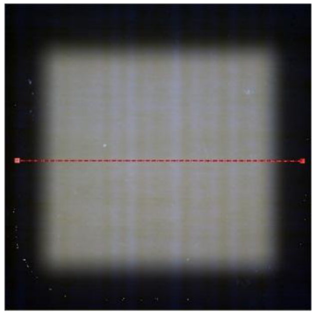
Multi-Channel Radiochromic Film Dosimetry

Adapted from A.Micke

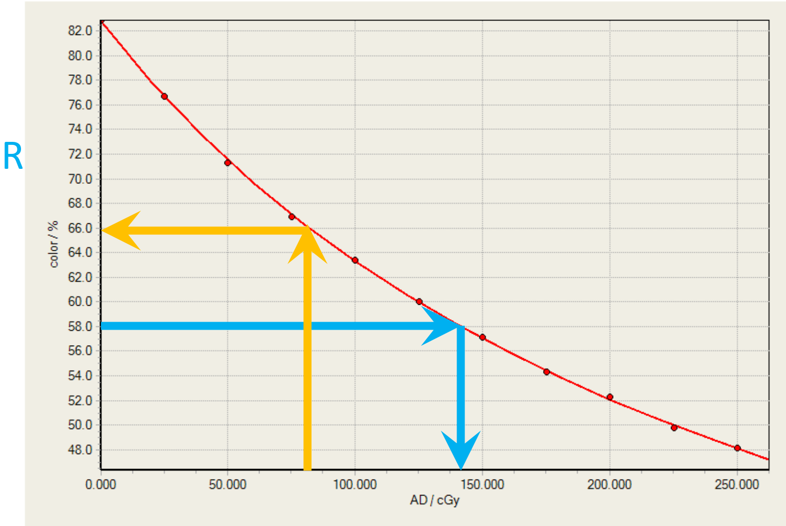
Spain, April 2014

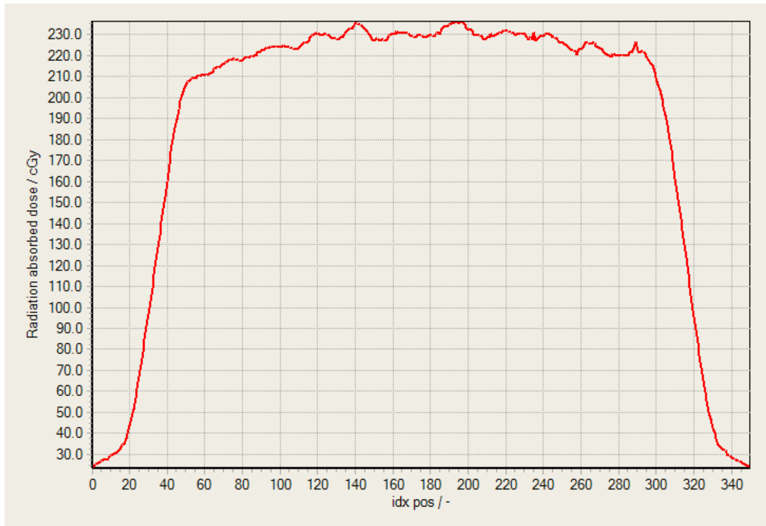
Single Channel Film Dosimetry

- 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:

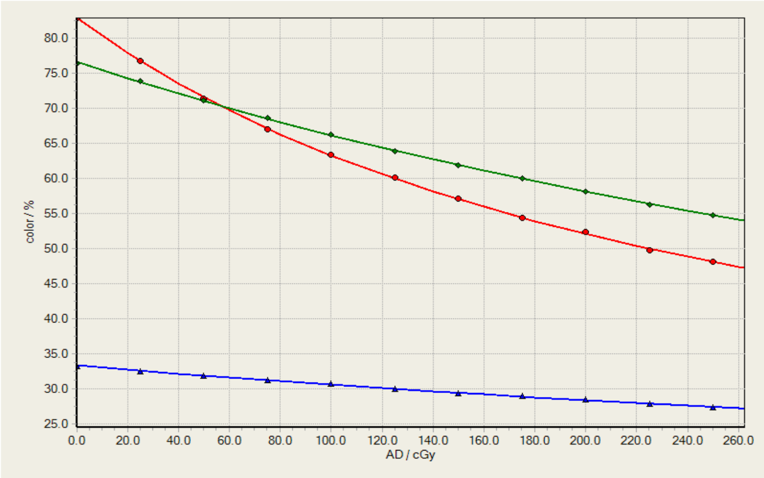
Specific pixel does
not behaves like average

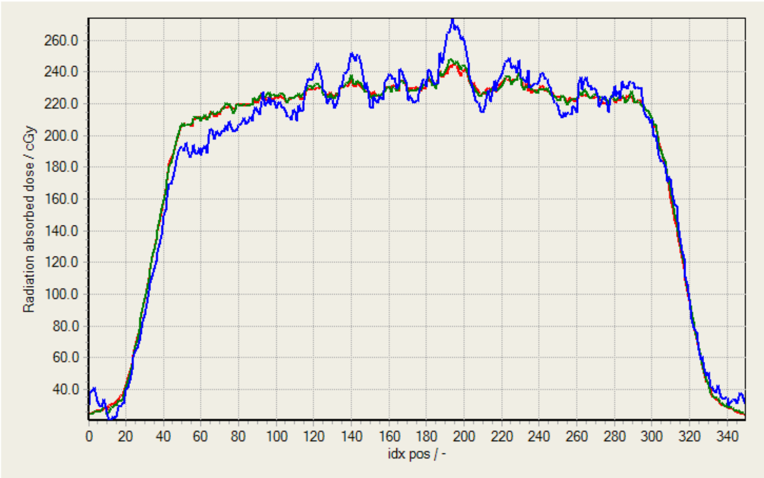
- Disturbance ΔX generates ΔD_X

$X + \Delta X \leftrightarrow D(X) + \Delta D_X$

  - 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?





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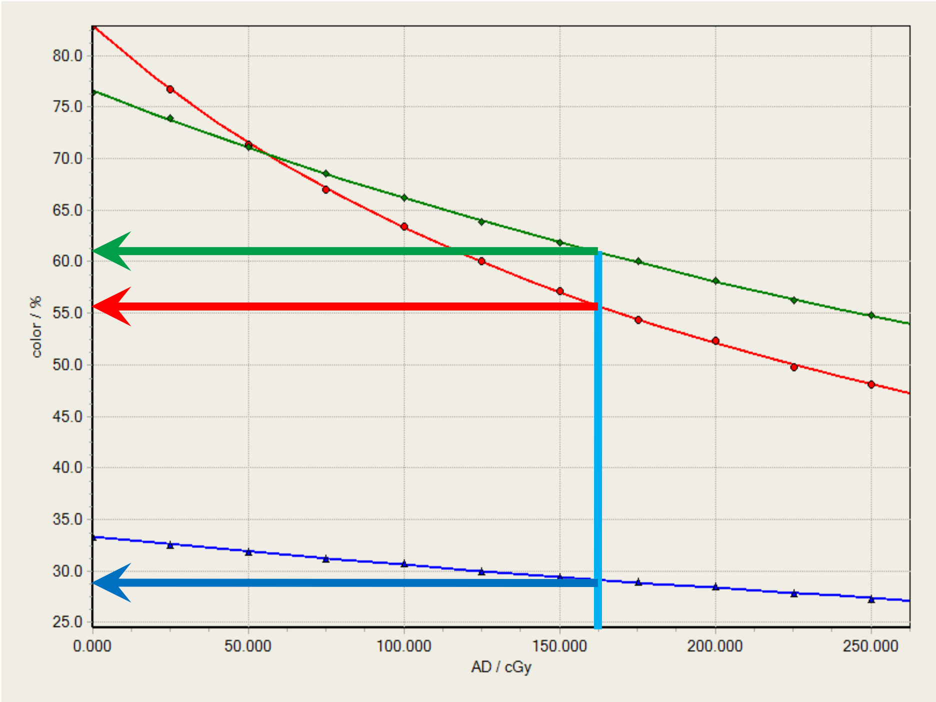
Multi-Channel Film Dosimetry



- 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 $d_{X,scan}$
  - $\mathbf{d_{X,scan}(D) = d_{X,D}(D)}$ * **Δd**d_X = -log(X) for X = RGB
  - $d_{X,D}$ is calibration function (average behavior)
  - ! disturbance Δd independent of dose + X (wave length) !but Δd = Δd(thickness, scanner, noise, artifacts)
- Solution:
  - Minimized function φ *vs.* disturbance Δd:

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

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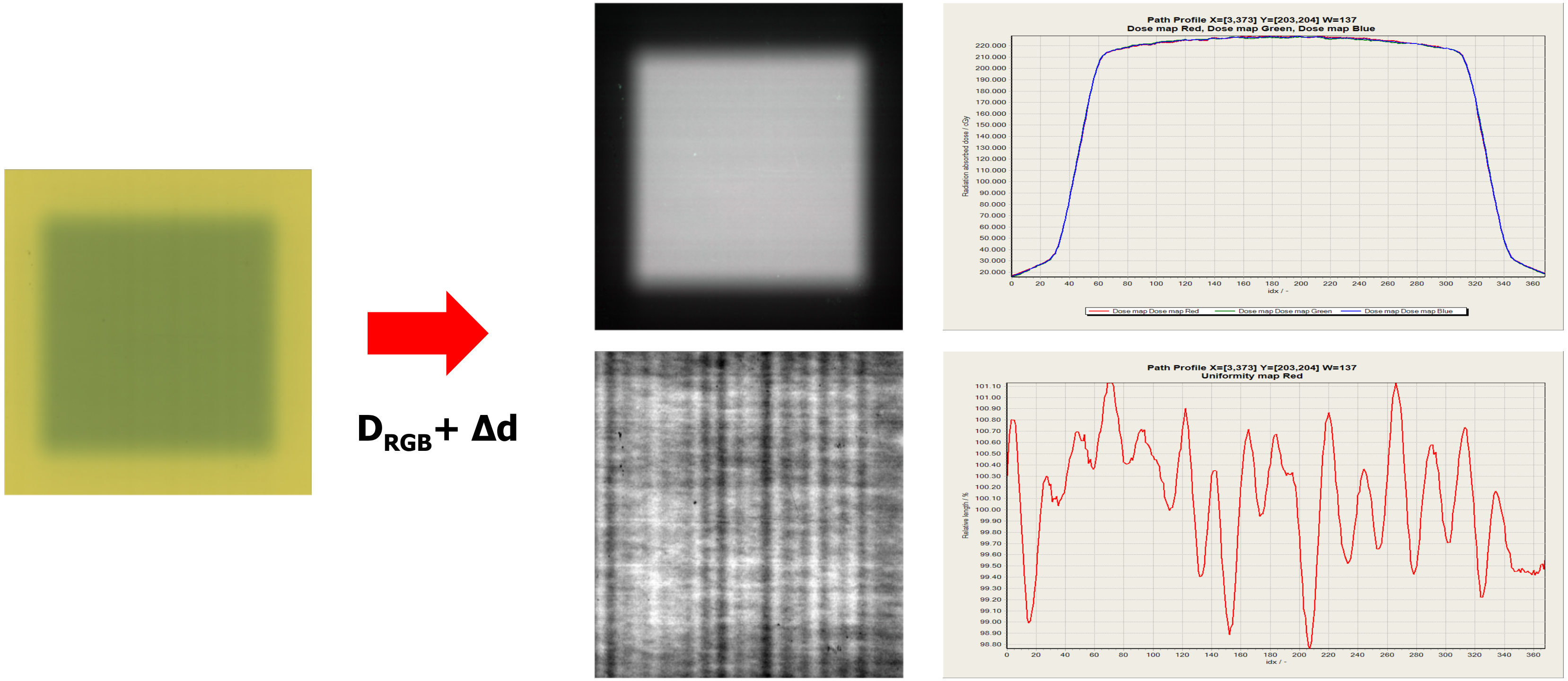
Triple Channel Film Dosimetry Example

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



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

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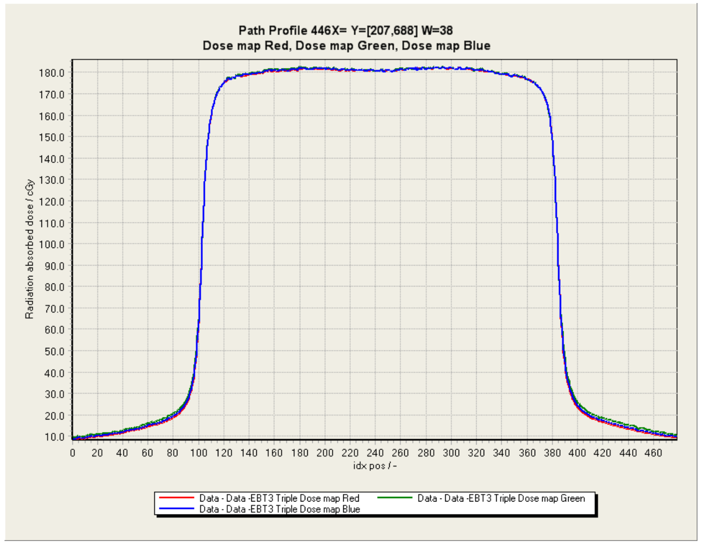
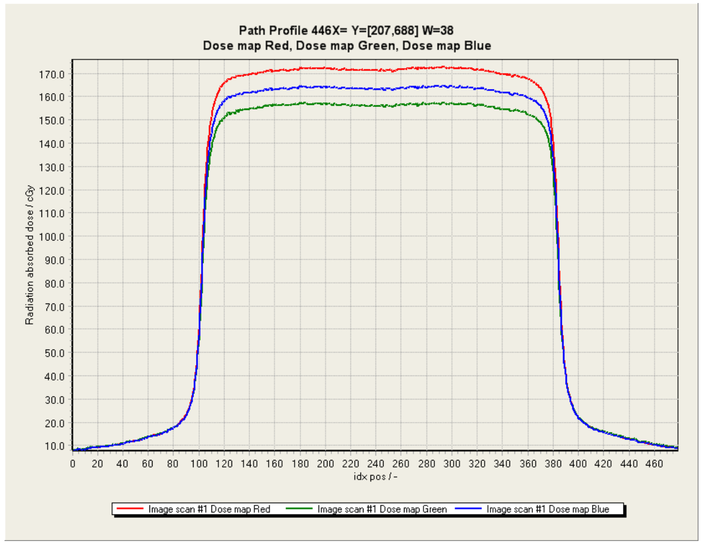
Triple Channel Dosimetry: Dose Consistency

