New Performance Standard:

Multi-channel and One-scan Radiochromic Film Dosimetry

David F. Lewis, Andre Micke and Xiang Yu
Advanced Materials Group
Ashland Specialty Ingredients

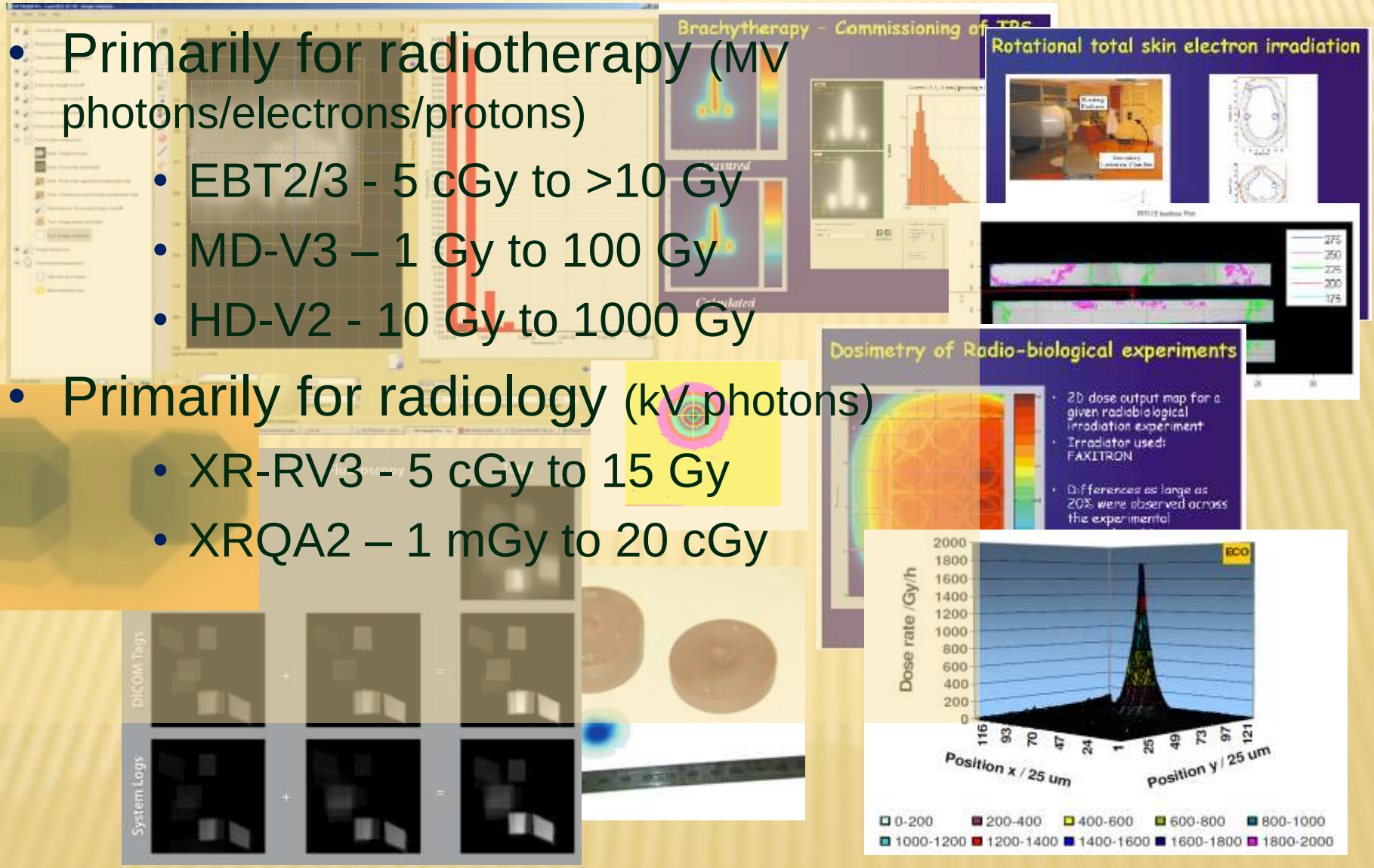
Strasbourg, June 2012

What is Radiochromic Film?

A film that instantly changes color upon exposure to ionizing radiation and needs no chemical or physical processing

WHAT FOR DOSE MEASUREMENT?

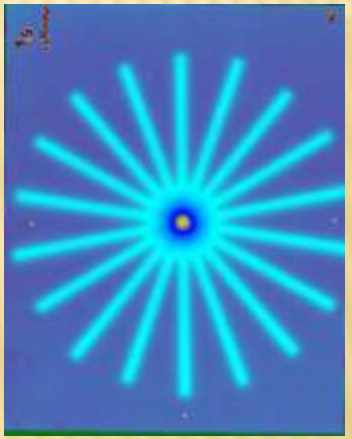
- Primarily for radiotherapy (MV photons/electrons/protons)
  - EBT2/3 - 5 cGy to >10 Gy
  - MD-V3 – 1 Gy to 100 Gy
  - HD-V2 - 10 Gy to 1000 Gy
- Primarily for radiology (kV photons)
  - XR-RV3 - 5 cGy to 15 Gy
  - XRQA2 – 1 mGy to 20 cGy

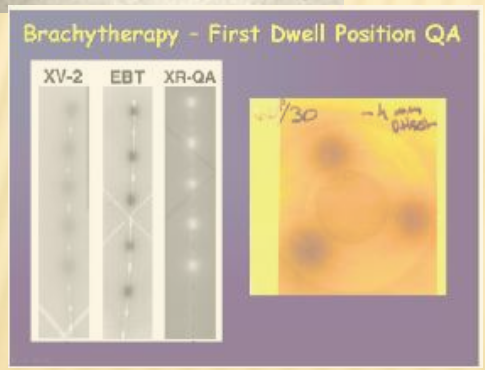


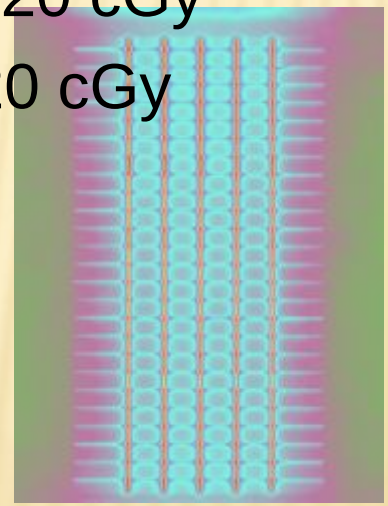
With acknowledgements to Slobodan and Nada Devic, Samuel Trichter, Eduardo Villarreal, Jeffrey Guild, Gary Arbique and Scott Sample

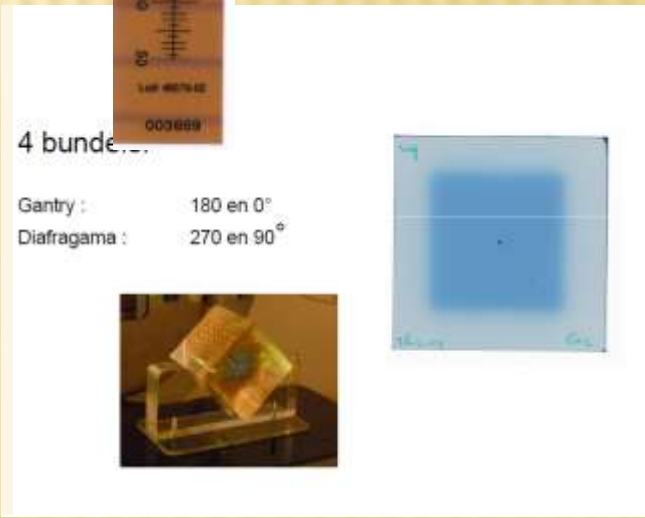
WHAT FOR BEAM LOCATION?

- Primarily for radiotherapy (MV photons, electrons, protons)
  - RTQA2 - 2 cGy to 8 Gy
- Primarily for radiology (kV photons)
  - XRQA2 - 1 mGy to 20 cGy
  - XRCT2 - 1 mGy to 20 cGy
  - XRM2 - 1 mGy to 20 cGy







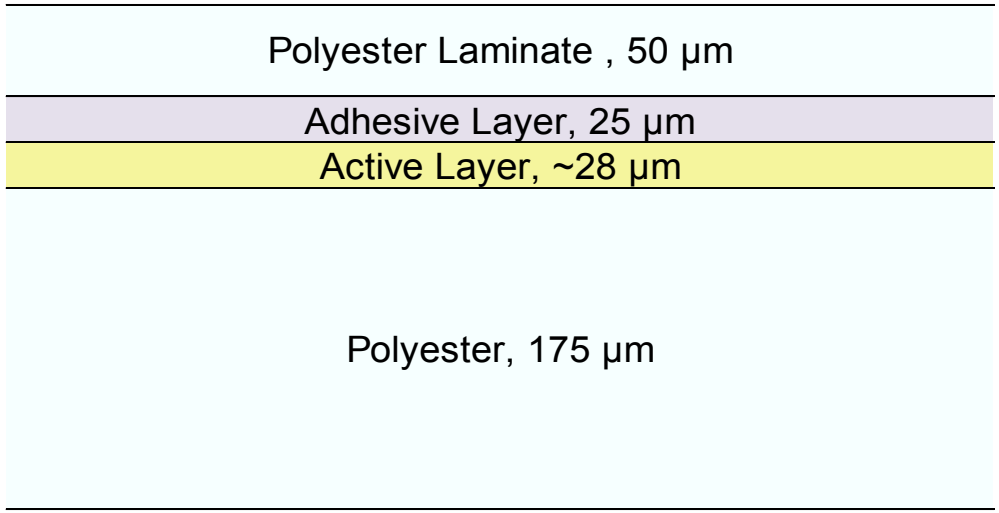


With acknowledgements to: Slobodan Devic, Theo van Soest, Andre Wopereis and Zheng Lu

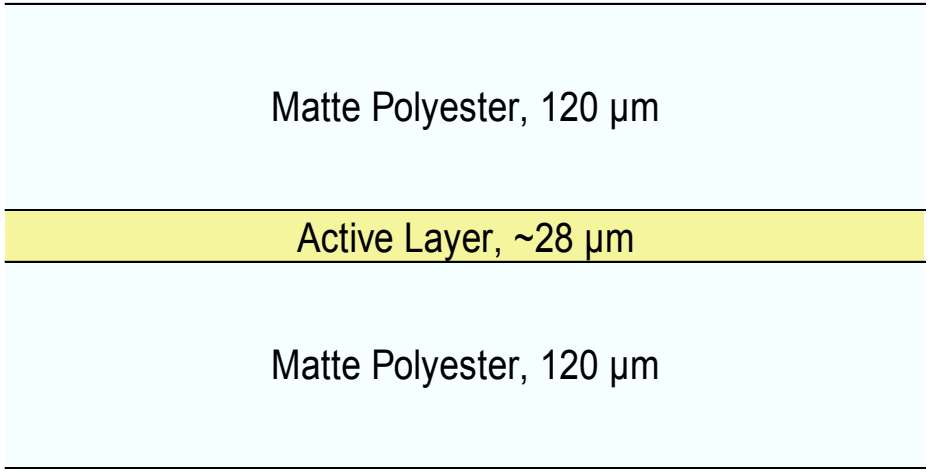
EBT3 AND EBT2 COMPARED

EBT2	EBT3	Comment
Active layer 26-28 μm	Active layer 26-28 μm	**Active layer composition and response unchanged**
Asymmetric structure	Symmetric structure	**Scan EBT3 from either side**
Smooth polyester substrate	Matte polyester substrate	**Change prevents Newton's Rings formation**
Density (unexposed) ~0.10 – 0.12	Density (unexposed) ~0.12 – 0.14	**Matte polyester slightly hazy**
Total thickness: ~ 0.28 mm	Total thickness: ~ 0.27 mm	

