PATIENT DOSIMETRY
IN
DIAGNOSTIC RADIOLOGY MODALITIES

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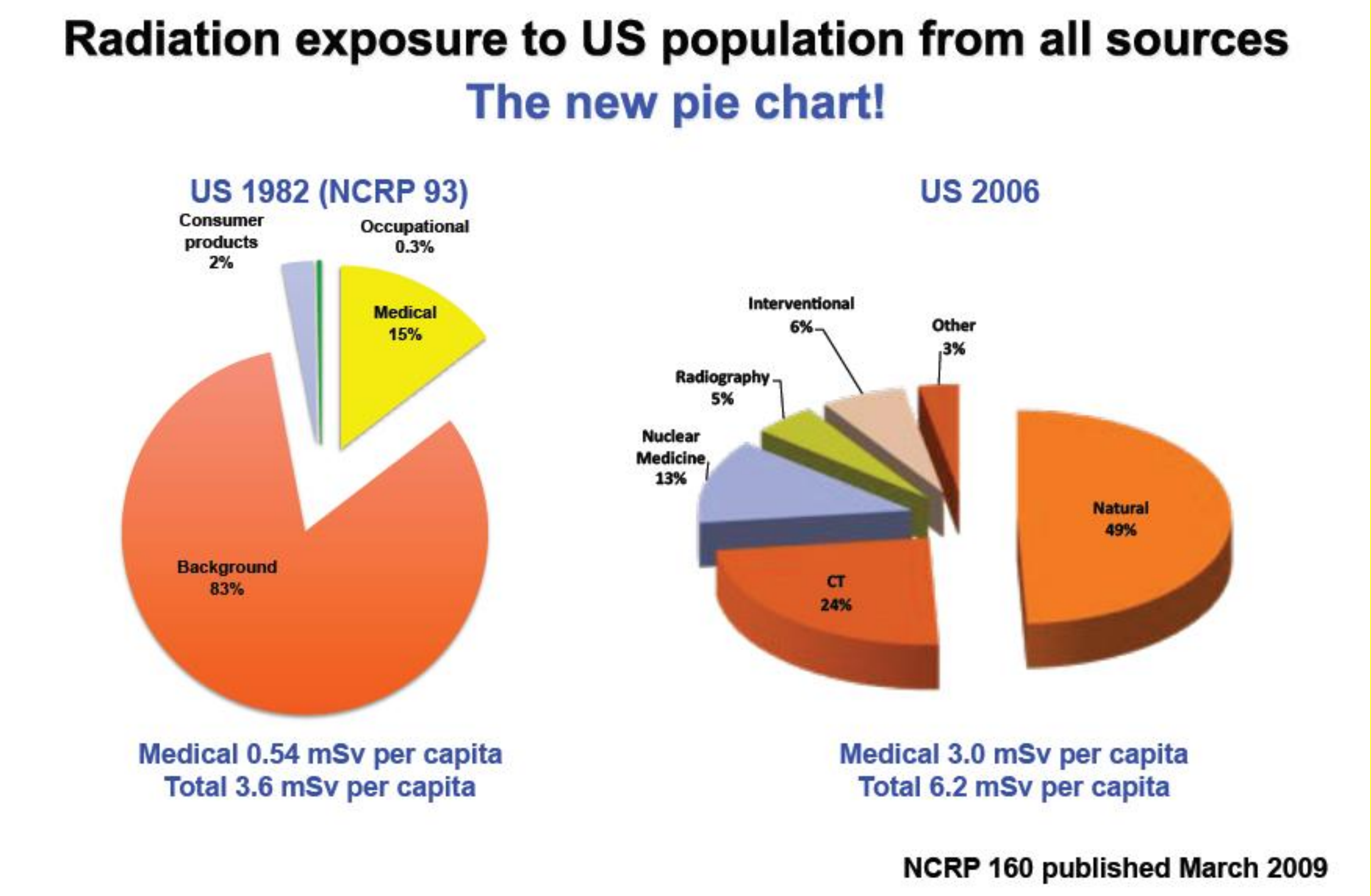
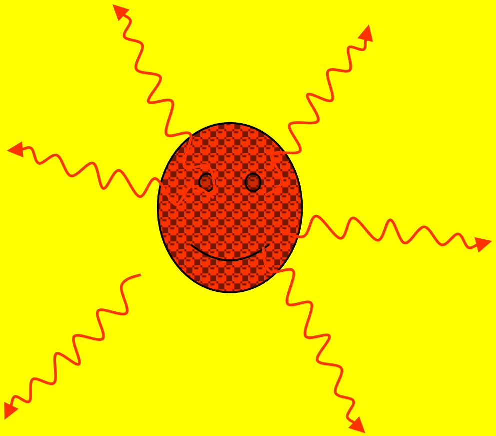
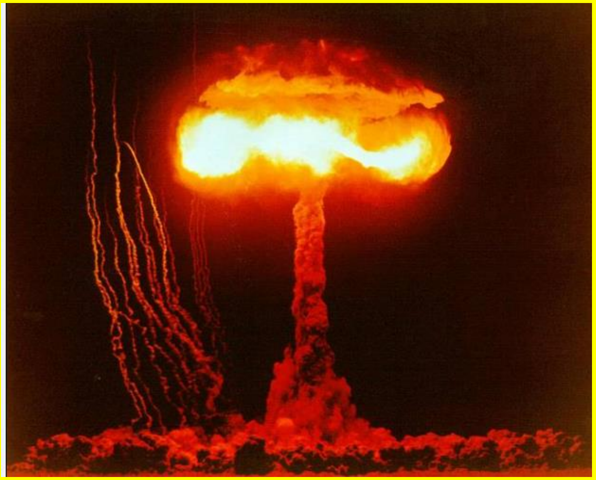
USE OF RADIATION! INCREASING?

Natural versus men-made radiation



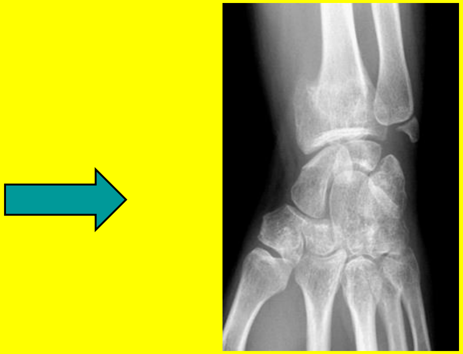
THE *INTENSITY* AND THE *ENERGY* OF GAMMA RADIATION





The SUN : High intensity low energy

Nuclear Bomb : High intensity and energy



Smart and safe use of Radiation

WHICH DOSIMETRIC QUANTITIES?

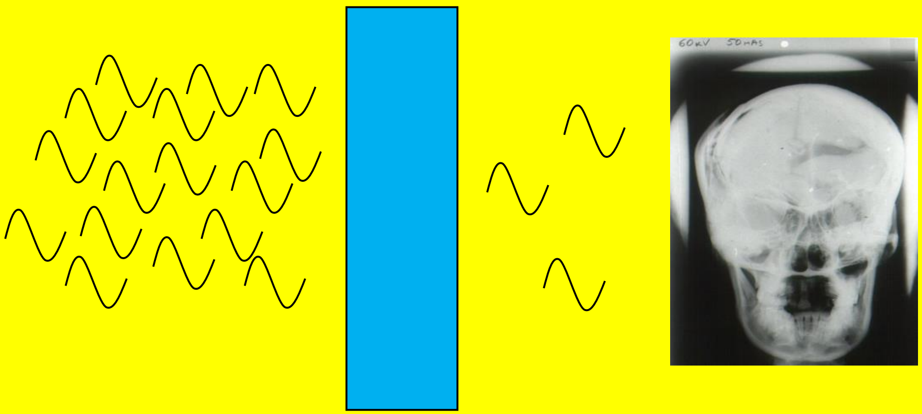
Measured Quantity

- **Exposure (Roentgen, Air kerma):** **Measurement of intensity**
- **Absorbed dose (Gray):** **Measurement of absorbed energy in a unit mass**
- **Equivalent dose (Sievert)** **Measurement of absorbed energy in a organ**

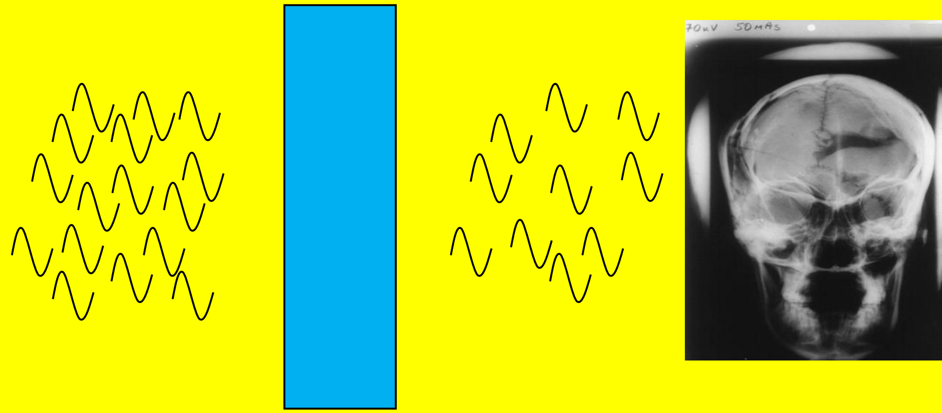
Calculated Quantity

- **Effective Dose (Sievert):** **Quantifies the stochastic risk due to radiation received by the tissue and organs**

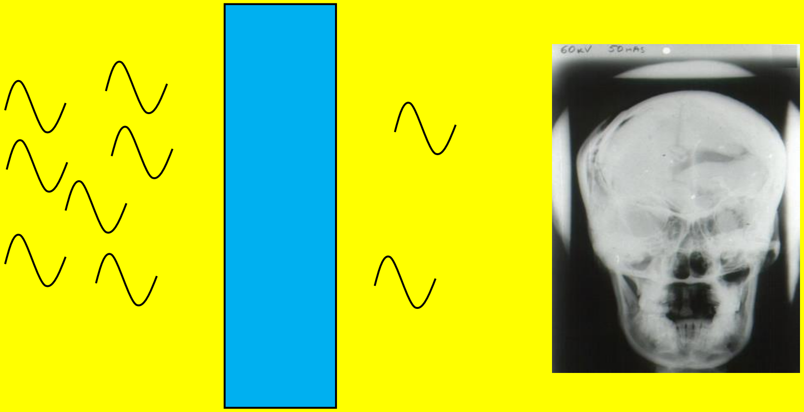
THE *INTENSITY* AND THE *ENERGY* OF GAMMA RADIATION



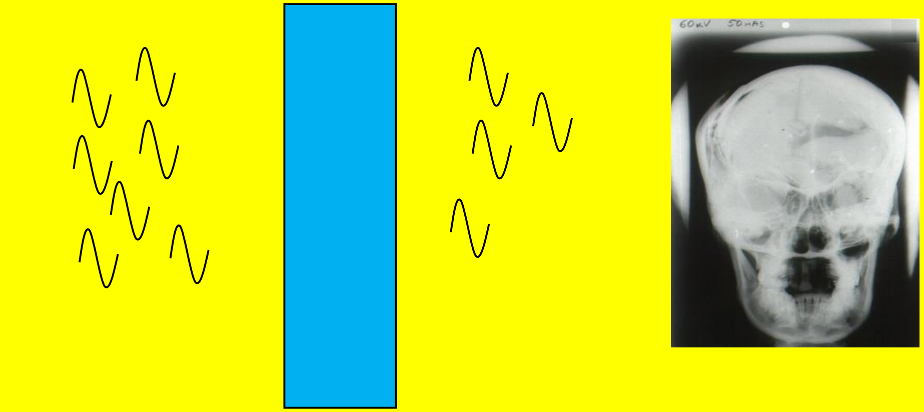
: High intensity low energy



High intensity and energy

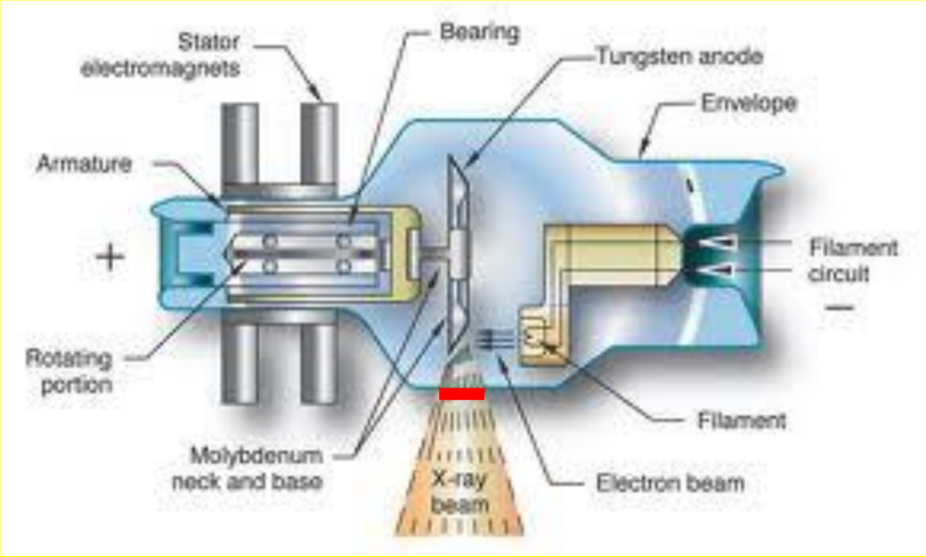


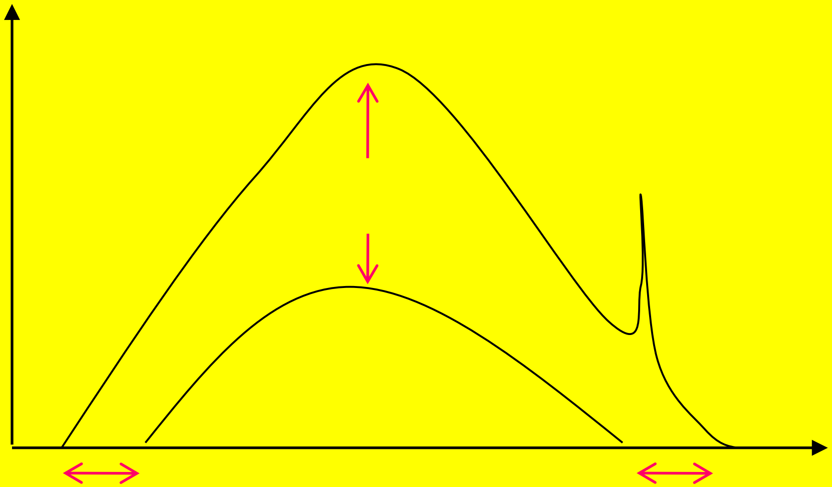
Low intensity and low energy



Low intensity and high energy

HOW WE CAN CHANGE THE INTENSITY AND ENERGY OF THE RADIATION?





kVp, mAs
distance,
Filter

WHAT ARE THE IMPORTANT REQUIREMENTS OF IMAGING WITH IONISING RADIATION?

- **Minimum radiation to patient and staff**
- **Optimum Image Quality**

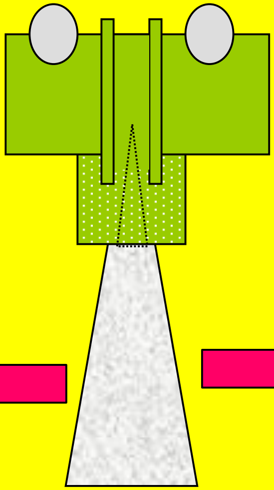
CHAOS!!!

Image Quality ↑

Radiation dose ↑

WHAT DO WE HAVE TO MEASURE?

THE RADIATION GIVEN BY THE X-RAY SYSTEM



THE RADIATION RECEIVED BY THE PATIENT

Occasionally

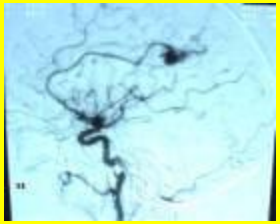
THE RADIATION RECEIVED BY THE STAFF

Occupationally

WHAT ARE THE CRITICAL EXAMINATIONS FOR PATIENTS AND STAFF?

Staff dose ↗↗

Patient Dose ↗↗



Interventional Radiology

Patient Dose ↗↗

Tomography

Staff dose ↗

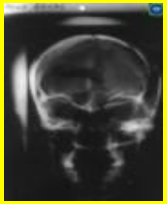
Patient Dose ↗

Fluoroscopy

Patient Dose ↗↗

Mammography

Patient Dose ↗



Radiography

WHEN DOSE MEASUREMENTS ARE NECESSARY?

- Comparison of patient doses with reference levels

- Radiological examination of Pregnant or potentially pregnant patients

- Evaluation and optimization of quality control studies

- Before the screening studies of large populations

- Radiological examinations of pediatric patients

- In case of high dose examinations (i.e. interventional procedures)

- In follow up studies

HOW WE MEASURE THE RADIATION?

General Radiography and Fluoroscopy (Analog-Digital)

- Measurements on patient and phantom
- Skin dose and Dose-area measurement

Mammography (Analog-Digital)

- Measurements on patient and phantoms
- Skin dose measurement

Computed tomography

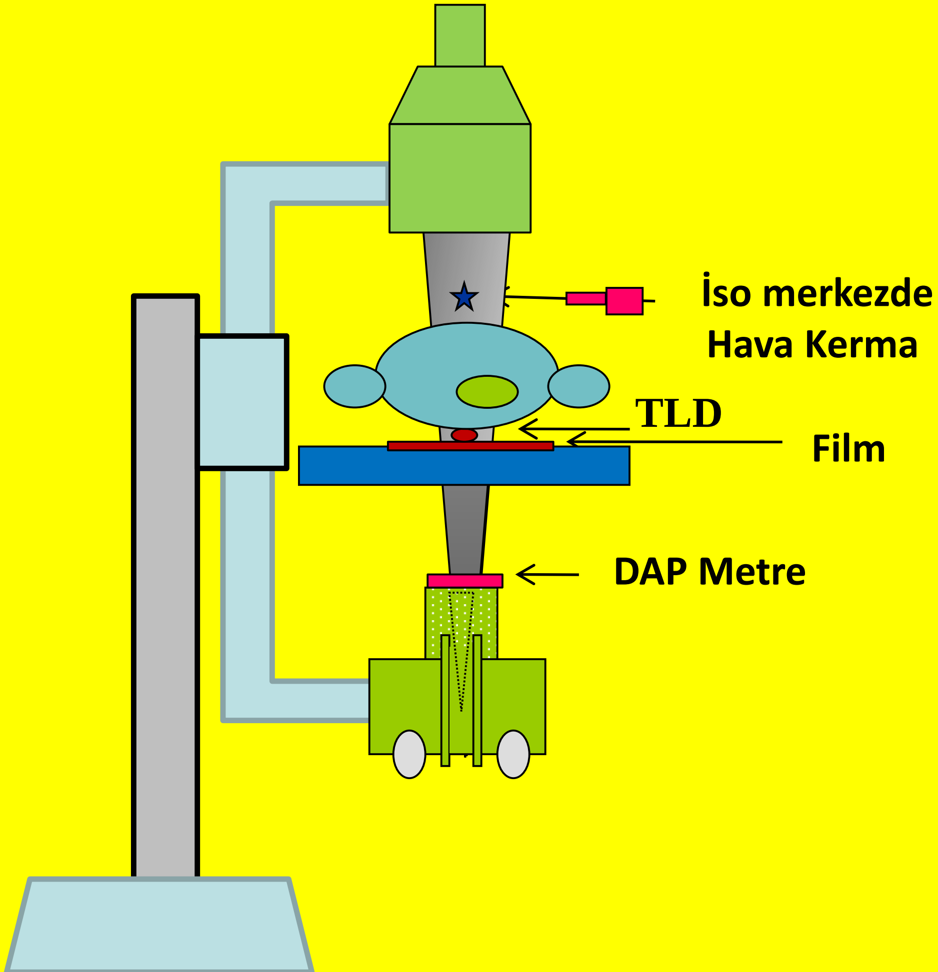
- Measurement of CTDI in air and phantom

WHAT ARE THE DOSE MEASUREMENT TECHNIQUES!

