Basic Film Dosimetry

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Basic Film Dosimetry

What is a film?
Why to use film ?
How to use film?
Where to use film?

Historical Perspective

1826	Joseph Niepce	First Photograph
1836	J. M. Daguerre	Concept of developer
1889	Eastman Kodak	Cellulose nitrate base for emulsion
1890	Hurter &Driffield	Defined the term optical density
1895	Roentgen	First Radiograph
1896	Carl Schlussner	First glass plate for radiography
1913	Kodak	Film on Cellulose nitrate base
1918	Kodak	Double emulsion film
1933	Dupont	X-ray film with blue base
1942	Pako	Automatic film processor
1960	Dupont	Polyester base introduced
1965	Kodak	Rapid film processing
1972	Kodak	XTL and XV film for therapy
1983	Fuji	Computed radiography system
1994	3M	Dry process laser imaging

Film Dosimetry

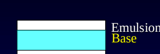
- Silver halides
  - Radiographic film
    - Available in various sizes
    - Radiation range (mGy-Gy)
    - Wet chemical processing
    - Strong energy dependence
    - Densitometer- any
- Self Developing
  - Radiochromic, Gafchromic film
    - Relatively smaller film (10x10 cm^2)
    - Radiation range (Gy-100Gy)
    - No processing
    - Little energy dependence
    - Densitometer- Specialized (light sensitive)

Radiochromic Film

Niroomand-Rad et al, Radiochromic film dosimetry: Recommendations of AAPM Radiation Therapy Committee Task group 55, Med. Phys. 25(11), 2093-2115, 1998

Radiographic Film

- Base (Cellulose nitrate or Polyester) (typically 200 µm)
- Emulsion (10-20 µm; 2-5 mg/cm^3)
  - Gelatin (derivative from bone)
  - grain (size: 0.1 -3 µm diameter)
    - AgBr (cubic crystal with lattice distance of 28 nm
    - AgI
    - KI
  - There are 10^9-10^{12} grains/cm^2 in x-ray films
- Coating
  - Very sensitive which may determine X & Y direction uniformity



Photographic Process

- Silver halides (AgBr, AgCl, AgI) are sensitive to radiation.
- Radiation event (latent image) can be magnified by a billion fold (10^9) with developer.

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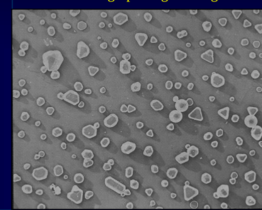
Emulsion of Film/Radiograph

The heart of film is emulsion which contains grains (crystals of silver halides) in gelatin

Gelatin is suitable due to

- it keeps grains well dispersed
- it prevents clumping and sedimentation of grains
- it protects the unexposed grains from reduction by a developer
- it allows easy processing of exposed grains
- it is neutral to the grains in terms of fogging, loss of sensitivity

Electron micrograph of grain in gelatin



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Film Processing

- Developing [(Metol; methyl-p-aminophenol sulphate or Phenidone; 1phenol 3pyrazolidone)]
  - Converts all Ag^+ atoms to Ag. The latent image Ag^+ are developed much more rapidly.
- Stop Bath
  - dilute acetic acid stops all reaction and further development
- Fixer, Hypo (Sodium Thiosulphate)
  - it dissolves all undeveloped grains.
- Washing
- Drying

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Latent image

- The change which causes the grains to be rendered developable on exposure is considered to be the formation of latent image.
- It is composed of an aggregate of a few silver atoms (4-10).
- On average 1000 Ag atoms are formed per x-ray quantum absorbed in a grain.
- Gurney & Mott provided a clear picture of latent image

Ref. Herz, 1969

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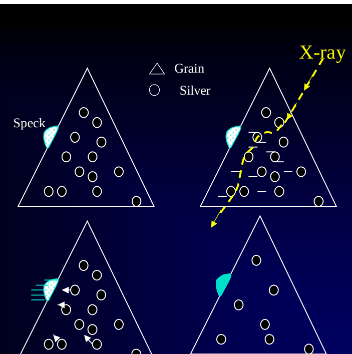

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Hurter & Driffield (1890)
Optical Density (OD)

OD= $\log_{10}(Io / I)$

OD=$\log_{10}$ (T) where T is transmittance

$T=e^{an}$

a= average area / grain; n is number of exposed grains / cm^2; N is number of grains / cm^2

OD = log (T) = an $\log_{10}e$ = 0.4343 an

n / N = aΦ ; where Φ electron fluence

OD = 0.4343 $a^2N\Phi$

OD is proportional to Φ and hence dose and square of grain area.

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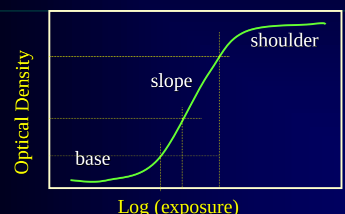
Characteristic curve
H&D Curve

Gradient, gamma, slope = $(D_2-D_1)/\mathrm{Log}(E_2/E_1)$

Speed (sensitivity)= 1/Roentgens for OD equal to unity

Latitude (Contrast): range of log exposure to give an acceptable density range



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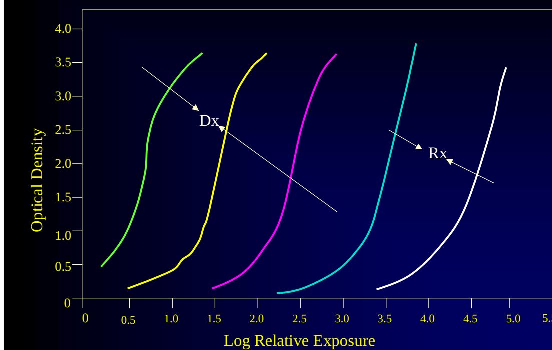
Characteristic curves of various film



Haus et al 1997

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Characteristics of Commercially Available Radiographic Films

Film	Optimum Dose	Gamma	Latitude
CEA TVS	60	4.4	0.35
CEA TLF	19	3.6	0.4
Agfa Ortho STG2	4.7	3.6	0.4
Agfa HTA	3.5	2.7	0.3
Agfa RP1	1.5	2.6	0.5
Agfa MR3	4.2	2.1	0.6
Du Pont Cronex	4.0	2.6	0.5
Du Pont UV	1.5	1.9	0.5
Fuji MIMA	6.3	2.8	0.5
Fuji HRG	6.2	2.8	0.5
Kodak XV	50	2.9	0.6
Kodak TL	4	2.0	0.5
Kodak XL	1.7	2.0	0.6
Kodak MinR	12.3	1.8	0.4
Kodak TMATG	2.5	2.5	0.4
Kodak Ortho	4.5	2.3	0.4
Konica MGH	5.0	2.7	0.4

Roberts, BJR, 69, 70-71, 1996

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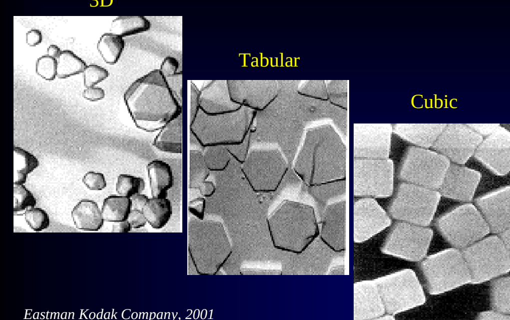
3D