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

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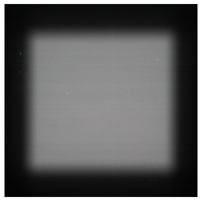
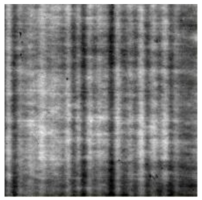
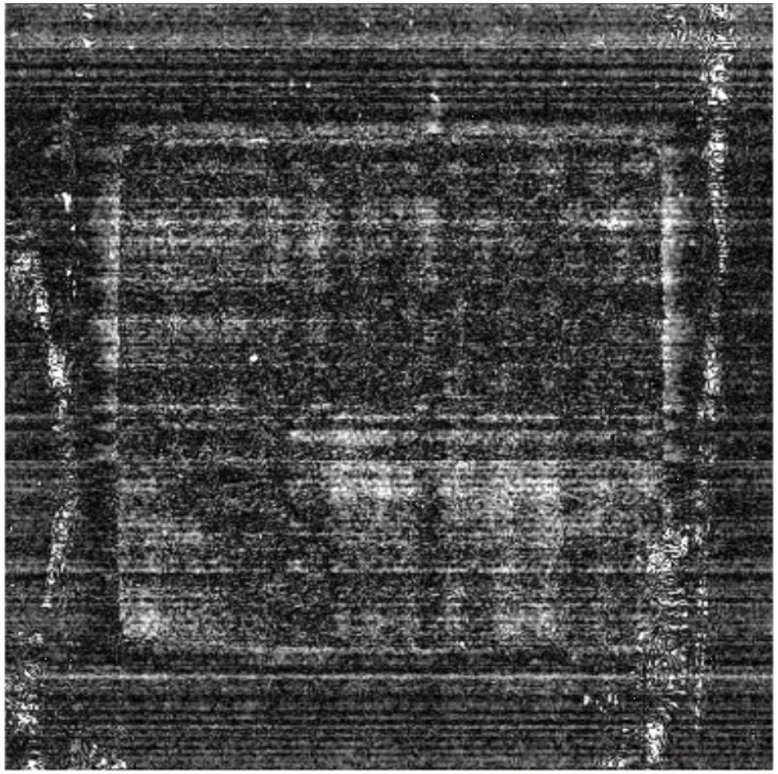
Triple Channel Dosimetry: Consistency Map

- 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

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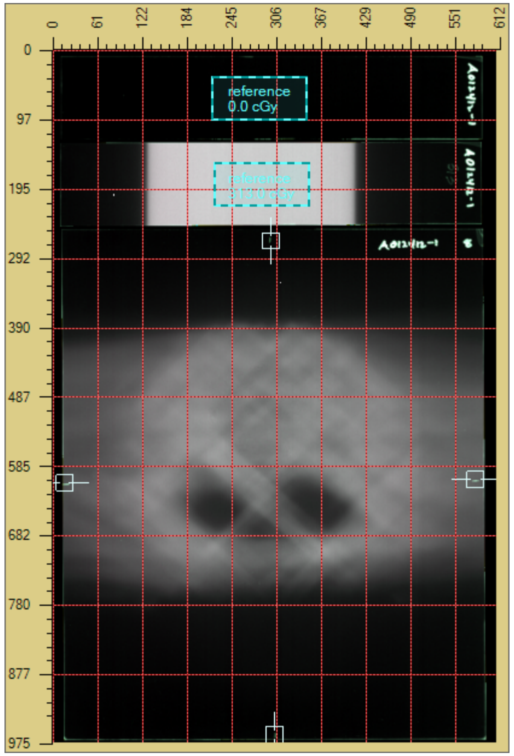
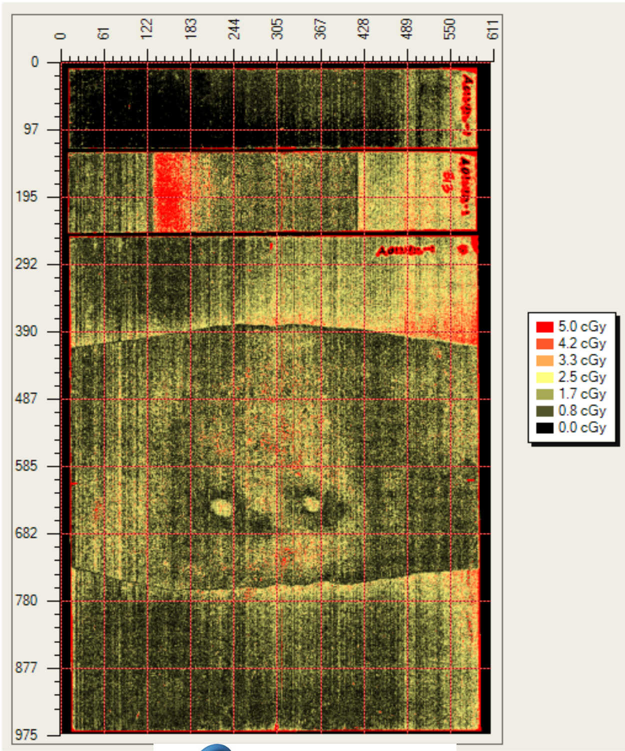
Triple Channel Dosimetry
Dose Map Consistency

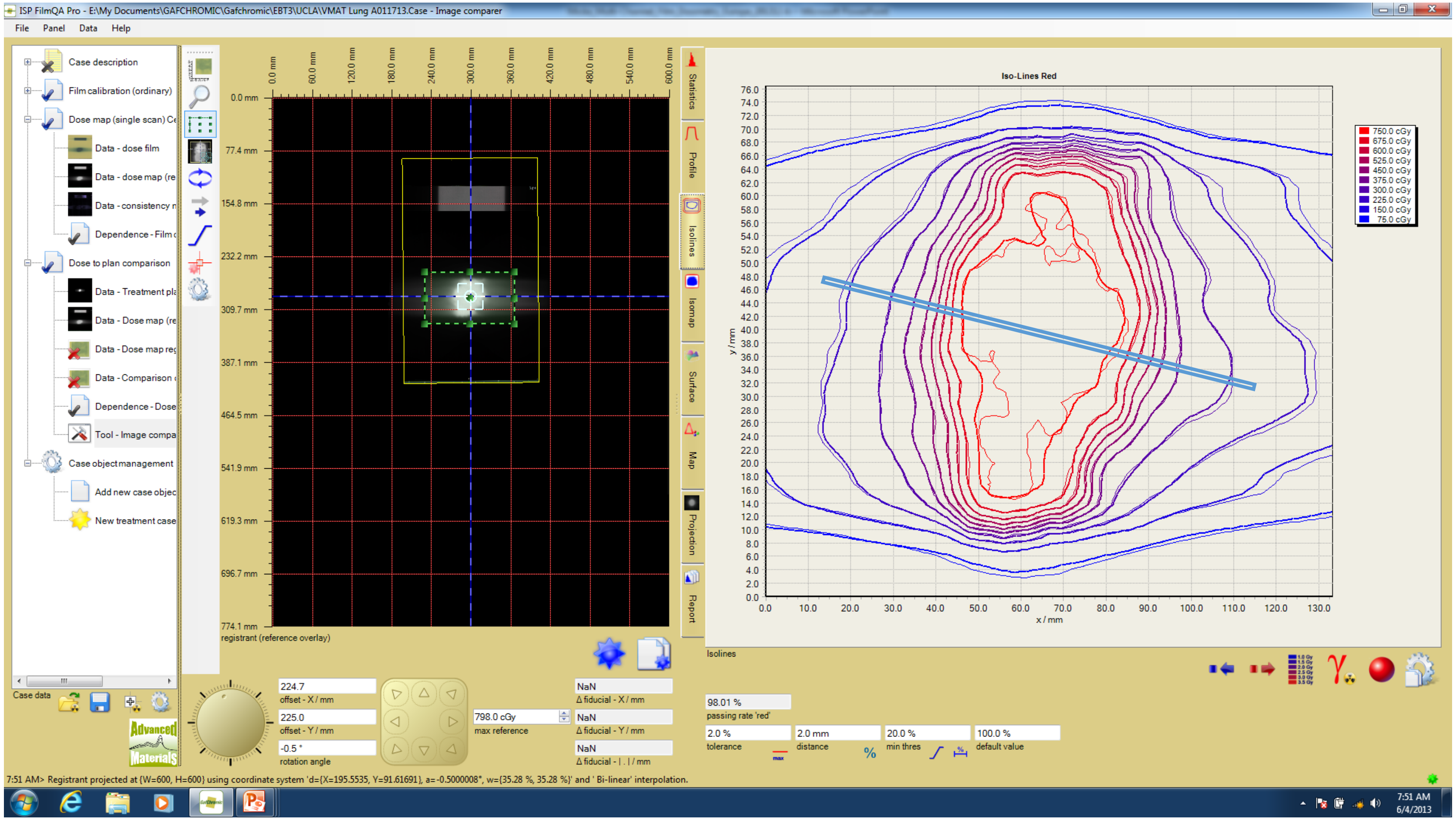
- Dose map error estimation known before comparison
- Detect ‘abnormal’ scans
  - 90° rotation, curling, Newton rings





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

Triple Channel Dosimetry: Film Consistency



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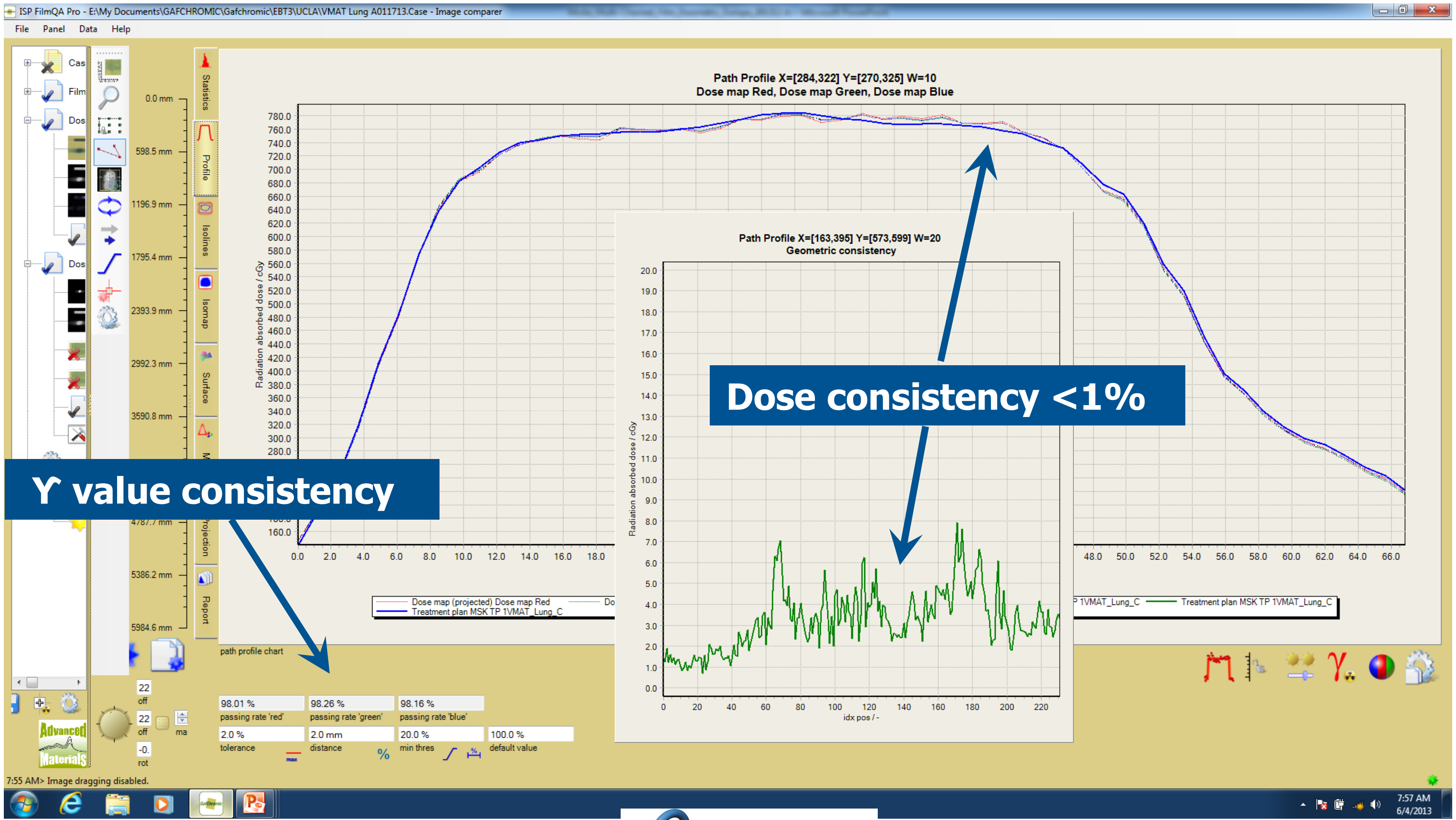
Triple Channel Dosimetry: Dose Consistency



One-scan Dosimetry: Stretching and Scaling

- **Fitting Function**
  - **$x(D) = j + k/(D-l)$** - j,k,l are coefficients to be fitted
- **Assumption**

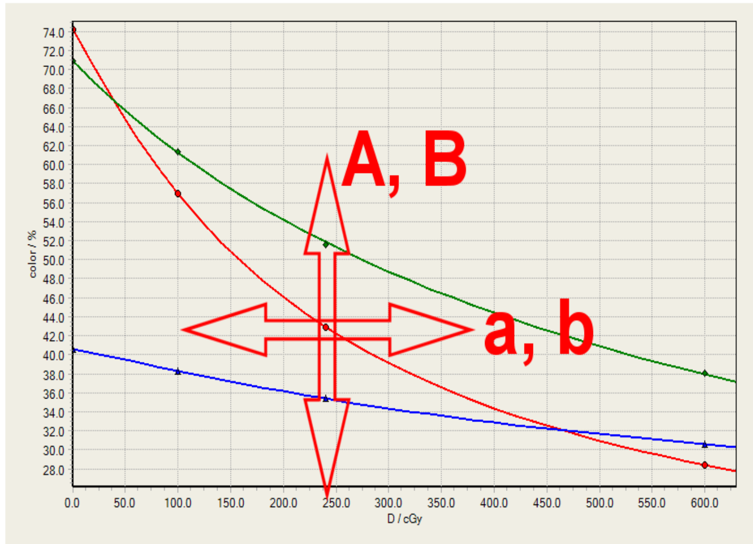
  Calibrations have the same shape

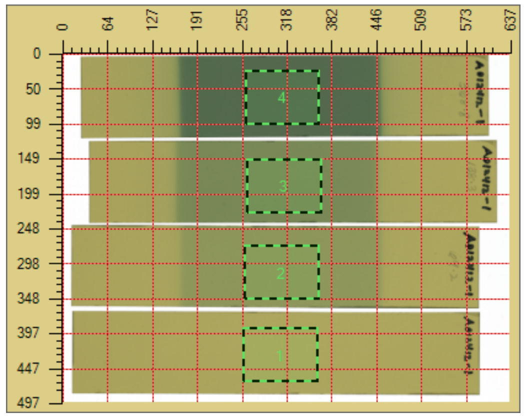
  $X(D) = A+B.x(D) = A+B(j+k/(D-l))$
- **General case**
  - **$X(D) = A + B\, x(a + b D)$**