Point measurements, Area measurements

On-line techniques

Off-line techniques



WHY WE CONCERN ABOUT THE RADIATON?

Deterministic Effect

(Skin injuries, cataract)

Stochastic Effect

(Probability of cancer development)

WE MEASURE and ESTIMATE THE

SKIN and **ORGAN DOSES**

DETERMINE

EFFECTIVE DOSES

WHY WE MEASURE SKIN AND ORGAN DOSES?

SKIN DOSES:

- To prevent the deterministic effects for high dose procedures
- Comparison of similar techniques
- Optimization of clinical protocols
- Quality control optimization
- For reference dose levels
- Input for effective dose estimation

ORGAN DOSES:

- Gonad doses for genetic effect
- Red Bone marrow for leukemia
- Thyroid, breast and lungs for cancer
- Input for effective dose estimation

ORGAN DOSES

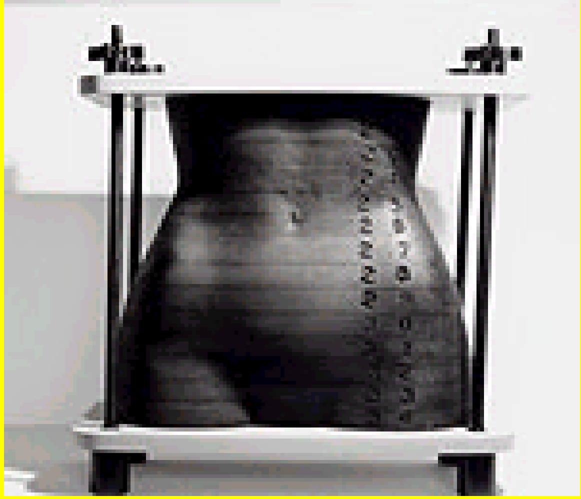
From measurements

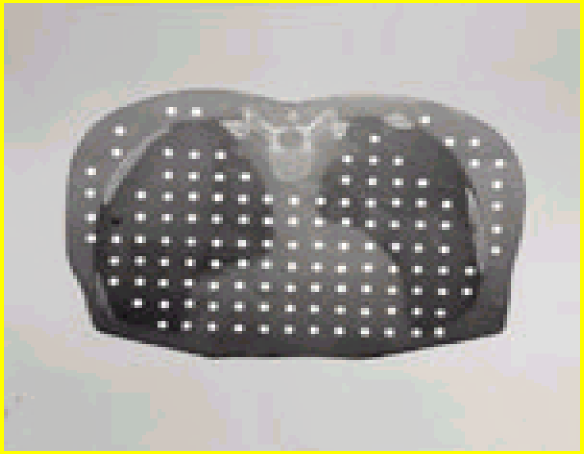
On patients → **Eye lens, breast, extremities**

On phantoms → **For standard body sizes**

From organ dose tables

ORGAN DOSE MEASUREMENTS (RANDO PHANTOM)





GSF ORGAN DOSE TABLE

Field size 12 cm* 40 cm
Patient thickness(f) 19 cm
Patient thickness(m) 20 cm

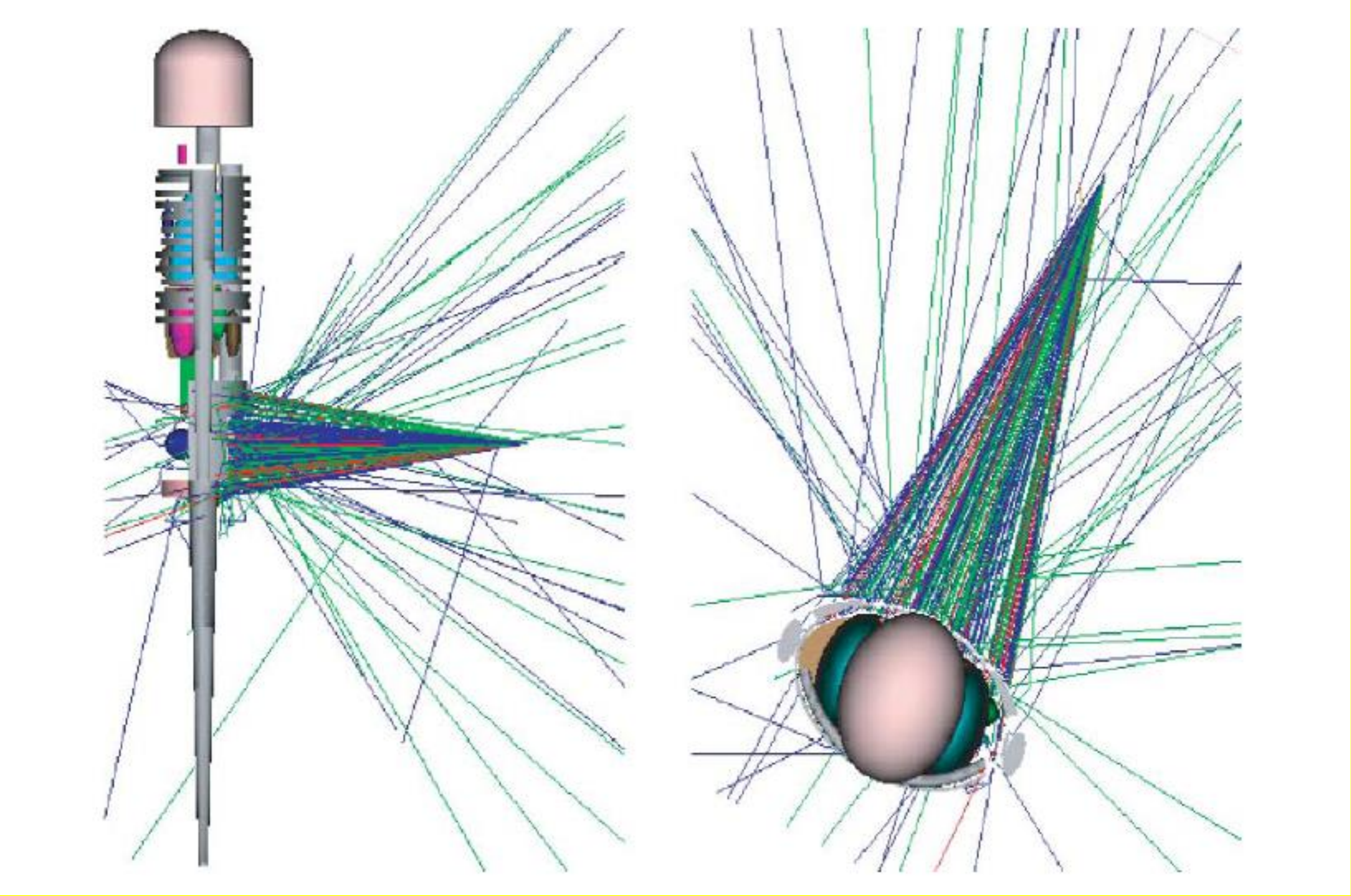
focus-film distance 115 cm
focus-skin distance 85 cm
total filtration 2,5 mm Al

MEAN ORGAN DOSE (mSv)/ ENTRANCE DOSE (mSv)

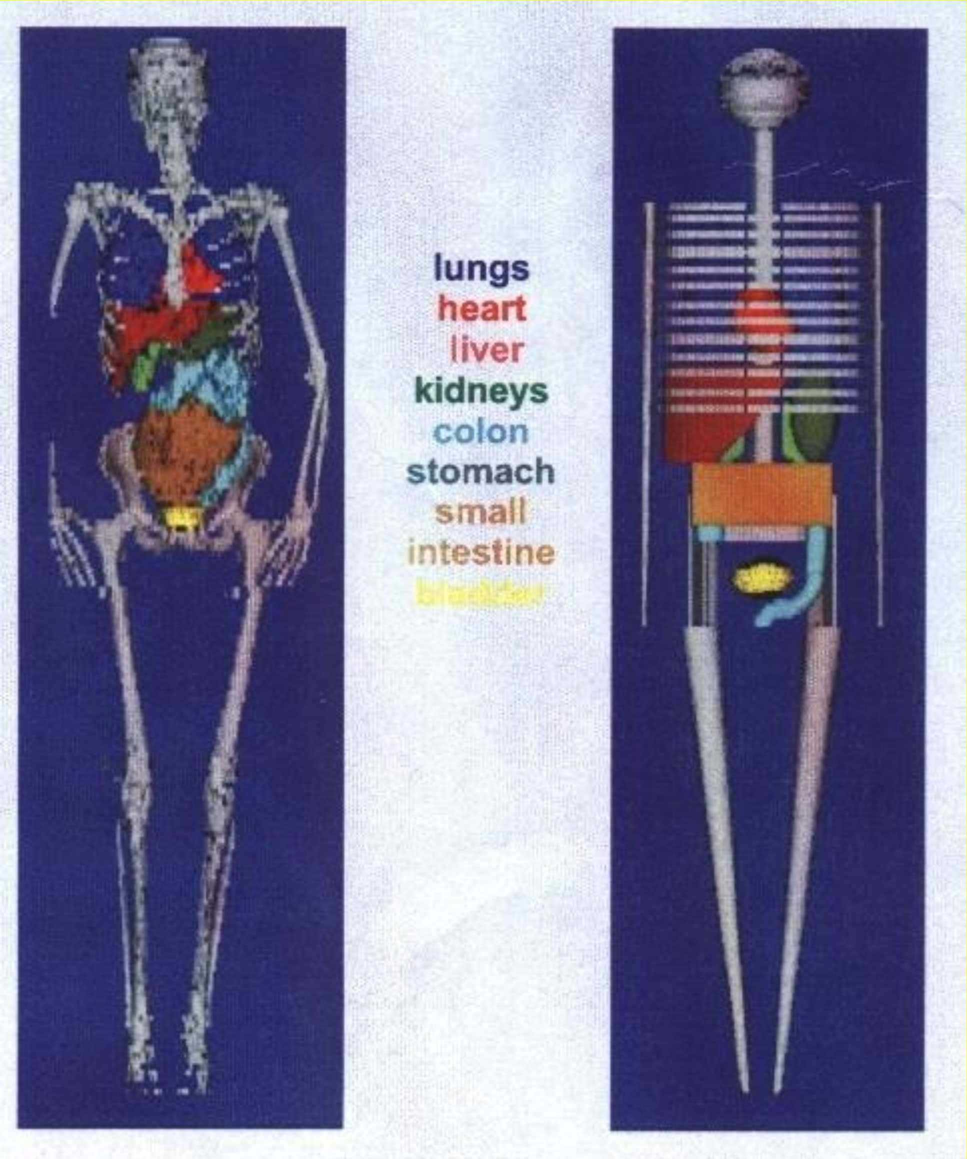
THORACIC SPINE a.p.

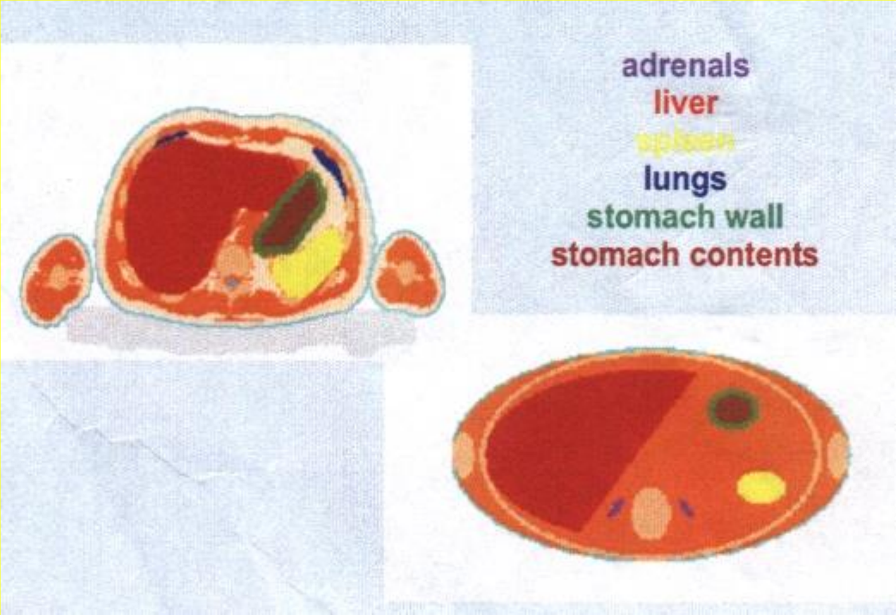
Tube voltage	70 kV		80kV		90kV		%a
Organ	m	f	m	f	m	f	
Thyroid	0.05	0.33	0.06	0.36	0.06	0.39	3.0
Breast	-	0.09	-	0.10	-	0.11	0.5
Lungs	0.04	0.05	0.05	0.06	0.06	0.07	0.4
Spleen	**	**	0.01	0.01	0.01	0.01	2.0
Pancreas	0.05	0.05	0.06	0.06	0.07	0.08	1.0
Stomach wall	0.02	0.02	0.02	0.02	0.03	0.03	1.5
Redbone marrow	0.01	0.01	0.02	0.02	0.02	0.02	0.2
Skeleton	0.05	0.05	0.05	0.06	0.05	0.06	0.2
Surface(entr.)	1.14	1.18	1.16	1.21	1.19	1.24	0.5
Surface(exit)	0.01	0.01	0.01	0.02	0.02	0.02	6.0

MONTE CARLO TEKNİKLERİ



MATHEMATICAL MODELS USED FOR ORGAN DOSE CALCULATIONS





Voxel Models

V.S

Mathematical Models

VOKSEL FANTOMLAR

SOURCE OF ERRORS

- Variations of   irradiation geometries (X-ray field size and position)
- X-ray spectrum diffrences (kVp and HVL)
- Differences of organ compositions, sizes, and densities
- Anatomical differences

CALCULATION OF EFFECTIVE DOSES

$$E = \Sigma_T \, w_T . H_T$$

W_T :Weighting factor for organ or tissue T

H_T : Equivalent dose in organ or tissue T

ORGAN / TISSUE	W_T	ORGAN / TISSUE	W_T
Bone marrow	0.12	Lung	0.12
Bladder	0.05	Oesophagus	0.05
Bone surface	0.01	Skin	0.01
Breast	0.05	Stomach	0.12
Colon	0.12	Thyroid	0.05
Gonads	0.20	Remainder	0.05
Liver	0.05		

WHY EFFECTIVE DOSE IS IMPORTANT?

It is used to estimate somatic risk

Cancer risk: : 5×10^{-2} Sv (ICRP 60)

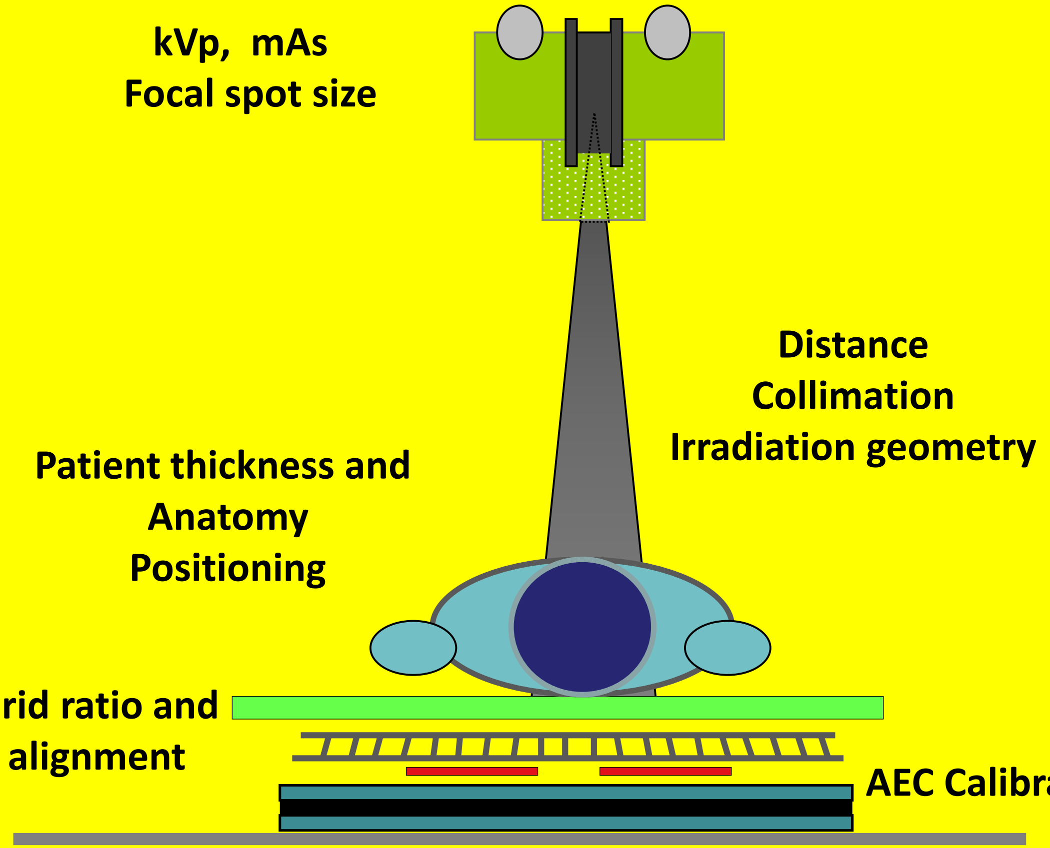
Chest film (0.05 mSv)	**2 -3 / 1 000 000**
Pelvis, abdomen CT (10-20 mSv)	**1/2000 – 1000**
Interventional (50 mSv)	**1 / 400**
Cardiac CT (40 yrs old female)	**1 / 270**

DOSIMETRY IN RADIOGRAPHY

CONVENTIONAL RADIOGRAPHY
IS IT EASY TO TAKE AN IMAGE?