Tabular

Cubic



Eastman Kodak Company, 2001

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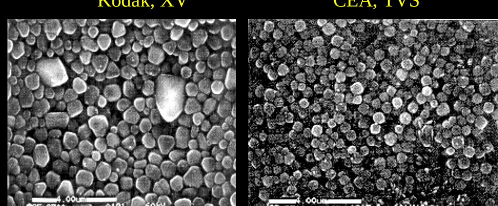
Kodak, XV

CEA, TVS



Cheng & Das, Med. Phys. 23, 1225, 1996

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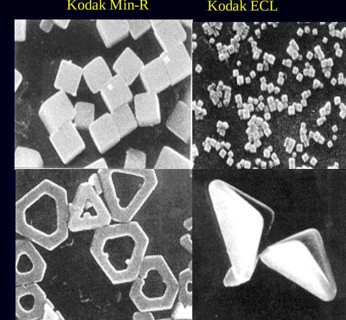
Kodak Min-R

Kodak ECL



Unusual silver halide grain morphologies

Haus, 2001

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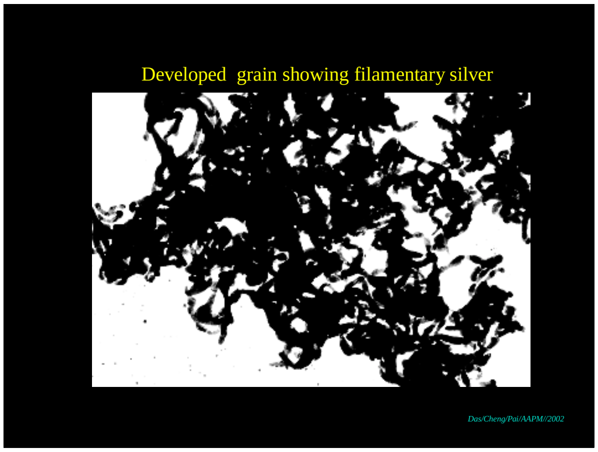
Developed grain showing filamentary silver
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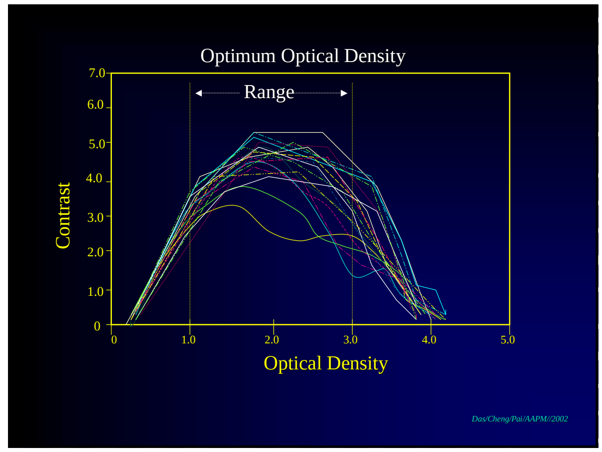
Optimum Optical Density
Range
Contrast
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0
0
1.0
2.0
3.0
4.0
5.0
Optical Density
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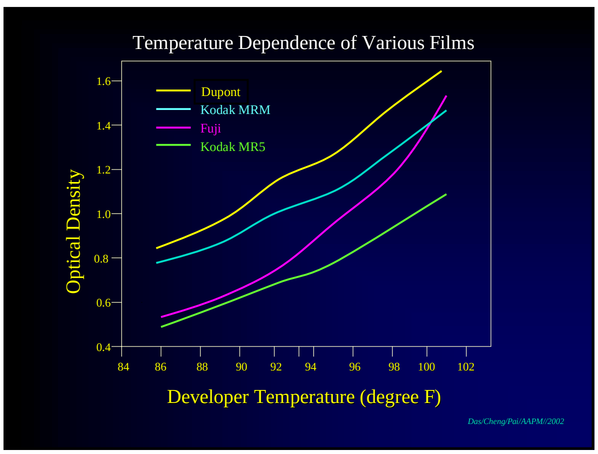
Temperature Dependence of Various Films
Dupont
Kodak MRM
Fuji
Kodak MR5
Optical Density
1.6
1.4
1.2
1.0
0.8
0.6
0.4
84
86
88
90
92
94
96
98
100
102
Developer Temperature (degree F)
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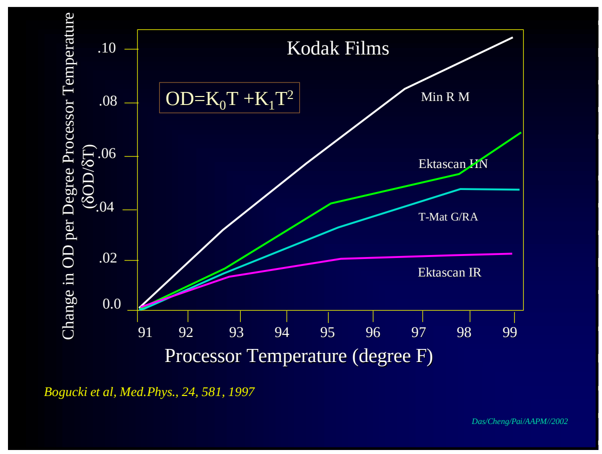
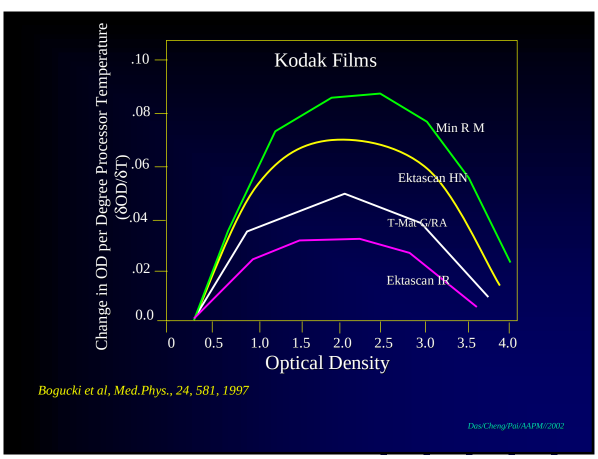
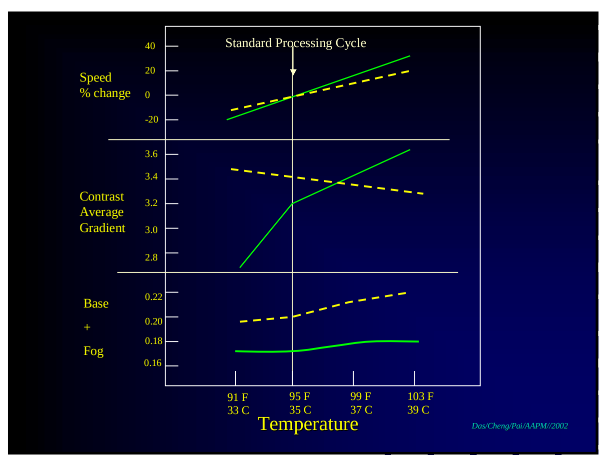

