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 asses 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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❶ Why we need to know patient dose?

❷ Modality specific dose metrics

❸ Patient specific metrics

Why we need to know patient dose?

Goal: To assess the radiation risk to individuals

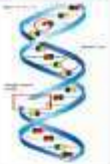
LOW DOSES

Cell mutation

Somatic cells — Cancer, leukaemia

Germ cells — Hereditary effect

STOCHASTIC EFFECTS



HIGH DOSES

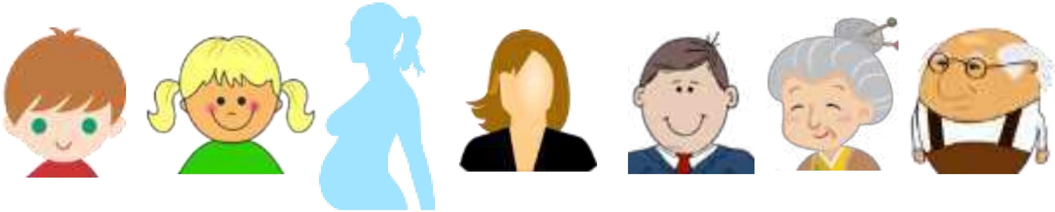
Cell death

Loss of function (organ/ system/ organism)

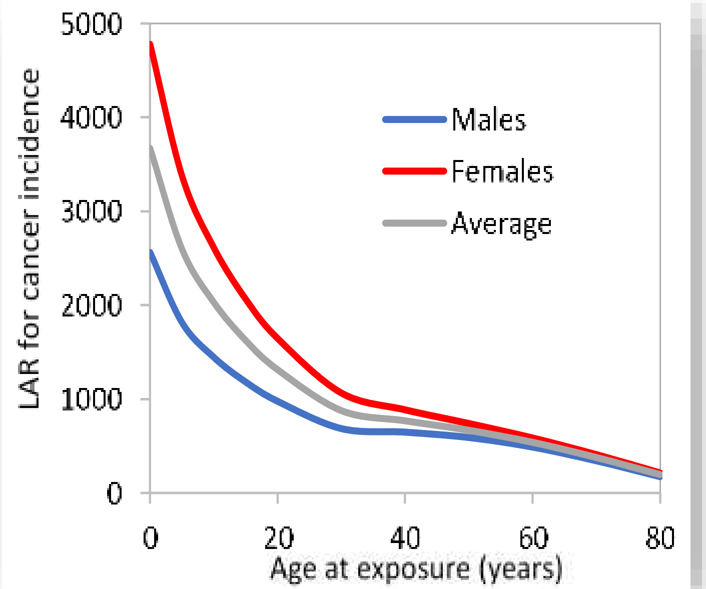
TISSUE REACTIONS

Why we need to know patient dose?

Goal: To assess the radiation risk to individuals



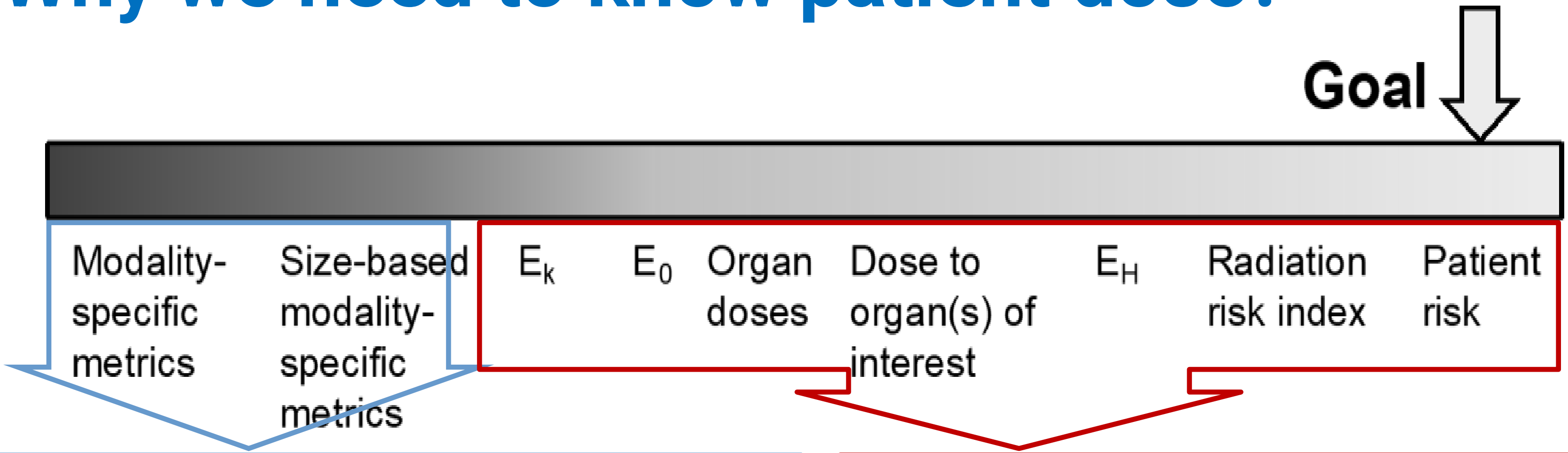
Risk depends on individual factors
- Body habitus, Age, Gender
- Health status (incl. life expectancy due to disease)



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

Risk often unknown or unknowable

Why we need to know patient dose?



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 injures
- