Multi-Channel Film Dosimetry and Gamma Map Verification

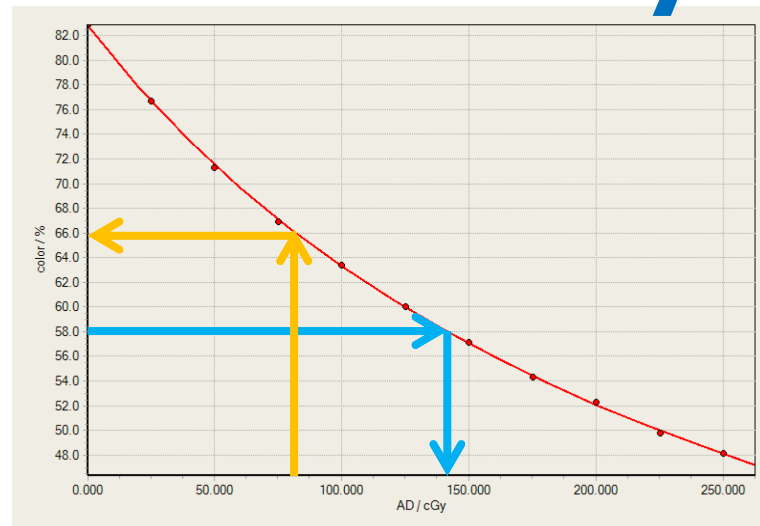
Micke A

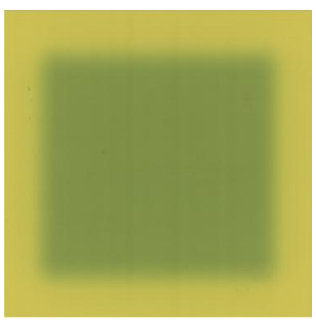
International Specialty Products – Ashland Inc.

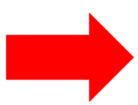
Ashland proprietary technology, patents pending

Single Channel Film Dosimetry

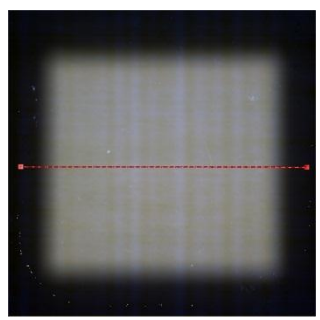
- Calibration Curve X=R
  $R_{ave} = R_{ave}(D) \leftrightarrow D_R = D_R(R_{ave})$
- Color channels X=RGB
  $D_X = D(\ X_{ave}\ )$
  correlates average response of film-scanner system
- Robust method
  any X value delivers dose $D_X(X)$

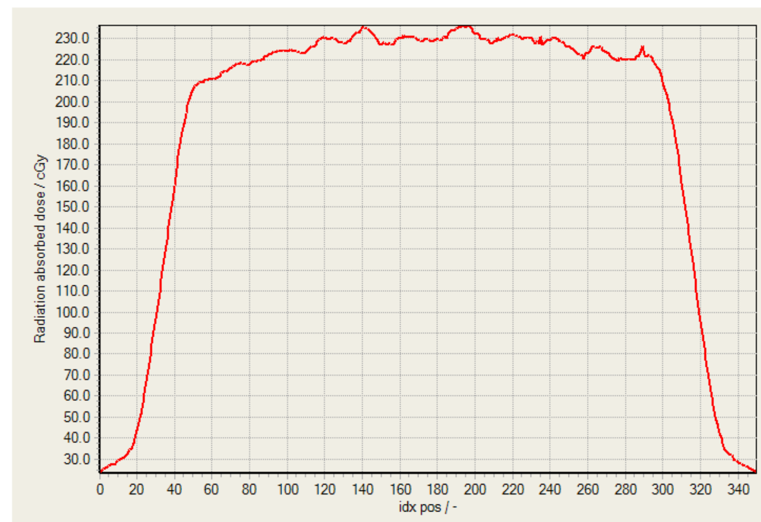






$D{=}D_X$





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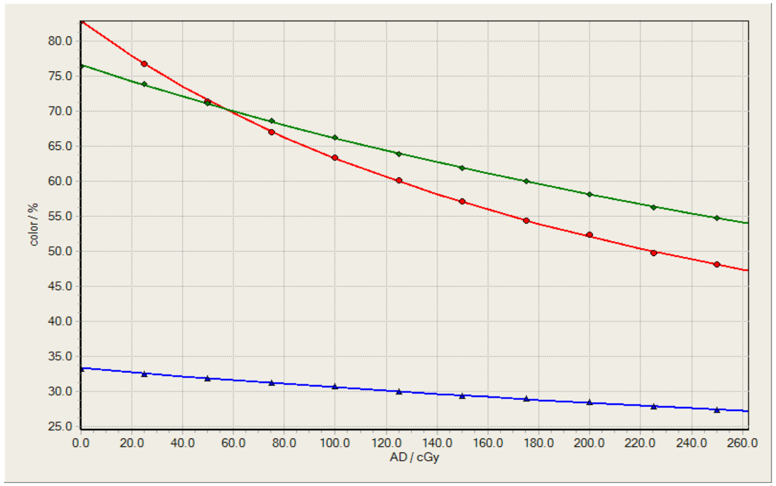
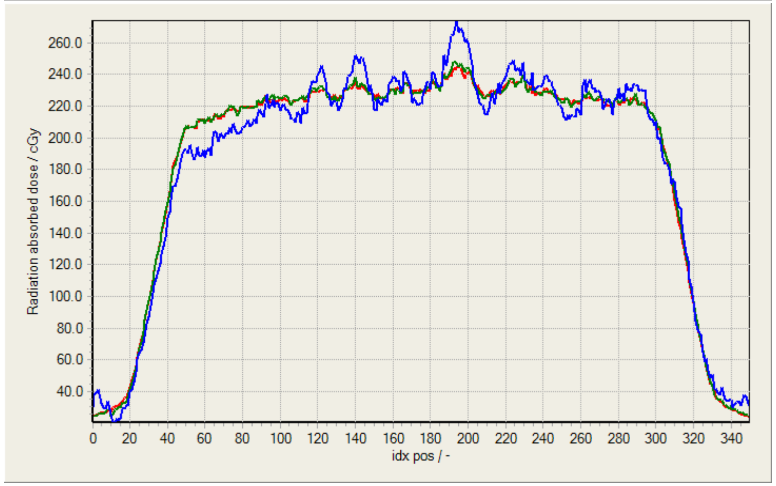
Single Channel Film Dosimetry

Problem:

Specific pixel does
not behaves like average

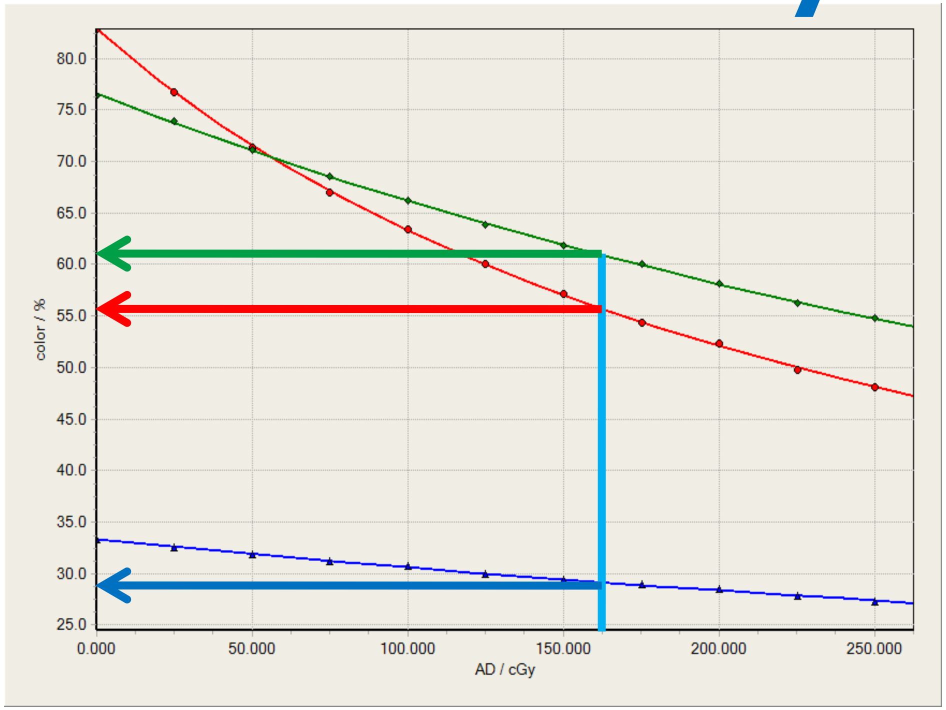
- Disturbance ΔX generates ΔD_X
  X + $\Delta X \leftrightarrow$ D(X) + ΔD_X
  - Film uniformity variations
  - Scanner non-linearities
  - Newton rings, noise, finger prints curling, …
- Any X value delivers dose $D_X(X)$
  - Each channel specific ΔD_X
  - No indication of 'big' ΔD_X
  - What dose D_X 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
  - $| C_{scan} - C(D) | \rightarrow \min_D$

Triple Channel Film Dosimetry

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

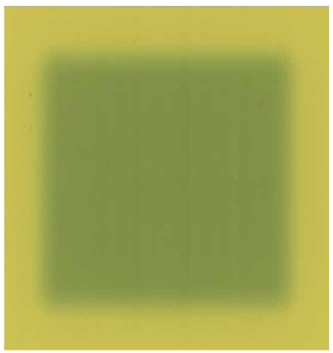
    $d_X = -\log(X)$ for $X = RGB$
  - $d_{X,D}$ is calibration function (average behavior)
  - ! disturbance Δd independent of dose + X (wave length) !

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

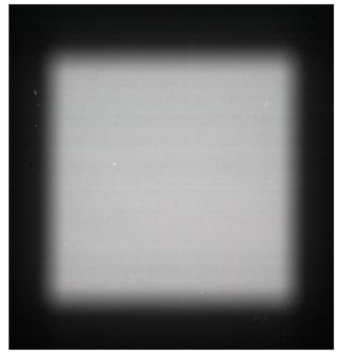
$$\phi(\Delta d) = (D_R - D_B)^2 + (D_B - D_G)^2 + (D_G - D_R)^2 \rightarrow \min_{\Delta d}$$

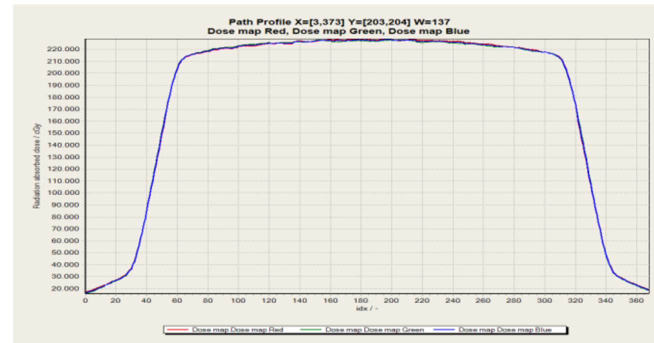
Triple Channel Film Dosimetry Example

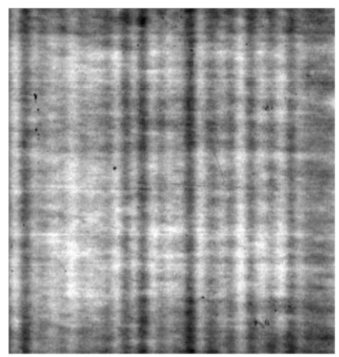
- Signal split into *dose dependent* and *dose independent* part

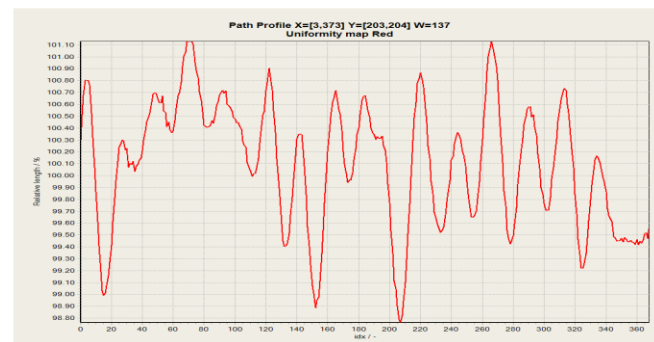


D_{RGB} + Δd









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

Triple Channel Correction
What happen to the Marker Dye?

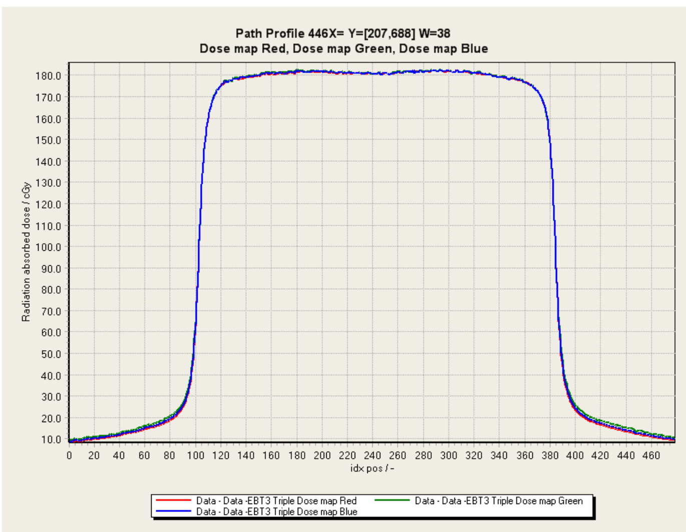
- Marker Dye needed at 'lower' dosage:
  - $\Delta d \cong d_{B,scan}(0) / d_{B,D}(0)$