Kodak Films
OD=K0T +K1T2
Min R M
Ektascan HN
T-Mat G/RA
Ektascan IR
Change in OD per Degree Processor Temperature
(δOD/δT)
.10
.08
.06
.04
.02
0.0
91
92
93
94
95
96
97
98
99
Processor Temperature (degree F)
Bogucki et al, Med.Phys., 24, 581, 1997
Das/Cheng/Pai/AAPM//2002


Kodak Films
Min R M
Ektascan HN
T-Mat G/RA
Ektascan IR
Change in OD per Degree Processor Temperature
(δOD/δT)
.10
.08
.06
.04
.02
0.0
0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
Optical Density
Bogucki et al, Med.Phys., 24, 581, 1997
Das/Cheng/Pai/AAPM//2002


Standard Processing Cycle
Speed
% change
40
20
0
-20
Contrast
Average
Gradient
3.6
3.4
3.2
3.0
2.8
Base
+
Fog
0.22
0.20
0.18
0.16
91 F
33 C
95 F
35 C
99 F
37 C
103 F
39 C
Temperature
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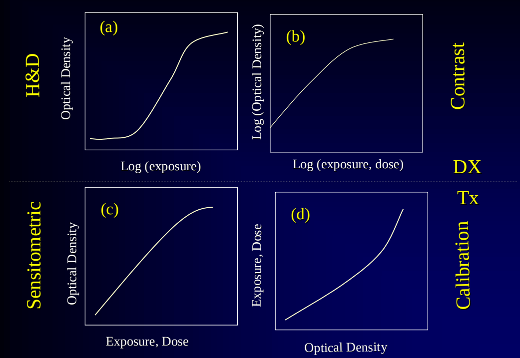
Various types of plots for film response



Optical Density = OD(D, Dr, E, T, d, FS, Θ)

D = Dose
Dr = Dose rate
E = Energy
T = type of radiation (x-rays, electrons etc)
d = depth of measurement
FS= Field Size
Θ = Orientation: parallel or perpendicular

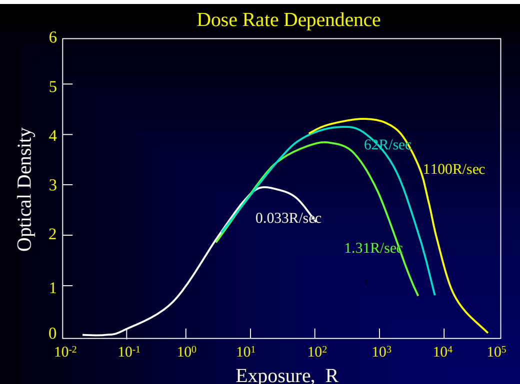
Film Dosimetry in therapy

- 1954, Granke et al; tissue dose studies with 2 MV x-rays
- 1969, Dutreix et al; highlights of the problems in film dosimetry
- 1981, Williamson et al; Provided solution to the film dosimetry problems
- 1996, Cheng & Das; CEA film, better film for dosimetry
- 1997, Burch et al & Yeo et al; lateral scatter filtering

Optimum properties

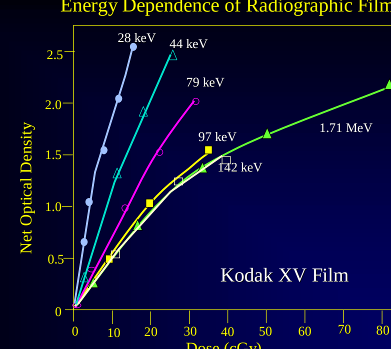
- **Linear with dose (dose dependence)**
- **Linear with dose rate (dose rate independence)**
- **Radiation type (independent of photon and electron)**
- **Energy independent**
- **Uniformity in x & y (coating artifact)**
- **Processing condition**
  - Fading
  - Delayed processing
  - Atmospheric condition, temperature, humidity

