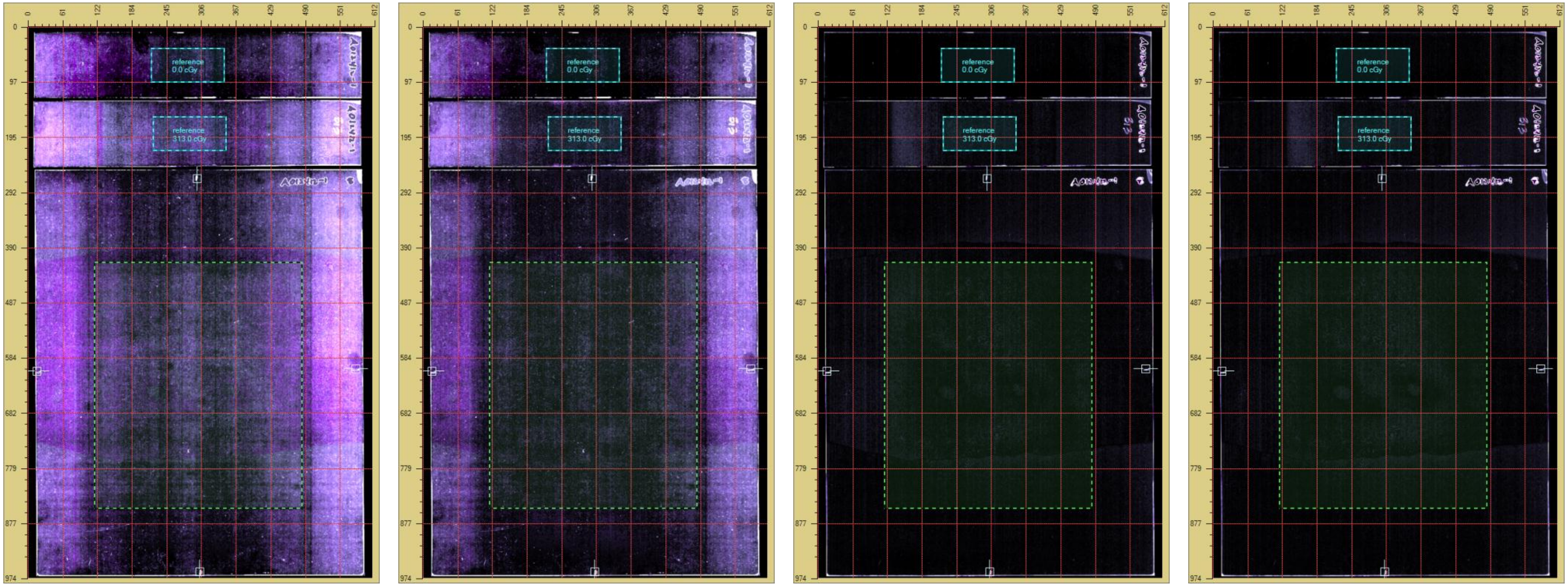
Multi Channel Calibration

- **Two point recalibration**
  - 1 unexposed + 1 exposed film
    Minim cost possible
  - *Dose* scaling (A=0, B=1)
    X(D) = x(a + b D) , X = RGB
  - *Color* scaling (a=0, b=1)
    X(D) = A + B x(D) , X = RGB
- **Assumption**
  - Calibration functions keep shape
    Shape(x) = Shape(X) , x, X=RGB
- **Single scan Evaluation**

  compensates for
  - Ambient conditions: temperature, humidity
  - Inter-scan scanner variations,
  - Post exposure time, film aging



