

RC VII.

Patient dose assessment in diagnostic radiology: from modality specific to patient specific metrics

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IAEA

The course will present the current developments in the patient dose assessment approaches in diagnostic radiology, with a focus on metrics representing risks for individual patients for tissue reactions or stochastic effects associated with radiological procedures. An overview will be presented of the modality-specific measurable dose quantities and the approaches to assess organ doses using generic or patient-specific phantoms, and the associated uncertainties.



IAEA

International Atomic Energy Agency

RC7: Patient dose assessment in diagnostic radiology: from modality specific to patient specific metrics

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① Why we need to know patient dose?

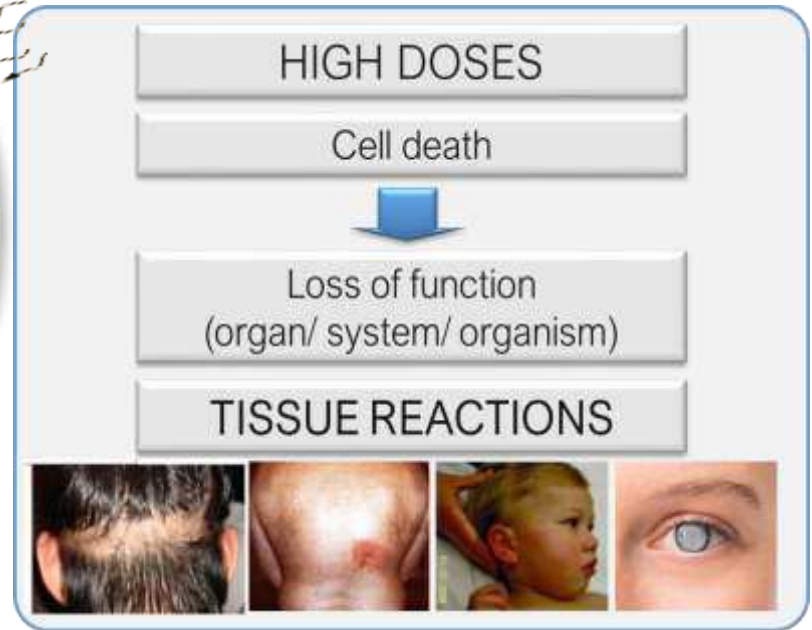
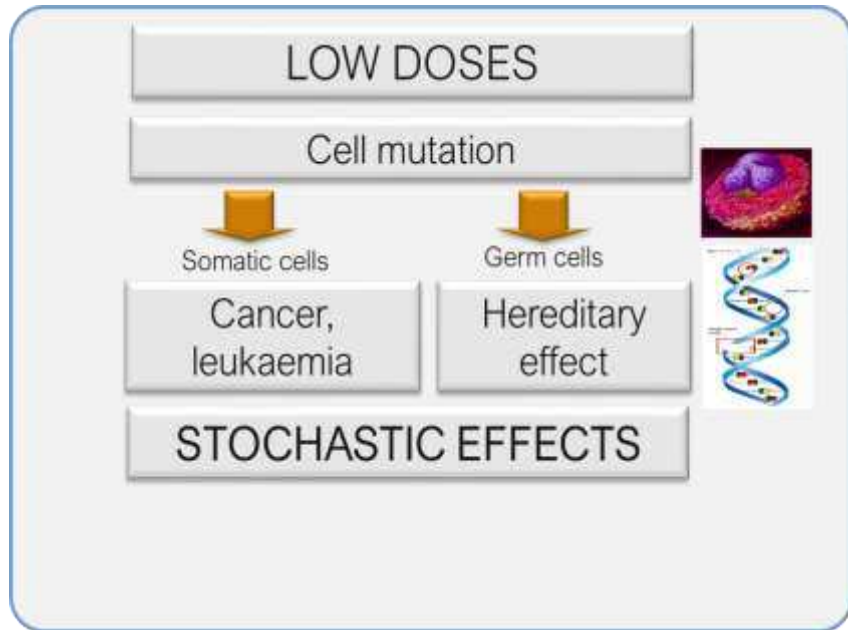
② Modality specific dose metrics

③ Patient specific metrics



Why we need to know patient dose?

Goal: To assess the radiation risk to individuals



Why we need to know patient dose?

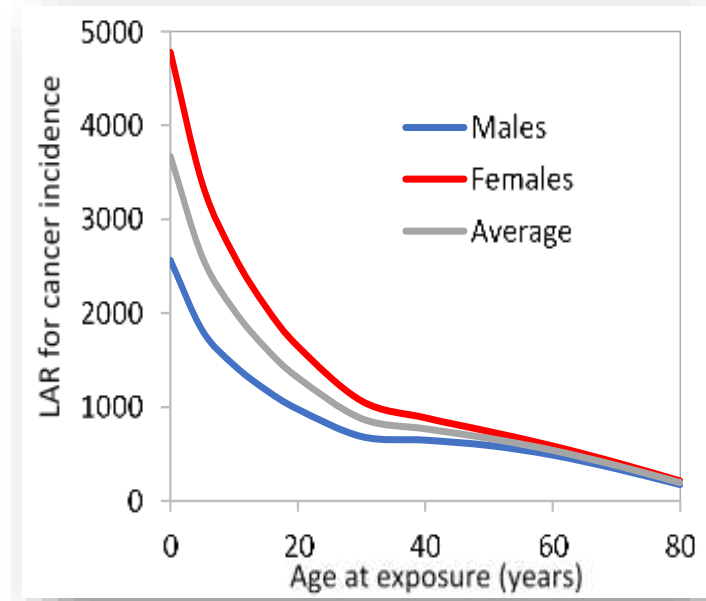
Goal: To assess the radiation risk to individuals



Risk depends on individual factors

- Body habitus, Age, Gender
- Health status (incl. life expectancy due to disease)

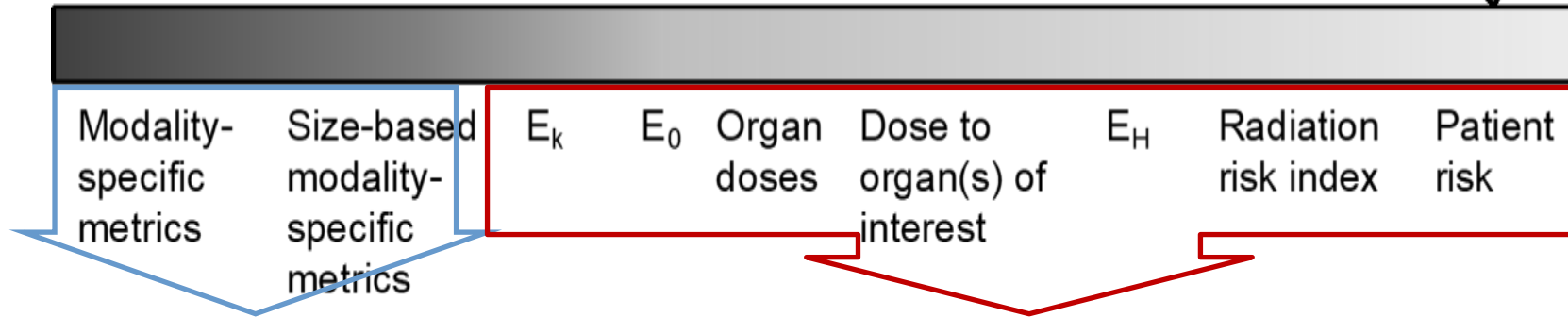
Risk often unknown or unknowable



Lifetime attributable risk (LAR) for cancer incidence (all types of cancer) expressed as cases per 100,000 persons exposed to a single dose of 100 mGy, as function of age at exposure

Why we need to know patient dose?

Goal



Measurable quantities

- Quality assurance
- For performance assessment of an imaging system and QC
- For benchmarking to DRLs
- For optimization of clinical protocols

Calculated dose quantities

- Comparison of risks from different imaging methods and procedures
- Prevention of skin injuries
- Estimation of risk to embryo/ fetus
- Assessment of individual patient risk

① Why we need to know patient dose?

② Modality specific dose metrics

③ Patient specific metrics

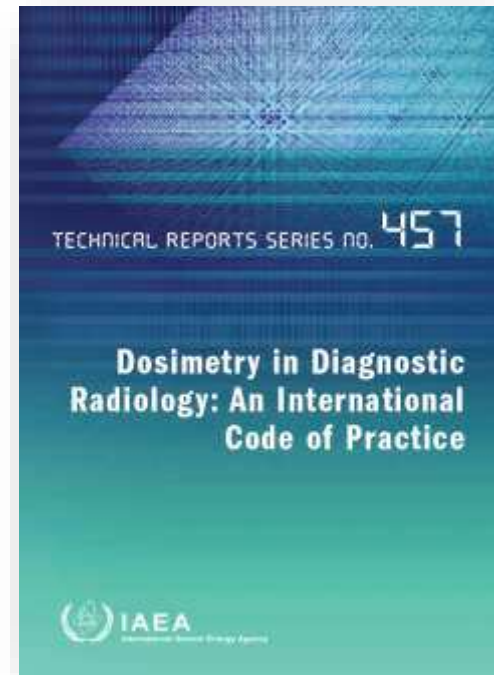


Modality specific metrics

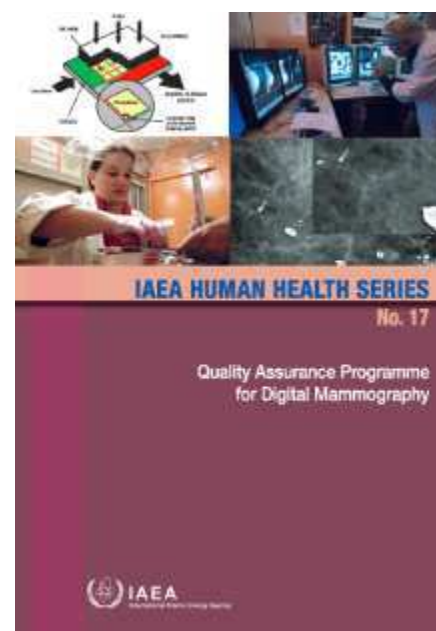
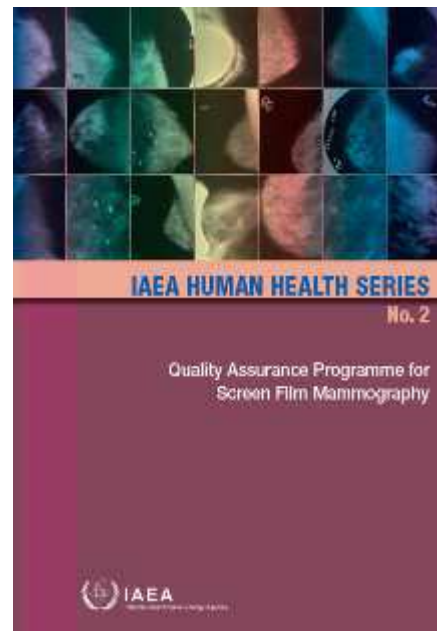
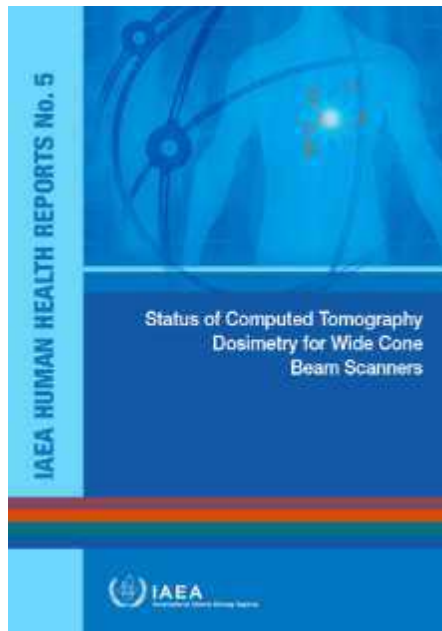
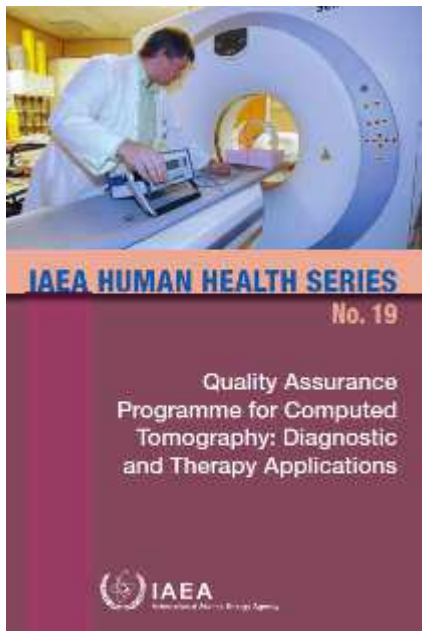
ICRU Report 74. Patient Dosimetry for X-Rays used in Medical Imaging. ICRU, 2005.



IAEA. Dosimetry in Diagnostic Radiology. An International Code of Practice. TRS 457, 2007



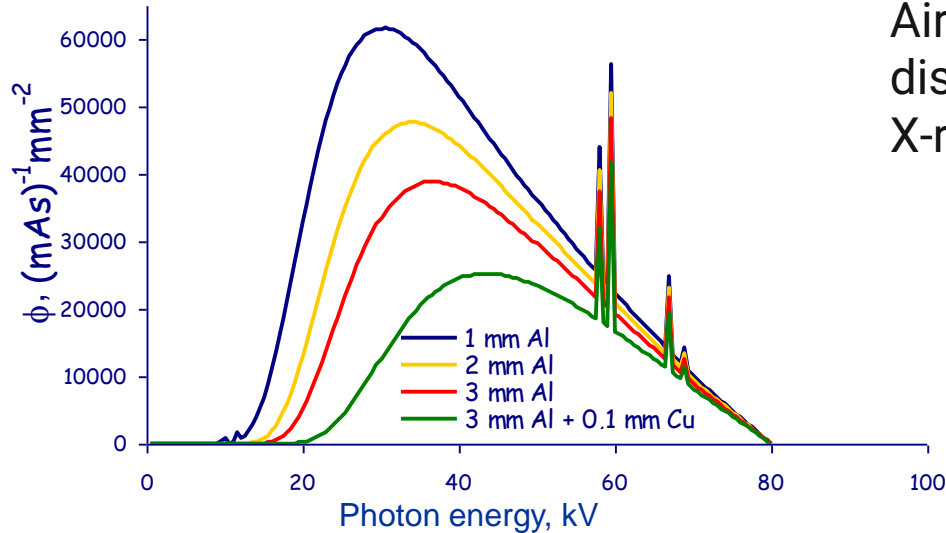
Modality specific metrics



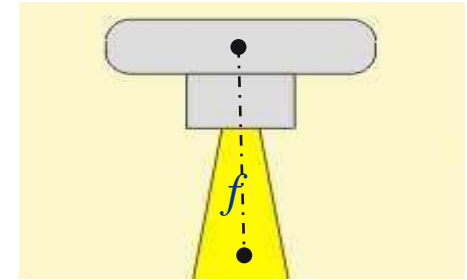
The measurements are a responsibility of qualified medical physicists

X-ray beam

- X-ray spectrum with maximum energy 150 keV
- Spectrum depends on kVp, mAs, filtration



Air kerma at distance f from X-ray focus:

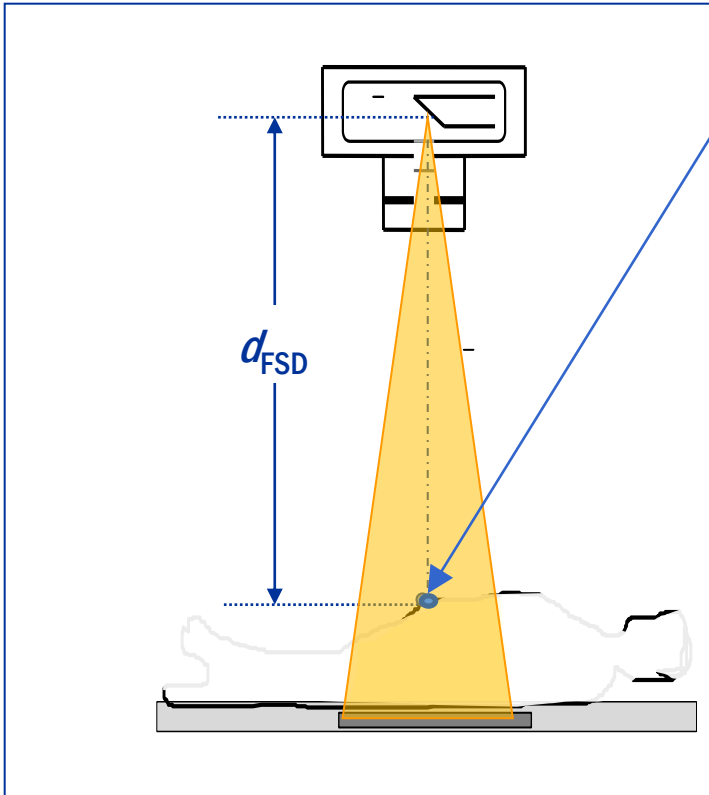


$$K_{air} \sim \frac{U^n \cdot (I \cdot t)}{f^2}$$

$$D = (1 - g)K$$

$$D_{air} \approx K_{air}$$

Dose quantities: Radiography

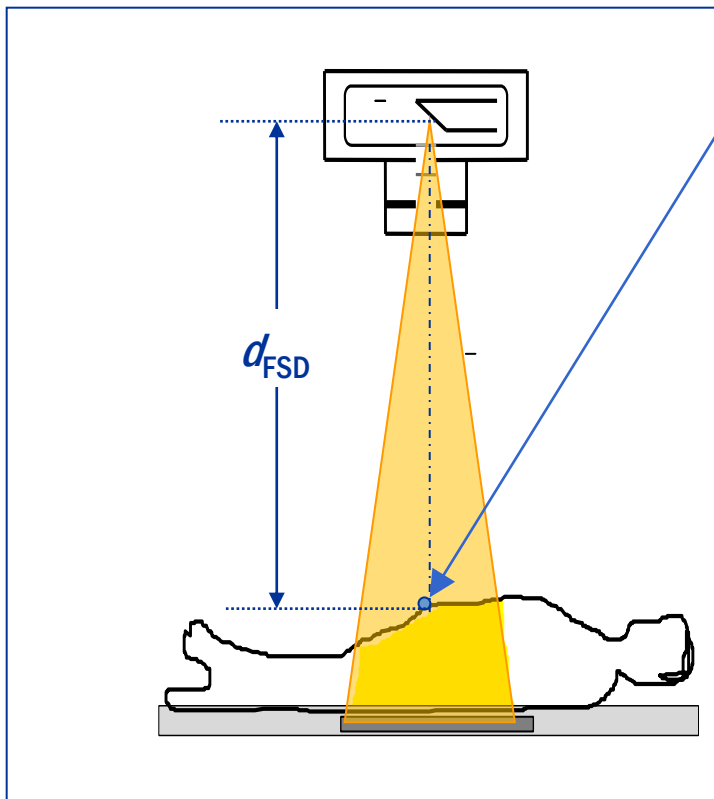


Incident air kerma, K_i

Unit: Gy

Free in air (no patient) at the patient entrance point

Dose quantities: Radiography



Entrance surface air kerma, K_e

Unit: Gy

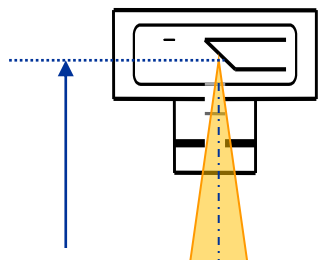
Also known as

Entrance surface dose, ESD

$$ESD \approx K_e$$

$$D_{\text{air}}(d) \approx K_{\text{air}}(d)$$

Dose quantities: Radiography



Entrance surface air kerma, K_e

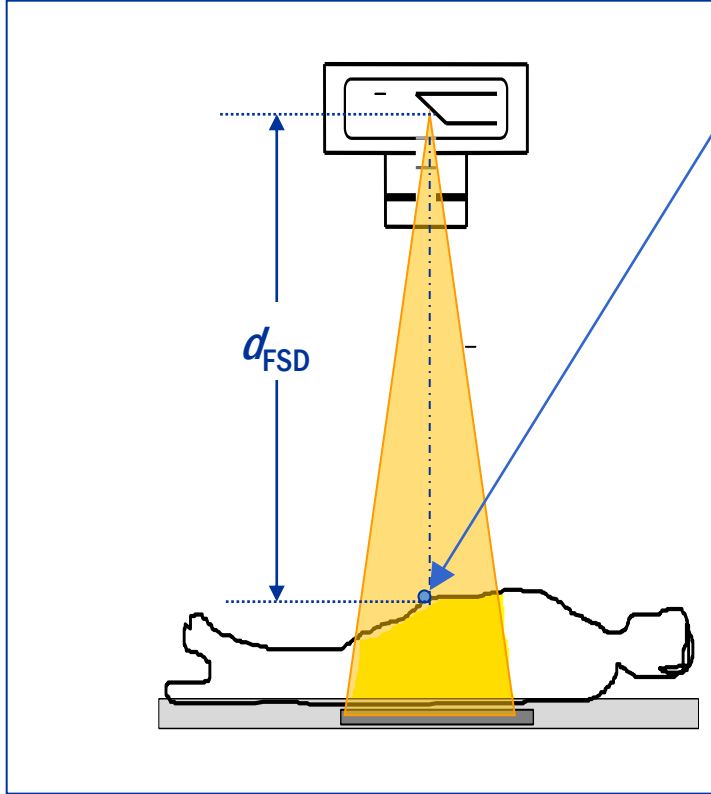
Unit: Gy

$$K_e = K_i \cdot B$$

Table A.2. Backscatter factors calculated by Monte Carlo techniques in an anthropomorphic phantom (Hart *et al.*, 1994a; 1994b).

HVL ₁ /mm Al	Peak tube voltage/kV	Total filtration/mm Al	Projection		
			Lateral LSJ ^a 11 cm × 14 cm	AP Abdomen 26 cm × 35cm	PA Chest 30 cm × 38cm
2.0	60	2.5	1.23	1.31	1.23
2.5	80	2.0	1.25	1.37	1.27
3.0	80	3.0	1.27	1.41	1.30
4.0	110	2.5	1.29	1.45	1.34

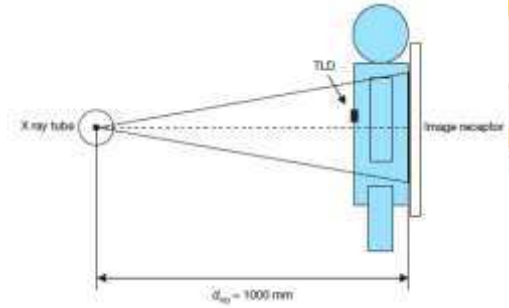
Dose quantities: Radiography



Entrance surface air kerma, K_e

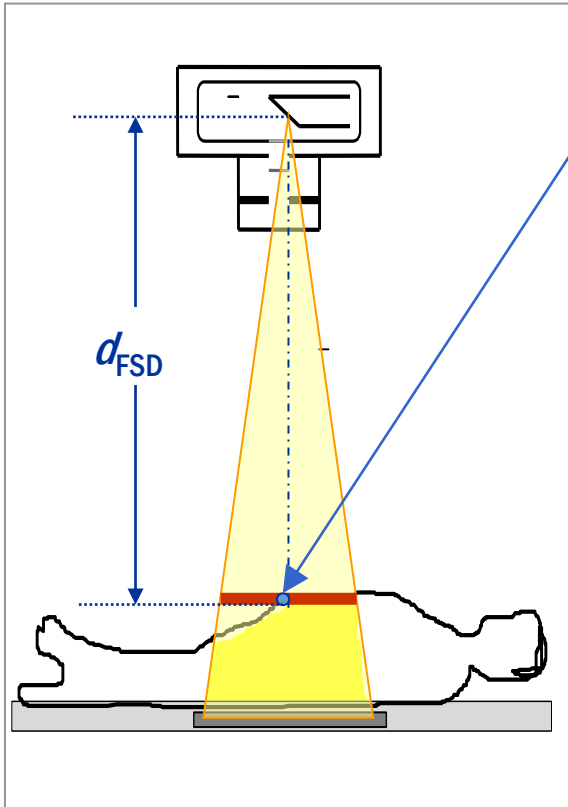
Method 1: Measurements using phantom

Method 2: Measurements with patients using TLDs



Method 3: Calculation from the tube output

Dose quantities: Radiography and fluoroscopy



Air kerma-area product, P_{KA}

$$P_{KA} = \iint_A K(A) dA$$

If $K = \text{const}$

$$P_{KA} = K \cdot A$$

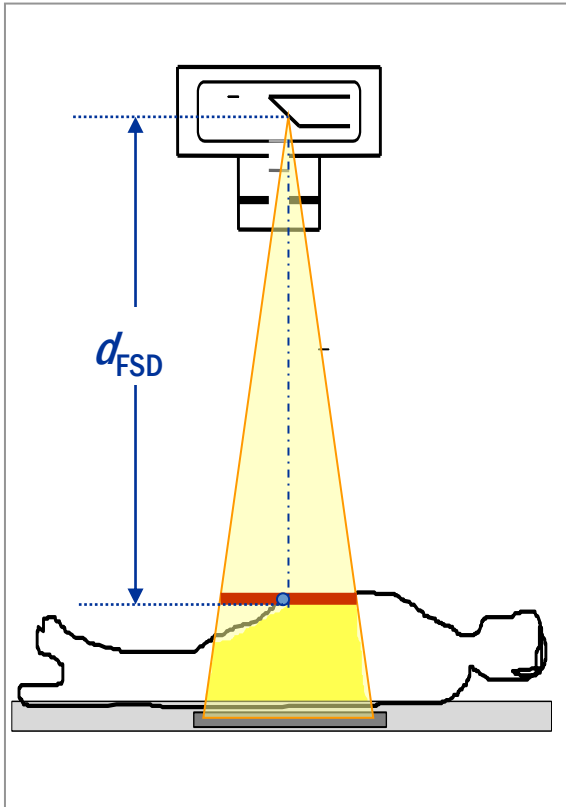
Also known as **Dose Area Product, DAP**

Unit: $\text{Gy} \cdot \text{m}^2$

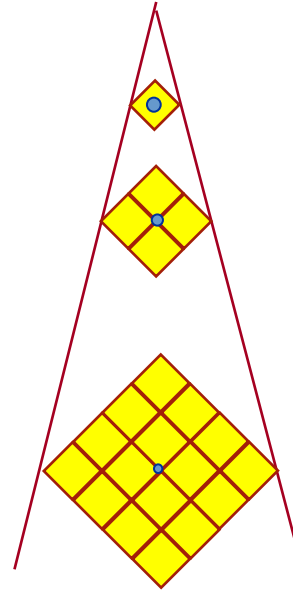
Practical units:

$$1 \mu\text{Gy} \cdot \text{m}^2 = 1 \text{cGy} \cdot \text{cm}^2$$

Dose quantities: Radiography and fluoroscopy



Air kerma-area product, P_{KA}



Kerma (dose) $\sim (1/f)^2$
Field area $\sim f^2$



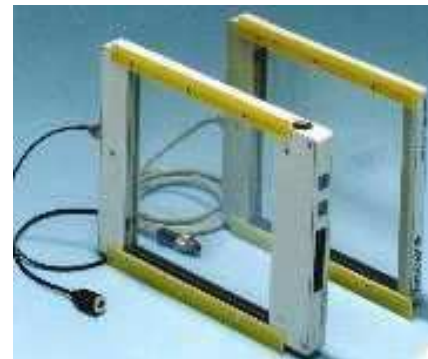
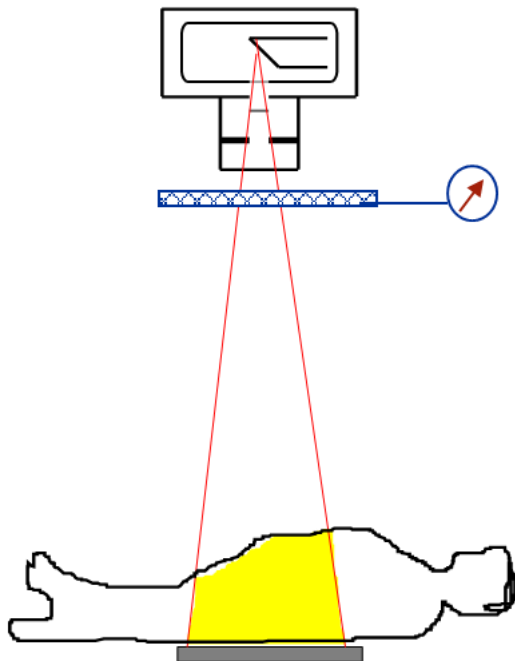
KAP is independent on
distance from focus

(neglecting attenuation in air,
extra-focal and scatter radiation)

Dose quantities: Radiography and fluoroscopy

Air kerma-area product, P_{KA}

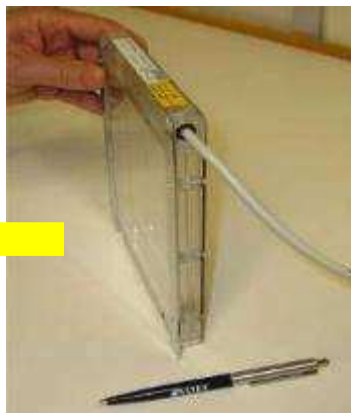
In-beam measurement with a large-size transparent ion chamber



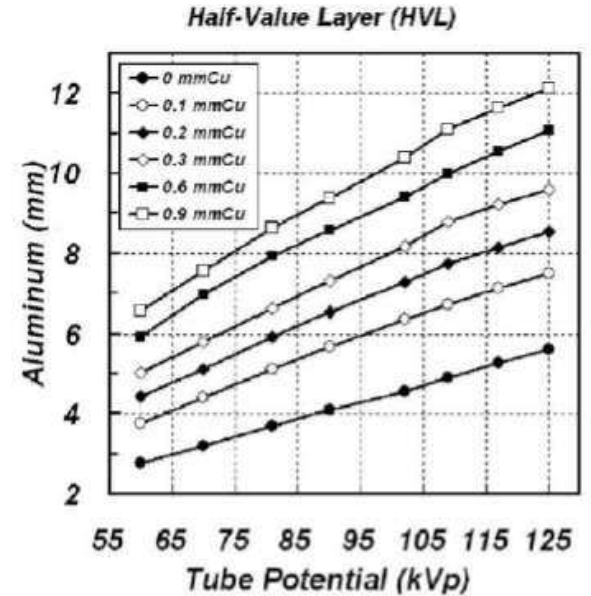
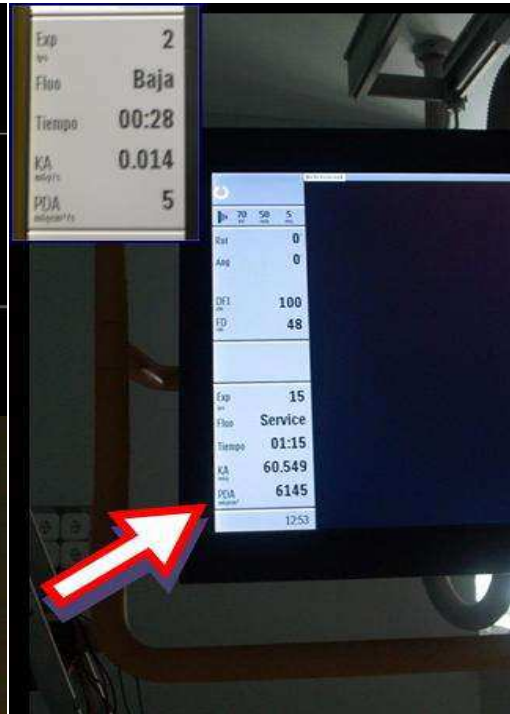
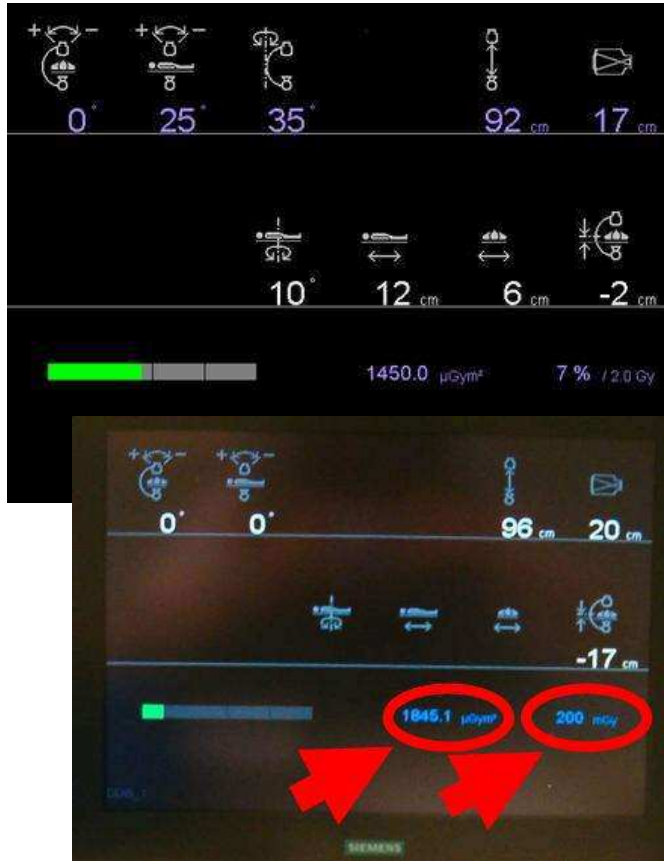
Measurement uncertainty 20 - 25 %
at the 95% confidence level