CONFIGURATION CHANGE EBT2 TO EBT3

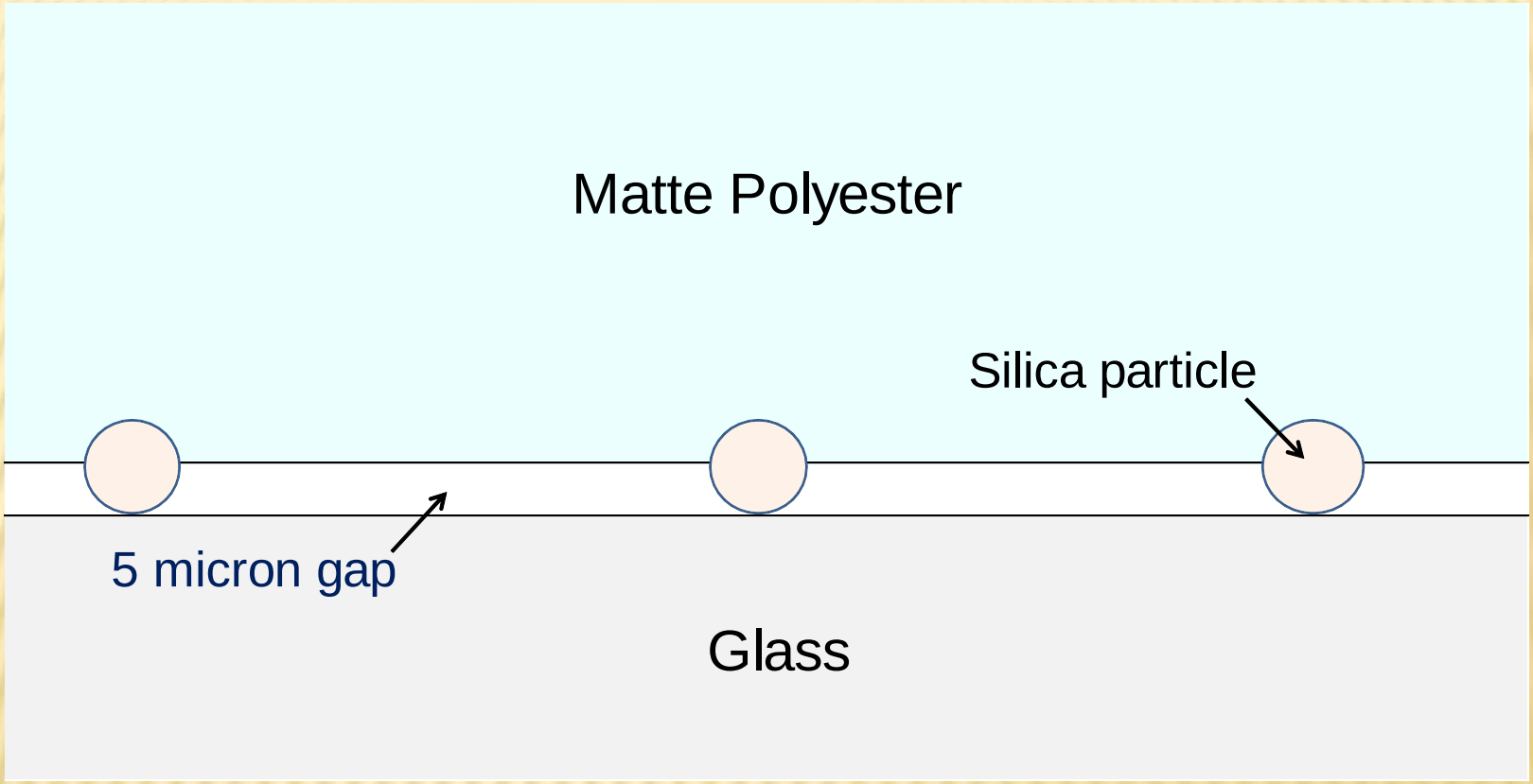


EBT2



EBT3

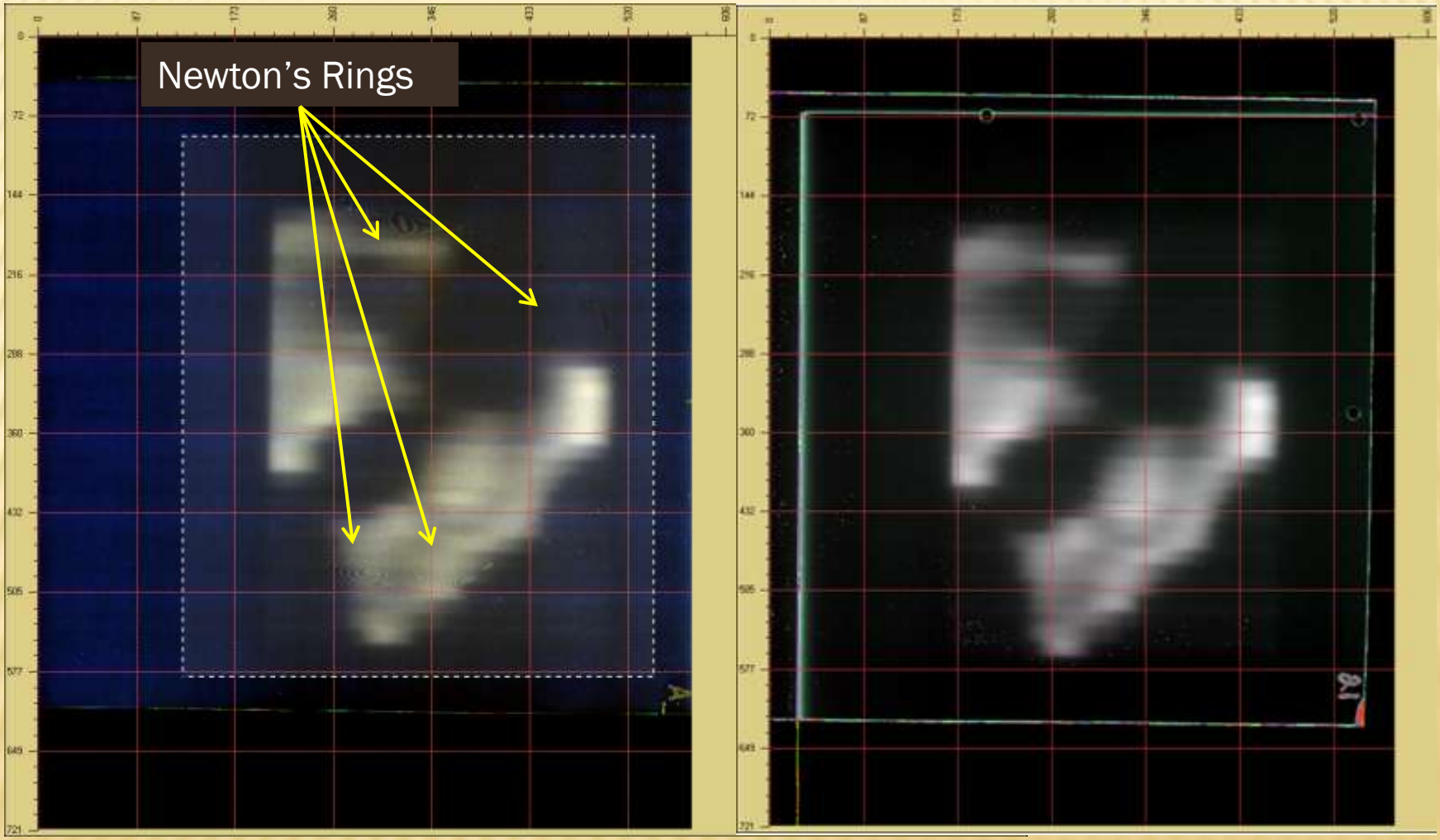
MATTE POLYESTER SURFACE



Gap >> λ_{light}

- Frustrates Newton's Rings formation

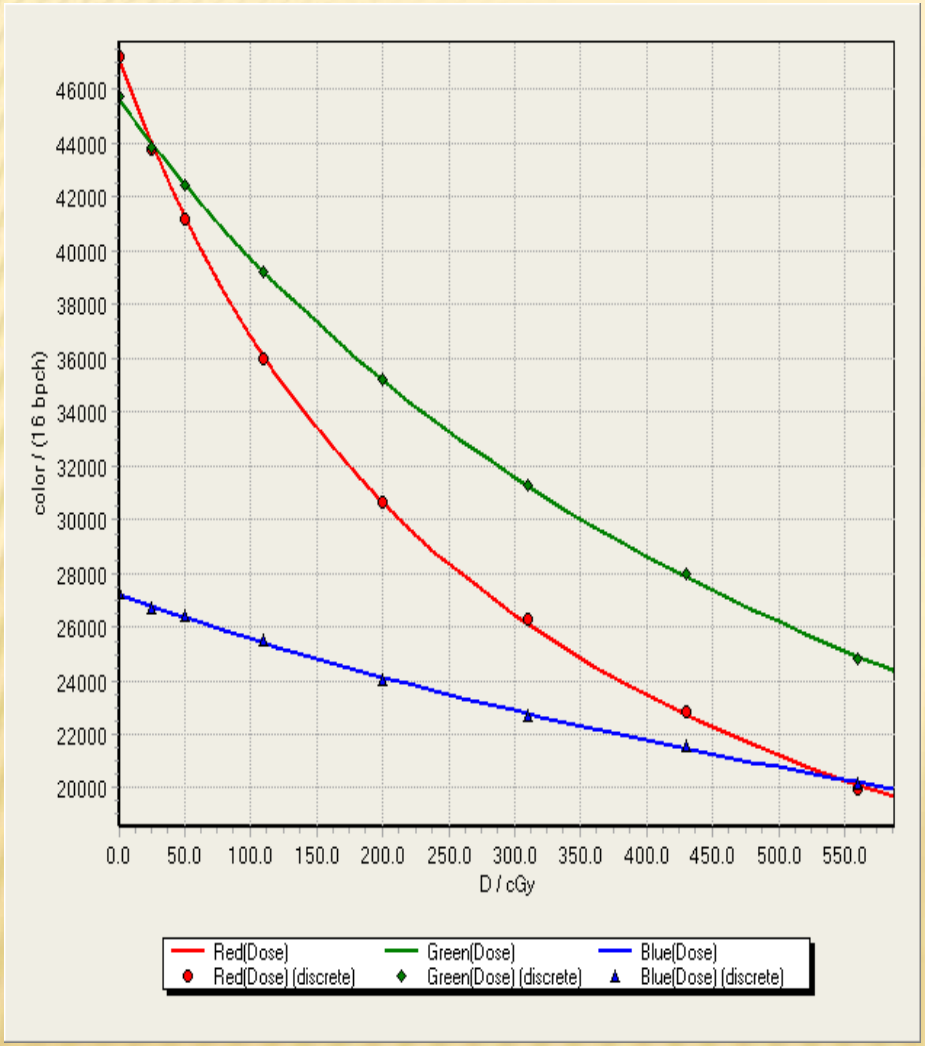
EBT3 ELIMINATES NEWTON'S RINGS ARTIFACT



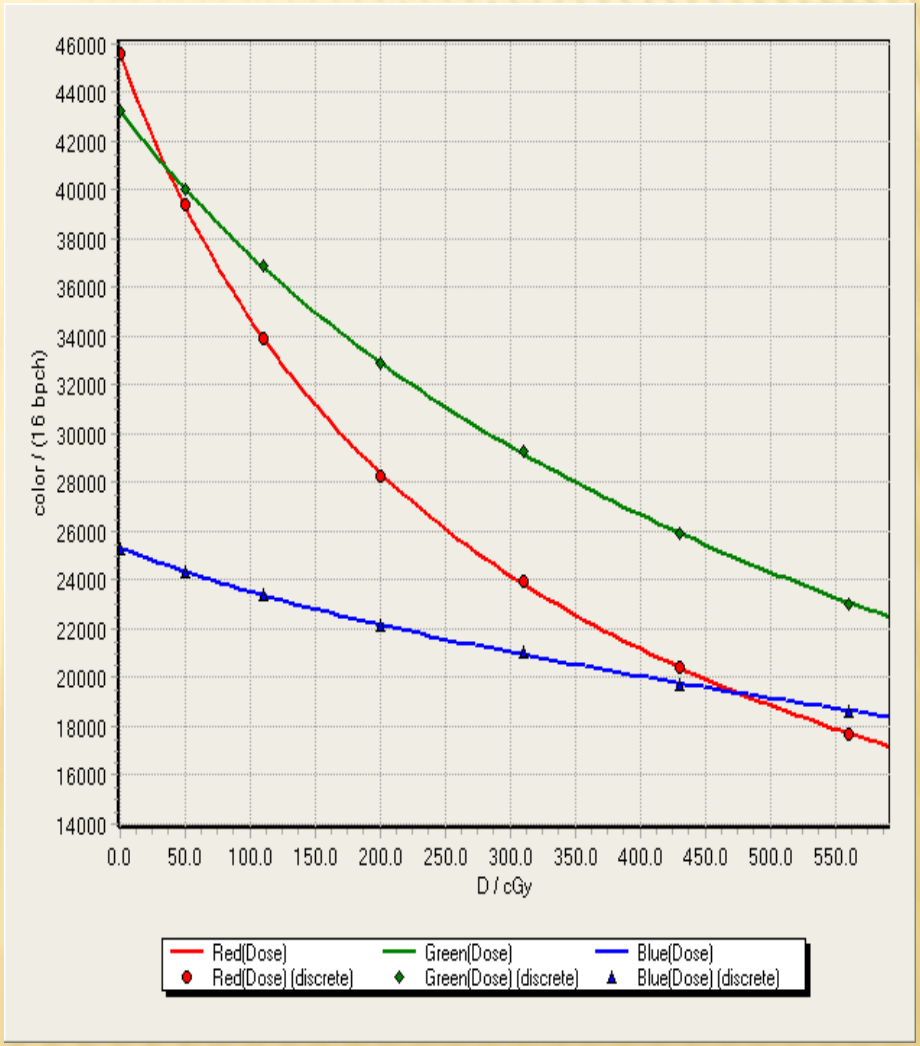
EBT2

EBT3

RESPONSE OF EBT3 SIMILAR TO EBT2



EBT2 – Lot A011411



EBT3 – Lot A071111

COMPARISON EBT SERIES OF FILMS

- Gafchromic EBT film was well regarded in market
- Early EBT2 film had occasional problem
- Current EBT2 and EBT3 films are as good as if not better than original EBT
- Superior solution especially if combined with FilmQA Pro software
- New protocol will make dosimetry easier and faster

RADIOCHROMIC FILM DOSIMETRY THE ADVANTAGES

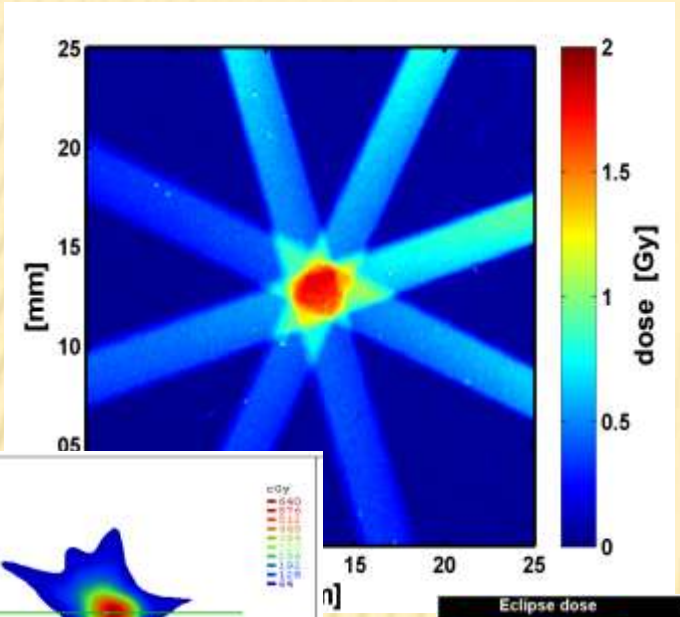
- Handle in light
- Cut to size
- Bend to shape
- Immerse in water
- Wide dynamic range
- High spatial resolution

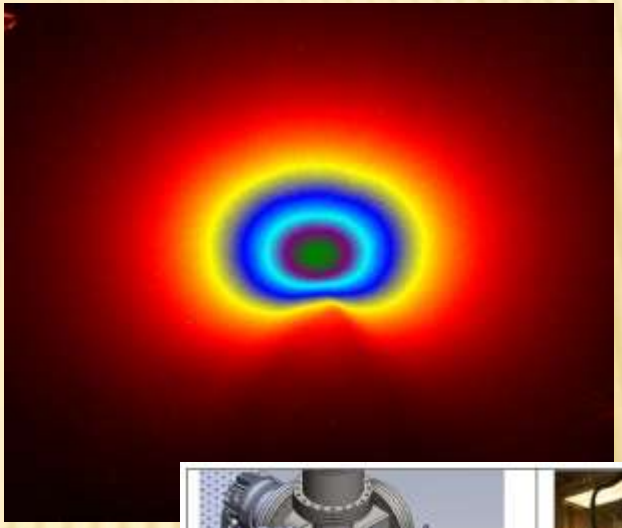
Specially valuable for new conformal therapies

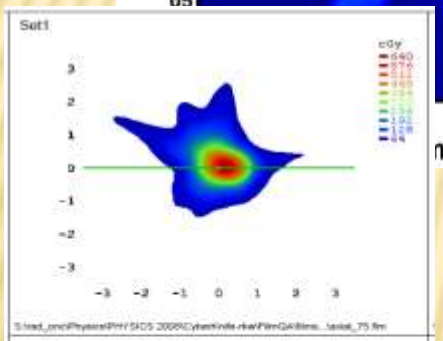
RADIOCHROMIC FILM AND NEW THERAPY MODALITIES

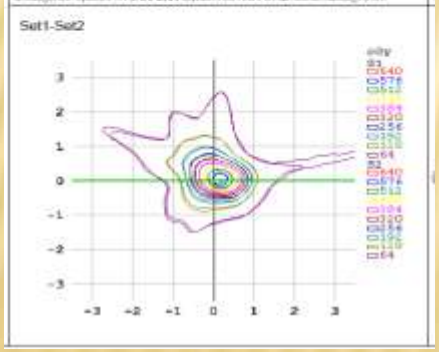
- Trends in conformal therapy
  - Less fractions
  - Higher doses per fraction
  - Tighter conformity
- Trending to a higher value on
  - Spatial resolution, spatial resolution, spatial resolution
  - Dynamic range

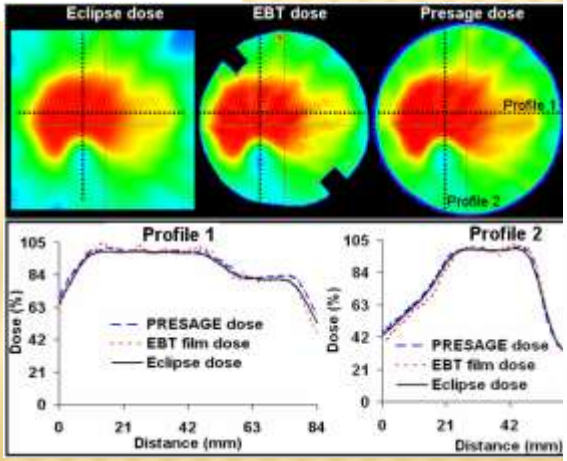
SMALL FIELD – HIGH SPATIAL RESOLUTION

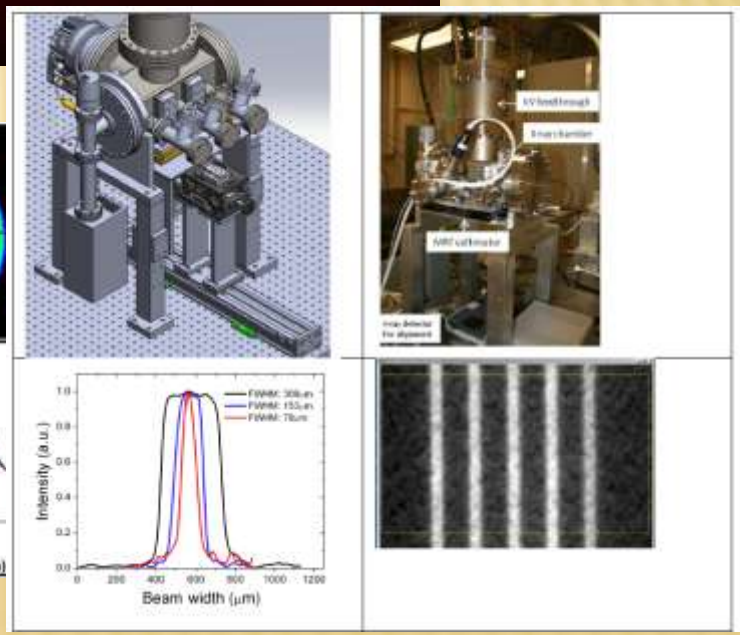












With acknowledgements to: Steve Sorensen, Stefan van Hoof, Mark Oldham, Frank Verhagen, Guillaume Landry, Shane White and Sha Chang

PRESENT/FUTURE OF FILM DOSIMETRY

- Post-exposure waiting
- Film artifacts
- Scanner artifacts
- Environmental

How we turn film from a hassle to a snap?

NEW PERFORMANCE STANDARD

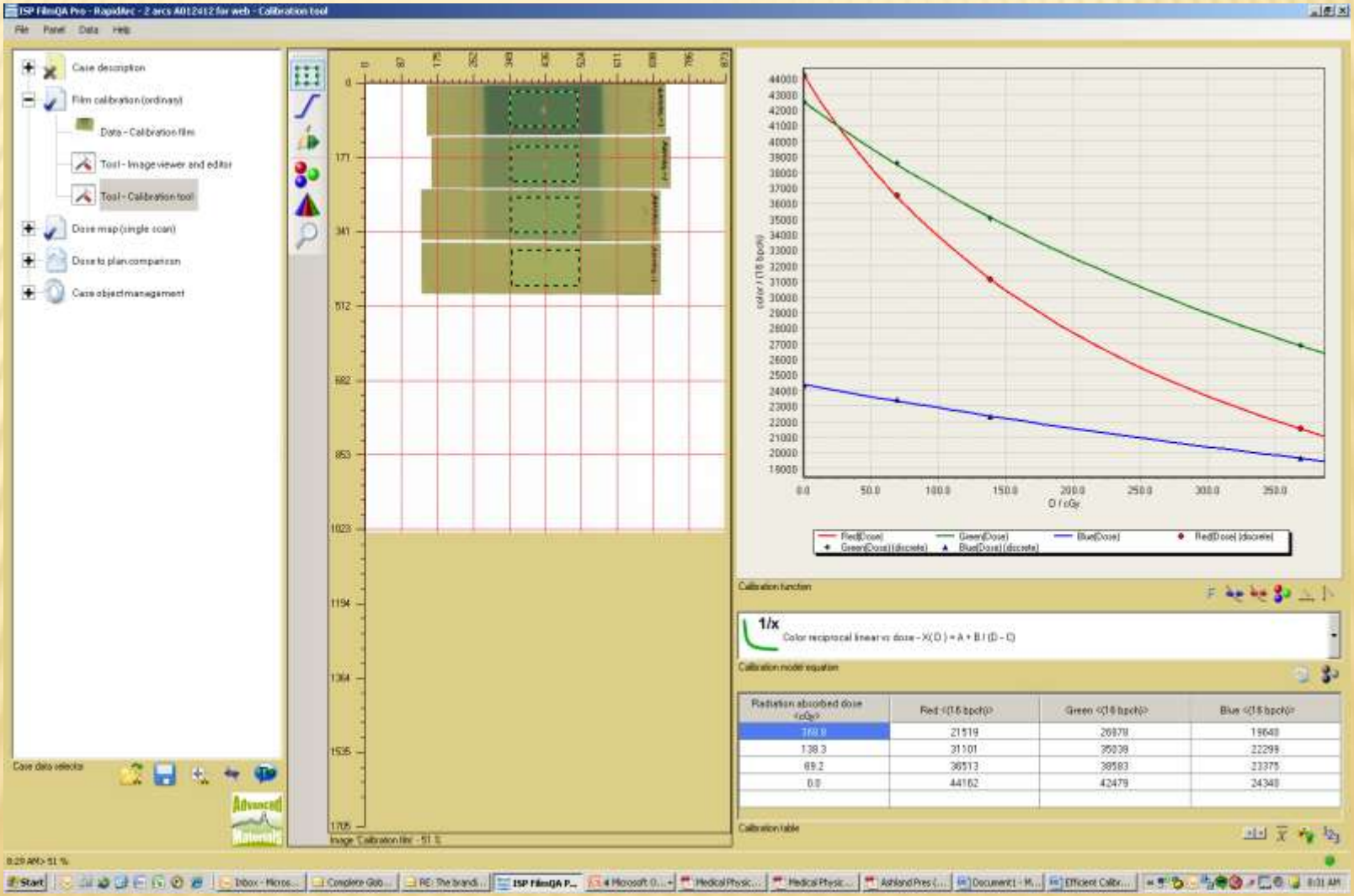
- Simplify calibration
  - Less films and all scanned together
  - Fitting functions that act like film
- Combine verification with calibration
  - Every patient film scanned with reference films
  - Eliminates environmental effects
  - Eliminates inter-scan variability
- Reduce post-exposure waiting to minutes
- Introduce multi-channel dosimetry
  - Eliminates or mitigates film and scanner artifacts

ONE SCAN CALIBRATION

- Expose three calibration films – doses approx. D(>maximum possible dose), 0.4D and 0.16D
- Scan the exposed films and an unexposed film all together
- Fit response data to a rational function like $X(D)=a + b/(D-c)$ where a, b and c are constants
- Defines the shape of the calibration function
- Once per production lot