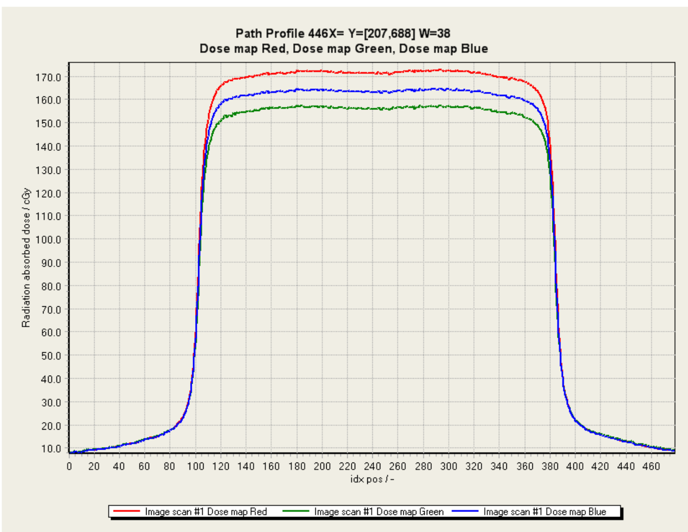
  otherwise 'scanner noise' dominates Δd
  (sufficient low dosage ~ 100 – 200 cGy)
- At 'higher' dosage Red channel is saturating and has function like Marker Dye
  (sufficient high dosage > 400 cGy)

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

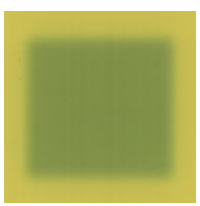




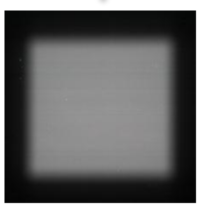
Example: Profiles original calibration patch and 90° rotated scan

Triple Channel Dosimetry Consistency Map

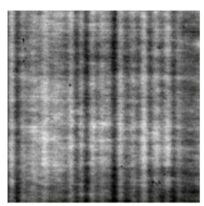
- Dose map
  – measurement result
- Disturbance map
  – removed error
- Consistency map
  – remaining error
  ideal case: noise only



