

Monitoring of Radiation Doses to Patients and Staff

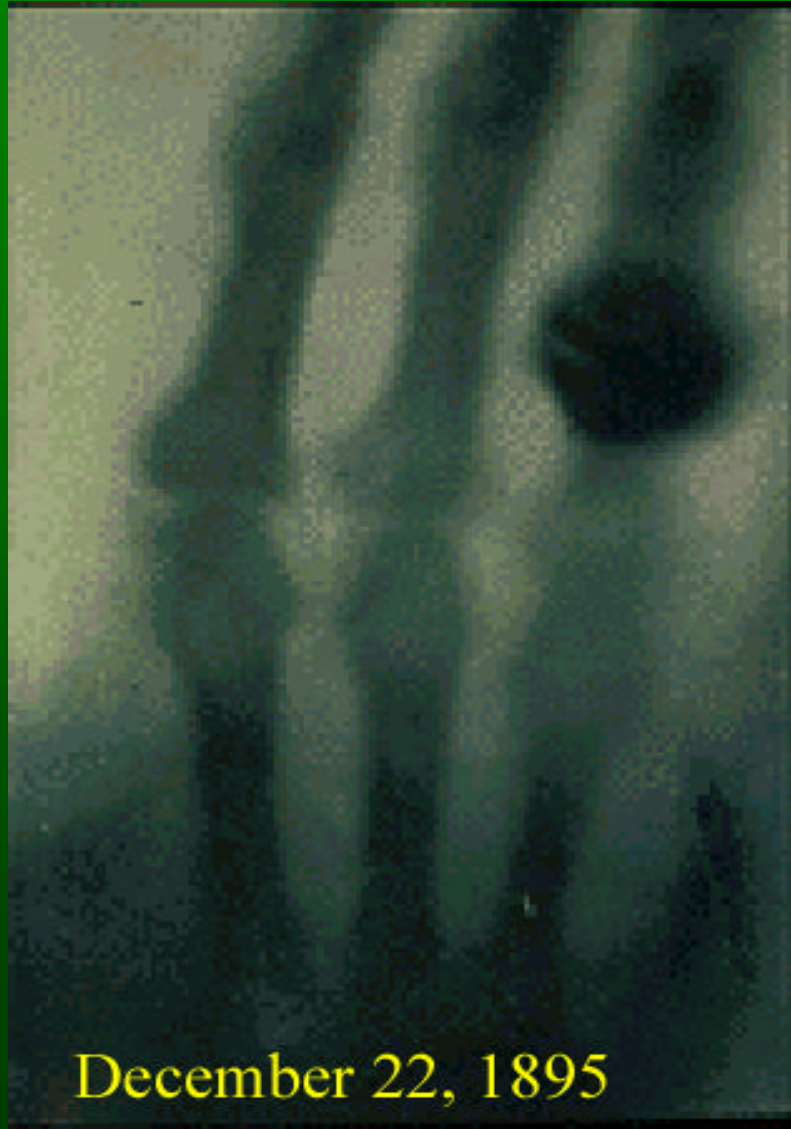


Ng Kwan-Hoong, PhD, ABMP
Department of Radiology
University of Malaya Medical Centre

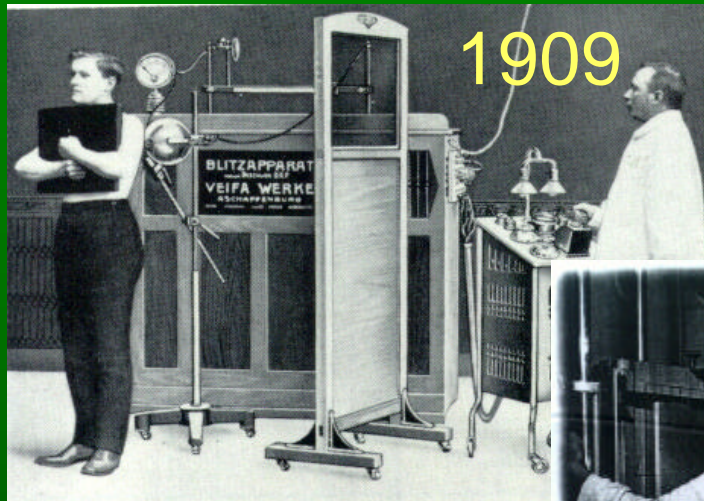
*Tremendous Advances in
Imaging in the last century*

Medicine is becoming *image-centric* and
radiation dose is becoming an issue

Radiography



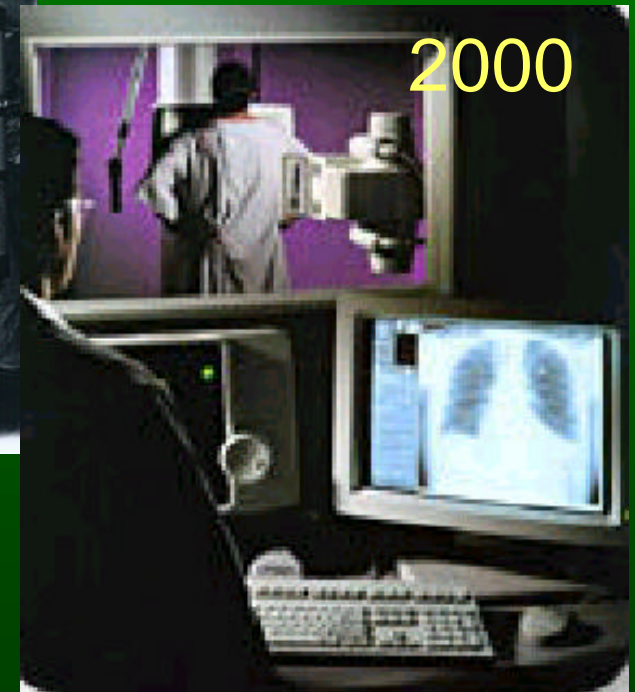
Chest Imaging Technology



‘The Trail of the Invisible Light’
Grigg 1965

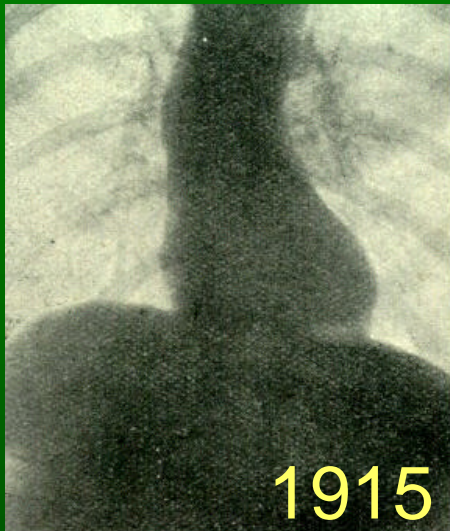


‘The Early Years 1947-1972’
Dr. Mahathir Mohamad

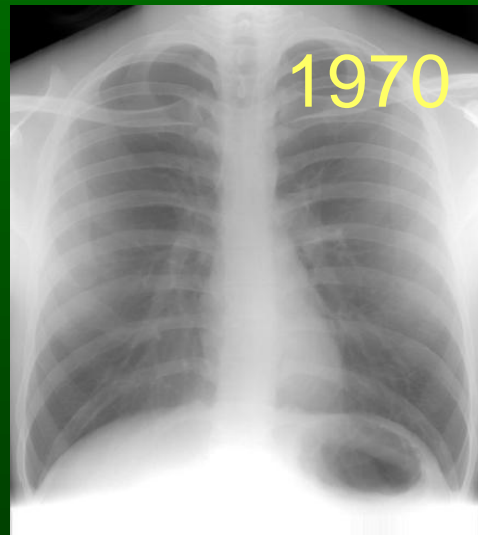


GE XQ/i DR System

Chest Imaging Technology



'X-Rays'
GWC Kaye 1923



Conventional
Screen/film

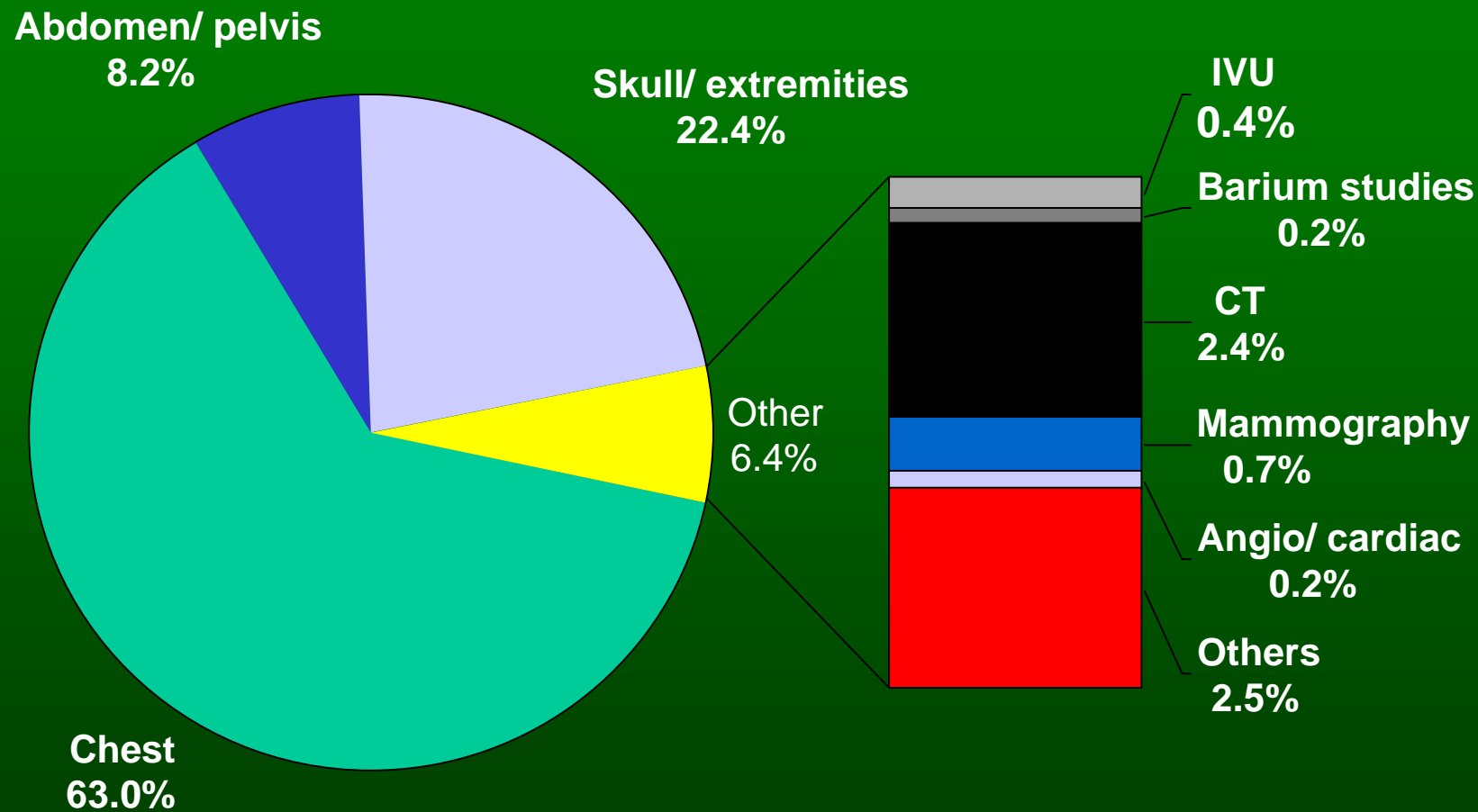


2000



Dual Energy Subtraction

Frequency of the types of x-ray examinations in Malaysia, 1994



Why measure Dose?

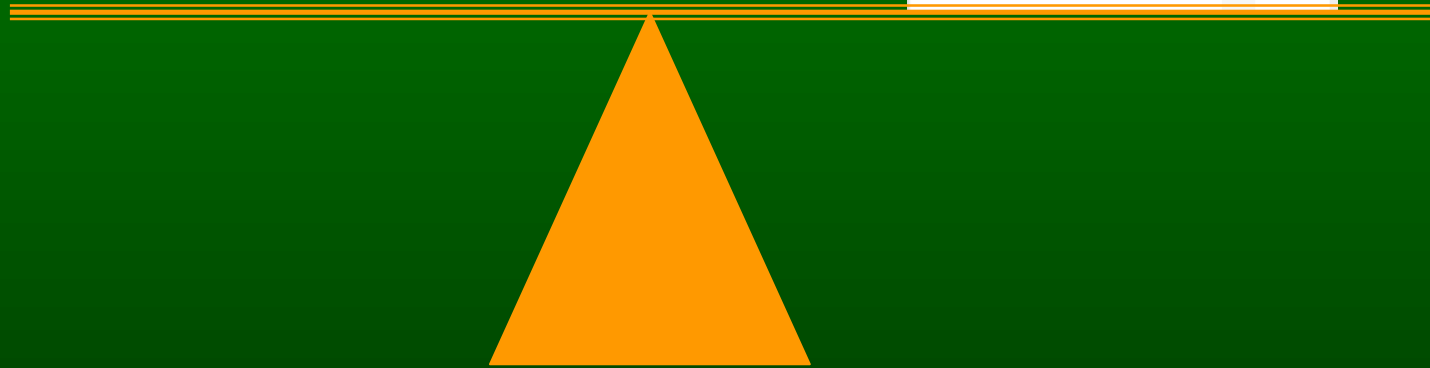
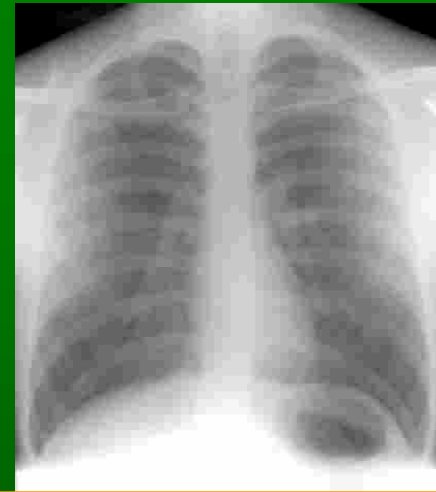
- Optimization - obtaining radiological images with lowest amount of radiation requisite
- Assessment of radiation detriment as a factor of patient-outcome efficacy
- Development of 'reference levels'
- An indicator of radiology QA
- Clinical audit
- Medico-legal

Is Dose the Only Concern?

NO!!!

High doses usually mean poor image quality!

Low doses sometimes mean poor image quality!



Balancing Radiation Dose and Image Quality

ABSORBED DOSE (Gy)

Energy imparted by radiation to unit mass of tissue



Radiation weighting factor

EQUIVALENT DOSE (Sv)

Absorbed dose weighted for harmfulness of different sources of radiation



Tissue weighting factor

EFFECTIVE DOSE (Sv)

Equivalent dose weighted for susceptibility to harm of different tissues



COLLECTIVE EFFECTIVE DOSE (man-Sv)

Effective dose to a group from a source of radiation

SOURCE QUANTITIES

Tube current
Exposure time
Applied potential
Filtration

FIELD QUANTITIES

Photon fluence
Energy fluence
Exposure
Absorbed dose in air
Air Kerma

Dose-area product

PATIENT DOSE QUANTITIES

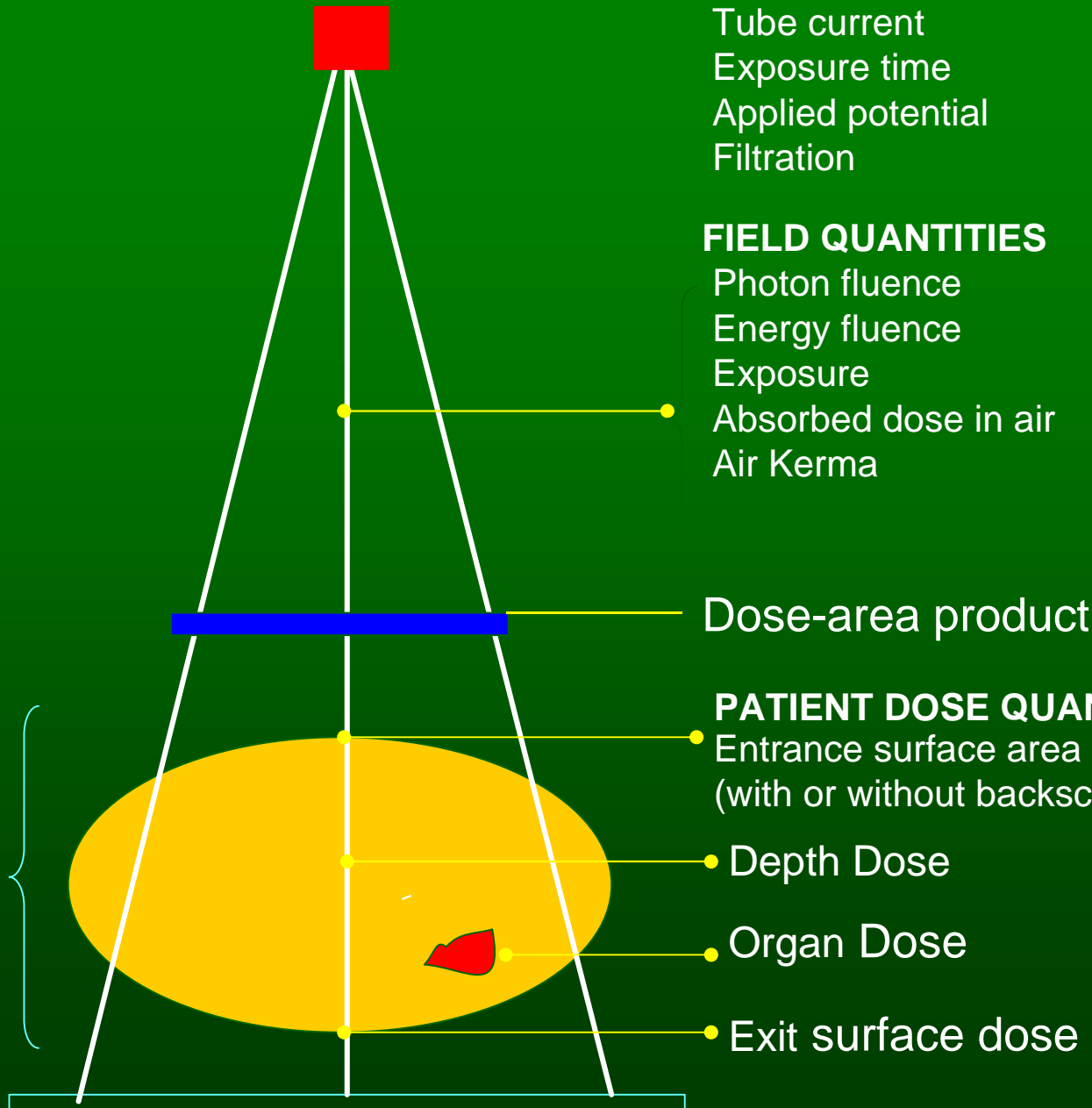
Entrance surface area
(with or without backscatter)

Depth Dose

Organ Dose

Exit surface dose

Energy imparted



Patient Dosimetry Technique

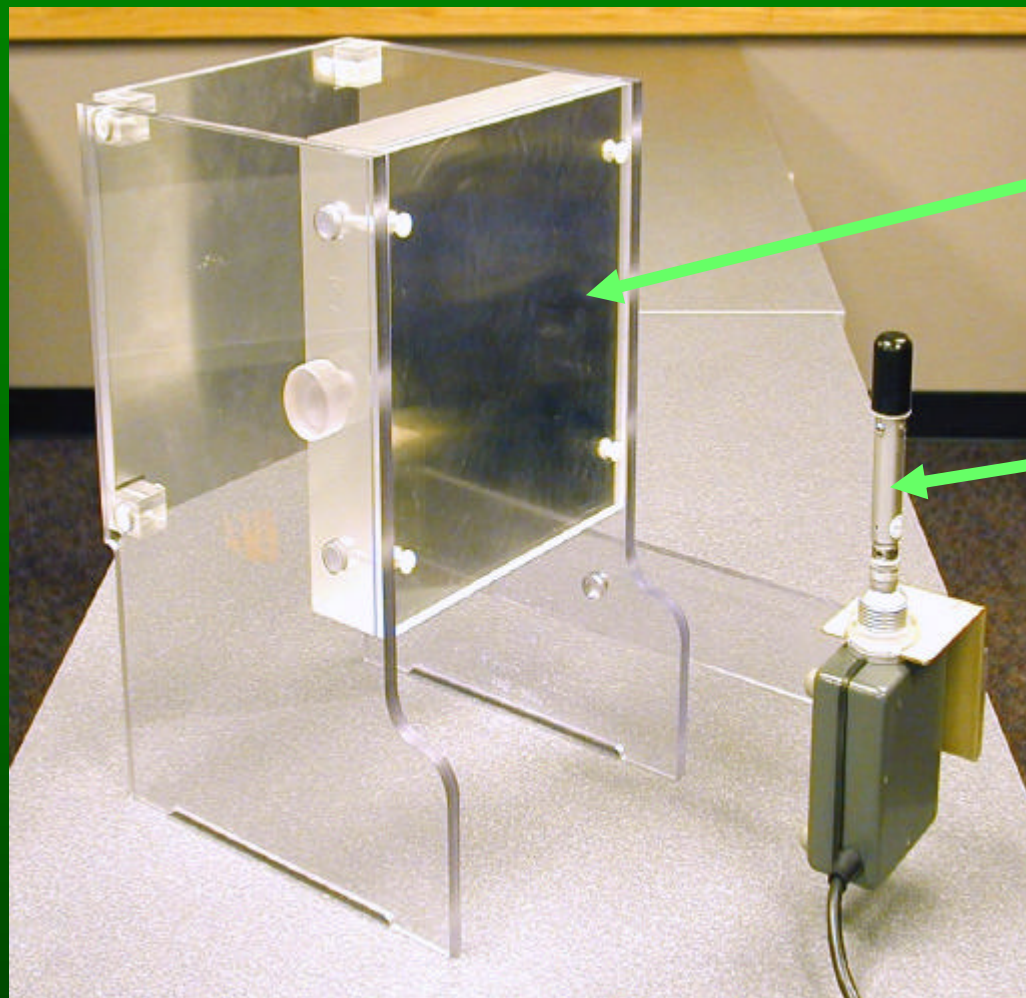
- Indirect Measurement
- Direct Measurement

Indirect Measurement

- Semi-empirical method - calculation based on output (Gy/mAs at 100 cm FFD), exposure factors, radiographic technique.
- Computer modelling



Measuring Entrance Skin Dose
using thermoluminescent dosimeter (TLD)