Parameters effecting image quality and radiation dose

kVp, mAs
Focal spot size



Distance
Collimation
Irradiation geometry

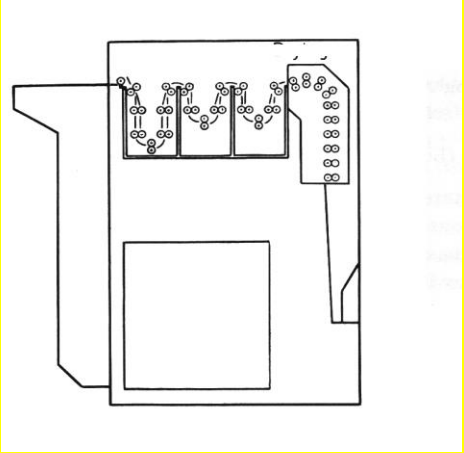
Patient thickness and
Anatomy
Positioning

Grid ratio and
alignment

AEC Calibration

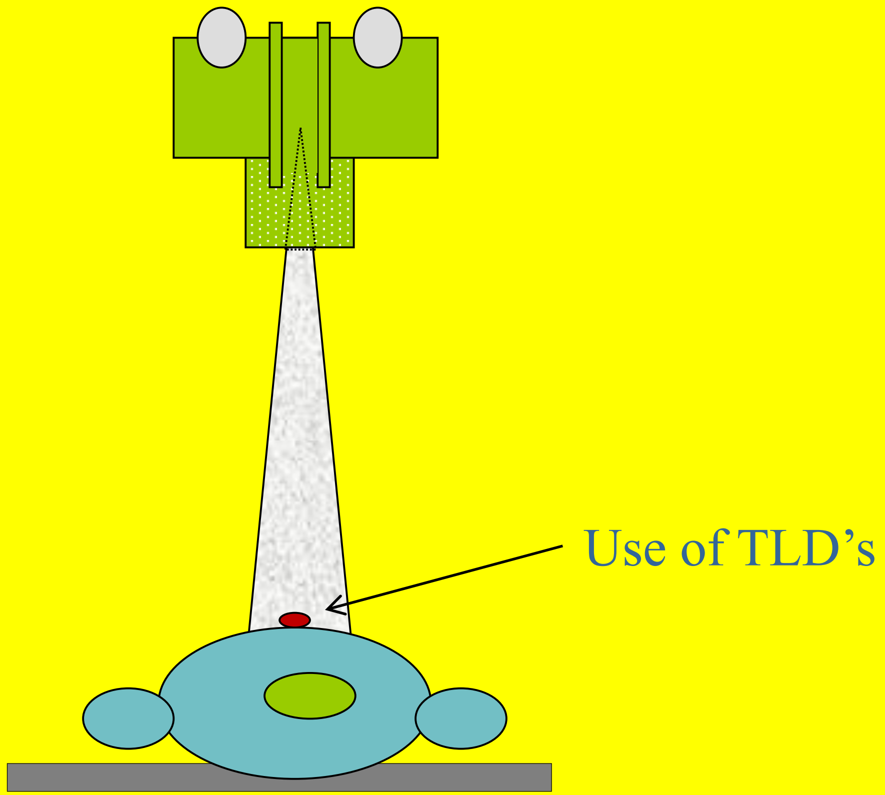
Film type → Screen type and speed

Film Processing:



HAPPY !!!

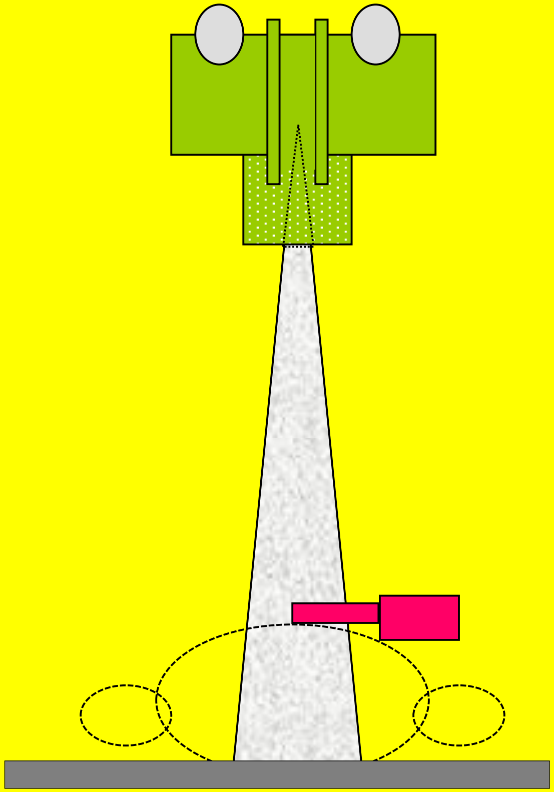
SKIN DOSE MEASUREMENTS



ENTRANCE SURFACE AIR KERMA – ESAK- MEASUREMENTS

Ion Chambers

Elektronic Dosimeters (Diod, MOSFET)

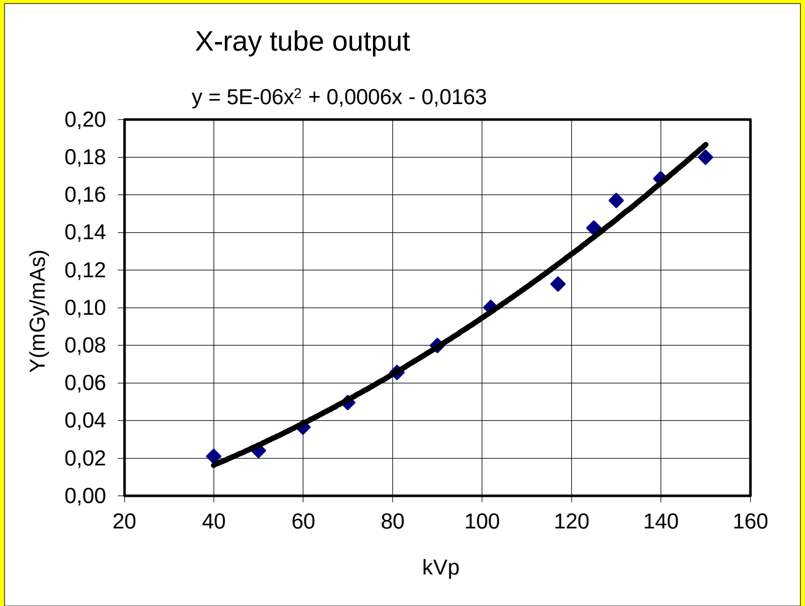


ESD = AK x BSF x (Distance Correction) x μ_d / μ_h

TUBE OUTPUT MEASUREMENTS

Dose value at a specific pont in the air

No	kVp_o	mAs_o	M (mGy)	Ka (mGy)	Y(kVp, F, FDD) (mGy/mAs)
1	40	100	2.10	2.10	0.02
2	50	100	2.40	2.40	0.02
3	60	100	3.64	3.64	0.04
4	70	100	4.96	4.96	0.05
5	81	100	6.56	6.56	0.07
6	90	100	7.98	7.98	0.08
7	102	100	10.01	10.01	0.10
8	117	100	11.25	11.25	0.11
9	125	100	14.23	14.23	0.14
10	130	100	15.69	15.69	0.16
11	140	100	16.85	16.85	0.17
12	150	100	18.00	18.00	0.18



PATIENT DOSES DEPENDS ON !

- **Accurate selection of exposure parameters**
- **Selection of optimum film/screen combination**
- **Correct positioning of the patient**
- **Collimation of the X-ray beam**
- **Limitation of patient movement**
- **Optimization of film processing**
- **Use of carbon fiber (grids, patient bed etc.**
- **Quality control**

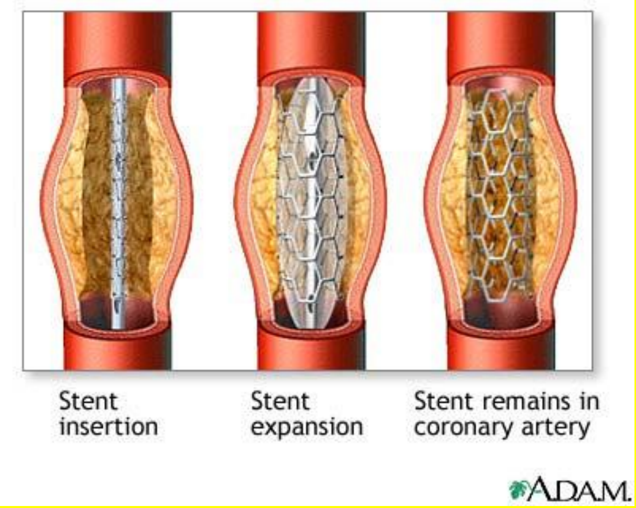
RETAKES !!!!

REFERENCE LEVELS

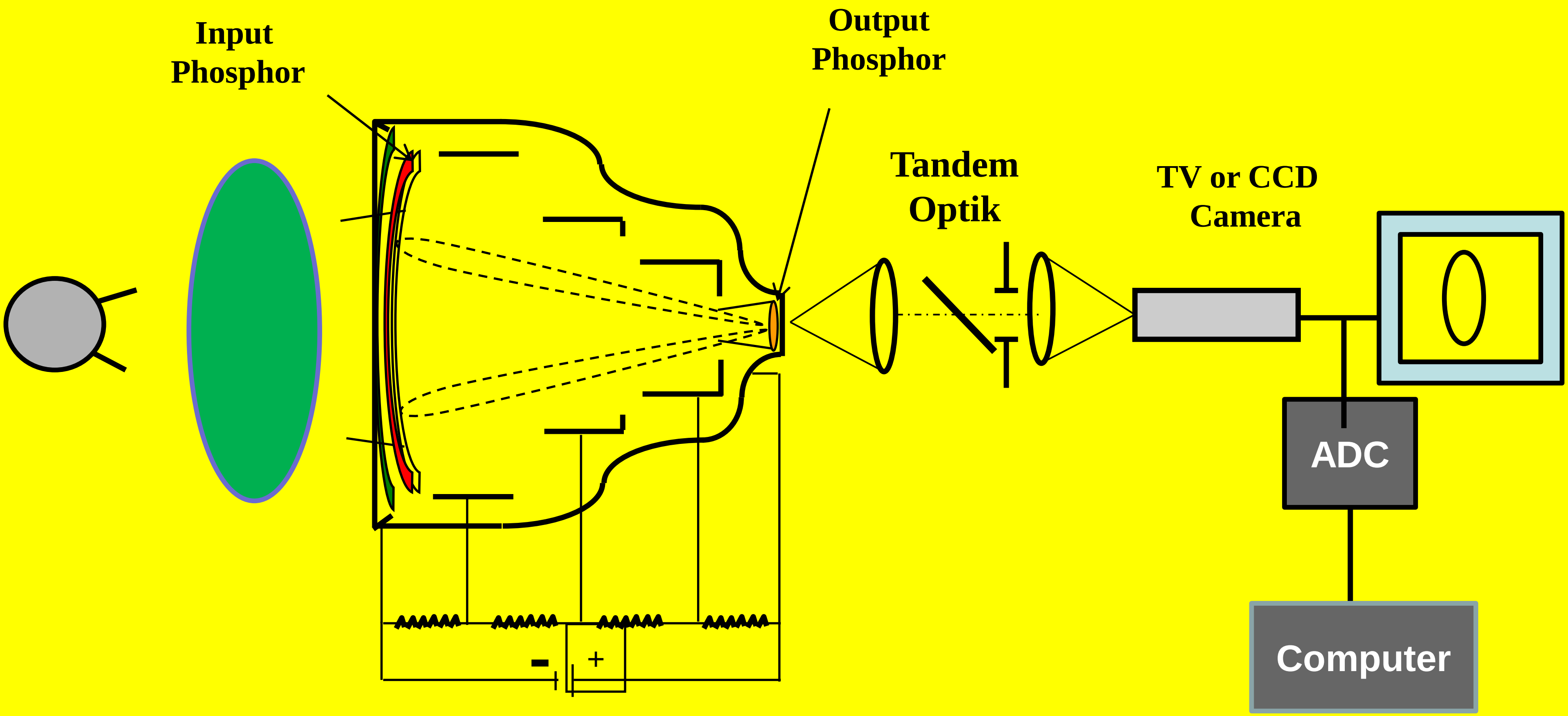
Comparison of similar techniques
Optimization of clinical protocols
Quality control

Examination	Entrance surface dose per radiograph (mGy)
Lumbar spine AP	10
Lumbar spine LAT	30
Lumbar spine LSJ	40
Abdomen, intravenous, urography and cholecystography AP	10
Pelvis AP	10
Hip joint AP	10
Chest PA	0.4
Chest LAT	1.5

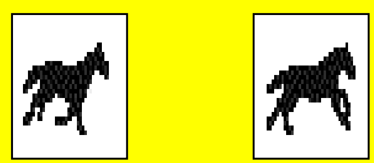
DOSIMETRY
IN
FLUOROSCOPIC
AND
INTERVENTIONAL EXAMINATIONS



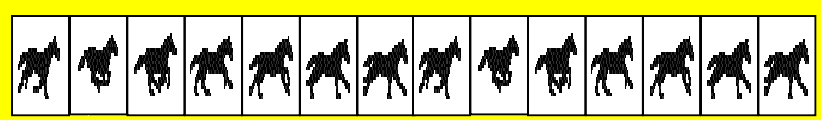
FLUOROSCOPIC SYSTEMS



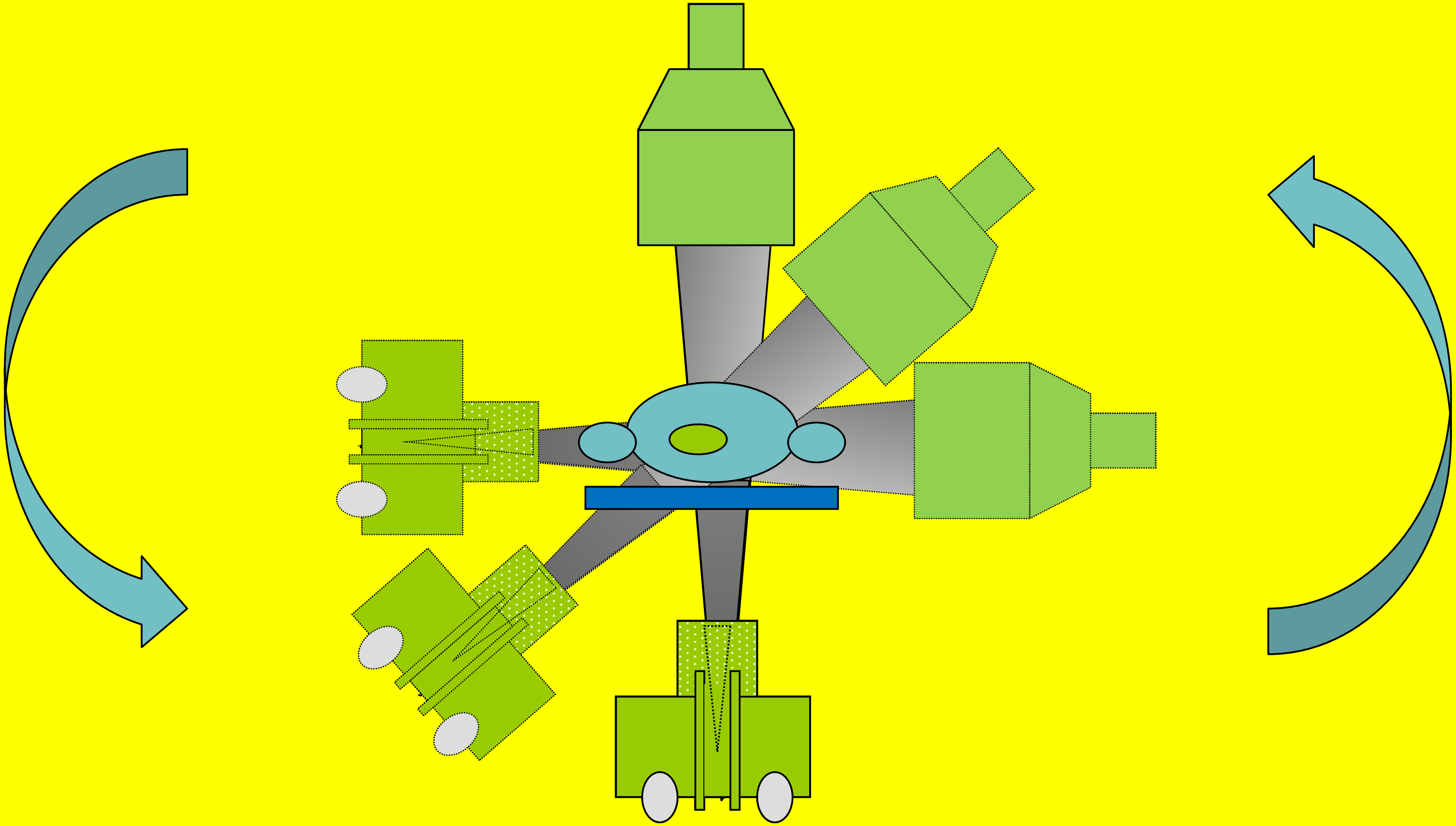
Radiographic Exposures



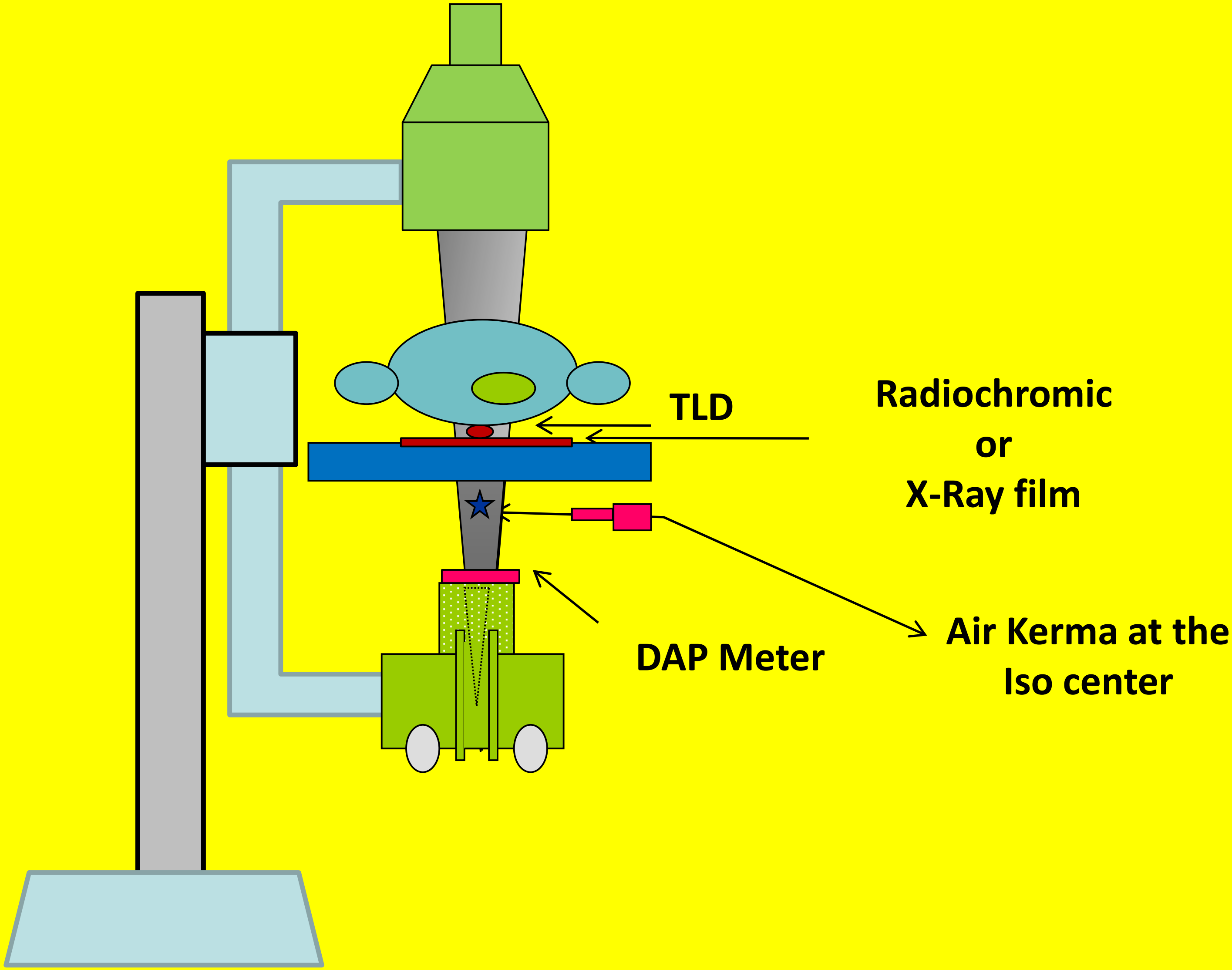
Fluoroscopic Exposures



SKIN DOSES - ORGAN DOSES
EASY TO MEASURE?