Typical completion time <~20 minutes

ONE SCAN CALIBRATION

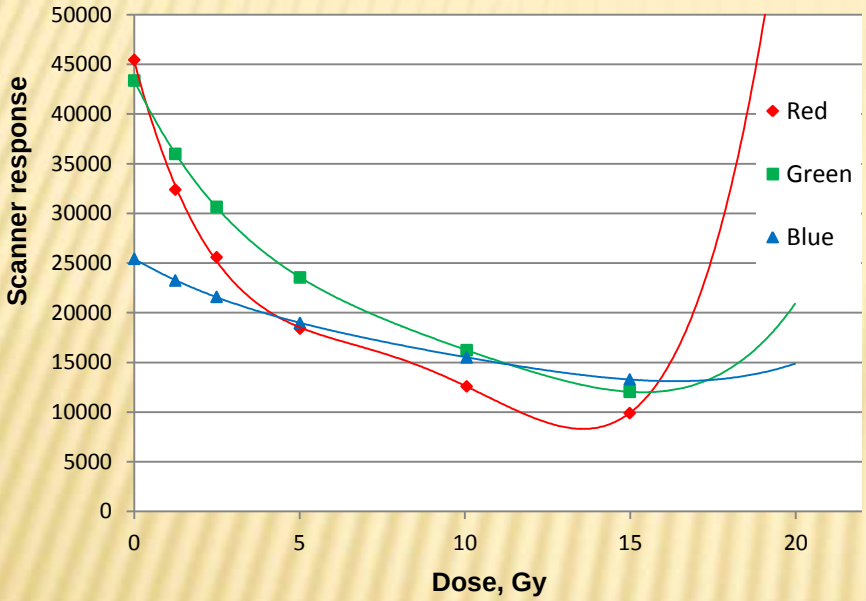


FITTING CALIBRATION-BASIS FOR FEWER POINTS

Polynomial Functions

$X(D) = A_1.D^n + A_2.D^{n-1} + ... A_n.D + C$

D = dose, X(D) = response



Not consistent with fundamental properties of film ✘

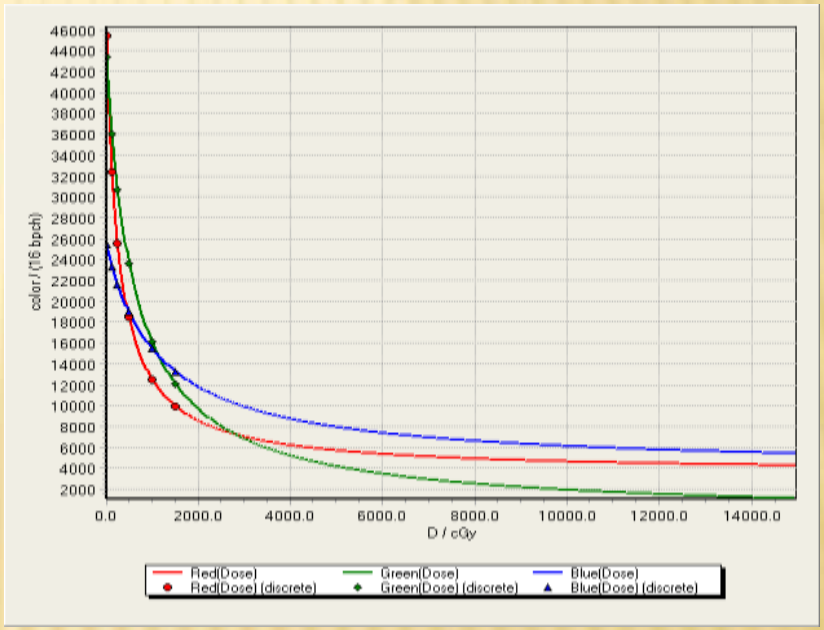
Function can oscillate between values ✘

Cannot be inverted ✘

Rational Functions

$X(D) = A + B/(D-C)$

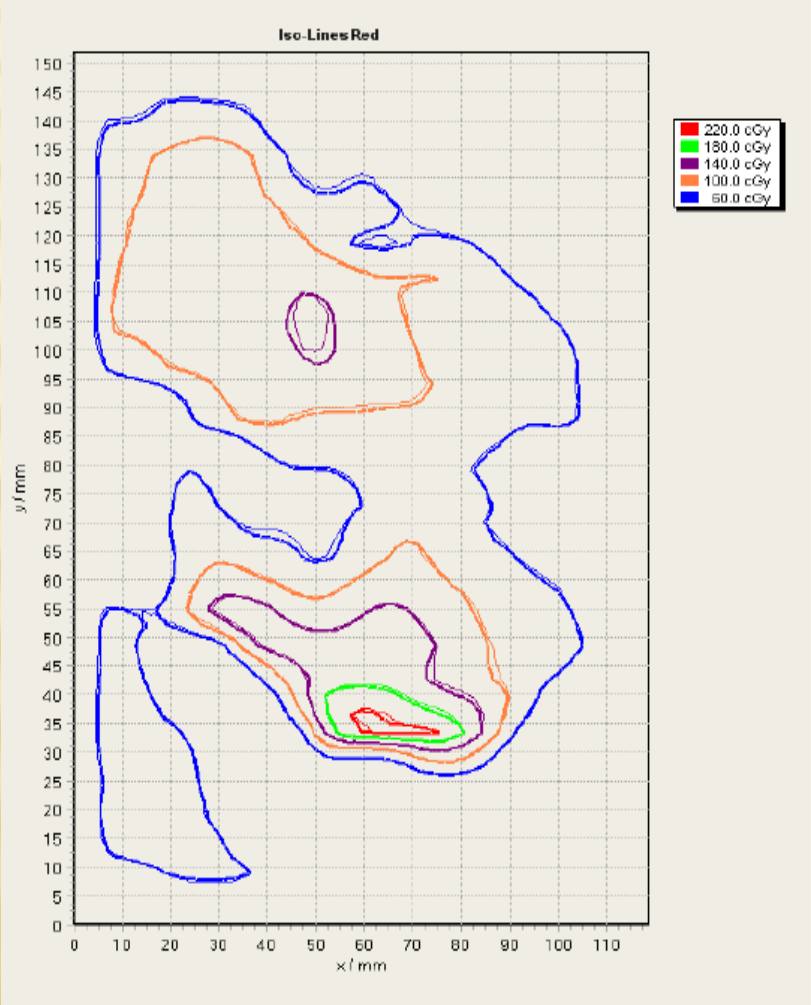
D = dose; X(D) = response

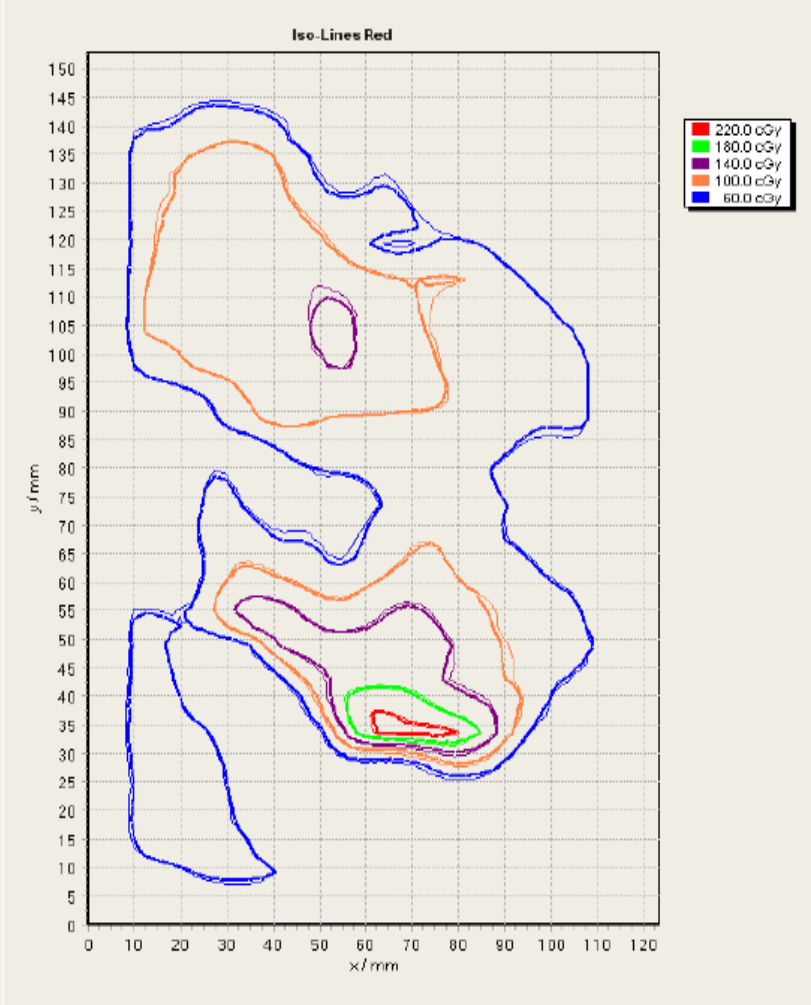


Consistent with the behavior of film ✓

Easily inverted - $D = C + B/(X(D)-A)$ ✓

COMPARISON OF 3 POINT CALIBRATION VS 7 POINT CALIBRATION



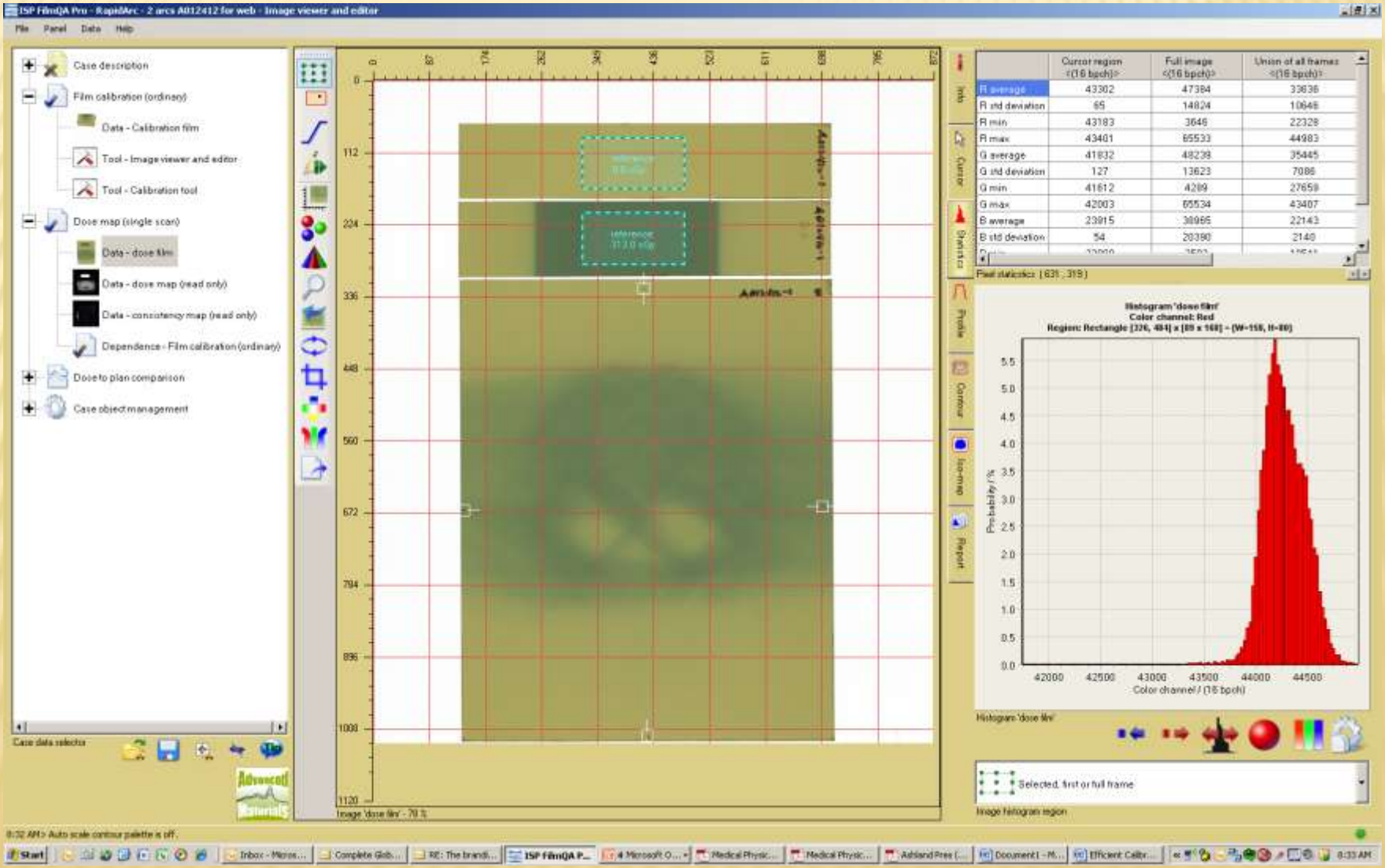


ONE SCAN DOSIMETRY-TWO POINT SCALING

- Set up patient film and expose treatment plan
- Expose a reference film (same lot as patient film) to dose similar to maximum dose on patient film
- Scan patient film, reference film and an unexposed film all together
- Convert to response to dose and analyze

Typical completion time ~20 minutes

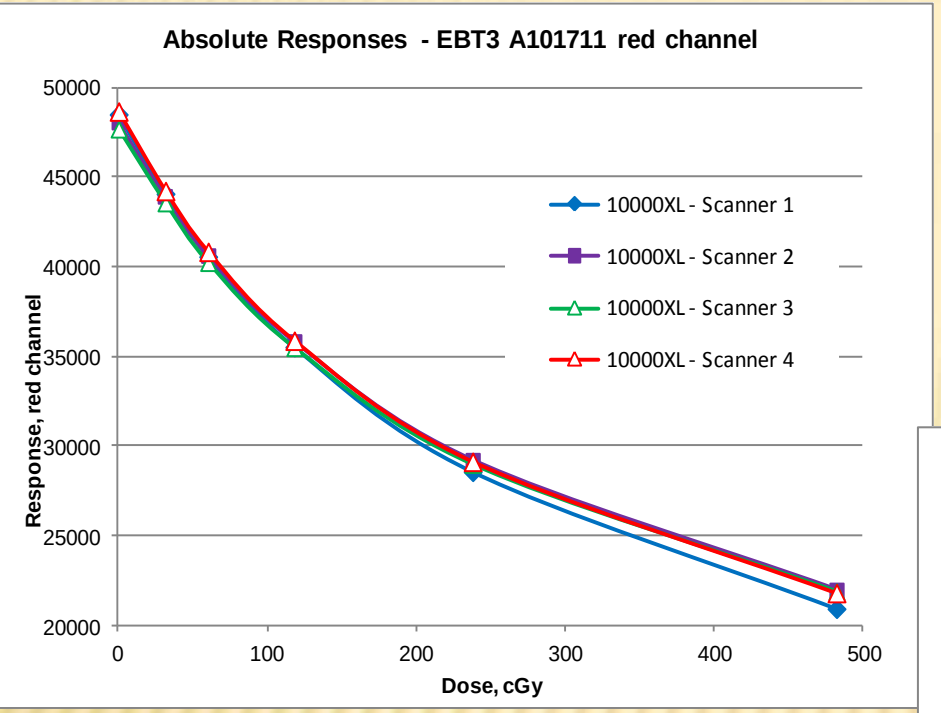
ONE SCAN DOSIMETRY-TWO POINT SCALING



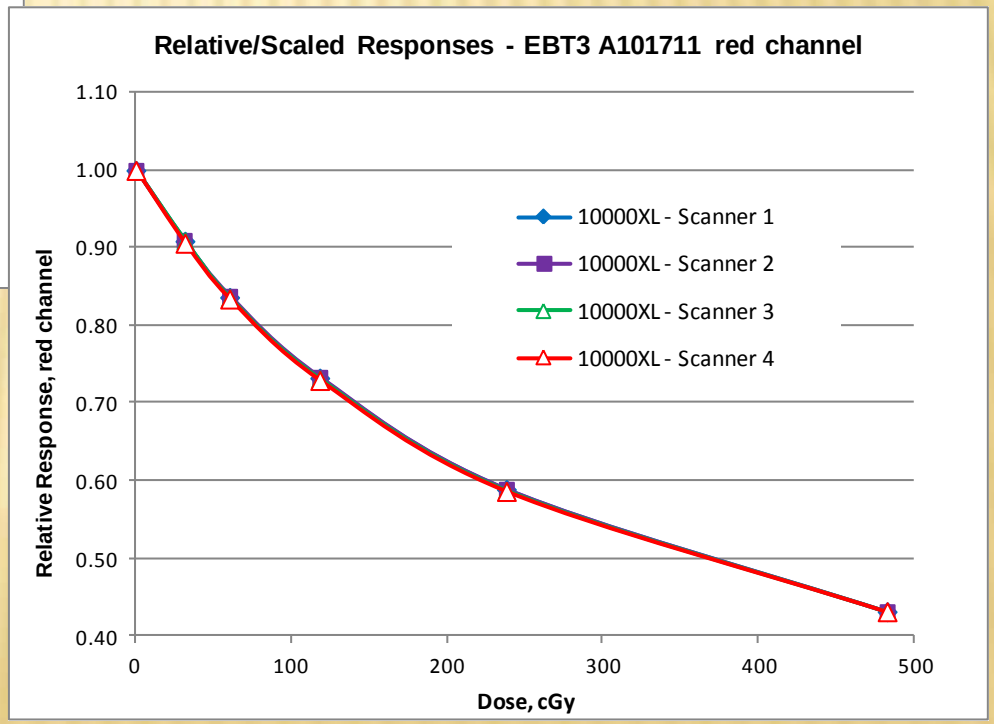
BASIS FOR 'ONE-SCAN' DOSIMETRY

- All dose response curves have similar shape
- Scan the patient and reference films together
- Two-point re-scaling – one exposed reference plus an unexposed film - applies to most situations
  - Post-exposure change
  - Inter-scan variation
  - Ambient temperature/moisture change
  - Photon energy
  - Type of scanner used
  - Film-scanner orientation
- Three-point re-scaling for lot-to-lot differences

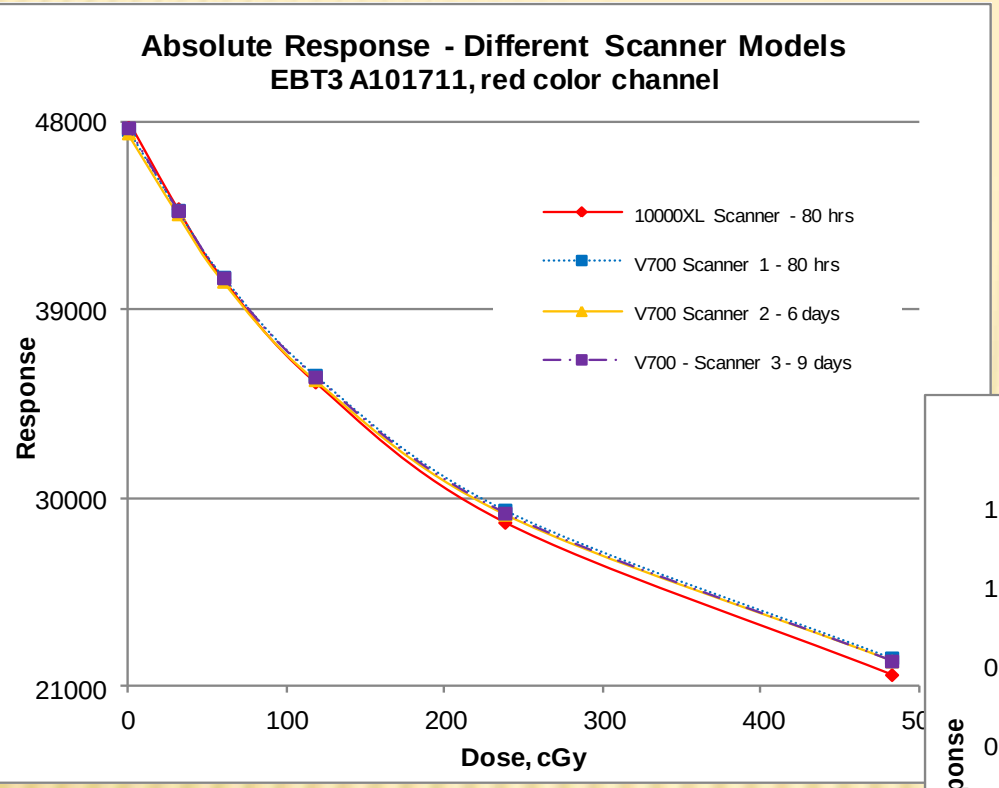
DIFFERENT SCANNERS OF THE SAME TYPE

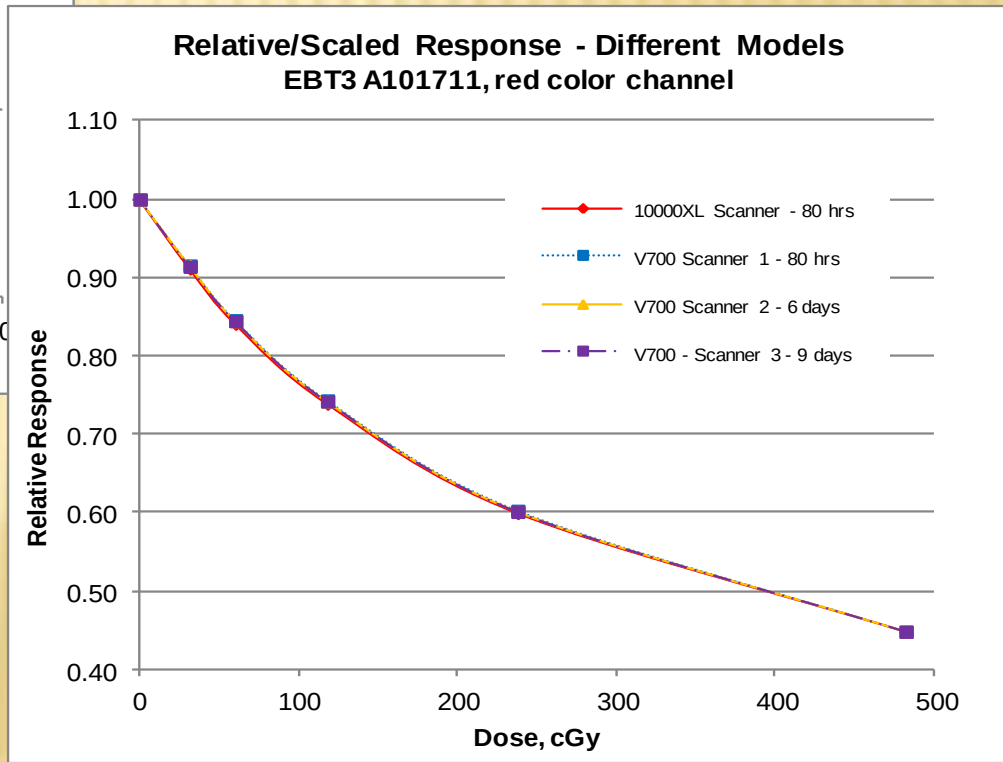


- Normalize responses to the response of unexposed film
- Scale normalized responses to the net response at a selected dose (480 cGy)