    X = RGB

    rescales calibration x

    a, b dose scaling, A, B color scaling





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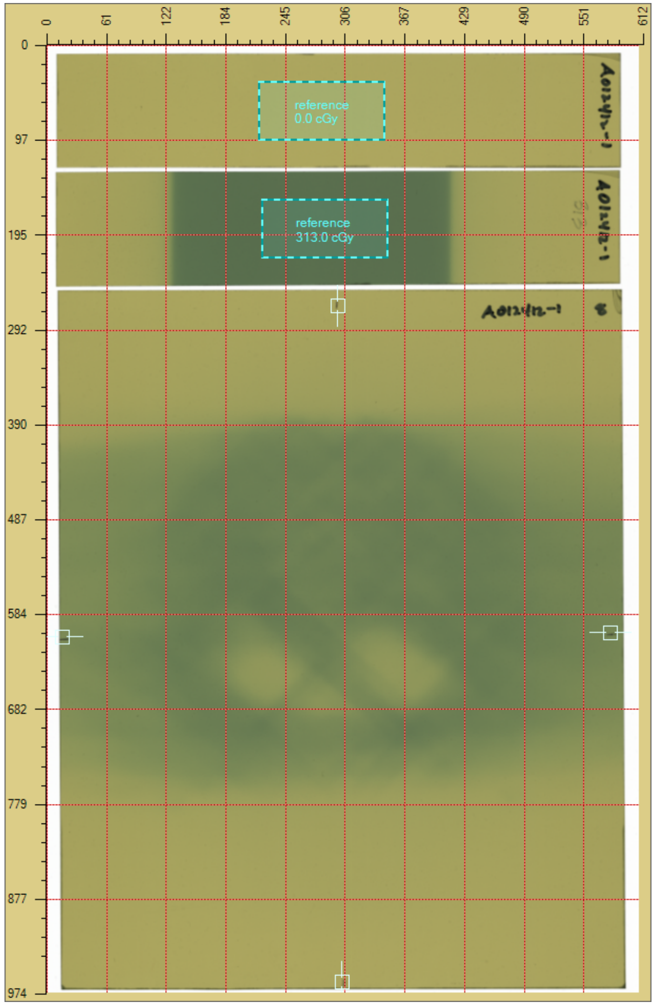
Two Point re-Calibration

- **Two point recalibration**
  - 1 unexposed + 1 exposed film
    Minimum 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
- **"One-scan" Evaluation**

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



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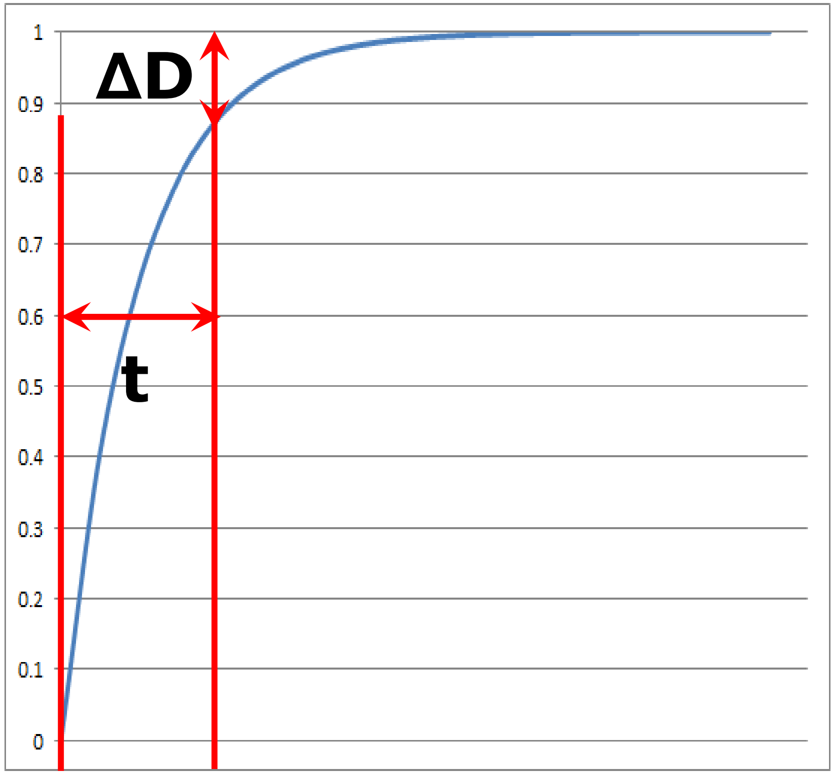
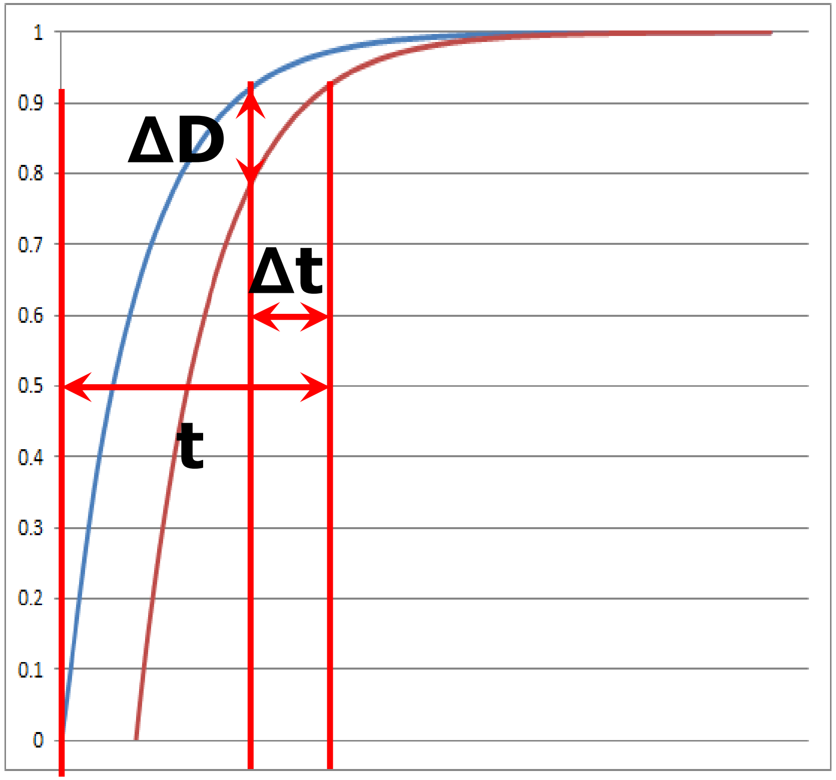
Rescaling and Post Exposure Aging





Absolute aging
wait t = 24 hΔD(t) < 0.5%

Relative aging
wait t = 4 Δt ΔD(t) < 0.5%

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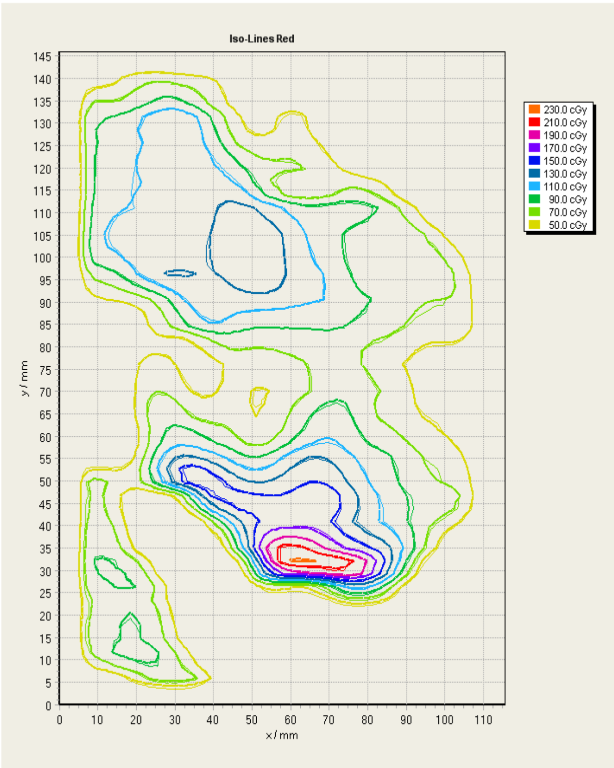
IMRT Plan Examples vs. Time

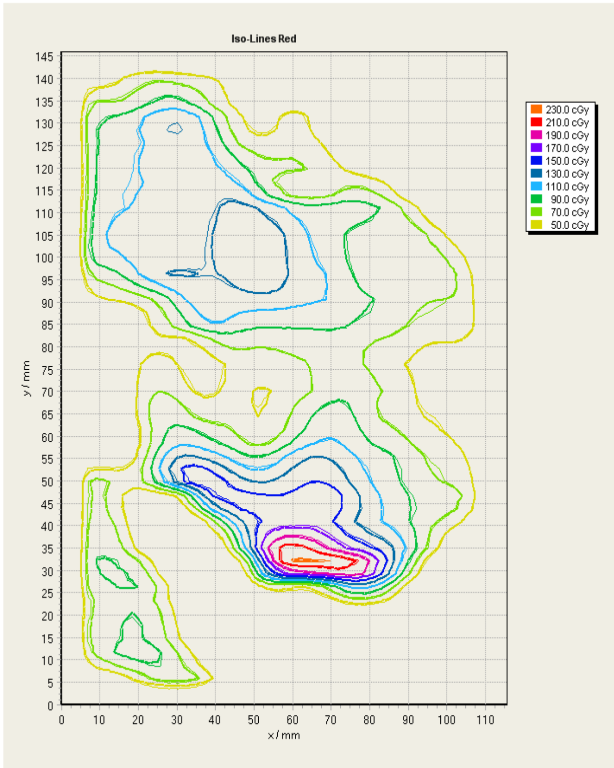
Calibration films scanned two hours after exposure

Patient/reference films scanned at various times



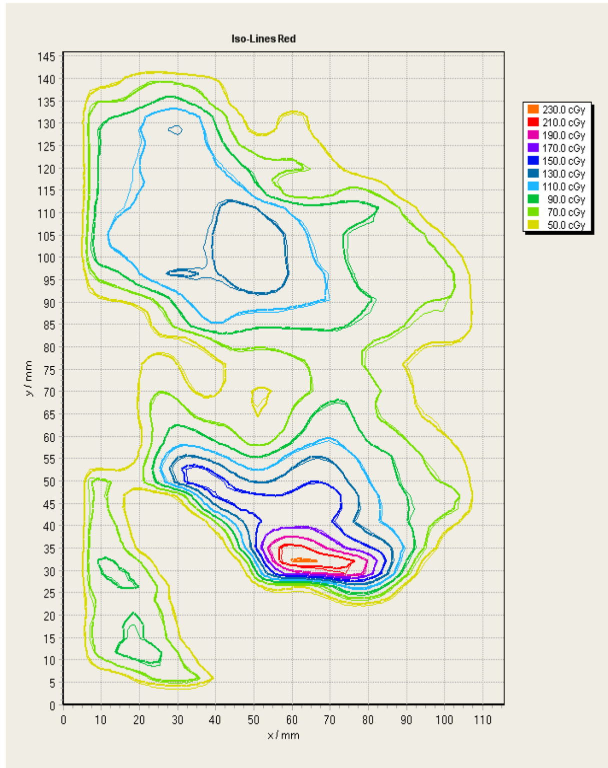
30 min. after

97.9% @2%/2mm



4 hours after

97.7% @2%/2mm



3 days after

97.9% @ 2%/2mm

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Consistency of Color Channels

Time after exposure		Gamma % passing for 2%@2mm		
Calibration	Patient film and reference	Red	Green	Blue
2 hr	30 min.	97.9	97.0	97.6
2 hr	60 min.	97.6	96.2	97.3
2 hr	4 hr	97.7	96.3	97.3
2 hr	24 hr	97.9	97.0	97.8
2 hr	72 hr	97.9	97.6	97.9

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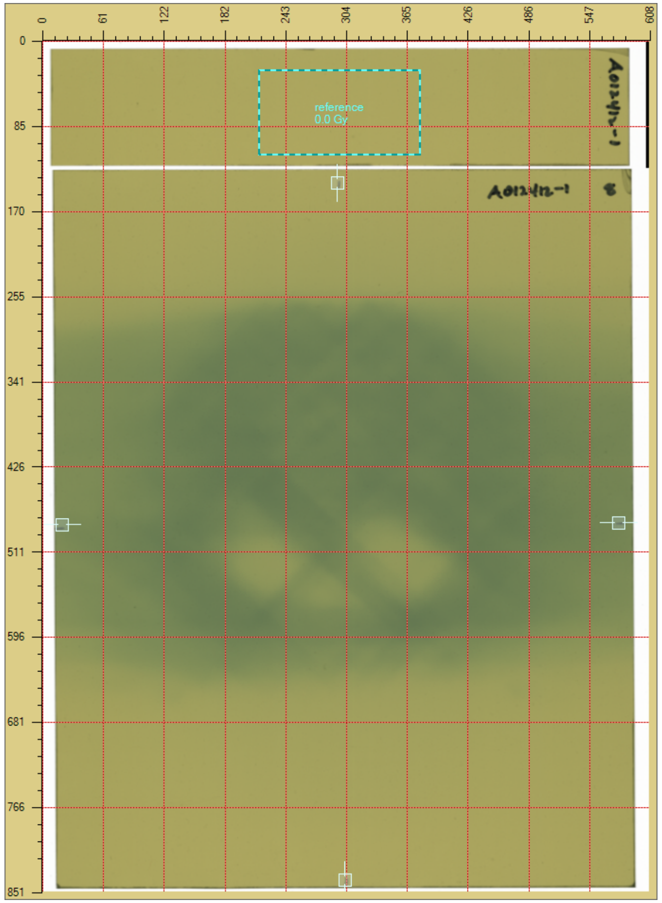
Single Point re-Calibration

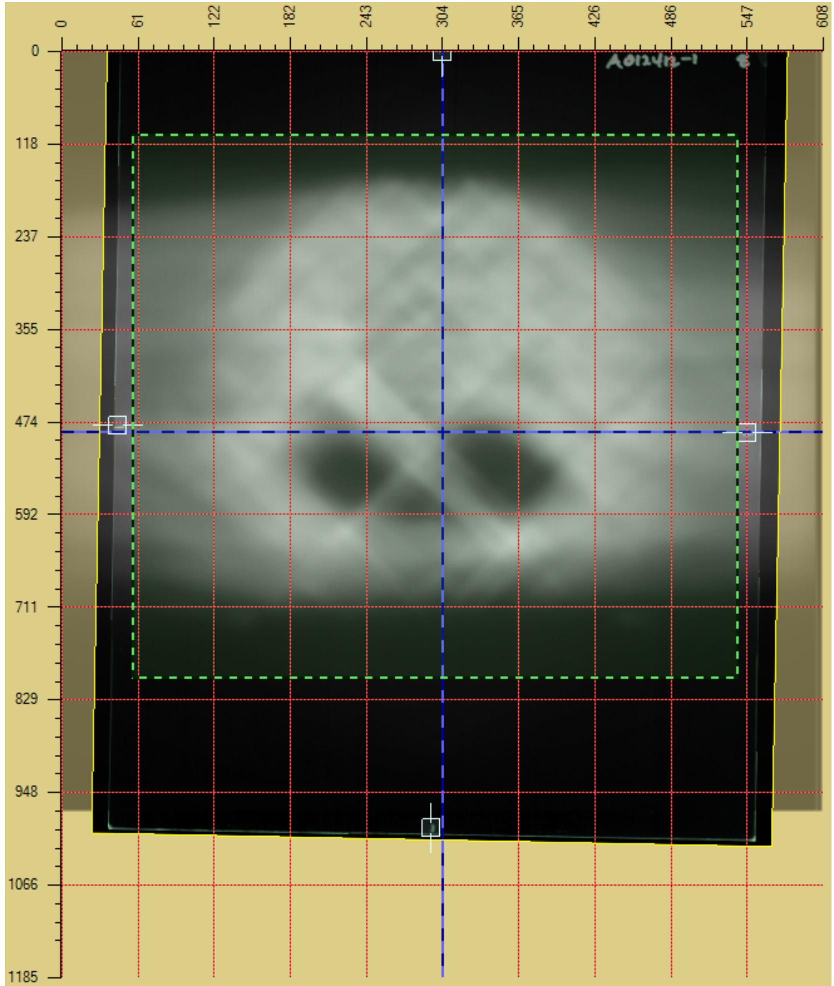
- **Single point recalibration**
  - 1 unexposed
    it's **free** and always possible
  - *Dose* shift (A=0, B=1, b=1)
    X(D) = x(a + D) , X = RGB
  - *Color* shift (a=0, b=1, B=1)
    X(D) = A + x(D) , X = RGB
- **Assumption**
  - Calibration functions keep shape
    Shape(x) = Shape(X) , x, X=RGB
    disturbance caused by offset only
- **Single scan Evaluation**

  compensates for
  - Offset generating disturbances



Dosimetry with Re-Calibration

Recalibration Comparison Triple Channel Method			
	None	1 point recalibration	2 point recalibration
Passing rate 3%/3mm	99.6	99.8%	99.9%
Passing rate 2%/2mm	94.3%	96.3%	97.1%
Example range: D_{max} = 243 cGy, D_{ave} = 139 cGy			