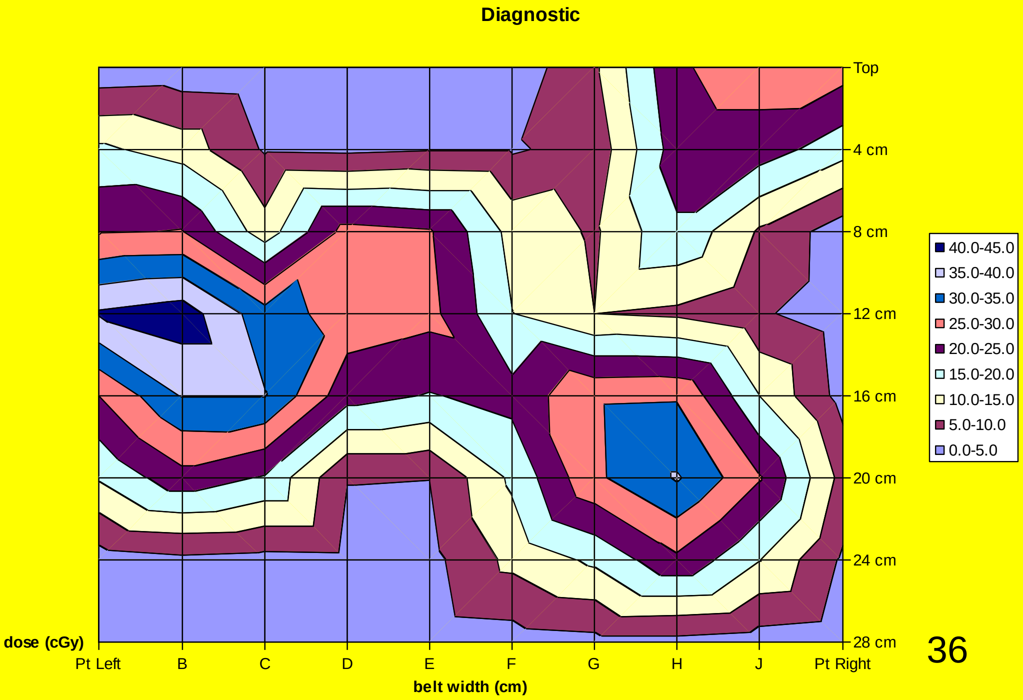


MEASUREMENT TECHNIQUES



DOSE-AREA PRODUCT MEASUREMENT

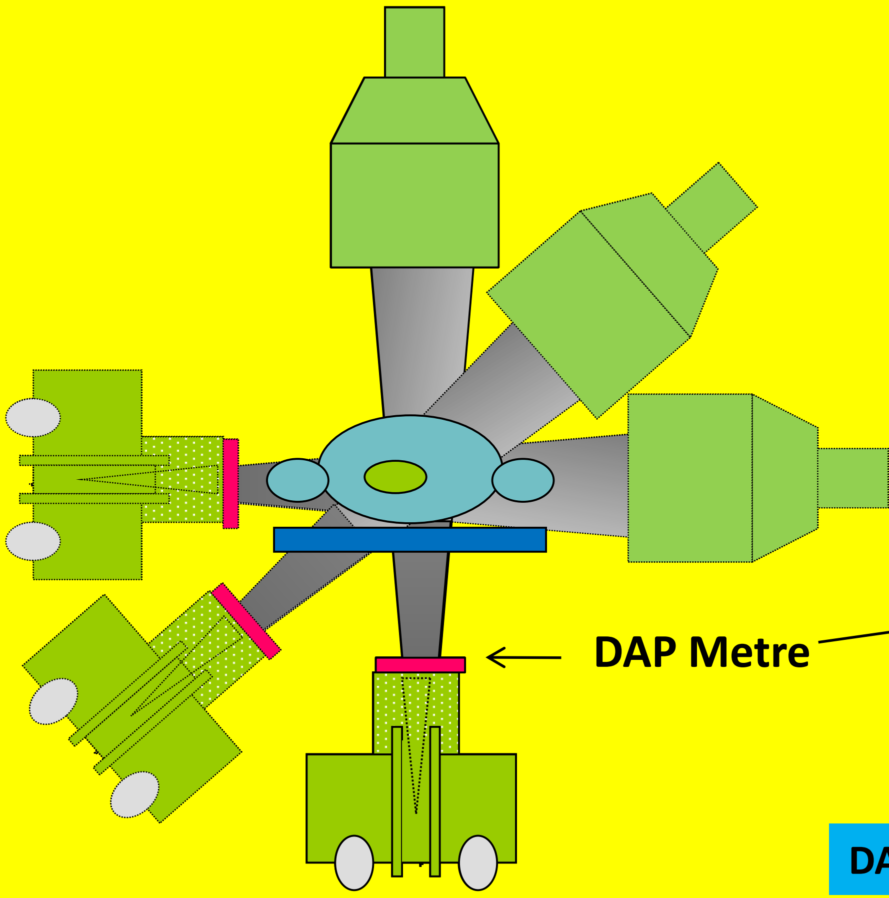
- Use of TLD grid
  - Dose distribution is obtained with interpolation of point dose data



EASY TO MEASURE ??

DOSE-AREA PRODUCT MEASUREMENT

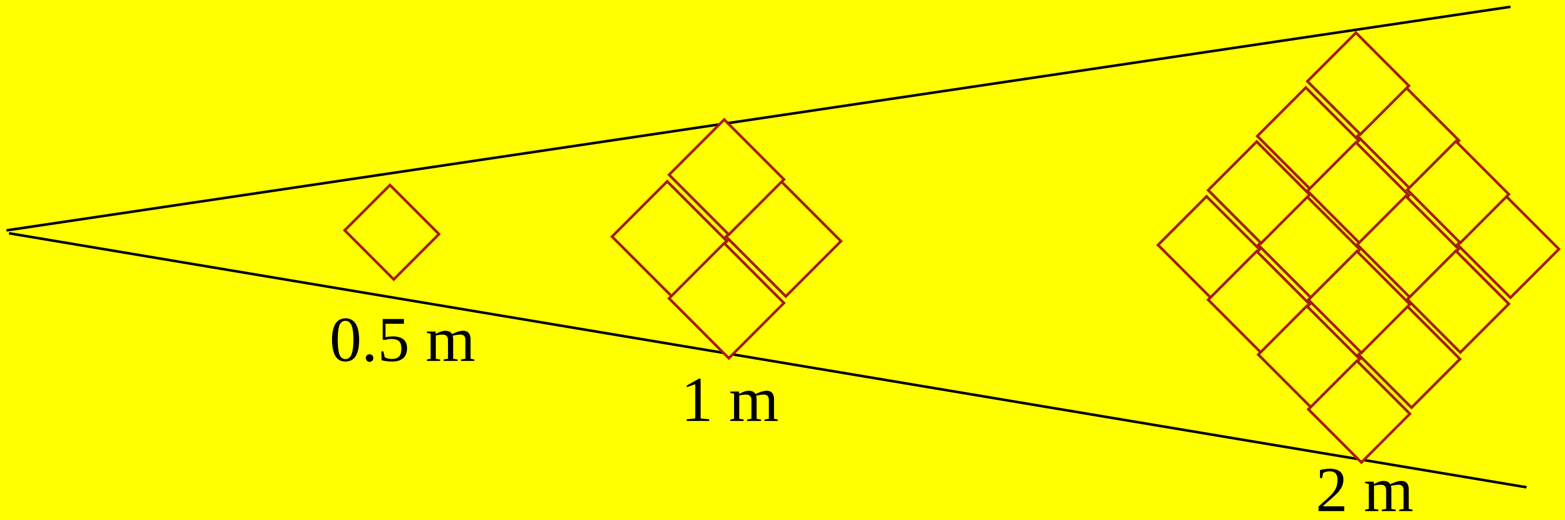
Continuous measurement of radiographic and fluoroscopic exposures



DAP Value: 50 Gy-cm^2

Skin doses can be estimated from the size of exposed area!

DOSE-AREA PRODUCT MEASUREMENT

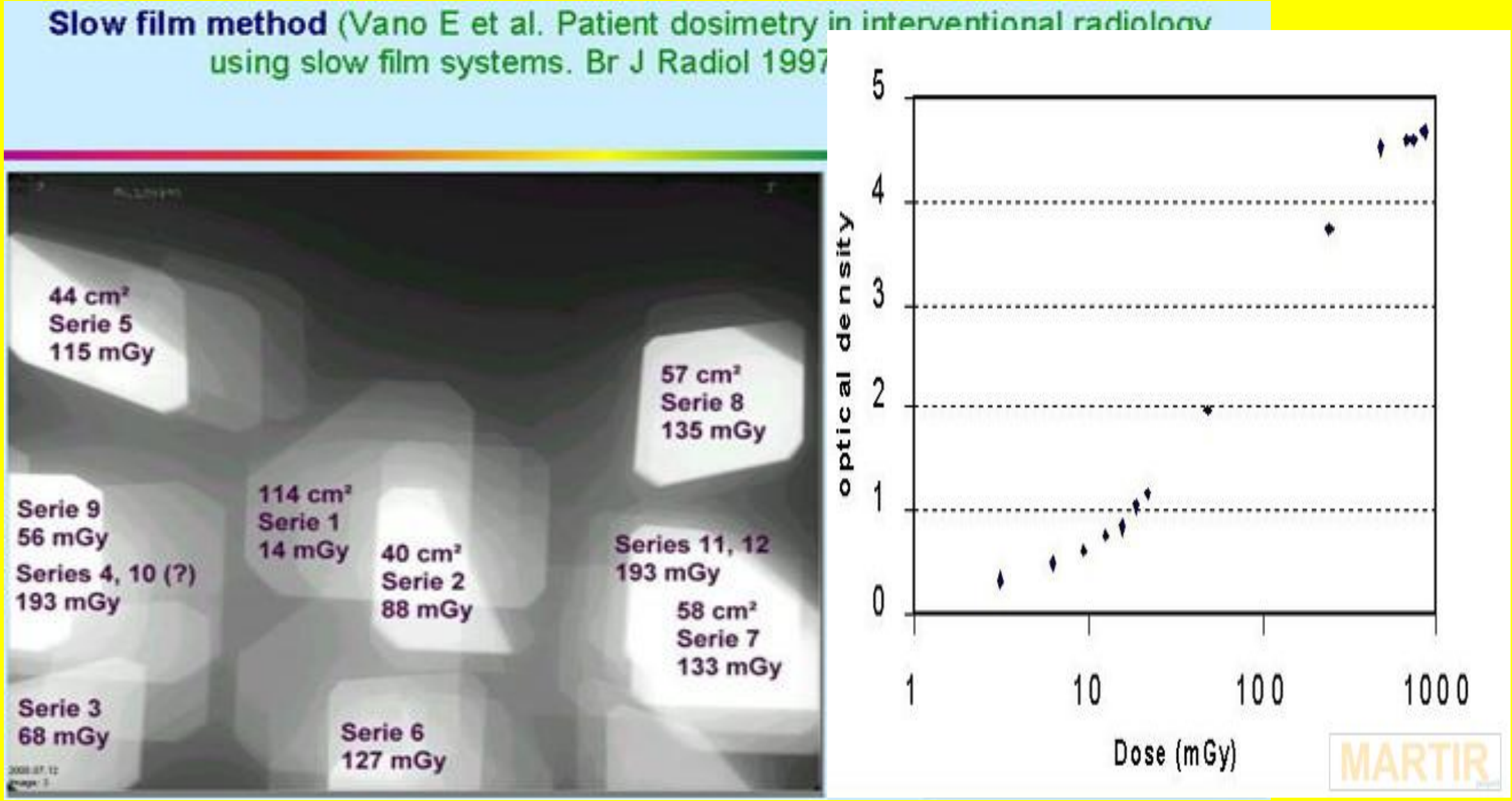


Air Kerma :	$40*10^{3}$ □Gy	$10*10^{3}$ □Gy	$2.5*10^{3}$ □Gy
Area :	$2.5*10^{-3}$ m^2	$10*10^{-3}$ m^2	$40*10^{-3}$ m^2
Area x Air Kerma	100 □Gy m^2	100 □Gy m^2	100 □Gy m^2

DOSE-AREA PRODUCT MEASUREMENT

Radiotherapy films:

Require chemical processing
Maximum dose 0.5-1 Gy

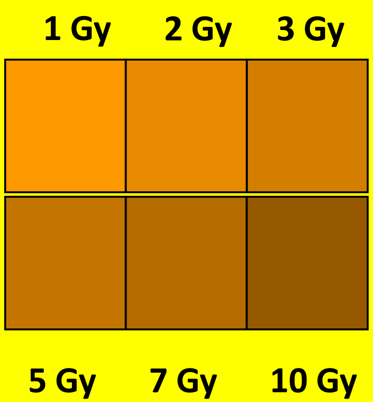


Measurement of skin dose and DAP simultaneously

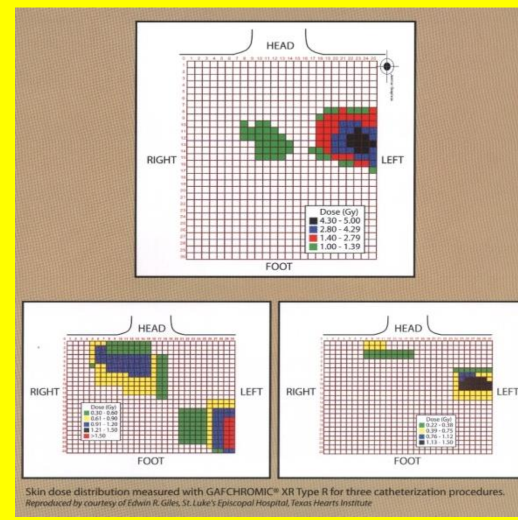
DOSE-AREA PRODUCT MEASUREMENT

Radiochromic detectors:

- No film processing
- Immediate information about of dose distribution
- Dose measurement up to 15 Gy



Calibration scale



Measurement of skin dose and DAP simultaneously

Types of procedures associated with severe injuries

Coronary Angioplasty

Courtesy F Mettler MD

Radiofrequency Ablation

Vañó, Br J Radiol
1998; 71, 510 - 516

TIPS placement

Nahass et al, Am J Gastroent
1998; 93: 1546-9

Uterine embolization

Courtesy: Shope, FDA

Renal angioplasty

Dandurand et al, Ann Derm
Vener 1999; 126: 413-417

Neuroembolization

MORE CONCERN ABOUT RADIATION!

ICRP INTERNATIONAL COMMISSION ON RADIOLOGICAL PROTECTION

Statement on Tissue Reactions

Approved by the Commission on April 21, 2011

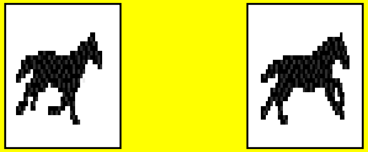
(2) The Commission has now reviewed recent epidemiological evidence suggesting that there are some tissue reaction effects, particularly those with very late manifestation, where threshold doses are or might be lower than previously considered. For the lens of the eye, the threshold in absorbed dose is now considered to be 0.5 Gy.

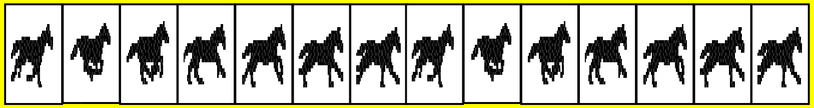
(3) For occupational exposure in planned exposure situations the Commission now recommends an equivalent dose limit for the lens of the eye of 20 mSv in a year, averaged over defined periods of 5 years, with no single year exceeding 50 mSv.

150 mSv → 20 mSv

REFERENCE LEVELS FOR FLUOROSCOPIC EXAMINATIONS

3rd level **“Patient risk”**	**Level 2 + DAP** **+ Maximum Skin Dose (MSD)**
2nd level **“Clinical protocol”**	**Level 1** **+ No. images + fluoroscopy time**
1st level **“Equipment performance”**	***Dose rate*** **and dose/image**



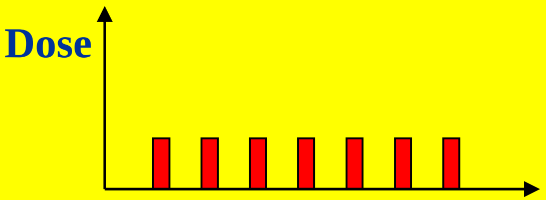


HOW WE CAN REDUCE THE PATIENT DOSES!

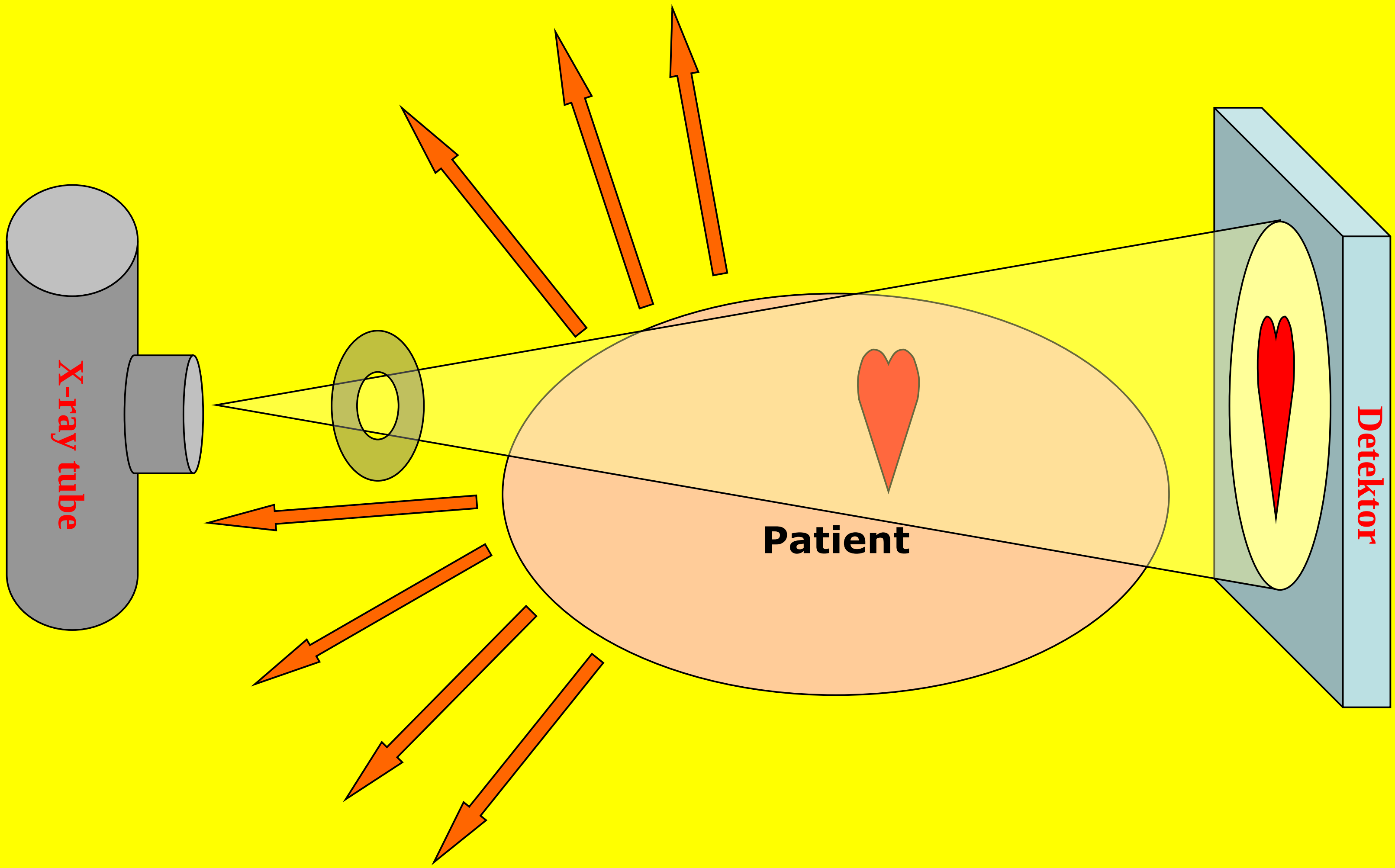
- Always collimate closely to the area of interest
- Minimize: fluoro time, & number of acquisitions
- Keep beam-on time to a minimum
- Keep tube current as low as possible and tube potential (kVp) as high as possible
- Minimize or avoid the use of high rate fluoroscopy

