



SKIN DOSE

Determination, effects and evidence for current limits



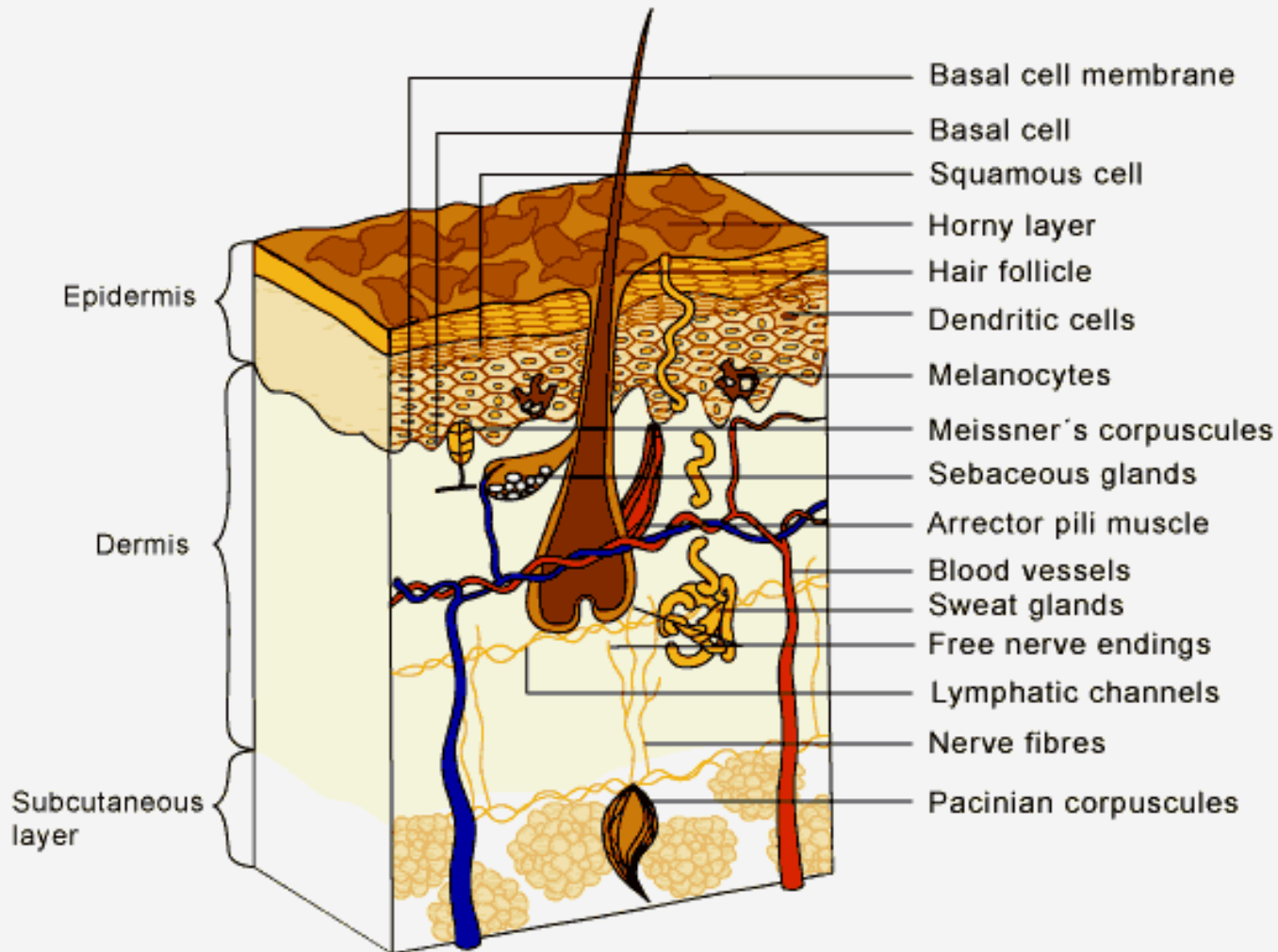
BRIGHAM AND
WOMEN'S HOSPITAL



HARVARD
MEDICAL SCHOOL
TEACHING AFFILIATE

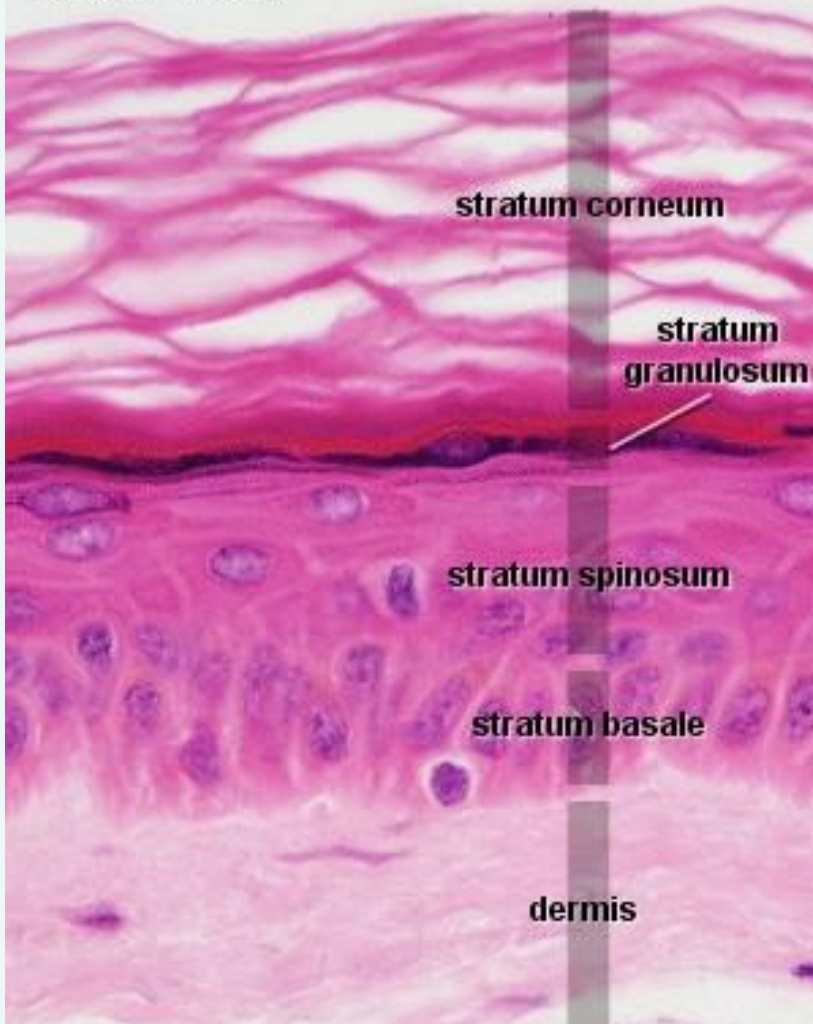
- Anatomy of skin
- X-Ray interactions in skin tissue
- Skin dose and measurements
- Why don't we see more skin burns?
 - Basis for 2 Gy deterministic threshold
 - Other evidence on deterministic threshold
 - Regulatory guidelines and is 2 Gy too low?
 - What should the threshold be?