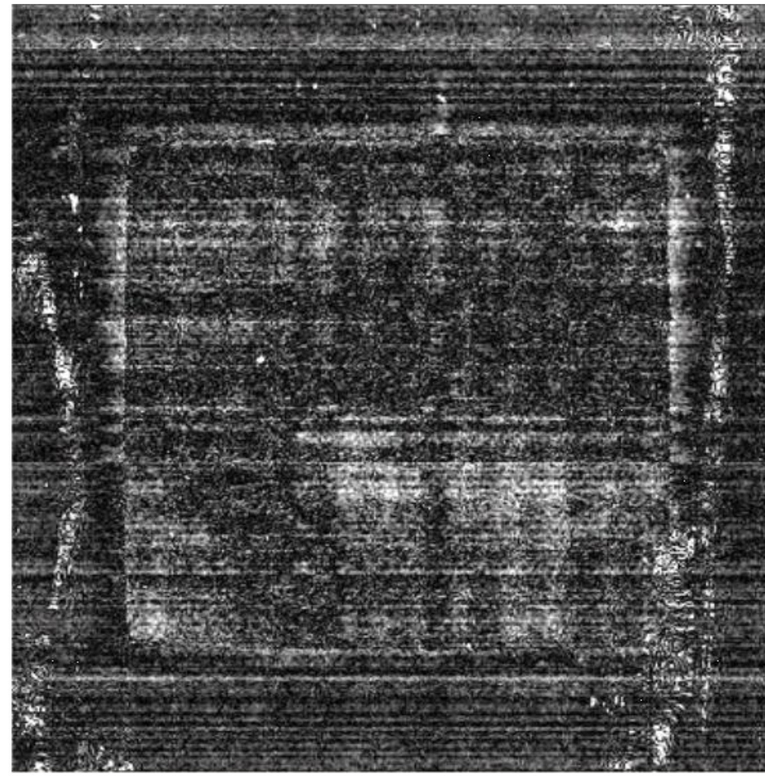
Film



Dose Map

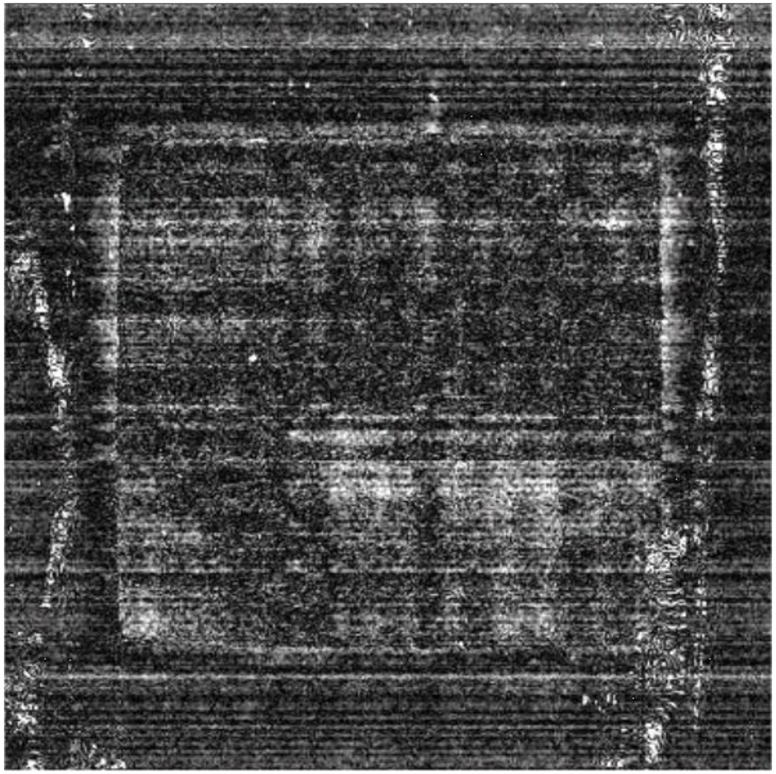


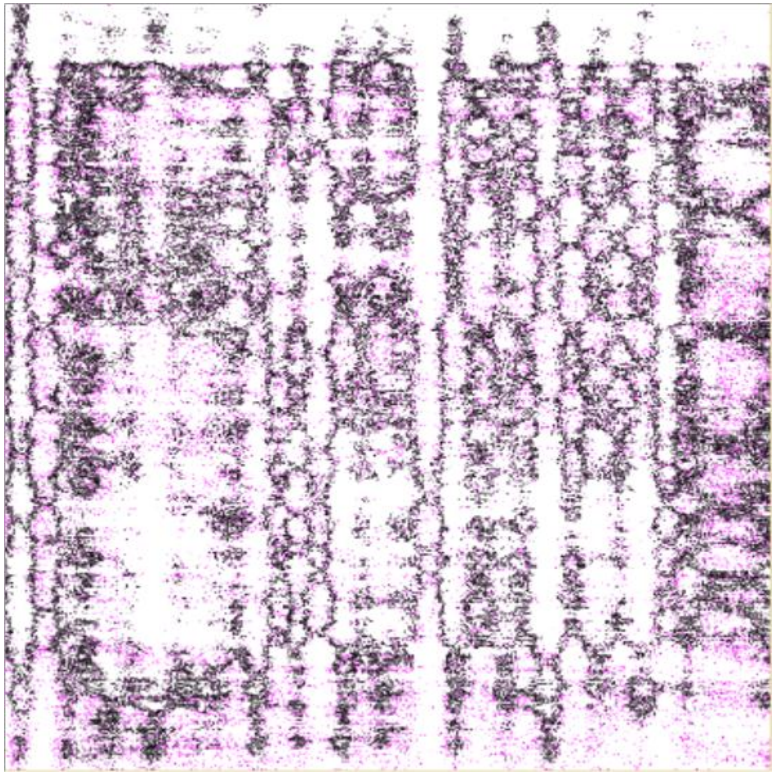
Disturbance Map



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

Consistency Map Comparison





Triple Channel Dosimetry | **Single Channel Dosimetry**

same patch, same contrast scaling, dark = +, light = -

Advanced Materials

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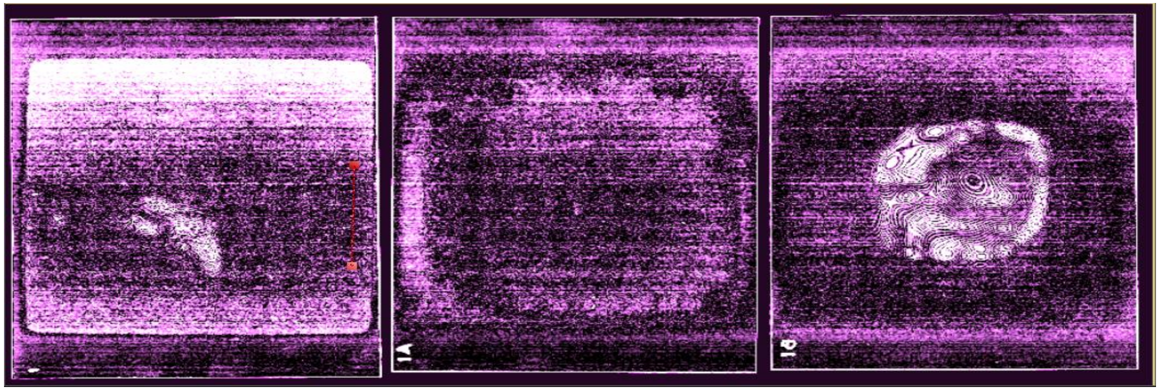
Triple Channel Dosimetry Calibration Consistency

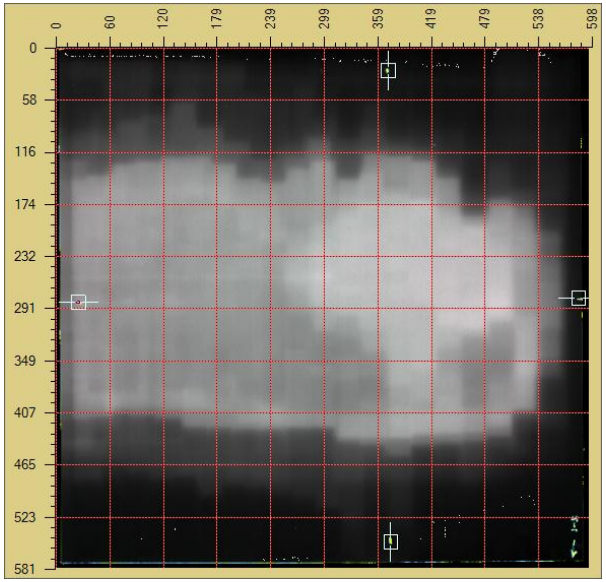
- Calibration inconsistent with calibration patches
  ↳ also inconsistent with application film !
- Minimize inconsistency (numeric value)
  - is uniformity corrected
  - Calibration optimization (e.g. dose range)
- Detect ‘abnormal’ patches
  - 90° rotation, curling, Newton rings, ‘top sheets’ anomaly

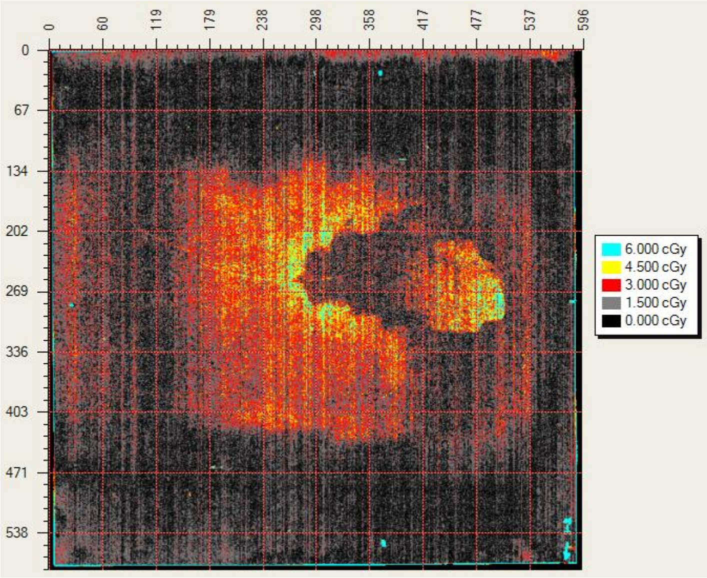


Examples of calibration patch consistency map

Triple Channel Dosimetry
Dose Map Consistency

- Dose map error estimation known before comparison
- Recognize mismatch of Calibration and Dose map
  - e.g. batch mismatch
- Detect ‘abnormal’ scans
  - 90° rotation, curling, Newton rings, ‘top sheets’ anomaly