Normal dose rate	**25 mGy / Min**
High dose rate	**100 mGy / Min**

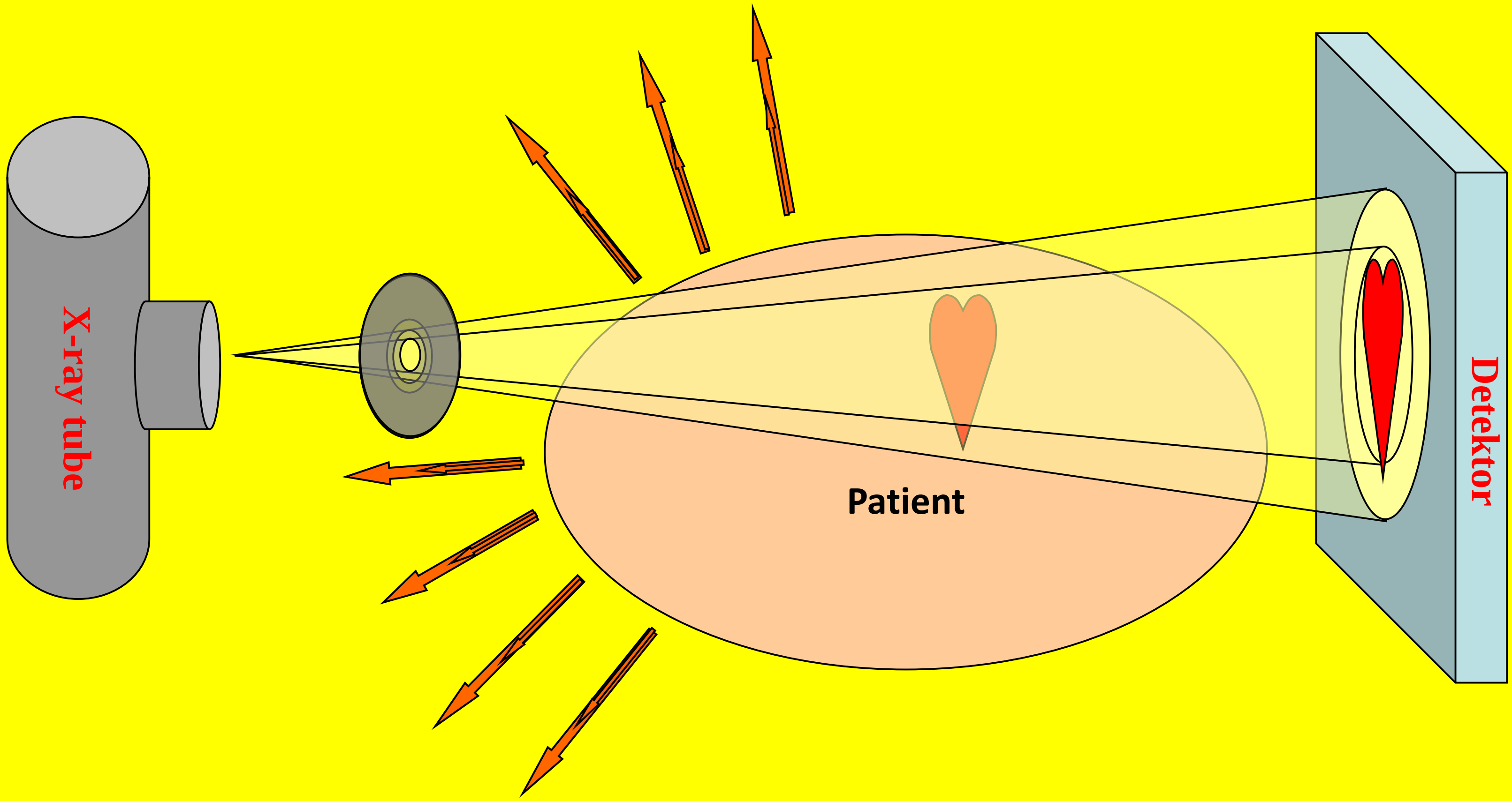
- Optimize the use of pulsed fluoroscopy