Consistency Comparison

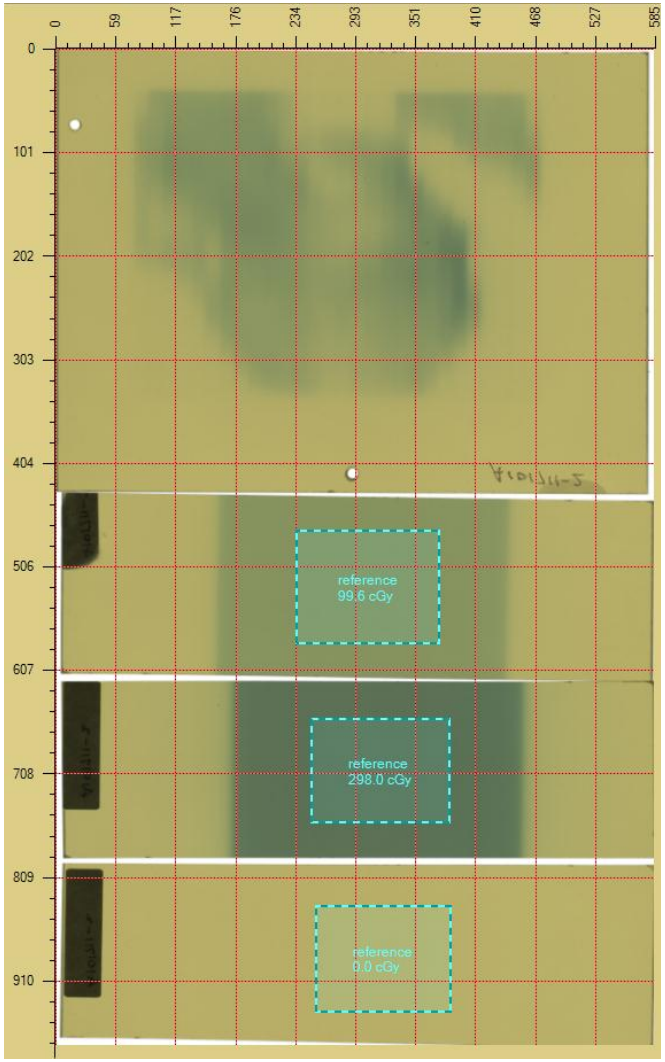


Single Channel	Single Channel Recalibrated	Multi Channel	Multi Channel Recalibrated
10.2 cGy	3.6 cGy	1.3 cGy	1.2 cGy

Consistency measured across frame D_{max} = 243 cGy, D_{ave} = 139 cGy

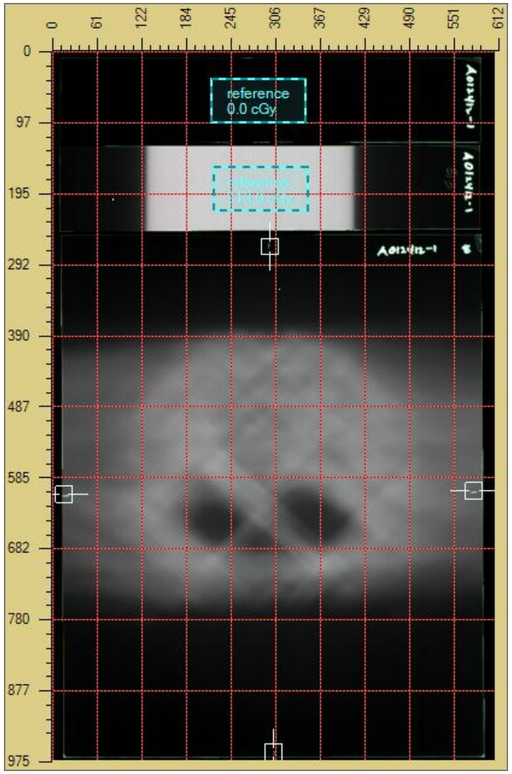
Multi Channel Calibration

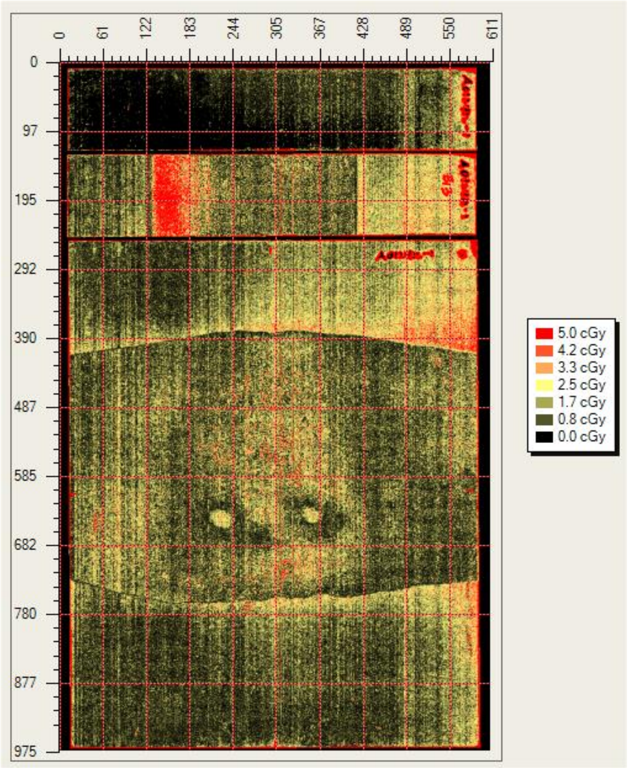
- **Triple point recalibration**
  - 1 unexposed + 2+ exposed film
    Higher cost
  - X(D) = A + B x(C D) (3 point rescaling)
  - X(D) = A + B x(D^C)
    X = RGB
- Requires 2 exposures
  - Enforces perfect consistency at references
  - Recalibration includes rescaling and shape correction
- Single scan Evaluation compensates for
  - All two point recalibration benefits
  - Shape changing properties
    i.e. any primary calibration can be used