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

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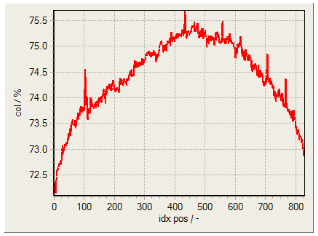
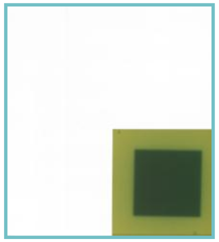
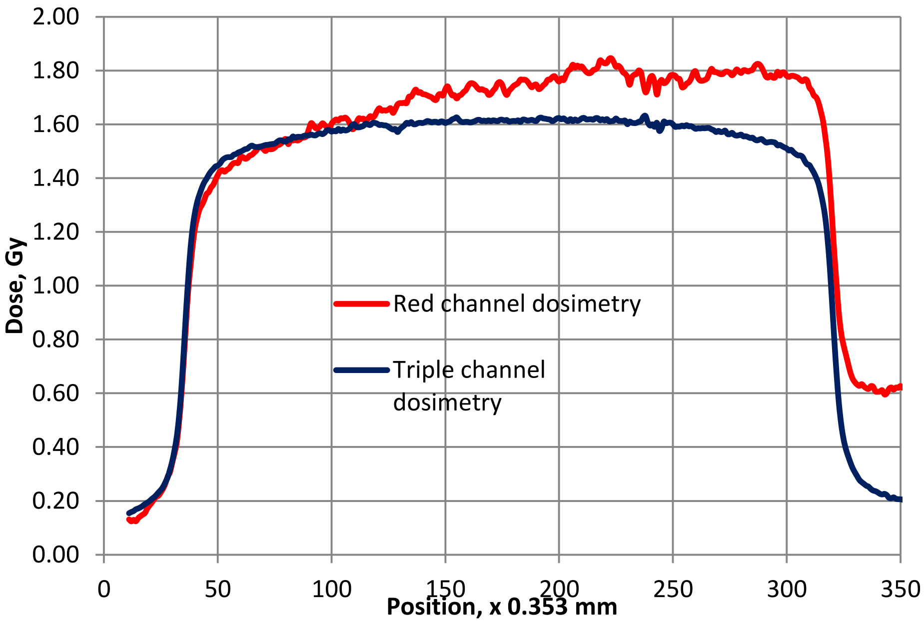
Triple Channel Dosimetry Lateral Scanner Non-Linearity

Scanner signal changes with lateral position (sensor direction)

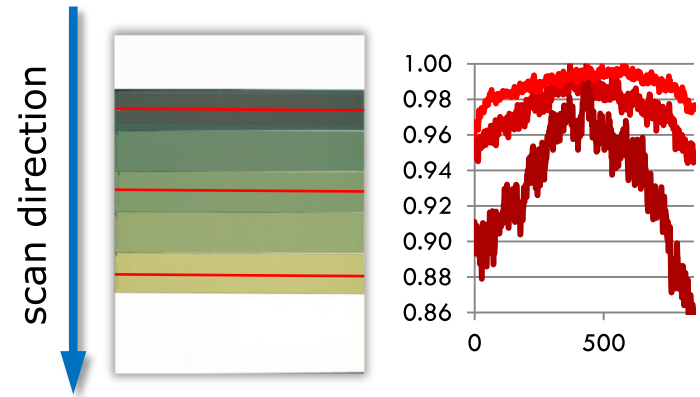




- EBT film polarization amplifies lateral effect
- Non-dose-dependent part of lateral effect is compensated
- Mitigation only (partial compensation)



Lateral Scanner Non-Linearity Normalized Blank Scan



Lateral effect increases with dose

- Compensates only weakest occurrence of lateral effect
- Adding disturbances
  - Non-uniformity of blank film
  - Noise of blank scan
- Worsens consistency for exposed areas

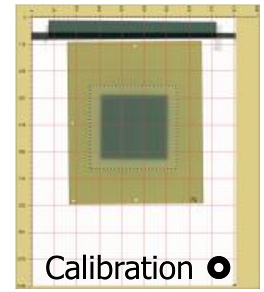
! DO NOT USE !

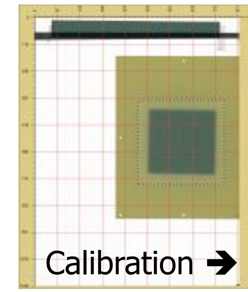
Calibration patch consistency comparison

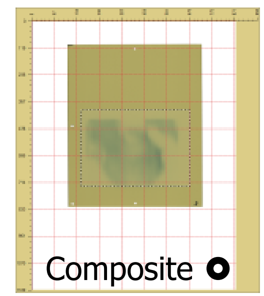
dose <cGy>	Consistency <cGy>		Consistency <%>	
	None	Blank scan	None	Blank scan
202.0	**8.8**	**11.1**	**4.3**	**5.5**
151.5	**6.8**	**8.9**	**4.5**	**5.9**
101.0	**5.9**	**8.4**	**5.9**	**8.3**
50.5	**5.9**	**7.9**	**11.6**	**15.6**
0.0	**4.8**	**0.4**	Infinity	Infinity

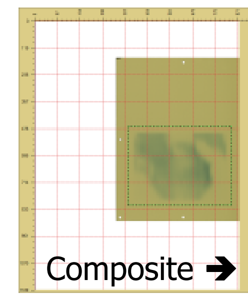
Lateral Scanner Non-Linearity
Single vs. Triple Channel

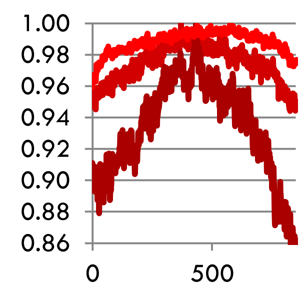
Gamma map Criterion	Calibration	Composite	Passing rate	
			Single Channel	Triple Channel
2% / 2mm	○	○	90%	96%
	→	→	87%	96%
	○	→	98%	98%
	→	○	94%	97%
1% / 1mm	○	○	58%	71%
	→	→	64%	69%
	○	→	81%	85%
	→	○	73%	78%
	○ = centered → = right edge		absolute dosimetry (no dose re-scaling), <5% (<12cG) lowest dose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