Dose quantities: Radiography and fluoroscopy

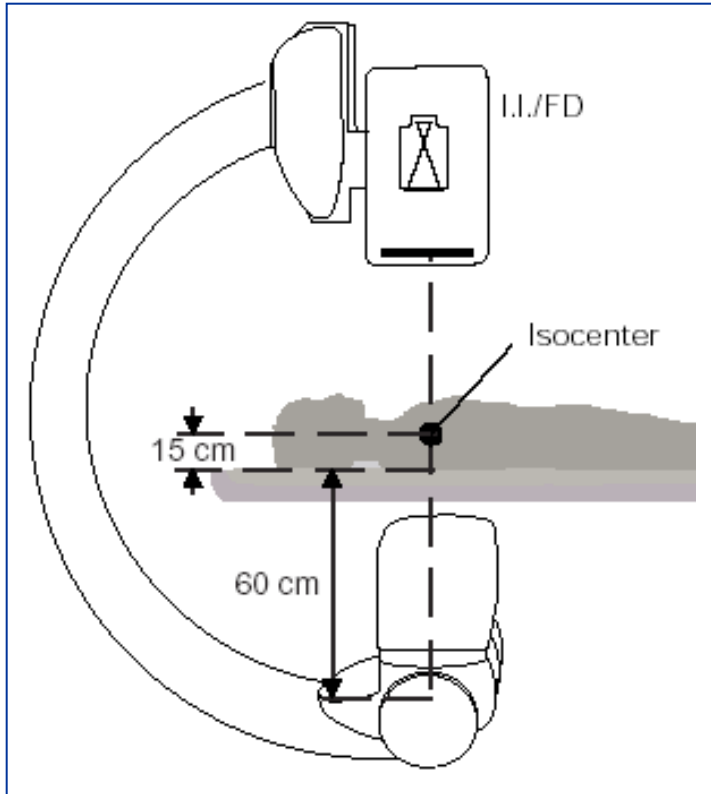
Air kerma-area product, P_{KA}



Dose quantities: Fluoroscopy

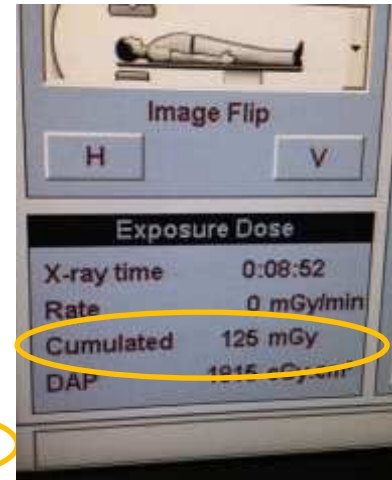


Dose quantities: Fluoroscopy

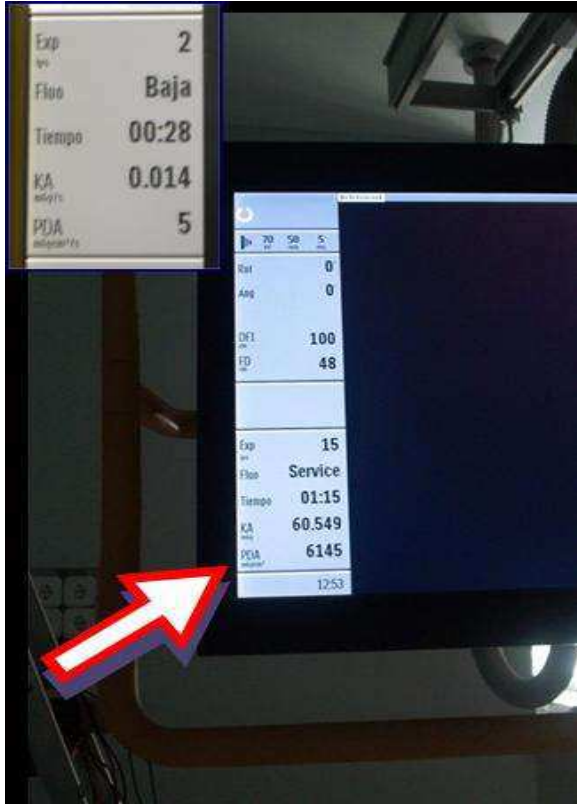


Air kerma at the interventional reference point, $CK_{a,r}$

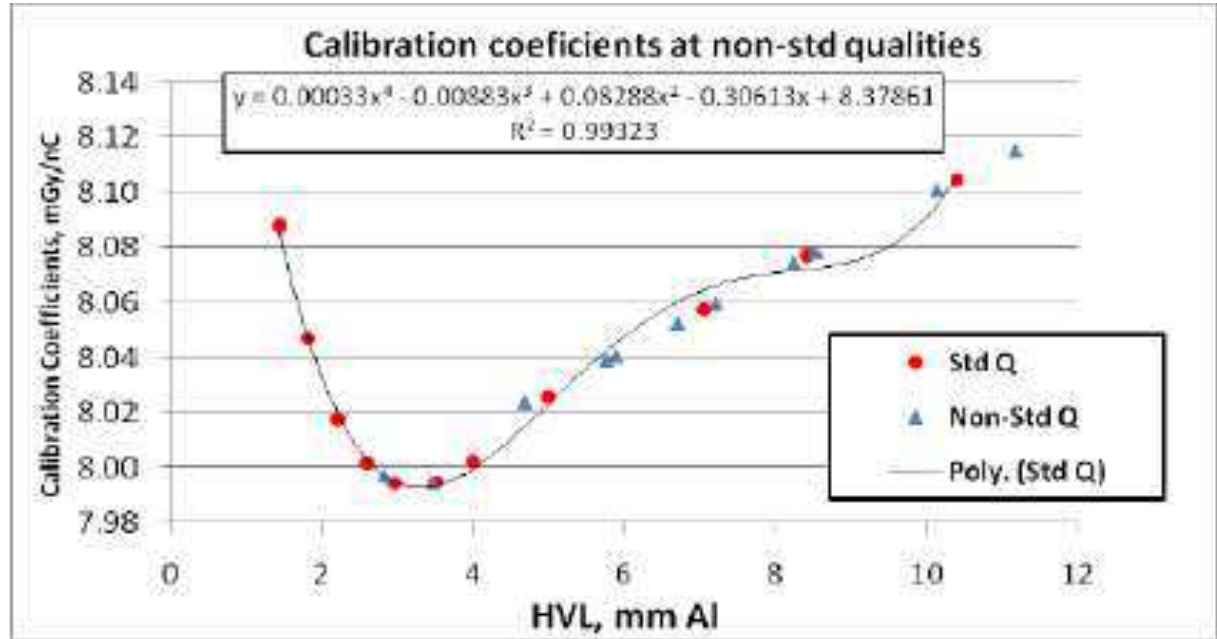
Unit: mGy (Cumulative dose)



Dose quantities: Fluoroscopy

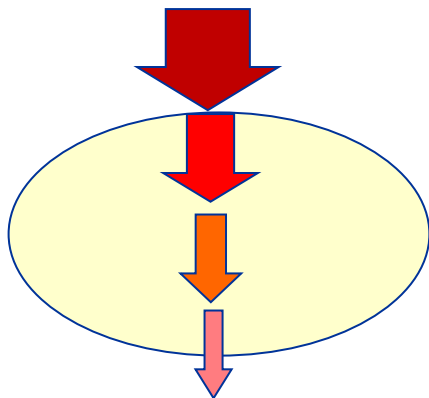


$K_{a,r}$ is calculated as $K_{a,r} = P_{KA} / A$



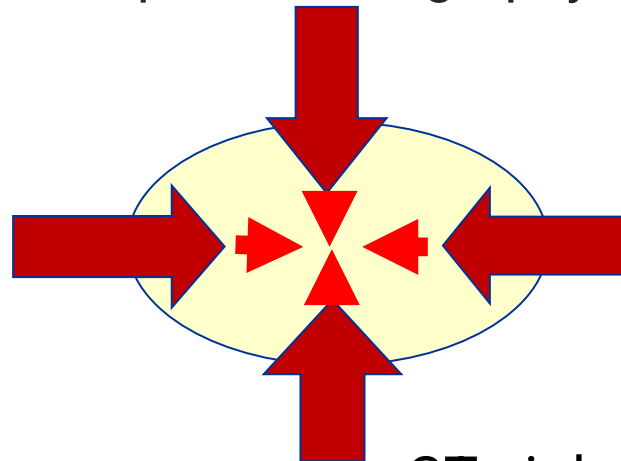
Dose quantities: Computed tomography

Radiography



Entrance surface air kerma

Computed tomography



CT air kerma index

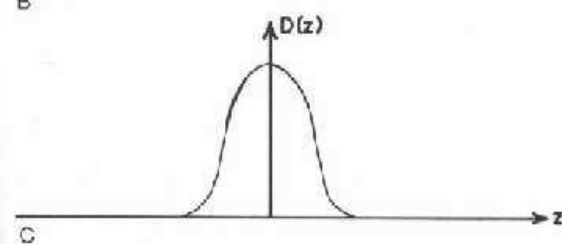
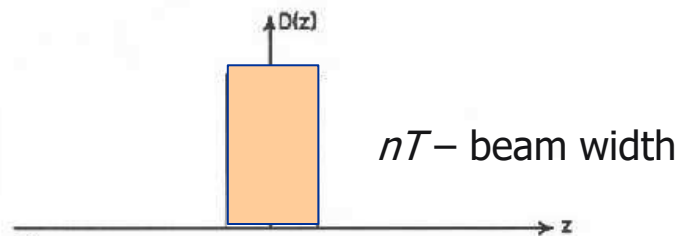
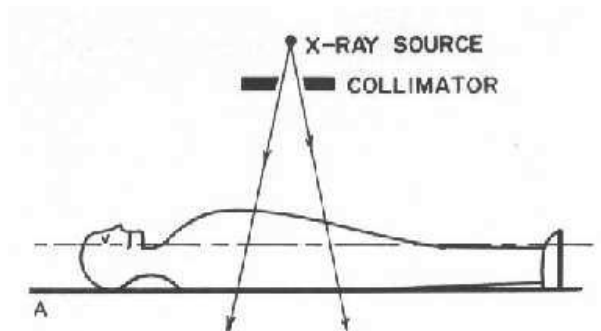
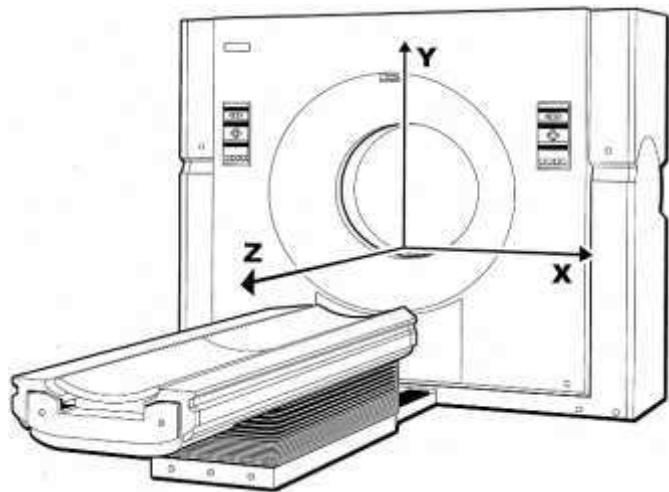
Dose quantities: Computed tomography



CT air kerma index C

Unit: Gy

$$C = \frac{1}{nT} \cdot \int K(z) \cdot dz$$

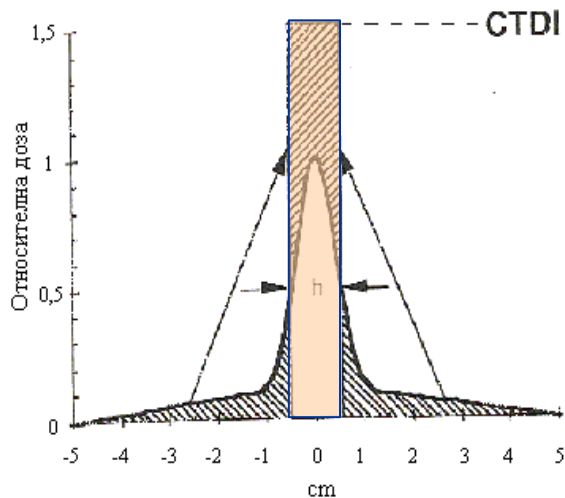


Dose quantities: Computed tomography

CT air kerma index C_{100} (also known as CTDI)

Unit: Gy

$$C_{100} = \frac{1}{nT} \cdot \int_{-50}^{+50} K(z) \cdot dz$$



Measured with ion chamber with a length 100 mm

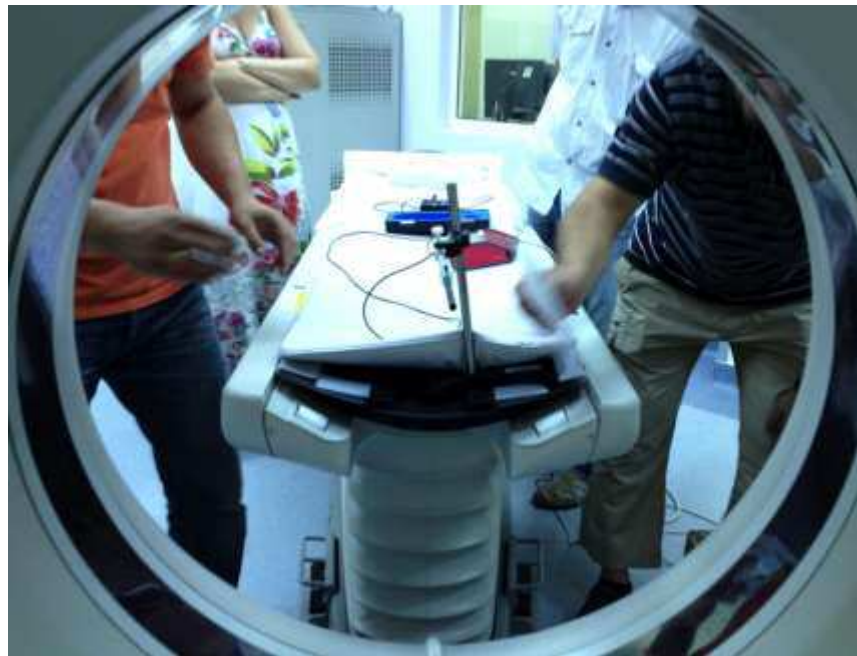
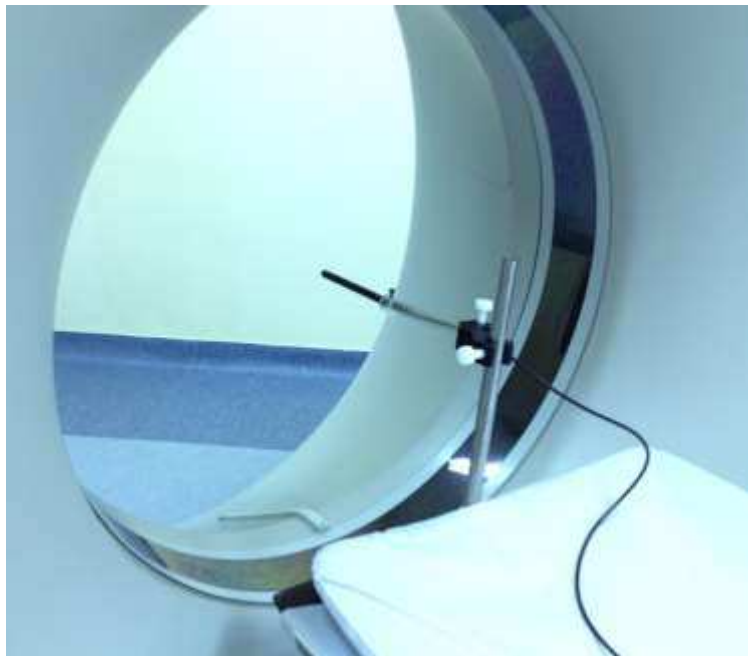


- In air
- In a phantom

Dose quantities: Computed tomography



CT air kerma index C_{100}
Measurements in air



Dose quantities: Computed tomography

CT air kerma index C_{100}

Measurements in a standard phantom



Body

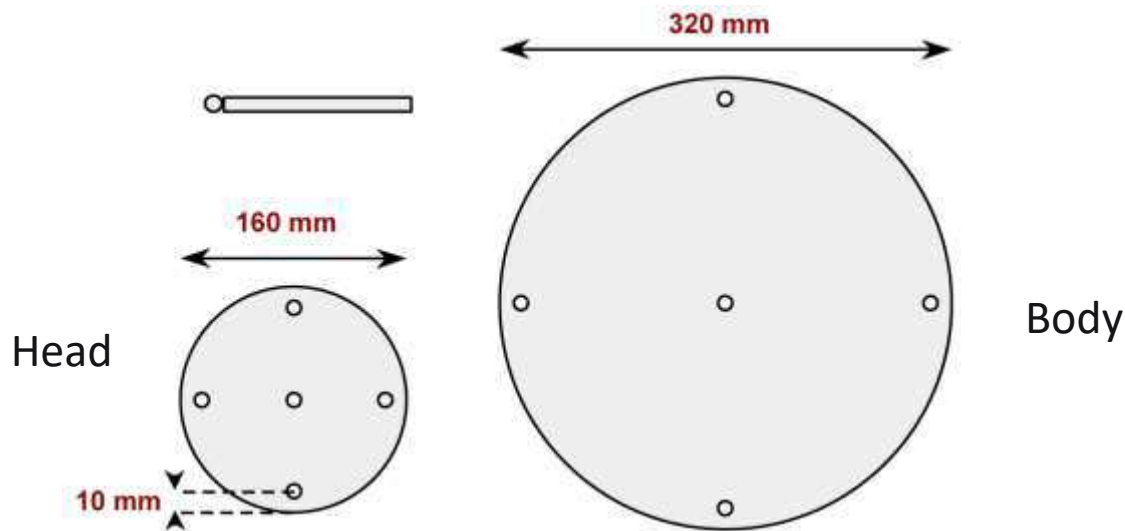


Head

Dose quantities: Computed tomography



Standard CT phantom



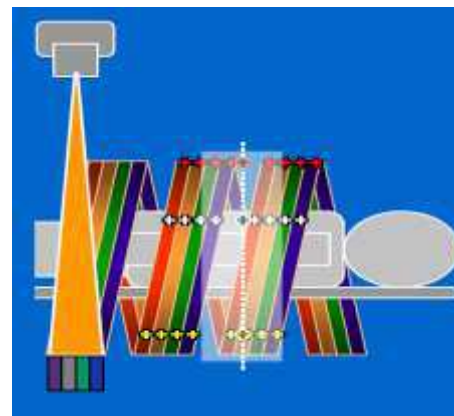
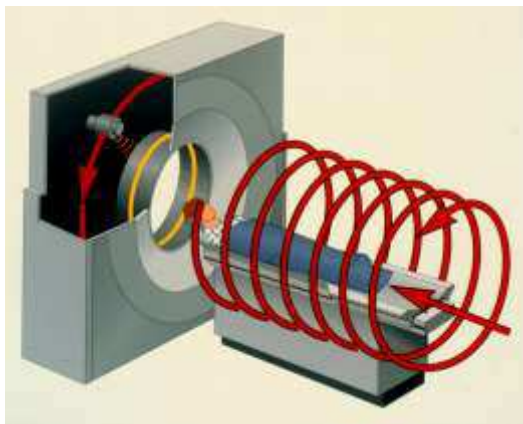
Weighted CTDI_w

$$C_w = \frac{1}{3}(C_{100,PMMA,c} + 2C_{100,PMMA,p})$$

$C_{100,PMMA,c}$ – in central hole

$C_{100,PMMA,p}$ – in peripheral holes (mean value)

Dose quantities: Computed tomography



For helical and MDCT: Volume CT kerma index, C_{vol}

$$C_{\text{vol}} = \frac{C_w}{p}$$

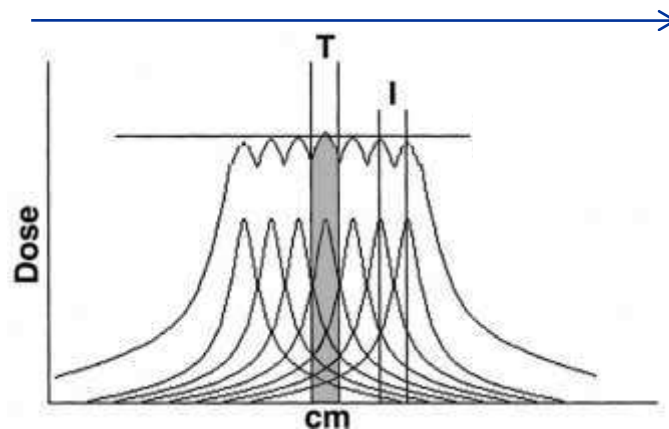
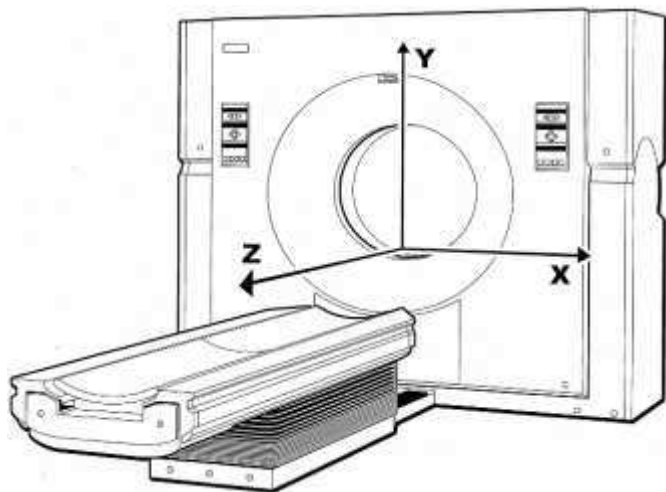
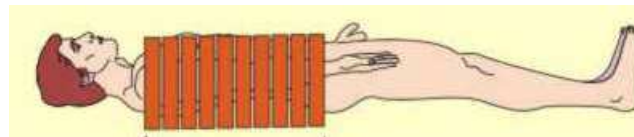
$$p = \frac{l}{NT}$$

p is pitch factor

Dose quantities: Computed tomography

For the entire exam: CT air kerma length - product P_{KL}
(also known as DLP) Unit: $mGy.cm$

$$DLP = CTDI_{vol} \times (Exposure_length)$$



Dose quantities: Computed tomography

The screenshot displays the control interface of a CT scanner. Key elements include:

- Anatomical Reference:** A 3D model of a patient on the scanner table.
- Filmng:** Settings for 'Camera' (None) and 'Apertion Setup'.
- Patient Orientation:** Head First, Patient Position: Supine.
- Buttons:** SN, Auto Store, Auto Transfer, Dose Report Auto Transfer, Show Localizer, Copy Pt Orient, Preparation and Ref.
- Series Description:** Perfusion D/O - 40min/1cc sec.
- Projected series DLP:** 1884.15 mGy·cm
- Accumulated exam DLP:** 0.00 mGy·cm
- Table:** A table with 19 columns: Images, Scan Type, Start Location, End Location, No. of Images, Thick Spred, Interval (mm), Gantry tilt, SFOV, kV, mA, Total Exposure Time, Prep Group (sec), 200 (sec), Breath Hold (sec), Breath time (sec), Voice Lights Timer, Cine Duration (sec).