Anatomy of Skin

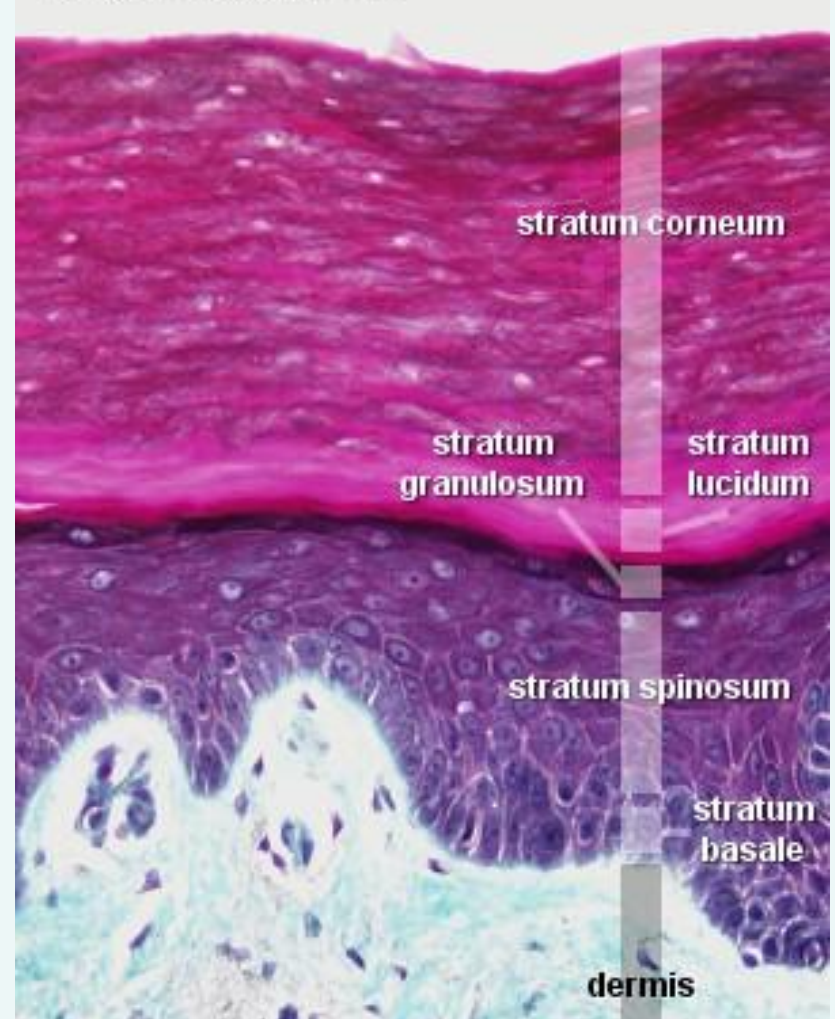


Anatomy of Skin

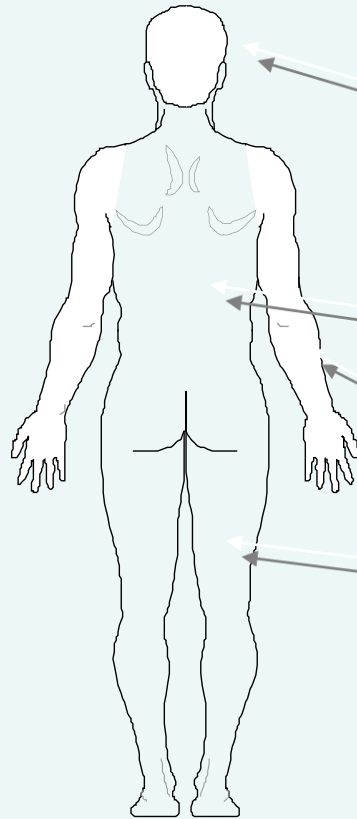
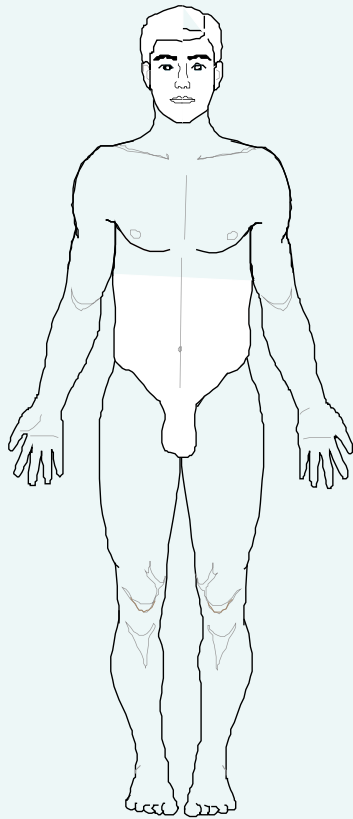
Skin, thin H&E



Skin, thick trichrome



Anatomy of Skin



**Mean \pm SD
(μm)**

50 \pm 22

42 \pm 12

60 \pm 19

Fingertips: 369 \pm 112

Fingers: 223 \pm 93

Ref: ICRP Pub. 59

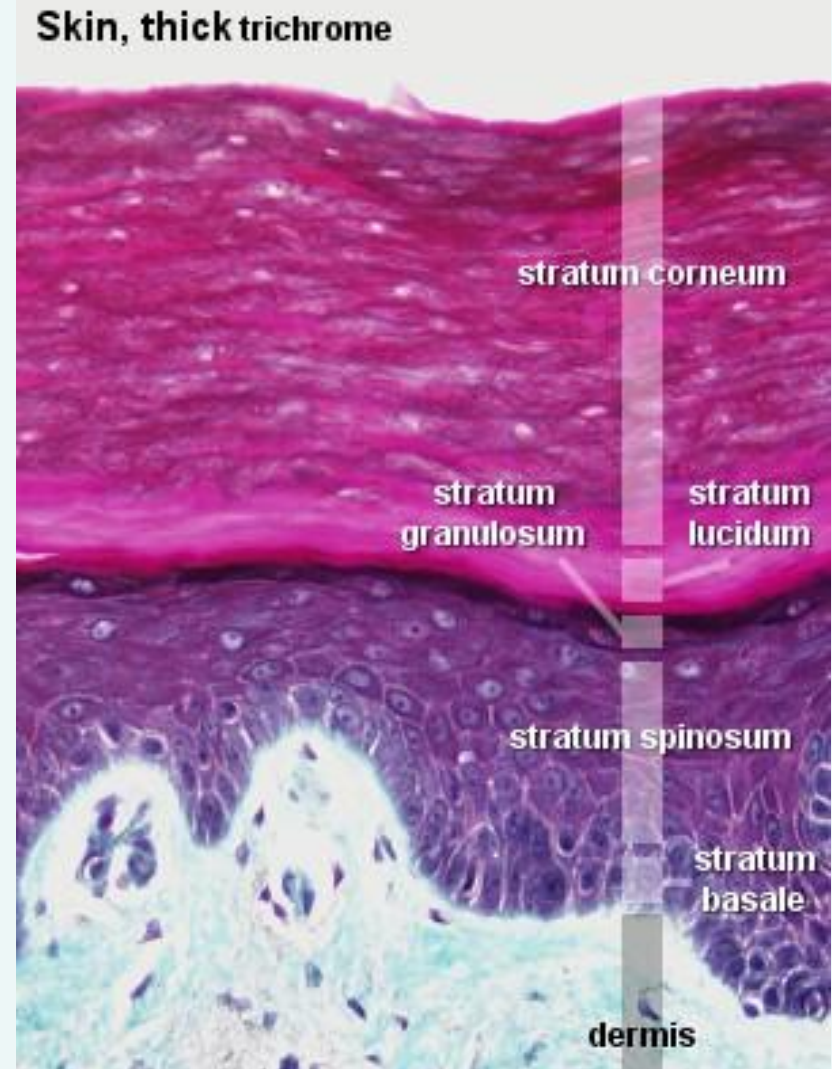
Anatomy of Skin

- Total skin area is about 2 m².
- Weight of skin is about 2.1 kg.
- Role of skin
 - Physical barrier to protect the body from hazards in the environment
 - Cools the body
 - Heat retention
 - Sensory system for the external environment
- Epidermis – 25% of dermal tissue by dry weight
- Dermis – 75% of dermal tissue by dry weight

Ref: ICRP Pub. 59

Anatomy of Skin

- Stratum corneum
 - 15 to 20 layers of dead cells
 - Thicker on palms of hands and soles of feet.
- Stratum granulosum
 - 4 to 5 layers of cells
 - Become flattened and lose nucleus
 - Become the stratum corneum



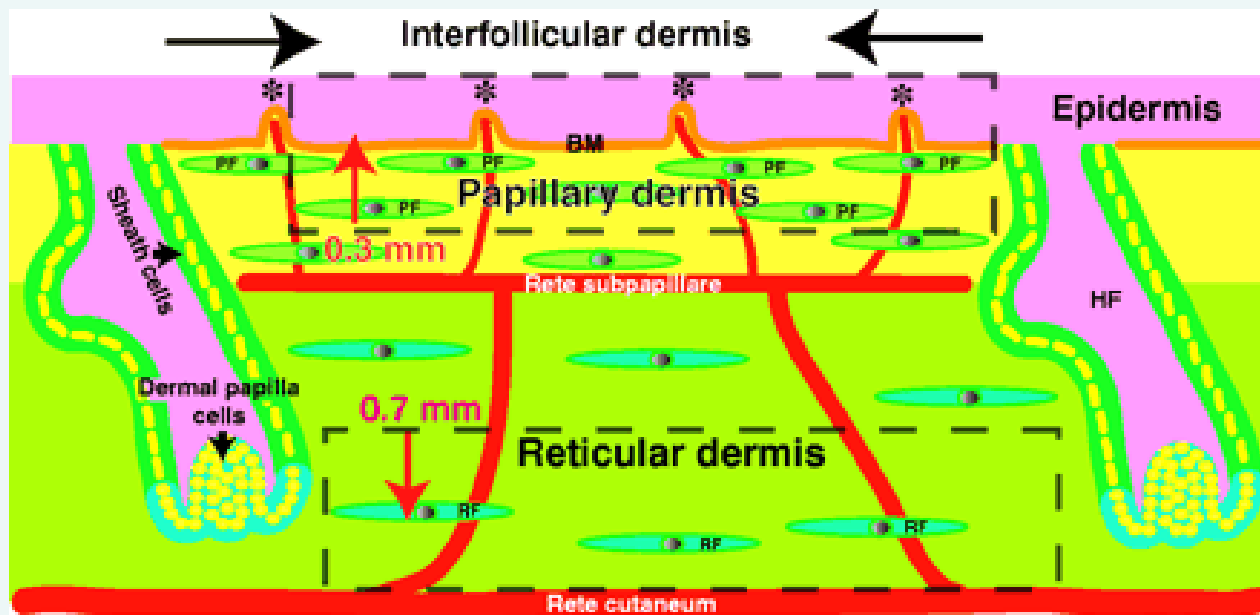
Anatomy of Skin

- Stratum spinosum
 - Variable number of cell layers
- Stratum germinativum
 - Single layer of cells
 - Referred to as the basal layer
- Stratum germinativum and spinosum are the two layers which determines the response to radiation induced injuries.