**Chest equivalent
phantom**

**Ionisation
Chamber**

**FDA Lucal CXR Phantom
– used in NEXT survey**

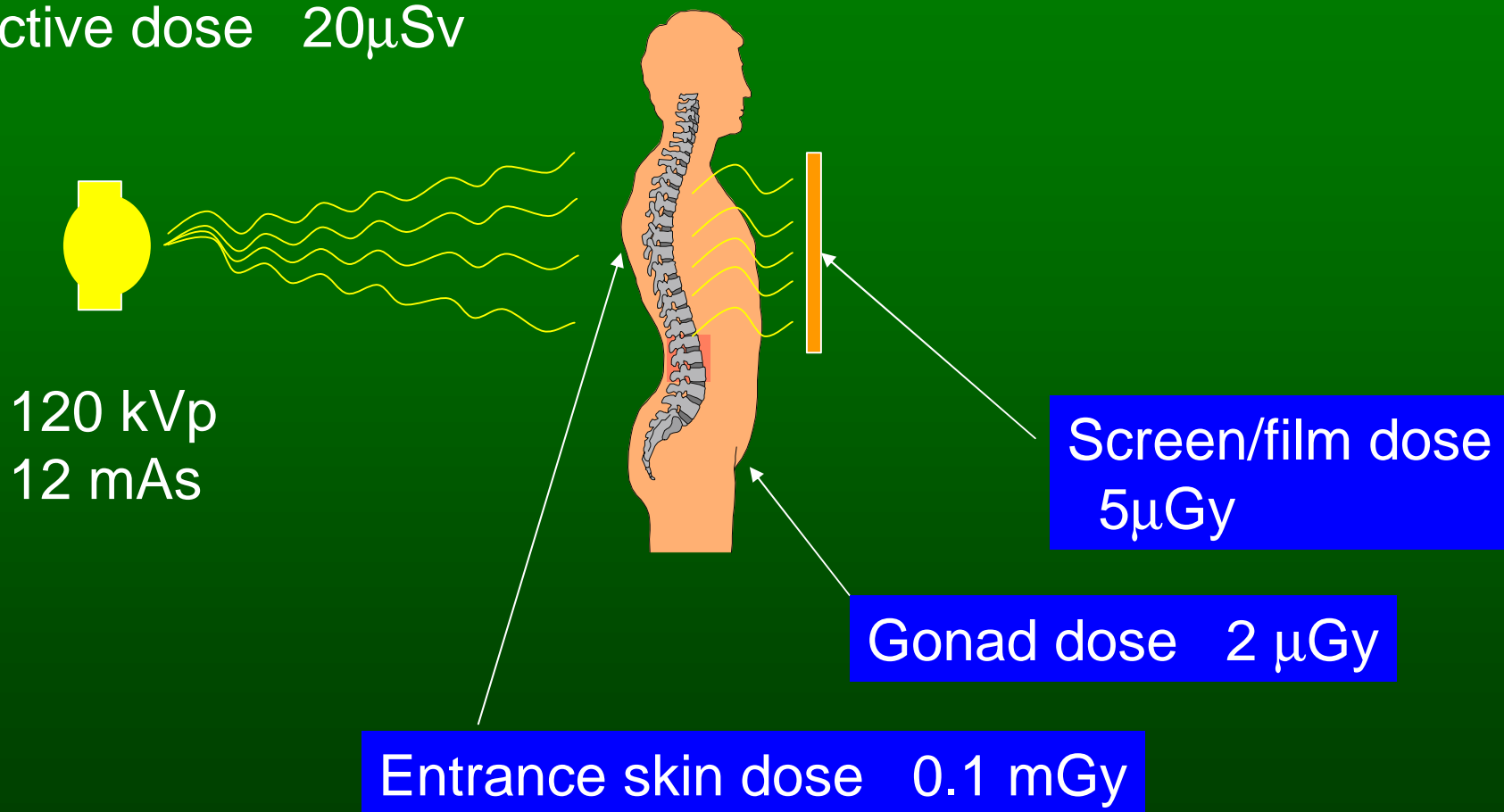
Some clinical examples of
patient doses

Chest radiograph

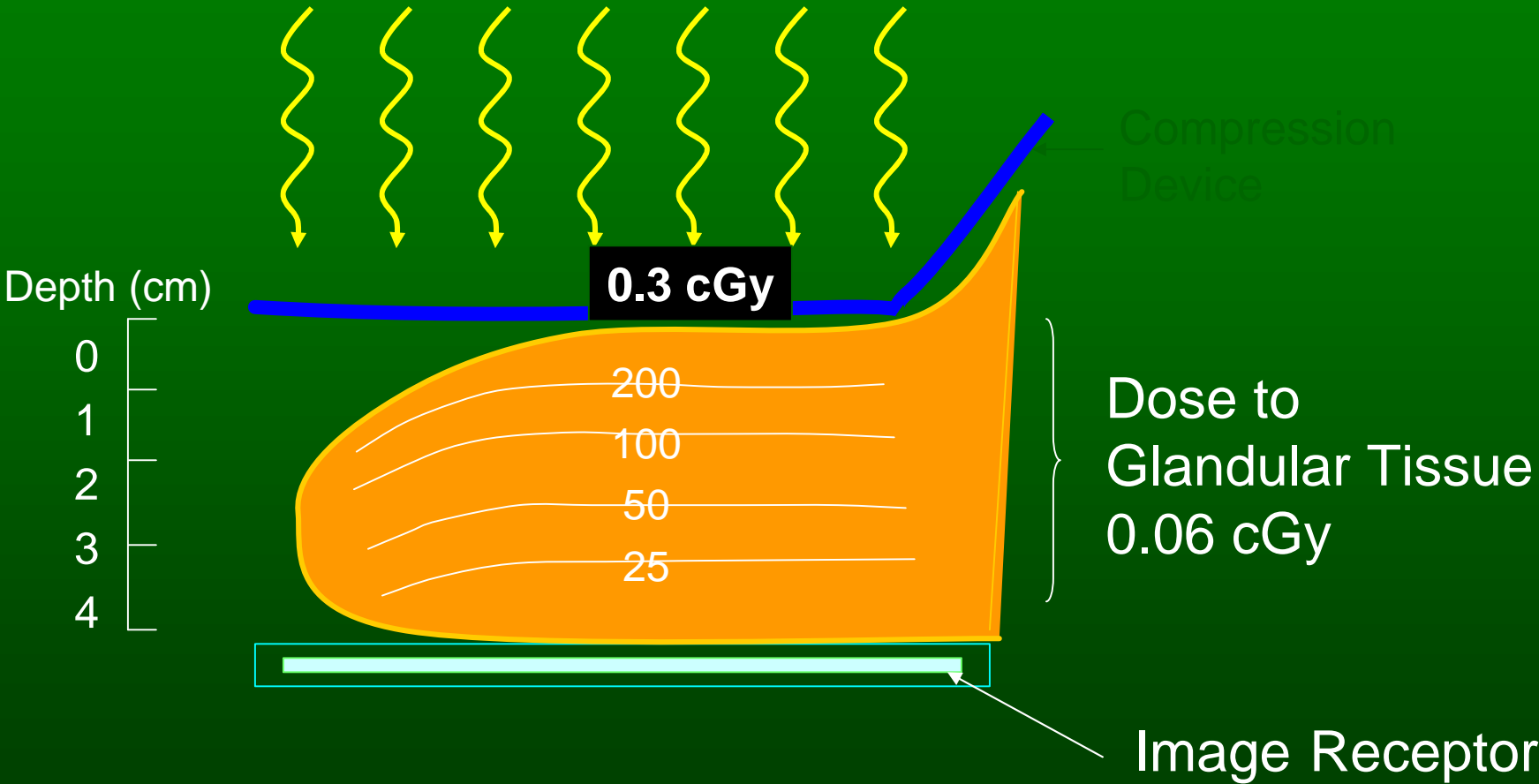
Dose area product 100 mGy cm^2

Integral dose 1 mJ

Effective dose 20 μSv



X-ray Beam



Screen-film Mammography

Is there any risk to a developing fetus from mammography?

CC Projection Entrance dose $\sim 2\mu\text{Gy}$

If uterus is 10 cm deep within pelvis

\Rightarrow dose to uterus is 1/1000 of entrance dose
 $\sim 0.002 \mu\text{Gy}$

\Rightarrow **Total exposure (scatter + primary) $\sim 0.004 \mu\text{Gy}$**

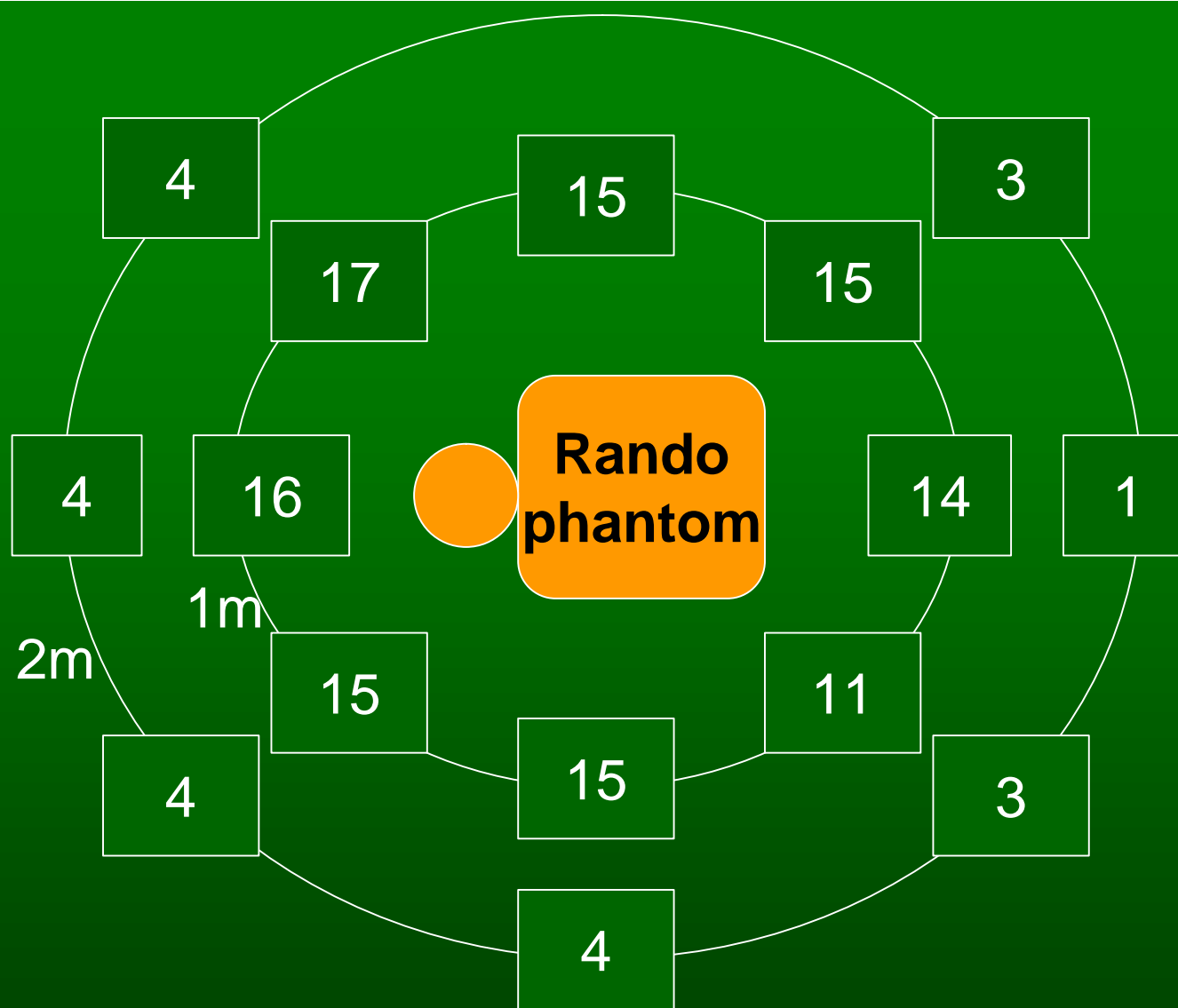
cf. Fetus receives $\sim 20 \mu\text{Gy}$ each week from background radiation

Scattered Radiation from ward (mobile) X-ray

How far is considered safe?

Scattered Radiation from Mobile X-ray

- Technique Factors for AP CXR:
60 KVp, 4 mAs at 100cm FFD
- The average scattered radiation at 2m
from the mobile X-ray machine is 3 μ Gy.
 \Rightarrow 660 exposures to reach annual
background radiation.

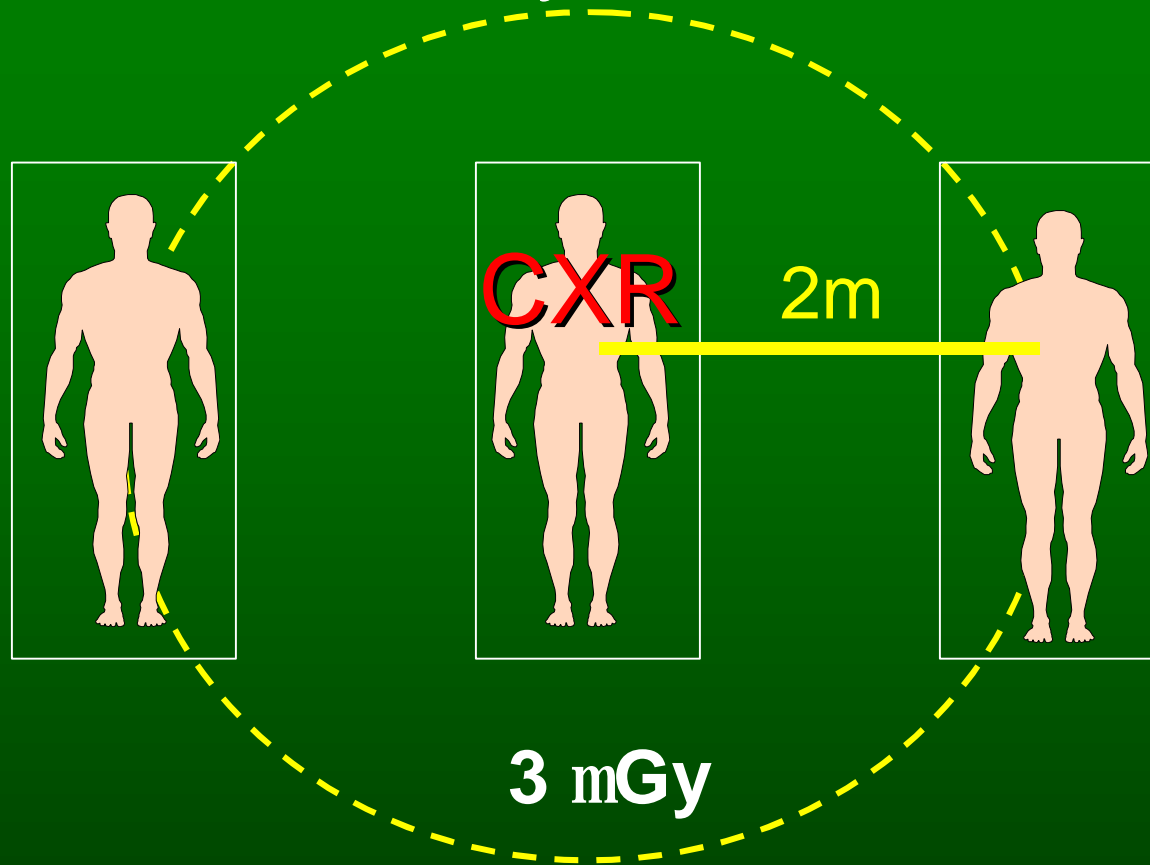


Entrance air kerma = 0.3 mGy

Exit air kerma = 30 μGy

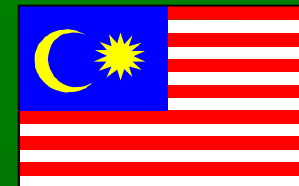
Scattered air kerma in μGy

Radiation contour for a PA CXR from a mobile X-ray unit



A min distance of 2 m from centre of X-ray field is considered to be 'safe'