Images	Scan Type	Start Location	End Location	No. of Images	Thick Spred	Interval (mm)	Gantry tilt	SFOV	kV	mA	Total Exposure Time	Prep Group (sec)	200 (sec)	Breath Hold (sec)	Breath time (sec)	Voice Lights Timer	Cine Duration (sec)
1-180	Dist Full 3.0 sec	115.000	115.000	180	5.0 43 1.00 sec	0.000	0.0	Head	80	300	45.01	5.0	1.0	N	N	N	45.0

Dose quantities: Computed tomography

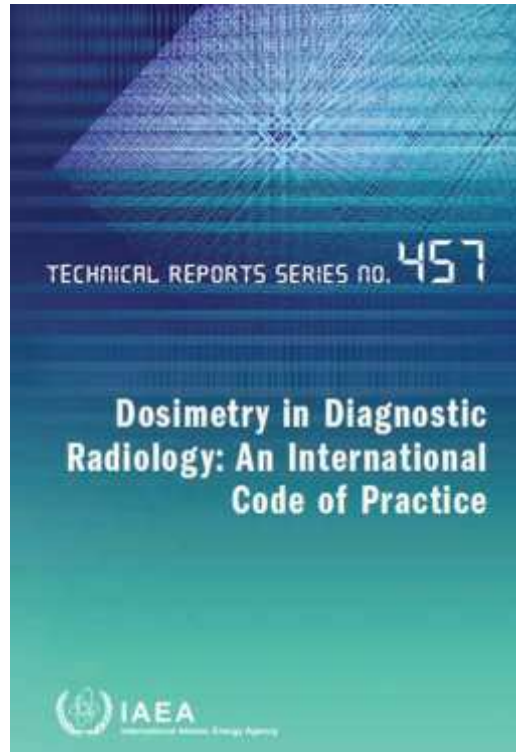


Exam Description: QA CT3

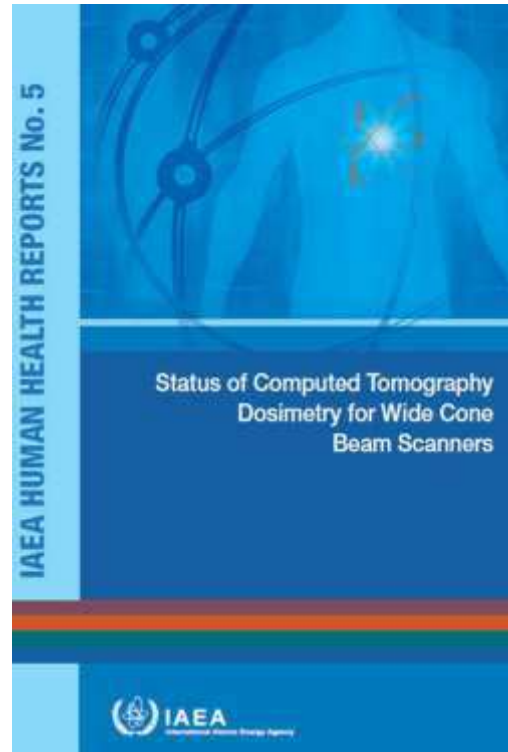
Dose Report

Series	Type	Scan Range (mm)	CTDIvol (mGy)	DLP (mGy-cm)	Phantom cm
1	Axial	50.000-50.000	64.38	64.38	Head 16
1	Axial	535.000-535.000	64.38	64.38	Head 16
1	Axial	550.000-550.000	64.38	64.38	Head 16
Total Exam DLP:				193.14	

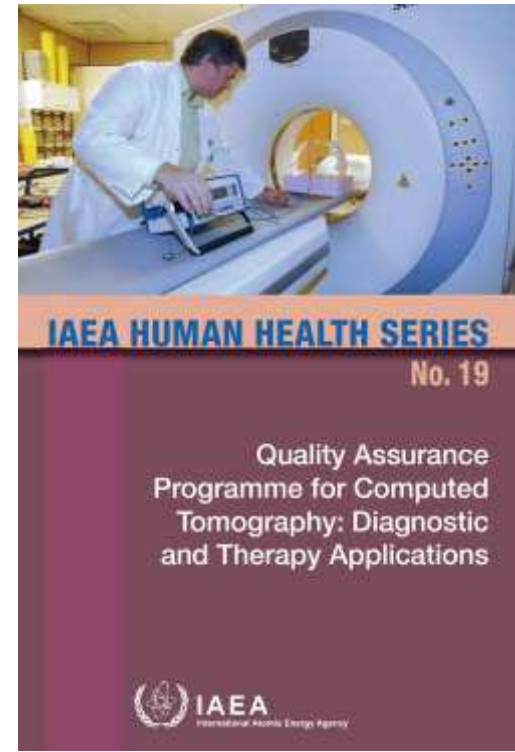
Dose quantities: Computed tomography



2007



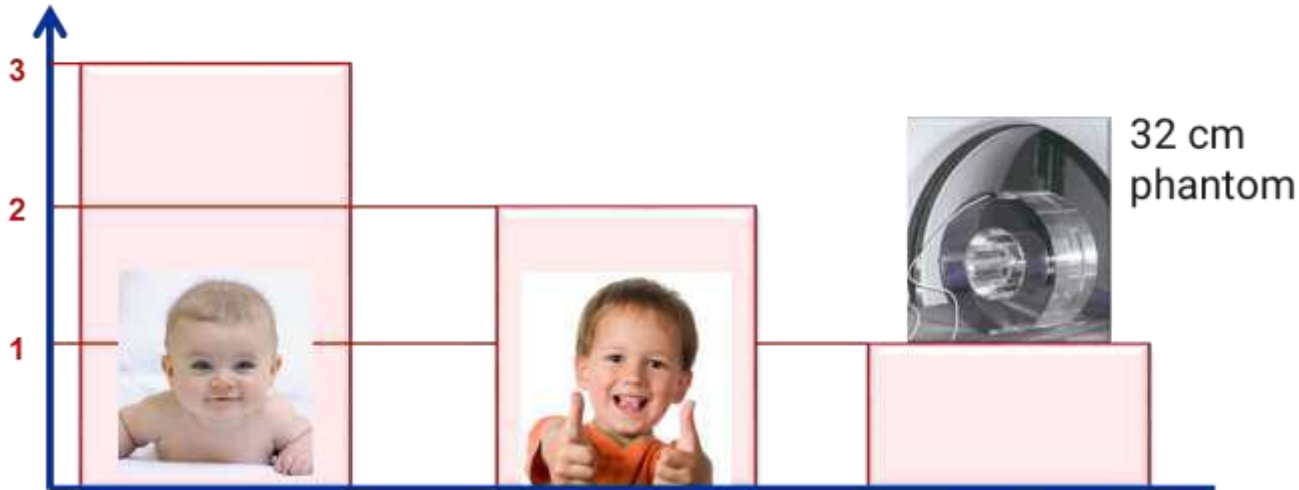
2011



2012

Dose quantities: Computed tomography

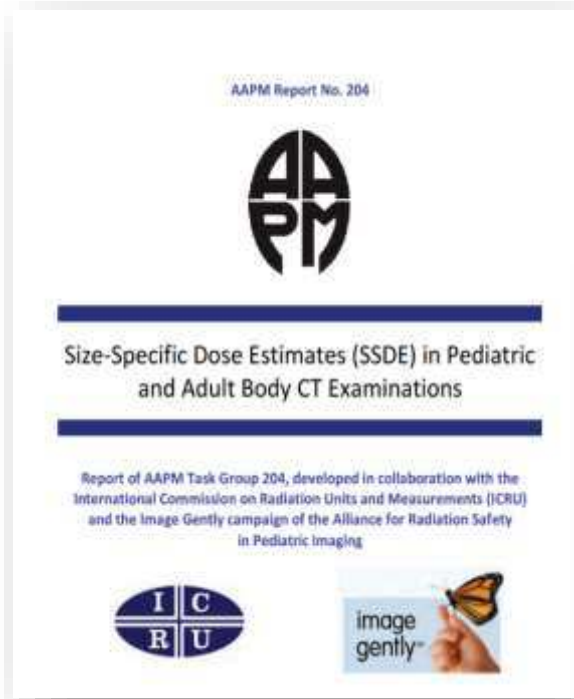
- CTDI \neq patient dose
- For the same protocol (set of exposure parameters) for an adult and a child \Rightarrow the same CTDI



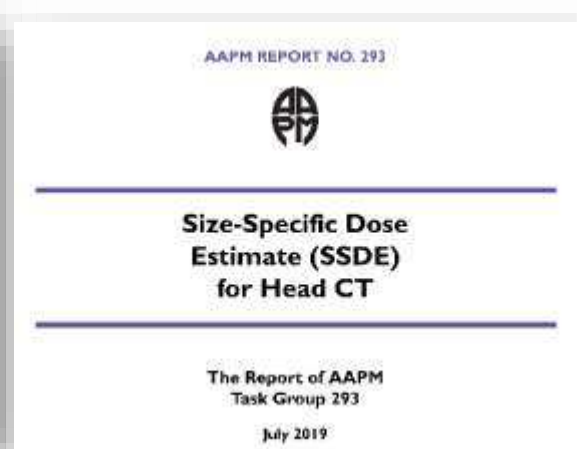
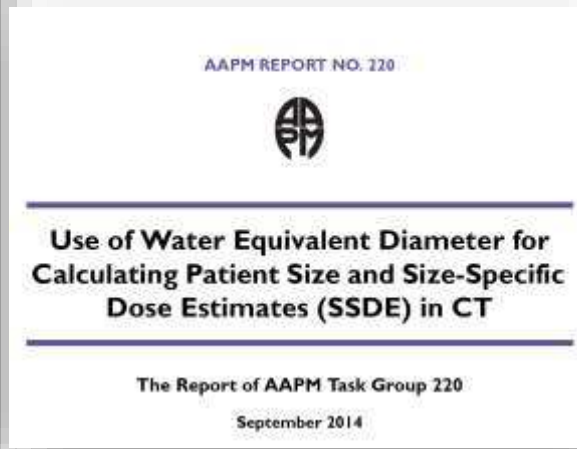
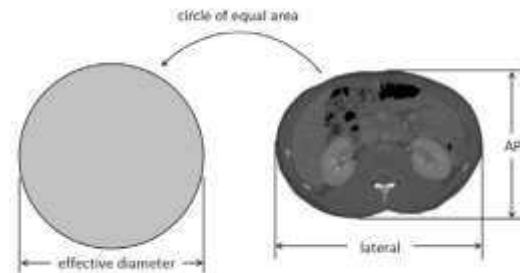
Absorbed dose in the child body will be 2-3 times higher

Dose quantities: Computed tomography

Size-specific dose estimate (SSDE)



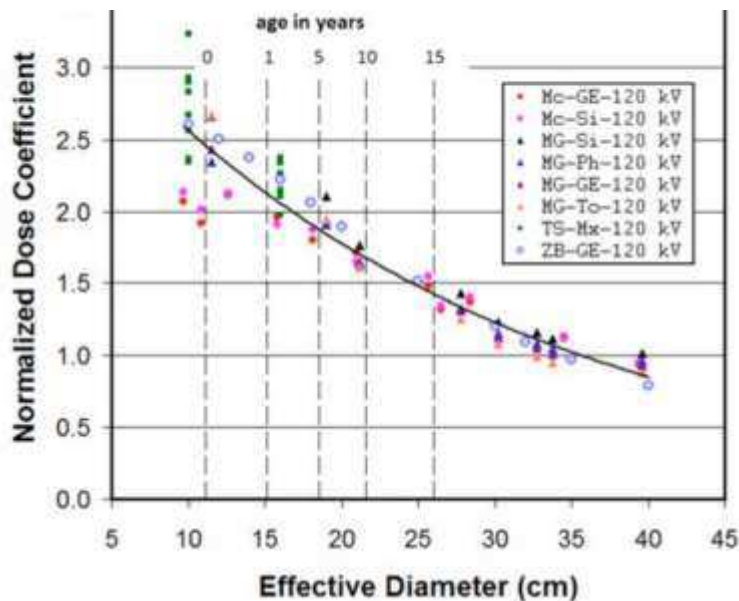
$$\text{effective diameter} = \sqrt{AP \times LAT}$$



Dose quantities: Computed tomography

Size-specific dose estimate (SSDE)

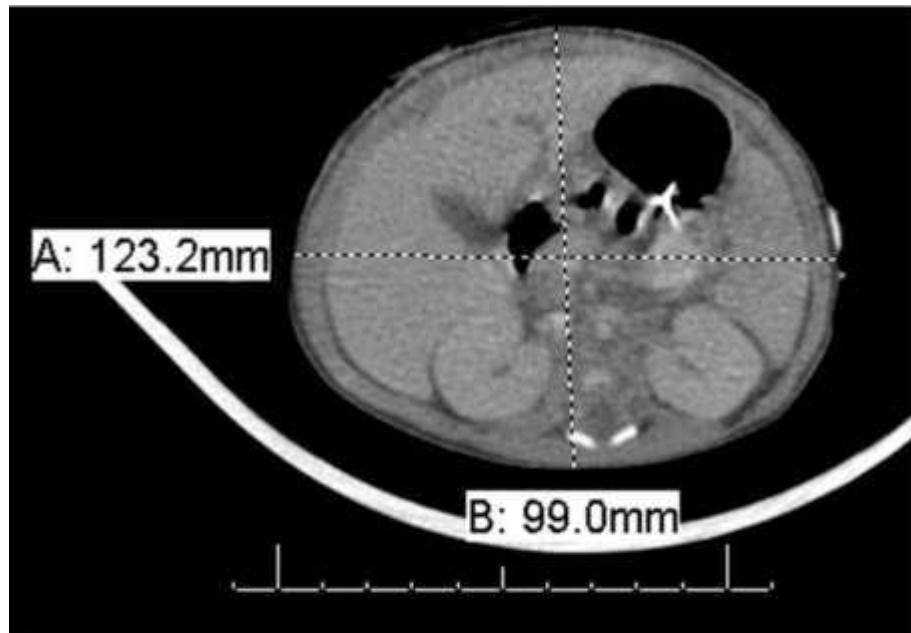
$$\text{size specific dose estimate} = \text{SSDE} = f_{\text{size}}^{32X} \times \text{CTDI}_{\text{vol}}^{32}$$



Effective Dia (cm)	Conversion Factor
8	2.76
9	2.66
10	2.57
11	2.47
12	2.38
13	2.30
14	2.22
15	2.14
16	2.06
17	1.98
18	1.91
19	1.84
20	1.78
21	1.71
22	1.65
23	1.59
24	1.53
25	1.48
26	1.43
27	1.37
28	1.32
29	1.28
30	1.23
31	1.19
32	1.14
33	1.10
34	1.06
35	1.02
36	0.99
37	0.95
38	0.92
39	0.88
40	0.85
41	0.82
42	0.79
43	0.76
44	0.74
45	0.71

Dose quantities: Computed tomography

Size-specific dose estimate (SSDE)



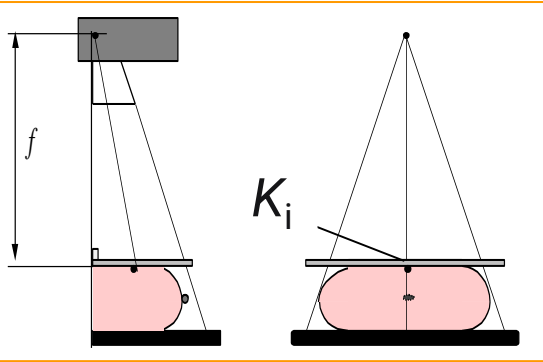
5.40 mGy = CTDIvol (32 cm phantom)

Example: Effective diameter 11 cm

$$f = 2.5$$

$$\text{SSDE} = 5.4 \times 2.5 = 13 \text{ mGy}$$

Dose quantities: Mammography



- Incident air kerma, K_i
the air kerma from the incident beam on the central x-ray beam axis at the skin entrance plane, backscatter excluded



- Measured with an ionization detector:
- Free in air
 - With a standard PMMA phantom



Modality specific metrics

Modality

Plain radiography,
including dental

Mammography

Fluoroscopy &
fluoroscopy guided
interventional
procedures

Computed tomography

Dose quantity

Entrance surface air kerma, K_e
Kerma-area product, P_{KA}

Incident air kerma, K_i
Mean glandular dose, MGD

Kerma-area product, P_{KA}
Cumulative air kerma at the
interventional reference point

CT air kerma index, C
Air kerma-length product, L_{KP}

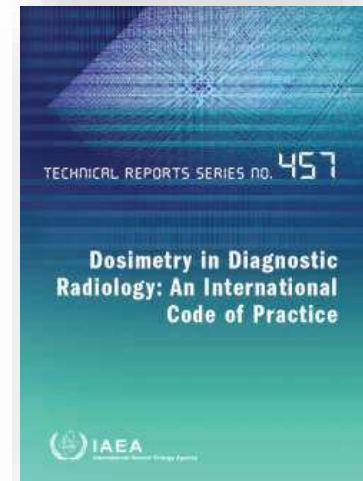
Dose unit

mGy
 $\mu\text{Gy}\cdot\text{m}^2$

mGy
mGy

$\text{Gy}\cdot\text{cm}^2$
mGy

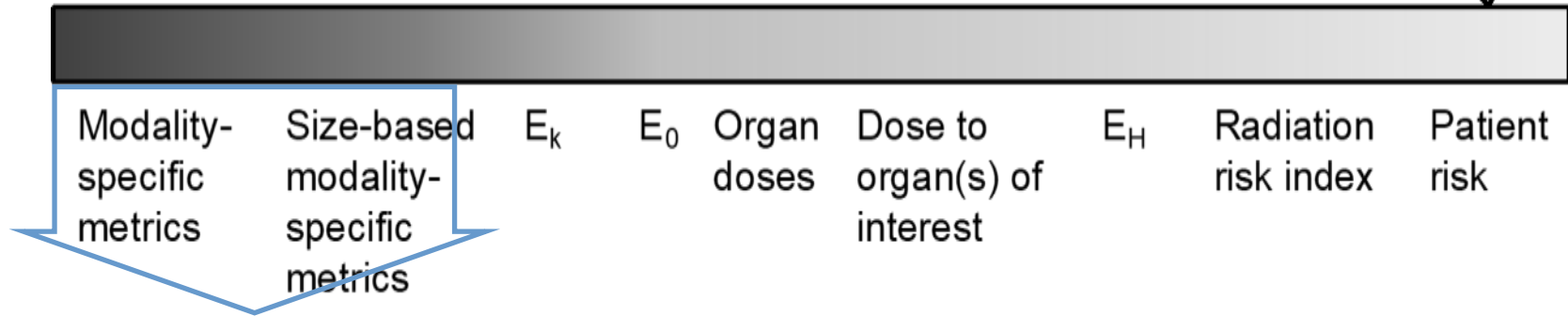
mGy
 $\text{mGy}\cdot\text{cm}$



Why we need to know patient dose?