Anatomy of Skin

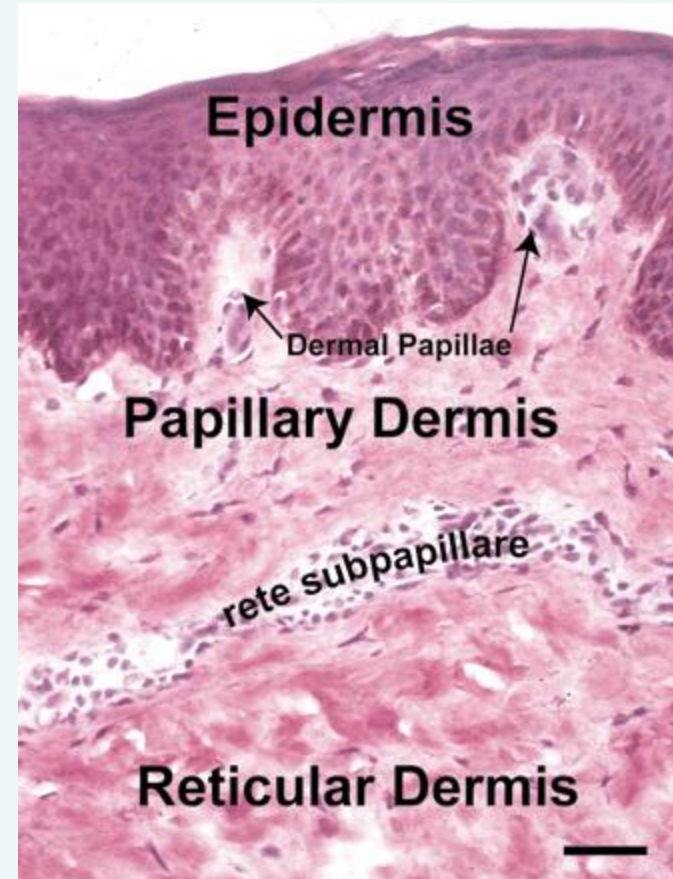
- The dermis is composed of two layers: the superficial papillary dermis and the reticular dermis.



www.biology-online.org

Anatomy of Skin

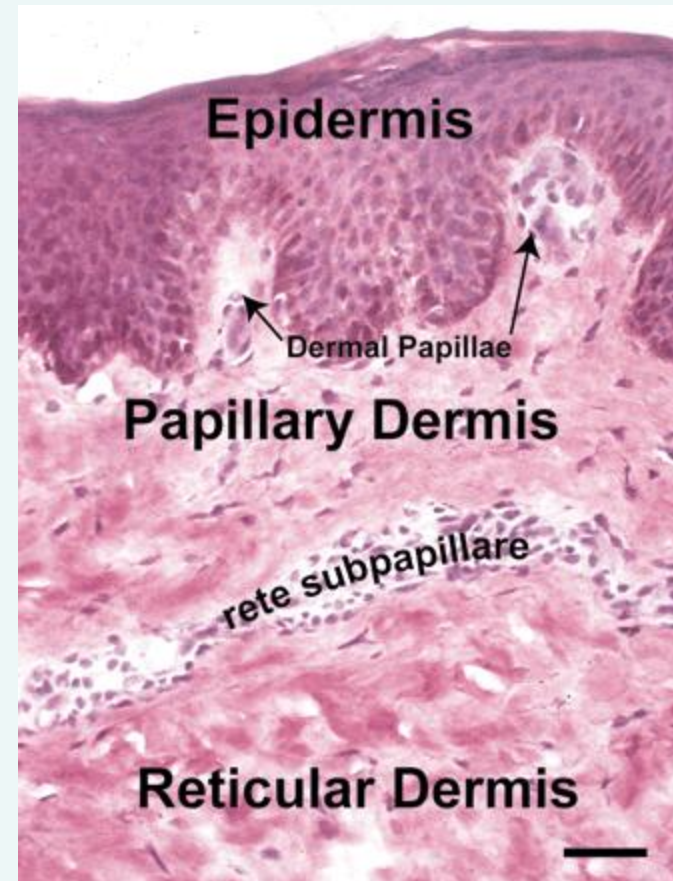
- Papillary dermis
 - consists of thin collagen bundles interwoven with elastic fibers
 - Richly vascularized
 - Provides thermoregulation and maintains metabolic requirements of the basal layer.



www.biology-online.org

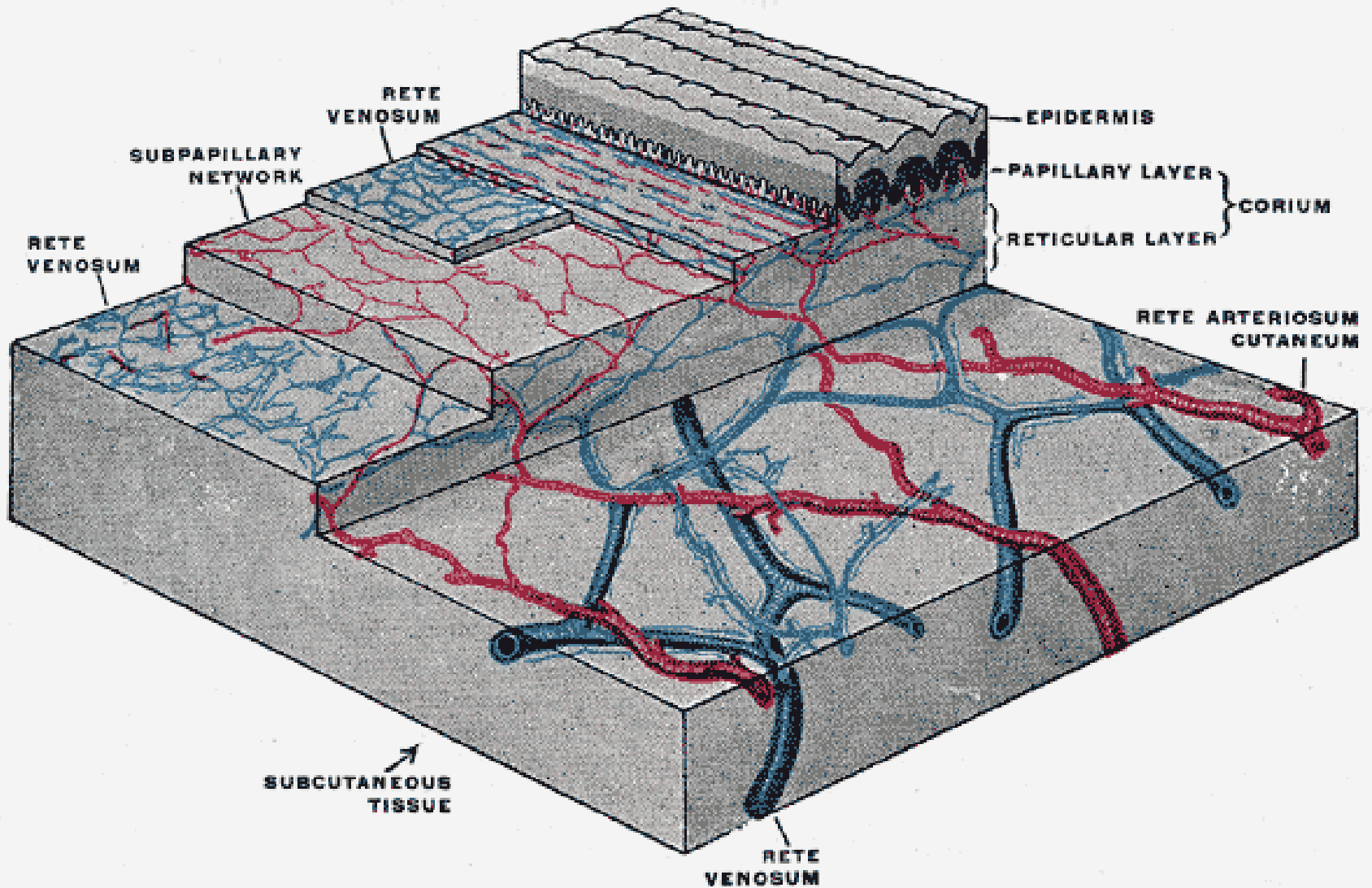
Anatomy of Skin

- Reticular dermis
 - Primary structural and mechanical component of skin
 - Densely fibrous
 - Fewer blood cells and vessels than papillary dermis



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Anatomy of Skin



Measuring Skin Dose

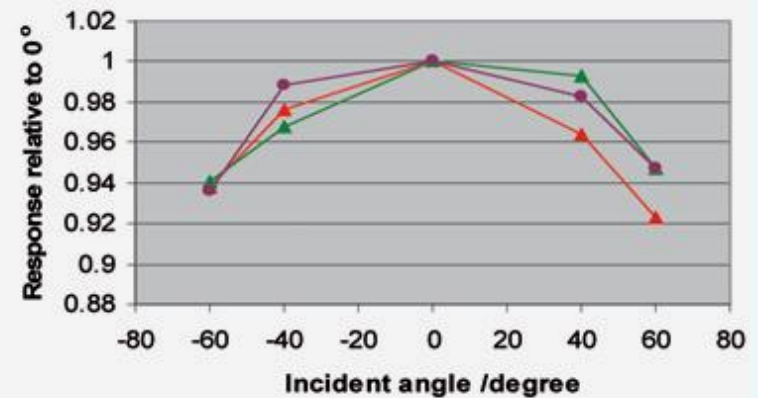
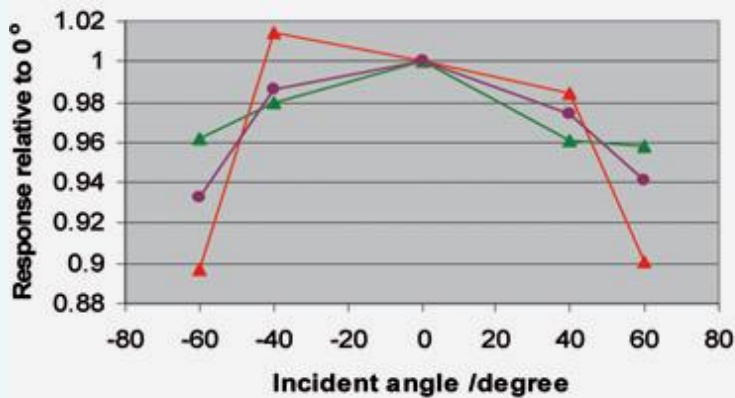
- Direct measuring methods
 - TLDs (OSLs)
 - Radiochromic film
 - Electronic dosimeter
- Indirect measuring methods
 - Cumulative air kerma
 - Dose area product
 - Dose mapping
 - Fluoroscopic time

Measuring Skin Dose – Direct Methods



Landauer
OSL

Vertical rotation



Measuring Skin Dose – Direct Methods

Gafchromic® XR-QA Film

- Dynamic dose range from 0.1cGy to 20cGy
- Develops in real time, there is no post-exposure treatment
- Can be handled in room light
- Cut, size and shape it to needs
- Water resistant for use in a water phantom
- Shelf life: 18 month at room ambient temperature



Measuring Skin Dose – Direct Methods

The Unfors PSD is used in CT and fluoroscopy procedures to prevent excessive dose usage and consequential patient lesions.