Malaysian National Dose Survey



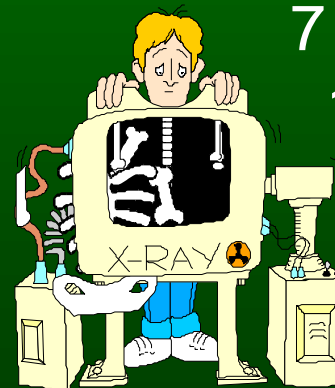
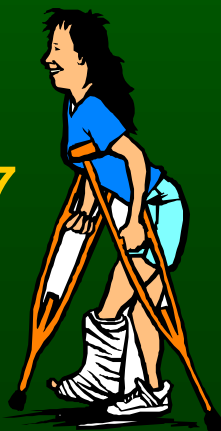
1993



1995



867



7 types of examinations
12 projections

1st National Dose Survey

7 Types of X-ray Examinations

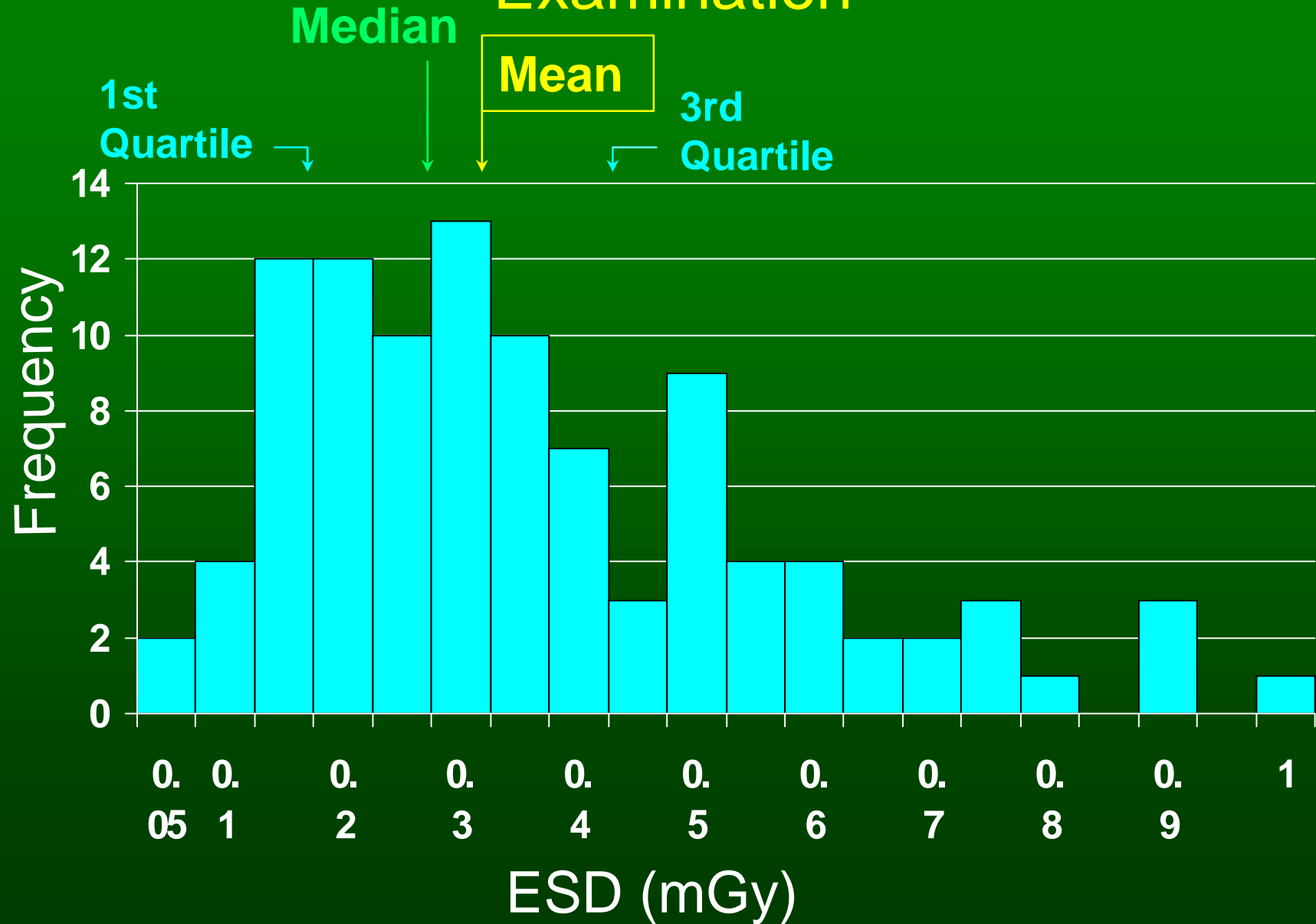
12 projections

- Chest PA, Lat
- Abdomen AP
- Pelvis/ Hip Joint AP
- Skull AP/PA, Lat
- Cervical Spine AP, Lat
- Thoracic Spine AP/PA, Lat
- Lumbar Spine AP, Lat

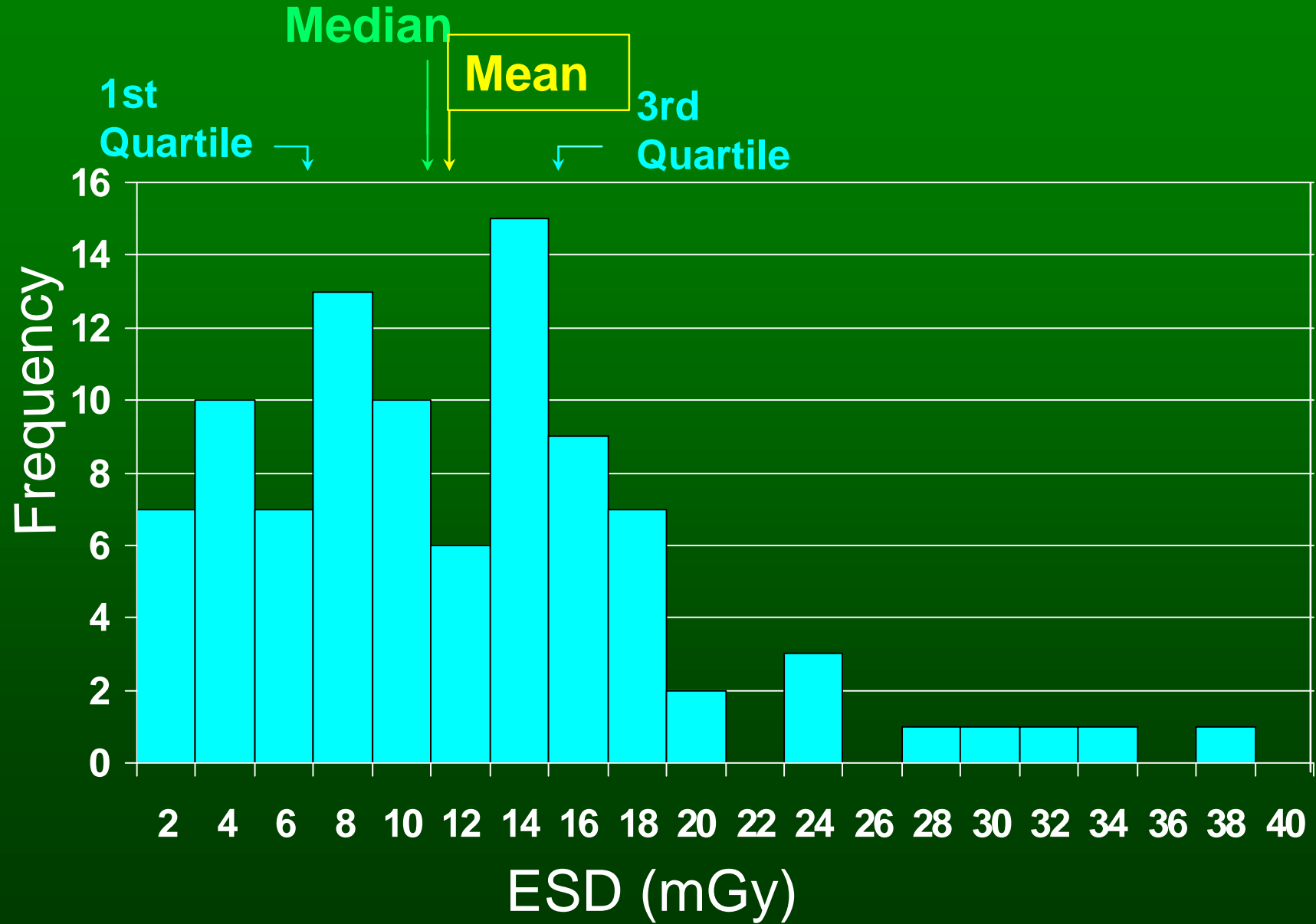


Participating Hospitals

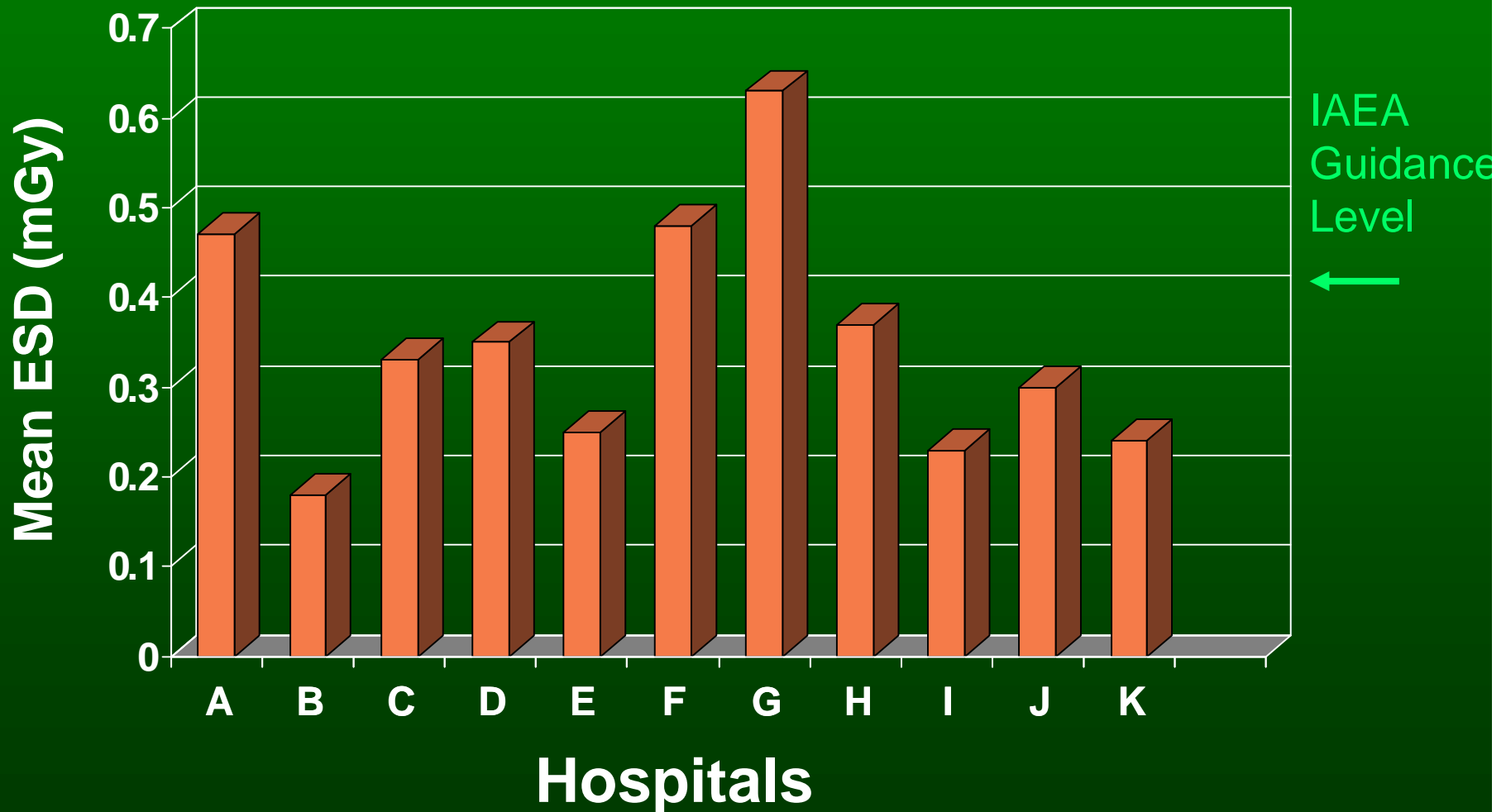
Entrance Surface Dose for Chest PA Examination