Dose Rate Dependence

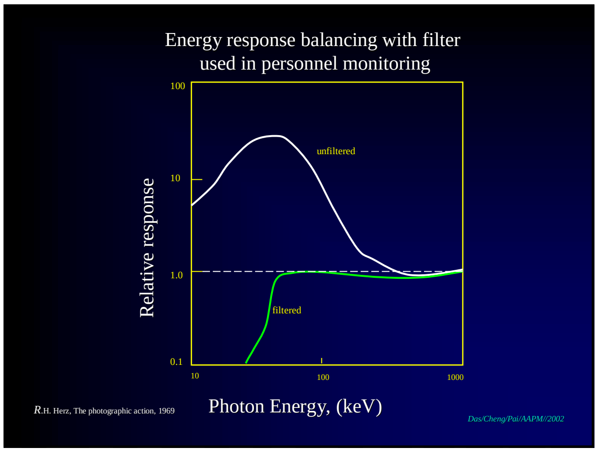


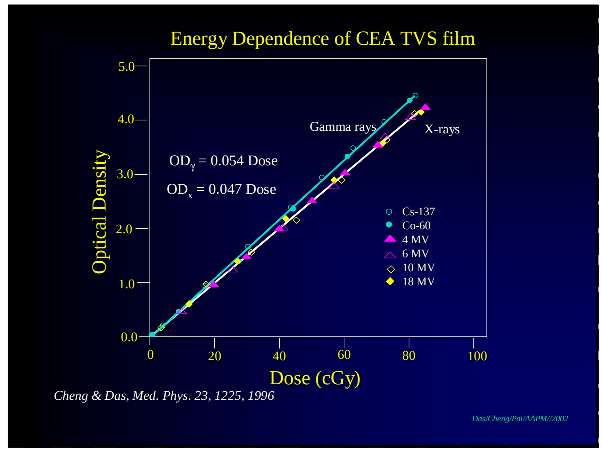
Ehrlich, J.Opt.Soc.Am. 46,801, 1956

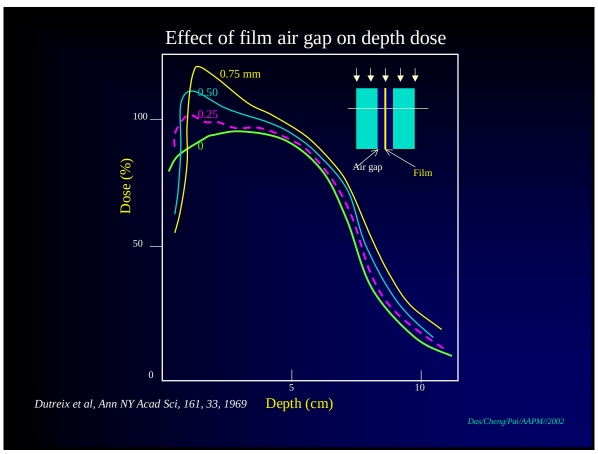
Energy Dependence of Radiographic Film

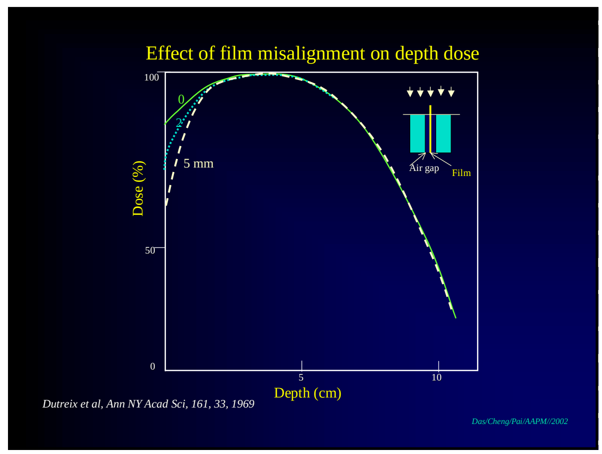


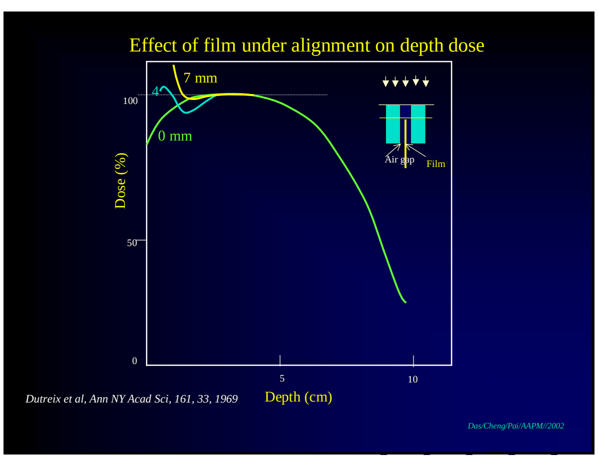
Muench et al, Med. Phys. 18, 769, 1991











Methods to eliminate problems with Film

- To eliminate air trapped inside jacket, vacuum packing could be used (CEA film).
- To keep identical position and pressure, RMI sells film cassettes for dosimetry.
- Use film in water as suggested by van Battum et al, Radiother.Oncol. 34, 152, 1995
- Special phantom; Bova, Med. Dos. 15, 83, 1990

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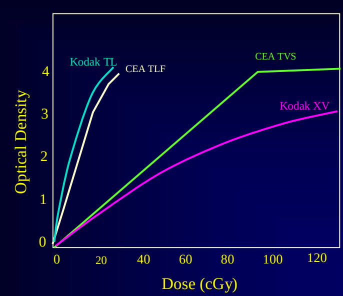
CEA Films (TLF, TVS)



Cheng & Das, Med. Phys. 23, 1225, 1996

OD Vs Dose

Dose = a+b(OD) +c(OD)^2

PDD = $[a+b(OD)+c(OD)^2]_d$ / $[a+b(OD)+c(OD)^2]_{max}$

OAR= $[a+b(OD)+c(OD)^2]_x$ / $[a+b(OD)+c(OD)^2]_{cax}$

For limited range and linear film

D = m(OD) then

$D_2/D_1 = OD_2/OD_1$

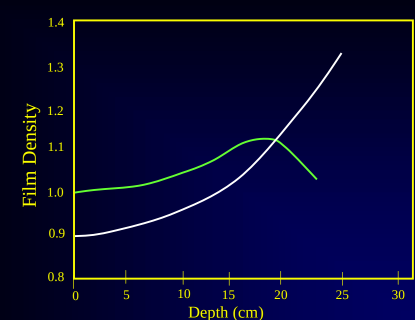
Williamson et al , Med. Phys. 8, 94, 1981

OD depth and field size dependent

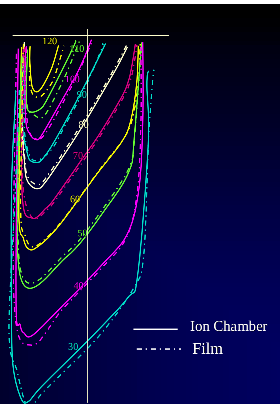
$OD(D, d) = OD_s[1-10^{-\alpha(d)D}]$

$\alpha(d) = \alpha(d_m)[1+\beta(d-d_m)]$

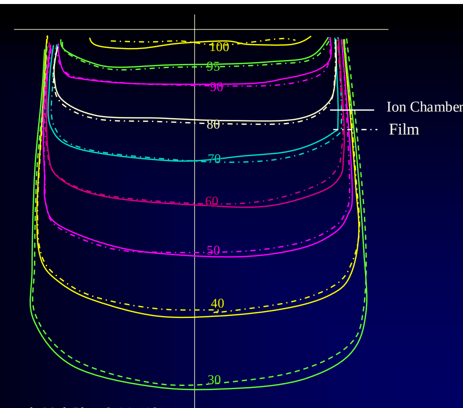
β = 0.0182	Co-60
β = 0.0150	4 MV
β = 0.0062	10 MV



Williamson et al , Med. Phys. 8, 94, 1981



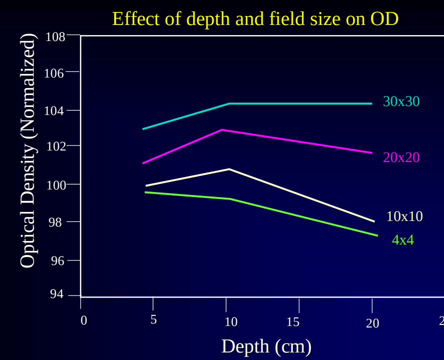
Williamson et al , Med. Phys. 8, 94, 1981



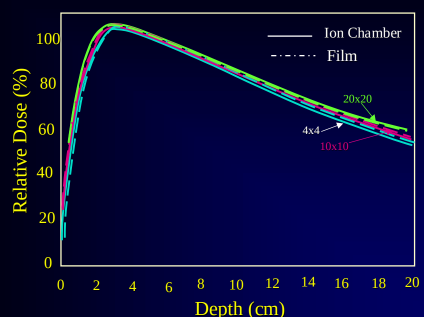
Williamson et al , Med. Phys. 8, 94, 1981

Sensitivity of film to scatter

- Depth and field size dependence of OD
- Van Battum et al, film in water
- Burch et al, lead filter
- Yeo et al , Lead filter
- Skyes et al, against filter method
  - “although scatter filtering method appears to have the desired effect it seems intuitively wrong to introduce a high Z filter in order to make an inadequate dosimeter, film, behave as if it is water equivalent”
- Suchowerska et al MC simulation to prove scatter as a problem

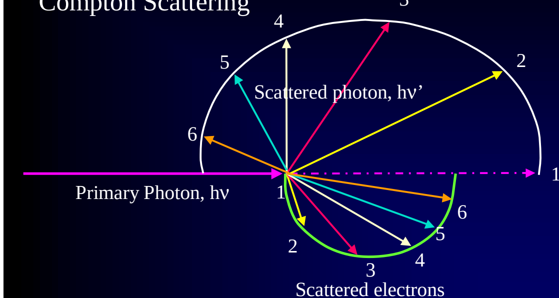


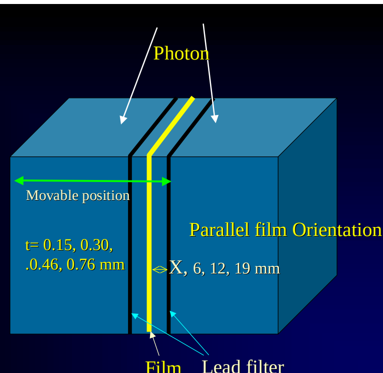
Van Battum et al , Radiother Oncol, 34, 152, 1995