- Monitors patient dose
- Audible and visual warnings
- Small silicon sensors

(INMED SOLUTIONS Co.,Ltd.)



Measuring Skin Dose – Indirect Methods

- Cumulative Air Kerma (CAK)
 - Kinetic energy transferred to charged particles by indirectly ionizing radiation
 - Units of Joules/Kg or Gray
 - Dose accumulated at a reference point defined as 15 cm from the isocenter towards the x-ray tube.

Measuring Skin Dose – Indirect Methods

- Dose Area Product and Air Kerma

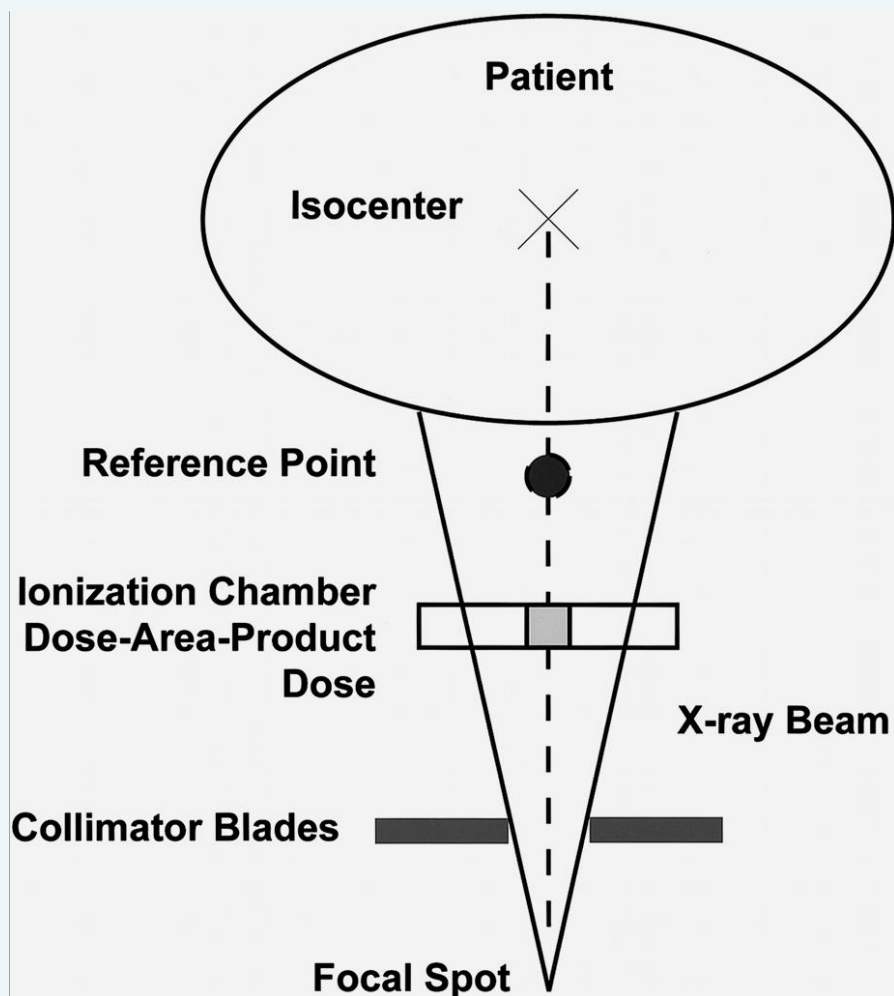


Diagram of a C-arm fluoroscopic unit.

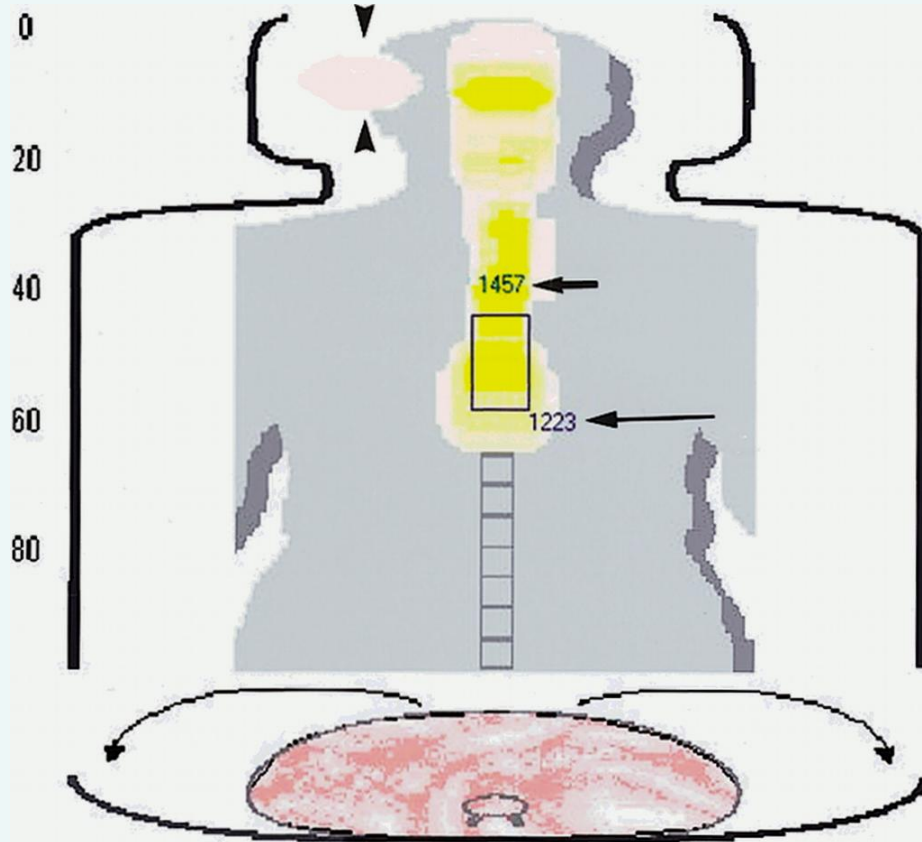


Miller D L et al. Radiology 2002;225:329-336

Radiology

©2002 by Radiological Society of North America

Measuring Skin Dose – Indirect Methods



Skin-dose map display obtained during spinal arteriography.

Miller D L et al. *Radiology* 2002;225:329-336

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Radiology

Measuring Skin Dose – Indirect Methods

- Each Method has weaknesses:
 - CAK: Cumulative dose does not reflect beam motion and only approximates total radiation to the skin; therefore, it tends to overestimate skin dose.
 - DAP: DAP meters do not account for patient size, mode selection, beam geometry, or motion, but rather provide an average of patient dose, which does not correlate directly with skin dose. Tends to underestimate skin dose.

Measuring Skin Dose – Indirect Methods

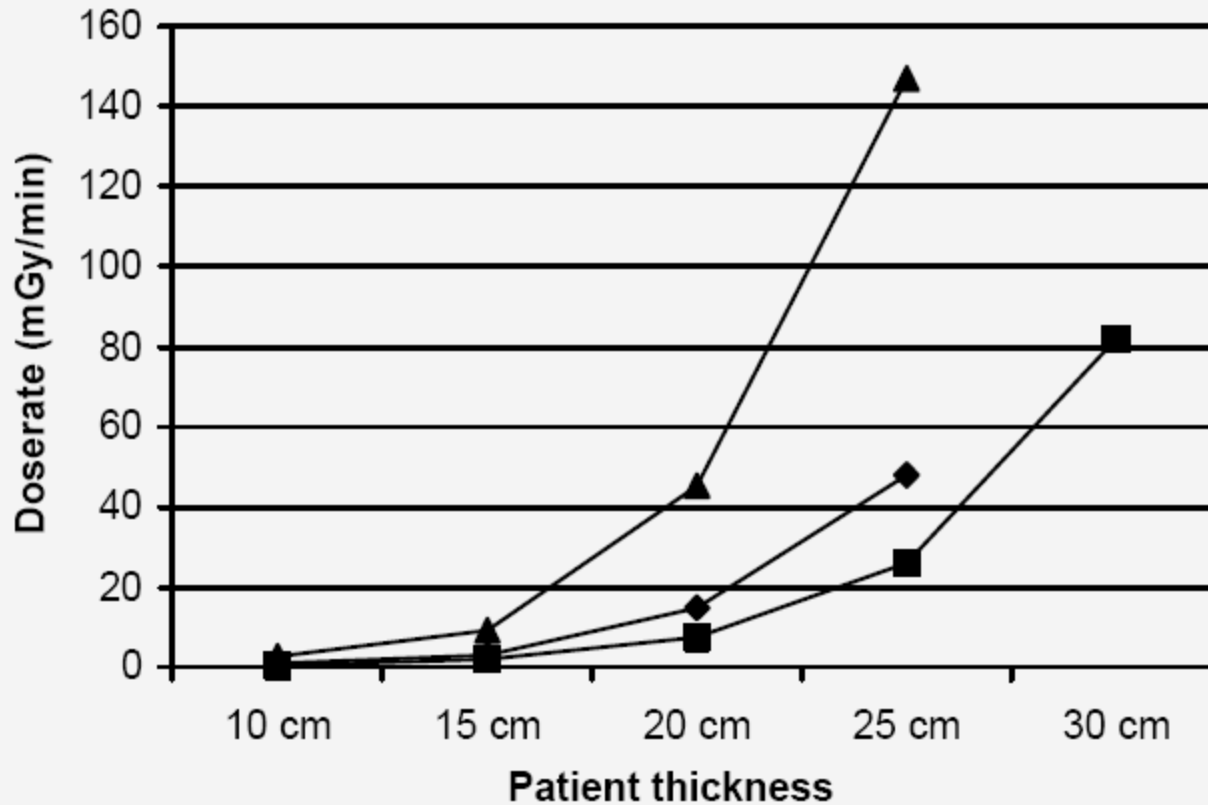
- Dose Mapping: utilizes computers to track where the beam is located on the patient as well as radiation output data to determine the skin dose to locations on the patient's body. These systems currently not generally available on the market.
- Fluoroscopy Time: it does not account for patient size, mode selection, beam geometry or motion. Dose estimates based on fluoroscopic time alone can over or under estimate the cumulative dose by as much as a factor of 10.