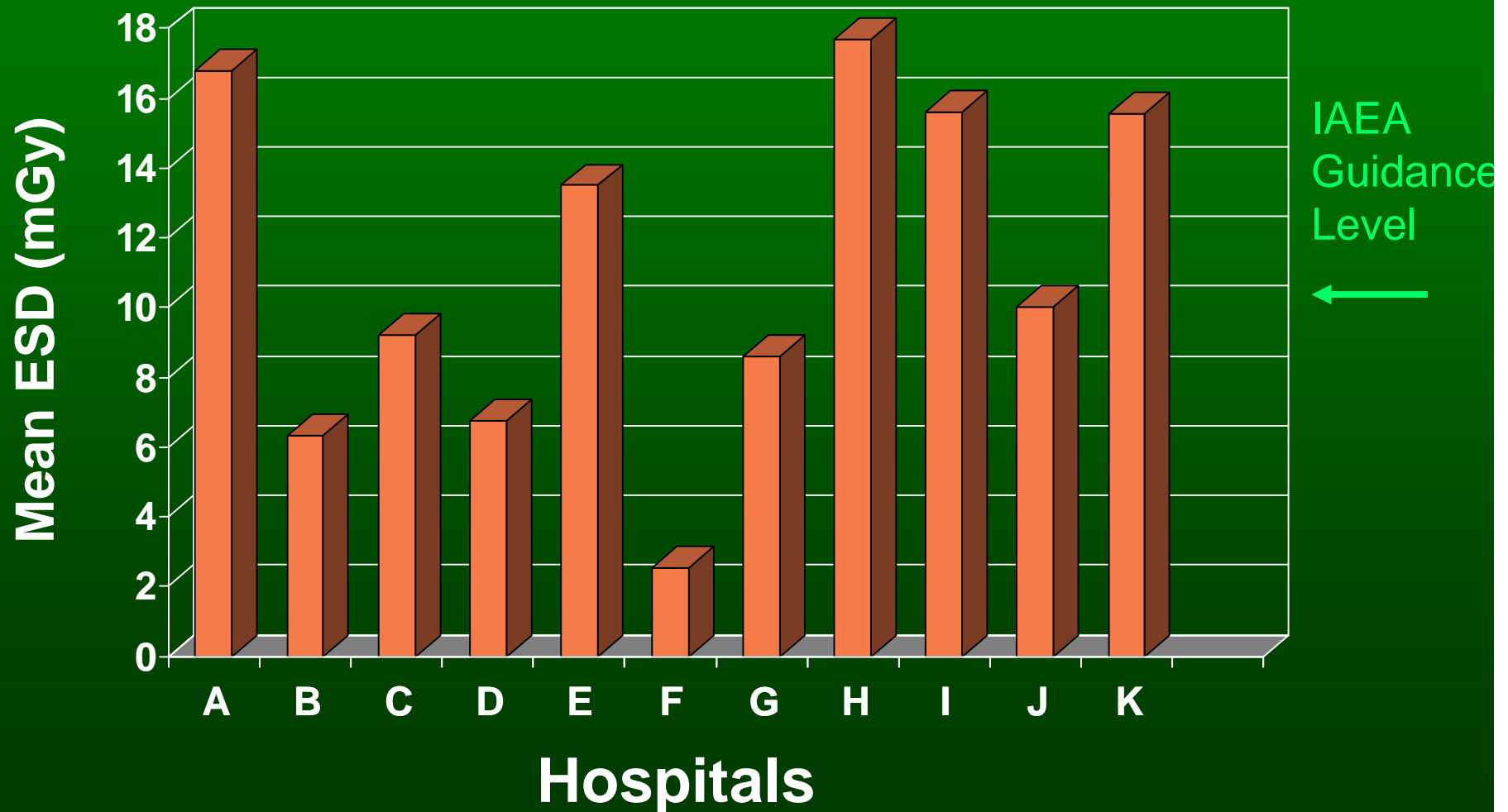
Entrance Surface Dose for Abdomen AP Exam



Inter-Hospital Variation for Chest PA Mean ESD Values



Inter-Hospital Variation for Abdomen AP Mean ESD Values



Radiograph	Projec- tion	This study	NRPB (1990)	UK National Ref Dose	IAEA BSS
Chest	PA	0.3	0.18	0.3	0.4
	Lat	1.2	0.99	1.5	1.5
Abdomen	AP	9.9	6.68	10	10
Pelvis/ Hip	AP	5.2	5.67	10	10
Skull	AP/PA	5.9	4.20	5	5
	Lat	4.0	2.19	3	3
Cervical Spine	AP	1.1	-	-	-
	Lat	1.5	-	-	-
Thoracic Spine	AP	4.6	-	7	7
	Lat	8.8	-	20	20
Lumbar Spine	AP	10.2	7.68	10	10
	Lat	17.9	19.7	30	30

Benefits of National Dose Survey

- Increased awareness among radiology professionals
- Implementation of dose reduction techniques
- Greater emphasis on QAP
- Basis for a national guidance dose levels for Basic Safety Standard
- Provide patient dosimetry information for healthcare level II countries

Some References:

Doses to patients in routine X-ray examinations in Malaysia

- KH Ng, P Rassiah, HB Wang, AS Hambali, P Muthuvellu and HP Lee
British Journal of Radiology 1998; 71:654-60

X-ray based Radiological Procedures in Malaysia - 1990-1994

- KH Ng, BJJ Abdullah, P Rassiah, S Sivalingam
Medical Journal of Malaysia 1999; 54(2): 185-191.

Medical radiation exposures for diagnostic radiology in Malaysia

- KH Ng, BJJ Abdullah, S Sivalingam
Health Physics 77(1):1-4, 1999

Comparison of dose between conventional and digital CXR

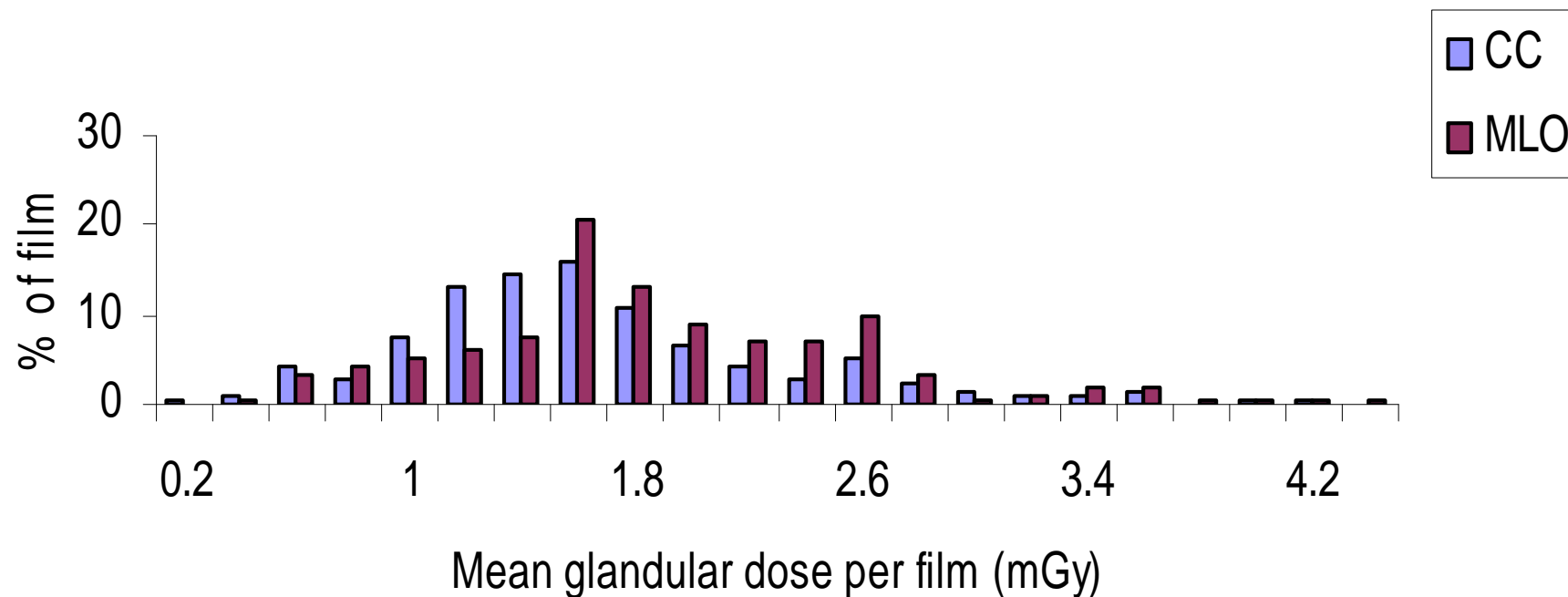
Detector	ESD (mGy)
Film/screen	0.2 (0.06-0.34)
Storage phosphor plate (Agfa)	0.2 (0.05-0.38)
Direct digital (Thoravision)	0.25 (0.11-0.56)

Mammography

Mammography

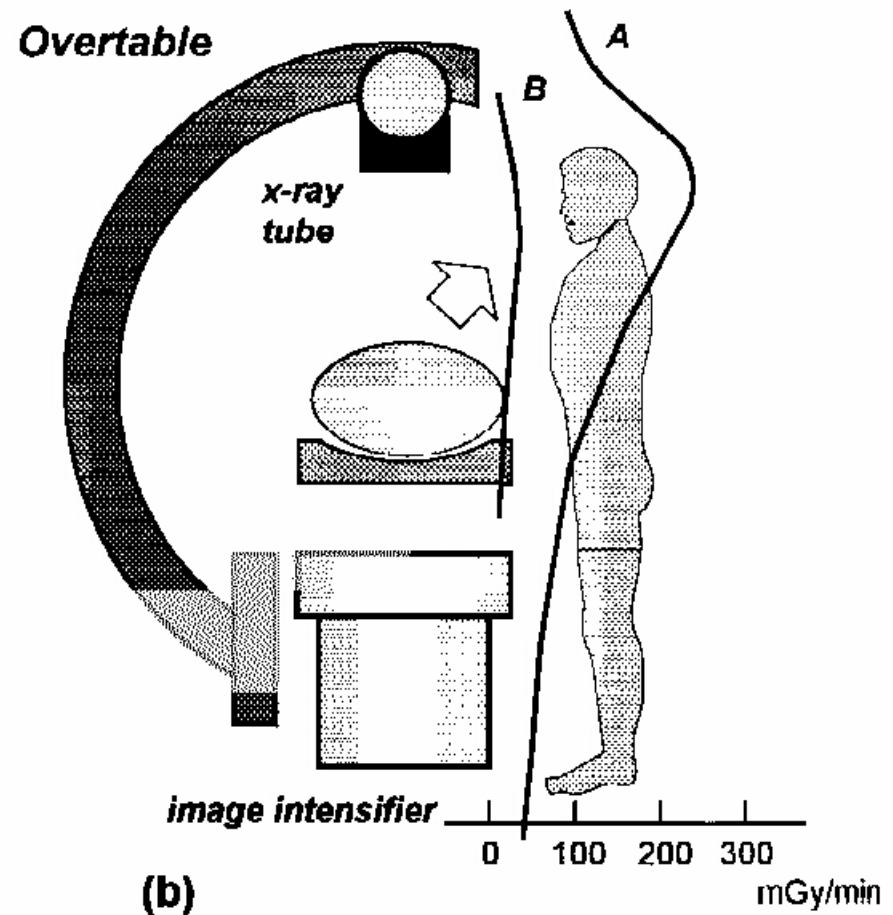
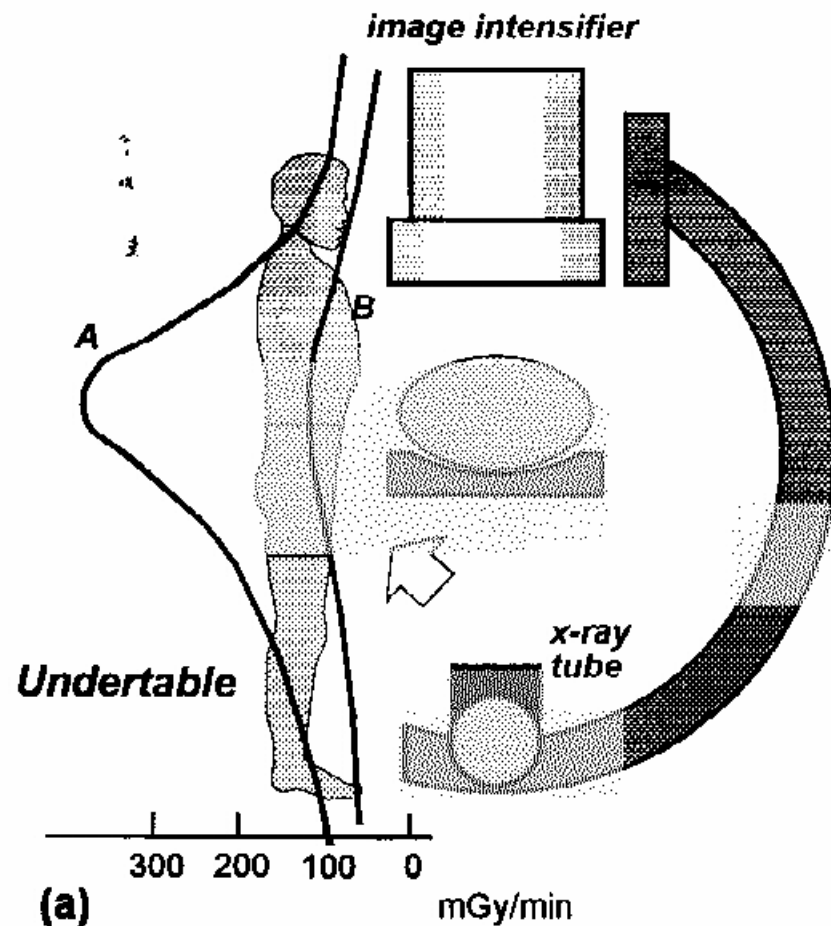
Mean glandular dose

- Glandular tissue is highly radiosensitive
- an indicator of risk
- Well-established and monitored



Histogram of mean glandular dose per film for craniocaudal (CC) and mediolateral oblique (MLO). (n=300)

Fluoroscopy

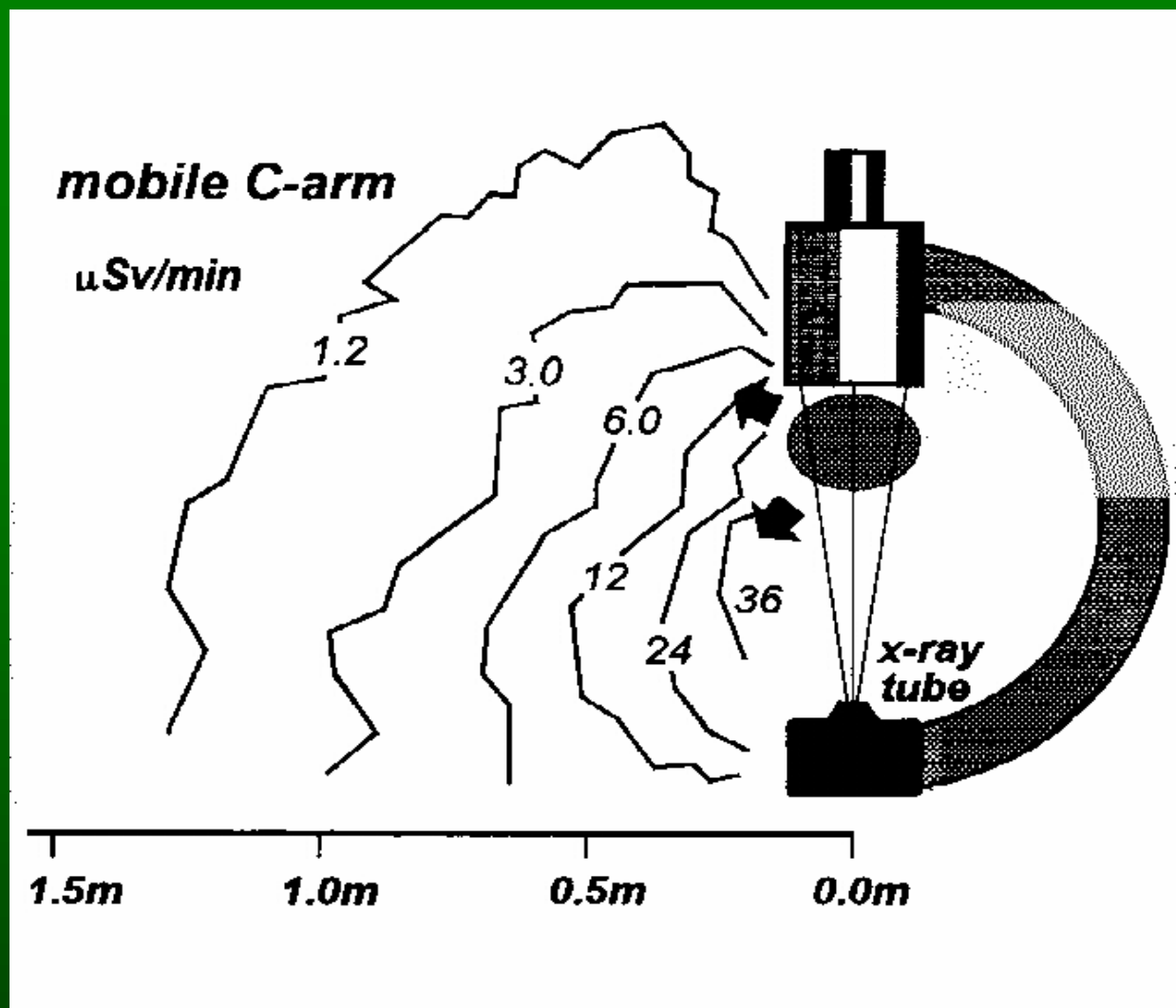


Radiation contour for two C-arm positions

(a) undercouch tube

(b) overhead tube

Change in radiation exposure with shielding (B) and without (A) shielding



Mobile C-arm radiation contours, showing the low dose rates at 1.5 m from the machine

The Commandments for Minimizing Risks from Fluoroscopic X Rays -1

1. Remember, dose rates will be greater and dose will accumulate faster in larger patients.
2. Keep the tube current as low as possible.
3. Keep the kVp as high as possible (and mA as low as possible) to achieve the appropriate compromise between image quality and low patient dose.
4. Keep the patient at maximum distance from the x-ray tube.
5. Keep the image intensifier as close to the patient as possible.

The Commandments for Minimizing Risks from Fluoroscopic X Rays -2

6. Don't overuse geometric or electronic magnification
7. If image quality is not compromised, remove the grid during procedures on small patients or when the image intensifier cannot be placed close to the patient.
8. Always collimate down to the area of interest.
9. Personnel must wear protective aprons, use shielding, monitor their doses, and know how to position themselves and the machines for for minimum dose.
10. Keep beam-on time to an absolute minimum!

- The Golden Rule

Wagner & Archer, 2000

Interventional Radiology



U.S. Department of Health and Human Services

Food and Drug Administration

**FDA Public Health Advisory:
Avoidance of Serious X-Ray-Induced
Skin Injuries to Patients During
Fluoroscopically-Guided Procedures**

September 30, 1994

Prolonged, fluoroscopically-guided, invasive procedures

- percutaneous transluminal angioplasty (coronary and other vessels),
- radiofrequency cardiac catheter ablation,
- vascular embolization,
- stent and filter placement,
- thrombolytic and fibrinolytic procedures,
- percutaneous transhepatic cholangiography,
- endoscopic retrograde cholangiopancreatography,
- transjugular intrahepatic portosystemic shunt,
- percutaneous nephrostomy,
- biliary drainage and
- urinary/biliary stone removal.

FDA suggests

- Establish **standard operating procedures** and **clinical protocols** for each specific type of procedure performed. The protocols should address all aspects of the procedure, such as patient selection, normal conduct of the procedure, actions in response to complications and consideration of limits on fluoroscopy exposure time
- Know the **radiation dose rates** for the specific fluoroscopic system and for each mode of operation used during the clinical protocol. These dose rates should be derived from measurements performed at the facility.

FDA suggests

- **Assess the impact** of each procedure's protocol on the potential for radiation injury to the patient.
- **Modify the protocol**, as appropriate, to limit the cumulative absorbed dose to any irradiated area of the skin to the minimum necessary for the clinical tasks, and particularly to avoid approaching cumulative doses that would induce unacceptable adverse effects. Use equipment which aids in minimizing absorbed dose.
- Enlist a qualified medical physicist to assist in implementing these principles in such a manner so as not to adversely affect the clinical objectives of the procedure.

Typical threshold absorbed dose in the skin required to cause skin injury

3 Gy	temporary epilation
6 Gy	main erythema
15 to 20 Gy	moist desquamation, dermal necrosis and secondary ulceration

The absorbed dose rate in the skin from the direct beam of a fluoroscopic x-ray system

Typically bet. 0.02 Gy/min and 0.05 Gy/min, but may be higher, depending on the mode in which the equipment is operated and the size of the patient.

Even typical dose rates can result in skin injury after less than one hour of fluoroscopy.

Patient	Sex/Age	Procedure	Nature of Injury	Fluoroscopic Exposure Time
A	M/40	Coronary angiography and PTCA followed by second coronary angiography	Skin necrosis requiring 12 cm x 10 cm skin graft	Unknown - Estimated to exceed 120 min.
B	F/?	RF Cardiac Catheter Ablation	7.5 cm x 12.5 cm second degree skin burn	Unknown
C	F/25	RF Cardiac Catheter Ablation	Skin breakdown 3 weeks post procedure	Unknown - Procedure time of 325 min
D	F/34	RF Cardiac Catheter Ablation	Draining skin lesion on on back 5 weeks post procedure	Unknown - Procedure time of 190 min.
E	F/62	Balloon dilation of bile duct anastomosis	Burn-like injury on back requiring skin graft	Unknown
F	F/61	Renal angioplasty	Skin necrosis requiring skin graft	Unknown - Procedure time of 165 min.



*(a) Condition of patient's back
6-8 weeks following multiple
coronary angiography
and angioplasty procedures*



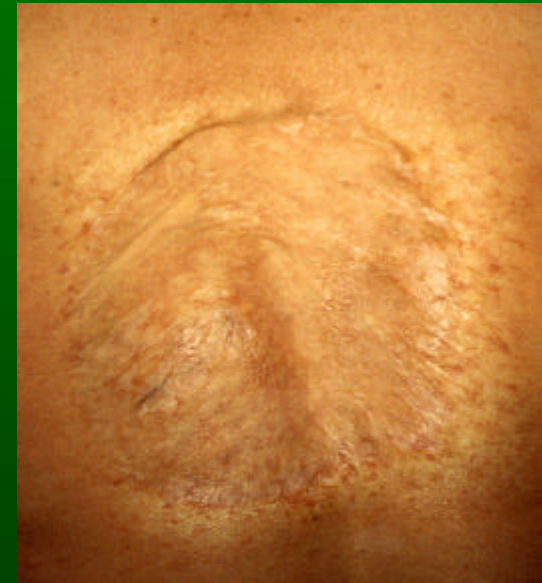
*(b) Appearance of skin injury approx
16 to 21 weeks following the
procedures with small ulcerated
area present*



(c) Appearance of skin injury approx 18 to 21 months following procedures, evidencing tissue necrosis



(d) Close-up view of lesion shown (c)