Goal



Measurable quantities

- Quality assurance
- For performance assessment of an imaging system and QC
- For benchmarking to DRLs
- For optimization of clinical protocols

Modality specific dose metrics

- Used to estimate typical dose values

Chest X-ray, Adult patient (average weight 70 kg)

Room 1:

Median = 0.1 Gy.cm²

Room 2:

Median = 0.05 Gy.cm²

Room 2:

Median = 0.2 Gy.cm²

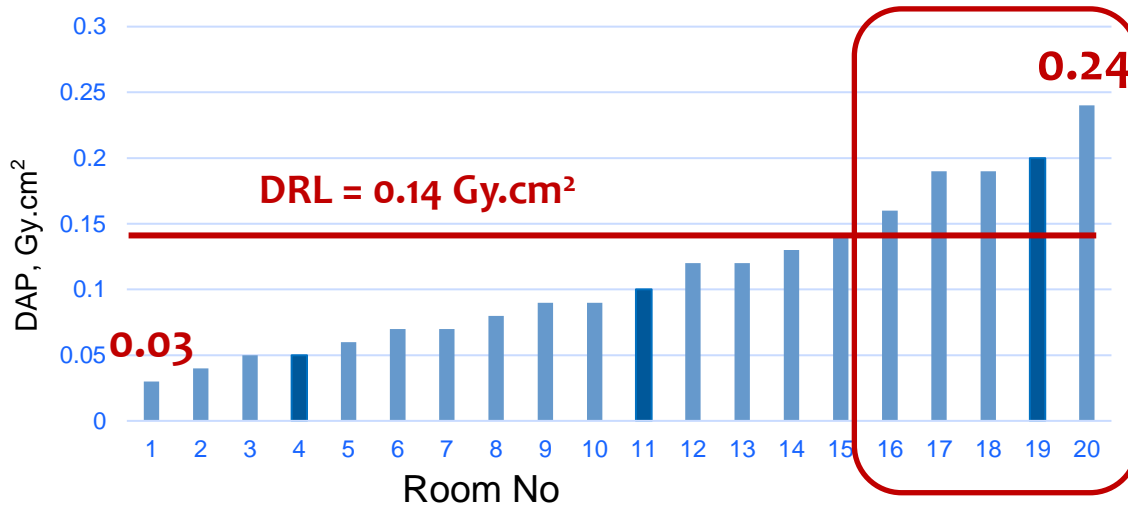


Modality specific dose metrics

- Used to establish DRLs

Chest X-ray, Adult patient (average weight 70 kg)

Typical DAP values in 20 X-ray rooms



Investigation and actions to reduce doses!

Patient exposure monitoring workflow



1. Manual recording (at modality):

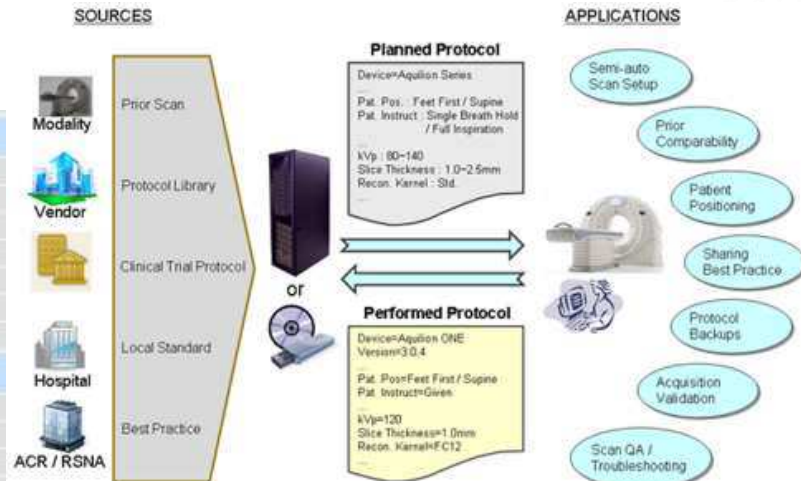
- Paper
- Into RIS

2. Electronic recording of radiation exposure details in a standard format (at modality):

- Non-DICOM dose objects
 - Modality Performed Procedure Step (MPPS) to HIS/RIS
 - Image “header” attributes
 - Bitmap (graphic) images in PACS and Optical character recognition (OCR) conversion
- DICOM object:
 - For each radiation event
 - Collected in a unique object (**DICOM Radiation Dose Structured Report**): Includes patient demographics, study information, imaging technique, geometry and dose metrics

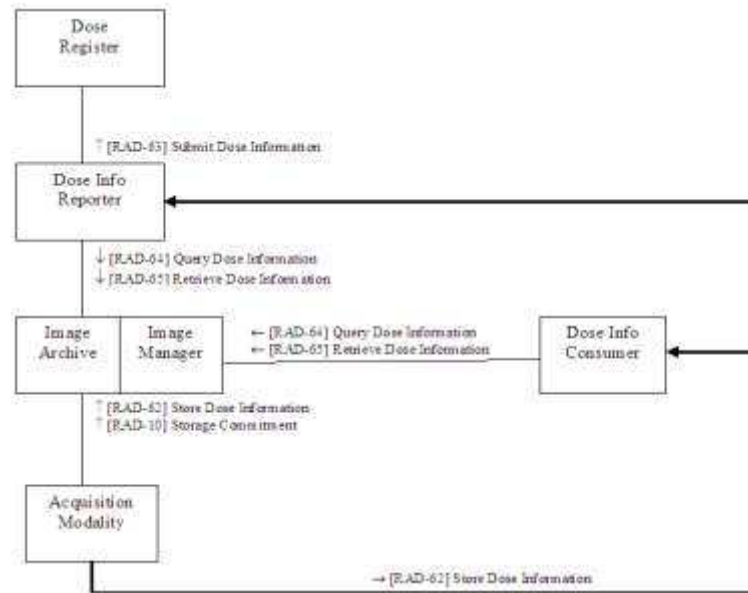
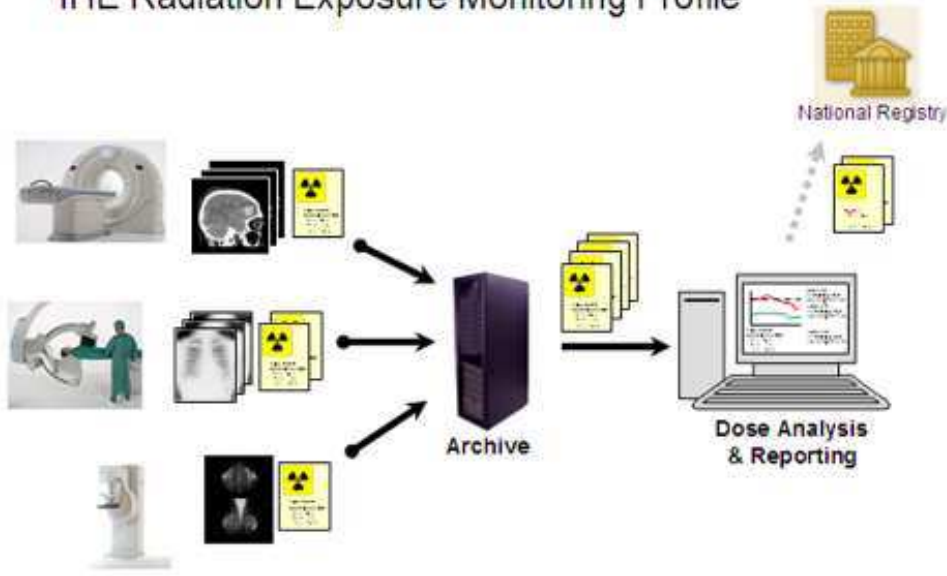
DICOM RDSR

CT Acquisition Parameters	
Exposure Time	7.98s
Scanning Length	357mm
Exposed Range	350mm
Nominal Single Collimation Width	0.6mm
Nominal Total Collimation Width	19.2mm
Pitch Factor	1.2ratio
Number of X-Ray Sources	1X-Ray sources
CT X-Ray Source Parameters	
Identification of the X-Ray Source	A
KVP	120kV
Maximum X-Ray Tube Current	391mA
X-Ray Tube Current	161mA
Exposure Time per Rotation	0.5s
CT Dose	
Mean CTDIvol	5.11mGy
CTDIw Phantom Type	
DLP	183.31mGy.cm
Dose Check Alert Details	
DLP Alert Value Configured	
CTDIvol Alert Value Configured	
CTDIvol Alert Value	1000mGy
Dose Check Notification Details	
DLP Notification Value Configured	
CTDIvol Notification Value Configured	
X-Ray Modulation Type	XYZ_EC
Comment	Internal technical scan parameters: Organ Characteristic = Thorax, Body Size = Adult, Body Region = Body, X-ray Modulation Type = XYZ_EC



Automatic radiation exposure monitoring

IHE Radiation Exposure Monitoring Profile



<https://www.ihe.net/>

Automatic radiation exposure monitoring

- Commercial products



itn
IMAGING TECHNOLOGY NEWS

Last updated on November 28, 2018

Radiation Dose Management Comparison Chart

Company	Product
Agfa Healthcare	Enterprise Dose-Management (powered by DoseMonitor)
Bayer Healthcare LLC	Radimetrics Enterprise Platform
Bracco Diagnostics	NEXO[DOSE]
Canon Medical	Dose Tracking System
Canon Medical	Spot Fluoroscopy
Fujifilm Medical Systems U.S.A., Inc.	FDX Console (common acquisition workstation for all Fujifilm DR portable and room solutions)
Fujifilm Medical Systems U.S.A., Inc.	Aspire AWS Console (common acquisition workstation for all Fujifilm mammography solutions)
GE Healthcare	DoseWatch
GE Healthcare	DoseWatch Explore
Gaerbet LLC	Dose&Care
Imalogix	Imalogix
Infinitt Healthcare	DoseM
Medic Vision Imaging Solutions Ltd.	SafeCT
MyXrayDose Ltd.	MyXrayDose
PHS Technologies Group, LLC (PACSHesht, LLC) Group, LLC	DoseMonitor, NexoDose, NovaDose, Radiation Dose Monitoring by Agfa
Philips	DoseWise Portal
Qaelum	DOSE
Sectra Inc.	Sectra DoseTrack

<https://www.itnonline.com/chart/radiation-dose-management>

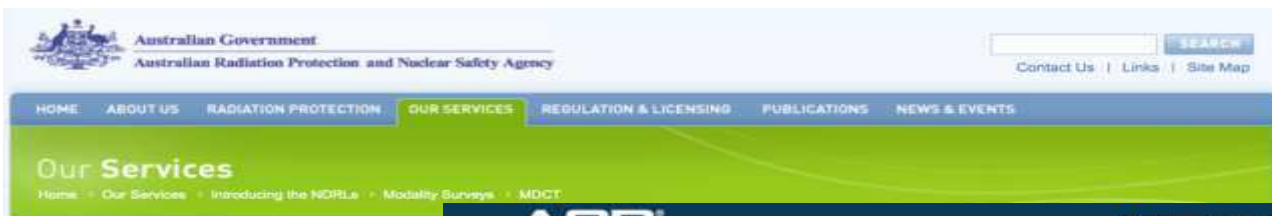
Automatic radiation exposure monitoring



- Free software
 - OpenREM by Ed McDonagh - Python SourceCode
 - Pixelmed DoseUtility
 - CT Dose OCR by Philip Cheng at USC - ARRS Abstract
 - Generalized Radiation Observation Kit (GROK) by Graham Warden at Brigham & Women's Hospital - Source Code
 - Siemens CARE Analytics (free Windows executable)
 - NIH-CIPS Radiation Exposure Extraction Engine (RE3) - Source Code - SPIE Abstract - JDI Article

Establishing DRLs and typical doses

- National/ regional dose registries



The screenshot shows the homepage of the Australian Radiation Protection and Nuclear Safety Agency. The header includes the Australian Government logo and the agency name. A search bar is located in the top right corner. The main navigation menu includes links for HOME, ABOUT US, RADIATION PROTECTION, OUR SERVICES, REGULATION & LICENSING, PUBLICATIONS, and NEWS & EVENTS. The 'Our Services' section is highlighted in green, with a breadcrumb trail: Home > Our Services > Introducing the NDRLs > Mortality Surveys > MDCT.



This screenshot shows a sidebar menu of services from the Australian Radiation Protection and Nuclear Safety Agency website. The services listed include: Introduction, Personal Radiation Monitoring Service, Equipment Calibration and Testing, Radioanalytical Services, ELF Magnetic Field Meter Hire, Ultraviolet Radiation (UVR) Services, UV Data, UV Resource Guide, Megavoltage Photon Audit Service, High Energy Radiation Beams (LINAC), and Radiation Safety Advice and Risk Evaluation. A 'Login to the Nation' button is visible at the bottom.



The screenshot displays the American College of Radiology (ACR) website, specifically the 'Dose Index Registry' page. The header features the ACR logo and navigation links for HOME, ANNUAL MEETING, EDUCATION, QUALITY & SAFETY, ADVOCACY, MEMBERSHIP, RESEARCH, NEWS & PUBLICATIONS, and MEETINGS/COURSES. The main content area is titled 'Dose Index Registry' and contains the following text:

The Dose Index Registry (DIR) is a data registry that allows facilities to compare their CT dose indices to regional and national values. Information related to dose indices for all CT exams is collected, anonymized, transmitted to the ACR, and stored in a database. Institutions are then provided with periodic feedback reports comparing their results by body part and exam type to aggregate results.

The American Board of Radiology has qualified the DIR registry as meeting the criteria for practice quality improvement (PQI), toward the purpose of fulfilling requirements in the ABR Maintenance of Certification Program.

Read more about Data Transmission and Compatible Vendors>>

Please see our Registration Process and Fee Schedule to get started with the registration process.

On the right side of the page, there is a 'LOG IN TO NRDR' section with a 'LOGIN' button, and a promotional banner for 'amphion Transcription Solutions' with a 'Learn More >>' link. At the bottom right, there is a 'PowerServer™ Cloud' logo.

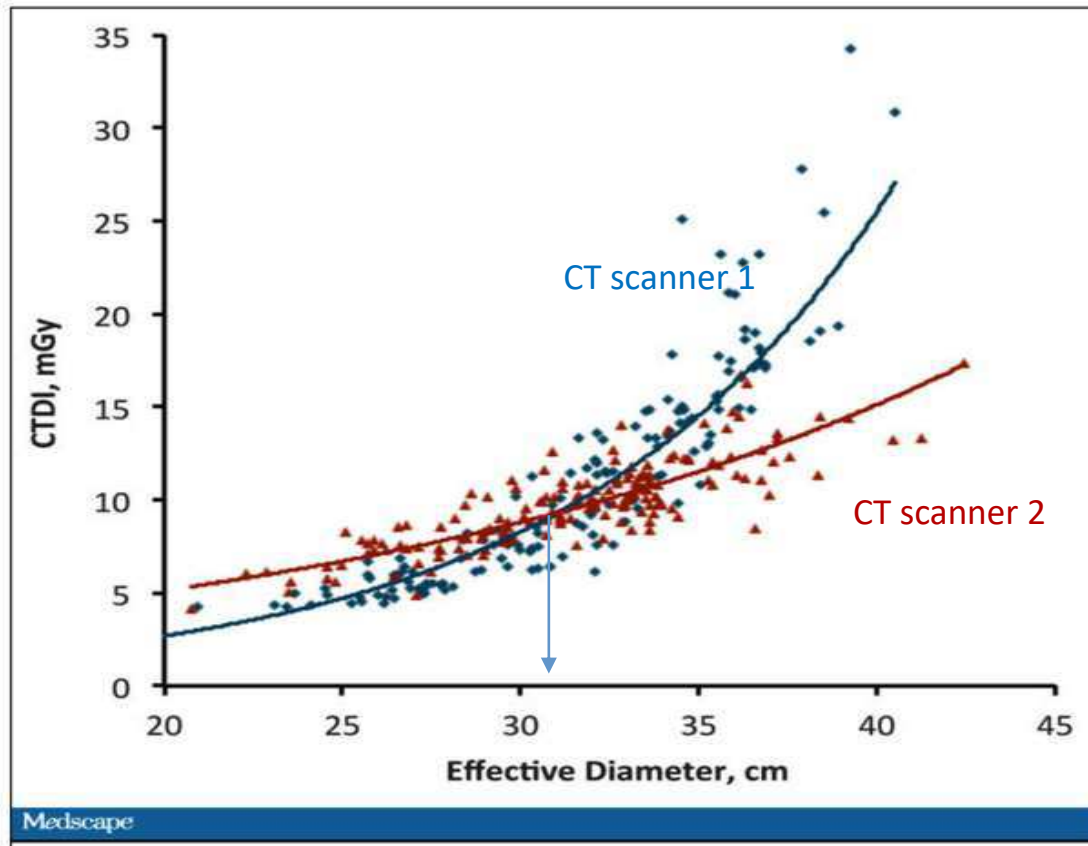
Analysis: Benchmarking against DRLs



Sum of DIAPHRAGM vs. Position of DIAPHRAGM broken down by facility_description and protocol_name. Details are shown for various dimensions. The view is filtered on study_date_time_Quarter, se_name, series_type, standard_study_description and facility_description. The study_date_time_Quarter filter keeps 8 of 20 members. The se_name filter keeps CT15A-UWMC/CT15A, CT15B-UWMC/CT15B, CT15C-UWMC/CT15C, CT15D-UWMC/CT15D, CT15E-UWMC/CT15E, CT15F-UWMC/CT15F, CT15G-UWMC/CT15G, CT15H-UWMC/CT15H, CT15I-UWMC/CT15I, CT15J-UWMC/CT15J, CT15K-UWMC/CT15K, CT15L-UWMC/CT15L, CT15M-UWMC/CT15M, CT15N-UWMC/CT15N, CT15O-UWMC/CT15O, CT15P-UWMC/CT15P, CT15Q-UWMC/CT15Q, CT15R-UWMC/CT15R, CT15S-UWMC/CT15S, CT15T-UWMC/CT15T, CT15U-UWMC/CT15U, CT15V-UWMC/CT15V, CT15W-UWMC/CT15W, CT15X-UWMC/CT15X, CT15Y-UWMC/CT15Y, CT15Z-UWMC/CT15Z. The series_type filter keeps Sequential and Spiral. The standard_study_description filter keeps RPID249:RAD ORDER CT CHST ABD PELVIS W/VC0N. The facility_description filter keeps University of Washington.