Measuring Skin Dose – Key Factors

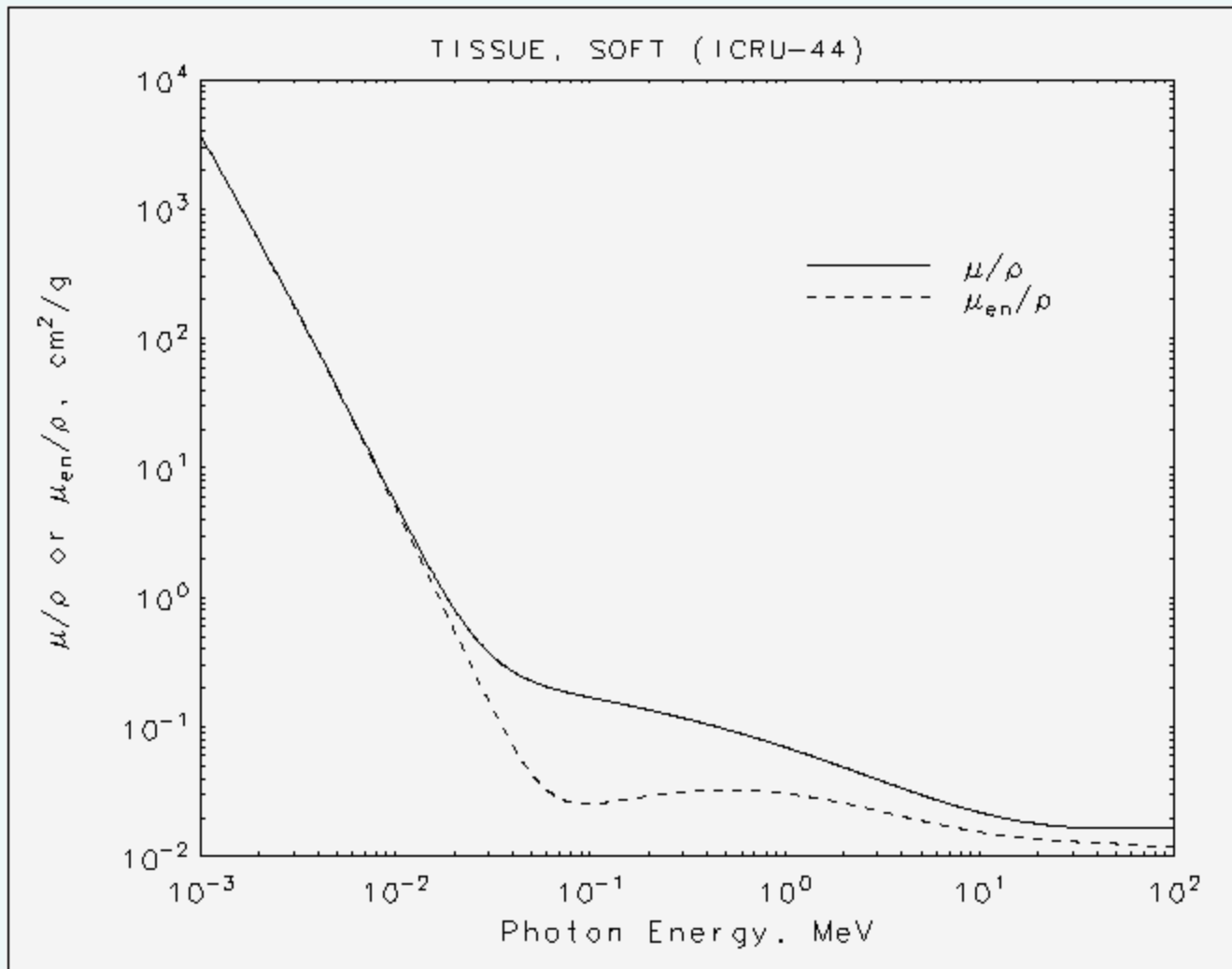
Key factors include:

- patient size
- beam position
- technical factors
- source-to-image distance and source-to-skin distance
- Backscatter (increases skin dose between 20-40%)
- equipment capabilities