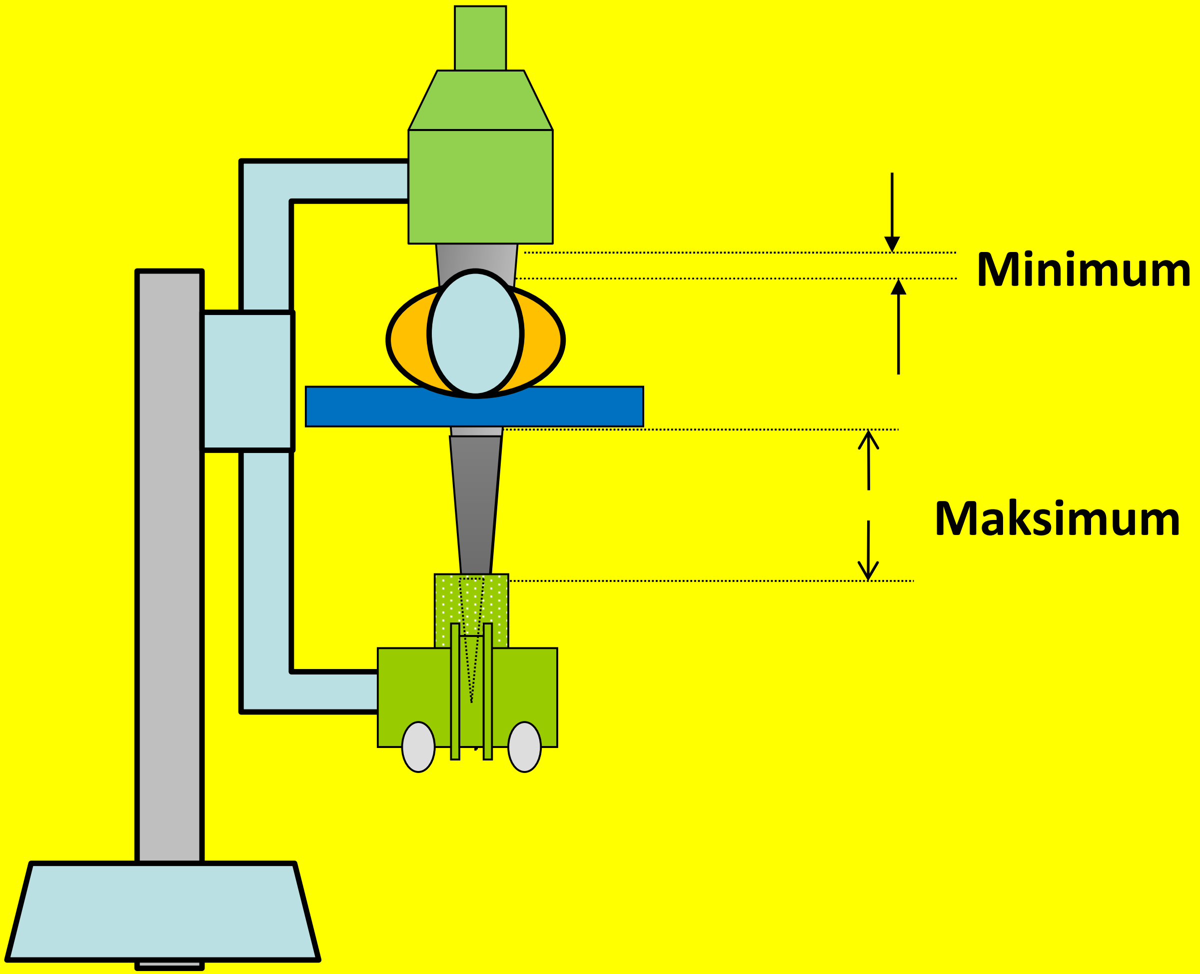
COLLIMATION



COLLIMATION

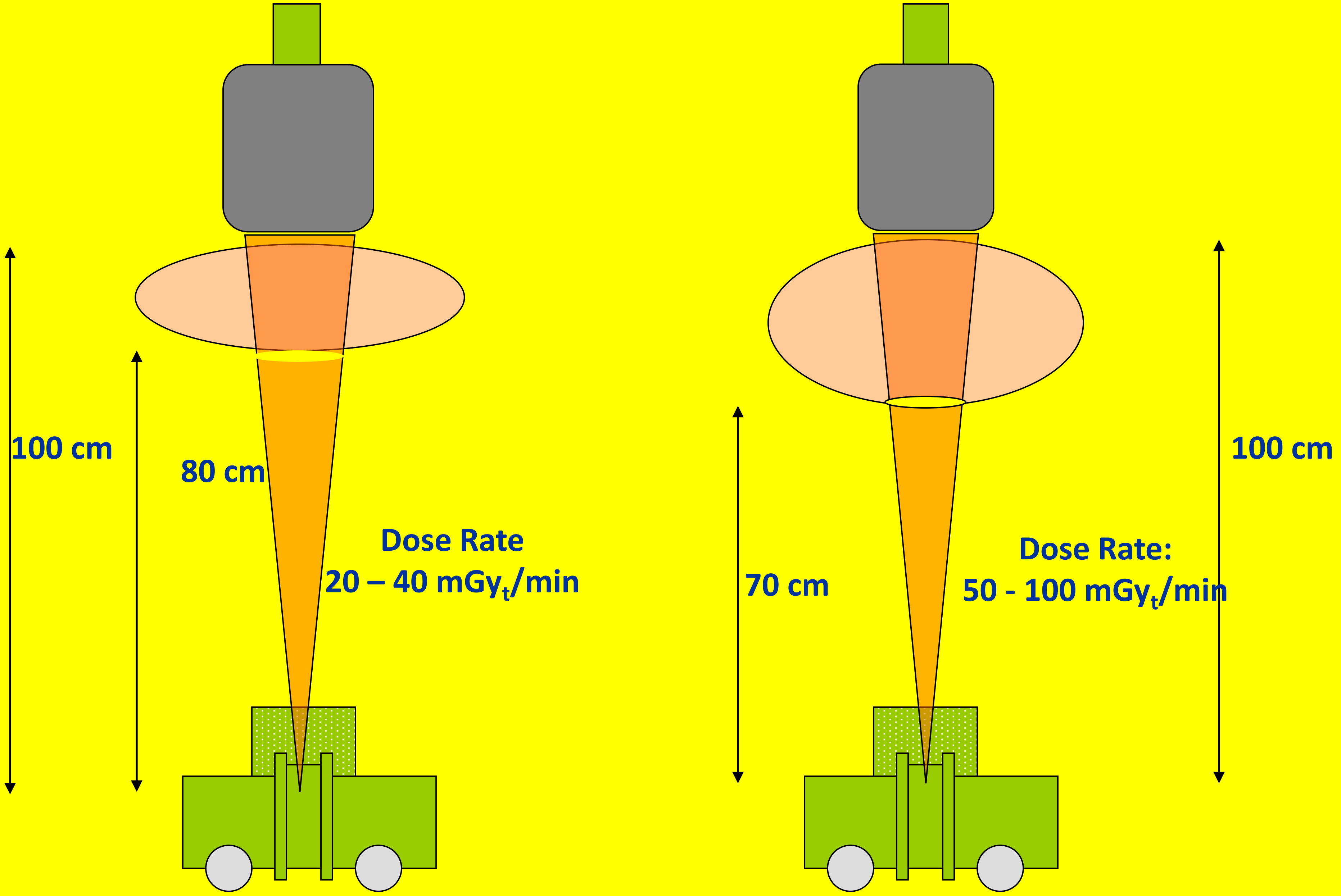


PATIENT POSITIONING

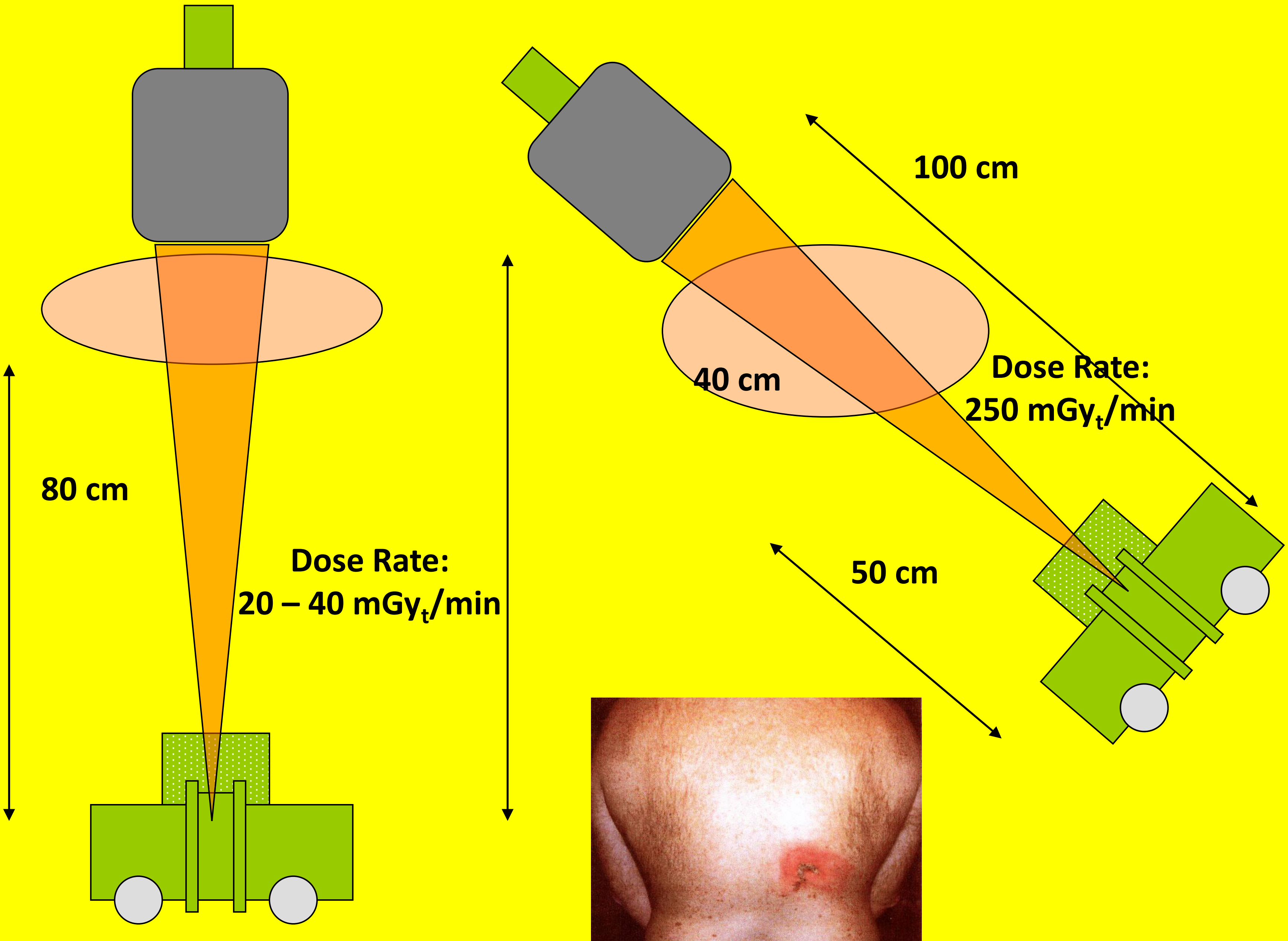


MINIMUM GEOMETRICAL MAGNIFICATION

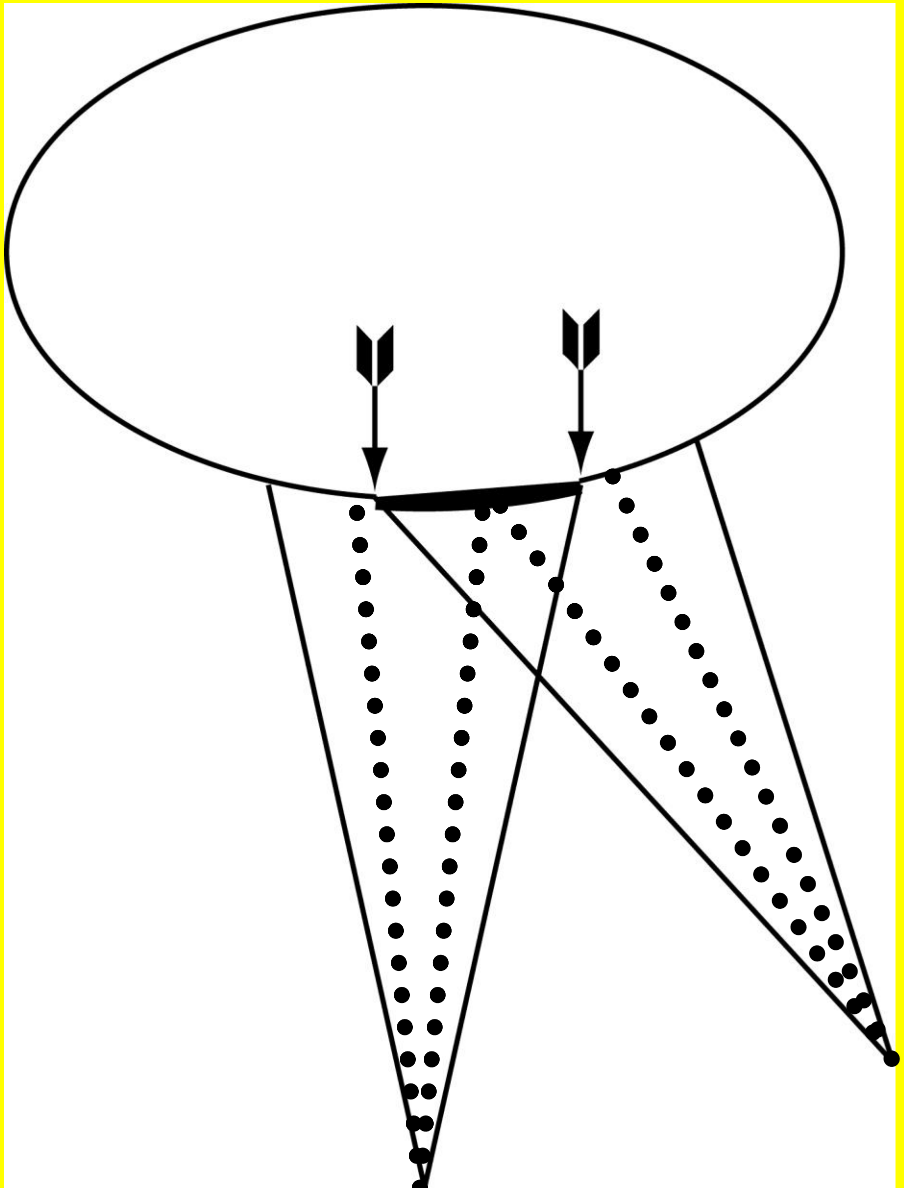
THICKNESS OF THE PATIENT

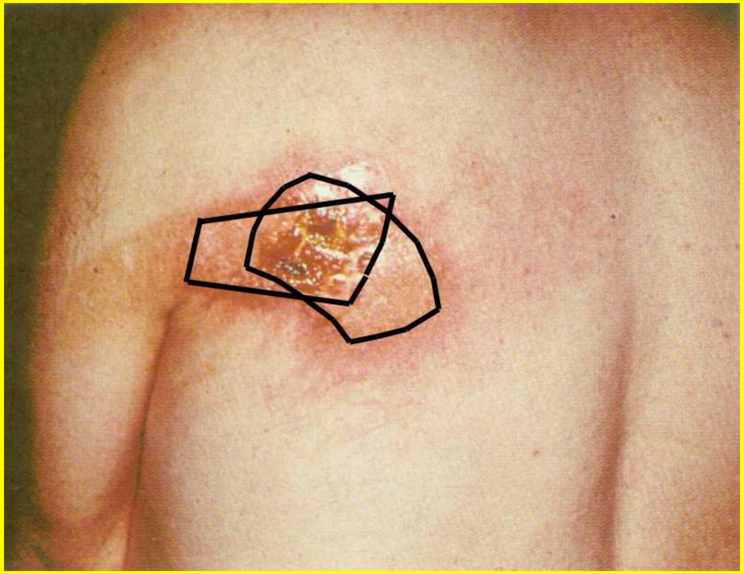


OBLIQUE PROJECTIONS



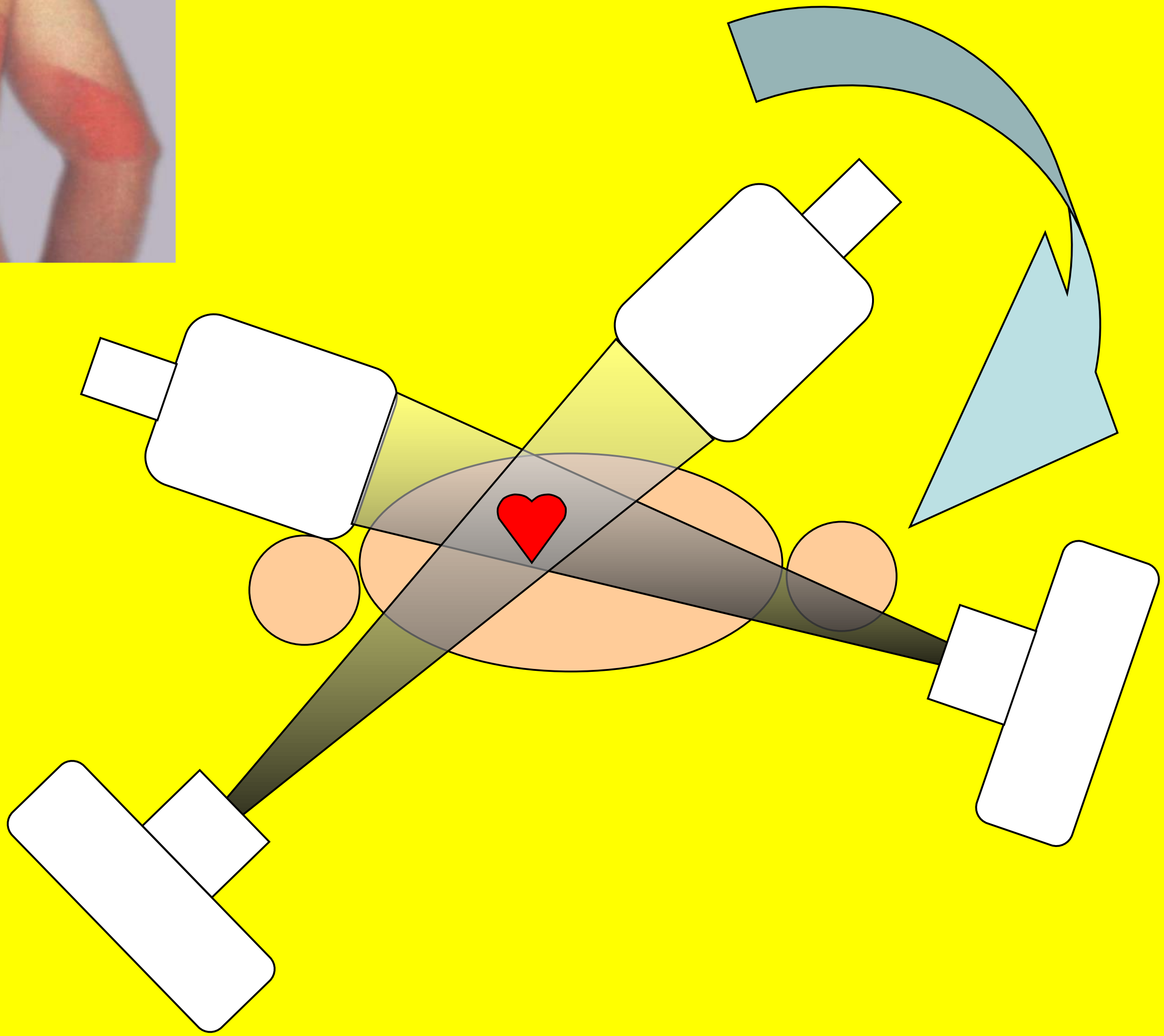
OVERLAP OF THE PROJECTIONS





Change the beam angle slightly

POSITIONING OF PATIENT ARMS



POSITIONING OF PATIENT ARMS

At 3 wks

At 6.5 mos

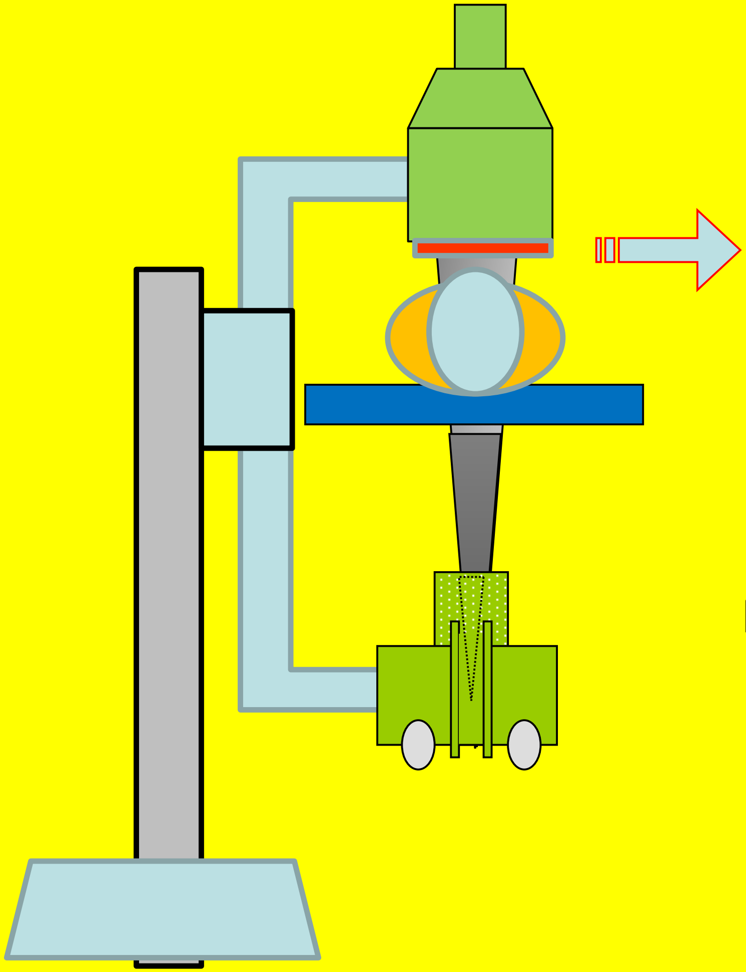
Surgical flap

Following ablation procedure with arm in beam near port and separator cone removed. About 20 minutes of fluoroscopy.

Wagner and Archer. Minimizing Risks from Fluoroscopic X Rays. Partners in Radiation Management, Houston, TX 1998

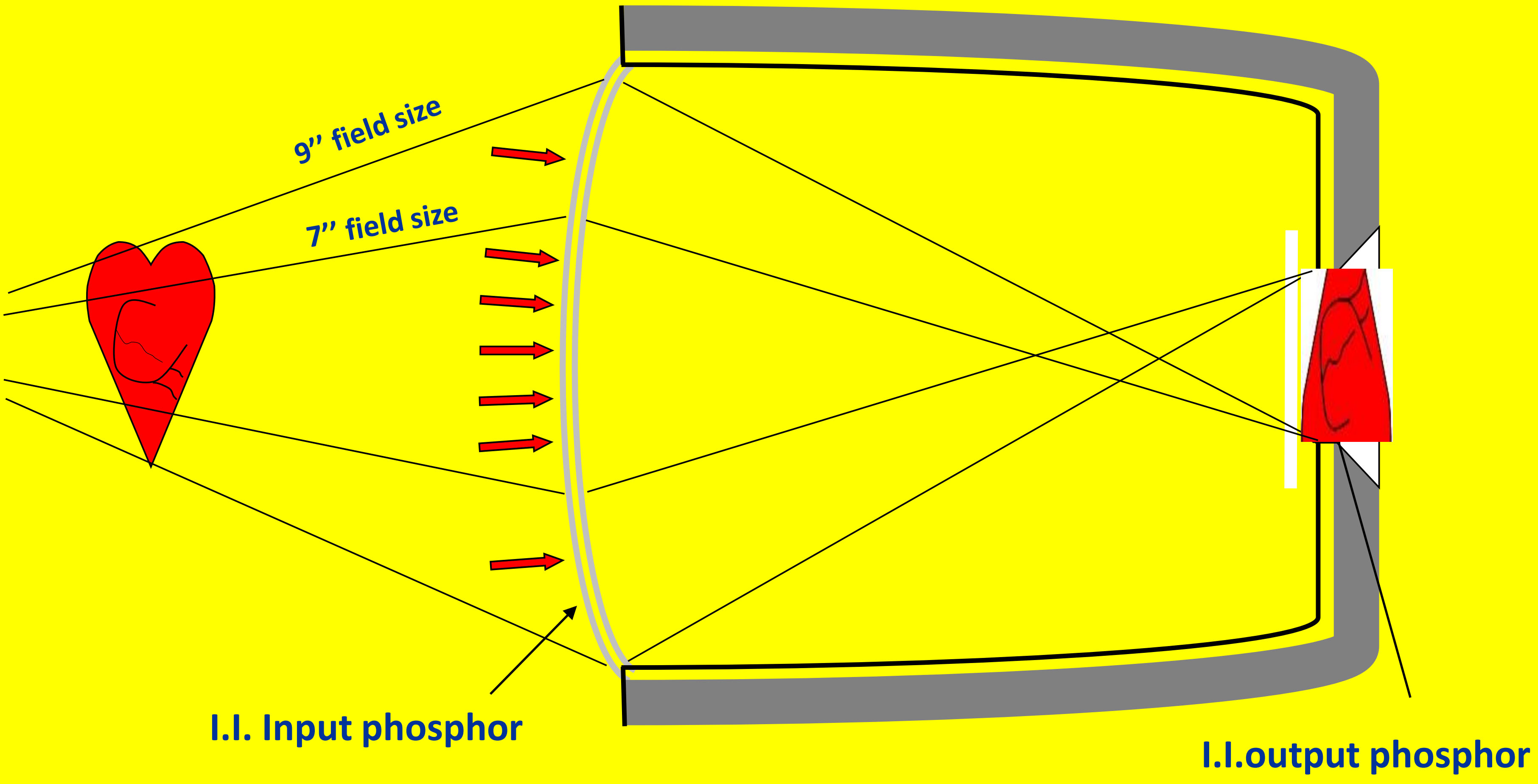
USE OF GRIDS !!

Patient dose increase up to 2-6 times !!



Remove for pediatric patients

ELEKTRONİC MAGNIFICATION



WARNINGS !!!!!

Parameter	Threshold value
Maximum skin dose	3 000 mGy
Dose for a single point	5 000 mGy
DAP Value	500 Gy-cm^2
Fluoroscopy time	60 Min.

ESTIMTION OF EFFECTIVE DOSE FROM DAP MEASUREMENT

Conversion coefficients to give effective dose from dose –area product: abdomen and pelvis(mSv $Gy^{-1}cm^{-2}$)

Applied potential (kV)	Filtration (mm Al)	kidneys		abdomen		pelvis		Urinary bladder
		AP	PA	AP	PA	AP*	PA*	AP
50	2	0.110	0.056	0.094	0.047	0.130	0.128	0.171
	2.5	0.122	0.063	0.105	0.053	0.141	0.139	0.189
	3	0.133	0.069	0.115	0.059	0.152	0.149	0.206
60	2	0.140	0.075	0.123	0.066	0.158	0.155	0.218
	2.5	0.155	0.083	0.137	0.075	0.172	0.169	0.240
	3	0.168	0.091	0.150	0.082	0.184	0.181	0.261
70	2	0.167	0.093	0.150	0.086	0.183	0.181	0.260
	2.5	0.184	0.103	0.166	0.096	0.198	0.196	0.285
	3	0.198	0.112	0.180	0.105	0.212	0.209	0.308
80	2	0.194	0.112	0.177	0.107	0.208	0.205	0.301
	2.5	0.212	0.124	0.194	0.119	0.224	0.221	0.328
	3	0.227	0.133	0.209	0.129	0.239	0.235	0.352

NRPB

ESTIMTION OF EFFECTIVE DOSE FROM ESAK MEASUREMENT

Conversion coefficients to give effective dose from entrance surface dose: abdomen and pelvis(mSv mGy^{-1})

Applied potential (kV)	Filtration (mm Al)	kidneys		abdomen		pelvis		Urinary bladder
		AP	PA	AP	PA	AP*	PA*	AP
50	2	0.041	0.021	0.068	0.035	0.099	0.100	0.038
	2.5	0.045	0.023	0.075	0.039	0.108	0.107	0.041
	3	0.048	0.025	0.081	0.043	0.113	0.113	0.045
60	2	0.050	0.028	0.087	0.049	0.117	0.117	0.047
	2.5	0.055	0.030	0.095	0.054	0.127	0.125	0.051
	3	0.059	0.033	0.102	0.059	0.134	0.132	0.054
70	2	0.059	0.034	0.102	0.062	0.134	0.133	0.055
	2.5	0.063	0.037	0.111	0.068	0.143	0.141	0.059
	3	0.067	0.039	0.119	0.074	0.150	0.148	0.063
80	2	0.067	0.040	0.148	0.076	0.149	0.147	0.062
	2.5	0.071	0.043	0.128	0.083	0.158	0.156	0.067
	3	0.076	0.046	0.136	0.089	0.165	0.163	0.071

DOSIMETRY IN MAMMOGRAPHY

DETERMINATION OF AVERAGE GLANDULAR DOSE

DOSE TO TYPICAL BREASTS SIMULATED WITH PMMA

PMMA with different thicknesses

CLINICAL BREAST DOSES

For individual patients

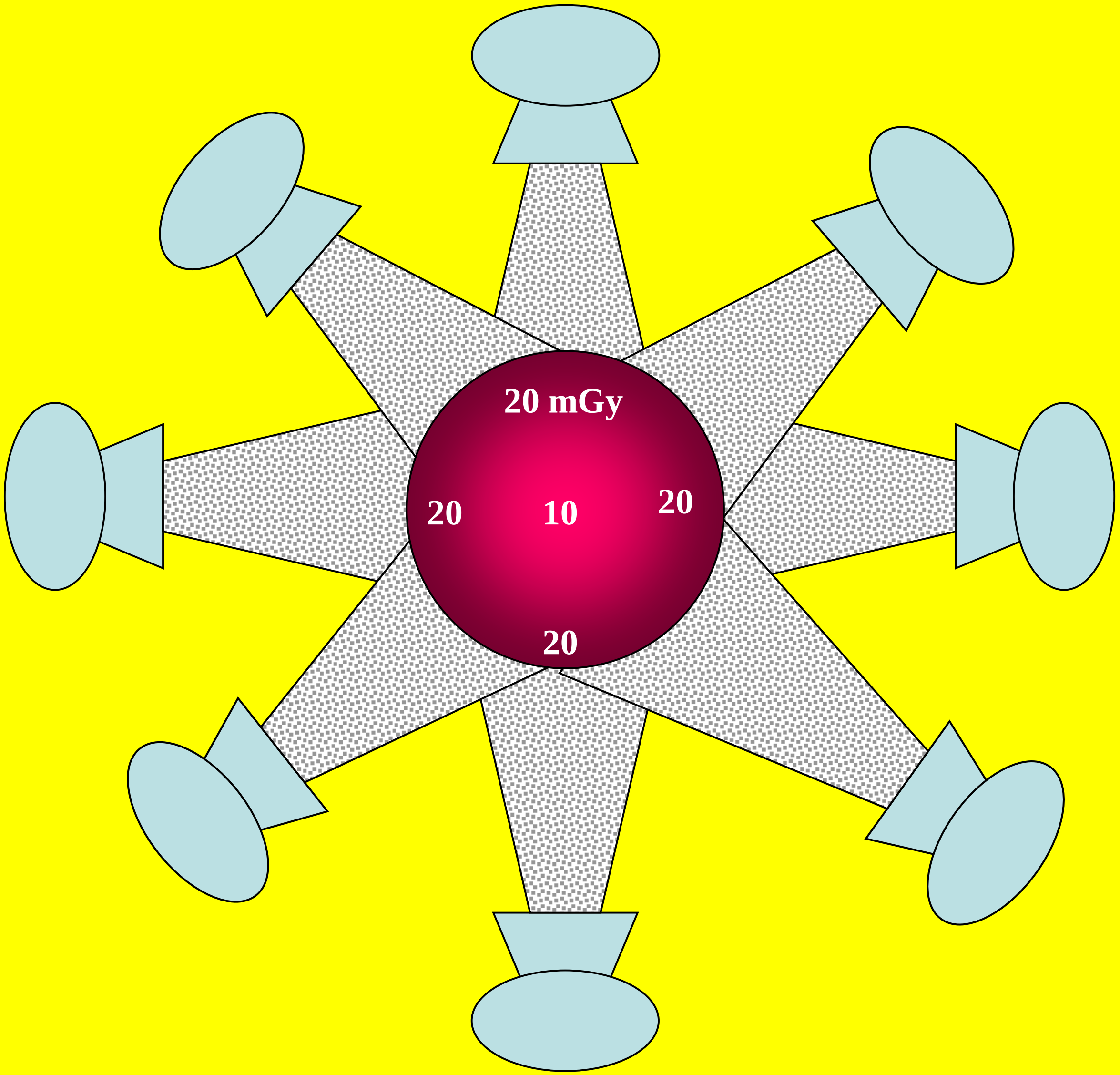
$$D = K\,g\,c\,s$$

K: Entrance air kerma (without backscatter)
g : Factor corresponding to glandularity content of 50%
c : factor corrects for the differences in composition of typical breast fro 50%
s: Factor corrects for diffrences due to the choice of X-ray spectrum

Glandular dose – PMMA thickness at 4.5 cm : < 2.0 mGy (Desirable level)

DOSIMETRY IN CT

TOMOGRAPHIC EXPOSURES



ORGAN DOSES IN CT

Increased cancer risk

	Organ Doses
Doses of Japanese survivors	**20 – 40 mSv**
CT Procedures (2-3 scan)	**30 – 90 mSv !!!**

New England J Medicine 357;22, 2007

REPORTS OF CANCER RISK !!

Approximately 40% of the population will be diagnosed as having cancer at some point in their lives

20-25% of them will probably loose their life

The additional cancer risk from radiation is around 0.5% - 3%

REPORTS OF CANCER RISK !!