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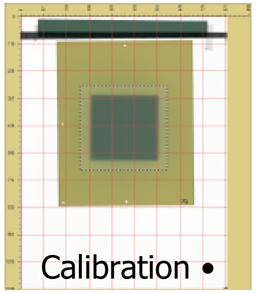
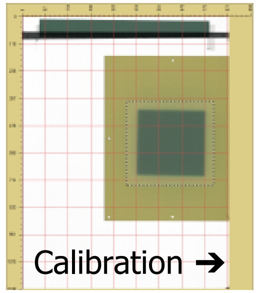
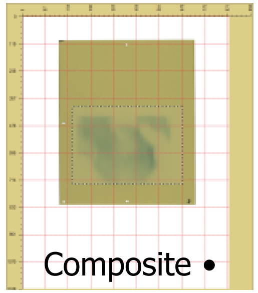
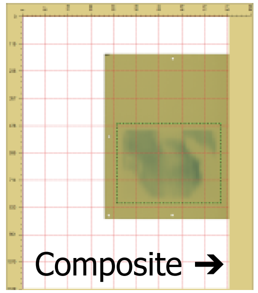
Lateral Scanner Non-Linearity
Single vs. Triple Channel

Gamma map Criterion	Calibration	Composite	Passing rate	
			Single Channel	Triple Channel
2% / 2mm	•	•	90%	96%
	→	→	87%	96%
	•	→	98%	98%
	→	•	94%	97%
	• = centered → = right edge		absolute dosimetry (no dose re-scaling), <5% (<12cG) lowest dose ignored,	

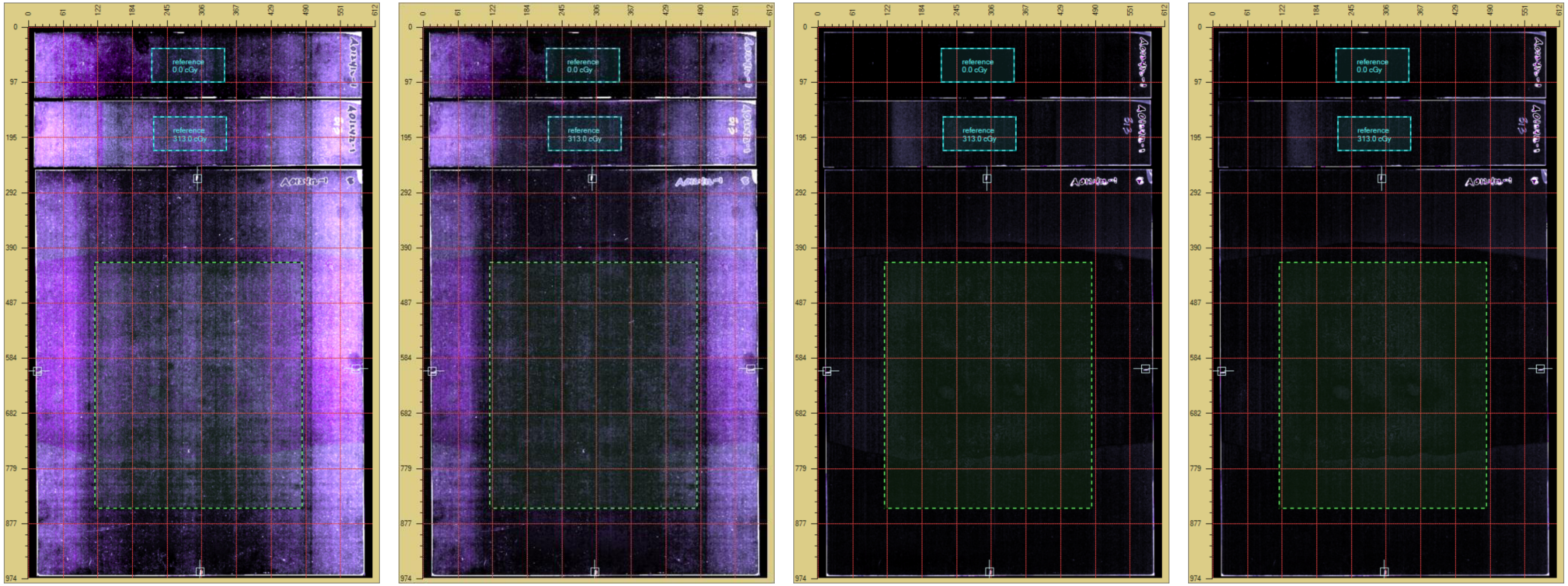








Consistency Comparison

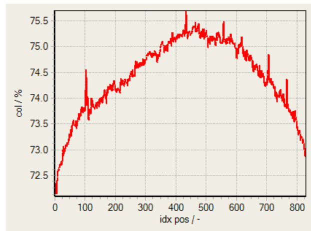


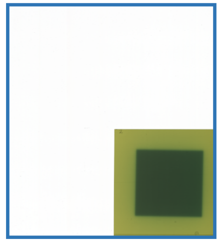
Single Channel	Single Channel Recalibrated	Multi Channel	Multi Channel Recalibrated
10.2 cGy	3.6 cGy	1.3 cGy	1.2 cGy

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

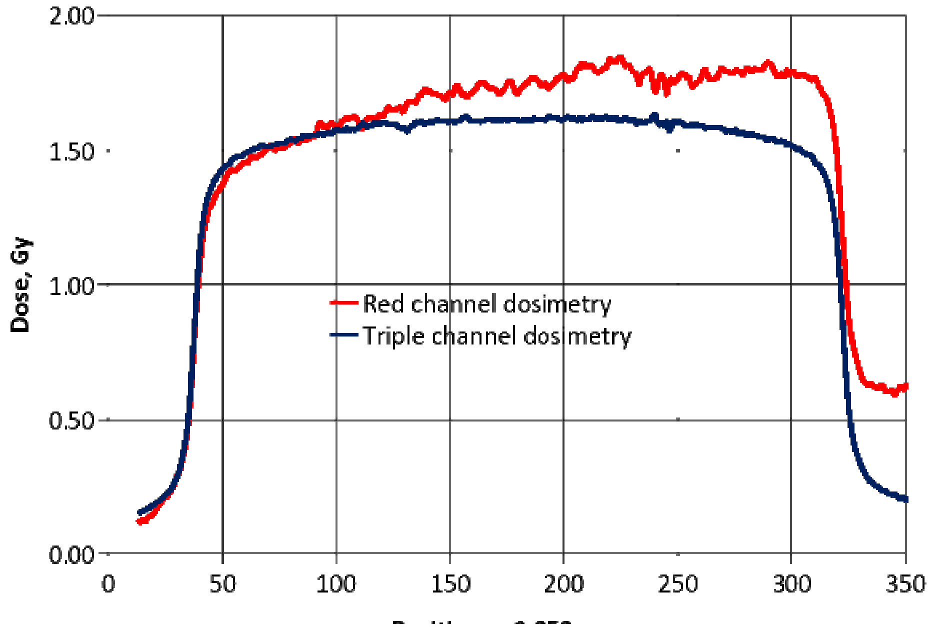
Triple Channel Dosimetry
Lateral Scanner Non-Linearity

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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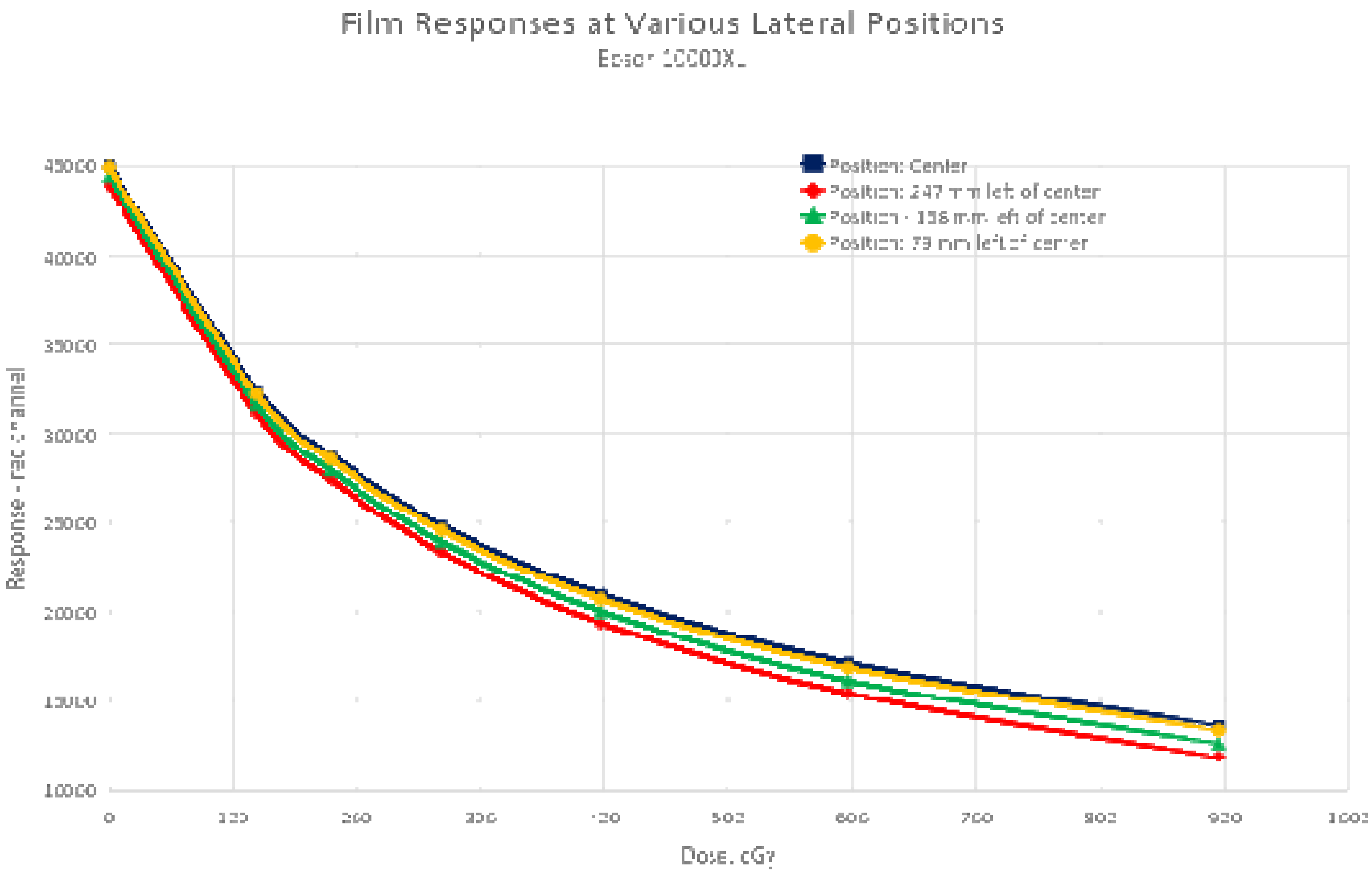
Lateral Response Artifact



Response Scaling

For any dose D at any two lateral positions P and p, film responses are related by

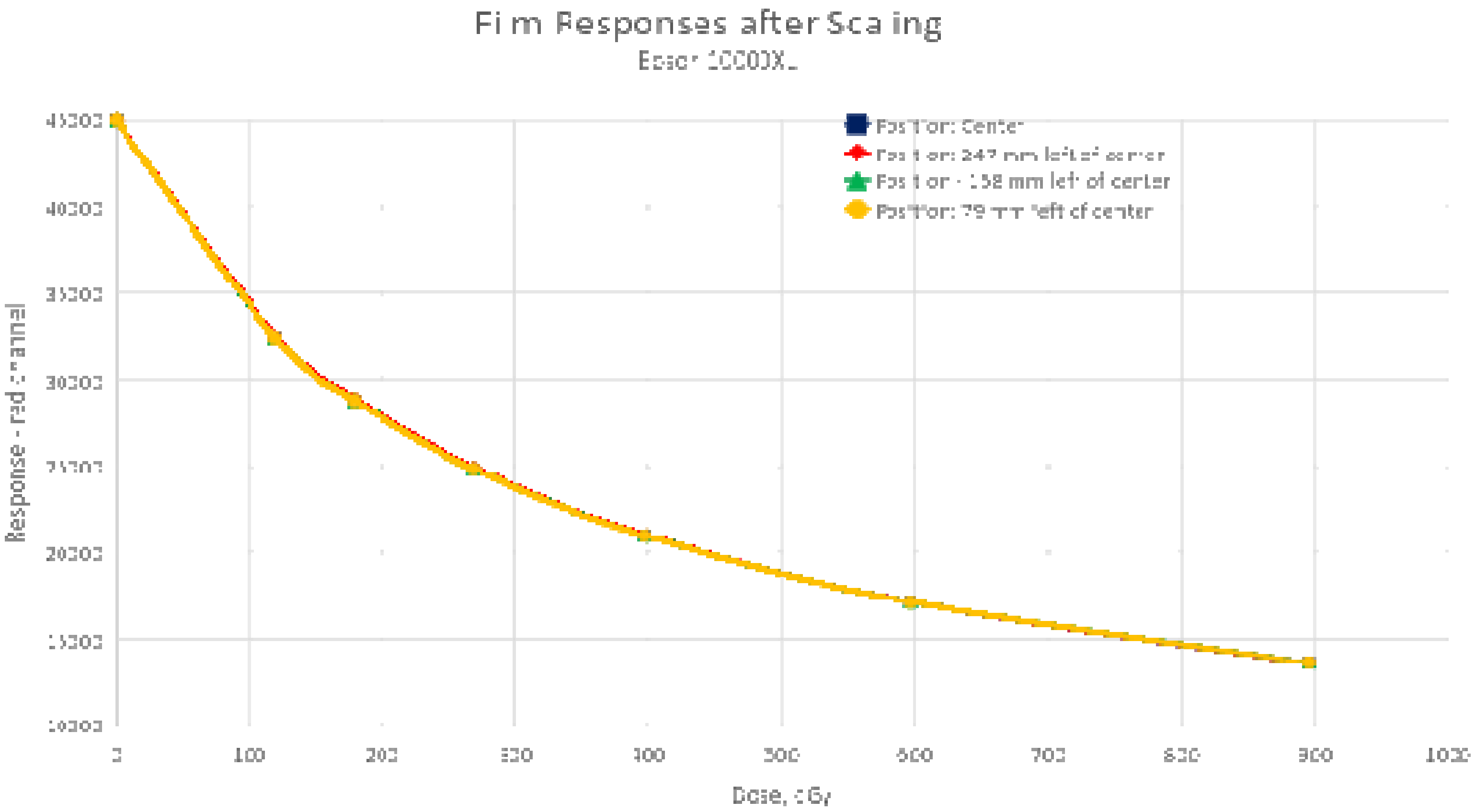
$$\text{Response}(P,D)=a_{P,p} + b_{P,p}*\text{Response}(p,D)$$

where $a_{P,p}$ and $b_{P,p}$ are constants

Measure responses at two doses to determine $a_{P,p}$ and $b_{P,p}$

- One exposed film and one unexposed film
- Position P is the lateral center of the scanner