Measuring Skin Dose – Key Factors



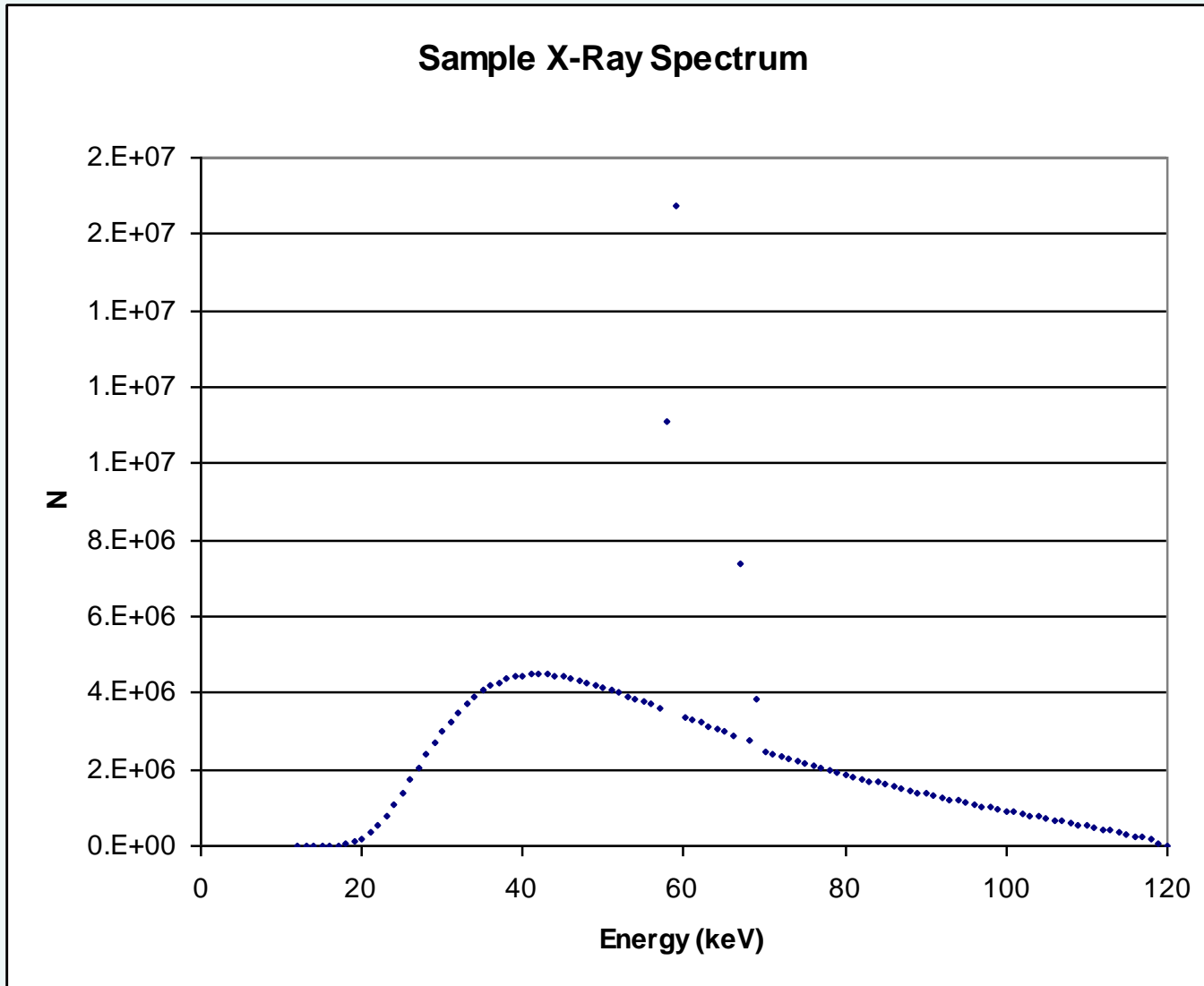
Absorption of X-Rays



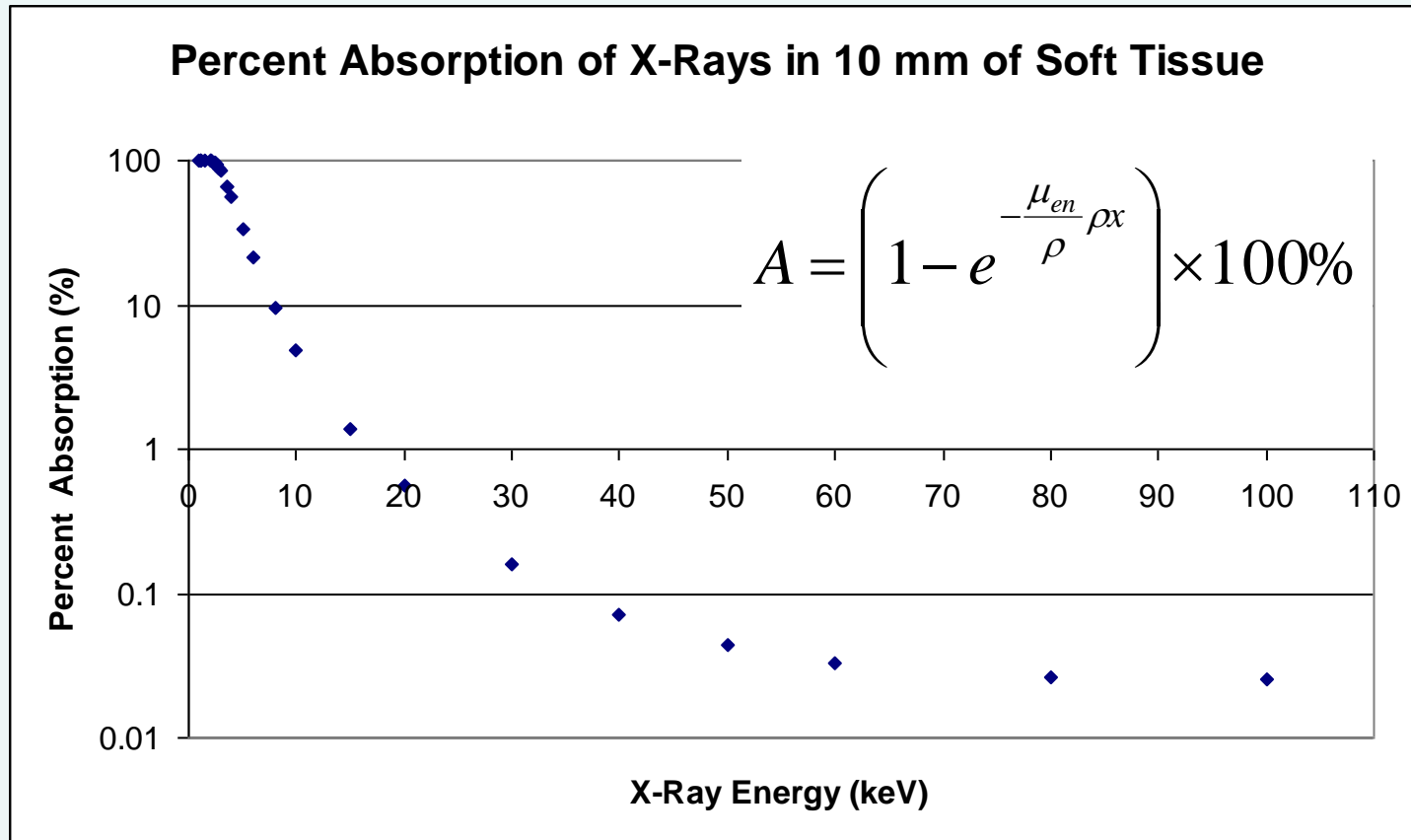
NIST Standard Reference Database 126

Online: May 1996 - **Last update:** July 2004

X-Ray Spectrum



X-Ray Absorption in Soft Tissue

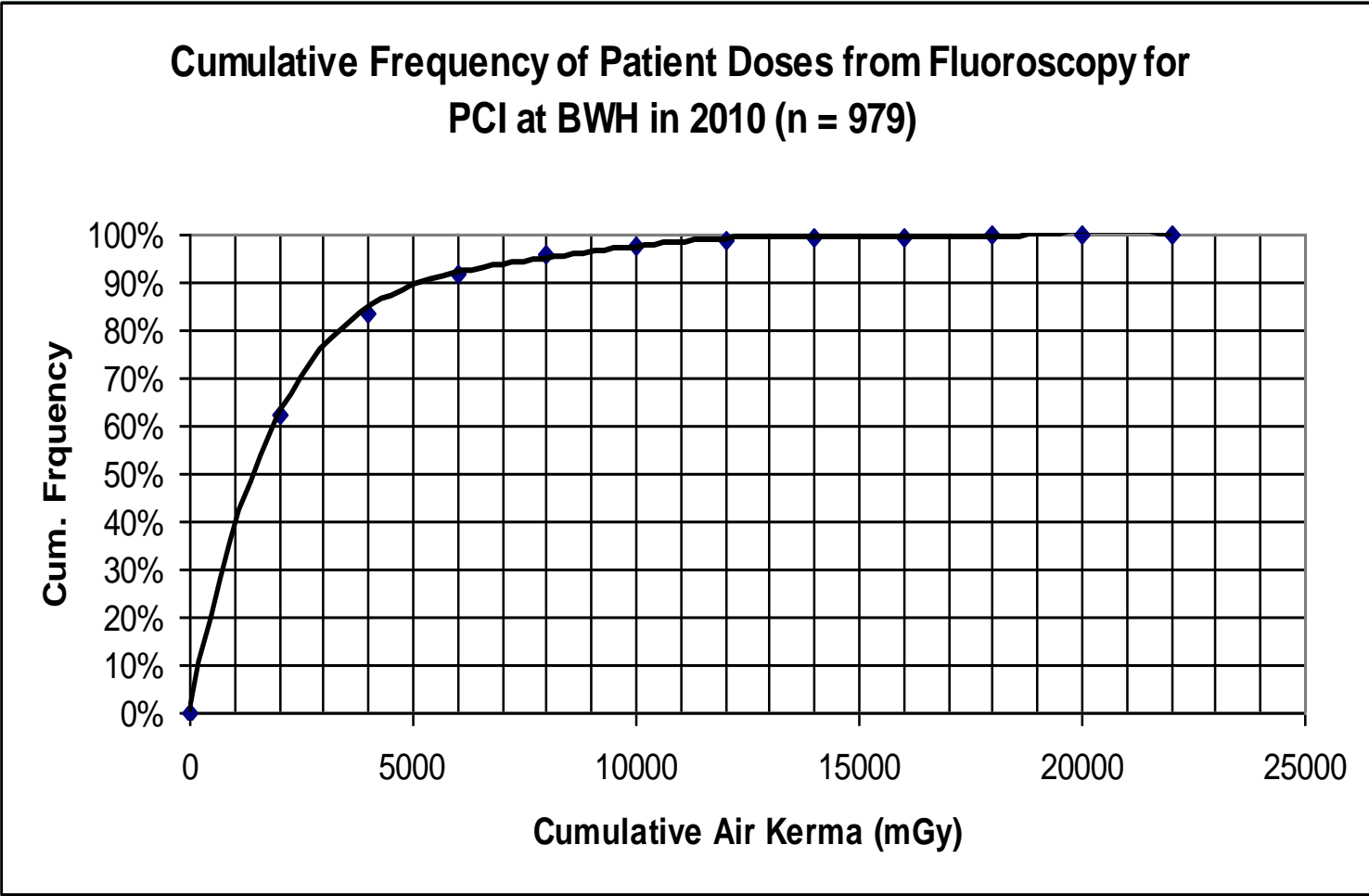


NIST Standard Reference Database 126
Online: May 1996 - **Last update:** July 2004

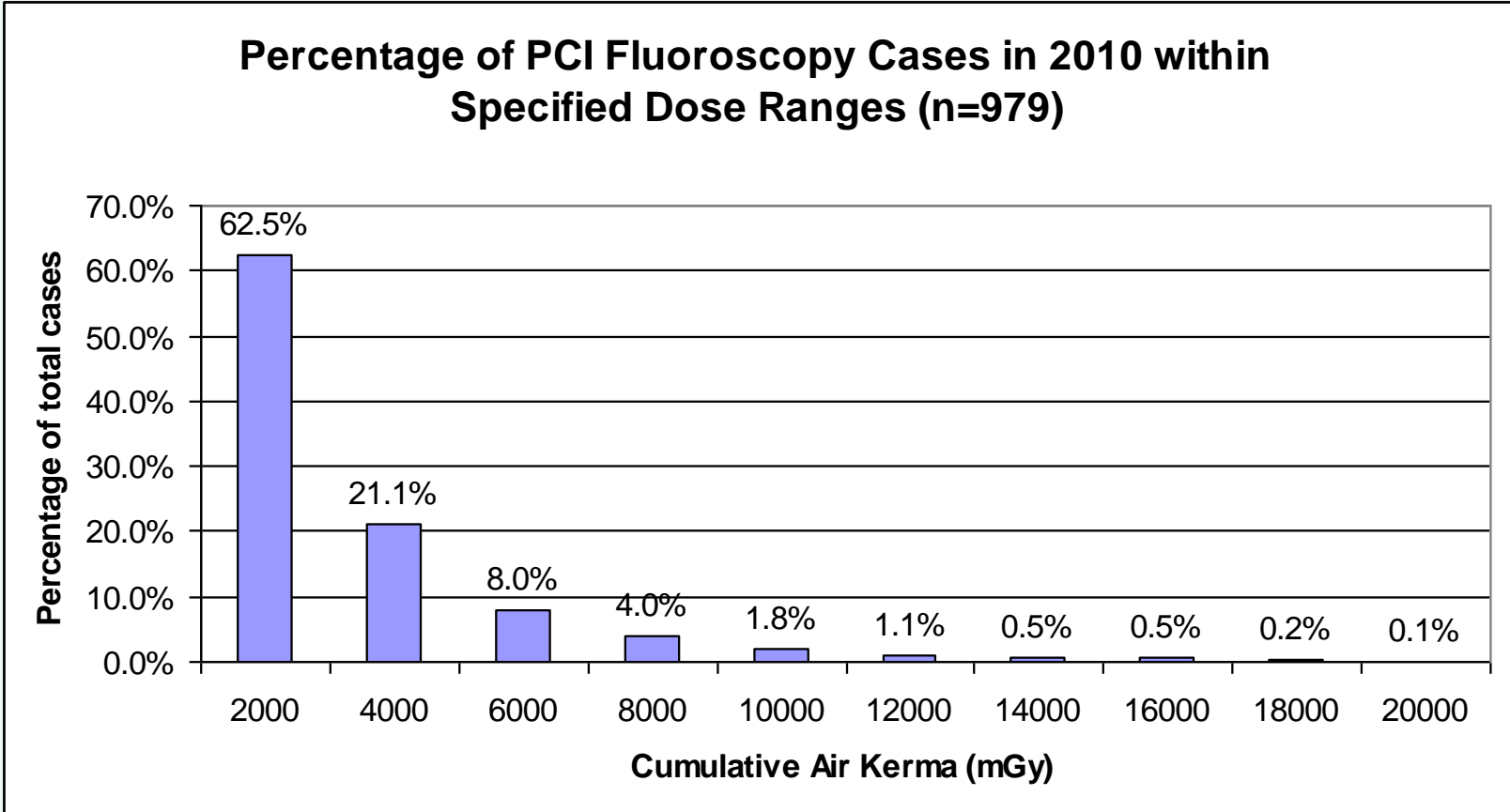
Top 6 Procedures at BWH (mGy)