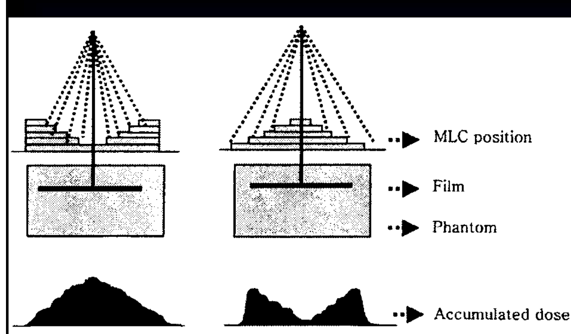
Van Battum et al , Radiother Oncol, 34, 152, 1995

Compton Scattering

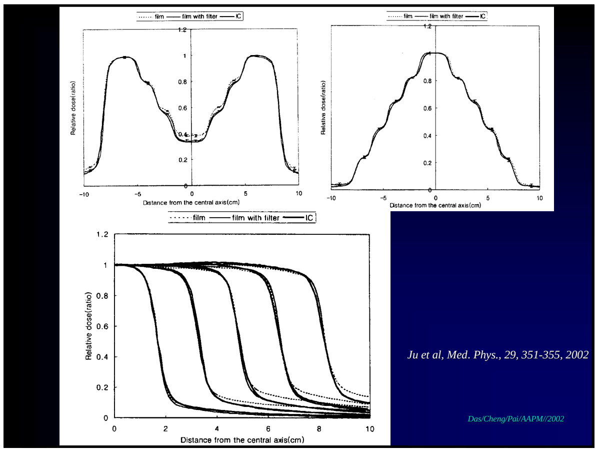


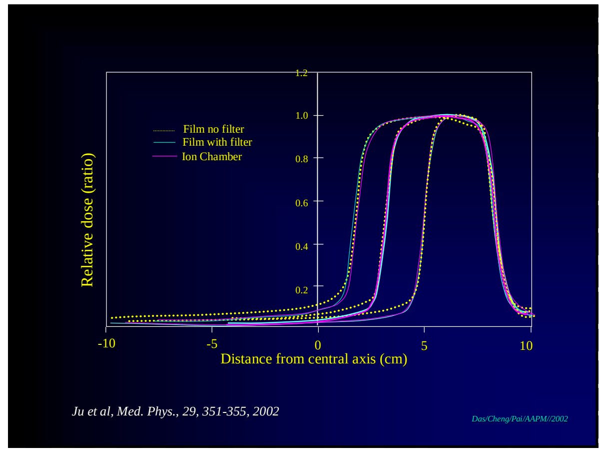


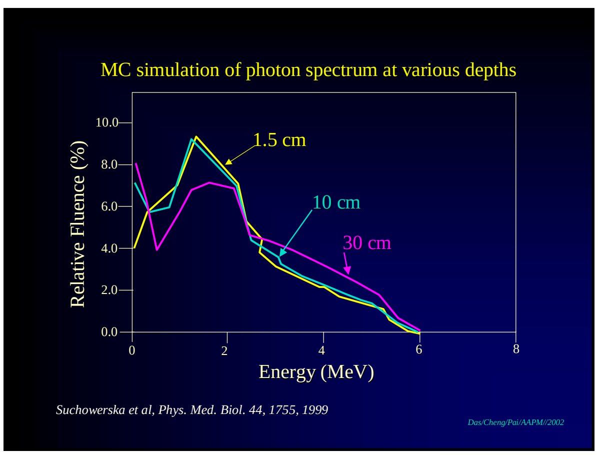
Yeo et al Med. Phys. 24, 1943, 1997
Burch et al, Med. Phys. 24, 775, 1997

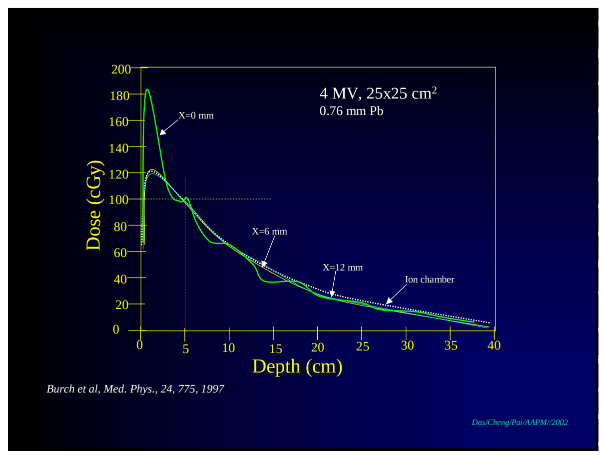


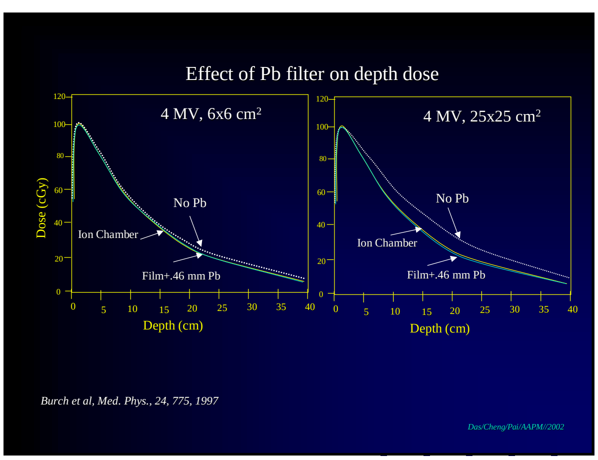
Ju et al, Med. Phys., 29, 351-355, 2002

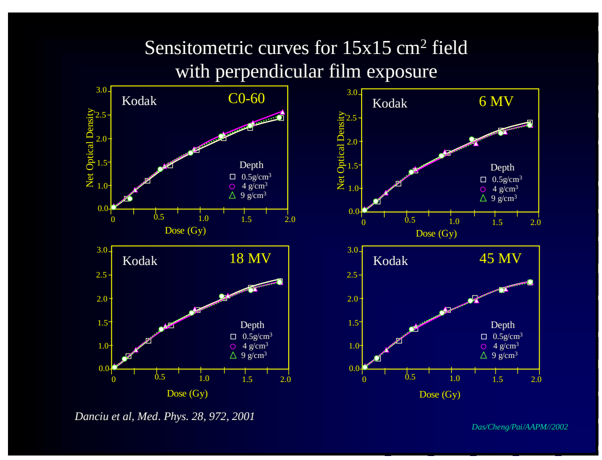

film — film with filter — IC
Relative dose(ratio)
Distance from the central axis(cm)
Distance from the central axis(cm)
Ju et al, Med. Phys., 29, 351-355, 2002
Das/Cheng/Pai/AAPM//2002