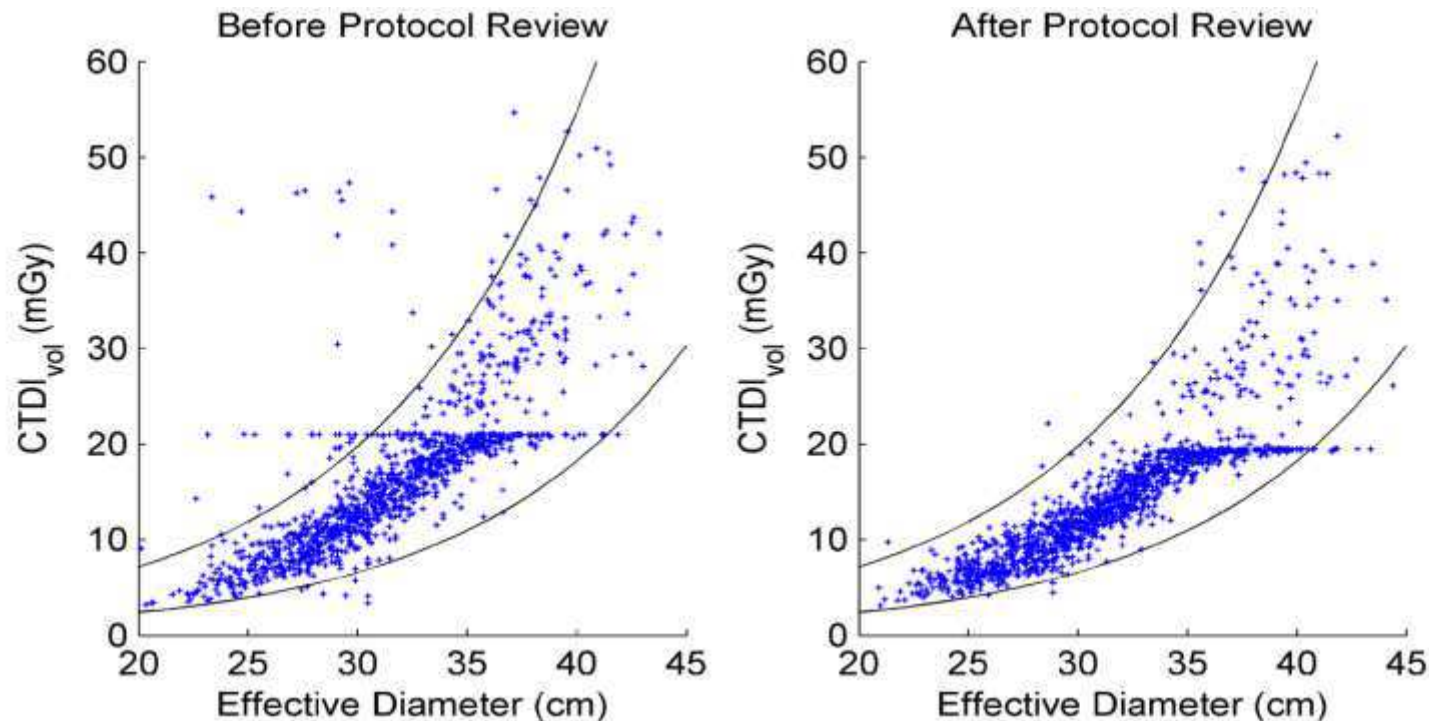
Courtesy K. Kanal

Analysis: Inter-system variability



D.Frush; E. Samei, CT Radiation Dose Monitoring: Current State and New Prospects, Medscape Radiology, 2015

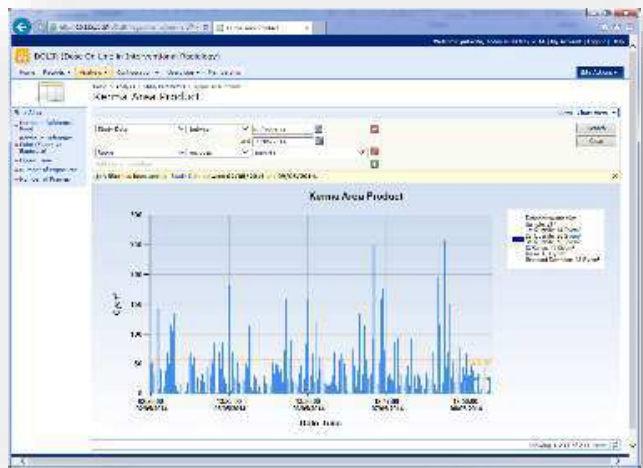
Analysis: Identifying and investigating over-exposure and under-exposure



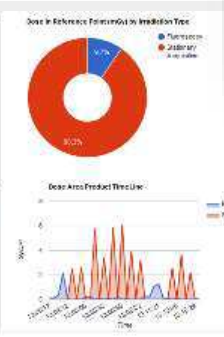
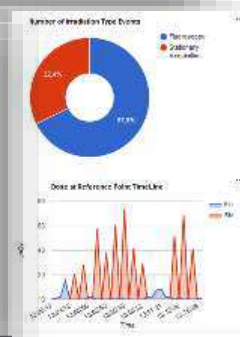
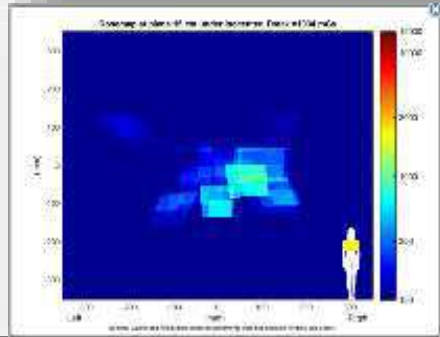
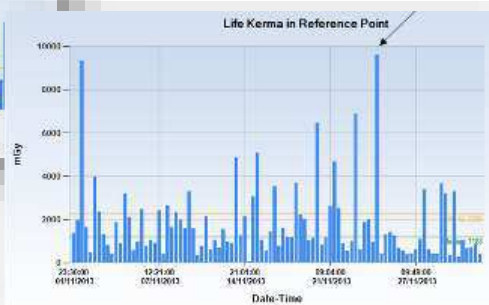
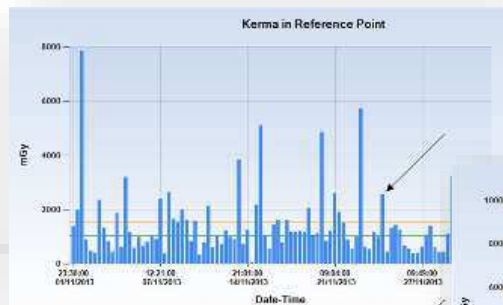
Courtesy E. Samei, DUMC

Dose monitoring in interventional radiology

Madrid: DOLIR (Dose On Line for Interventional Radiology)



“Life KAP” and “Life CAK” – cumulative doses values of all the procedures performed on the same patient
Clinical follow-up protocol for patients with CAK and Life CAK values > 5 Gy



Courtesy E. Vano & R. Sanchez

① Why we need to know patient dose?

② Modality specific dose metrics

③ Patient specific metrics



Dose metrics



Modality-specific metrics



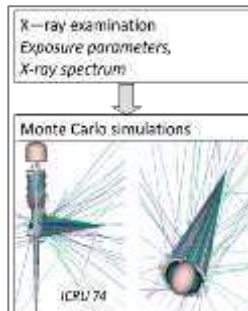
Modality specific metrics

Size-specific metrics

For CT: SSDE (AAPM TG204, 220 and 293)



Organ doses



Effective dose

$$E = \sum_T w_T H_T$$

	ICRP 60	ICRP 103
Brain (nasal cavity, lung, stomach)	0.12	0.13
Brain	0.05	0.12
Colon	0.35	0.09
Bladder, oesophagus, liver, thyroid	0.05	0.04
Stomach, skin, bone	0.01	0.01
Breast	0.01	0.01
Salivary glands, haematopoietic tissue	0.01	0.12

Radiation risk index

To account for organs exposed, patient age, gender (BEIR 2006, ICRP 2007)

Individual risk

Ideally to account for patient size, age; gender; morphology...



Size-specific metrics (for CT)

SSDE = $CTDI_{vol}$ • patient size correction factor

SSDE is still size-corrected dose to phantom

but closer to organ doses in the scanned volume

Table 1. This table provides conversion factors based on the use of the 32 cm diameter PMMA phantom for $CTDI_{vol}$. Table 1A shows the conversion factor as a function of the sum of the lateral and AP dimensions. Table 1B shows conversion factors as a function of the lateral dimension, and Table 1C is for the AP dimension. Table 1D provides conversion factors as a function of effective diameter. It is essential that these data be used when the $CTDI_{vol}$ reported is known to be based on the 32 cm diameter body dosimetry phantom.

Table 1A			Table 1B			Table 1C			Table 1D	
Lat-AP Dia (cm)	Effective Dia (cm)	Conversion Factor	Lateral Dia (cm)	Effective Dia (cm)	Conversion Factor	AP Dia (cm)	Effective Dia (cm)	Conversion Factor	Effective Dia (cm)	Conversion Factor
18	7.7	2.79	8	6.2	2.65	8	8.8	2.68	8	2.75
20	8.7	2.69	9	9.7	2.60	9	10.2	2.65	9	2.65
22	9.7	2.59	10	10.2	2.55	10	11.6	2.42	10	2.57
24	10.7	2.50	11	10.7	2.50	11	13.0	2.30	11	2.47
26	11.7	2.41	12	11.3	2.45	12	14.4	2.18	12	2.38
28	12.7	2.32	13	11.8	2.40	13	15.7	2.08	13	2.30
29	13.7	2.24	14	12.4	2.35	14	17.0	1.98	14	2.22
30	14.7	2.16	15	13.1	2.29	15	18.3	1.89	15	2.14
32	15.7	2.08	16	13.7	2.24	16	19.6	1.81	16	2.06
34	16.7	2.01	17	14.3	2.19	17	20.8	1.73	17	1.98
36	17.6	1.94	18	15.0	2.13	18	22.0	1.65	18	1.91
38	18.6	1.87	19	15.7	2.08	19	23.2	1.58	19	1.84
40	19.6	1.80	20	16.4	2.03	20	24.3	1.52	20	1.78
42	20.6	1.74	21	17.2	1.97	21	25.5	1.45	21	1.71
44	21.6	1.67	22	17.9	1.92	22	26.6	1.40	22	1.65
46	22.6	1.62	23	18.7	1.86	23	27.8	1.34	23	1.59
48	23.6	1.56	24	19.5	1.81	24	28.7	1.29	24	1.53
50	24.6	1.50	25	20.3	1.76	25	29.7	1.25	25	1.48
52	25.6	1.45	26	21.1	1.70	26	30.7	1.20	26	1.43
54	26.6	1.40	27	22.0	1.65	27	31.8	1.16	27	1.37
56	27.6	1.35	28	22.9	1.60	28	32.6	1.12	28	1.32
58	28.6	1.30	29	23.8	1.55	29	33.5	1.08	29	1.28
60	29.6	1.25	30	24.7	1.50	30	34.4	1.05	30	1.23
62	30.6	1.21	31	25.6	1.45	31	35.2	1.02	31	1.19
64	31.5	1.16	32	26.6	1.40	32	36.0	0.99	32	1.14
66	32.6	1.12	33	27.6	1.35	33	36.8	0.96	33	1.10
68	33.6	1.08	34	28.6	1.30	34	37.6	0.93	34	1.06

AAPM Report No. 204



Size-Specific Dose Estimates (SSDE) in Pediatric and Adult Body CT Examinations

Report of AAPM Task Group 204, developed in collaboration with the International Commission on Radiation Units and Measurements (ICRU) and the Image Gently campaign of the Alliance for Radiation Safety in Pediatric Imaging



AAPM REPORT NO. 220



Use of Water Equivalent Diameter for Calculating Patient Size and Size-Specific Dose Estimates (SSDE) in CT

The Report of AAPM Task Group 220
September 2014

AAPM REPORT NO. 293



Size-Specific Dose Estimate (SSDE) for Head CT

The Report of AAPM Task Group 293
July 2019

Organ doses

Organ dose = absorbed energy in the organs of interest

If organ doses of a patient are known, detriment can be estimated using life attributable risk (LAR)

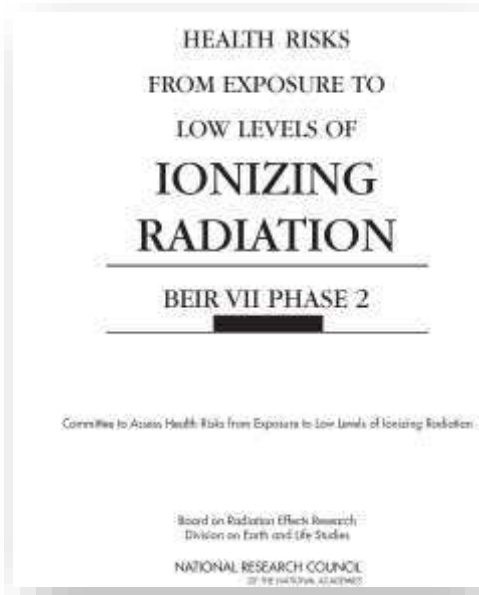
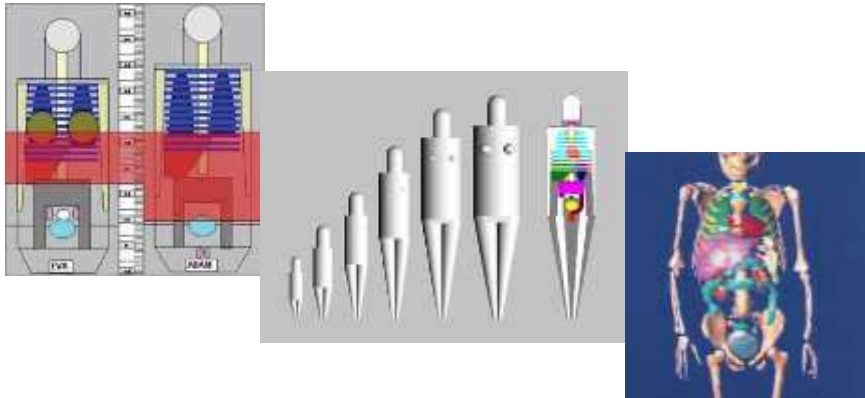


TABLE 12D-2 Lifetime Attributable Risk of Cancer Mortality^a

Cancer Site	Age at Exposure (years)										
	0	5	10	15	20	30	40	50	60	70	80
<i>Males</i>											
Stomach	41	34	30	25	21	16	15	13	11	8	4
Colon	163	139	117	99	84	61	60	57	49	36	21
Liver	44	37	31	27	23	16	16	14	12	8	4
Lung	318	264	219	182	151	107	107	104	93	71	42
Prostate	17	15	12	10	9	7	6	7	7	7	5
Bladder	45	38	32	27	23	17	17	17	17	15	10
Other	400	255	200	162	134	94	88	77	58	36	17
All solid	1028	781	641	535	444	317	310	289	246	181	102
Leukemia	71	71	71	70	67	64	67	71	73	69	51
All cancers	1099	852	712	603	511	381	377	360	319	250	153
<i>Females</i>											
Stomach	57	48	41	34	29	21	20	19	16	13	8
Colon	102	86	73	62	53	38	37	35	31	25	15
Liver	24	20	17	14	12	9	8	8	7	5	3
Lung	643	534	442	367	305	213	212	204	183	140	81
Breast	274	214	167	130	101	61	35	19	9	5	2
Uterus	11	10	8	7	6	4	4	3	3	2	1
Ovary	55	47	39	34	28	20	20	18	15	10	5
Bladder	59	51	43	36	31	23	23	22	22	19	13
Other	491	287	220	179	147	103	97	86	69	47	24
All solid	1717	1295	1051	862	711	491	455	415	354	265	152
Leukemia	53	52	53	52	51	51	52	54	55	52	38
All cancers	1770	1347	1104	914	762	542	507	469	409	317	190

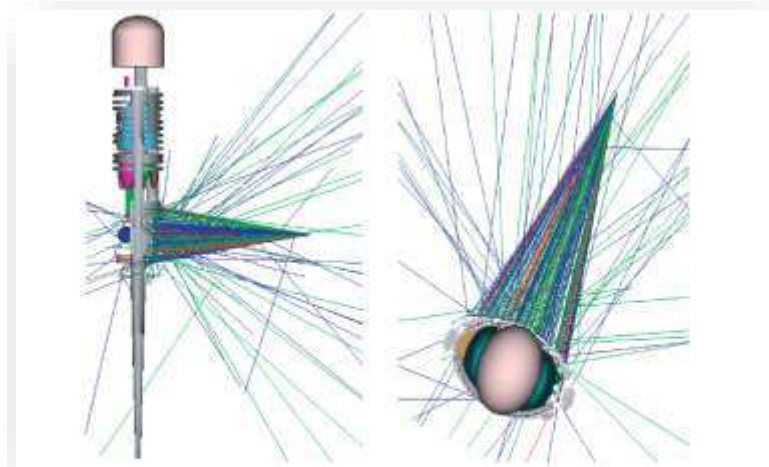
Organ doses

Assessed using patient-representing models of body/organs and the irradiation field:



Patient dependent and variable across patients (and not readily available)