Lateral Response Scaled (Corrected)



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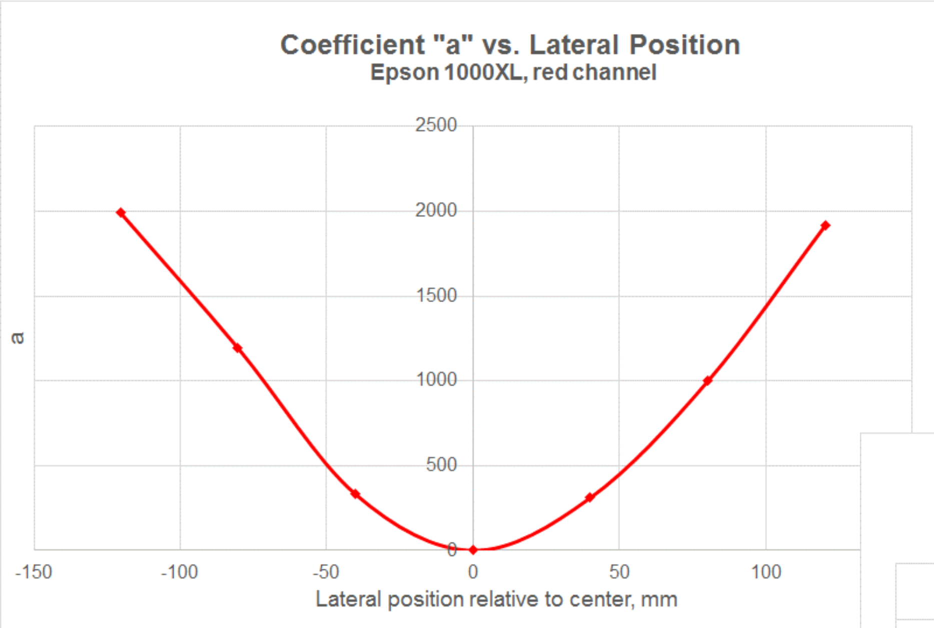
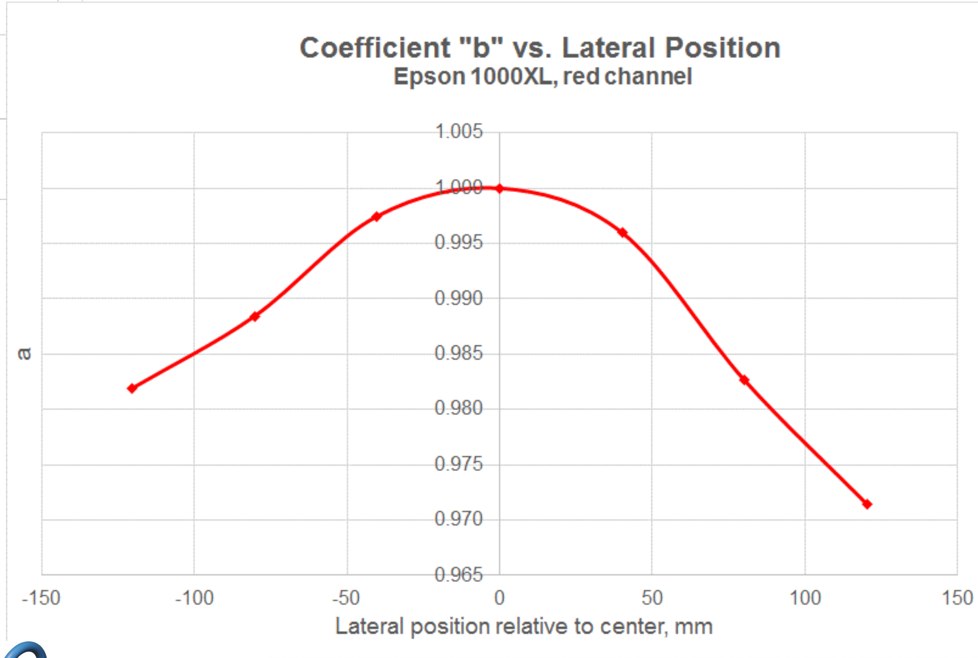
Coefficients vs. Position





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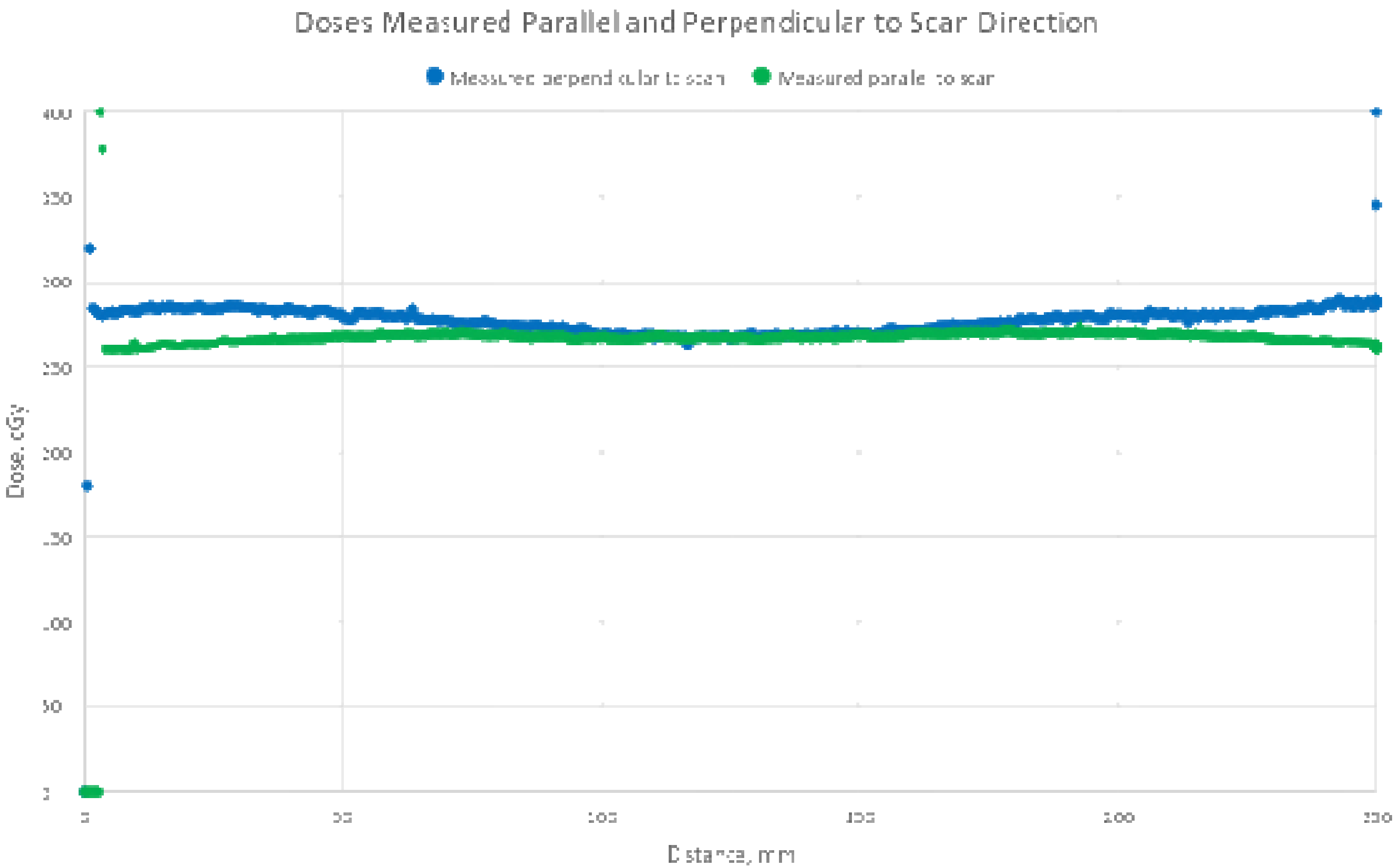
Lateral Artifact and Dose Measurement



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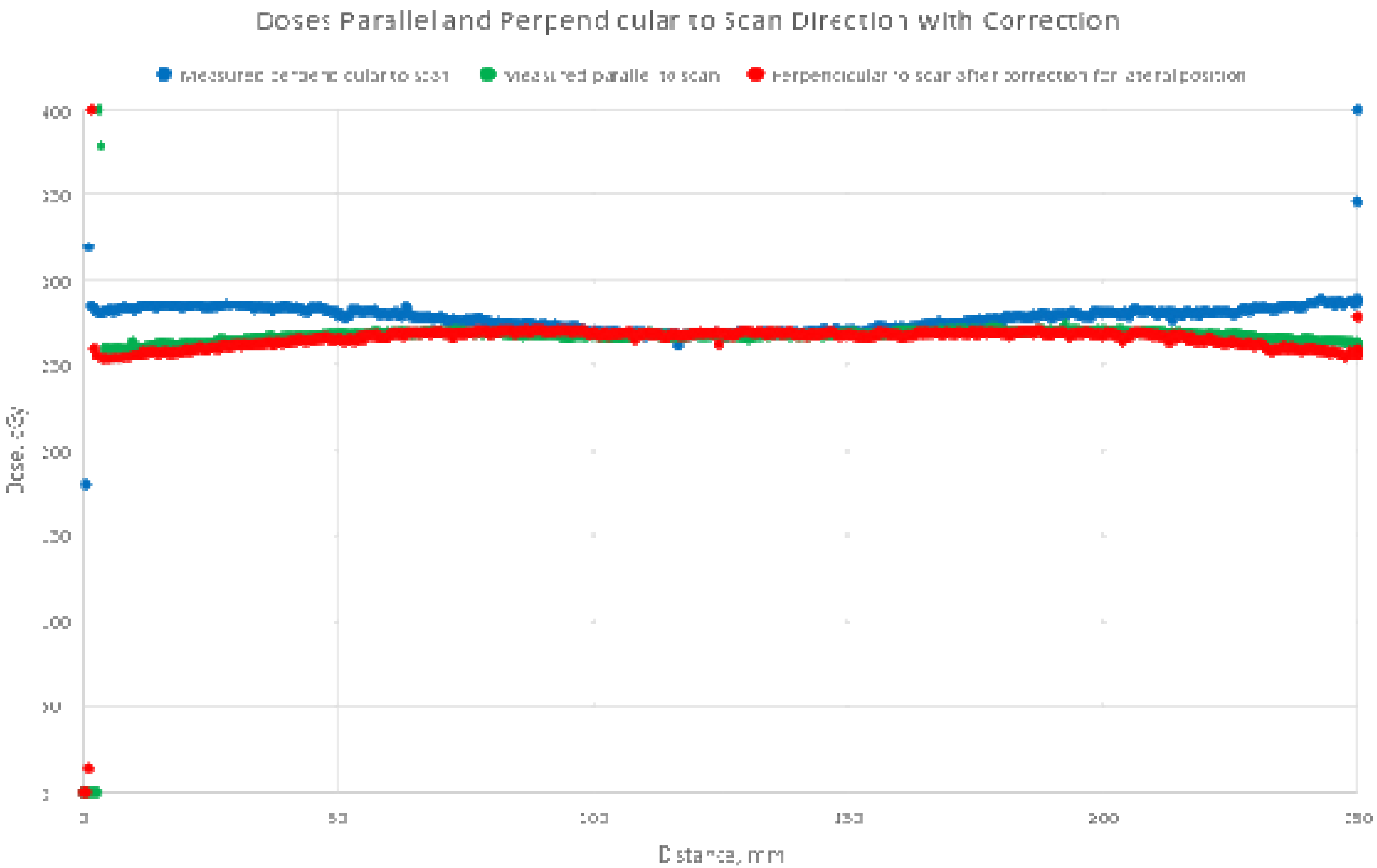
Lateral Artifact Corrected



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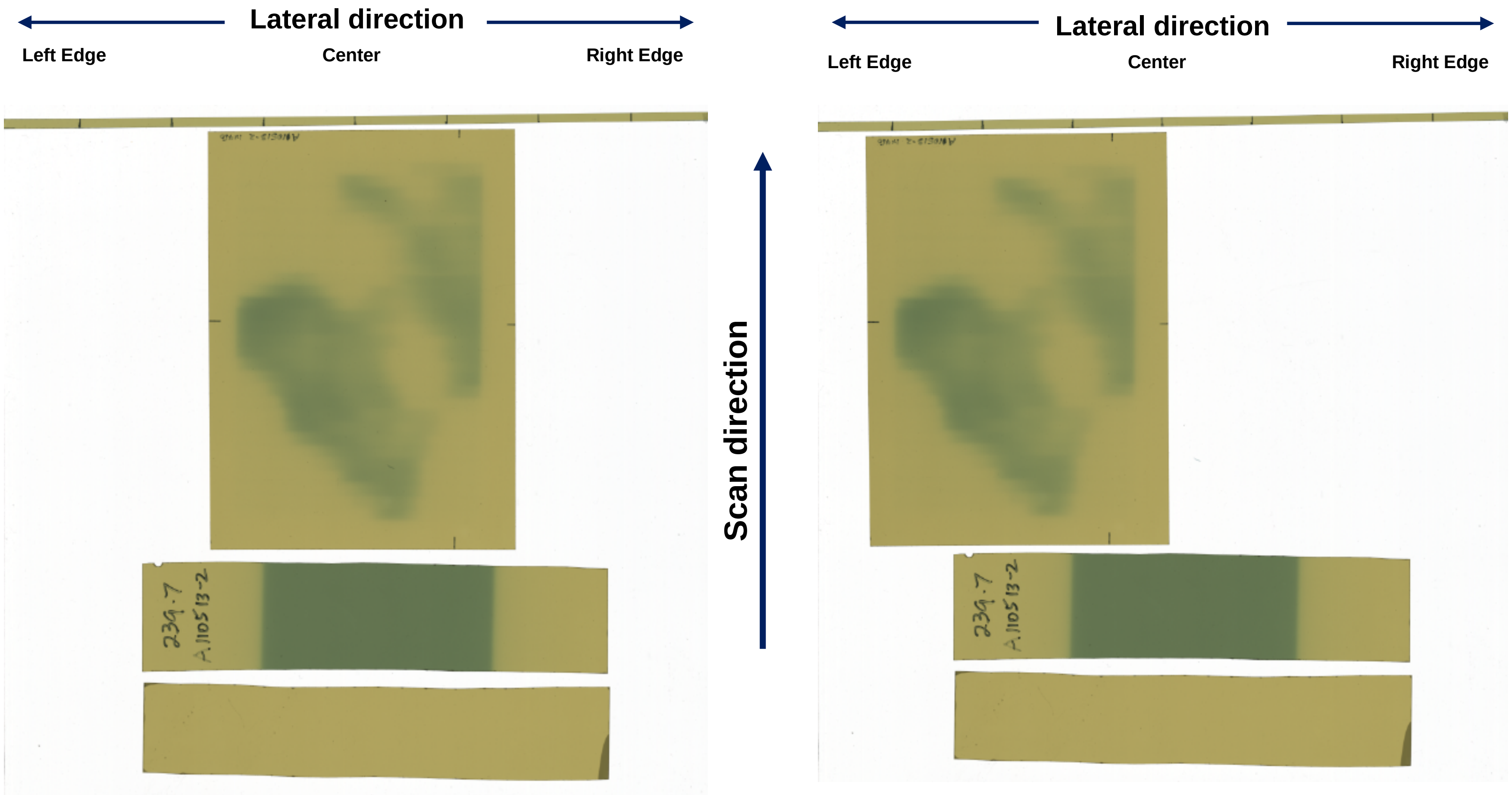
Testing Lateral Response Compensation