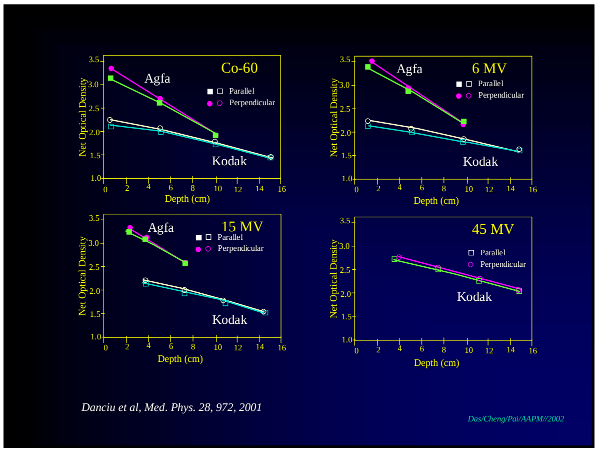

Film no filter
Film with filter
Ion Chamber
Relative dose (ratio)
Distance from central axis (cm)
Ju et al, Med. Phys., 29, 351-355, 2002
Das/Cheng/Pai/AAPM//2002

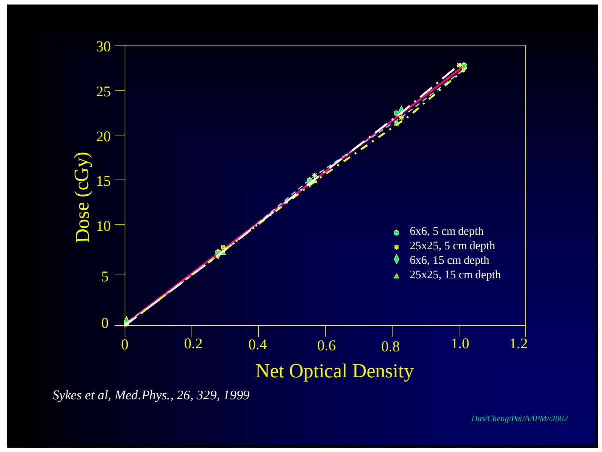

MC simulation of photon spectrum at various depths
1.5 cm
10 cm
30 cm
Relative Fluence (%)
Energy (MeV)
Suchowerska et al, Phys. Med. Biol. 44, 1755, 1999
Das/Cheng/Pai/AAPM//2002

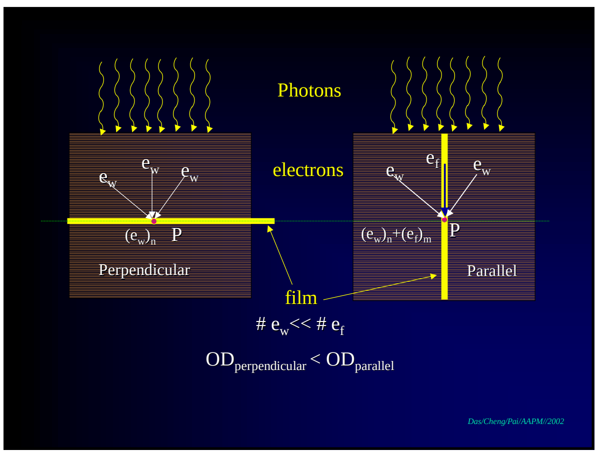

4 MV, 25x25 cm²
0.76 mm Pb
X=0 mm
X=6 mm
X=12 mm
Ion chamber
Dose (cGy)
Depth (cm)
Burch et al, Med. Phys., 24, 775, 1997
Das/Cheng/Pai/AAPM//2002

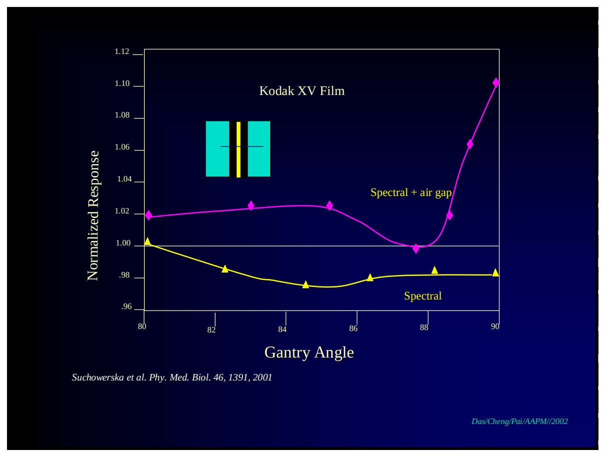

Effect of Pb filter on depth dose
4 MV, 6x6 cm²
4 MV, 25x25 cm²
No Pb
Ion Chamber
Film+.46 mm Pb
Dose (cGy)
Depth (cm)
Burch et al, Med. Phys., 24, 775, 1997
Das/Cheng/Pai/AAPM//2002

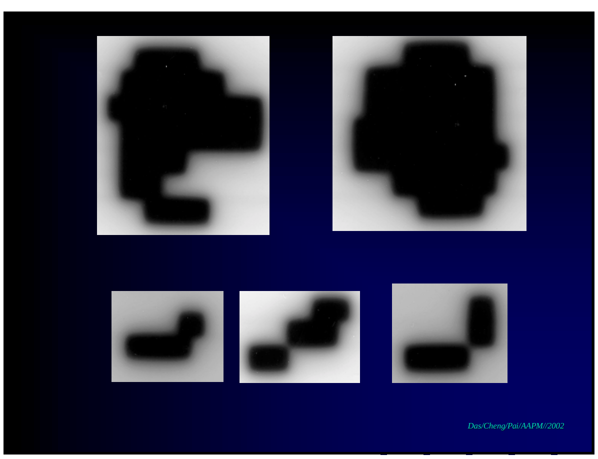

Sensitometric curves for 15x15 cm² field
with perpendicular film exposure
Kodak C0-60
Kodak 6 MV
Kodak 18 MV
Kodak 45 MV
Depth
0.5g/cm³
4 g/cm³
9 g/cm³
Net Optical Density
Dose (Gy)
Danciu et al, Med. Phys. 28, 972, 2001
Das/Cheng/Pai/AAPM//2002

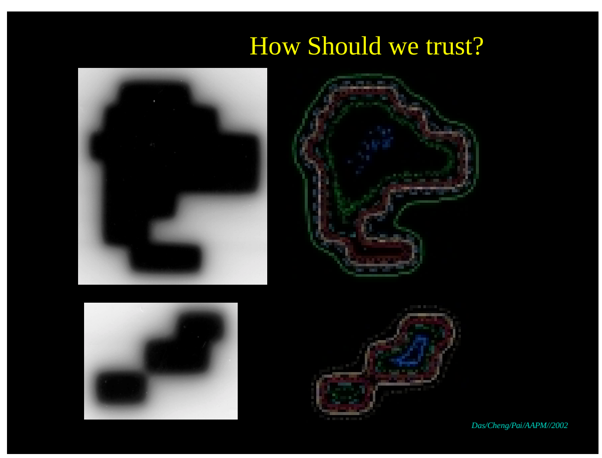

Agfa
Co-60
Parallel
Perpendicular
Kodak
Net Optical Density
Depth (cm)
Agfa
6 MV
Parallel
Perpendicular
Kodak
Agfa
15 MV
Parallel
Perpendicular
Kodak
45 MV
Parallel
Perpendicular
Kodak
Danciu et al, Med. Phys. 28, 972, 2001
Das/Cheng/Pai/AAPM//2002