Projected Cancer Risks From Computed Tomographic Scans Performed in the United States in 2007

A commonly quoted estimate for excess cancer mortality from radiation exposure is 1 death per 2000 scans (assuming an effective dose of 10 mSv per scan and a risk of 5% per sievert).[25] Based on this crude approach, 57 million scans would result in about 29 000 future cancer deaths. Our detailed calculations suggested that these scans would result in about 29 000 incident cancers and, assuming approximately 50% mortality, these incident cancer cases would translate into about 14 500 cancer deaths. The main reason that the crude estimate is much higher is that it assumes that the age-distribution of patients undergoing CT scans is the same as that of the general population, whereas it is much older on average.[1]

RADIO FOBİA!

22-23 million of 57 million people will develope cancer from other reasons

Should also be stated!

PEDIATRIC CT

Unique Considerations for Radiation Exposure in Children

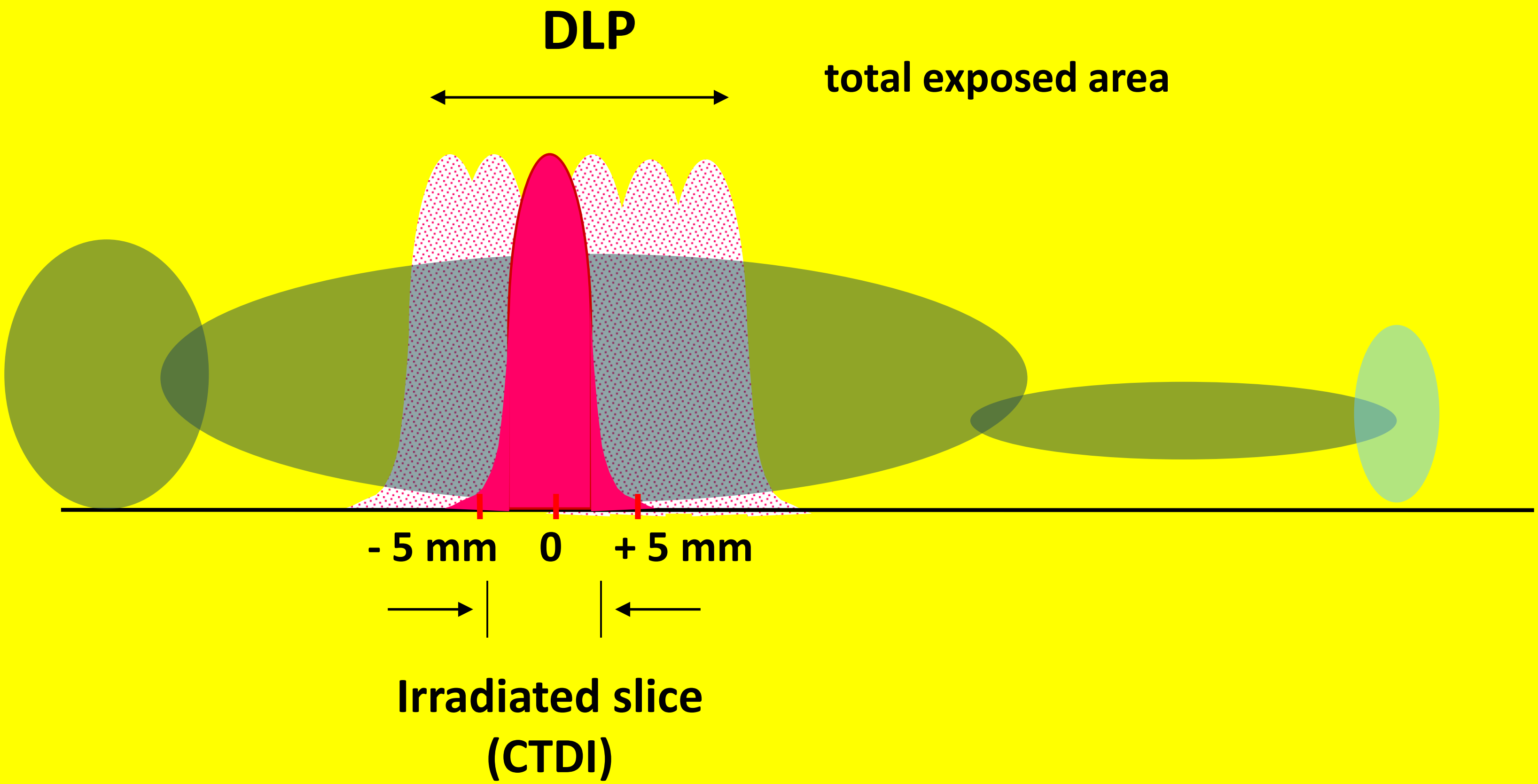
- Children are more sensitive to radiation
- Children have longer life expectancy
- Children received higher dose

mmediate Measures to Minimize CT Radiation Exposure in Children

- Perform only necessary CT exams
- Adjust exposure parameters for pediatric CT based on:
  - Consider child size
  - Minimize Region scanned
  - Select lower kV and mA
- Scan resolution.
  - Be familiar with the dose descriptors, minimize multiple scans

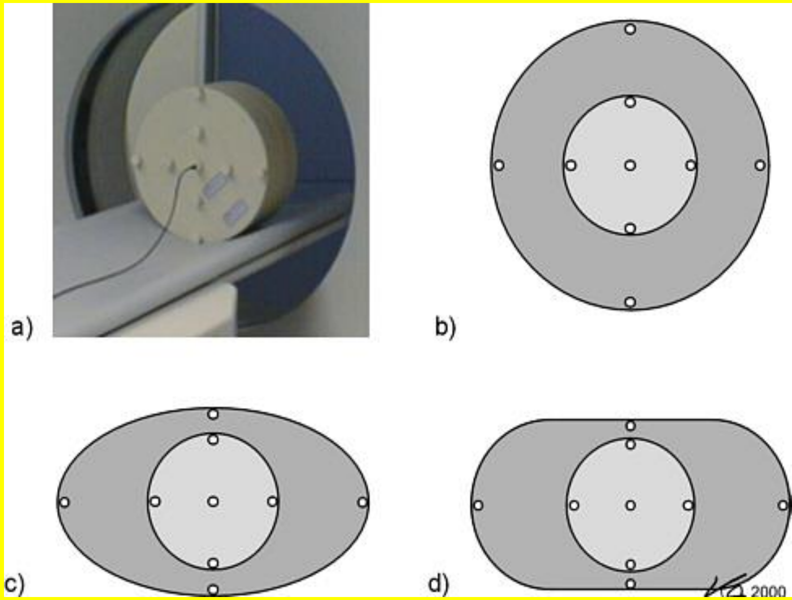
DOSIMETRIC QUANTITIES FOR CT

- COMPUTED TOMOGRAPHY DOSE INDEX (CTDI)
- DOSE LENGTH PRODUCT (DLP)
- ETKİN DOZ

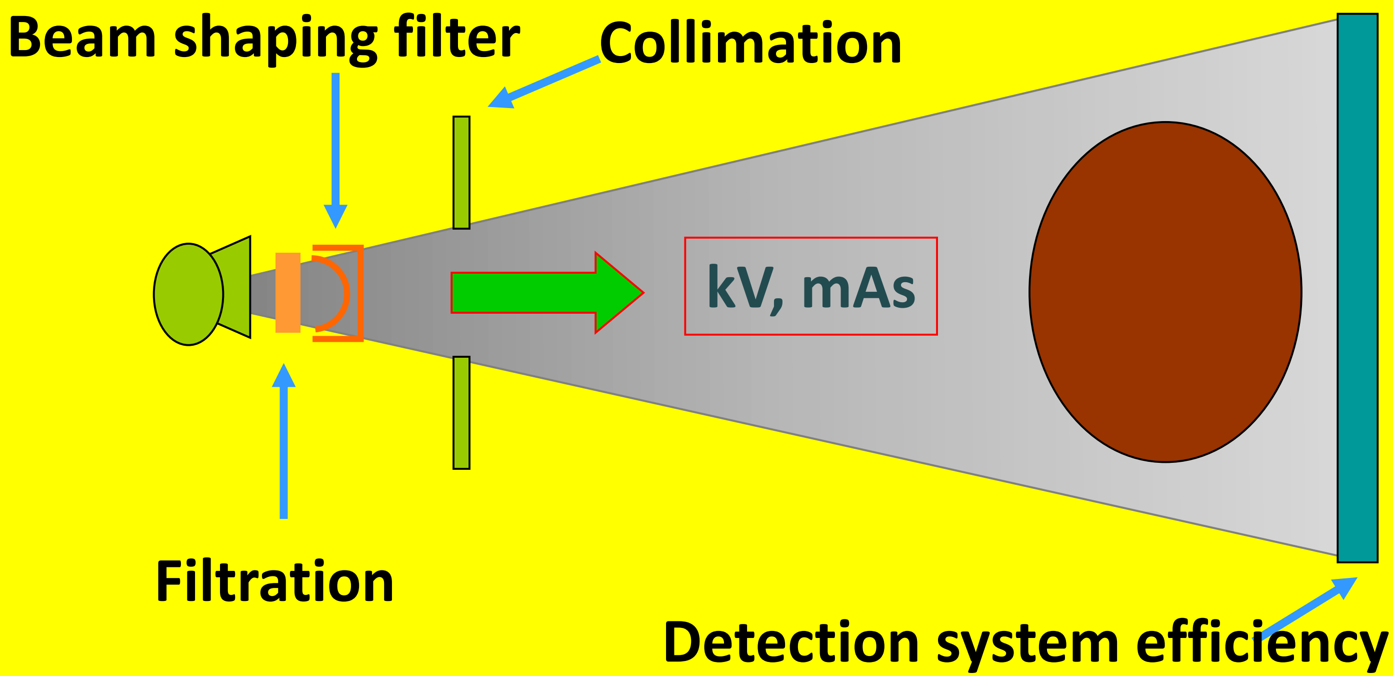


DOSIMETRIC QUANTITIES FOR CT

CTDI MEASUREMENT



PARAMETERS THAT AFFECT CT DOSE

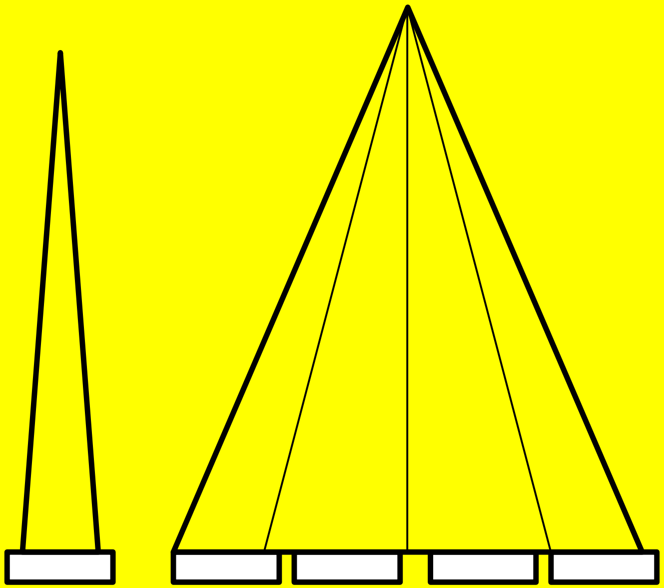


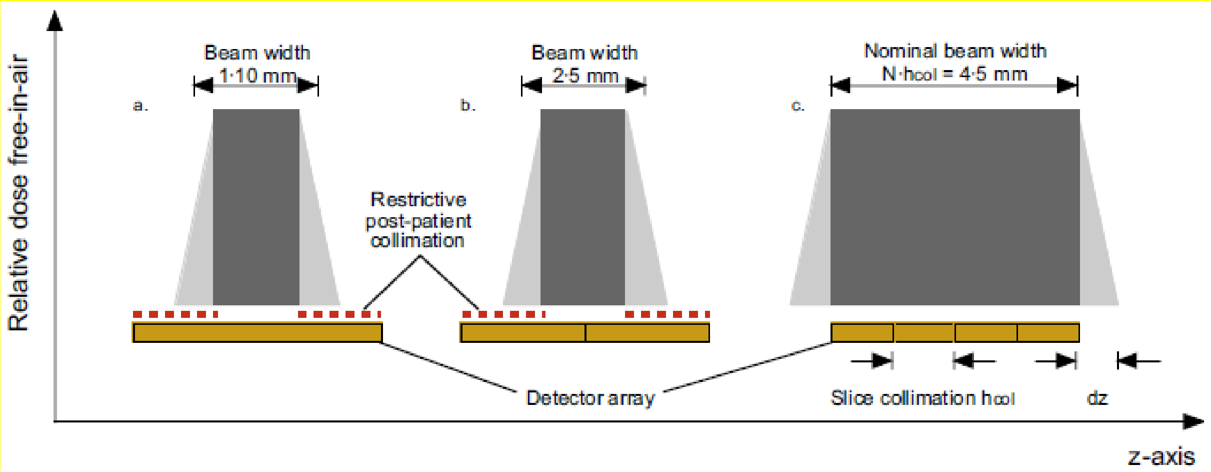
Scanning length, scanner geometry, beam collimation, rsw, pitch, algorithms, dose reduction tools

PARAMETERS THAT AFFECT CT DOSE

System related parameters:

- Filtration of the X-ray beam
- Geometric efficiency
- Beam shaper filter (Bow- tie filter)
- Beam colimation (Overbeaming)
  - Primary collimation
  - Colimation in front of the detector





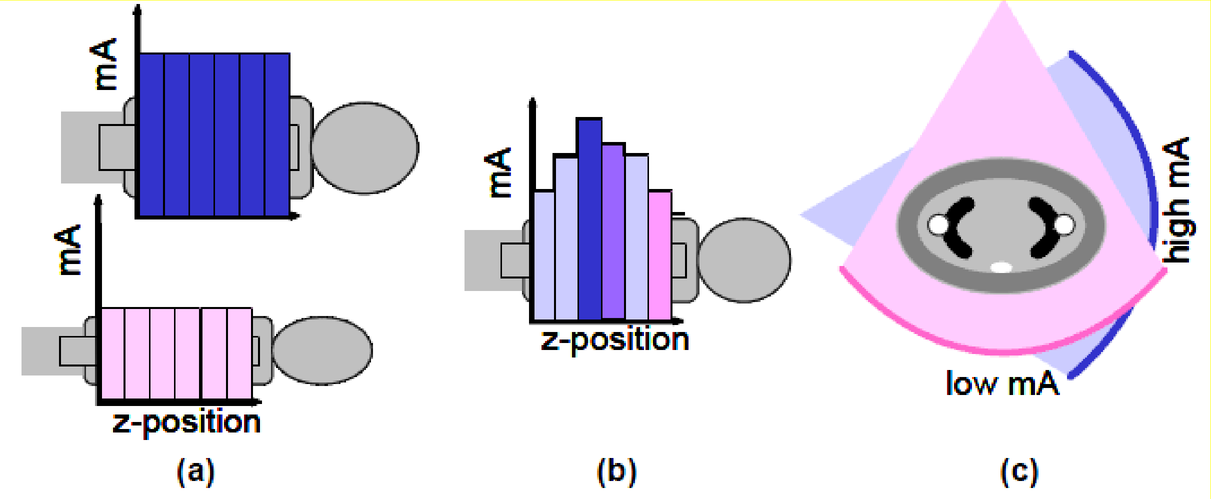
PARAMETERS THAT AFFECT CT DOSE

System related parameters:

- Spiral Interpolation

  Adaptif filtration

- Additional rotations ((Overranging)
- Exposure Indicator
- Automatic dose control



PARAMETERS THAT AFFECT CT DOSE

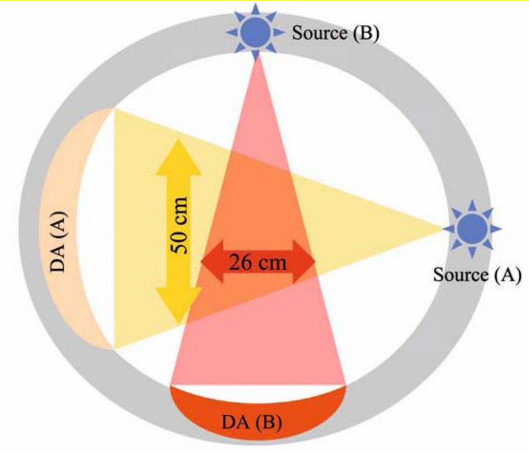
Scan and Processing Parameters

- mAs and kVp
- Slice colimation and slice width
- Pitch factor
-
- Number of scans
- Number of rotations in dynamic examination
- Reconstruction algorithms and filters

PARAMETERS THAT AFFECT CT DOSE

For Double Source CT Scanners

•Bow filter for cardiac examinations
•3-D Adaptice noise filtration
•Trigering of mAS with ECG
•Heart rate dependent pitch factors
•Autamatic setting of mA for the projections of radiation sensitive organs
•Selection of optimum X-ray spectrum

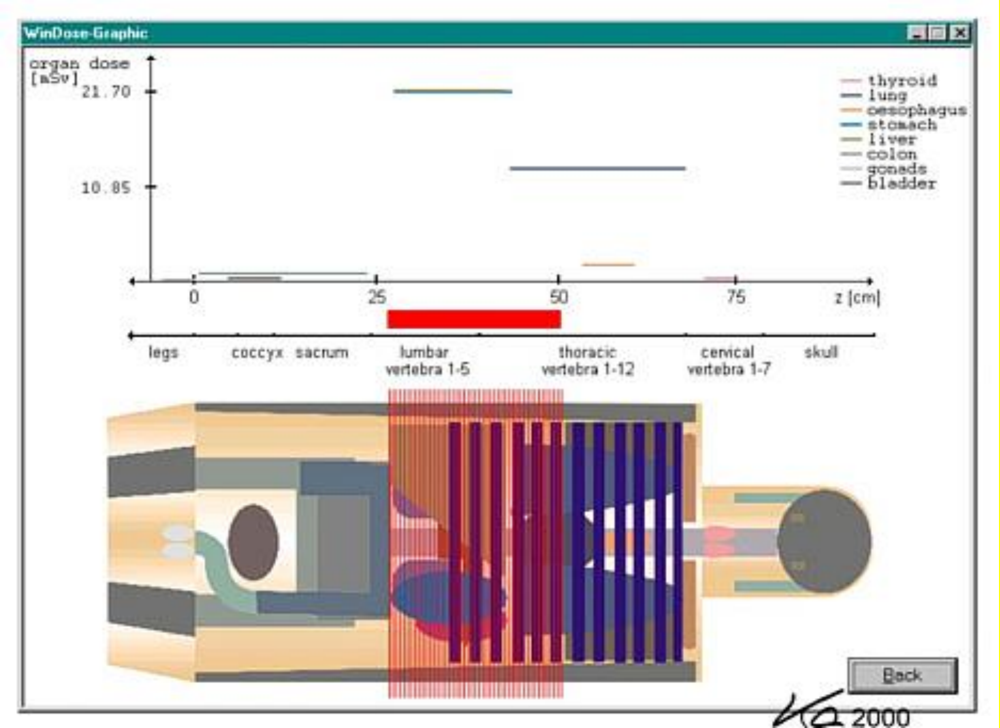


EFFECTIVE DOSES

Effective Dose = DLP x CF (mSv)

Conversion Factors (CF)

Head	0.0023 mSv mGy^{-1} cm^{-1}
Chest	0.017 mSv mGy^{-1} cm^{-1}
Abdomen	0.015 mSv mGy^{-1} cm^{-1}