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Testing Lateral Response Compensation

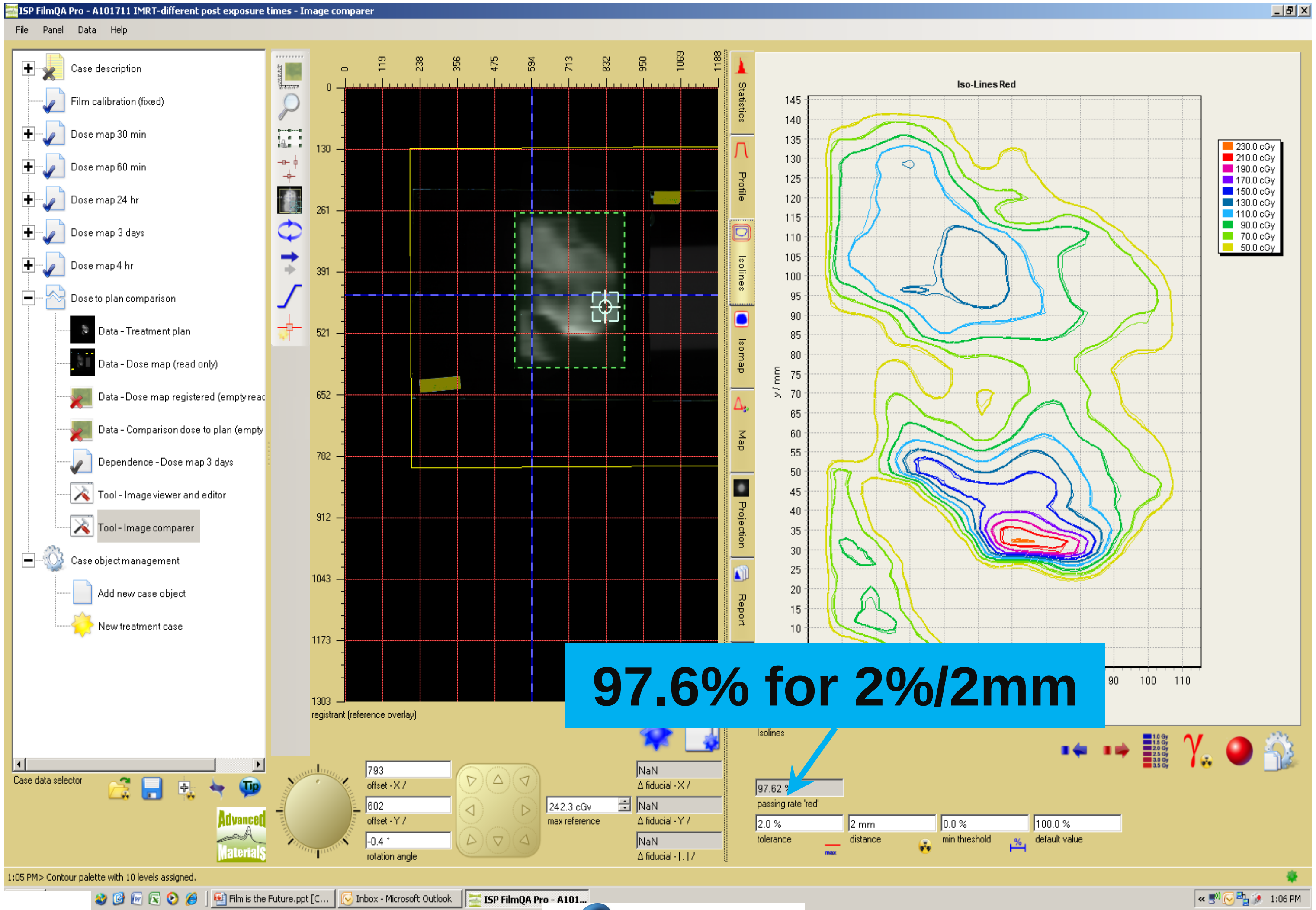
Results for IMRT Films Scanned in Different Lateral Positions			
Dose to Plan Comparison - Gamma test: % passing for 2%/2mm criteria			
	Extreme left edge[1]	Center of Scanner	Extreme right edge
No correction for lateral position	84.3	94.9	94.6
Responses corrected for lateral position	97.3	97.2	97.1

1. In this position the high dose areas on the film are at the edge of the scan window

Inadequacy of the 3%/3mm Gamma Evaluation Metric

- "Recent studies have demonstrated that per-beam IMRT QA passing rates may not predict clinically relevant patient dose errors" *Chan, et al., Technology in Cancer Research and Treatment, June 24 2013.*
- "….IMRT and VMAT commissioning, along with product validation, would benefit from the retirement of the 3%/3mm passing rates as a primary metric of performance and the adoption instead of tighter tolerances ……" *Nelms et al., Med. Phys. 40(11) 2013, 111722.*
- " … if gamma criteria are made more stringent (say 2%/2mm or less), the passing rate is a potentially useful metric to optimize for phantom dose analysis" *Nelms et al., Med. Phys. 38(10) 5477.*

Single IMRT Field- Multi-channel, 'One-scan'



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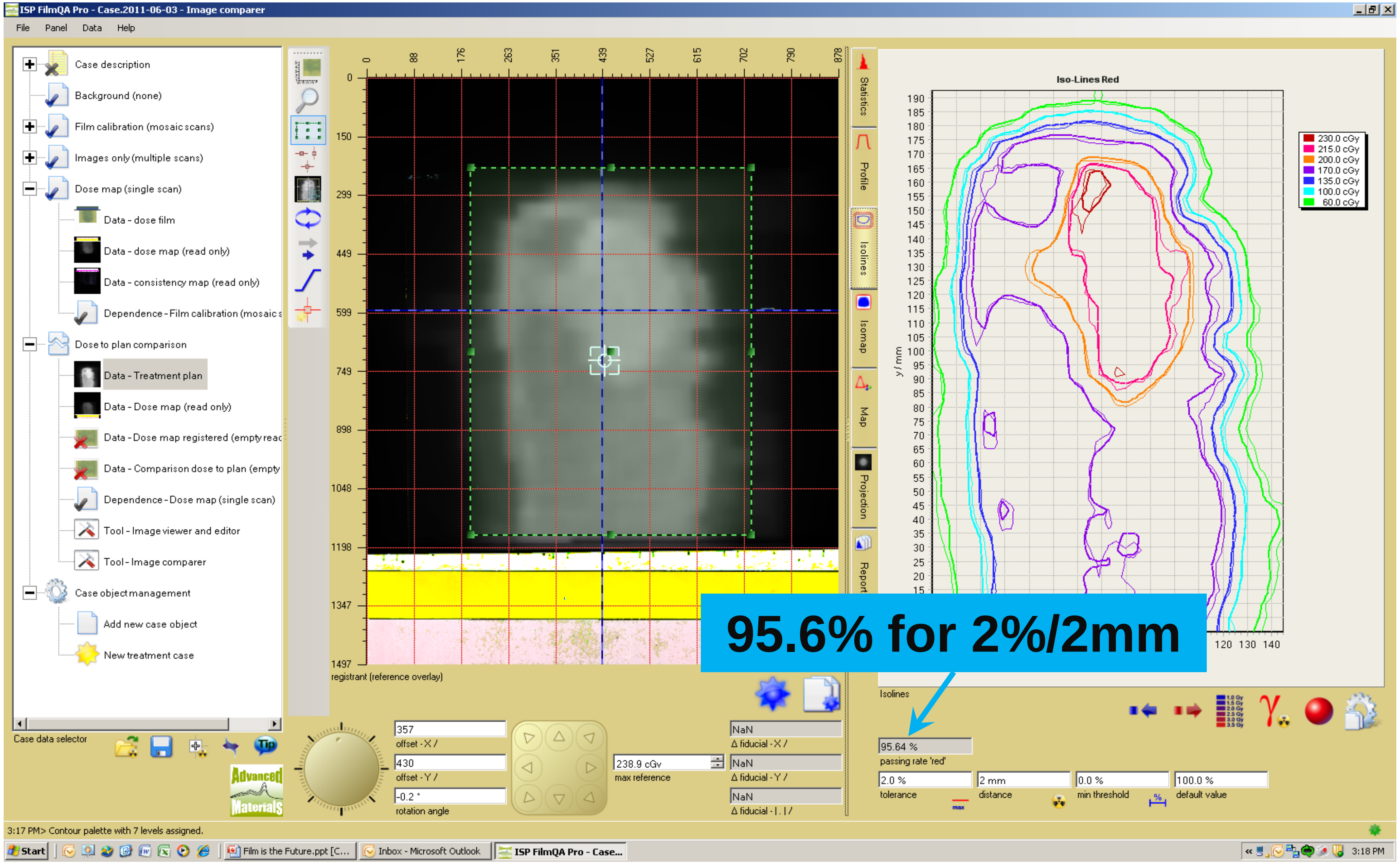
Composite IMRT-Multi-channel, ‘One-scan’



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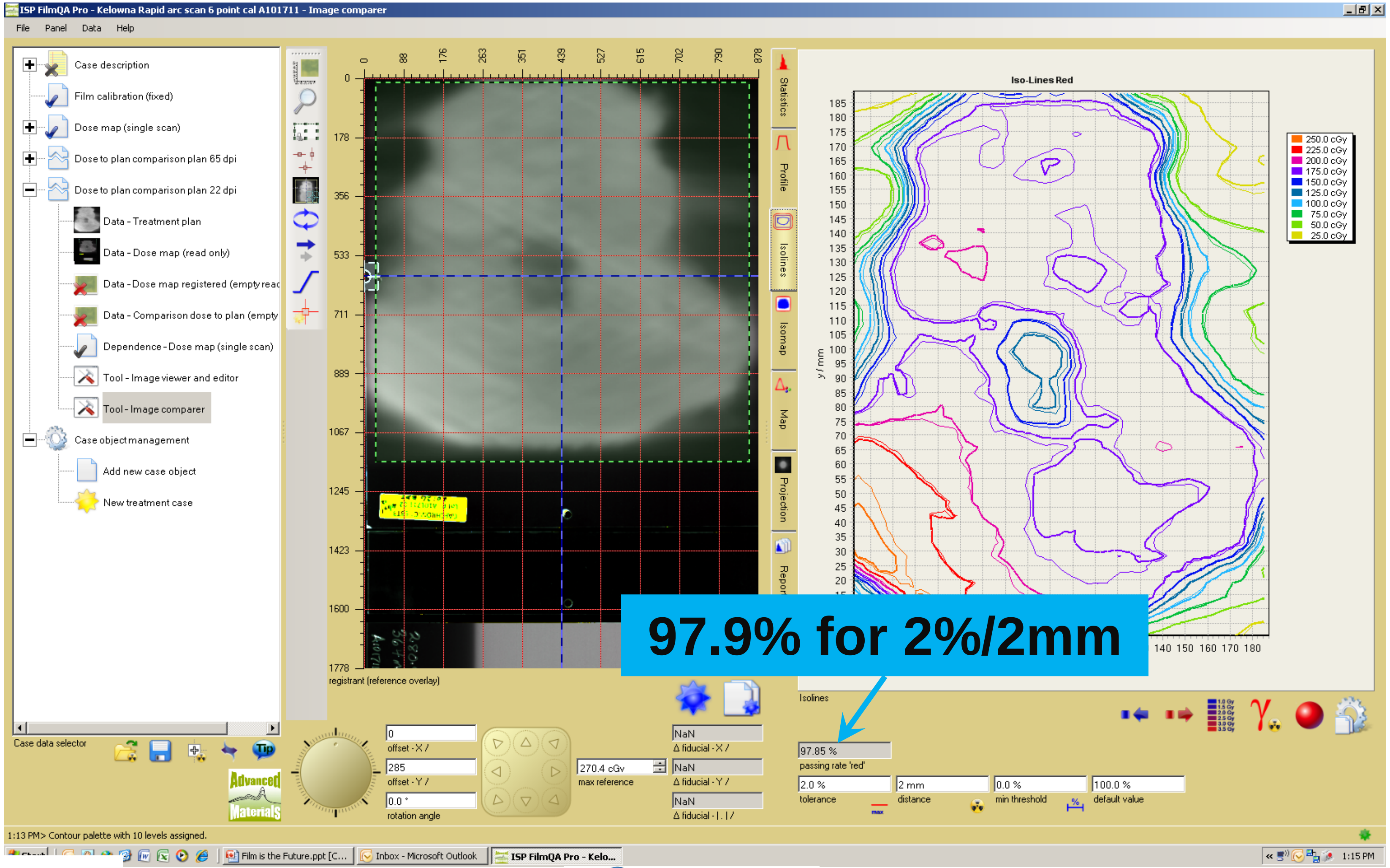
RapidArc™, One arc-Multi-channel, ‘One-scan’



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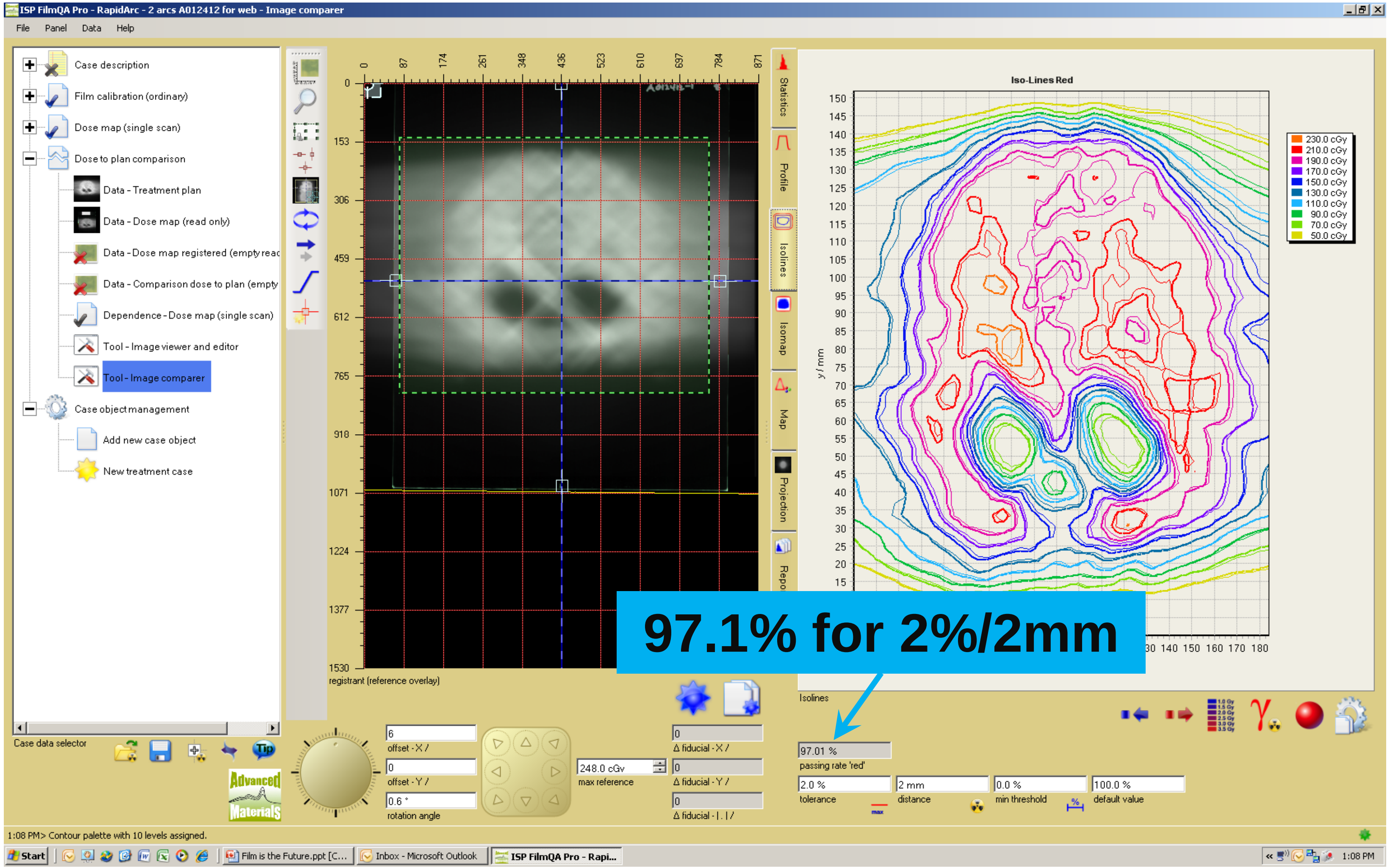
RapidArc™, Two arcs-Multi-channel, ‘One-scan’