Dose (cGy)
6x6, 5 cm depth
25x25, 5 cm depth
6x6, 15 cm depth
25x25, 15 cm depth
Net Optical Density
Sykes et al, Med.Phys., 26, 329, 1999
Das/Cheng/Pai/AAPM//2002

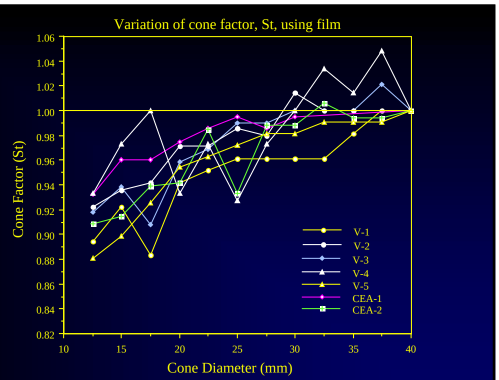

Photons
electrons
e w
e w
e w
(e w)n
P
Perpendicular
e w
e f
e w
(e w)n+(e f)m
P
Parallel
film
e w << # e f
OD perpendicular < OD parallel
Das/Cheng/Pai/AAPM//2002


Kodak XV Film
Normalized Response
Spectral + air gap
Spectral
Gantry Angle
Suchowerska et al. Phy. Med. Biol. 46, 1391, 2001
Das/Cheng/Pai/AAPM//2002


Das/Cheng/Pai/AAPM//2002


How Should we trust?
Das/Cheng/Pai/AAPM//2002

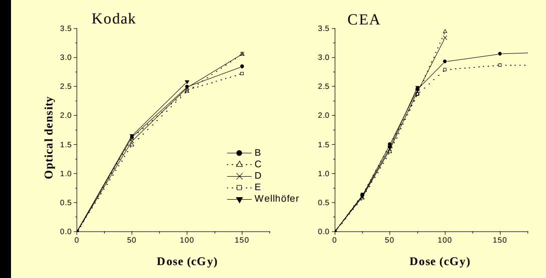
Variation of cone factor, St, using film



Das et al, J. Radiosurg. 3, 177, 2000

Das/Cheng/Pai/AAPM/2002

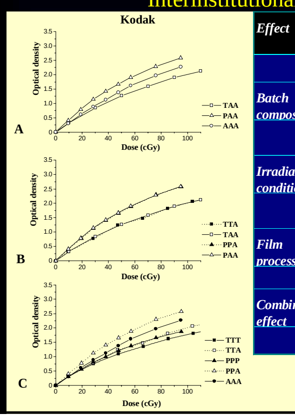
Film Scanner	*Light source*	*Wavelength/color*
Konica KFDR-S	diode-laser	780 nm
Multidata 9721	diode-laser	red
Vidar VXR-12	standard fluorescent light	white
Wellhöfer WD 102	infrared diode	950 nm
X-rite Model 301	tungsten halogen bulb	bluish white



Bos et al, Med. Phy. 29 (in press) 2002

Das/Cheng/Pai/AAPM/2002

Interinstitutional Variation in OD



Effect	*Comparison*	*OD difference at 50 cGy*	
		Kodak	CEA
Batch composition	TAA vs. AAA	14%	9%
	PAA vs. AAA	20%	2%
Irradiation conditions	TTA vs. TAA	2%	5%
	PPA vs. PAA	2%	5%
Film processing	TTT vs. TTA	11%	31%
	PPP vs. PPA	38%	16%
Combined effect	TTT vs. AAA	20%	32%
	PPP vs. AAA	13%	13%

Bos et al, Med. Phy. 29 (in press) 2002

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Advantage of film dosimetry

- Unrivaled spatial distribution of dose or energy imparted.
- Repeated reading of same film: permanent record
- 2-D distribution with single exposure
- Small detector size
- Wide availability: Kodak, Agfa, Fuji, Dupont, CEA
- Large area dosimetry: Especially for electron beam
- Linearity of dose (over a short dose range, OD can be treated linear with dose for most films)
- Dose rate independence

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Film dosimetry - Concerns

- The main problem in using radiographic film is the dependence of optical density (OD) on:
  - Strong energy dependence (high sensitivity to low energy photons due to photoelectric interactions in grains);
  - Film plane orientation with respect to the beam direction;
  - Emulsion differences amongst films of different batches, films of the same batch or even in the same film;
  - Densitometer / Digitizer artifacts.

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Film dosimetry - Concerns

- OD depends on:
  - Chemical processing
    - developer chemistry and temperature
    - Processing time
    - drying conditions
- Sensitivity to environment
  - High temperature & humidity creating fading
  - Storage stability
    - 0.05-0.1 OD in (6-60mR) among various films (ref Soleiman et al Med. Phy. 22, 1691, 1995)
- Microbiological growth in gelatin
- Solarization: At extremely higher doses, OD decreases

Das/Cheng/Pai/AAPM/2002

TG69 - RADIOGRAPHIC FILM FOR MEGAVOLTAGE BEAM DOSIMETRY

- Film Dosimetry for commissioning and verifying special procedures in radiotherapy.
  - Enhanced Dynamic Wedge (EDW)
  - Stereotactic Radiosurgery (SRS)
  - Intensity Modulated Radiotherapy (IMRT)

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Disadvantage of film dosimetry

- Chemical processing (except Gafchromic films)
  - OD depends on:
    - developer temperature
    - drying conditions
- Strong energy dependence (high sensitivity to low energy photons due to photoelectric interactions in grains)
- Sensitivity to environments
  - high temperature and humidity crating fading
  - Storage stability
    - 0.05-0.1 OD in (6-60mR) among various films (ref Soleiman et al Med. Phy. 22, 1691, 1995)
- Microbiological growth in gelatin
- Solarization: at extremely higher doses, OD decreases
- Absolute dosimetry is difficult

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Advantage of film dosimetry

- Unrivaled spatial distribution of dose or energy imparted.
- Repeated reading of same film: permanent record
- Wide availability: Kodak, Agfa, Fuji, Dupont, CEA etc.
- Large area dosimetry: Especially for electron beam
- Linearity of dose (over a short dose range, OD can be treated linear with dose for most films)
- Dose rate independence

Das/Cheng/Pai/AAPM//2002

TG69 RADIOGRAPHIC FILM DOSIMETRY

Task group members:

S. Pai -Chair
L. Reinstein – Co-Chair
J. Williamson
J. Palta
K. Lam
T. Losasso
E. Grein
I. Das
J. Dempsey
A. Olch

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TG69

- Film Dosimetry - Issues
  - Film selection
  - Film orientation
  - Phantom choice
  - Film handling
  - Beam quality issues
  - Film Processor
  - Film Digitizer characteristics

The primary mission of the task group is to develop guidelines to allow optimal external beam dose measurements.