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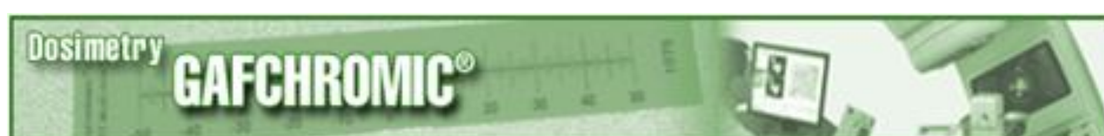
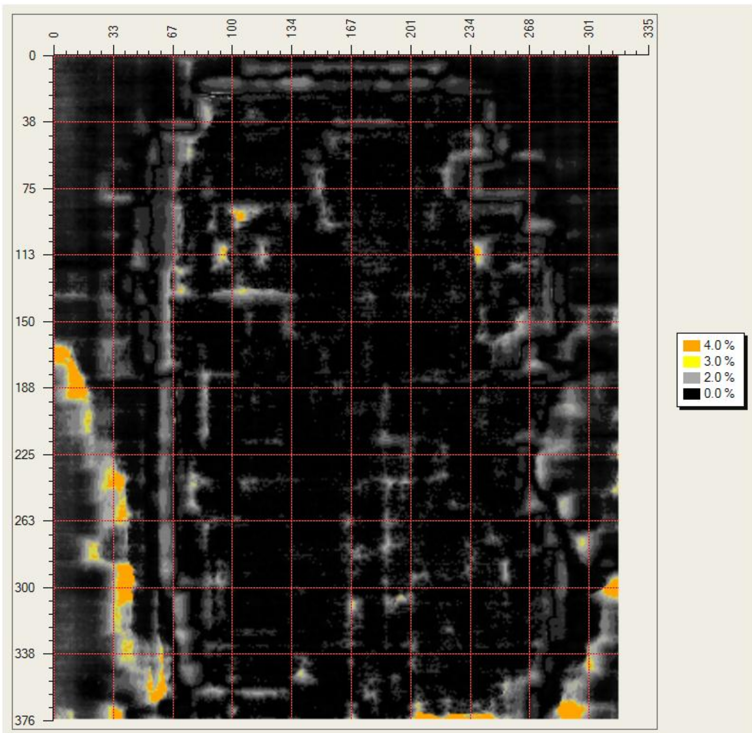
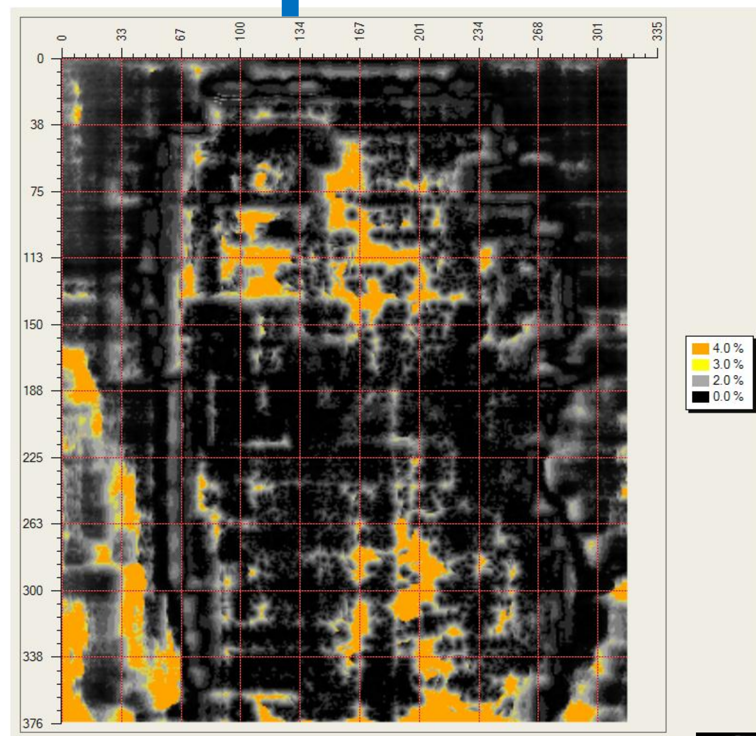


Triple Channel Film Dosimetry
Dose to Plan Comparison



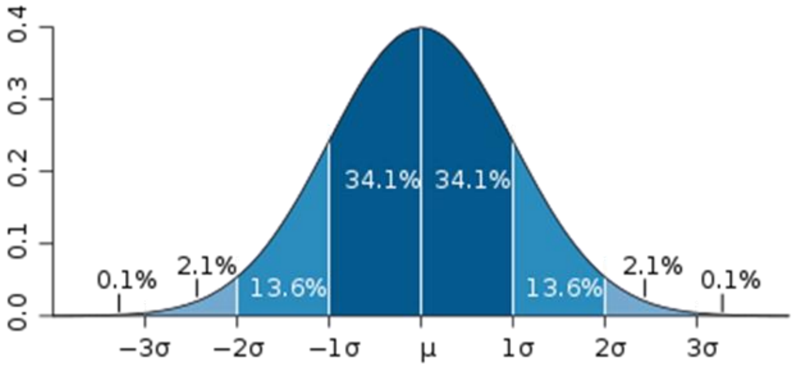


Triple Channel Passing rate R – **97.15** %	Single Channel Passing rate R - **87.48** %

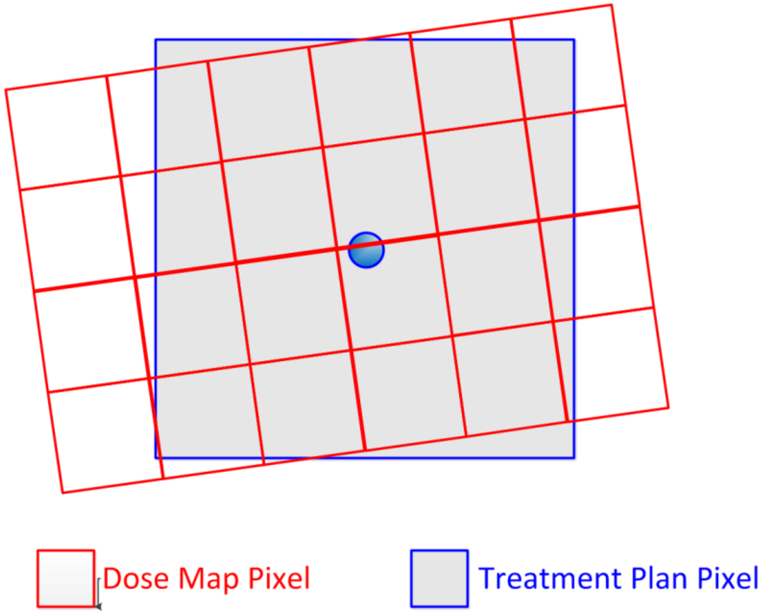
Gamma Map **2%/2mm** - IMRT example (part of FilmQA Pro installation)

Triple Channel Film Dosimetry Dose to Plan Comparison

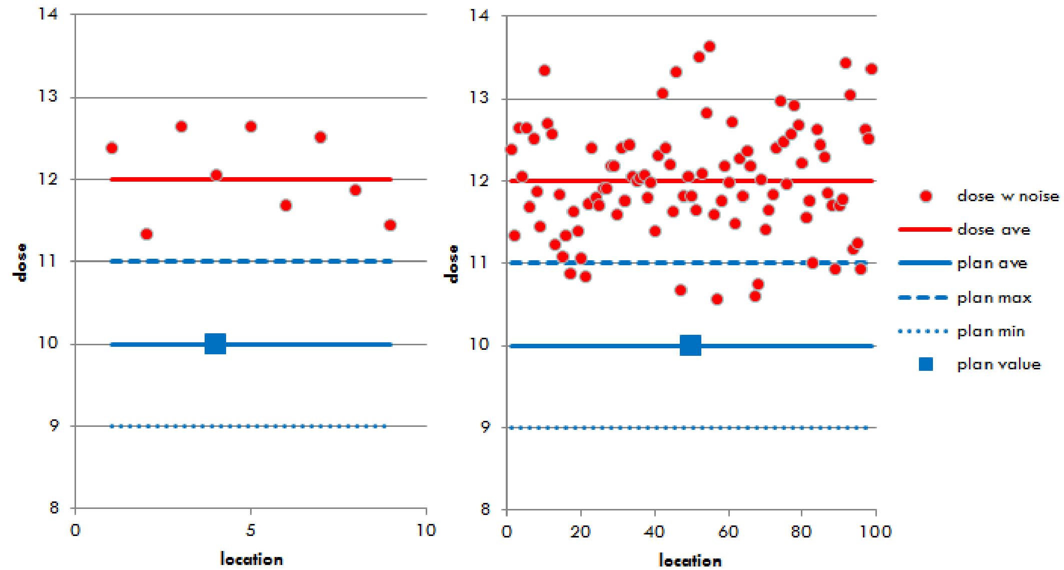
- Dose map error can dominate comparison
  - 1% achievable (*vs.* 3% with single channel method)
- Comparison Criteria 3%/3mm, 2%/2mm
  - Triple channel: 1% << 3%/2%, *i.e.* majority < tolerance
  - Single channel: 3% ~ 3% test, *i.e.* 50% > tolerance
- Passing rates improves more than dose accuracy