97.1% for 2%/2mm

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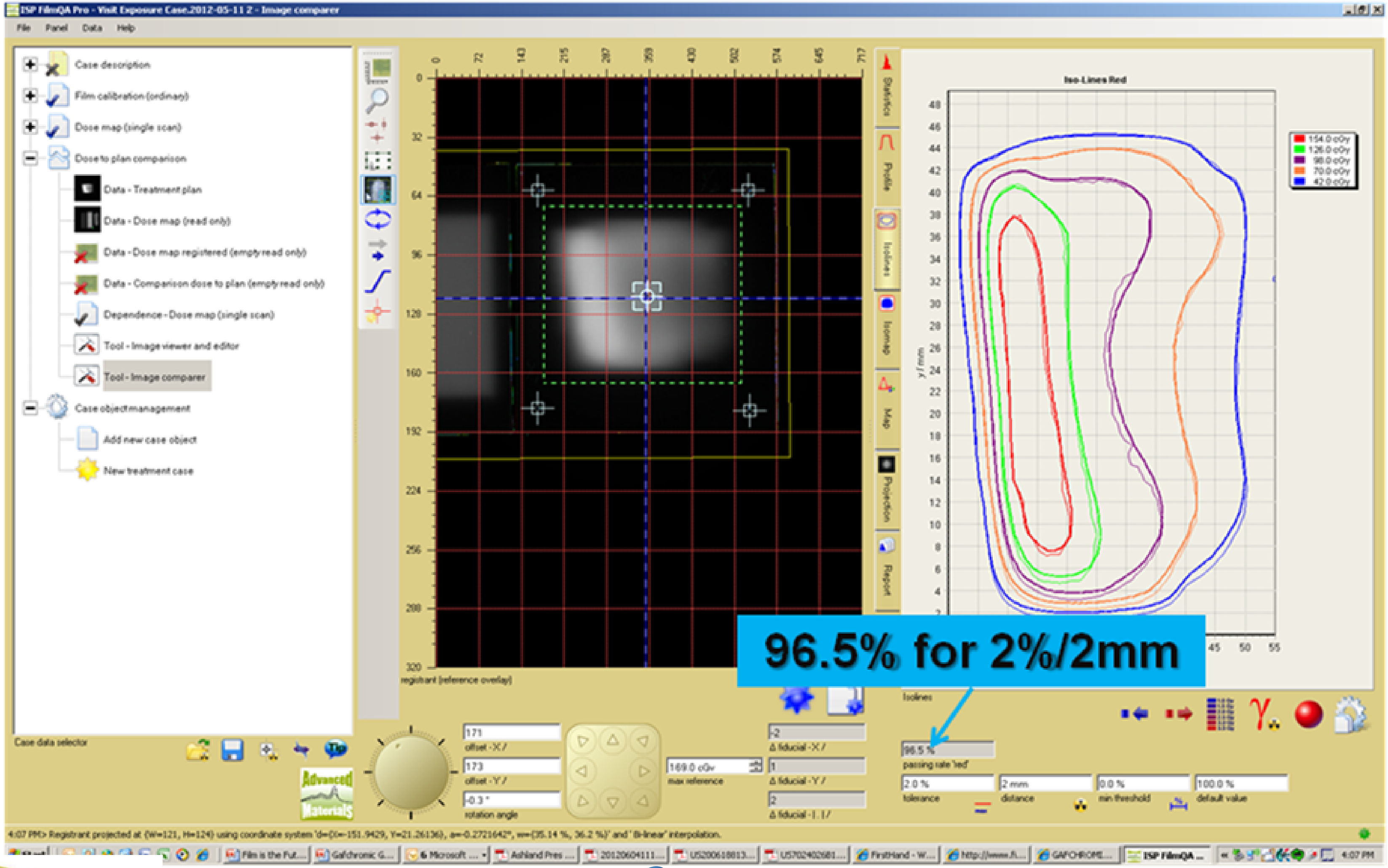
SRS One Field – Multi-channel, 'One-scan'



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Triple Channel, 'One-scan' Film Dosimetry

- Separates dose-dependent response from dose-independent artifacts
  - Compensates for film thickness variation
  - Noise reduction without dose change
  - Mitigates scanner distortions
  - Background compensation and/or double exposure unnecessary
- Enables entire film dose range
  - Dynamic range ratio >1000 (few cGy - >40 Gy)
- Significant improvement of dose map accuracy
  - <1% achievable (*vs.* 3% with single channel method)
  - Optimized calibration per specific scan
- Indication of inconsistency between film and calibration

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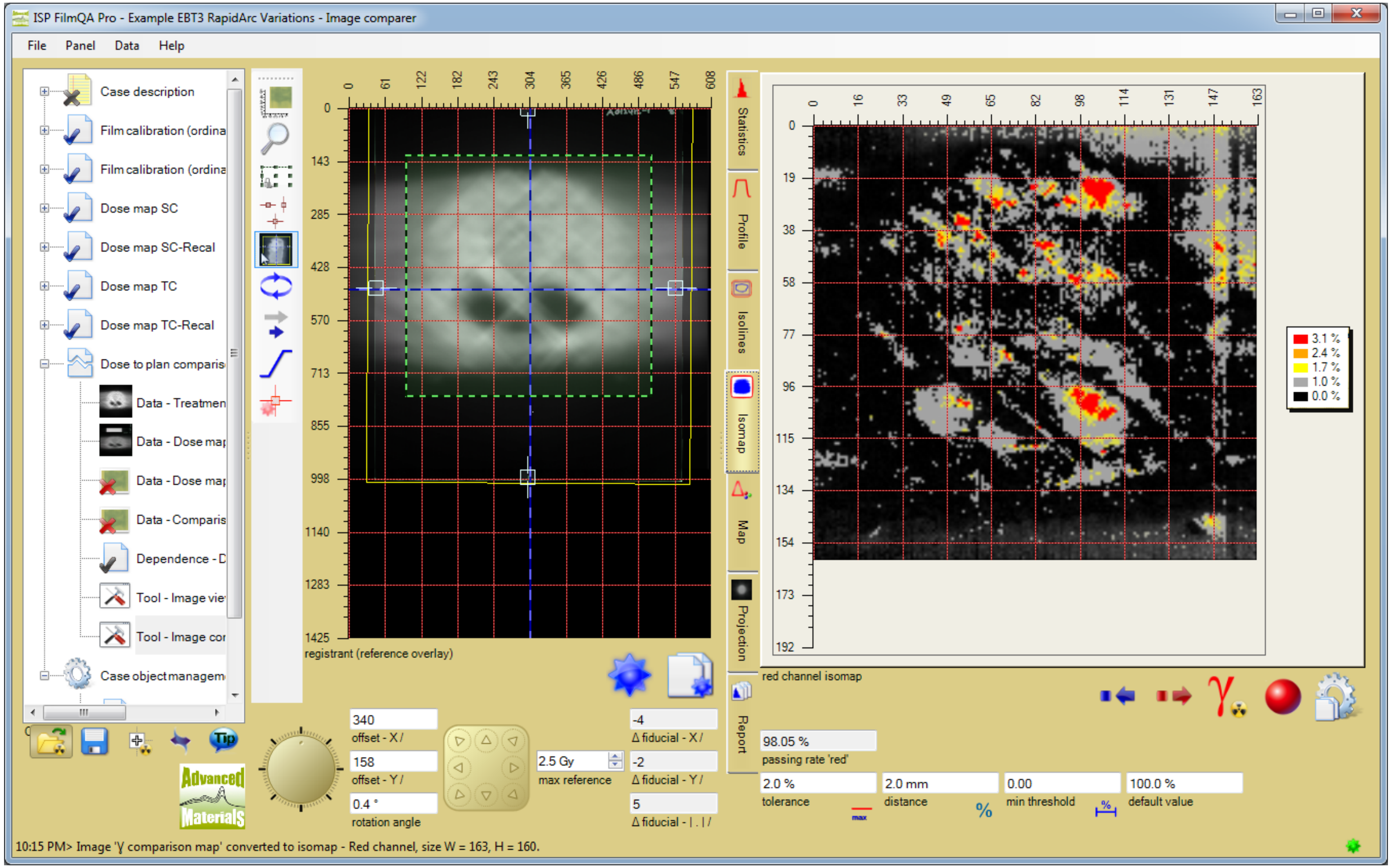

Micke, Lewis, Yu - Multi-channel Film Dosimetry with Non-Uniformity Correction, Medical Physics, 38 (2011) 5, pp. 2523

Lewis, Micke, Yu, Chan - An Efficient Protocol for Radiochromic Film Dosimetry combining Calibration and Measurement in a Single Scan, Medical Physics, 39 (2012) 10, pp. 6339.

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Don’t be obstinate

- Forget single channel dosimetry
  - All response errors convert to dose errors
  - <u>The errors are invisible to you</u>

- Use multi-channel dosimetry
  - Compensates for film/scanner artifacts
  - <u>Consistency map makes errors visible</u>

- Use the “One-scan” protocol
  - Eliminates scan-to-scan variability
  - Reduce post-exposure wait to minutes

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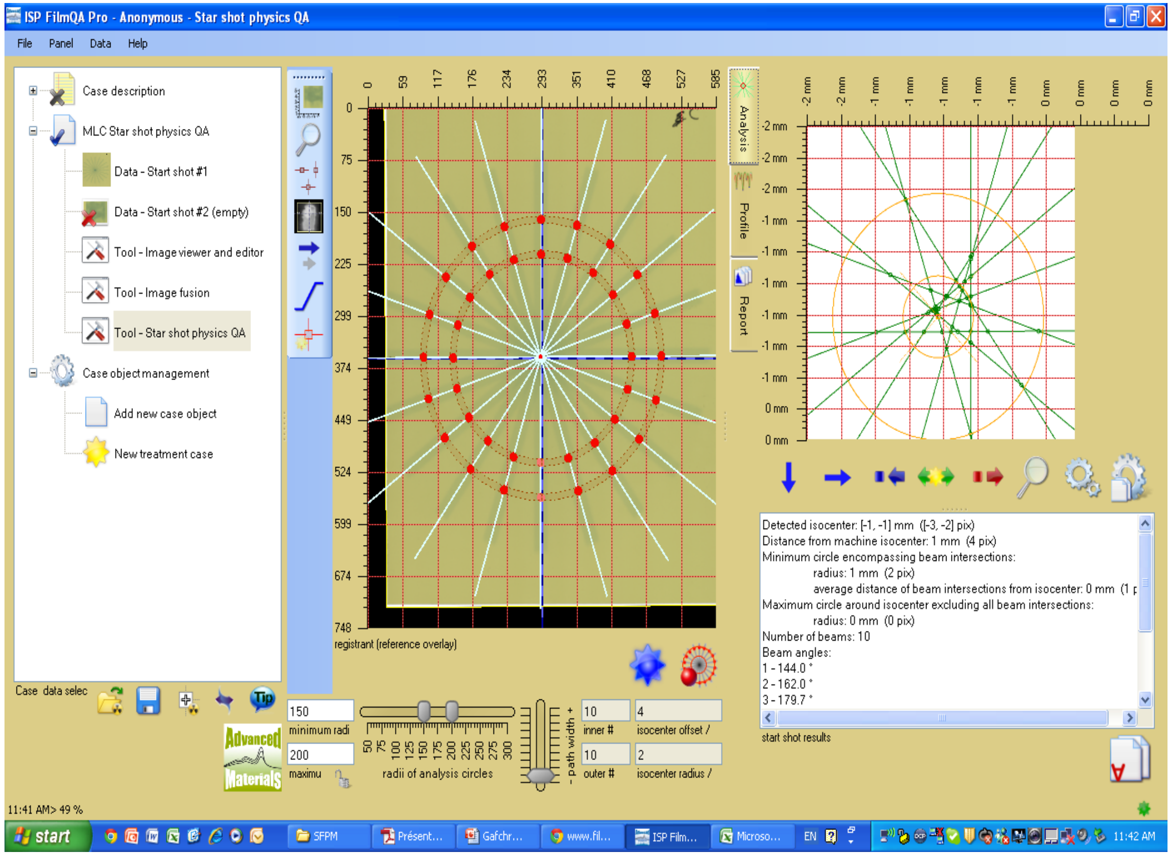
New Physics QA Tools in FilmQAPro



Automated Tools for

- Star Shots
- Flatness/symmetry
- MLC Picket Fence

More to come

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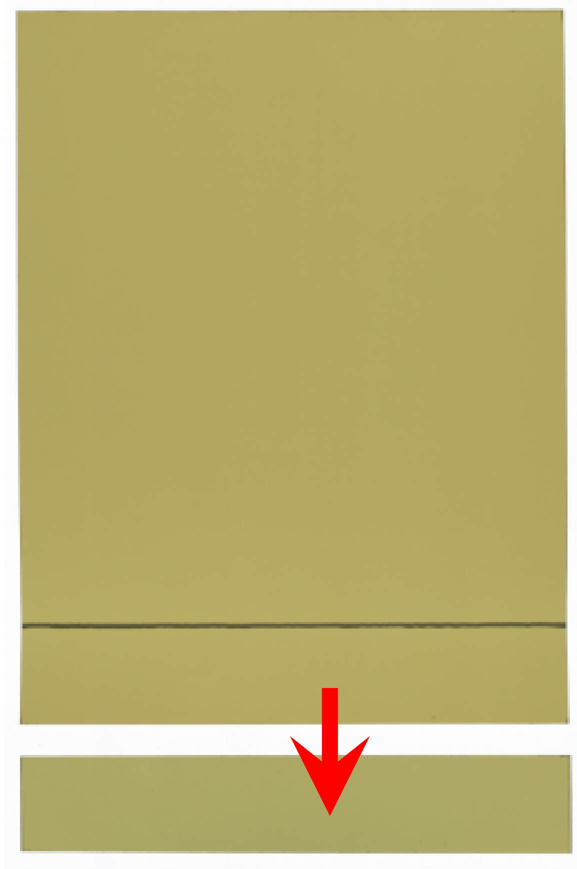
What is EBT3+?