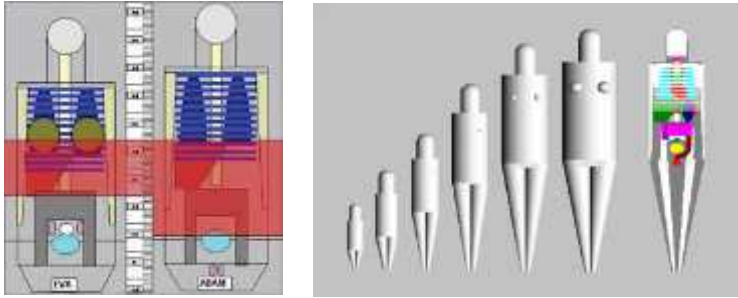
Geometrically aligned with the specific irradiation output from the imaging system and inputted into a radiation transport simulator to emulate the imaging procedure



Source: ICRU 74

Organ doses

Simplistic geometrical phantoms
uniform irradiation fields



- Generic attributes of the patient (size)
- Large uncertainties in reported organ doses estimates
- Conversion coefficients from a modality-specific quantity to organ doses (tabulated or software-based)

Patient-specific organ
dosimetry



- Matching a patient to an atlas of diverse, realistic human models
- Improved accuracy

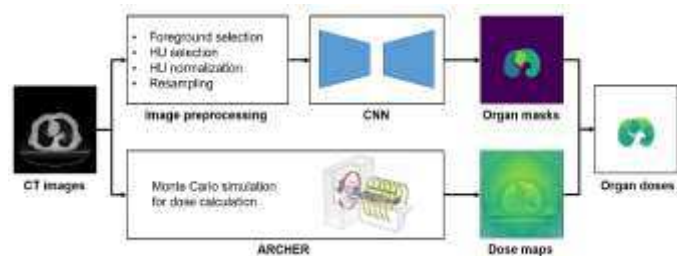
Organ doses

Patient-specific organ dosimetry



- Matching a patient to an atlas of diverse, realistic human models
- Improved accuracy

Machine learning methods



- Organ segmentation and characterization informed by the patient attributes
- The energy deposited in each organ is normalized by the organ mass to estimate the organ dose
- High accuracy with errors in doses to sensitive organs below 10%

Organ doses – software products



PCXMC

[<https://www.stuk.fi/palvelut/pcxmc-a-monte-carlo-program-for-calculating-patient-doses-in-medical-x-ray-examinations>]

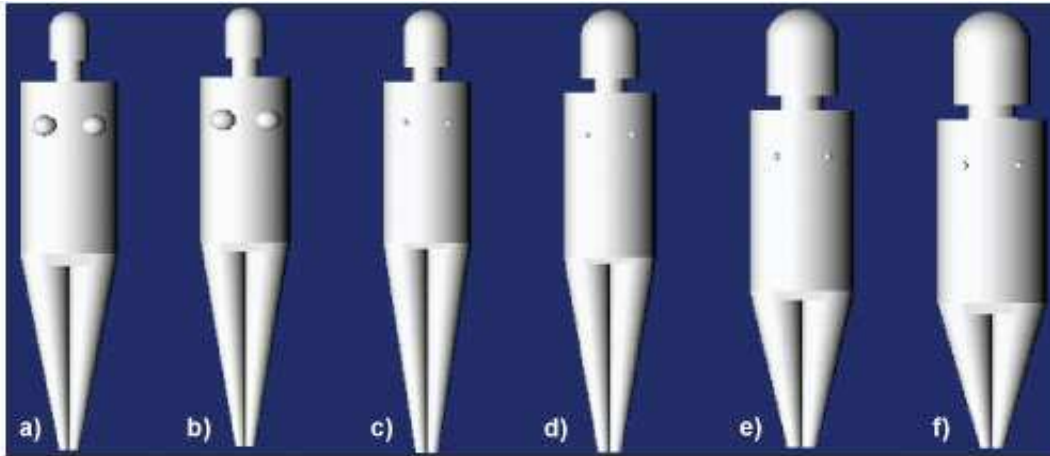


Figure 2: Anterior views of the basic phantom models in PCXMC, scaled to have identical heights. (a) Adult phantom 178.6 cm/73.2 kg, (b) 15-year old phantom 168.1 cm/56.3 kg, (c) 10-year old phantom 139.8 cm/32.4 kg, (d) 5-year old phantom 109.1 cm/19.0 kg, (e) 1-year old phantom 74.4 cm/9.2 kg (f) new-born phantom 50.9 cm/3.4 kg.

Organ doses – software products

CT-Expo

[www.sascrad.com]

Calculate

1. Age Group: Adult, Gender: Male

2. Scanner Model: Demo, Scanner: Spiral Scanner

3. Scan Range: Scan Range Data (Slice Positions): Scan Range z from z: 0.24, L: 0, S: 0

4. Select mode: Body mode for head/neck region, Spiral mode

5. Scan Parameters: U: 0, I: 0, t: 0, Q_{eff}: 0, I_{eff}: 0, h_{max}: 0, p: 1.0, Ser: 0

6. Results:

Dose Values per Scan or per Series*					Tissue or Organ H ₂ per Series		Remainder H ₂ per Series	
CTDI _w	CTDI _{vol}	DLP _w	E'	D _{area}	Organ	H ₂	Organ	H ₂
[mGy]	[mGy]	[mGy·cm]	[mSv]	[mSv]	[mSv]	[mSv]	[mSv]	[mSv]
0.0	0.0	0	0	n.s.	Thyroid	0.0	Brain	0.0
					Breasts	0.0	Thymus	0.0
					Oesophagus	0.0	Spleen	0.0
					Lungs	0.0	Pancreas	0.0
					Liver	0.0	Adrenals	0.0
					Stomach	0.0	Kidneys	0.0
					Colon	0.0	Small Intest.	0.0
					Testicles	0.0	Upp. large int.	0.0
					Ovaries	0.0	Uterus	0.0
					Bladder	0.0		
					Bone marrow	0.0	Misc.	H ₂ per Series
					Bone surface	0.0		[mSv]
					Skin	0.0	Eye lenses	0.0

Please note: All organ doses H₂ are based on conversion coefficients for ¹³⁷Cs and patients (ADMA, BVA, C&D, S&B) and series for estimation purposes only (in particular organs outside the scan range).

ImPACT

CT Patient Dosimetry Calculator
(www.impactscan.org)

ImPACT CT Patient Dosimetry Calculator
version 0.99m, 1/07/2002

Scanner Model: GE QX/i, LightSpeed, LightSpeed Pk
Scanner: GE QX/i, LightSpeed, LightSpeed Pk
kV: 120
Scan Region: Body
Data Set: MCSE119, Update Data Set
Current Data: MCSE119
Scan range: Start Position: -5 cm, End Position: 45 cm, Get From Phantom: Diagram
Patient Sex: F

Acquisition Parameters:
mA: 340
Rotation time: 0.8 s
mAs / Rotation: 272 mAs
Collimation: 5 mm
Slice Width: 10 mm
Pitch: 1.35
Rel. CTDI: 1.26
CTDI (air): 34.5 mGy/100mAs
CTDI (soft tissue): 36.9 mGy/100mAs
CTDI_w: 12.8 mGy/100mAs

Organ	w _r	H ₂	w _r ·H ₂
Gonads	0.2	33.434	6.687
Bone Marrow (red)	0.12	15.854	1.902
Colon	0.12	32.619	3.914
Lung	0.12	7.010	0.841
Stomach	0.12	35.678	4.281
Bladder	0.05	39.058	1.953
Breast	0.05	1.498	0.075
Liver	0.05	33.376	1.669
Oesophagus (Thymus)	0.05	1.209	0.060
Thyroid	0.05	0.100	0.005
Skin	0.01	13.381	0.134
Bone Surface	0.01	22.972	0.230
Remainder1	0.025	17.709	0.443
Remainder 2	0.025	17.709	0.443
Total Effective Dose (mSv)			22.637

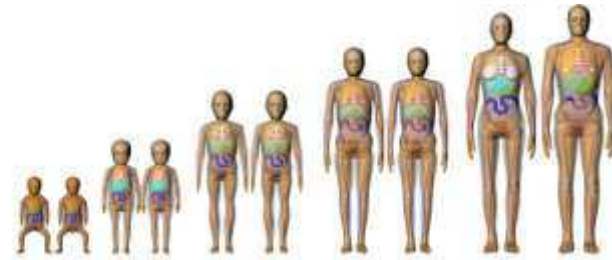
Remainder Organs	H ₂
Adrenals	30.370
Brain	0.006
Upper Large Intestine	35.786
Small Intestine	34.884
Kidney	38.987
Pancreas	30.545
Spleen	33.313
Thymus	1.209
Uterus	35.652
Muscle	17.640

CTDI _w (mGy)	34.7
CTDI _{vol} (mGy)	25.7
DLP (mGy·cm)	1284.5

Organ doses – software products

Virtual Dose (Virtual Phantoms, inc)

<http://www.virtualphantoms.com/our-products/>



 **VIRTUAL PHANTOMS, INC.**
Perfecting radiation dose management through innovative simulation technologies

[VirtualDoseCT](#) [VirtualDoseIR](#) [Welcome, fisicamedica!](#) [My account](#) | [Setting](#) | [Reset password](#) | [Log off](#)

VirtualDoseIR

Patient Phantoms: Overweight Male	Ray Direction: Postero Anterior	
Field of View (cm): 30	Tube Voltage (kVp): 90	
Filter Cu (mm): 0.1	Source-to-Imager Distance (cm): 60	
Source-to-Skin Distance (cm): 40	Dose Calculation Type: Dose Area Product	
Dose Area Product: (mGy·cm²) 1	Organ Weighting Scheme: <input checked="" type="radio"/> ICRP103 <input type="radio"/> ICRP60	
Calculate Dose Create Report		

Modules for

- CT
- Interventional procedures

Organ doses – software products

- XCATdose 3a iPhone (Duke University, USA)

http://www.isradiology.org/2017/isr/dose_calculator_xcatdose3.php



Organ doses from CT

Table 4: Summary of the sources and level of uncertainties with computational phantoms and Monte Carlo organ dose estimations

Source of Uncertainty	Contributing Factors	Estimated Uncertainty (\pm)
Computational phantoms	Depends on how accurately different types of computational phantoms resemble the anatomical structure of the actual patient	3–66%
Patient matching	Induced by geometry differences between a patient and the computational phantom that is used to represent that patient	10–15%
Organ start/end location	Induced by the heterogeneous dose pattern created across the body by the helical trajectory of the CT source	<10% for most organs 10–33% for the small surface organs
TCM simplification	Induced by using simplified tube current profiles (z-dimensional) to approximate organ dose under TCM	20% depending on the method used to model the dose field under TCM

Given the present refinement of methods for estimating patient organ dose, AAPM Task Group 246 and EFOMP recommend that efforts be made to perform uncertainty analysis of the respective methods, and that reports of patient organ dose should be accompanied by documented estimates of the uncertainty.

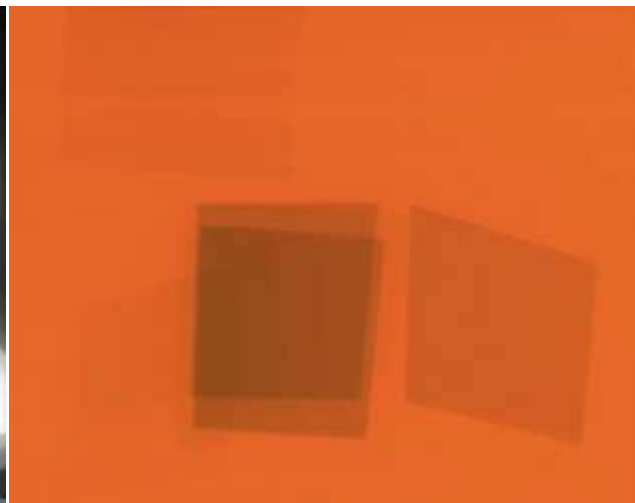
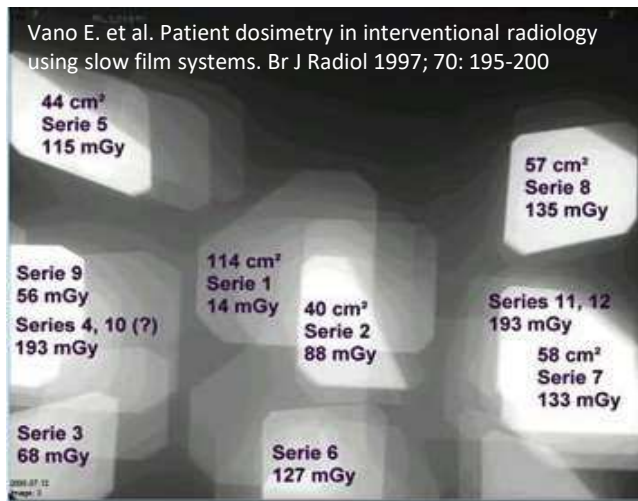
Organ doses to organs of interest



- Fluoroscopy guided procedures:
 - Skin dose in various FGI procedures
 - Brain dose in neuro-interventions
 - Heart dose in cardiac interventions
- Mammography or chest CT
 - Breast dose
- Head CT or neuroradiology
 - Eye dose
- High dose procedures involving abdomen of pregnant patients
 - Fetal dose

Skin dose in fluoroscopy

- Skin dose (mGy)



TLD

*Therapy film
Kodak X-Omat V*

Gafchromic film

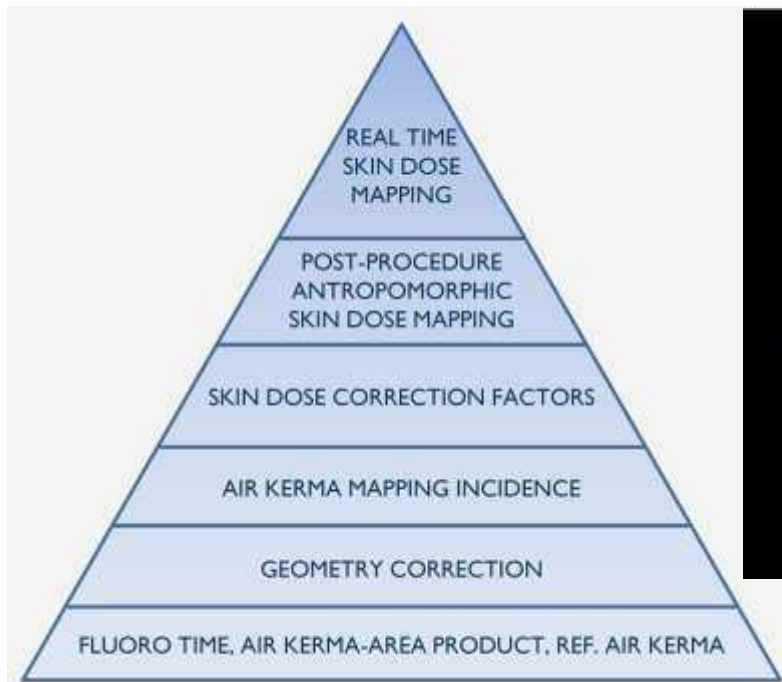
Skin dose in fluoroscopy

$$\text{Skin dose} = K_{a,r} \times CF \times Att \times BSF \times \left(\frac{d_{ref}}{d_{perp}}\right)^2 \times f_{skin}$$

JOURNAL OF APPLIED CLINICAL MEDICAL PHYSICS, VOLUME 12, NUMBER 4, FALL 2011

Calculating the peak skin dose resulting from fluoroscopically guided interventions. Part I: Methods

A. Kyle Jones,^{1a} and Alexander S. Pasciak²



Courtesy A. Trianni

Skin dose calculation and reporting

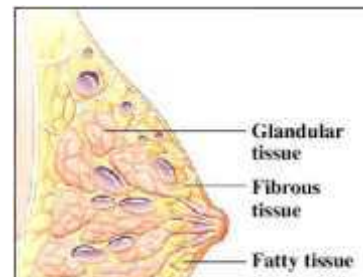


- Reviewed 19 available software products
 - 2 systems use Monte Carlo simulations to model the transport
 - All others use a formalism comparable to the methodology proposed by Jones and Pasciak (2011) for systems compliant with IEC standards.
 - $\pm 25\%$ agreement with measurements on phantoms for 10 SDC products
 - $\pm 43\%$ and $\pm 76\%$ agreement for 2 products validated on patients
 - No software validated for vendor-independent transportability
- Need for harmonizing both RDSRs and their exports in order to be able to calculate MSD from these data in an easy and straightforward way.