Procedure	No.	25th	Median	75th
Percutaneous Coronary Intervention	1586	853	1587	3220
Visceral Angiogram	25	721	1092	1703
Embolization	135	419	1021	1667
Peripheral Intervention	462	564	950	1617
Coronary Diagnostic Case	2864	284	492	923
Cerebral Angiogram	220	322	434	644

Cumulative Air Kerma for PCI at BWH



Cumulative Air Kerma for PCI at BWH

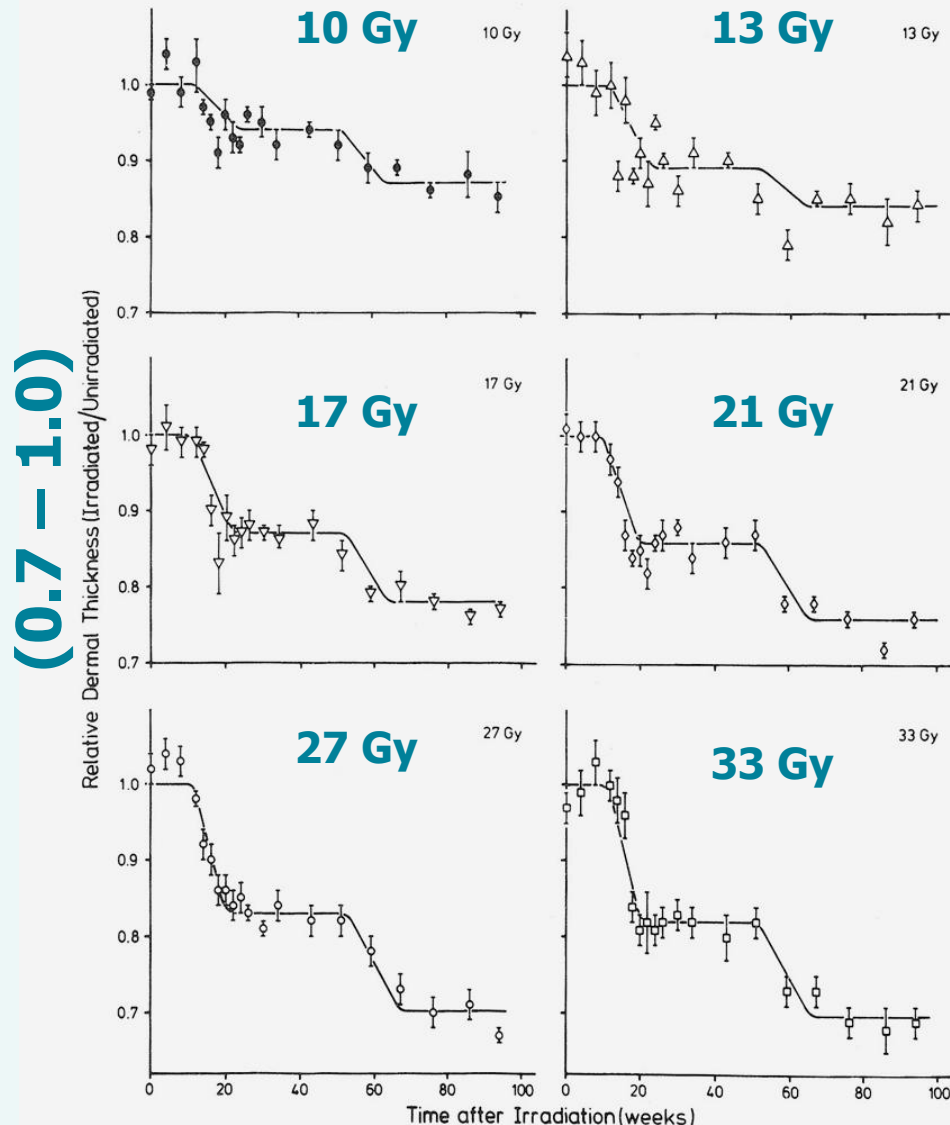


Radiation Effects on Skin

- More than 50% of basal cells are at a depth of 200 μm , distributed in the shaft of hair follicles.
- Total radiation dose of the basal layer and time between repeat exposures will determine the severity of the damage.
- The size of the skin area exposed will determine the long-term effects.
- As the dose increases, the number of viable basal and clonogenic cells decreases.
- As the number of viable basal cells decreases beyond 50%, the skin stem cells respond by rapidly producing more basal cells.

Ref: ICRP Pub. 59

Radiation Effects on Skin



(0.7 – 1.0)

Time (0 – 100 days)

Relative Dermal Thickness vs. Time after Irradiation

$\left(\frac{\text{Irradiated}}{\text{Unirradiated}} \right)$

ICRP Pub. 59; p. 30

Radiation Effects on Skin

- Transient Erythema
- Main Erythema
- Temporary and Permanent Epilation
- Dry desquamation
- Moist desquamation
- Ulceration
- Late Erythema
- Dermal Atrophy
- Telangiectasia
- Necrosis

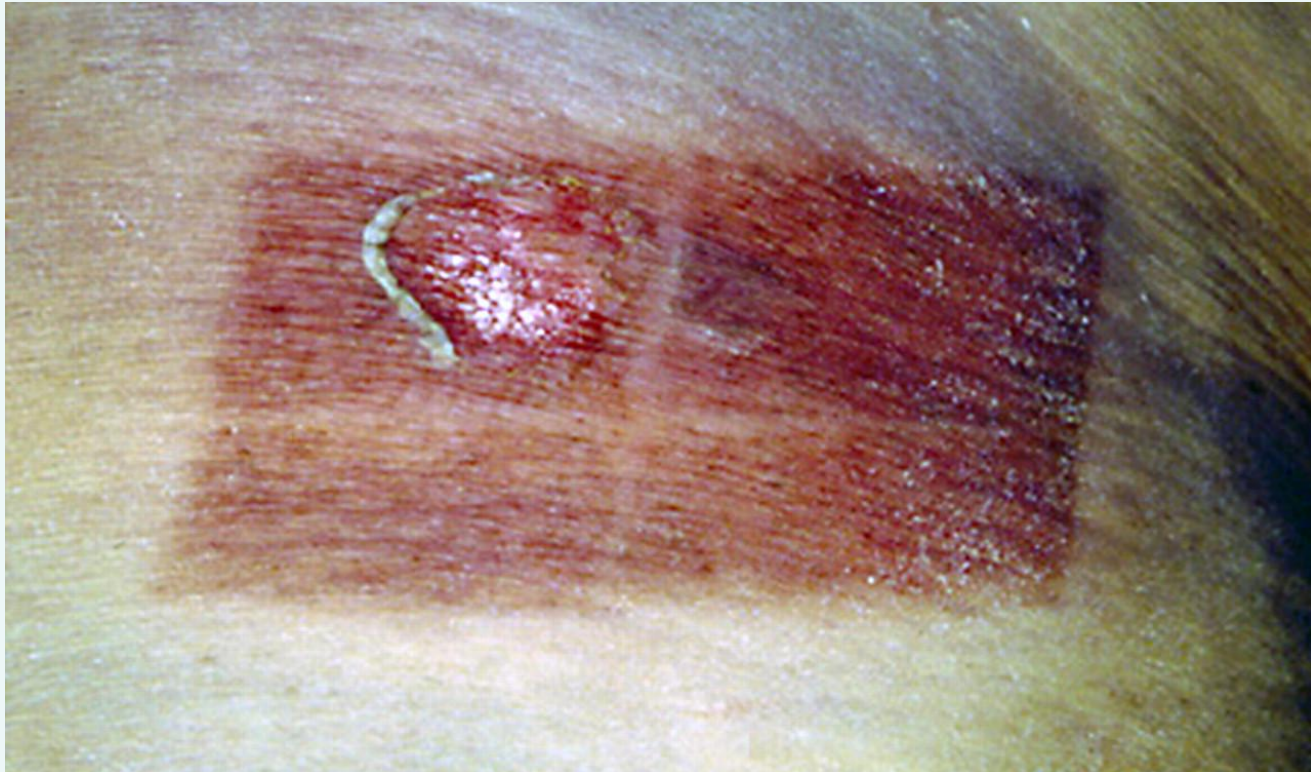
Radiation Effects on Skin

- Early transient erythema
 - May be seen within a few hours after irradiation of large fields (15x20 cm) and subsides after 24 – 48 hours.
 - Response is early phase of inflammation from increased permeability in the capillaries.
 - The repair of sub-lethal damage to DNA is completed within 24 hours.

Ref: ICRP Pub. 59

Radiation Effects on Skin

(a) Early erythema and developing moist desquamation in a diabetic woman caused by a localization radiographic exposure.



Radiation Effects on Skin

- Electrophysiology and ablation procedure with a bi-plane fluoroscopy unit



Wagner LK, Radiation injury is a potentially serious complication to fluoroscopically-guided complex interventions, Biomed Imaging Interv J 2007; 3(2):e22
<URL: <http://www.bijj.org/2007/2/e22/>>

Radiation Effects on Skin

- Epilation – hair loss
 - Cells at the base of the hair follicle are affected.
 - Detectable hair loss after 6 weeks occurs in about 50% of subjects at 5-10 Gy.



LA Times



Balter S et al. Radiology 2010;254:326-341

Radiology

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Radiation Effects on Skin

- Dry desquamation
 - An atypical thickening of the stratus corneum that may or may not be observed.