Triple Channel Dosimetry
Dose Map Consistency

- Dose map error estimation known before comparison
- Detect 'abnormal' scans
  - 90° rotation, curling, Newton rings, 'top sheets' anomaly

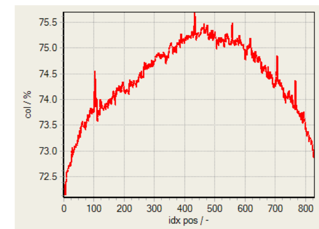




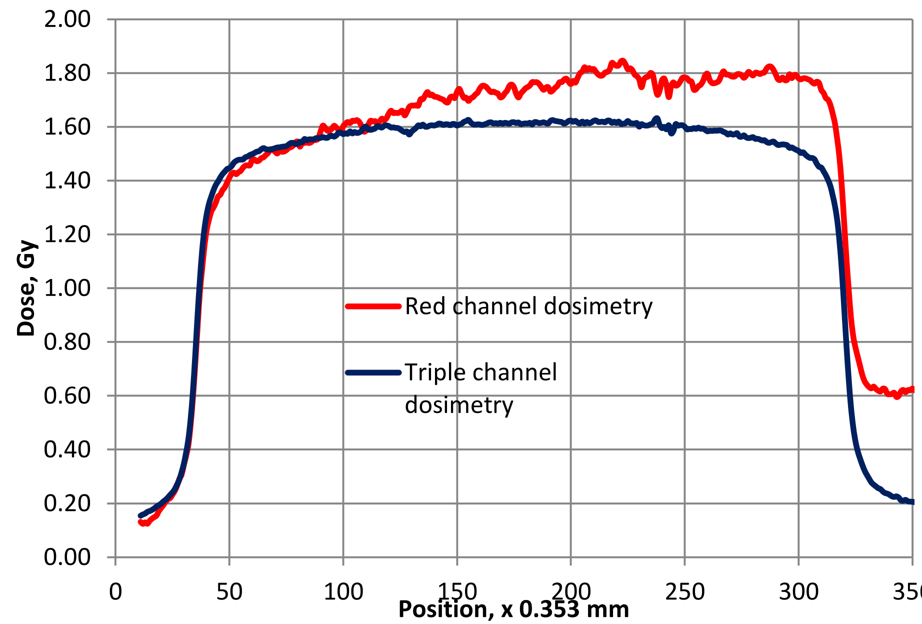
Example dose consistency map (iso-map) peak error ~2%

Triple Channel Dosimetry
Lateral Scanner Non-Linearity

Scanner signal changes with lateral position (sensor direction)



- EBT film polarization causes lateral effect
- Non-dose-dependent part of lateral effect is compensated
- Mitigation only (partial compensation)



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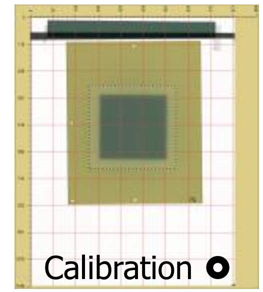
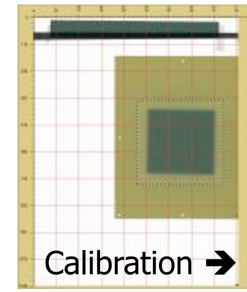
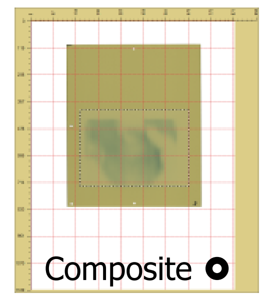
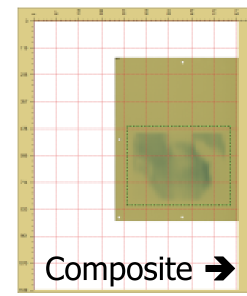
Lateral Scanner Non-Linearity
Single vs. Triple Channel