Mammography

Mean glandular dose (MGD)

mean absorbed dose in glandular breast tissue



$$D_g = K_i \cdot g \cdot c \cdot s$$

g, c, s – MC derived correction factors to account for breast thickness, HVL, breast granularity, and anode/filter combination

	PMMA thickness (mm)	Equivalent breast thickness (mm)	HVL (mm Al) ^a							
			0.25	0.30	0.35	0.40	0.45	0.50	0.55	0.60
g-factor	45	53	0.130	0.155	0.177	0.198	0.220	0.245	0.272	0.295
c-factor	45	53	-	1.109	1.105	1.102	1.099	1.096	1.091	1.088
g-factor	50	60	0.112	0.135	0.154	0.172	0.192	0.214	0.236	0.261
c-factor	50	60	-	1.164	1.160	1.151	1.150	1.144	1.139	1.134
s-factor	Mo/Mo		Mo/Rh				W/Rh			
	1.000		1.017				1.042			
			Quality Assurance Programme for Breast Mammography				Assurance Programme for Digital Mammography			

Dose to embryo or fetus

- First approximation: uterus dose (early pregnancy)
- Better accuracy: considering the gestation stage



A method of estimating conceptus doses resulting from multidetector CT examinations during all stages of gestation

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(Received 29 June 2010; revised 26 October 2010; accepted for publication 26 October 2010; published 23 November 2010)

Purpose: Current methods for the estimation of conceptus dose from multidetector CT (MDCT) examinations performed on the mother provide dose data for typical protocols with a fixed scan length. However, modified low-dose imaging protocols are frequently used during pregnancy. The purpose of the current study was to develop a method for the estimation of conceptus dose from any MDCT examination of the trunk performed during all stages of gestation.



embryodose.med.uoc.gr

J. Damilakis et al., Medical Physics 37(12):6411 – 6420, 2010

Effective dose

- Effective dose calculated from organ doses and weighting factors
 - Devised as a RP quantity for staff and public
 - Averaged among gender, age, size
 - Different from the real patient
 - Uncertainties due to organ dose calculations
 - phantoms, simulations
 - Change of w_T over time
- Advantages of effective dose:
 - one number to summarize the detriment
 - can be used among different types of exams
 - deemed appropriate with caution for application to individual risk (ICRP)

$$E = \sum_T w_T H_T$$

	ICRP 60	ICRP 103
Brain (nervous system)	0.12	0.12
Breast	0.05	0.12
Colon	0.20	0.09
Esophagus, oesophagus	0.05	0.04
Eye (lens)	0.01	0.01
Eye (retina)	0.01	0.01
Salivary glands	0.01	0.01
Remainder tissues	0.01	0.12

Effective dose assessment methods

Computed E using modality-specific conversion factors

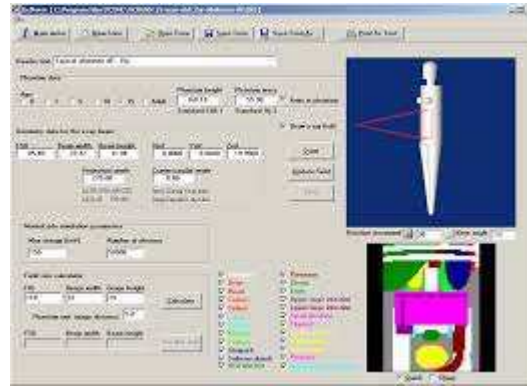
$$E_k = k \cdot F$$

F - modality specific metrics (DLP in CT or KAP in radiography/ fluoroscopy)

k - tabulated factor based on modelling of the patient by reference models

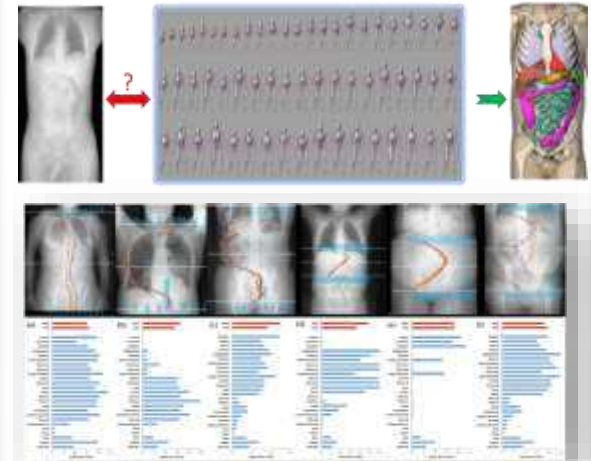
Ignores patient's habitus and irradiation field

Computed E using a generic patient model and Monte Carlo (e.g. PCXMC, CTE expo)



Closer representation of the patient exposure

Computed E using patient-specific organ doses



Most patient-relevant technique

Effective dose assessment methods

The three methods do not result in identical estimates

Fu W, Ria F, Wilson J, Kapadia A, Segars WP, Samei E. Effective Dose for Computed Tomography in Large, Clinical Populations. SSGI 2-05, RSNA 2018

- E calculated using conversion factor was higher than E from patient-specific calculations, especially in large patients:
 - by 80.2 % on average for the abdominopelvic protocol,
 - by 64.1 % for the chest protocol
- For patients with 22, 30, and 35 cm WED, method using conversion factor overestimated E :
 - for abdominopelvic protocol by 9.6%, 66.2%, and 115.6%
 - For chest: 30.2%, 77.9%, and 116.2%

When using effective dose, the exact methodology used should be specified.

Patient-specific risk indexes?

- Effective risk

Brenner D, BJR 81 (2008), 521–523

$$R = \sum_T r_T H_T,$$

r_T - lifetime radiation-attributable tissue specific cancer risks (BEIR VII)

- Radiation risk index

Li X et al, Med Phys 2011 Jan;38(1):408-419

Samei et al. Radiat Prot Dosimetry 2013 155(1):42-58

$$RRI_{ag} = \sum_T r_{T(a,g)} H_T$$

Tissue	Children	Adults	All ages
Stomach ^a	66	30	37
Lung ^a	373	166	208
Colon ^a	203	96	118
Liver ^a	32	14	18
Bladder ^a	153	75	91
Uterus ^{a,b}	37	14	19
Ovary ^{a,b}	76	28	37
Prostate ^{a,b}	67	34	41
Breast ^b	865	160	299
Thyroid	200	18	54
Leukemia	133	68	82



Task Group 79
The Use of Effective Dose as a Risk Related Radiological Protection Quantity

Task Group 113
Reference Organ and Effective Dose Coefficients for Common Diagnostic X-ray Imaging Examinations

Typical effective doses from a single exam

Single procedure	Typical E, mSv	LAR for fatal cancer
US, MRI	0	No radiation risk
Chest X-ray, limb X-ray, pelvis, lumbar spine, mammography	<1	<1 in 20,000)
Intravenous urography (IVU) Barium meal, barium enema Kidney scintigraphy, body scan ERCP, Cystography, MCU CT head and neck, CT chest	1 – 10	1 in 20,000 – 1 in 2,000
CT abdomen & pelvis, CTA PET/CT brain, cardiac, whole body,	10 - 30	1 in 2,000 – 1.5 in 1,000
CTA chest-abdomen-pelvis (multi-phases) TIPS	30 - 100	1.5 in 1,000 – 1 in 200

Typical effective doses from a single exam

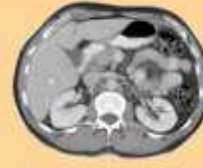
5-20 mSv
(equivalent to few years
exposure to natural
radiation)



Barium enema



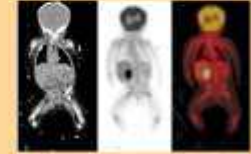
Chest CT



Abdominal CT



Cardiac
angiography



FDG PET CT

1-5 mSv
(equivalent to a few
months to 1-2 years of
exposure to natural
radiation)



2.4 mSv



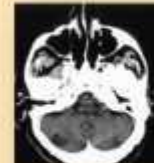
Dental
CBCT



Lumbar
spine X ray



Intravenous
urography



CT of head



CT of neck



Tc-99m
bone scan



CT-guided
bone biopsy

< 0.1 mSv
(equivalent to a few
days to few weeks of
exposure to natural
radiation)



Intraoral
dental



Panoramic
dental



Chest X ray



Knee X ray



Skull X ray



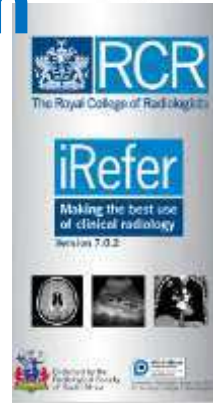
Neck X ray



Tc-99m
cystogram





Typical effective doses from a single exam


Communication of doses and risk to patients and referring physicians



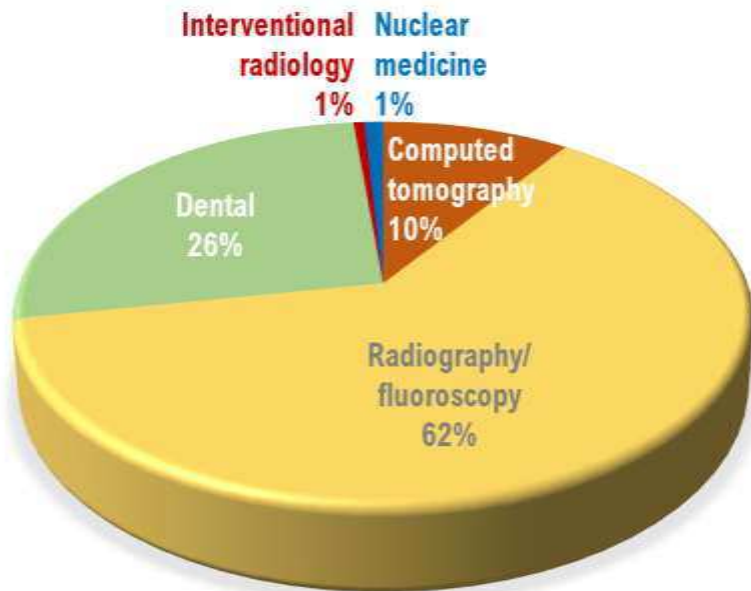
Diagnostic procedure	Typical effective dose (mSv)	Equivalent number of chest X-rays	Approx equivalent period of natural background radiation*
Radiographic examinations			
Limbs and joints (except hip)	<0.01	<1	<2 days
Chest (single PA)	0.015	1	2.5 days
Skull	0.07	5	12 days
Thoracic spine	0.4	30	2 months
Lumbar spine	0.6	40	3 months
Mammography (2 view)	0.5	35	3 months
Pelvis	0.3	20	1.5 months
Abdomen	0.4	30	2 months
IVU	2.1	140	11.5 months
Barium swallow	1.5	100	8 months
Barium meal	2	130	11 months

Table 3. Band classification of the typical doses of ionising radiation from common imaging procedures^{23,26}

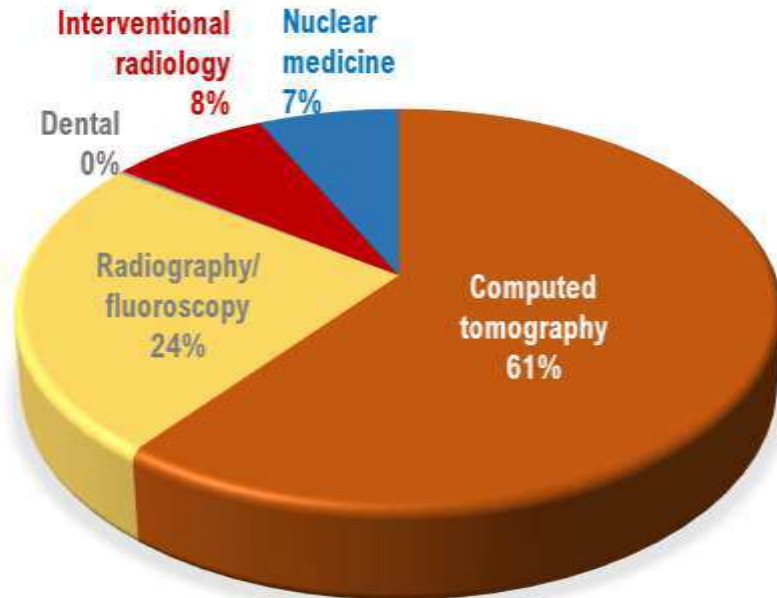
Symbol	Typical effective dose (mSv)*	Examples	Lifetime additional risk of fatal cancer/exam
None	0	US; MRI	0
	<1	CXR; XR limb, pelvis, lumbar spine; mammography	<1:20,000
	1–5	IVU; NM (eg, bone); CT head and neck	1: 20,000–1:4,000
	5.1–10	CT chest or abdomen; NM (eg, cardiac)	1: 4,000–1: 2,000
	>10	Extensive CT studies, some NM studies (eg, some PET-CT)	> 1: 2,000

*The average annual background dose in most parts of Europe falls within the 1–5 mSv range (). Cancer risks from radiation vary considerably with age and sex, with higher risks in infants and females.²⁴ Cancer risk indicated in this table is averaged for adults. This should be taken in the context of the considerably higher 1 in 3 average lifetime risk for cancer and must be balanced against the benefit of the investigation.

Population dose assessment



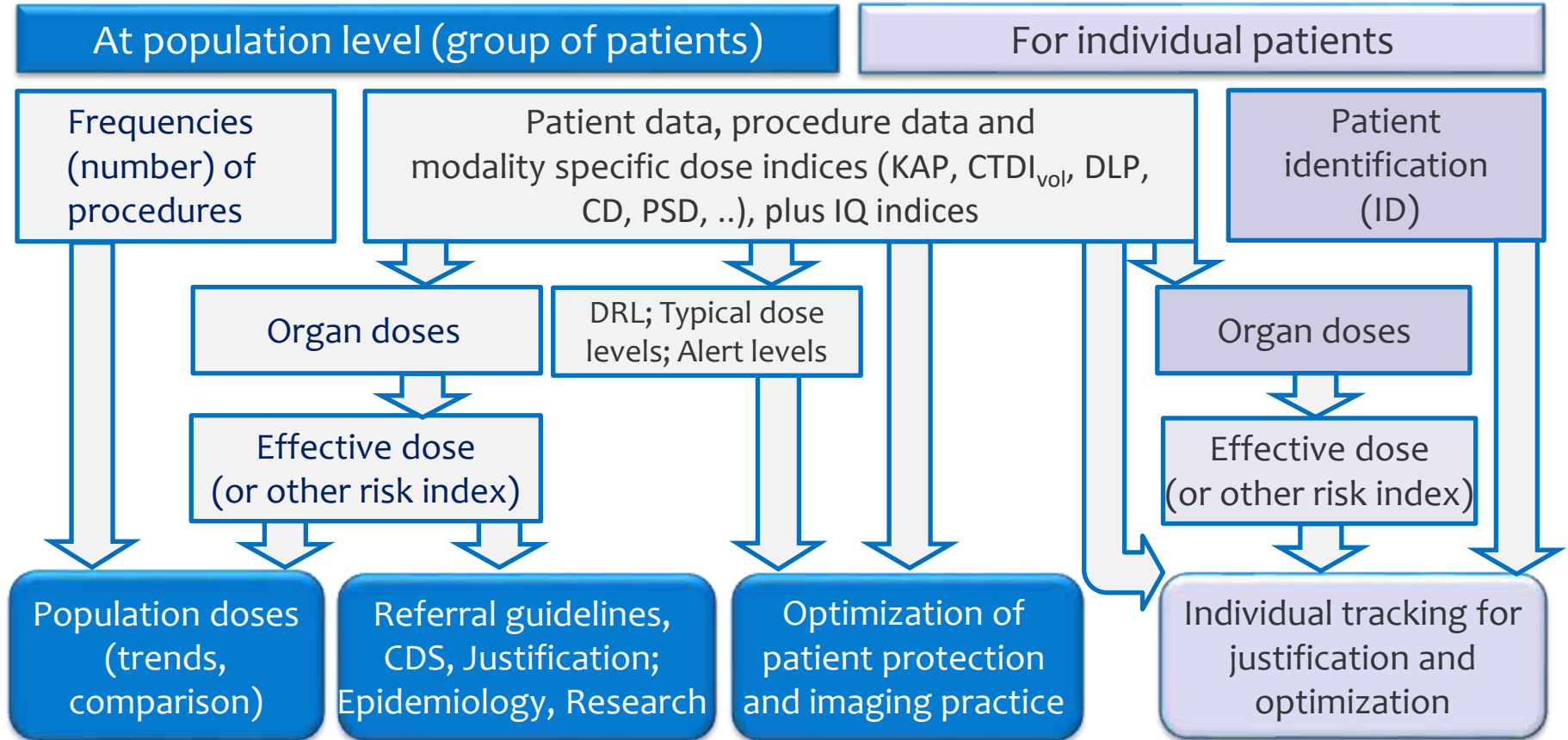
NUMBER OF PROCEDURES



COLLECTIVE DOSE

UNSCEAR, 2022

Patient exposure monitoring strategy



PATIENT RADIATION EXPOSURE MONITORING IN MEDICAL IMAGING

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1. INTRODUCTION	1
2. PATIENT RADIATION EXPOSURE MONITORING GOALS AND STRUCTURE	4
3. COMPONENTS OF PATIENT RADIATION EXPOSURE DATA	6
4. PATIENT RADIATION EXPOSURE MONITORING WORKFLOW	18
5. RECORDING PATIENT RADIATION EXPOSURE DATA	19
6. COLLECTION OF PATIENT RADIATION EXPOSURE DATA	27
7. ANALYSING PATIENT RADIATION EXPOSURE DATA	35
8. IMPLEMENTATION OF PATIENT RADIATION EXPOSURE MONITORING	51
APPENDIX	63
REFERENCES	66
GLOSSARY	80
LIST OF ABBREVIATIONS AND SYMBOLS	84

https://preprint.iaea.org/search.aspx?orig_q=patient+radiation+exposure+monitoring&src=ics

IAEA webinars related to the topic

<https://www.iaea.org/resources/rpop/resources/webinars>

Diagnostic Reference Levels

Webinar

21 March 2018

Recorded broadcast

Presented by Prof. Jolani Damirakis, Prof. Guy Enje

Date of broadcast: 21 March 2018, 3 pm CET

Organized jointly with European Society of Radiology

CT Diagnostic Reference Levels – experience of the United States with IOMP)

Webinar

14 April 2018

Recorded broadcast

Presented by Katarina Kjaer

Date of broadcast: 16 April 2018, 4 pm CET (check your corresponding time)

Organized jointly with the International Association for Medical Physics

Patient Radiation Dose Monitoring in Diagnostic Imaging

Webinar

1 October 2018



Recorded broadcast

Presented by Sarah Volkway

Date of broadcast: 1 October 2018, 4 pm CET (check your corresponding time)

Organized jointly with the International Organization for Medical Physics

Operationalizing a Vision of Safe Imaging: The American College of Radiology Dose Index Registry

Webinar

1 November 2017



Recording

Presented by Jenia Vassileva (IAEA), Judy Durrheim (IAEA)

Presented by William Sorenkovic, Myrreya Elshahid, Susan Goss, Michael Silverstein

Organized jointly with the American College of Radiology

Webinar on online dose data reporting for establishing and using diagnostic reference levels: experience of Australia, Sweden and Indonesia

Webinar

15 June 2021



Date and Time

Tuesday, 15 June 2021

09:00 (Sydney, Australia time)

Moderator: Jenia Vassileva (IAEA)

Presenters: Peter Thomas (SPPANSA), Anja Almshøj (SSM), Tarunrajah Handayani (SAPETEM)

Recording

Online monitoring of patient exposure in diagnostic imaging: Experience of Spain

Webinar

1 July 2021



Date and Time

Tuesday, 1 July 2021

14:00 (Sydney, Australia time)

Moderator: Jenia Vassileva

Presenters: José Miguel Ferrández (Iberpax), José Roberto Sánchez (Hospital Clínico San Carlos, Madrid, Spain)

Recording

Establishment of Pediatric CT Diagnostic Reference Levels

Webinar

1 June 2021



Date and Time: 1 June 2021, 10:00 AM (Sydney time)

Moderator: Jenia Vassileva (IAEA)

Presenters: Rebecca M. Boyd (Iberpax), Susana Goss

Webinar Series on the establishment and utilization of diagnostic reference levels in medical imaging in Europe

Webinar

1 September 2021



1 Webinar Recording

2 Webinar Recording



IAEA eLearning course on DRLs



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Diagnostic Reference Levels in Medical Imaging



Diagnostic Reference Levels in Medical Imaging

This e-learning programme is designed to provide continuing education to medical imaging professionals, regulators and others who are interested in establishment and use of diagnostic reference levels.

Through this course consisting of 13 modules, participants are expected to:

- Understand the concept of DRLs, what are the DRLs and what is their role in the optimization of protection of patients;
- Understand the DRL process and components that need to be considered;
- Understand dose metrics and values used in the DRL process;
- Learn how to establish and appropriately use DRLs in different imaging modalities;
- Learn about useful sources of information relevant to the DRL process.

Duration: 7 h | Interactivity: self-study | Language: English | Assessment: yes (pass mark: 80%) | Certificate: Certificate of Completion | Contact: [to be confirmed]





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