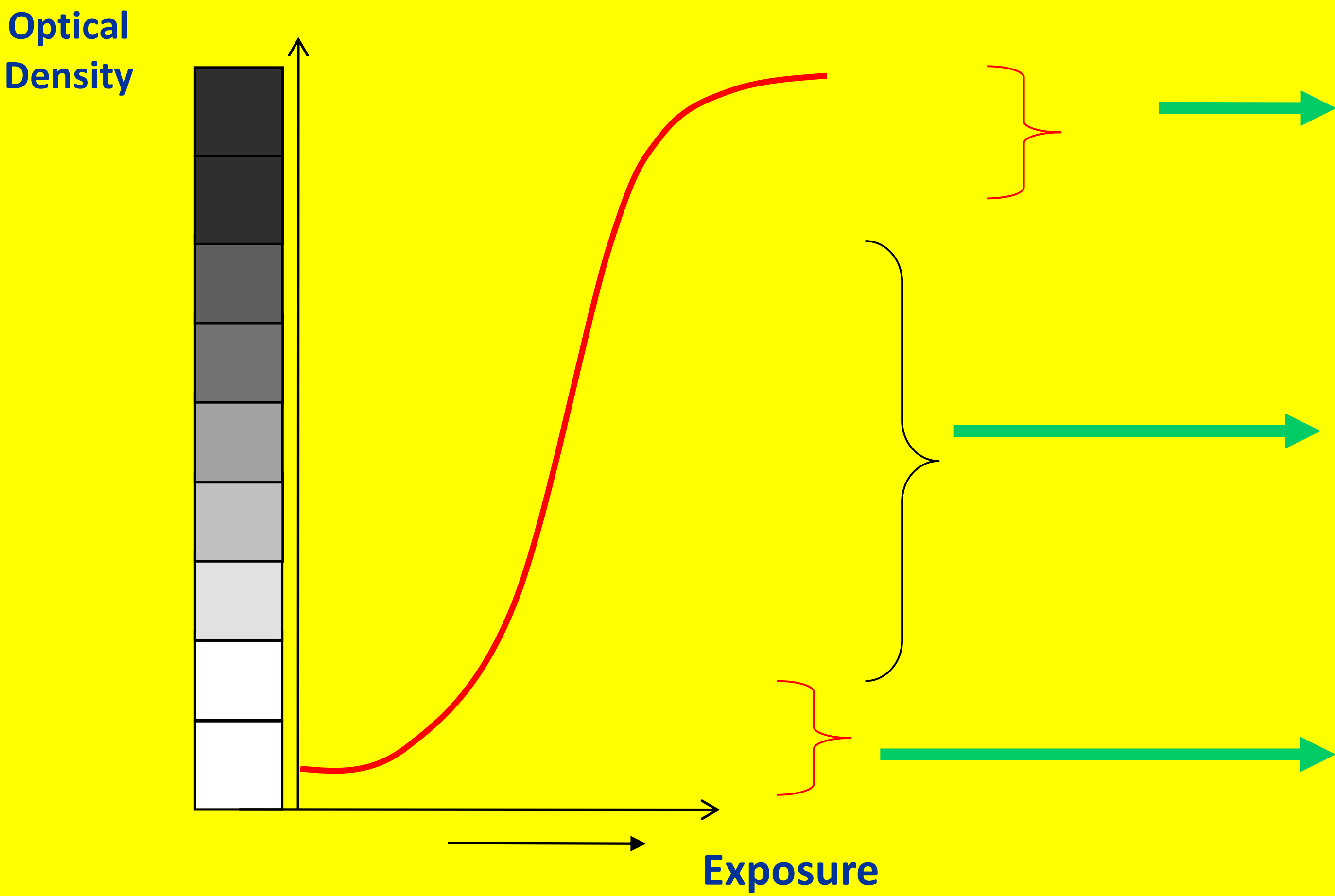


REFERENCE LEVELS

	Reference Levels $CTDI_{VOL}$(mGy)	Pass/Fail Criteria $CTDI_{VOL}$(mGy
Adult Head	75	80
Adult Abdomen	25	30
Pediatric Abdomen (5 year old)	20	25

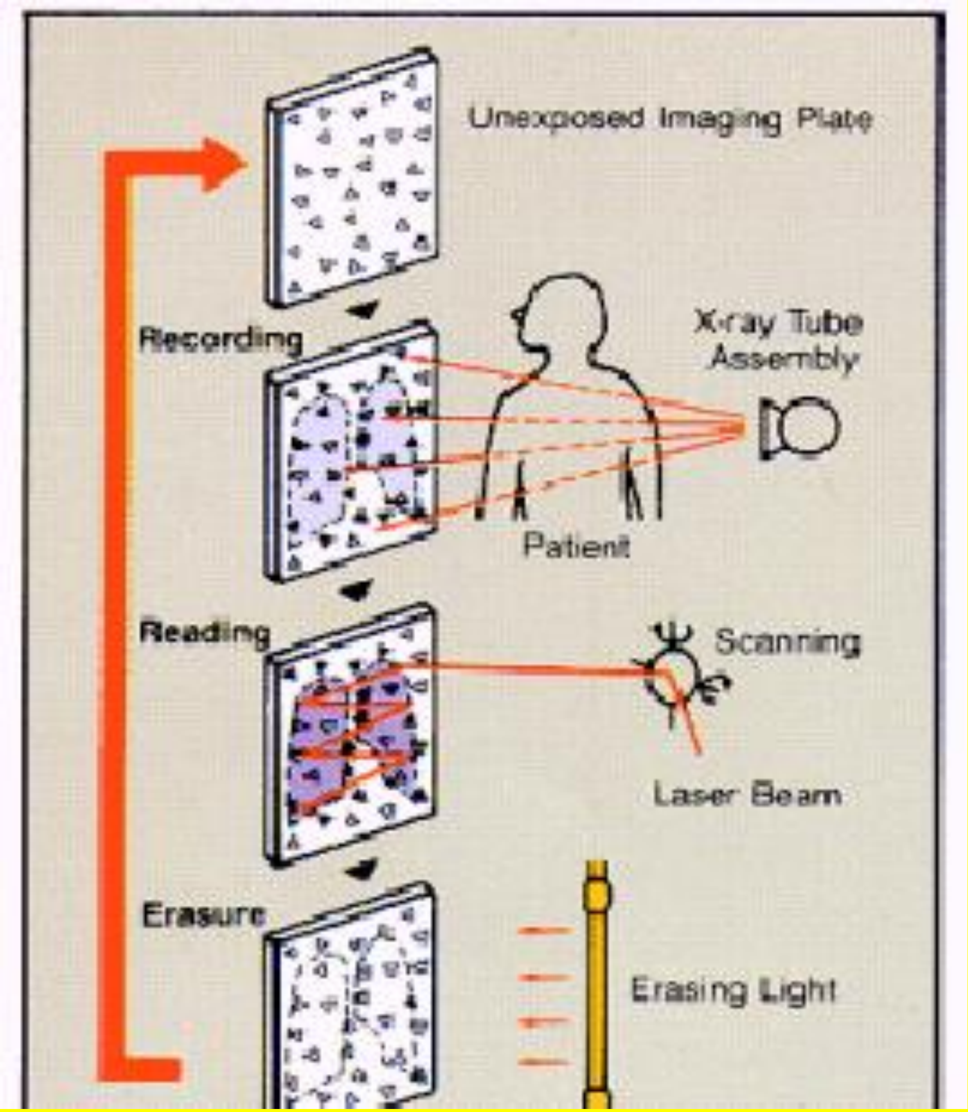
DOSIMETRY IN DR and CR SYSTEMS

FILM RESPONSE TO EXPOSURE

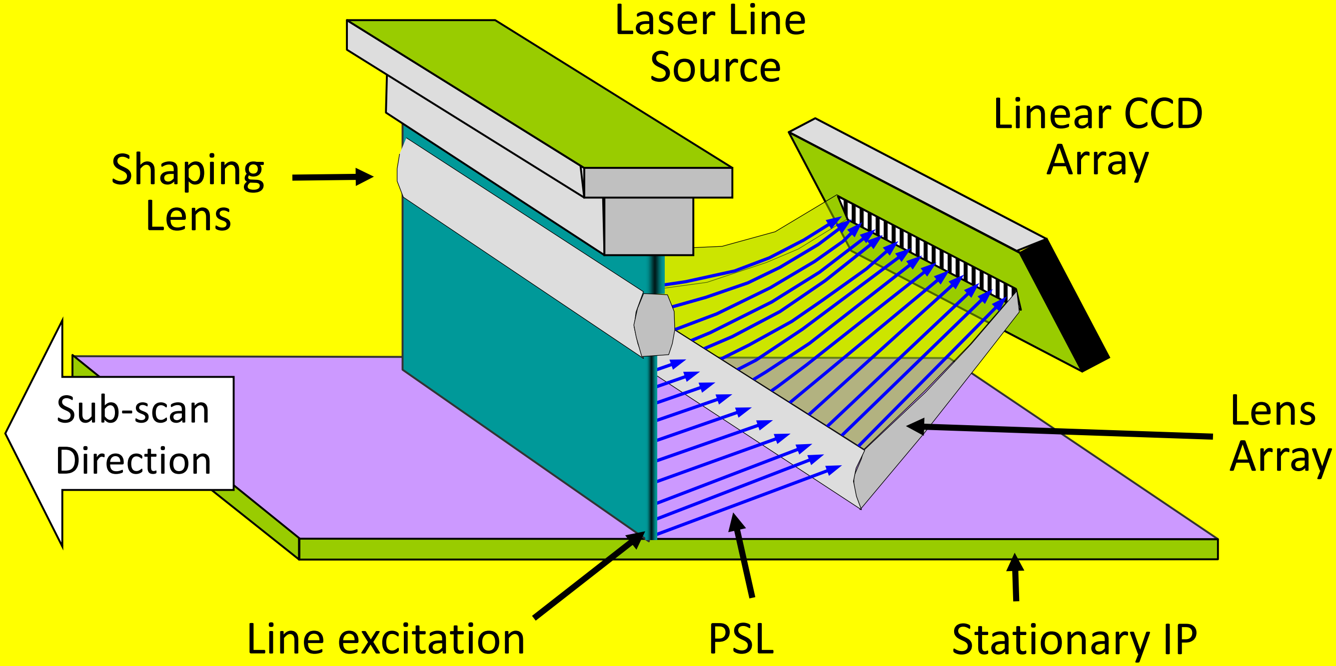


Retakes !!!!

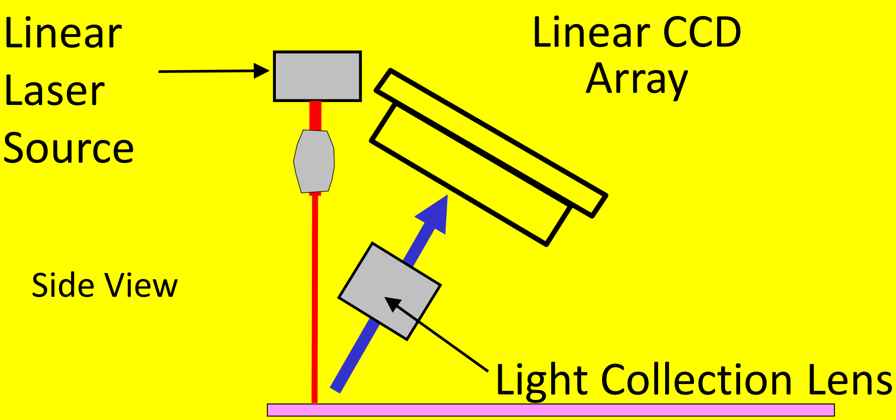
COMPUTED RADIOGRAPHY- CR SYSTEMS

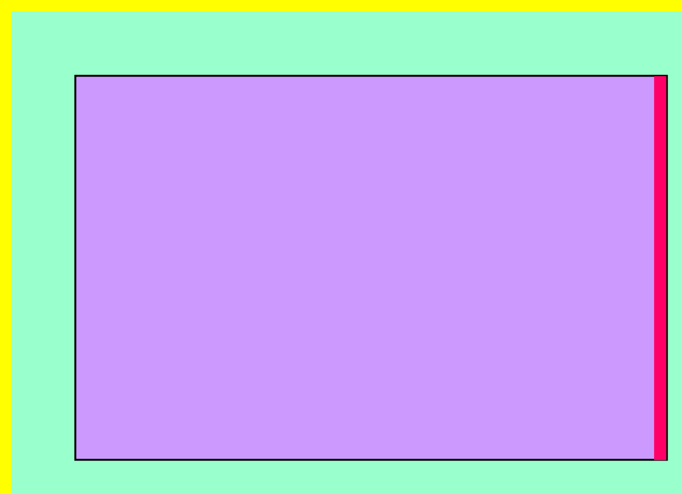


COMPUTED RADIOGRAPHY- CR SYSTEMS



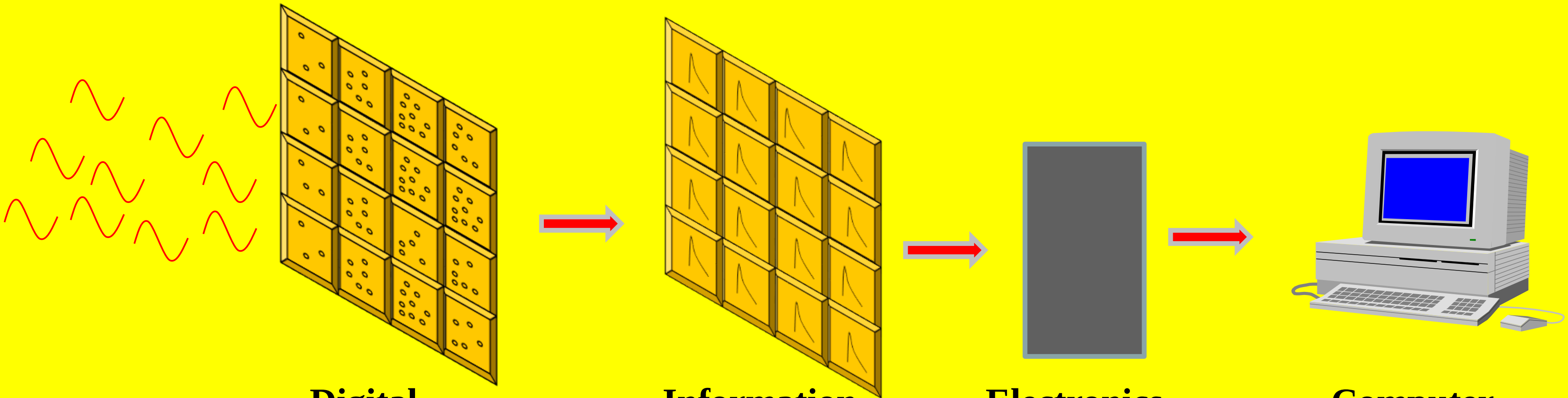
5 sec scan





DIGITAL DETECTORS –DR SYSTEMS

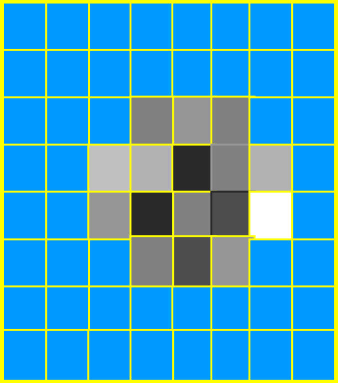
X-Rays ⇨ e^-



Digital detector | **Information in the detector** | **Electronics** | **Computer**

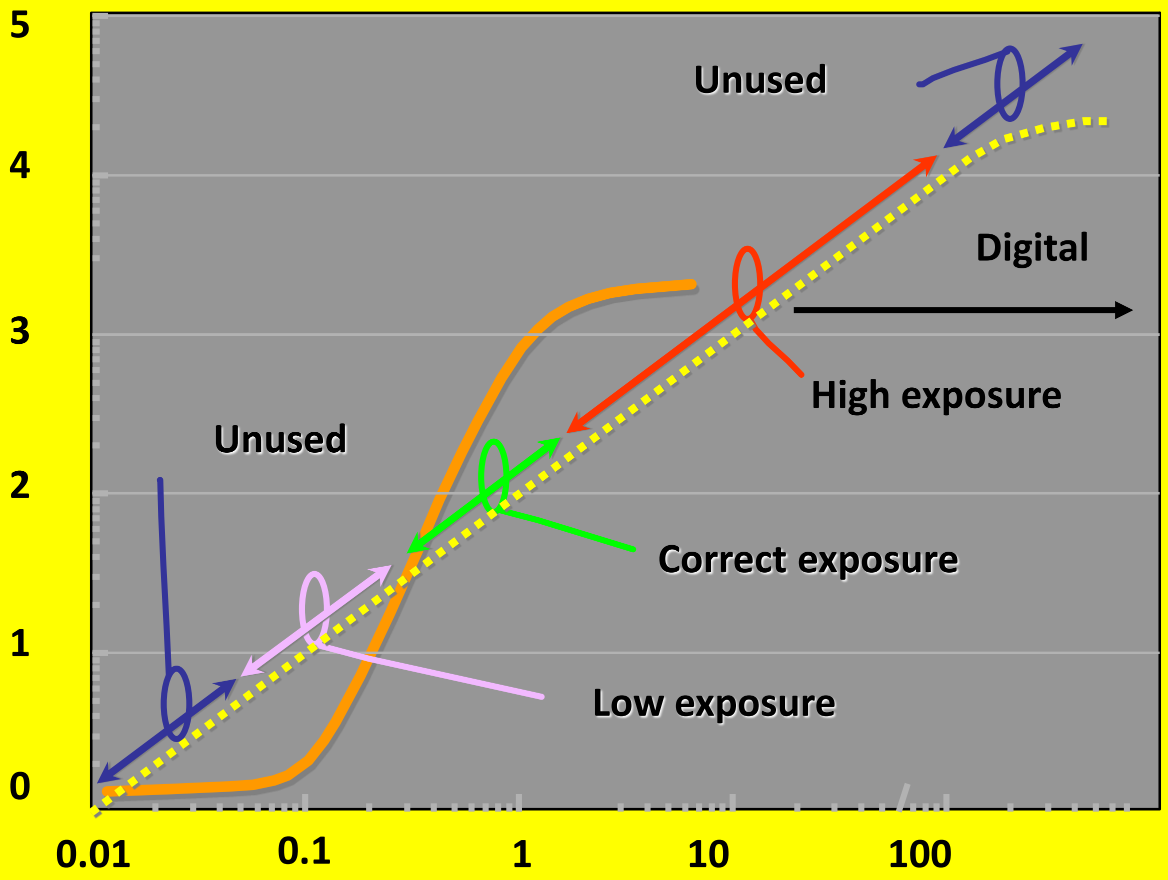
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0
1	0	2	3	4	2	1	0
0	0	2	3	2	1	0	0
0	2	1	3	4	5	1	0
0	0	2	3	0	4	1	0
0	0	1	1	2	1	0	0
0	0	0	0	0	0	0	0

Image in the memory



Digital image

RESPONSE OF DIGITAL DETECTORS TO EXPOSURE



- Wide exposure latitude !!!!!!!

OPTIMIZATION OF RADIATION

CR Dedectors

Exposure Index

Fuji, Philips, Konika : S Number

$S = 200 / (\text{Exposure mR})$

Kodak : Exposure Index EI

$EI = 1000 \times \text{Log}(\text{Exposure mR}) + 2000$

Agfa : lgM Database (100 (from the mean of 100 clinical exposures)

↓ ↓ ↓

Calibration of the automatic exposure control
(200 - 400 Film / Screen speed)

OPTIMIZATION OF RADIATION

DR Dedectors

Exposure Index

↓

?????

Calibration of the automatic exposure control (200 - 400 Film / Screen speed)

THANK YOU FOR YOUR ATTENTION

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