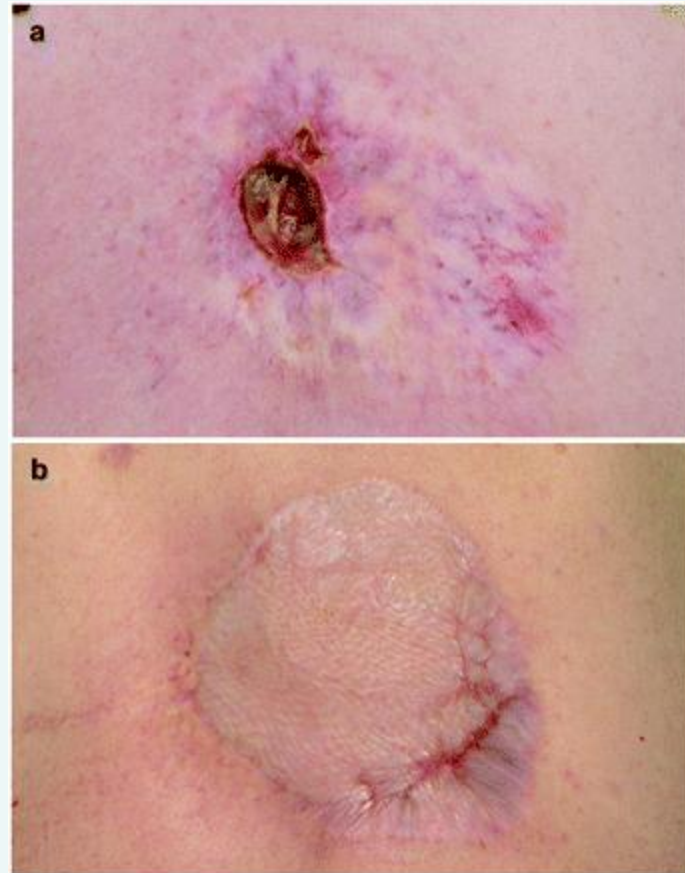
Radiation Effects on Skin



- Moist desquamation
 - Sloughing of the epidermis and exposure of the dermal layer clinically characterizes moist desquamation.

Radiation Effects on Skin

- Ulceration and necrosis
 - Basal layer and clonogenic cells sterilized
 - Surrounding skin not able to send new cells
 - Epidermis sloughs off



Interact CardioVasc Thorac Surg 2011;12:290-292.
doi:10.1510/icvts.2010.247395
© 2011 [European Association of Cardio-Thoracic Surgery](#)

Radiation Effects on Skin (Wagner, 1994)

Effect	Time to Onset	Dose Threshold (Gy)
Transient Erythema	2-24 hrs	2
Main Erythema	10 d	6
Temporary Epilation	3 wks	3
Permanent Epilation	3 wks	7
Dry desquamation	4 wks	14
Moist desquamation	4 wks	18
Ulceration	>6wks	24
Late Erythema	8-10wks	15
Telangiectasia	>1yr	10
Necrosis	>1Yr	>12

Radiation Effects on Skin

- Mettler, 2008 – Skin erythema or reddening occurs if a single dose of 6 to 8 Gray is given and is not identified till 1 to 2 days after irradiation.
- Balter, 2010 – For most patients, clinically important skin and hair reactions occur only when the skin dose is higher than 5 Gy.
- ICRP Rub. 59 – Early erythematous reaction well documented in man is seen within a few hours after irradiation of *large fields* with acute doses of ≥ 2 Gray.

Other Radiation Effects

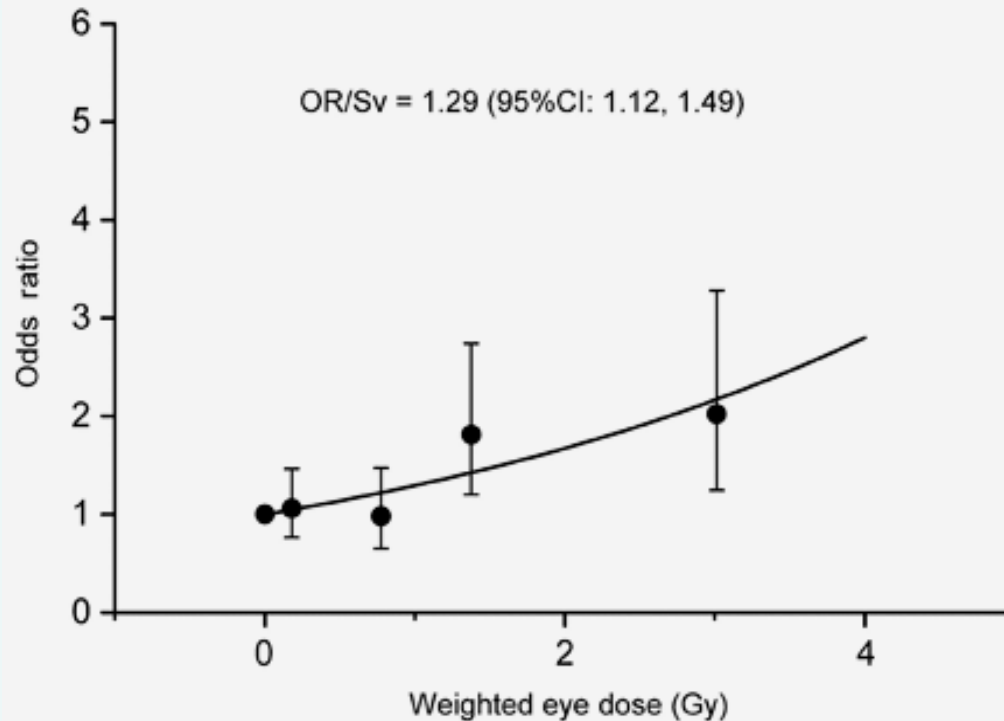
- Stochastic effects:
 - Skin cancer
 - Non-melanotic
 - Basal Cell Carcinoma – rarely fatal
 - Squamous Cell Carcinoma – lethality < 1 % (around 0.02%)
 - Both can be caused by radiation with BCC caused 20 times more frequently than SCC.
 - Melanoma – very weak association between radiation exposure and melanoma

Ref: ICRP Pub.59

Other Radiation Effects

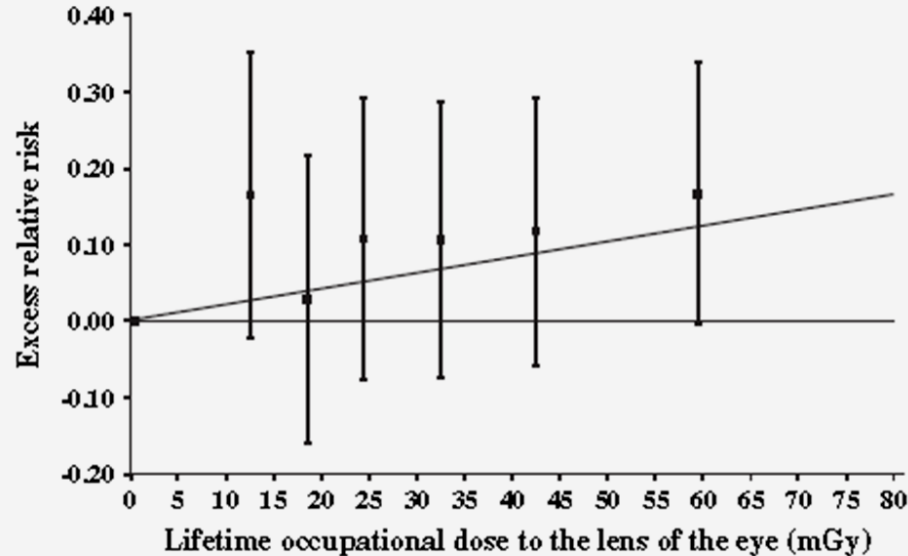
- Cataracts
 - Long held belief that cataracts are a threshold effect.
 - New epidemiological studies show can occur as low as 60 mGy.
 - excess cataracts seen are of the types generally associated with radiation: posterior subcapsular and cortical cataracts

Other Radiation Effects



- Neriishi K, Nakashima E, Minamoto A, Fujiwara S, Akahoshi M, Mishima HK, Kitaoka T, Shore R: Postoperative cataract cases among atomic bomb survivors: Radiation dose response and threshold. Radiation Research 2007; 168:404-8

Other Radiation Effects



**Cohort of
35,705 x-ray
techs**

In conclusion, our study provides evidence that exposure to relatively low doses of ionizing radiation may be harmful to the lens of the eye and increases the long-term risk of cataract formation...with no apparent threshold level.

Chodick, Gabriel, "Risk of Cataract after Exposure to Low Doses of Ionizing Radiation: A 20-Year Prospective Cohort Study among US Radiologic Technologists" 2008

Other Radiation Effects

- Stochastic Effects:
 - All other forms of cancer depending on the exposed region.

Recommendations

- Tracking patients:
 - FDA recommends > 1 Gy
 - ICRP Pub. 85 recommends > 3 Gy or > 1 Gy if procedure to be repeated
 - ACR recommends > 2 Gy
 - SIR Recommends > 3 Gy

Recommendations

- CRCPD recommends follow up if patients exceed the following:

Table 4. Thresholds for patient follow-up

<u>Parameter</u>	<u>Threshold</u>
PSD	3000 mGy
$K_{a,r}$	5000 mGy
P_{KA}	500 Gy·cm ²
FT	60 min

CRCPD Publication #E-10-7

**Technical White Paper:
Monitoring and Tracking
of Fluoroscopic Dose**

December 2010

Did you know?

- It is also required by the Safe Medical Devices Act 1990 that any serious injuries associated with the use of medical devices be reported to the FDA.
- This includes radiation burns and other deterministic injuries.
- Additionally, the FDA recommends the radiation safety committee/officer should monitor all recorded fluoroscopic doses for trends among current operators.

The End?