Gamma Map Comparison



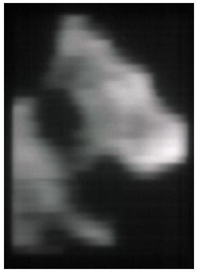
plan pixel and
overlaid pixels of
registered dose map



same standard deviation
low sample number **fails**,
high sample number **passes**

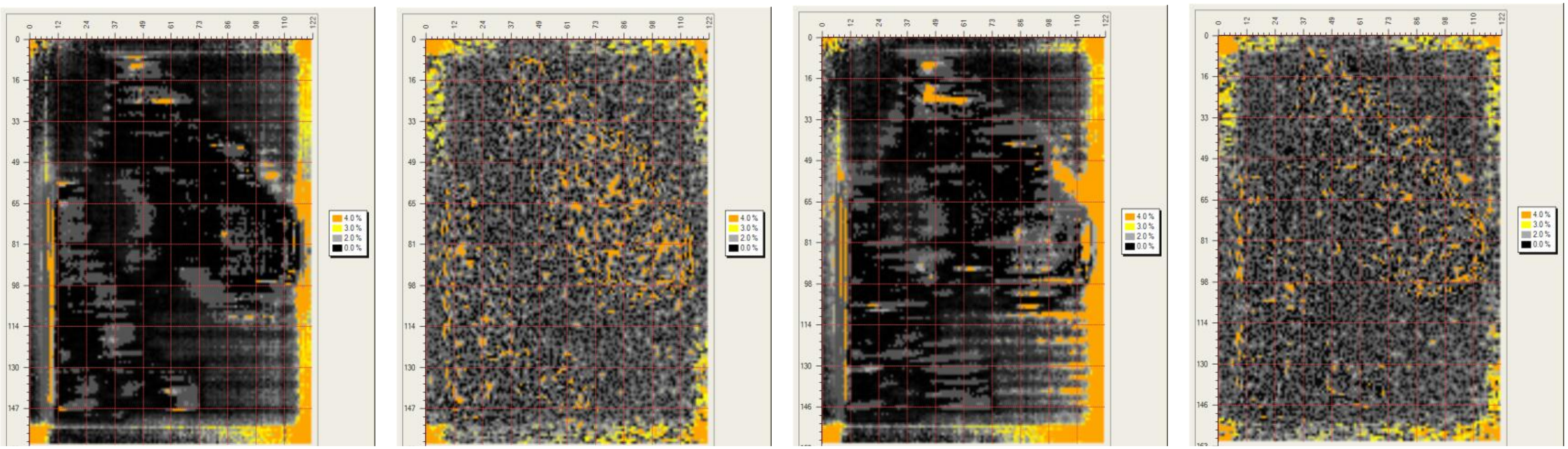
➥ Use dose average across plan pixel
e.g. Projection of dose map to plan coordinate system
Filtering cannot fix this problem!

Single vs. Triple Channel Noise Dependence



Triple Channel	Passing rate			
Criterion	0% noise	0.5% noise	1% noise	2% noise
3% / 3mm	97%	96%	95%	95%
2% / 2mm	94%	96%	94%	87%
1% / 1mm	68%	70%	58%	41%

Single Channel	Passing rate			
Criterion	0% noise	0.5% noise	1% noise	2% noise
3% / 3mm	94%	95%	95%	94%
2% / 2mm	89%	92%	94%	91%
1% / 1mm	57%	65%	61%	48%



2% / 2 mm Gamma map comparison at 0%, 2% noise

White noise with various standard deviation added to EBT3 film scan, Gamma map with projection

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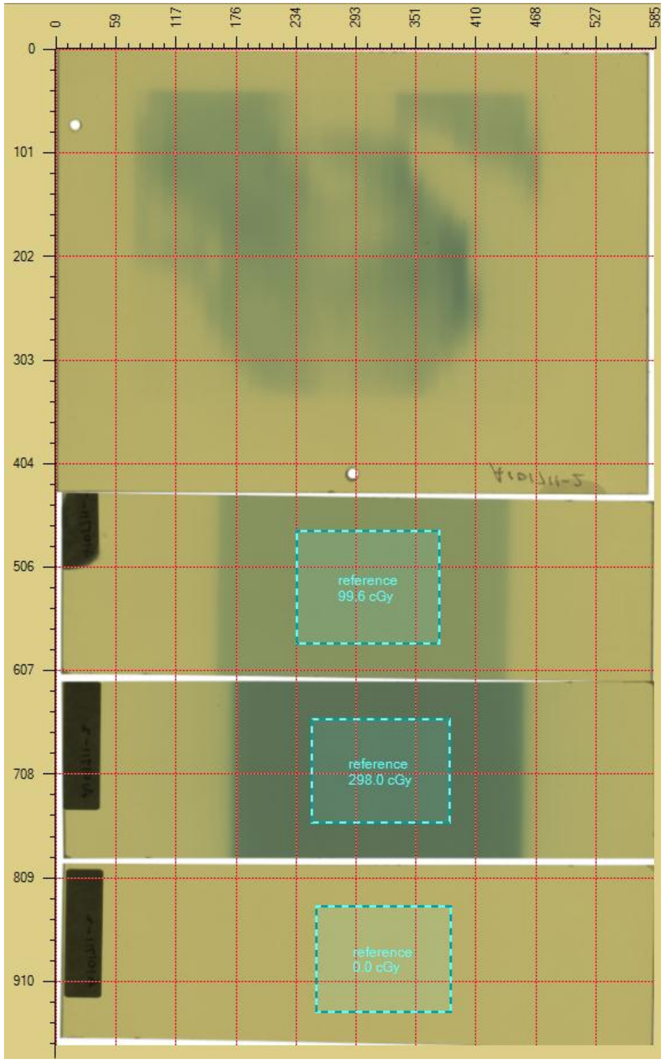
Multi Channel Calibration

- Calibration = average system response
  - x = x(D) (single channel calibration, x = RGB)
- Calculate dose map using single channel calibration x + multi channel dose map
- Correlate **multi-channel calibration** X
  - X(D) = A + B x(D) (2 point rescaling)
  - X(D) = A + B x(C D) (3 point rescaling)
  - X(D) = A + B x(D^C)
    X = RGB
- Requires only 1-2 exposures
  - Enforces perfect consistency at reference
- Single scan Calibration + Application compensates for
  - Ambient conditions: temperature, humidity
  - Inter-scan scanner variations,
  - Post exposure time, film aging