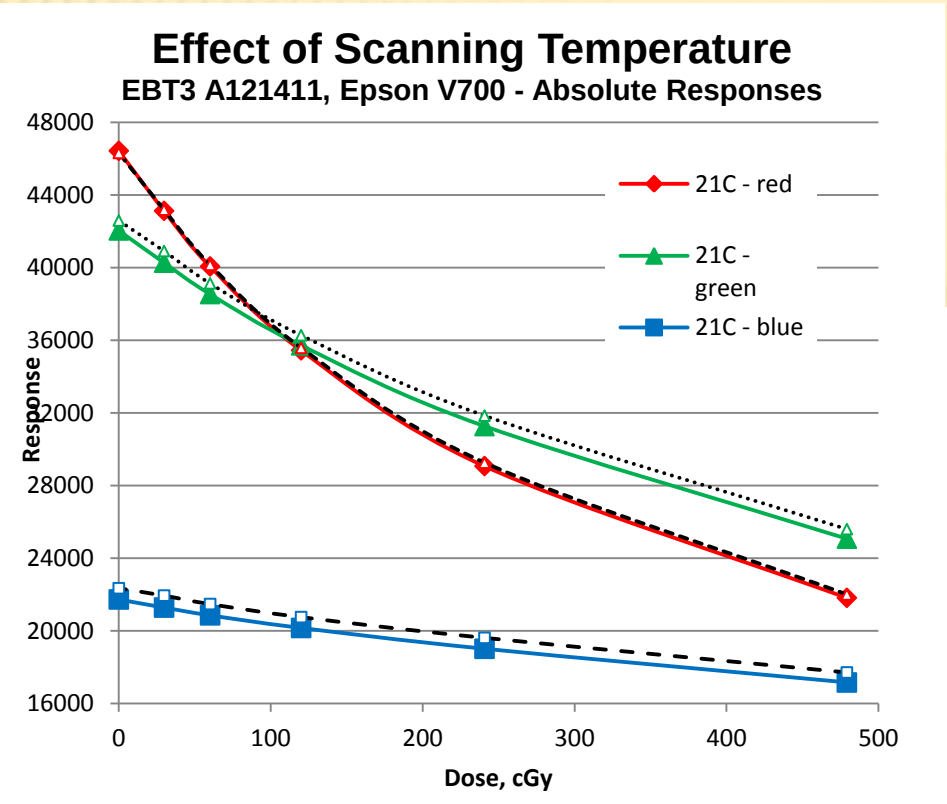


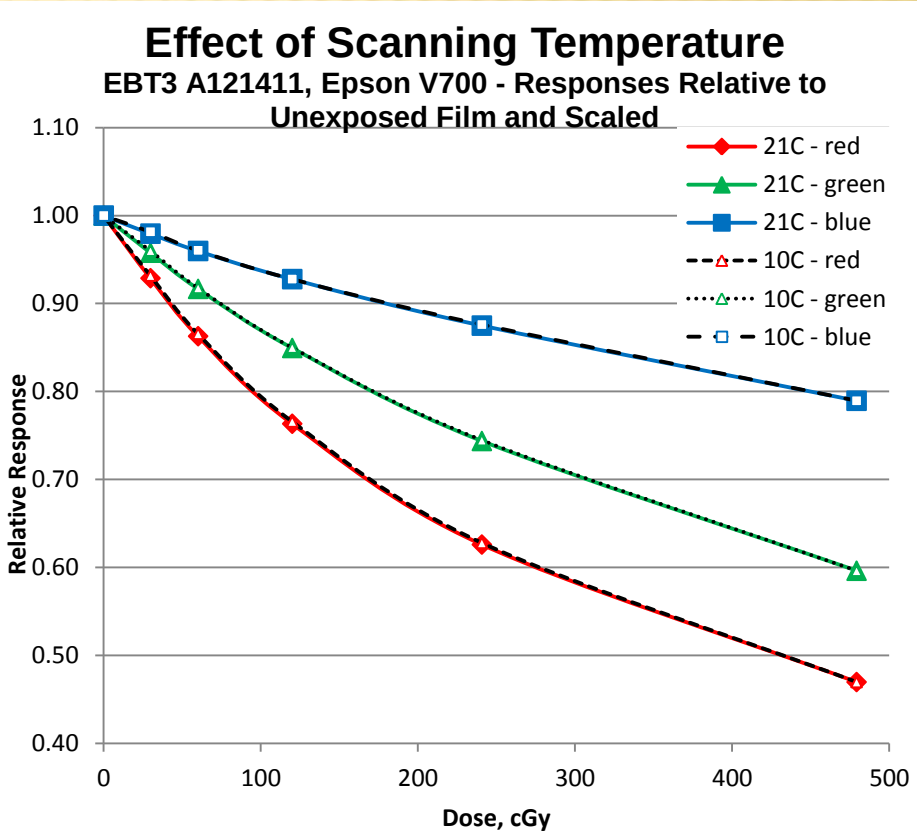
DIFFERENT SCANNER TYPES



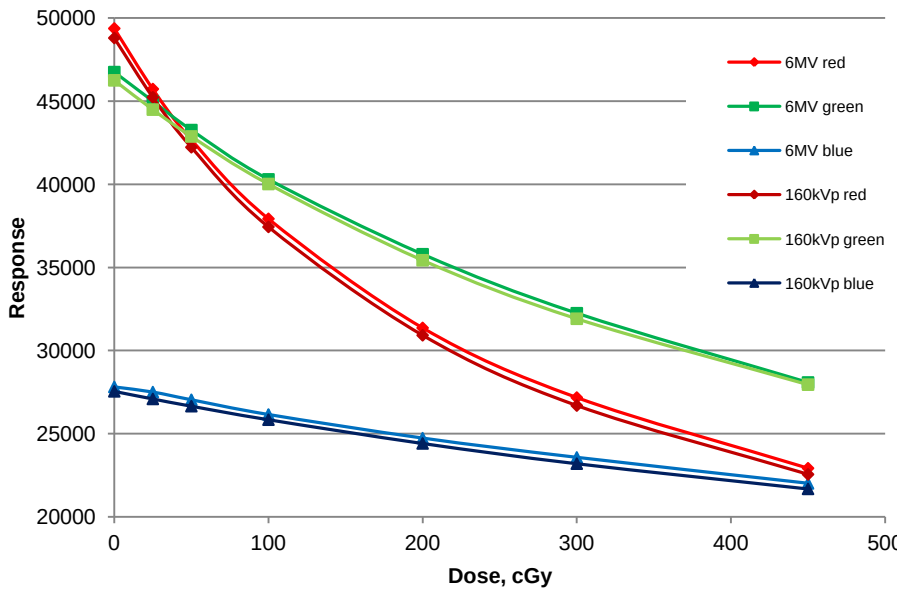


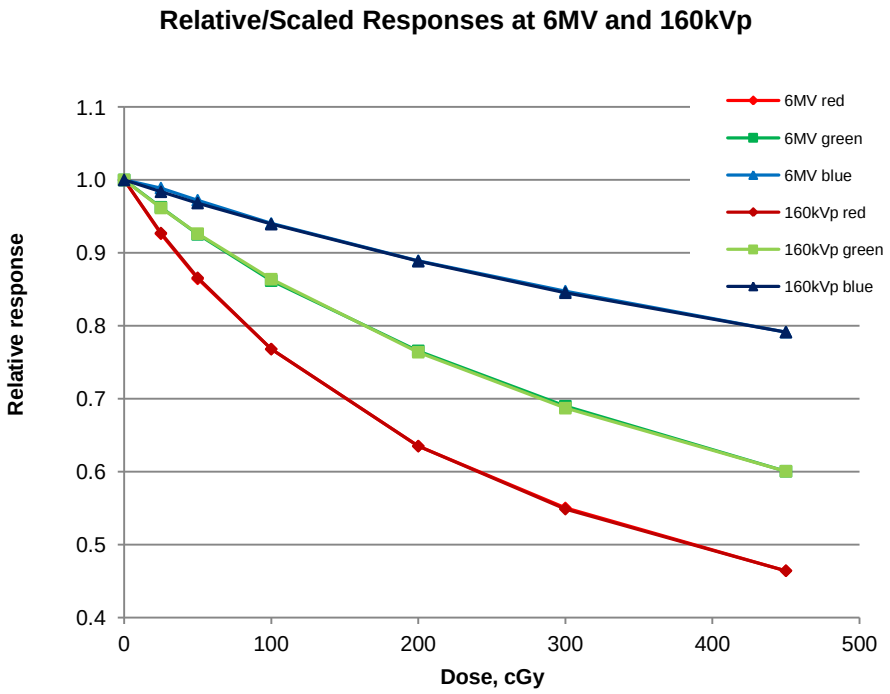
SCANNER TEMPERATURES



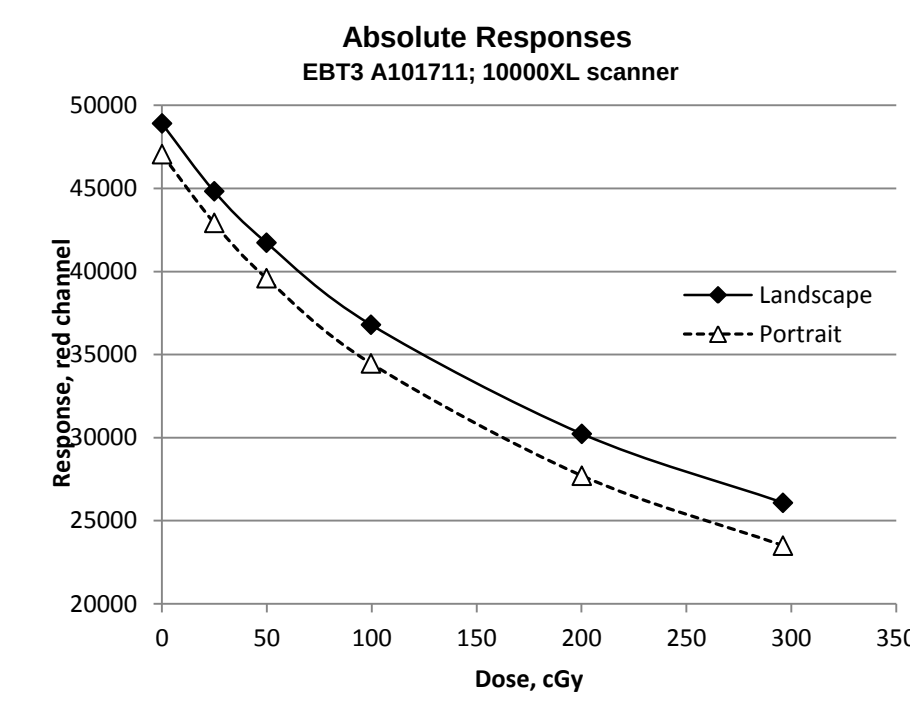


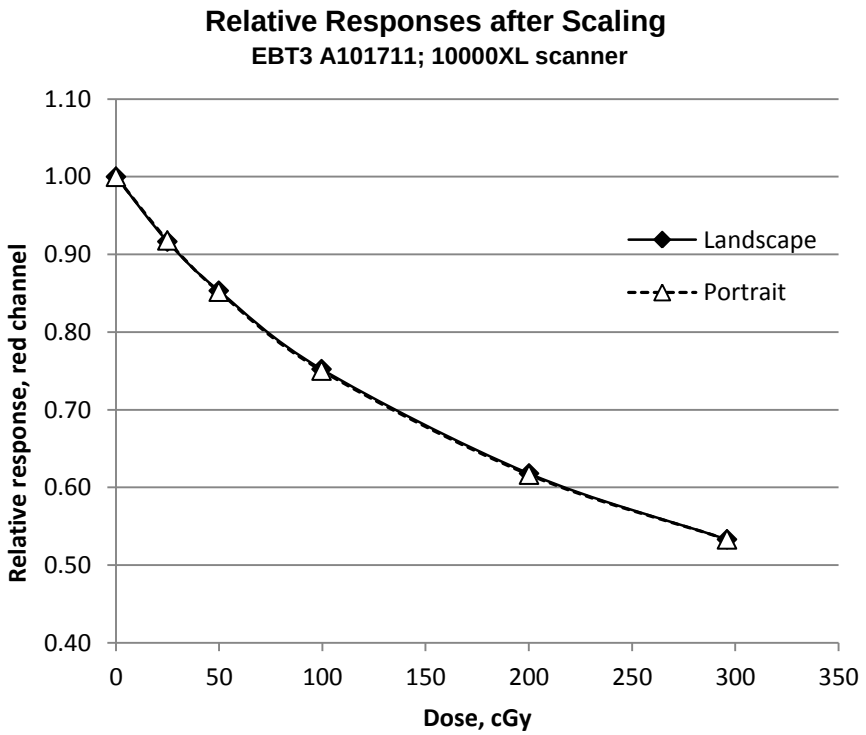
PHOTON ENERGY



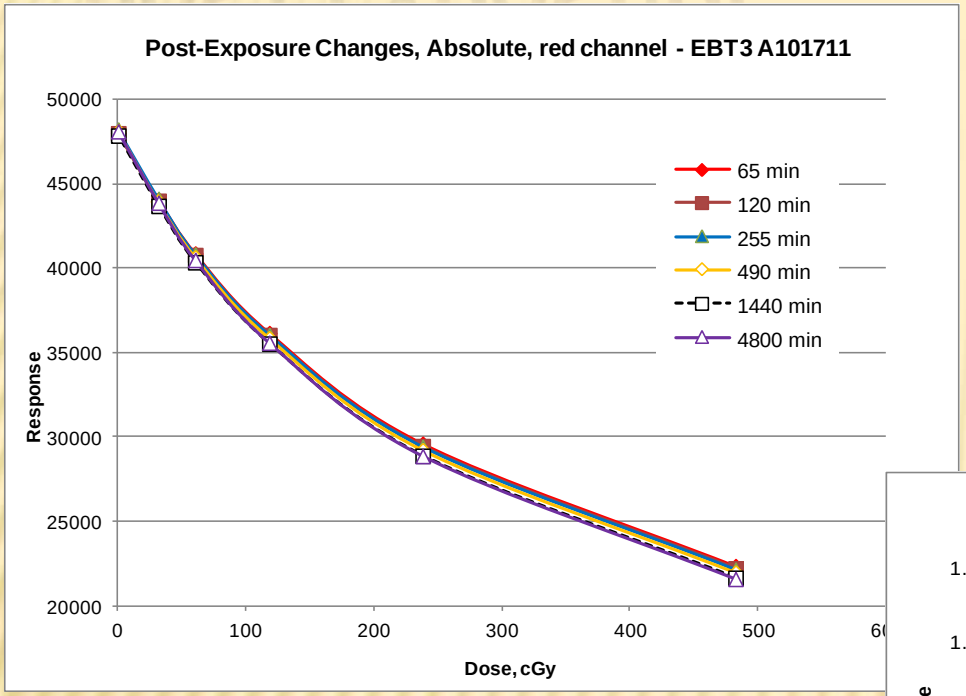


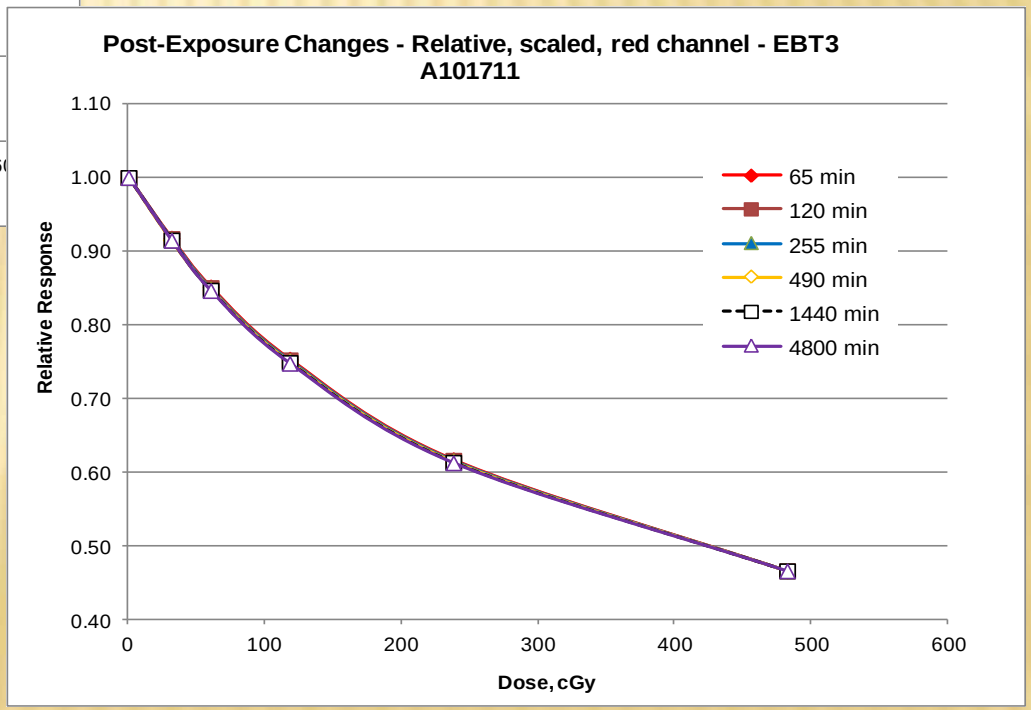
FILM ORIENTATION



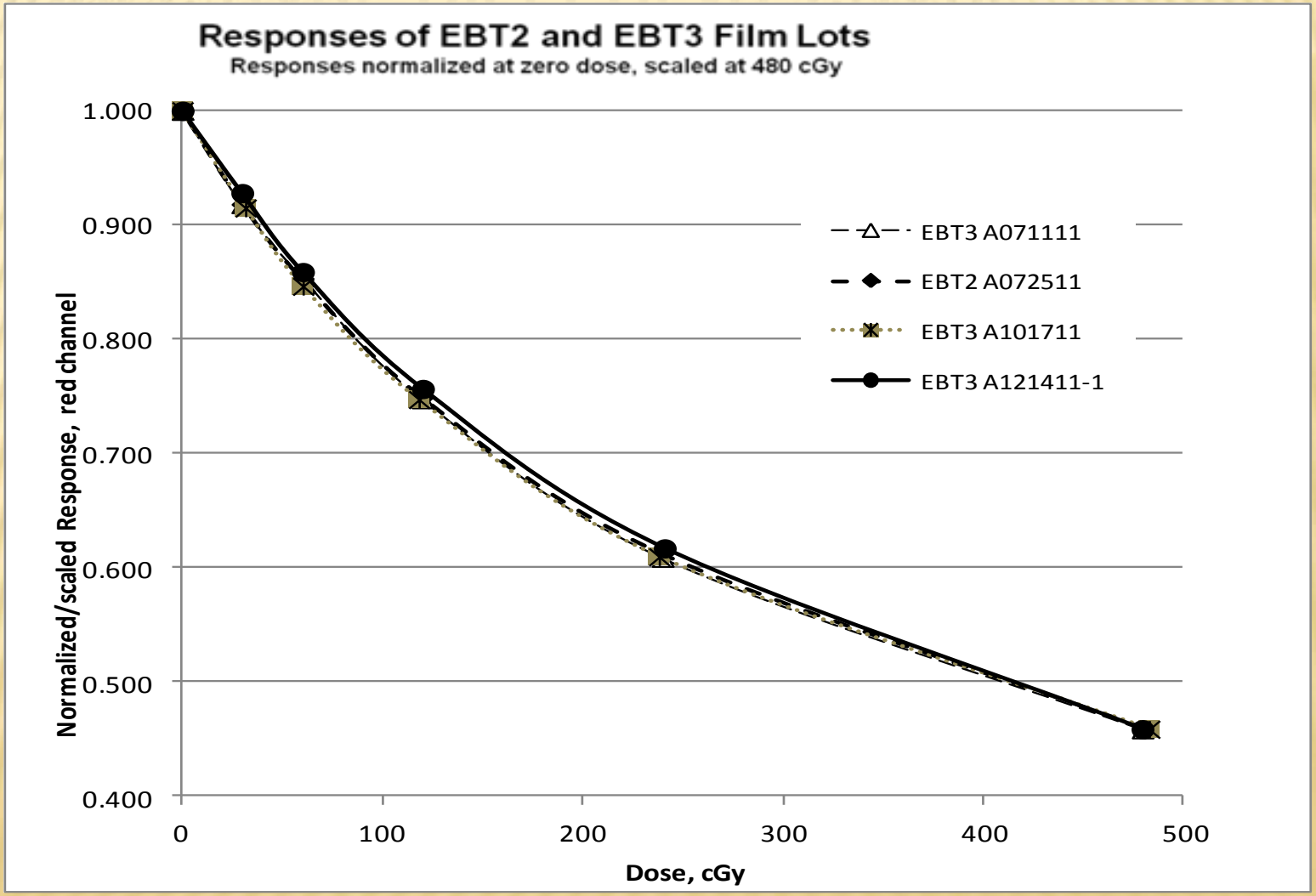


POST EXPOSURE

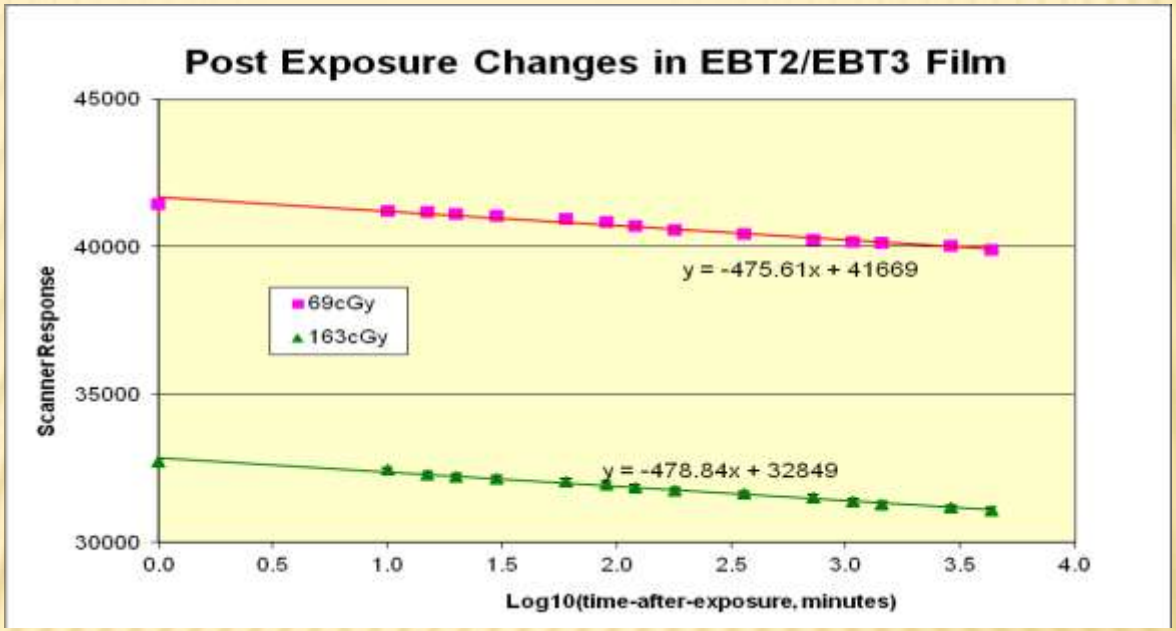




RECALIBRATION LOT-TO-LOT: CURVES HAVE DIFFERENT SHAPE



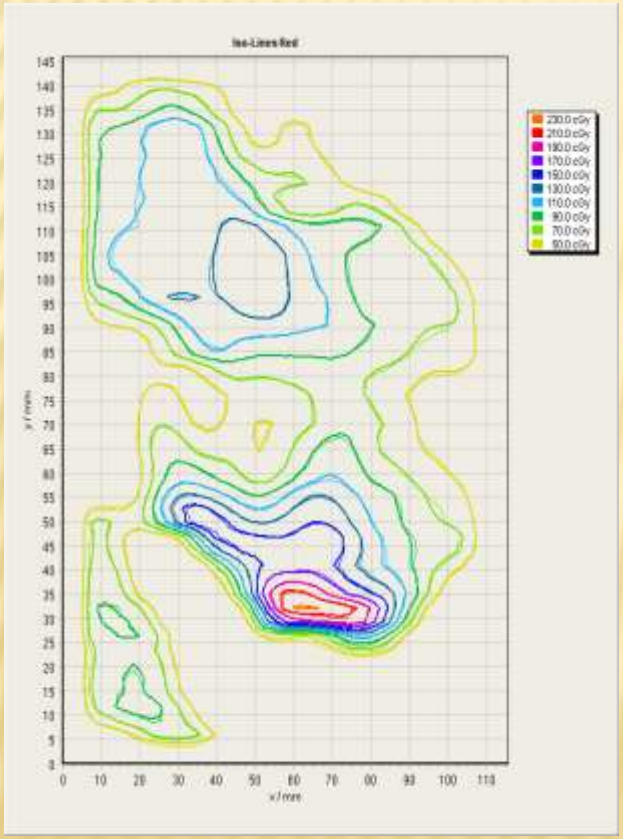
GOOD TIME MANAGEMENT:
THE EXPOSURE WINDOW FOR PATIENT AND REFERENCE FILMS



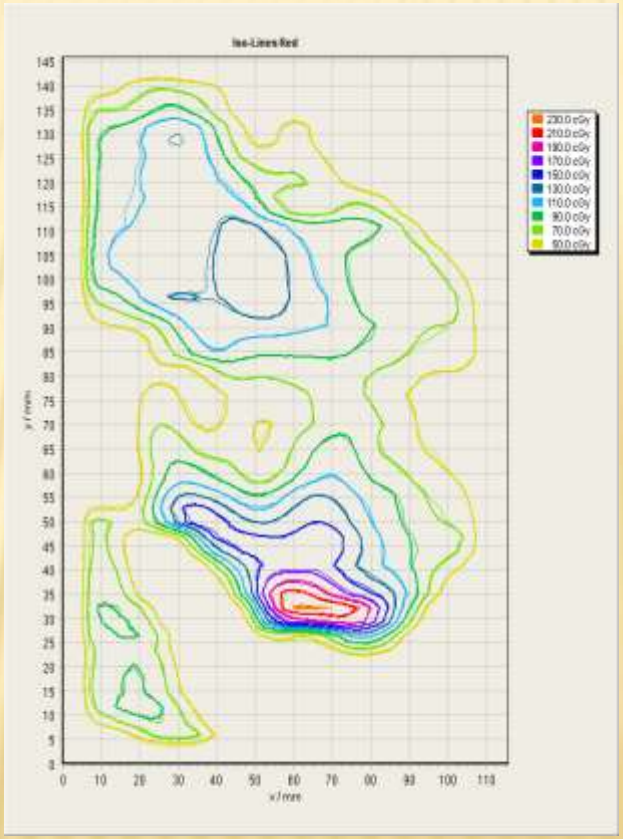
Time after exposure, minutes	Exposure window, minutes	Dose error
10	5	1.0%
20	5	0.5%
40	5	0.25%

EXAMPLES - RESULTS VS. TIME

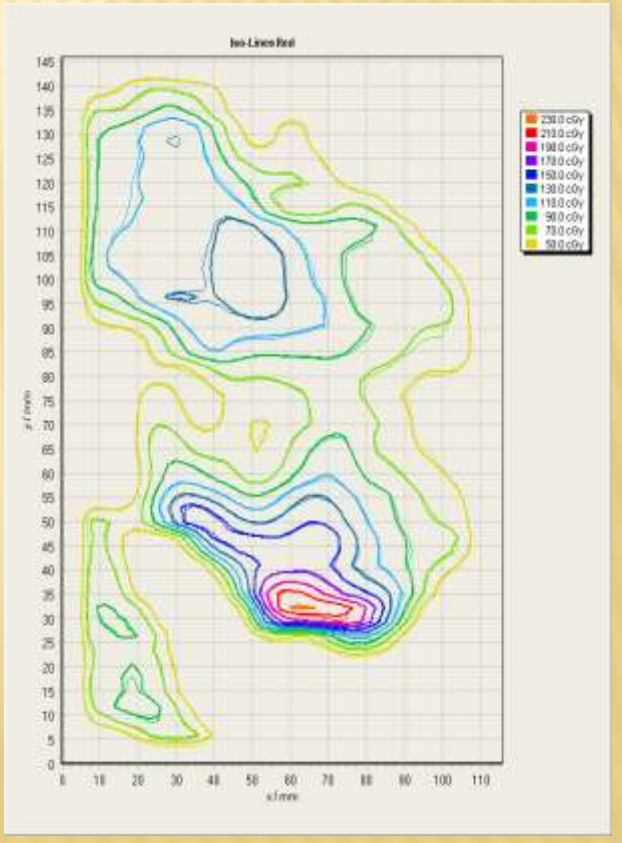
Calibration films scanned 2 hours after exposure
Patient/reference films scanned at different times



30 min. after



4 hours after



3 days after

EXAMPLES - RESULTS VS. TIME

Time after exposure		Gamma passing rate for 2%@2mm
Calibration	Patient film and reference	Red Channel
2 hr	30 min.	97.9
2 hr	60 min.	97.6
2 hr	4 hr	97.7
2 hr	24 hr	97.9
2 hr	72 hr	97.9

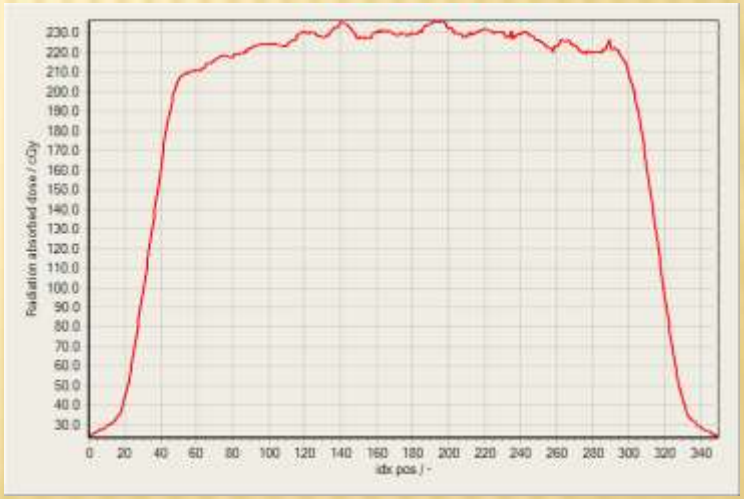
NEW PERFORMANCE STANDARD

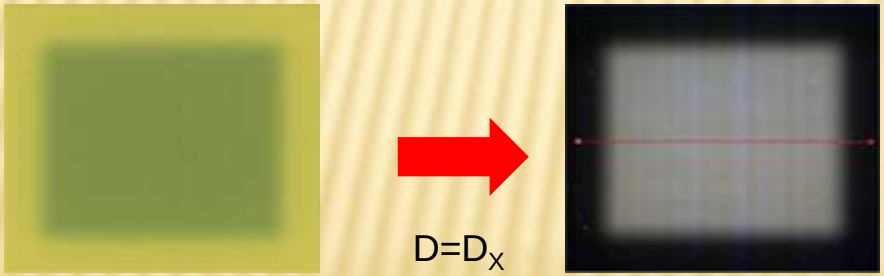
Why One-scan dosimetry?

- Fast – results in minutes
  - Less exposures and scanning
- Uncomplicated
  - Easy use
- Economical
  - Less film consumption
- Reliable and Accurate
  - Multi-Channel Dosimetry

SINGLE CHANNEL 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 $D_X(X)$





Every measured response maps directly to a dose
Every response artifact maps to a dose artifact
1% response artifacts map to 3% dose artifacts

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
  - $| C_{scan} - C(D) | \rightarrow \min_D$

MULTI-CHANNEL FILM DOSIMETRY

- Model:
  Scanned optical density $d_{X,scan}$
  - $d_{X,scan}(D) = d_{X,D}(D)$ * 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 $\Delta d = \Delta d$(film, scanner, noise, environment, artifacts)
- Solution:
  - Minimized function ϕ *vs.* disturbance Δd:

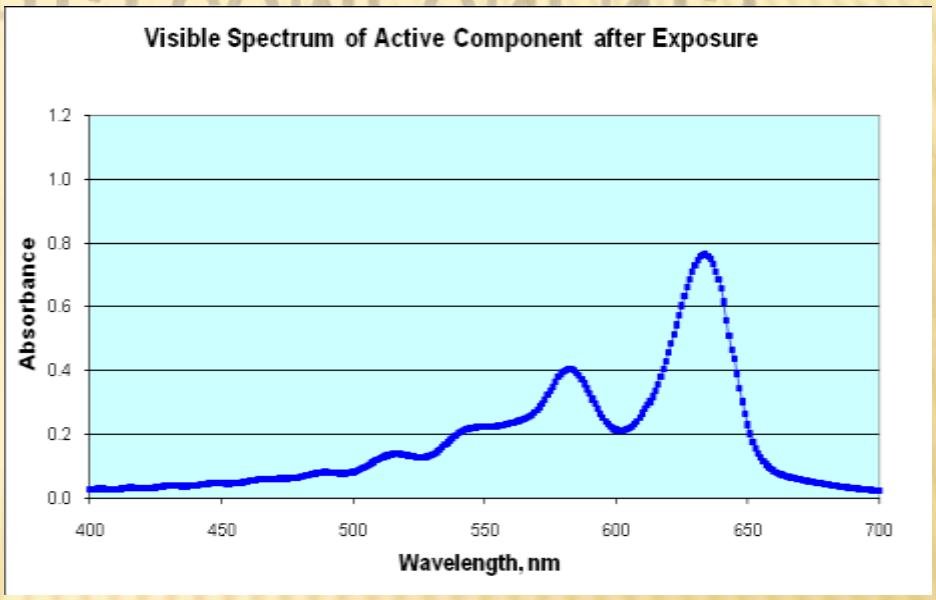
    $\phi(\Delta d) = (D_R - D_B)^2 + (D_B - D_G)^2 + (D_G - D_R)^2 \rightarrow \min_{\Delta d}$

WHY THE MARKER DYE?

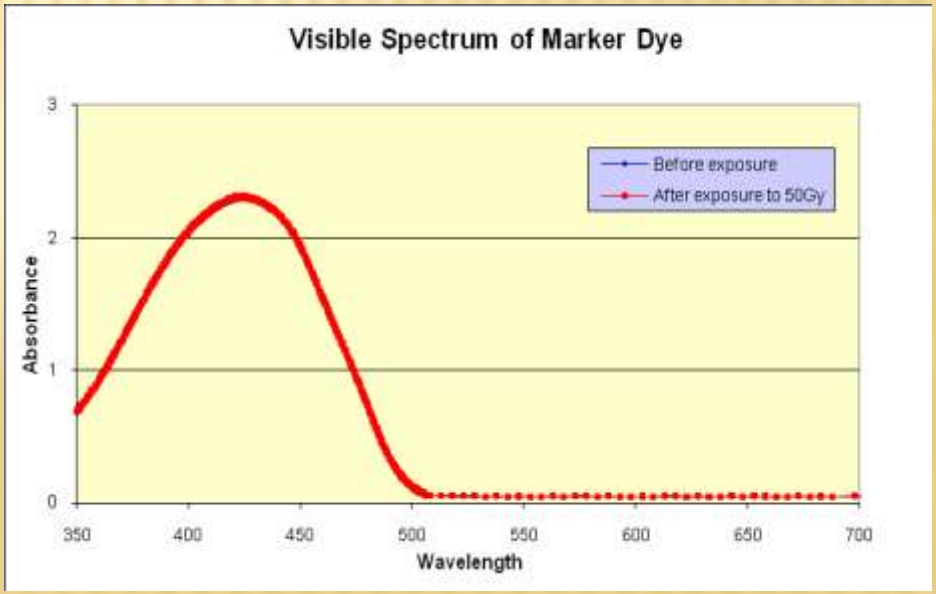
- Red channel signal dominated by dose information
- Blue channel signal dominated by uniformity information
- Facilitates correction of film non-uniformities
  - U.S. Patent 6,285,031 September, 2001
  - U.S. Patent Application ???????

SPECTRA OF EBT2/EBT3 COMPONENTS

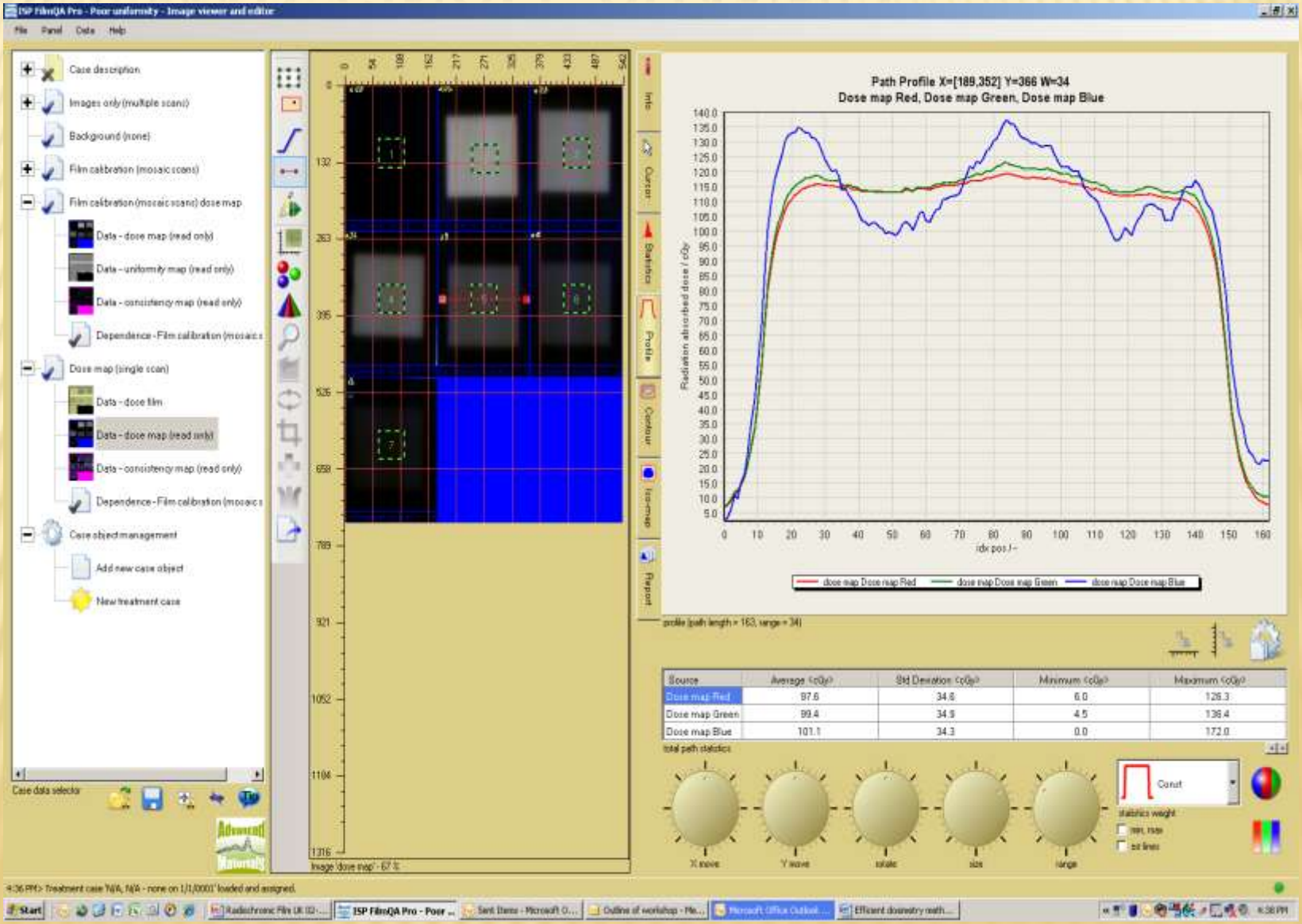
- Active component
  - Signal in red channel