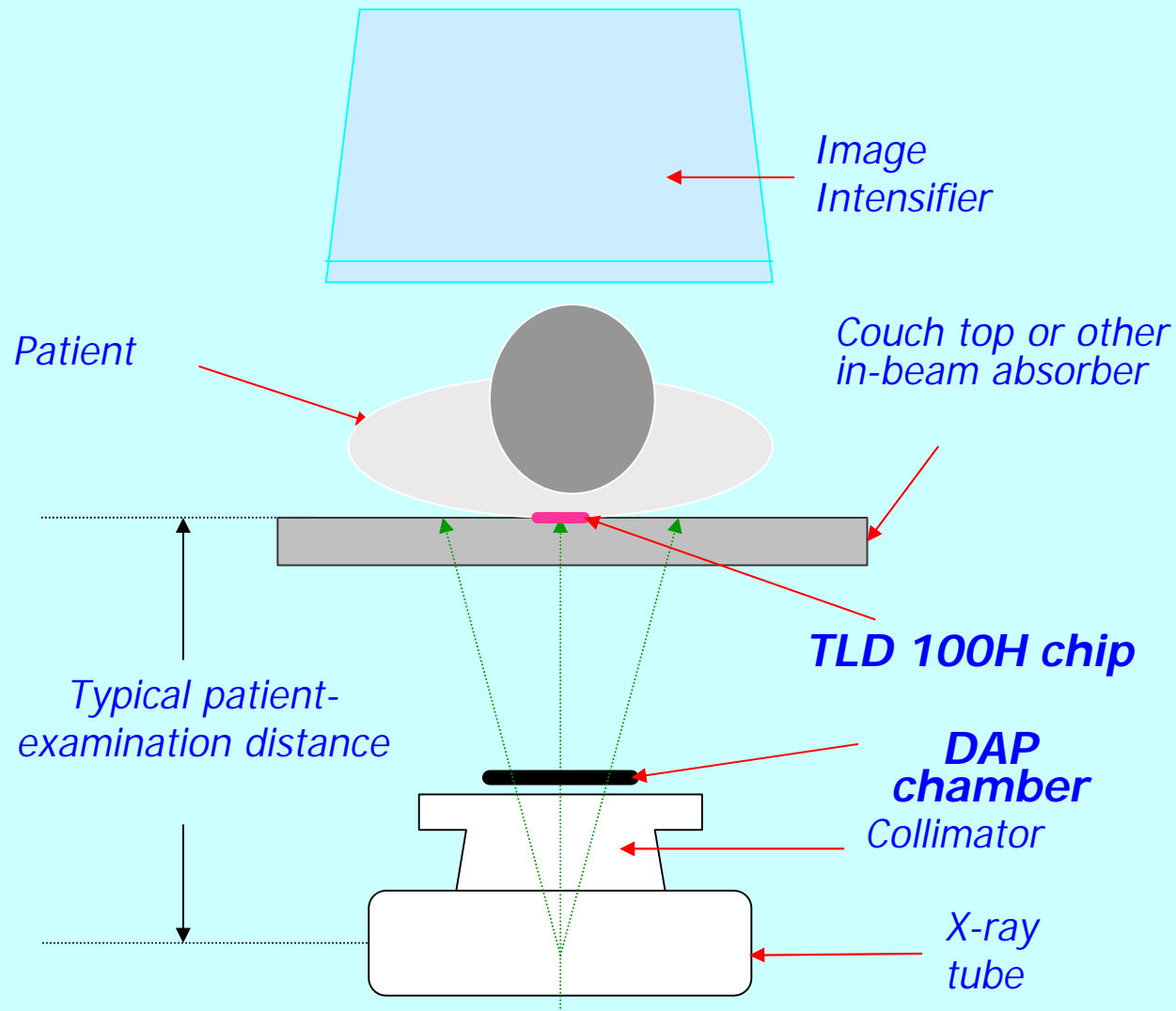


(e) Appearance of patient's back following skin grafting procedure

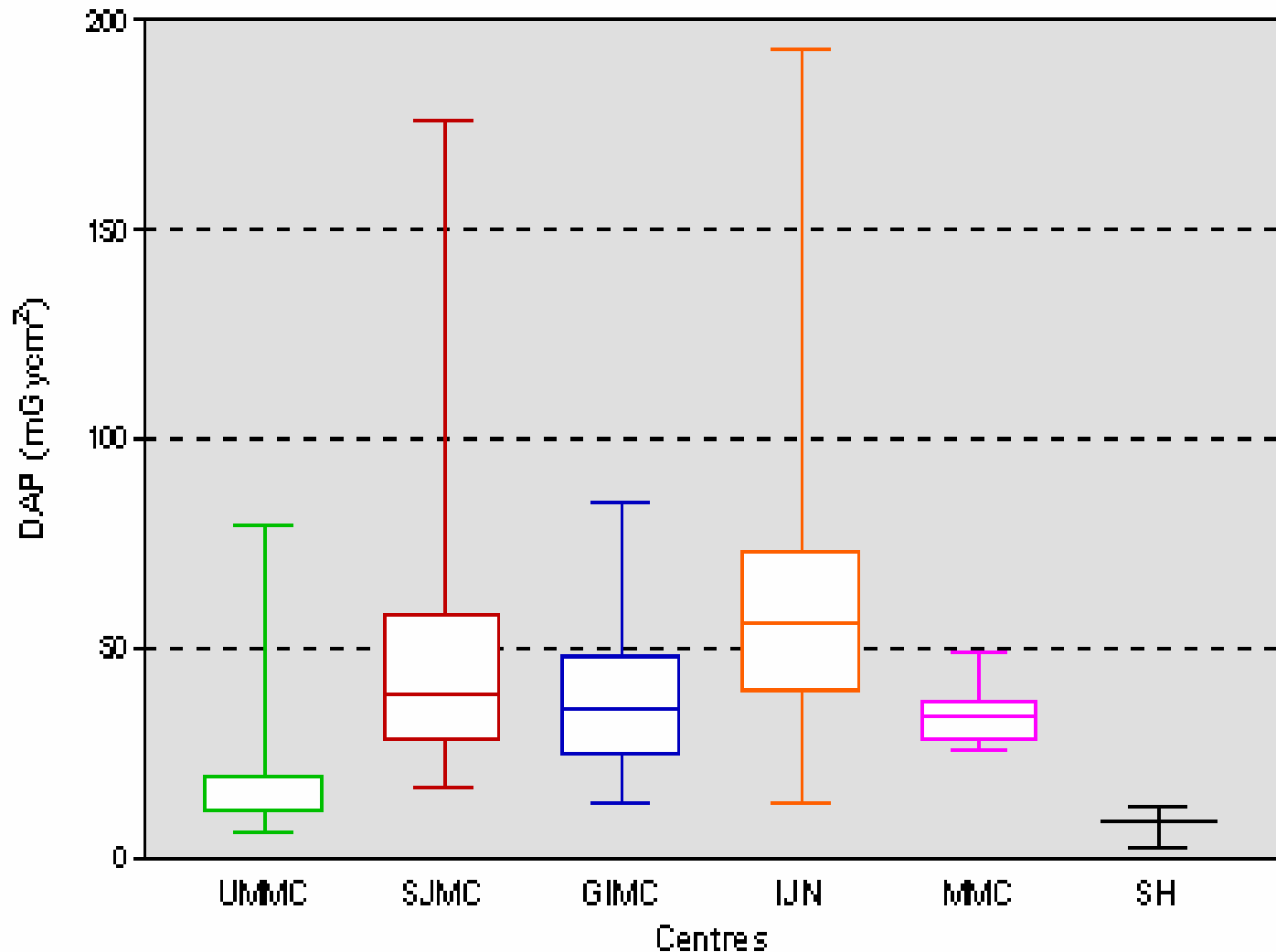
A SURVEY OF RADIATION DOSE TO PATIENTS UNDERGOING INTERVENTIONAL RADIOLOGICAL PROCEDURES IN MALAYSIA

Bazli bin Sapiin, KH Ng, BJJ Abdullah

Rad Prot & Dosimetry (submitted)



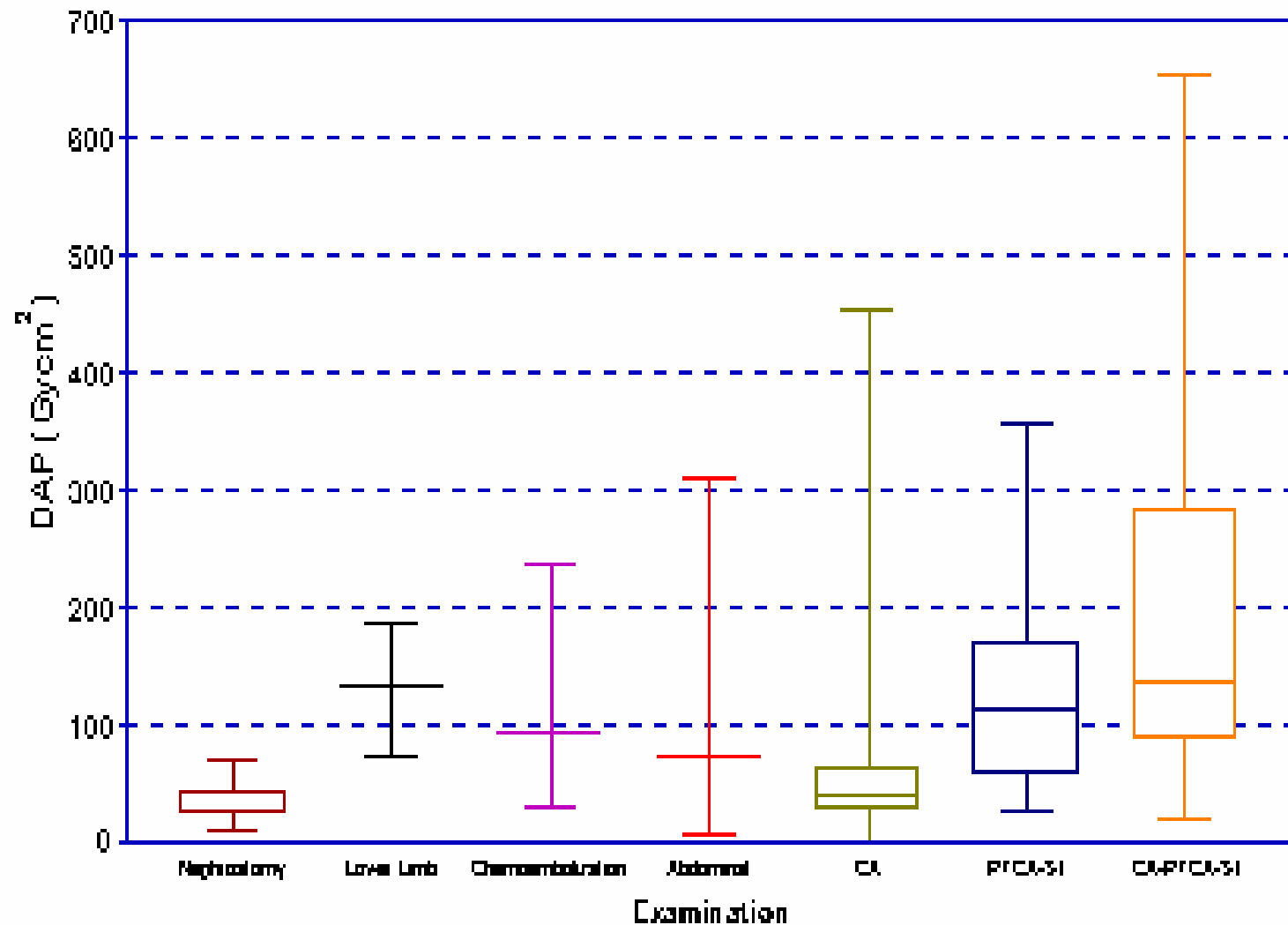
Patient Dose Measurement Set-up



DAP values for coronoray angiography performed at 6 centers

B Sapiin, KH Ng, BJ Abdullah, Rad Prot & Dosimetry (submitted)

Procedure	Mean Value		Effective Dose (mSv)
	DAP (Gycm ²)	Entrance Surface Air Kerma (mGy)	
Cardiac Procedures			
CA	48.6	Na	8.9
PTCA-SI	147.2	Na	26.9
CA-PTCA- SI	153.0	Na	28.0
Non-cardiac Procedures			
Nephrostomy	31.5	100.4	5.0
Lower limb angiography	109.4	64.9	17.5
Chemoembolization	127.7	107.0	20.4
Abdominal angiography	88.4	135.3	14.2



DAP values for Cardiac and Non-Cardiac Procedures

B Sapiin, KH Ng, BJ Abdullah, Rad Prot & Dosimetry (submitted)

Comparison of DAP and ESD with Published Data

Procedure	Study	No of Patients	DAP (Gycm ²)			ESD (mGy)
			Mean Value	Median	3 rd quartile	
CA	This study	138	55.0	41.7	64.7	Na
	Van de Putte, 2000	62	60.6	56.8	80.6	
	Betsou et al, 1998	29	30.4	na	na	
PTCA	This study	22	186.1	166.4	226.7	Na
	Van de Putte, 2000	13	115.2	108.8	140.9	
	Vano et al, 1995	45	87.5	66.7	122.3	
CA-PTCA-SI	This study	9	167.4	116.1	220.0	Na
	Van de Putte, 2000	10	165.9	131.6	185.83	
	Betsou et al, 1998	7	70.7	na	na	
Nephrostomy	This study	11	32.4	26.6	36.6	108.1
	Cruces, 1998	54	75	62	106	
	McParland, 1998	35	43.0	24.2	62.7	
Lower limb angiography	This study	4	80.3	50.8	215.5	98.9
	Cruces, 1998	35	30	27	36	
	William, 1997	323	77.9	68.6	97.5	
Chemoembolization	This study	5	124.5	97.8	219.9	126.4
	William, 1997	27	105.0	89.0	136.0	
Abdominal angiography	This study	4	91.1	92.2	129.2	152.5
	McParland, 1998	21	118	102	133	
	Cruces, 1998	16	61	33	92	

Our results showed that none of the ESD values approach the threshold for erythema and there was no evidence of these complications in the patients that made up the dose survey.