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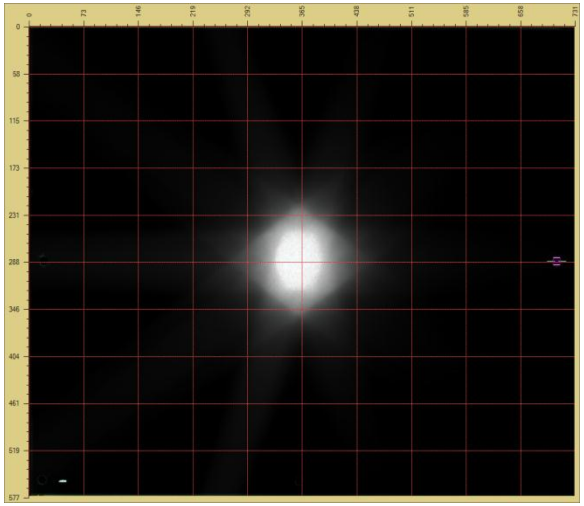
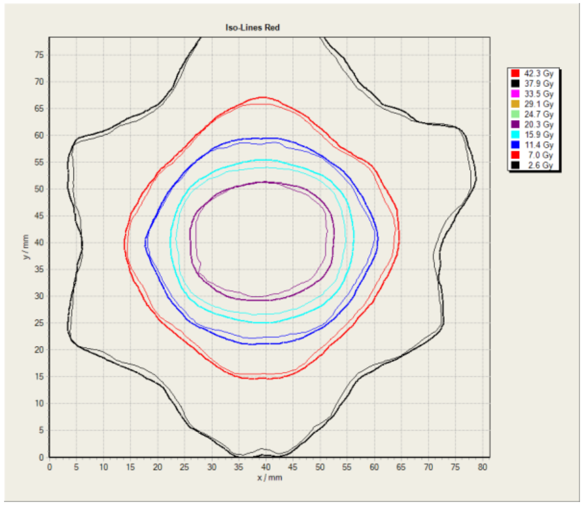
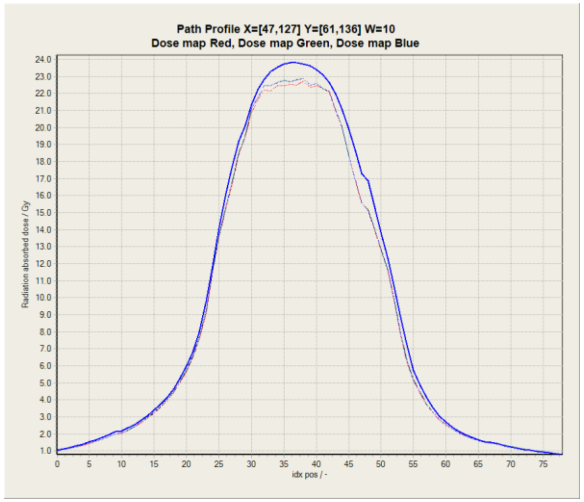
Triple Channel Film Dosimetry
Dynamic Dose Range

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







Example: Calibration range 0 – 30 Gy, Dose map 26 Gy peak

- passing rate 95.96 % @ 2%/2mm

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Triple Channel Film Dosimetry Features and Advantages

- 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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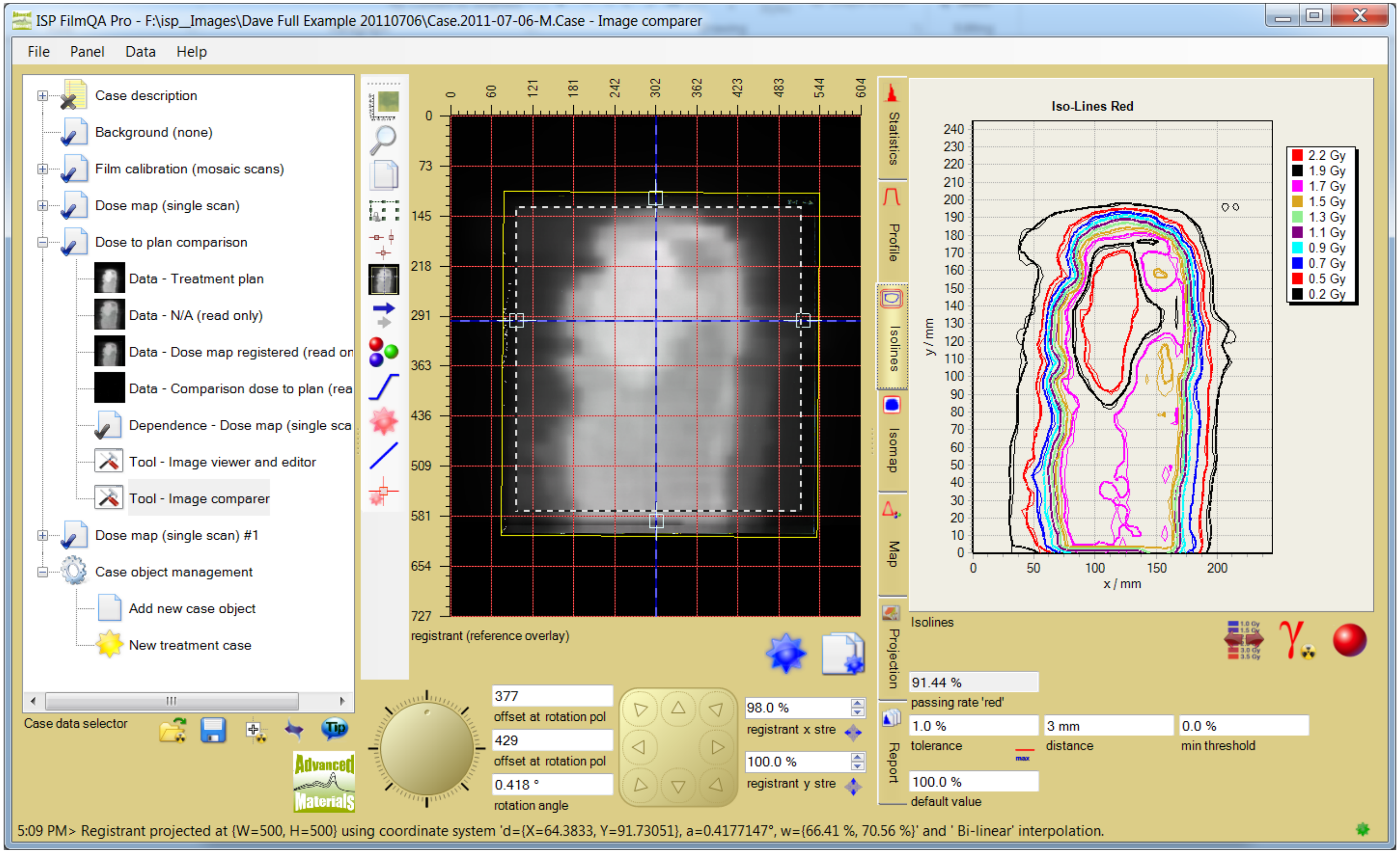

Lit.: Micke, Lewis, Yu - Multi-channel Film Dosimetry with Non-Uniformity Correction, Medical Physics, 38 (2011) 5, pp. 2523.

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