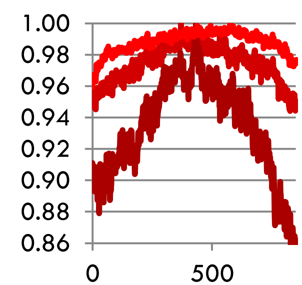
Gamma map Criterion	Calibration	Composite	Passing rate: Single Channel	Passing rate: Triple Channel
2% / 2mm	○	○	90%	96%
	→	→	87%	96%
	○	→	98%	98%
	→	○	94%	97%
1% / 1mm	○	○	58%	71%
	→	→	64%	69%
	○	→	81%	85%
	→	○	73%	78%
	○ = centered → = right edge		absolute dosimetry (no dose re-scaling), <5% (<12cG) lowest dose ignored,	





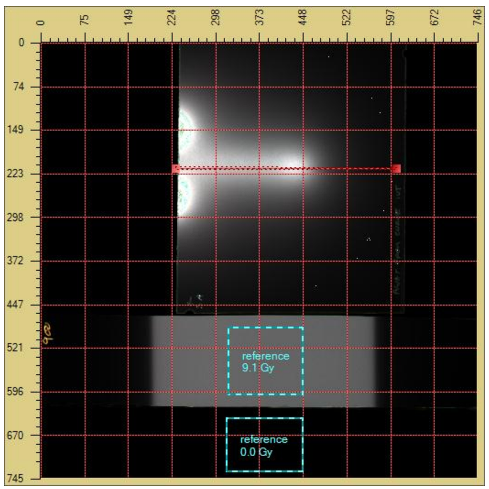


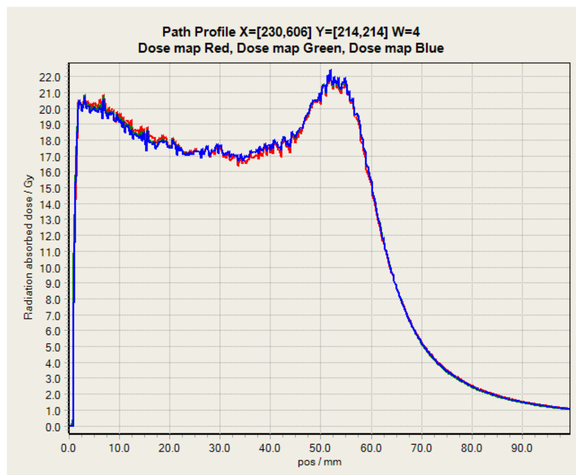


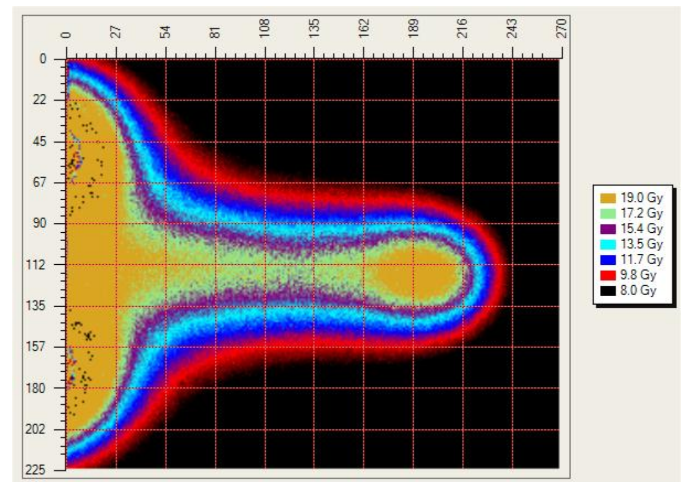


Triple Channel Film Dosimetry
Dynamic Dose Range

- Same dose mapping method for all channels
- Range adaptation as needed
- Enables EBT's full dynamic range - Factor >1000
- ✘ Lateral effect increases substantially!