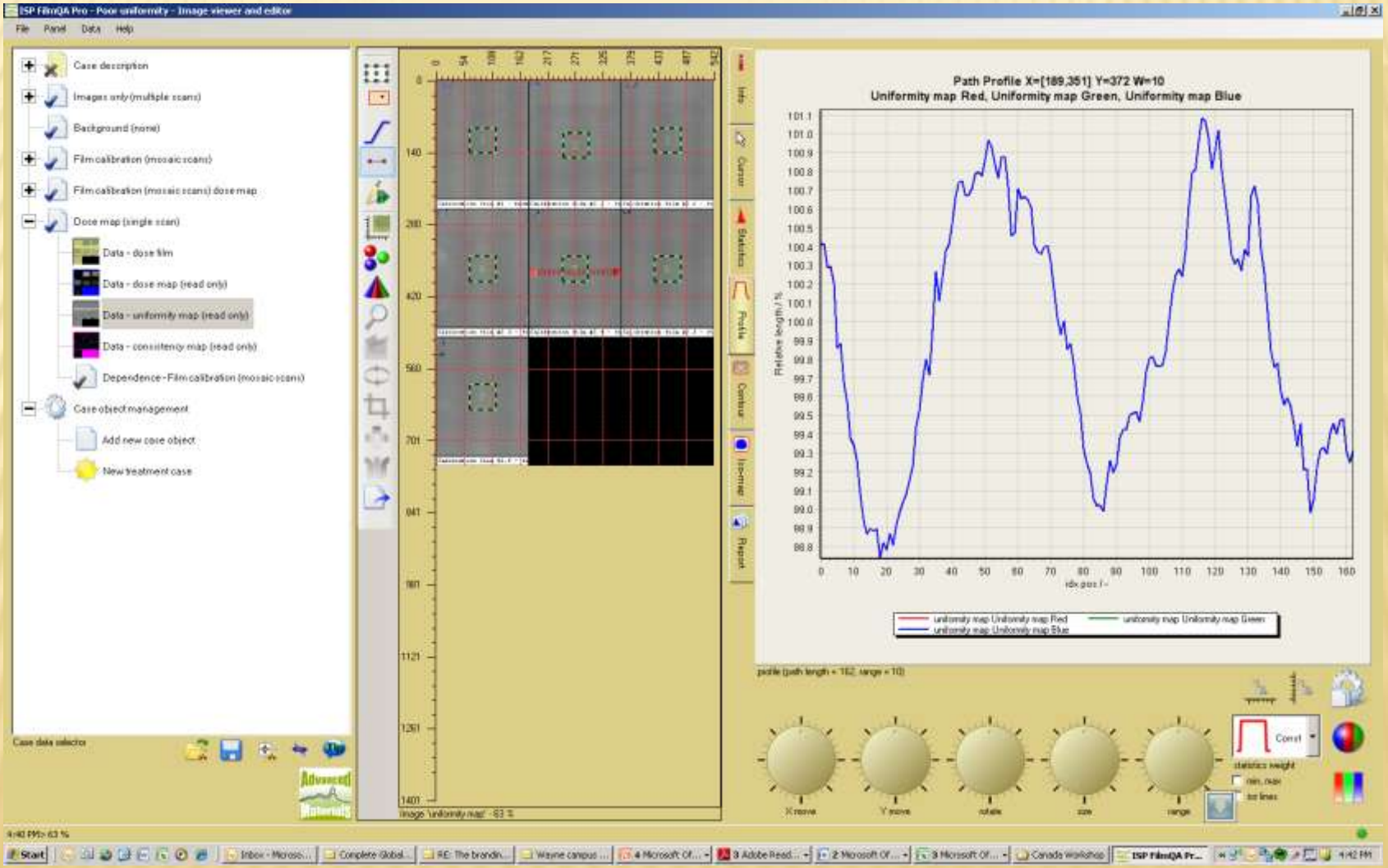
- Marker dye
  - Signal in blue channel



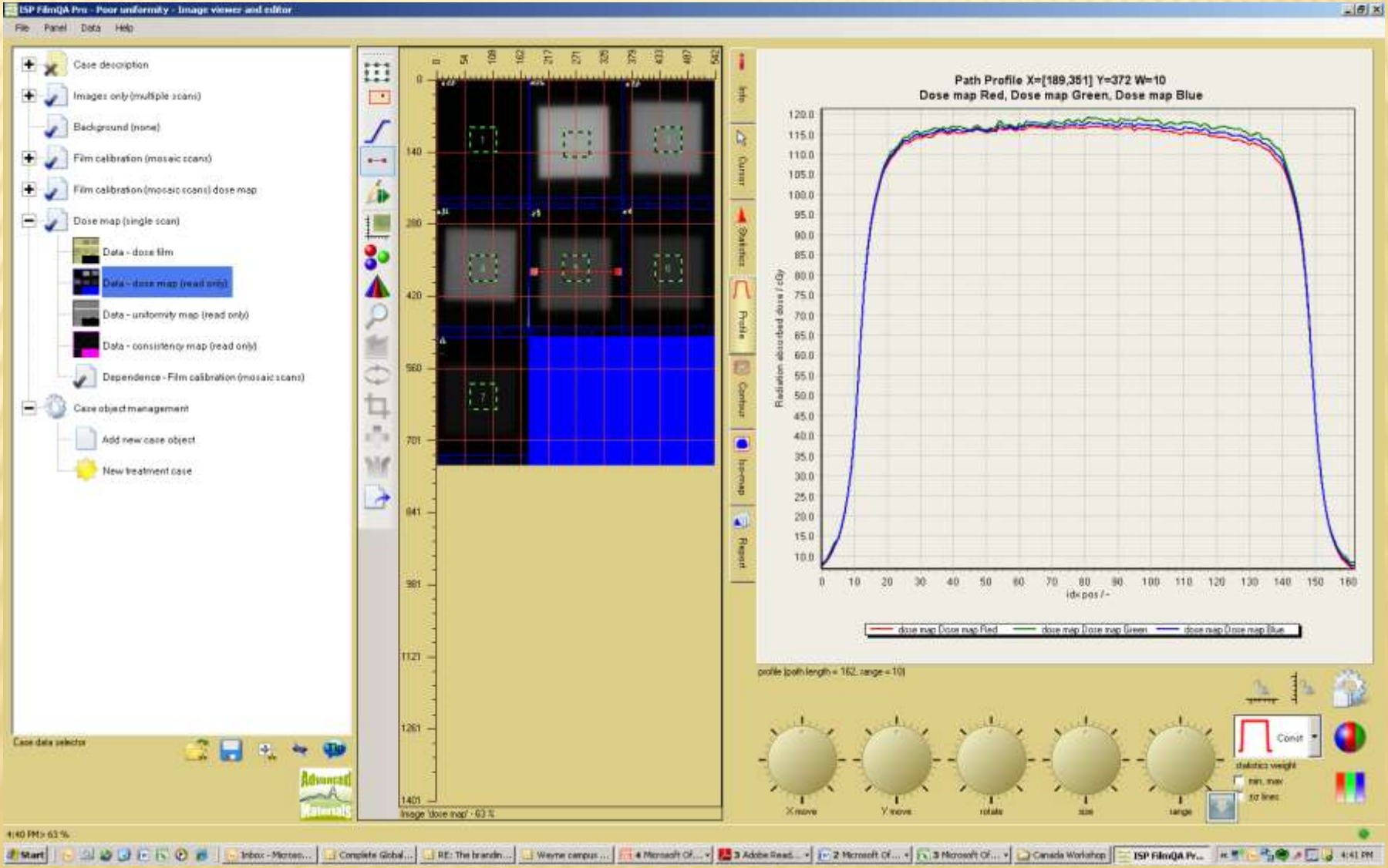
DOSE MAP- SINGLE CHANNEL



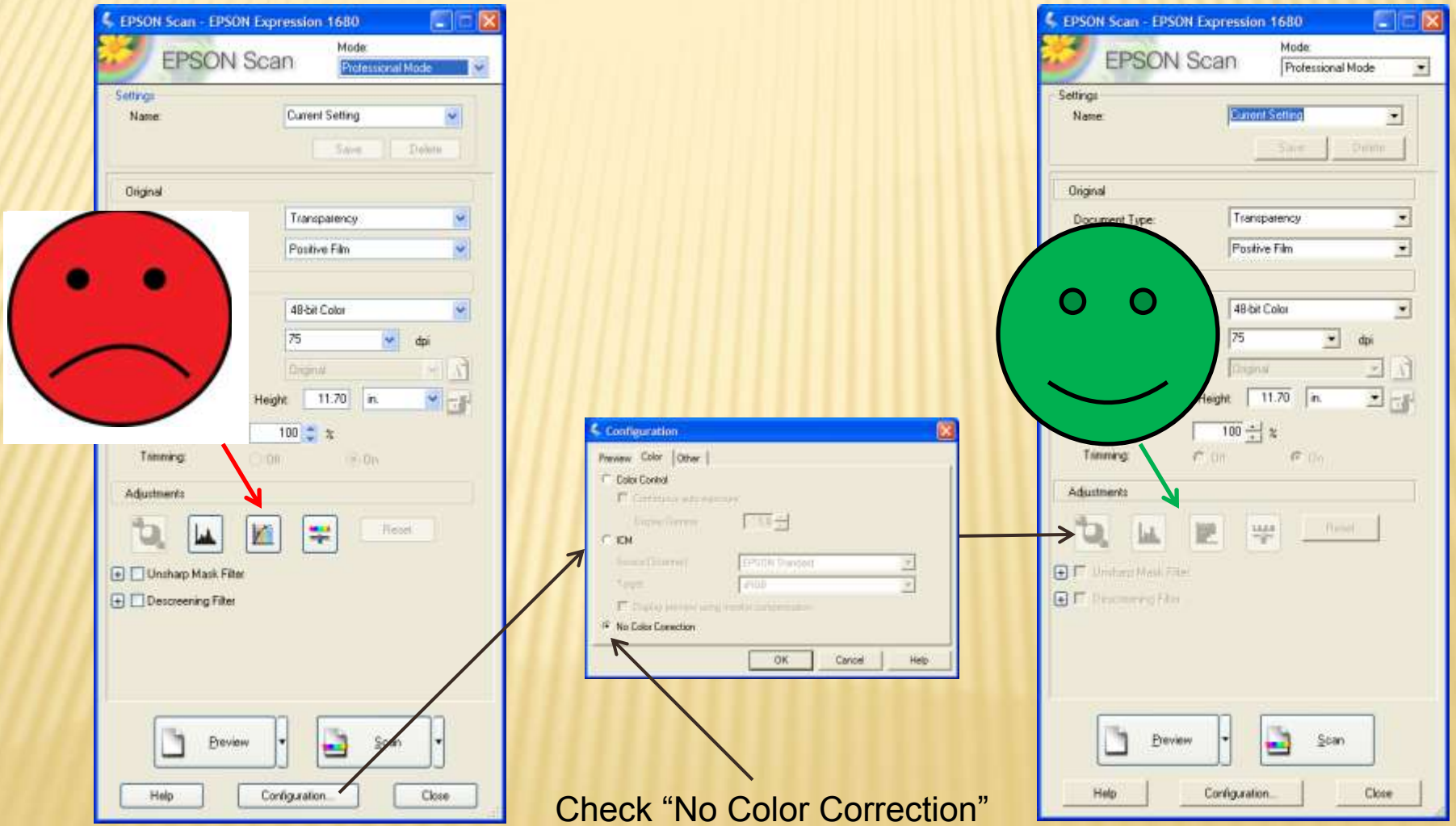
DOSE MAP- DISTRURBANCE



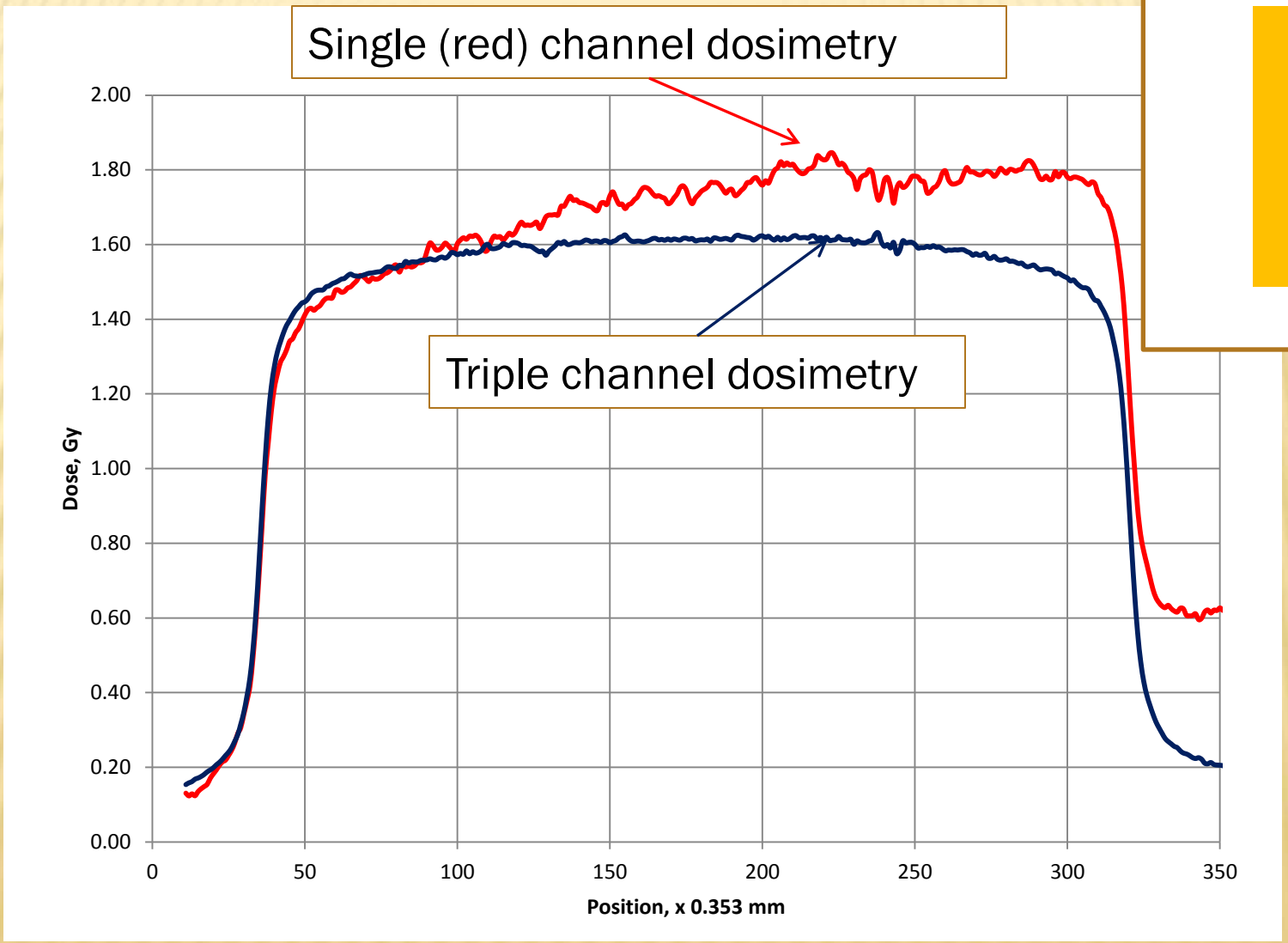
DOSE MAP- MULTI CHANNEL



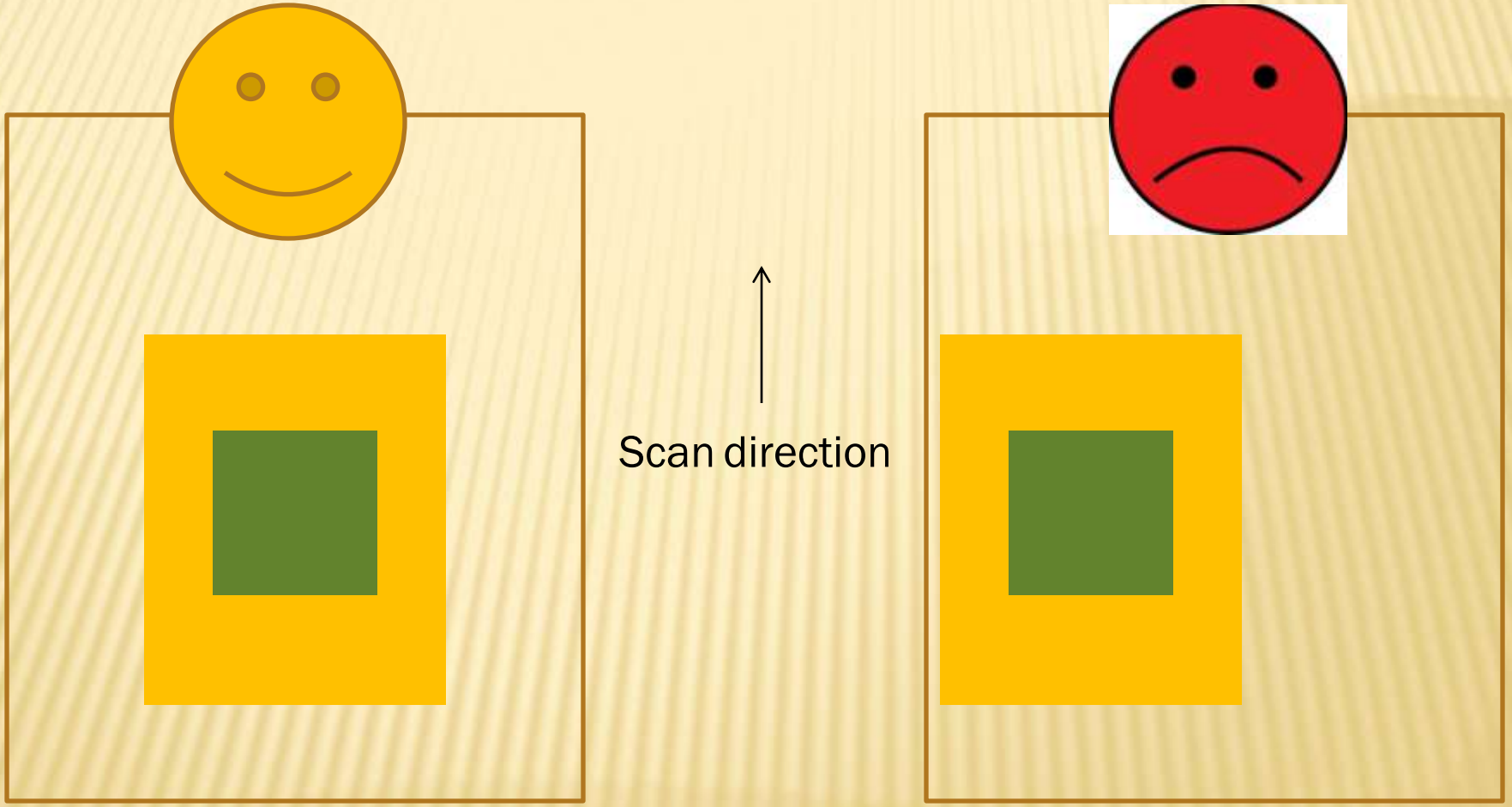
WHAT DO I NEED TO KNOW ABOUT SCANNING?
DISABLE ALL THE IMAGE ADJUSTMENT FEATURES