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Radiochromic film

Niroomand-Rad et al, Radiochromic film dosimetry: Task group 55, Med. Phys. 25(11), 2093-2115, 1998

Self developing, turns dark blue soon after irradiation

Near tissue equivalent, > 0.1MeV energy independent

- OD increases gradually with time (logt)
- Dependency on temperature during *and* post irradiation
- Dependency on densitometer wavelength and temperature
- Sensitivity may vary somewhat across film
- Affected by compression, water/humidity, high temperature
- Slightly reduced sensitivity at < 0.1MeV
- OD increases in UV and fluorescent light

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Processors

- Using the newer automatic processors
  - Developer temperature
  - Processing time
  - Chemistry activity of the processor

  held extremely stable to improve the reproducibility and the stability of the film density.
- Development of recommendation for the processor acceptance tests and QA.
- Determination of correction factors for temperature and chemical variations of the processors in general:
  - By processing the non-exposed films (known density films) intermixed with the experiment films and calibration films.

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Densitometers/ Digitizers

- Visual type densitometer (Dobson, Griffith & Harrison, 1926)
- Photoelectric type
  - light densitometer (wide spectrum)
    - Standard: McBeth, Xrite, Nuclear Associate etc
  - Light source coupled with CCD digitizer
    - Fluorescent light source – Vidar VXR-16 Digitizer
    - LED light source - Howtek MultiRAD 460 Digitizer
  - Laser densitometer (single wavelength)
    - Lumysis scanning system

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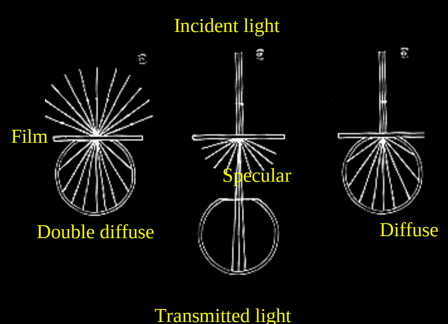

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Digitizers

- Scanning film Digitizer Artifacts:
  - Drift in OD; warm-up effect of fluorescent lamp
    - Use first 20-30 minutes as warm-up time
  - Scanner spatial distortion
    - Validated in both dimensions using known test patterns
  - Interference artifacts - at the interface of film and the glass plate/film support. (Multiple reflection due to changes in the index of refraction)
    - Use of diffused glass or antireflective coated glass

Reinstein et. al., Dempsey et.al.

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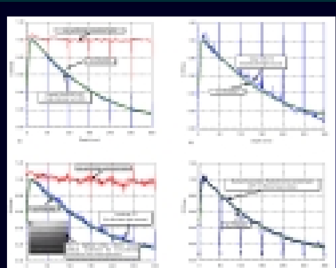
Digitizer Artifacts



Gluckman, et.al.

Das/Cheng/Pai/AAPM//2002

Digitizers

- Scanning film Digitizer Artifacts:
  - Internal light scatter at OD discontinuities introducing OD non-linearity
    - Reduced by applying DFFT (Dempsey et.al)
  - Light source/Detector response & linearity
  - Signal to Noise ratio
    - Temporal Noise (electronic noise)
      - Optimal OD of ≤ (??)
      - Lowering digitizing speed & using optimal resolution
      - Reduced through the averaging of multiple scans
    - Spatial Noise (interference artifacts)
      - Application of Linear signal processing techniques

Dempsey et.al., Mersseman et.al., and Meeder et.al.

Das/Cheng/Pai/AAPM//2002

Digitizers

- Scanning film Digitizer Characteristics:
  - Fast high resolution 2D scanners
    - Transmission optical densitometry
    - Reflection densitometry – limited OD range
  - Spatial resolution
    - Pixel dimension 0.34 – 0.042mm (72-600 dpi)
  - Dynamic range
    - 0 to upper limit of 2.5 to 4.0 OD
  - Scanner output
    - OD measurement (≥ 12 bit ADC)
    - Transmission measurement and then converted to OD (≥14 bit ADC)

Dempsey et.al.

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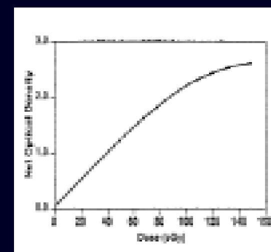
Digitizers

- Optimal OD



Reinstein et. al.

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Enhanced Dynamic Wedge

- Commissioning
  - EDW profiles are obtained in a single exposure using a multiple film loaded phantom
- **Concern: Energy Dependency of film**
  - Affects the measured wedge angle in EDW profiles for large field size and large depths.

Elder, et.al, Klein, et.al.

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TG69 - RADIOGRAPHIC FILM FOR MEGAVOLTAGE BEAM DOSIMETRY

Stereotactic Radiosurgery

- Energy Dependency
  - Overall error of 1%- by using mid-way calibration for F.S. upto 10x10 cm^2 and depths of 2-10cm.
- Output Factor
  - Small field output depends upon the spatial resolution.
- Penumbra Delineation
  - Detector size; TG 42 specification- detector dimension of 2mm or less is recommended.
- **Concern: Optical Scatter**
  - Light transmission artifacts of the scanner contaminating the signal (penumbra broadening)

Dempsey, et.al.,Tsai, et.al.

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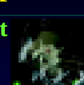
TG69 - RADIOGRAPHIC FILM FOR MEGAVOLTAGE BEAM DOSIMETRY

Intensity Modulated Radiation Treatment



- Film dosimetry - Best dosimeter to date
- Spatial resolution
  - Detector size; detector dimension of 2mm or less is recommended.
- **Concerns: Energy Dependency**
  - Varying component of primary to scatter ratio within the field poses a big problem .
- **Concerns: Spatial Distortion and Optical Scatter**
  - Scanner distortion which are most apparent in high dose gradient regions – throughout IMRT field
  - Optical scatter distorting the transmitted signal

Chui, et. al. Low, et.al.

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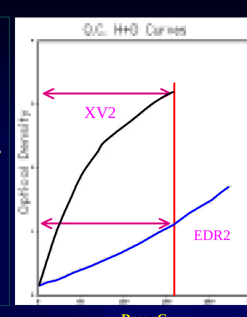
EDR2 vs. XV2

Kodak's New Extended Dose Range (EDR2) Film

Each grain is <u>10 times smaller</u> than XV grains,

Uniform cubic grains of AgBr rather than non-uniform potato shaped grains for XV.



Courtesy: Olch, A.

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KODAK'S NEW EDR2 FILM

- No MU reduction is required for EDR2 film IMRT QA.
  - Avoids Linac delivery problems with small number of MU per segment
  - Avoids round off errors for systems that can not deliver non-integer MU
  - IMRT QA can be performed on the IDENTICAL plan that is used to treat the patient.
- EDR2 film is less sensitive to processor variations than XV2 film.

Courtesy: Olch, A.

TG69 - RADIOGRAPHIC FILM FOR MEGAVOLTAGE BEAM DOSIMETRY

TG Chapters:

- Introduction and Background ------------- S. Pai
- Characteristics of AgH films ------------- I. Das
- Film types and Processors ------------- K. Lam
- Detection Equipment
  - Point Densitometers ------------- A. Olch / L. E. Reinstein
  - 2D scanners ------------- J. Dempsey / J. Williamson
- Phantom considerations and Film Calibration Protocol ------------- E. Grein
- Special Applications
  - QA of photon / Electron beams ------------- J. Palta
  - IMRT / EDW / SRS ------------- T. Lossaso

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