Example - Brachytherapy:
Calibration range 0 – 90 Gy, Dose map 22 Gy peak, Reference 9 Gy

Triple Channel Single Scan Film Dosimetry

- Separate Dose and Dose-independent effects
  - Compensates for film thickness variation
  - Noise reduction without dose change
  - Mitigates scanner distortions
  - Background compensation, double exposure unnecessary
- Enables entire film dose range
  - Ebt2 dynamic range ratio >1000 (1 cGy - >40 Gy)
- Significant improvement of dose map accuracy
  - <1% achievable (*vs.* 3% with single channel method)
- Indication of inconsistency between film and calibration, calibration inconsistencies

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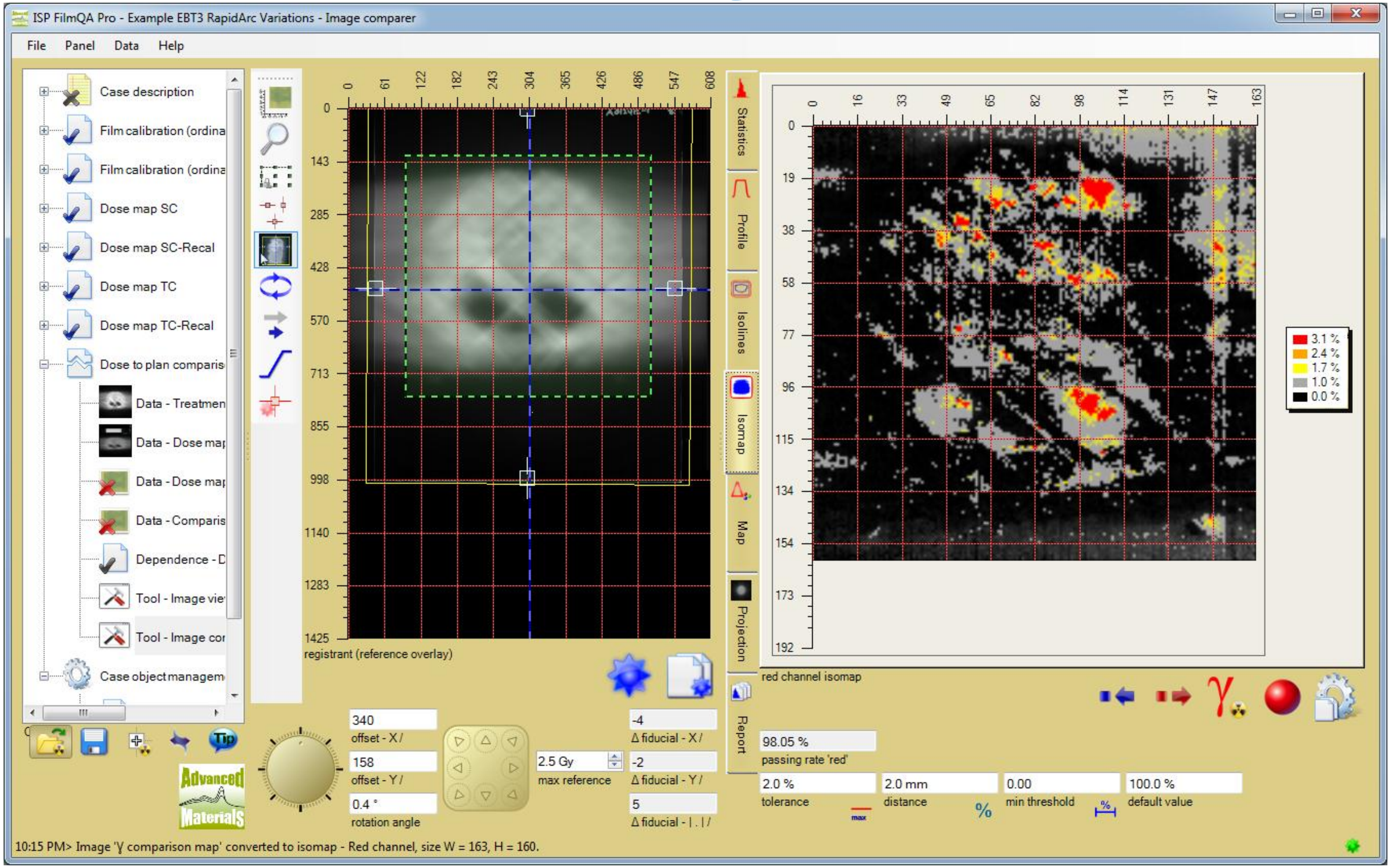

Lit.: Micke, Lewis, Yu - Multi-channel Film Dosimetry with Non-Uniformity Correction, Medical Physics, 38 (2011) 5, pp. 2523.