DOSIMETRY METHOD AND LATERAL DISPLACEMENT



FILM PLACEMENT ON THE SCANNER



CLINIC EXAMPLES OF MULTI CHANNEL ONE SCAN DOSIMETRY

SYNERGY

Gafchromic Films

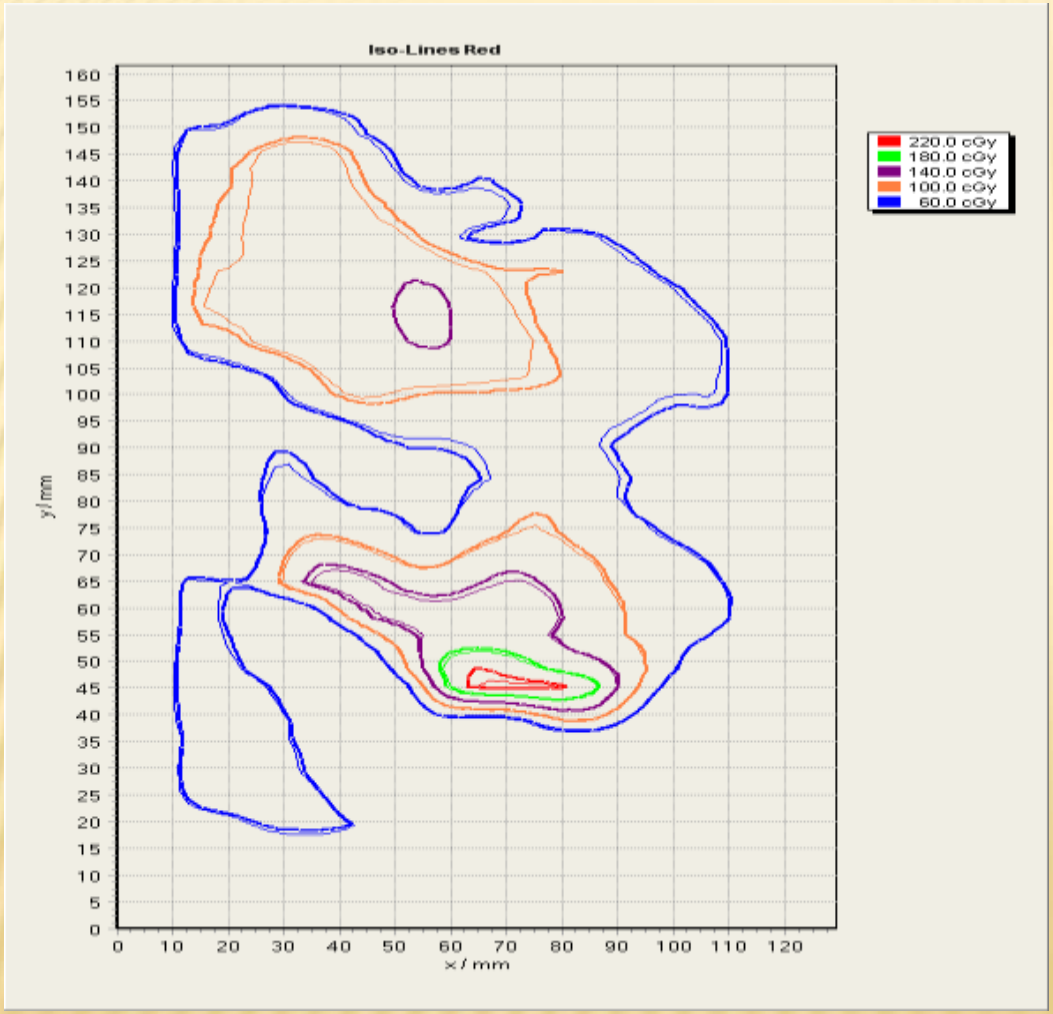
and

FilmQA Pro 3.0

GafChromic

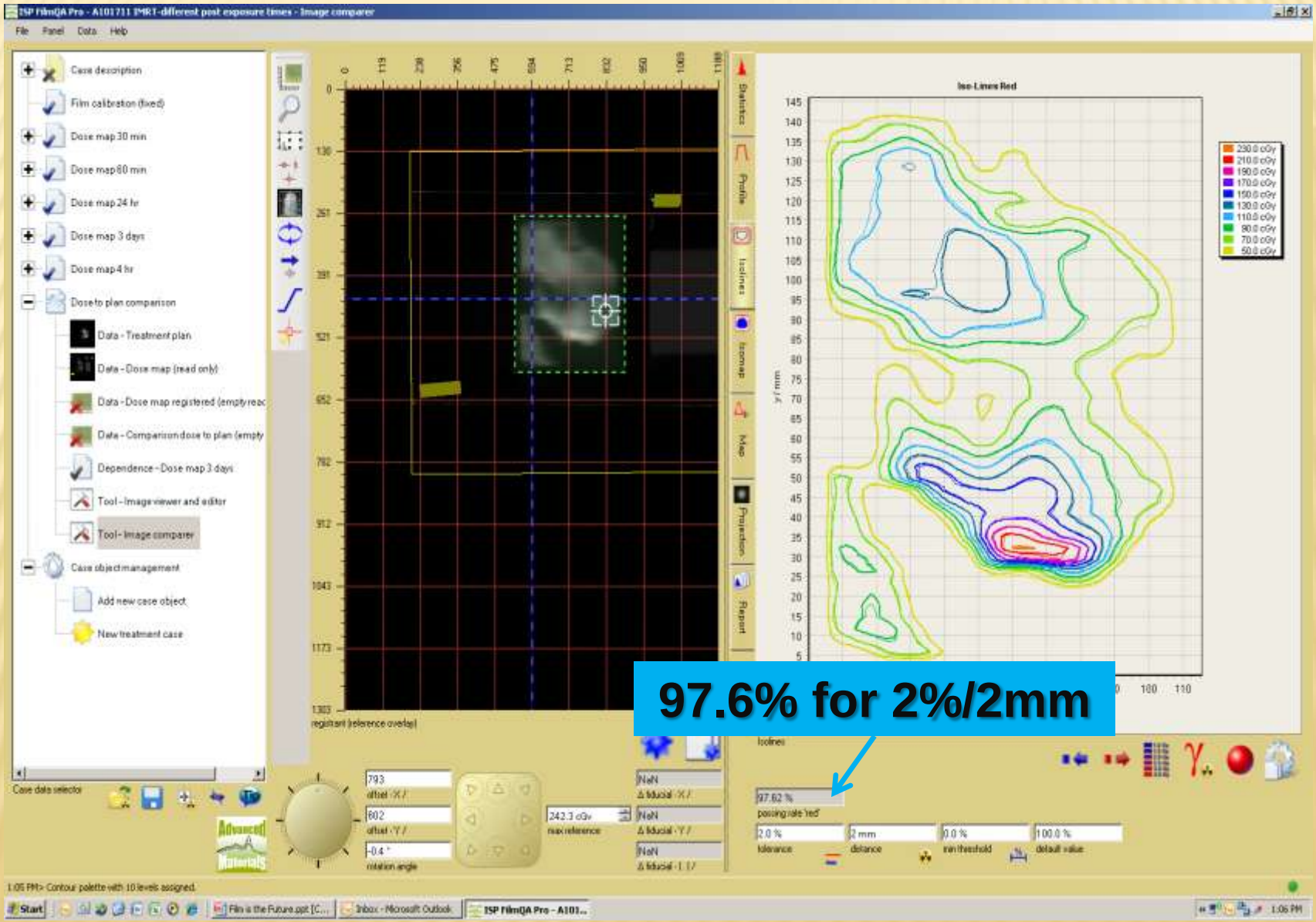
ASHLAND

CONVENTIONAL FILM DOSIMETRY

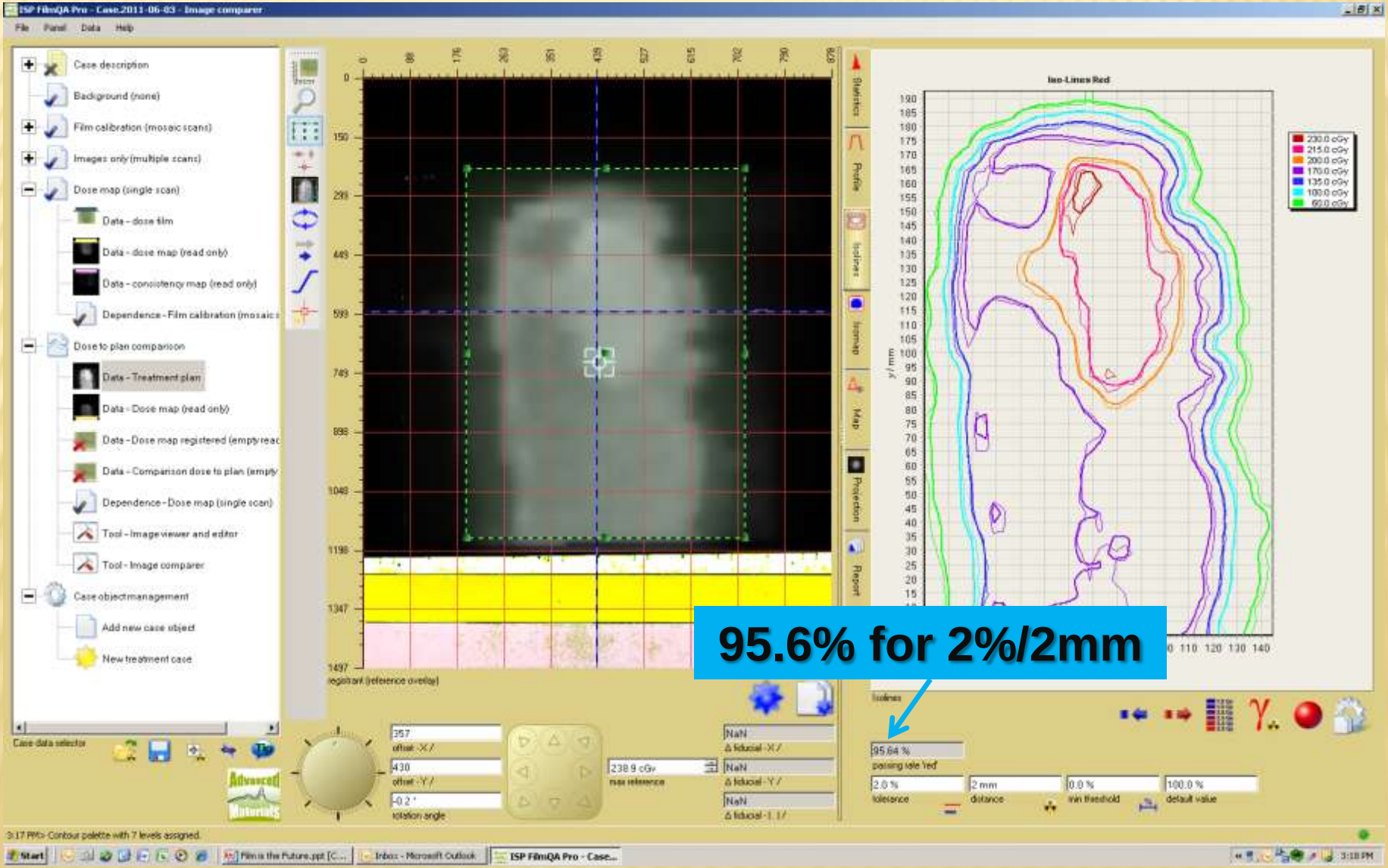


Typically >90% pixels passing gamma test of 3% at 3mm

SINGLE IMRT FIELD- MULTI-CHANNEL, ONE-SCAN

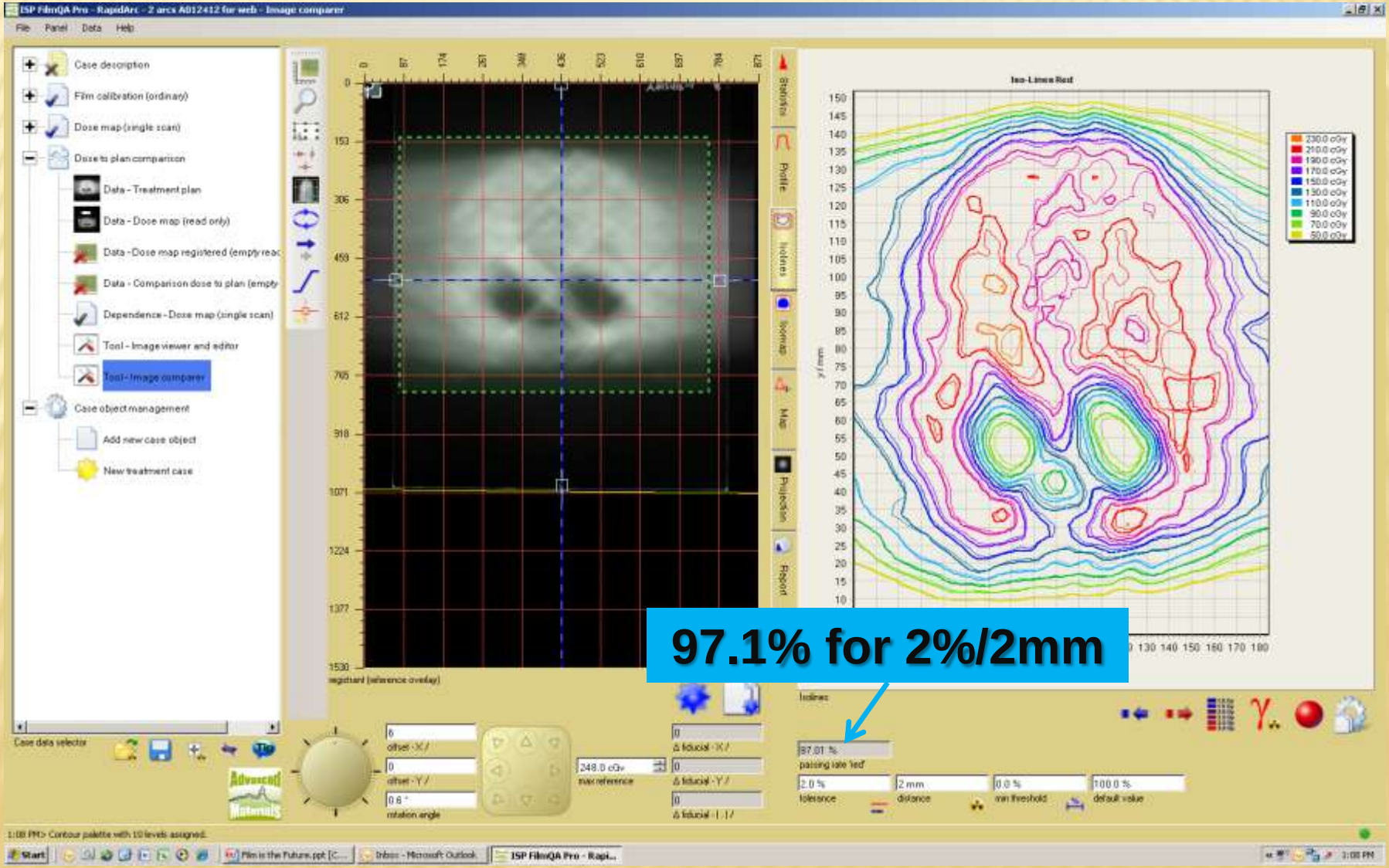


COMPOSITE IMRT-MULTI-CHANNEL, ONE-SCAN

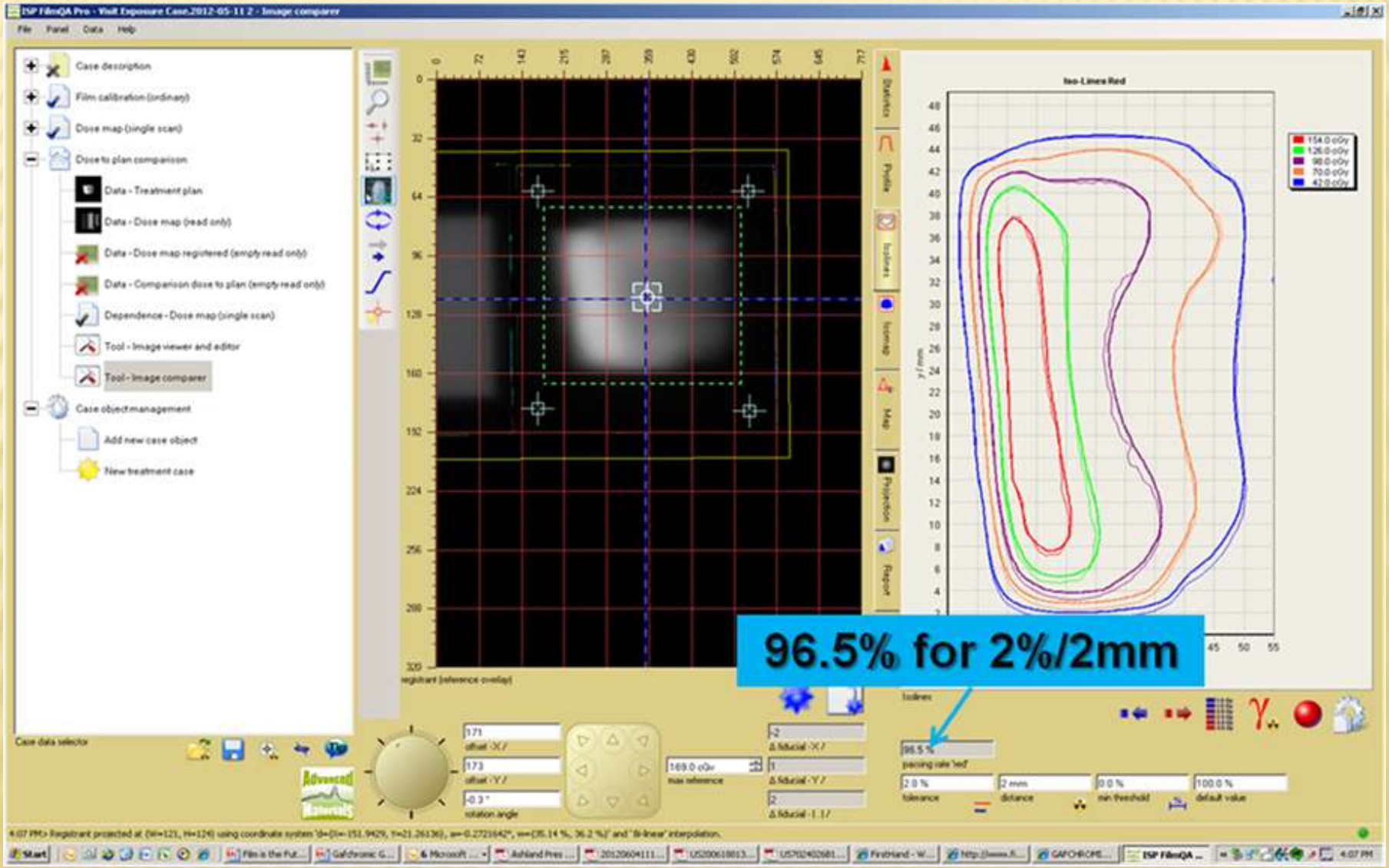


RAPIDARC™, ONE ARC-MULTI-CHANNEL, ONE-SCAN

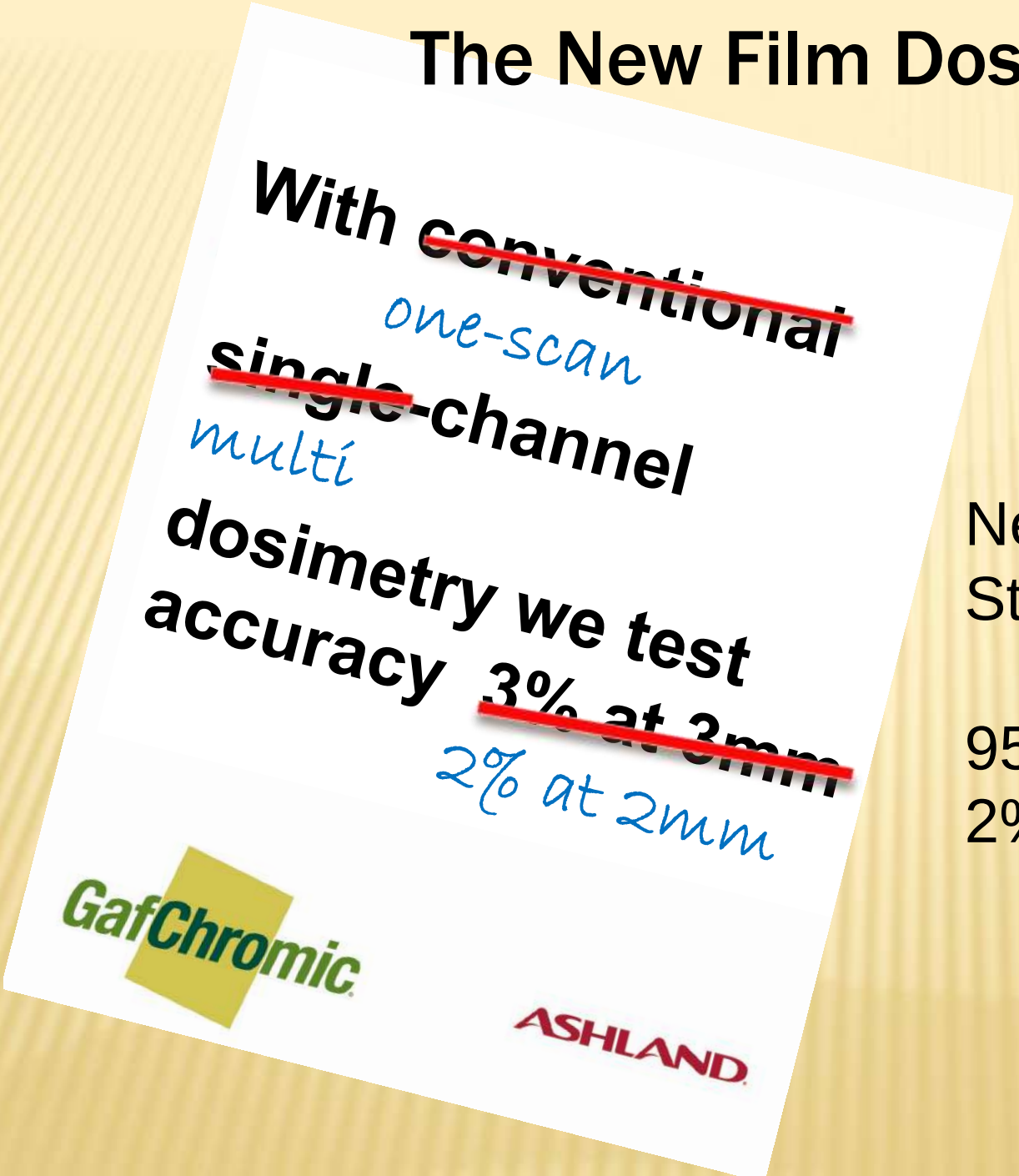
RAPIDARC™, TWO ARCS-MULTI-CHANNEL, ONE-SCAN