- Configuration same as EBT3
- Perforated sheet with easy to detach reference strip
  - Strip *properties as close as possible* to patient film
  - Saves film cutting
  - Standardized strip size
- EBT3+ available since Dec. 2012



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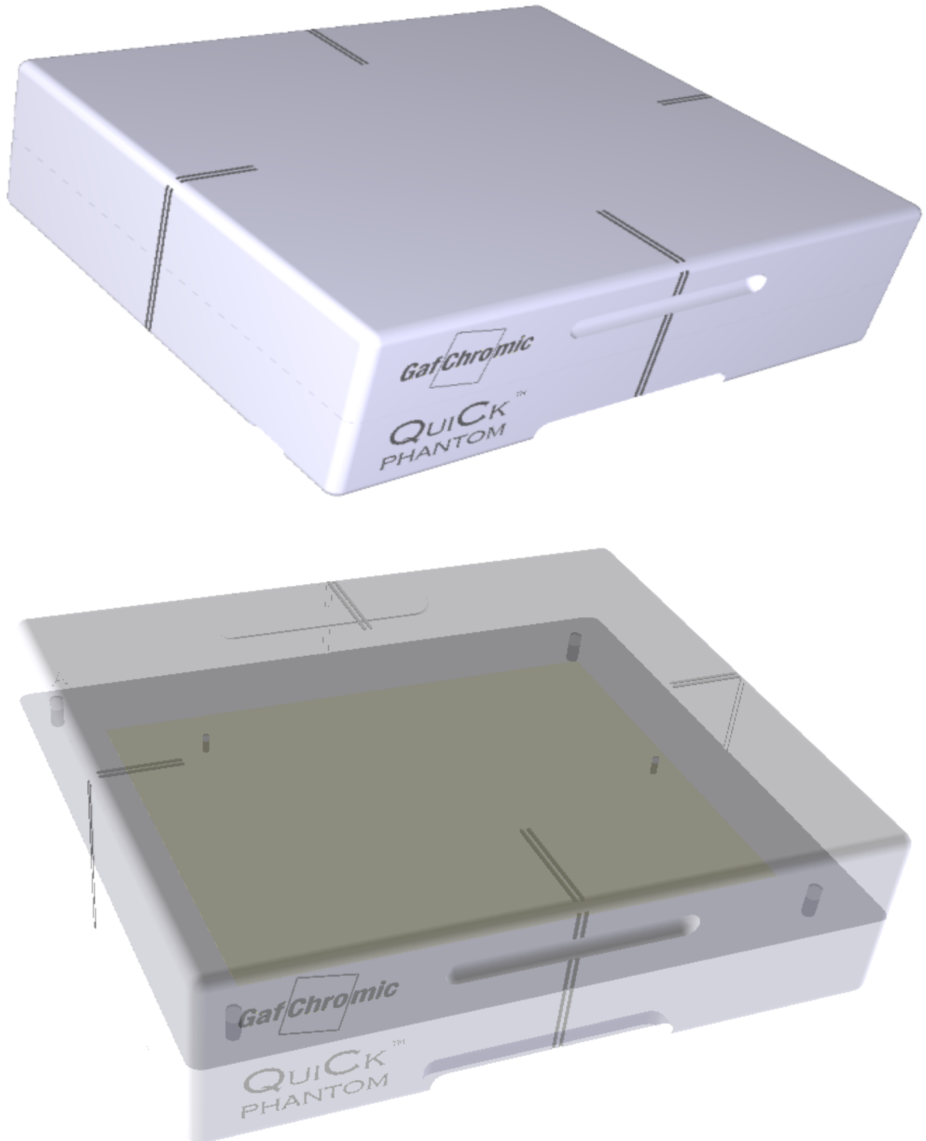
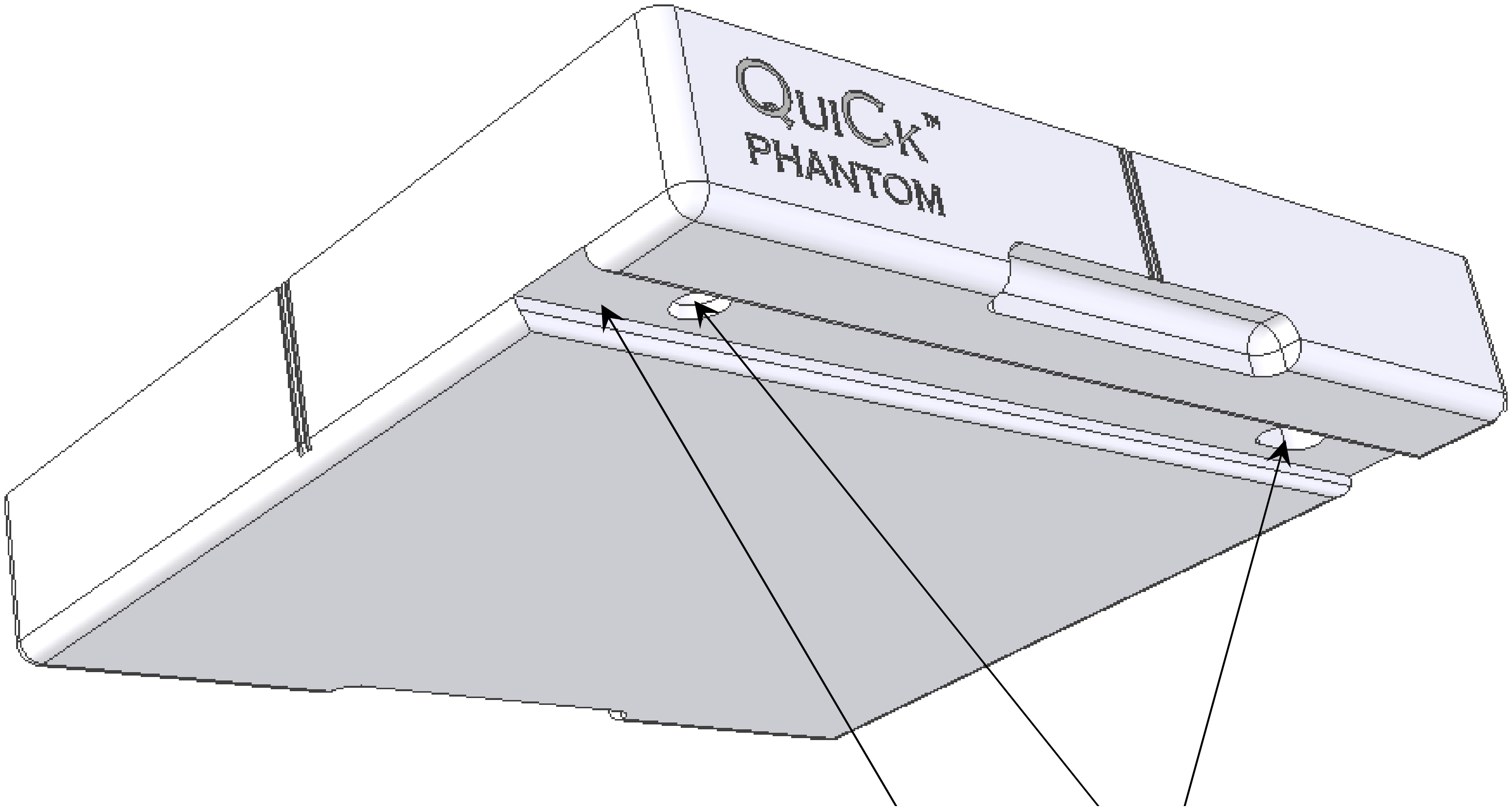
New GafChromic QuiCk Phantom



New GafChromic QuiCk Phantom



Groove and two holes to fit standard two-pin patient positioning index bar

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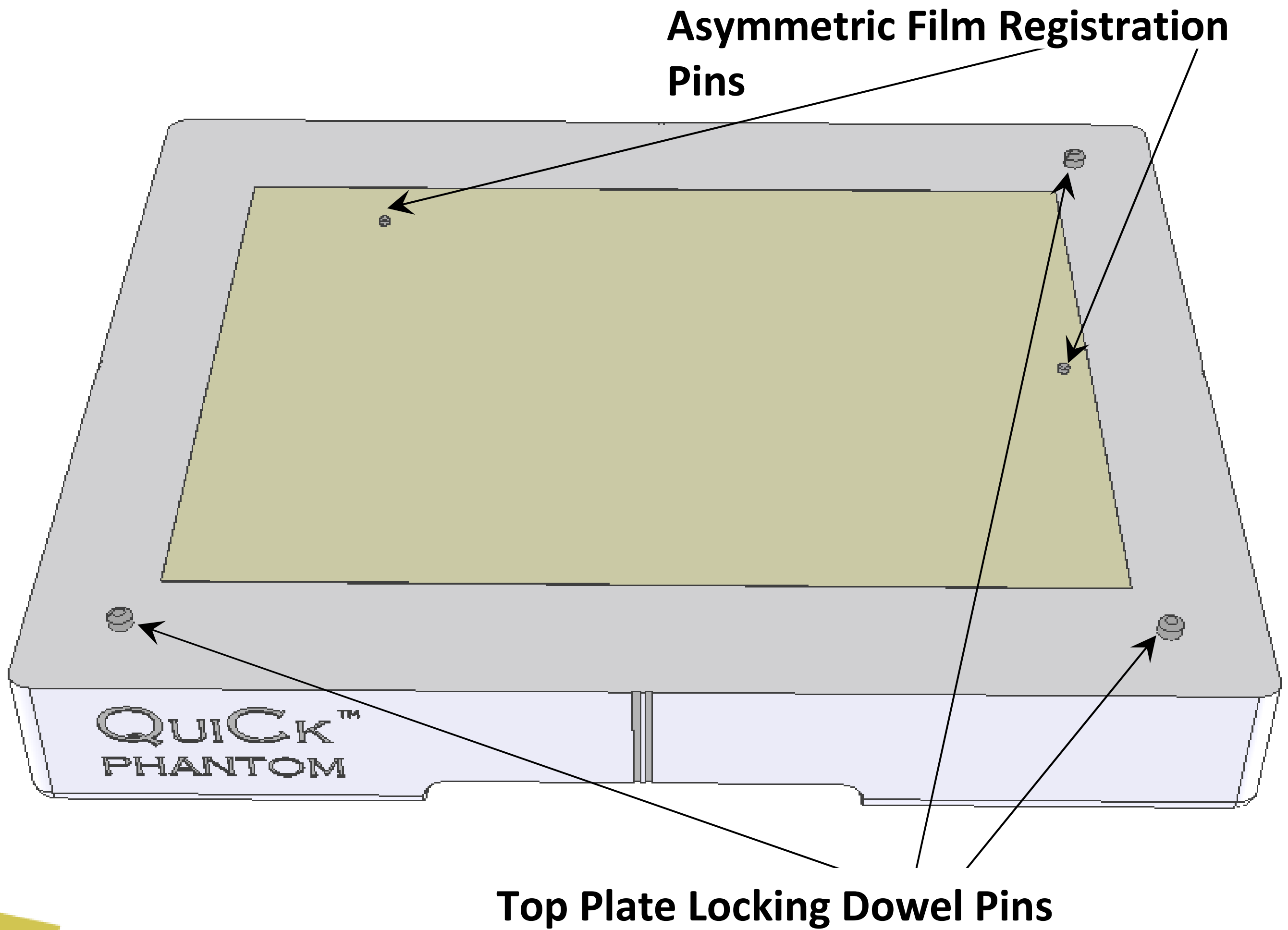
New GafChromic Quick Phantom



Be kind to yourself – FilmQAPro is here to help

- Multi-channel dosimetry removes non-uniformity and gives estimate of dose uncertainty

"One-scan" protocol eliminates variables and gets results in minutes

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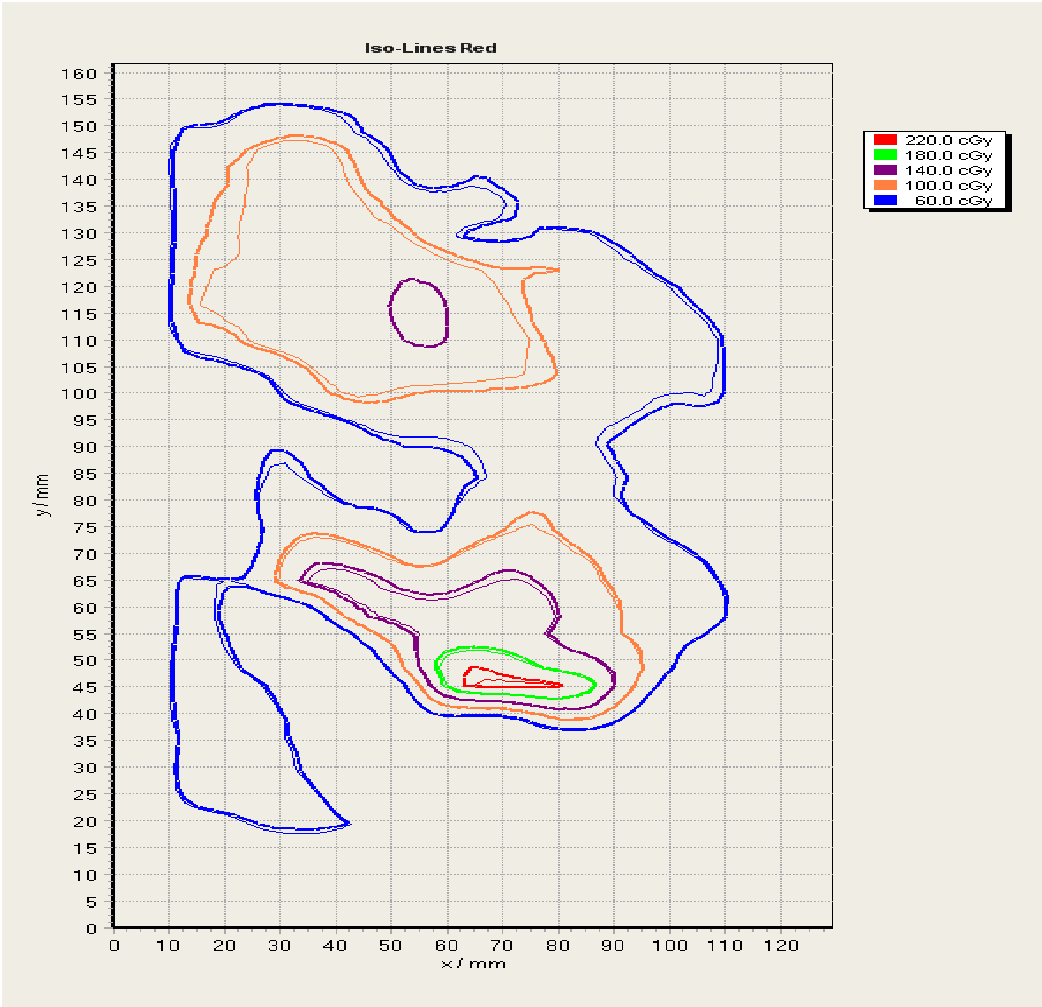
Conventional Single Channel Dosimetry



Typically >90% pixels pass gamma evaluation of 3% at 3mm

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