However, the potential for skin injury is increasing real.

Action:

We must create awareness and consider 'accreditation' for non-radiologists who use ionising radiation

Computed Tomography

Typical Mean Levels of Patient Dose from CT in the UK

Examination	Effective dose E (mSv)	<i>Equivalent period of natural radiation</i>
• Routine chest	8.3	<i>4.0 yrs</i>
• Routine abdomen	7.2	<i>3.5 yrs</i>
• Routine head	2.9	<i>1.3 yrs</i>
• Lumbar spine	3.6	<i>1.7 yrs</i>
• Routine pelvis	7.3	<i>3.5 yrs</i>

Recent concern regarding proliferating CT usage

- Pediatric CT – technique, dose
- Multi-detector row helical CT
- CT as a screening tool

Estimated Risks of Radiation-Induced Fatal Cancer from Pediatric CT

- Estimated lifetime cancer mortality risks attributable to radiation exposure from a CT in a 1-year-old are 0.18% (abdominal) and 0.07% (head)— 10 x higher than for adults
- 600,000 abdominal and head CT examinations annually performed in children < 15 years,
⇒ 500 of these individuals might ultimately die from cancer attributable to the CT radiation.

David Brenner, Carl Elliston, Eric Hall and Walter Berdon
AJR 2001; 176:289-296

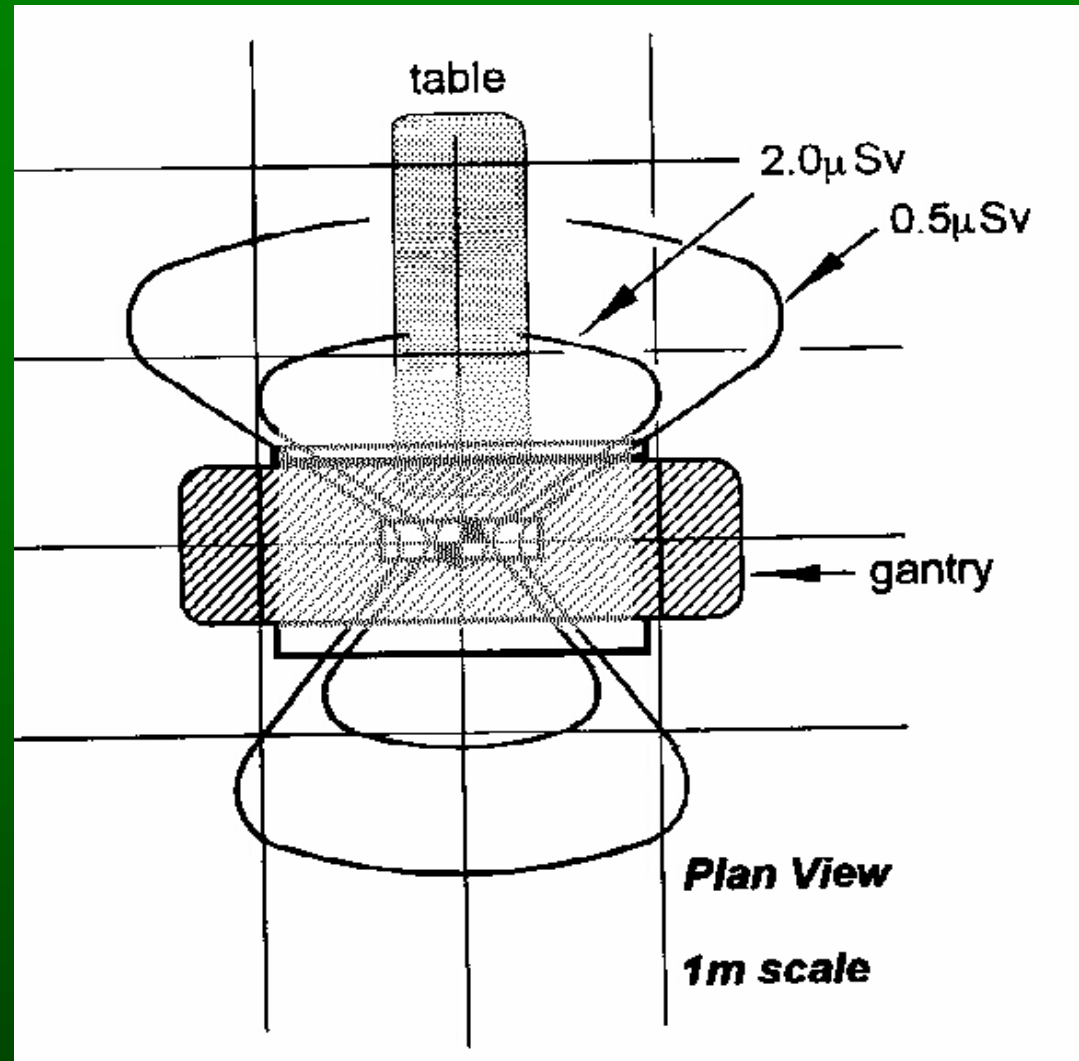
Helical CT of the Body

Are Settings Adjusted for Pediatric Patients?

- The mean tube current setting for chest was 213 mA and was 206 mA for the abdomen.
- 56% of the examinations of neonates, infants, or children 8 years old or younger were performed at a collimation of greater than 5 mm and 53% of these examinations were performed using a pitch of 1.0.
- Pediatric helical CT parameters are not adjusted on the basis of the examination type or the age of the child. These results suggest that pediatric patients may be exposed to an unnecessarily high radiation dose during body CT.

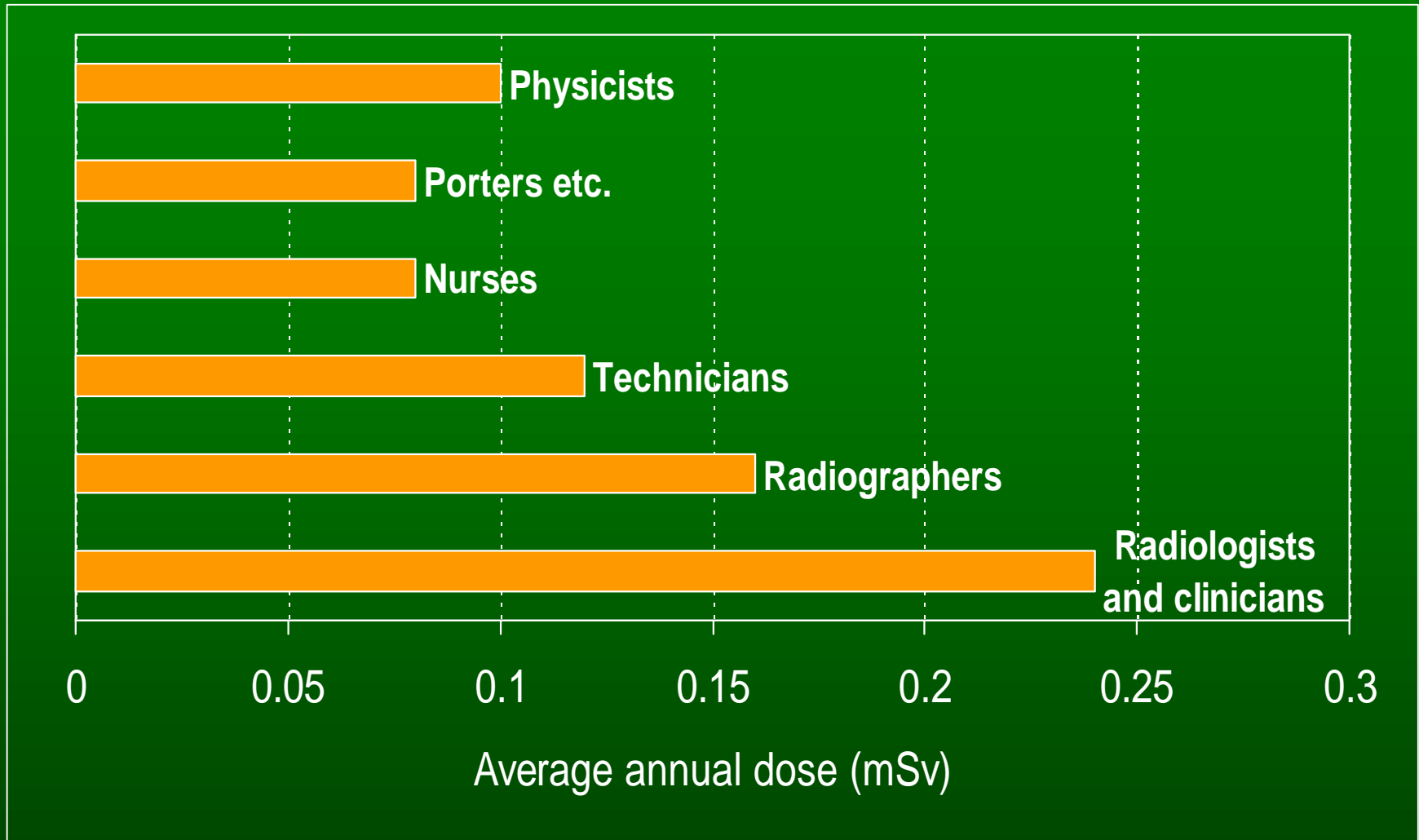
Anne Paterson, Donald P. Frush and Lane F. Donnelly

AJR 2001; 176:297-301



Radiation contours surrounding a CT machine

Radiation Doses to Staff



**Radiation doses to hospital staff in the UK
(NRPB)**

No published information on occupational dose to radiation workers in Malaysia

Action:

Relevant bodies (MOH, CoR) must initiate a survey of occupational dose

Regulatory Development

Guidance Level for Medical Exposure

A value of dose, dose rate or activity selected by professional bodies in consultation with the Regulatory Authority to indicate a level above which there should be a review by medical practitioners in order to determine whether or not the value is excessive, taking into account the particular circumstances and applying sound clinical judgement.

- IAEA BSS 1996

Schedule III

GUIDANCE LEVELS OF DOSE, DOSE RATE AND ACTIVITY FOR MEDICAL EXPOSURE

International Basic Safety Standards for
Protection against Ionizing Radiation and for the
Safety of Radiation Sources

IAEA 1996

TABLE III-I. GUIDANCE LEVELS OF DOSE FOR DIAGNOSTIC RADIOGRAPHY FOR A TYPICAL ADULT PATIENT

Examination	Entrance surface dose per radiograph (mGy)	
Lumbar spine	AP	10
	LAT	30
	LSJ	40
Abdomen, intravenous urography & cholecystography	AP	10
Pelvis	AP	10
Hip Joint	AP	10
Chest	PA	0.4
	LAT	1.5
Thoracic spine	AP	7
	LAT	20
Dental	Periapical	7
	AP	5
Skull	PA	5
	LAT	3

* For speed of 200

For 400-600, the values should be reduced by a factor of 2 to 3

TABLE II-II. DOSE GUIDANCE LEVELS FOR COMPUTED TOMOGRAPHY FOR A TYPICAL ADULT PATIENT

Examination	Multiple scan average dose (mGy)
Head	50
Lumbar spine	35
Abdomen	25

* Derived from measurements on the axis of rotation in water equivalent phantoms, 15 cm in length and 16 cm (head) and 30 cm (lumbar spine and abdomen) in diameter.

TABLE II-III. DOSE GUIDANCE LEVELS FOR MAMMOGRAPHY FOR A TYPICAL ADULT PATIENT

Average glandular dose per cranio-caudal projection

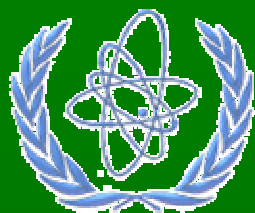
1 mGy (without grid)

3 mGy (with grid)

* Determined in a 4.5 cm compressed breast consisting of 50% glandular and 50% adipose tissue, for film-screen systems and dedicated Mo-target Mo-filter mammography units.

**TABLE II-IV. DOSE RATE GUIDANCE LEVELS
FOR FLUOROSCOPY FOR A TYPICAL ADULT
PATIENTT**

Mode of operation	Entrance surface dose rate (mGy/min)
Normal	25
High level	100



INTERNATIONAL ATOMIC ENERGY AGENCY



Dosimetry in X-ray Diagnostic Radiology – An International Code of Practice

F Pernicka, G Alm Carlsson, D Dance,
L A deWerd, H M Kramer, K H Ng

(in progress)

Recommendation

Information should be posted in each X-ray room :

- Technique chart
- Typical doses from the procedures

Recommendation

All Imaging procedures should be evaluated (audited) at least once a year :

- Clinical practice
- Image quality
- Dose assessment

Recommendation

We need to study and monitor closely:

- Interventional Radiology
- Computed Tomography
- Digital Radiography (CR, DDR)
- Usage by non-radiologists

The End