SRS ONE FIELD – MULTI-CHANNEL, ONE-SCAN



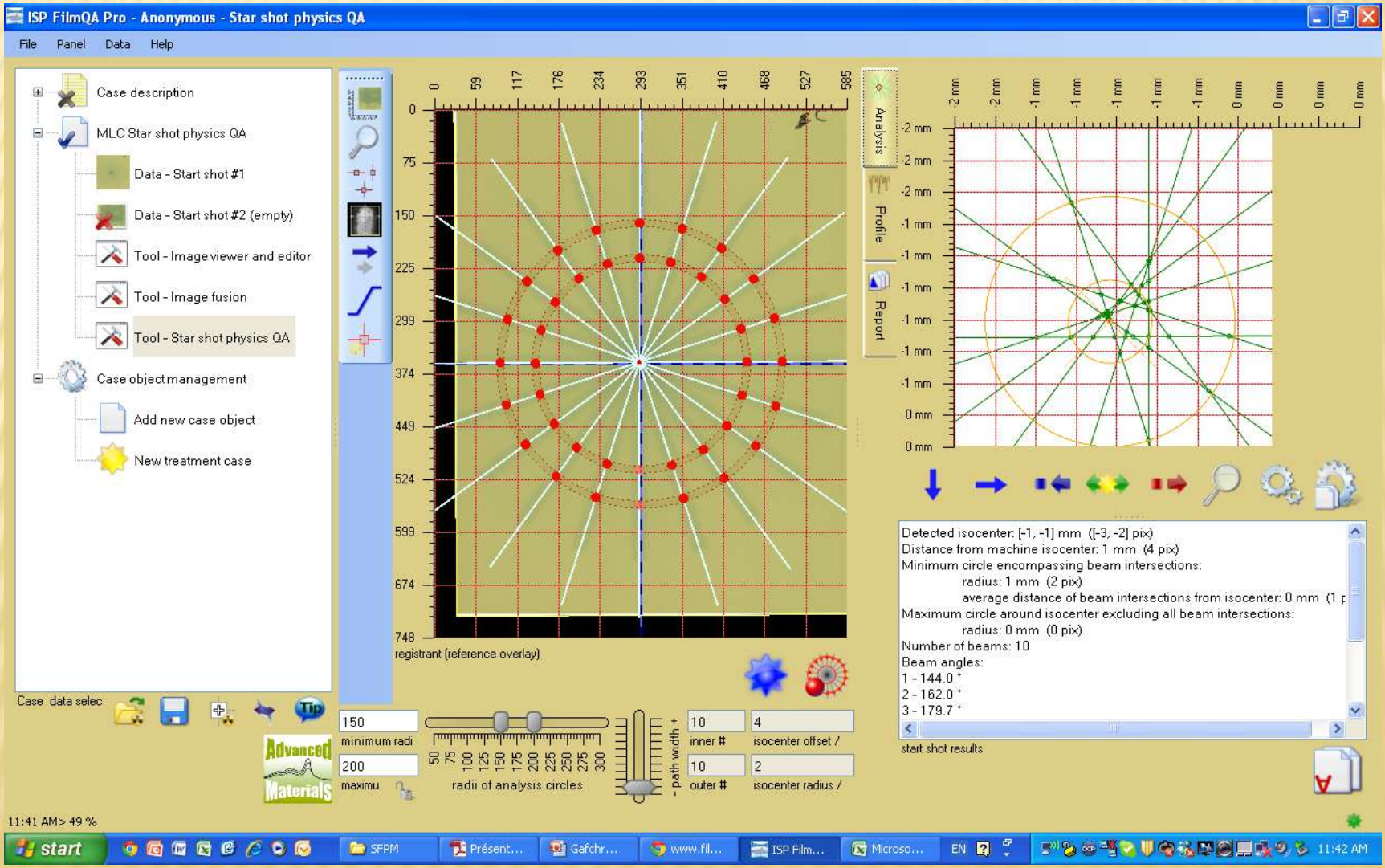
The New Film Dosimetry Standard



New Film Dosimetry Standard

95% pixels passing
2% at 2mm

NEW PHYSICS QA TOOLS



MULTI-CHANNEL AND ONE-SCAN DOSIMETRY IS THE NEW STANDARD

- Application and calibration films scanned simultaneously
  - Inter-scan variability is avoided
- Multi-channel dosimetry corrects/mitigates film and scanner artifacts
- Simplicity goes up and errors go down
- Gamma evaluation with 95% passing 2%/2mm

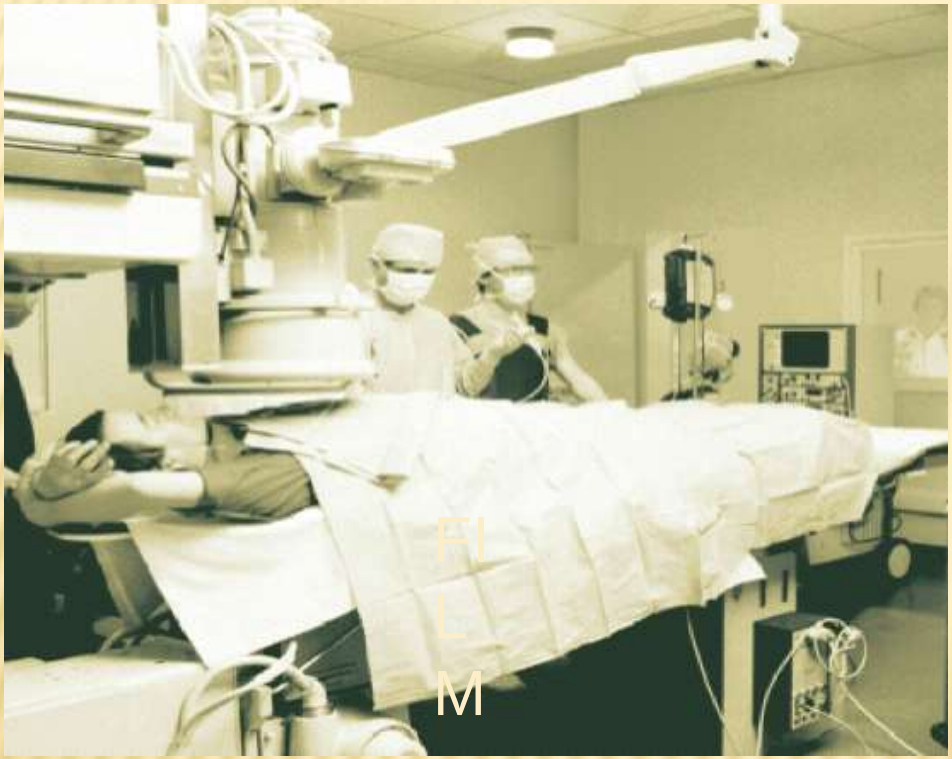
FILM DOSIMETRY SUMMARY OF ADVANTAGES

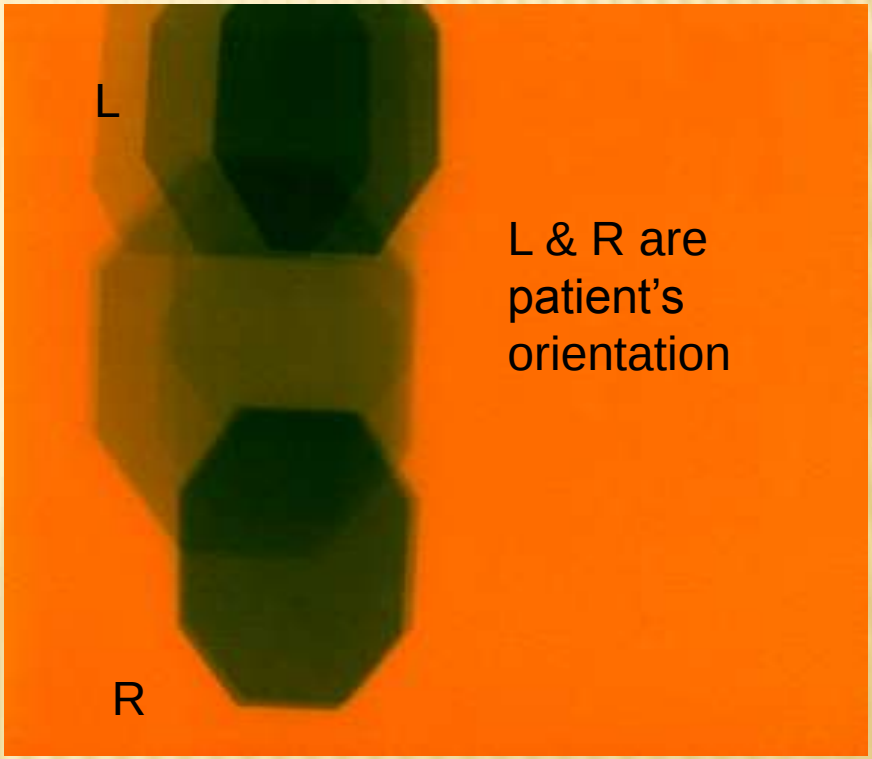
- Post-exposure timing rules are relaxed
- No concern whether a calibration is still valid
- Don’t need large number of calibration films
- Don’t need multiple scans
  - Entry costs - Film/Software/scanner
    - Much less than an array device
  - Running costs
    - Less film consumption
    - Less working time

EBT2/3 + FILMQAPRO 3.0-A COMPLETE SYSTEM

- Provides millions of measurements
  - Arrays only make 100 - 1000 measurements missing 99.9% of the picture
- Nothing is missed with film
- Shoot film from any angle
  - Shoot the whole plan on one film
  - Just like the patient gets it

DOSE MONITORING WITH GAFCHROMIC® XR-R





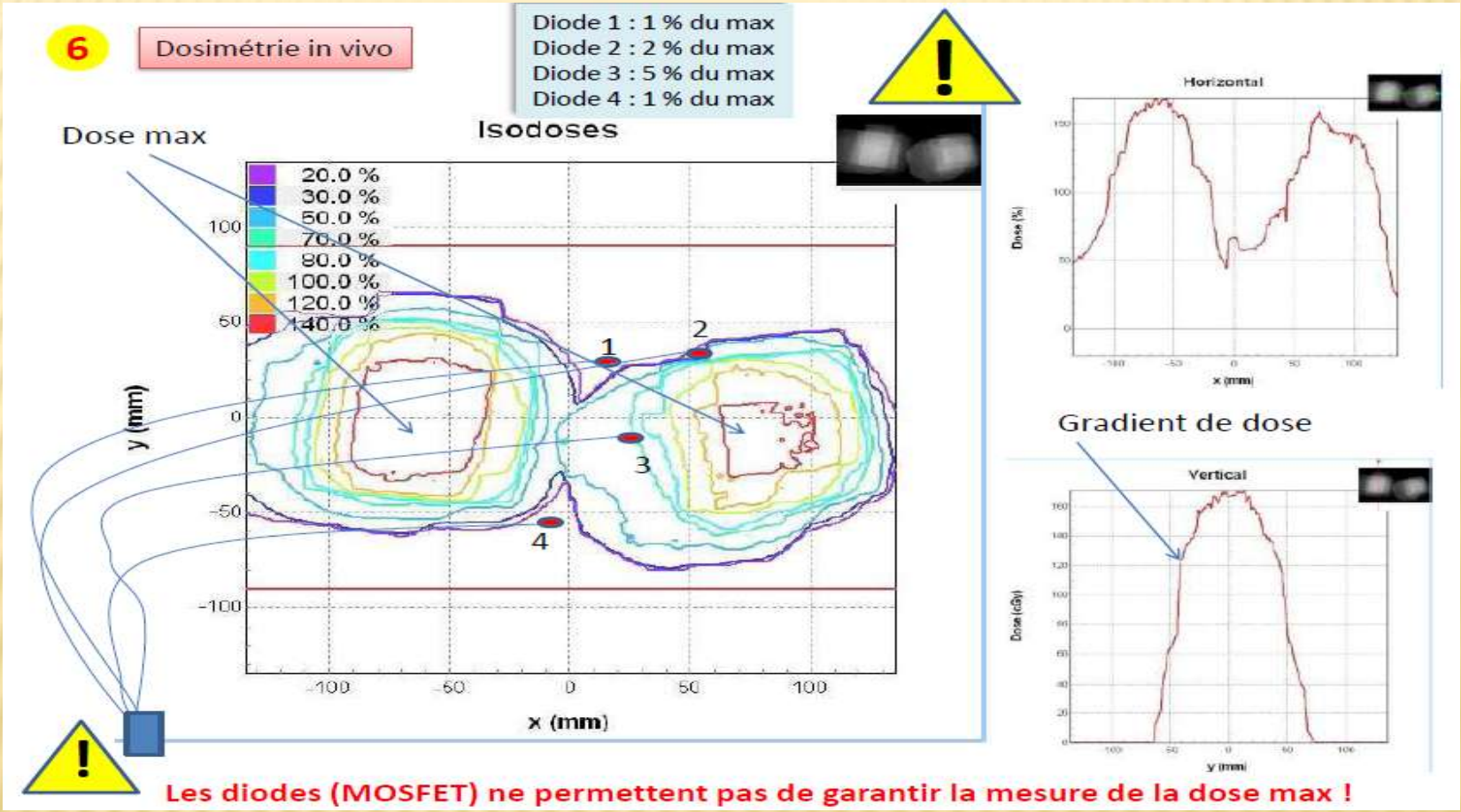
- **Immediate visualization** of patient exposure – magnitude and location
- Detailed **dose distribution**

IAEA STUDY RESULTS

	Coronary	Non-Coronary
# of patients	400	250
% > 2Gy	12	10
Repeat	40%	40%

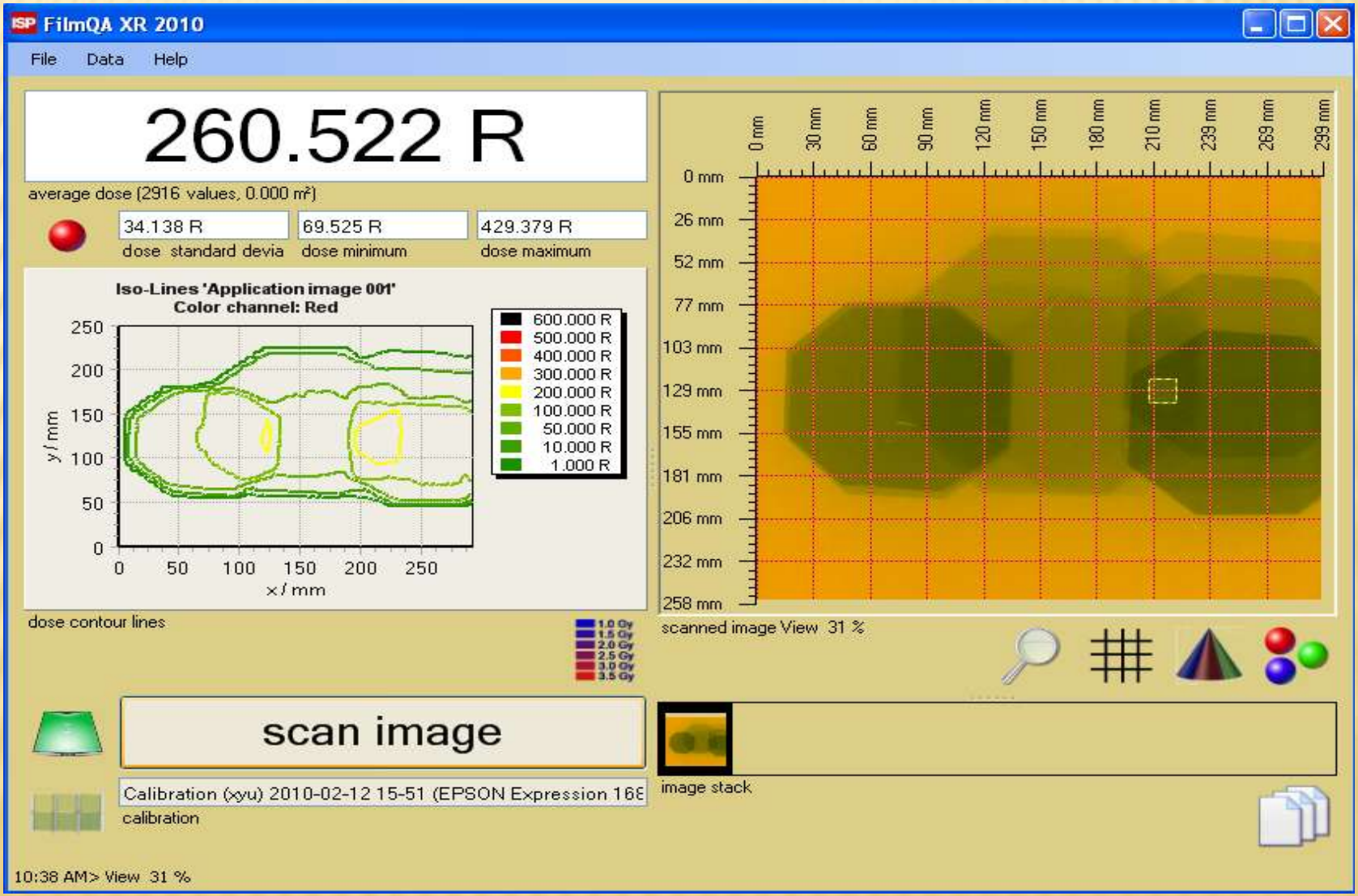
- Gafchromic ® XR Film
  - Easiest
  - Simple
    - Visual Reference
    - Feedback during procedure
  - Consistent and Reliable Results
- DAP/KAP
  - Difficult to correlate to peak skin dose
- Importance of Dose Monitoring

COMPARISON OF GAFCHROMIC XR-R WITH DIODES



*Data provide by Les Hopitaux Universitaires de Strasbourg, used with permission

FILMQA-XR SCREEN SHOT



FUTHER QUESTIONS?

- For more information
  - www.gafchromic.com
  - www.FilmQApro.com
  - www.FilmQAXR.com
- Contact us directly
  - amicke@ashland.com
  - xiangyu@ashland.com
  - dlewis@ashland.com

With the New Protocol and Your Efforts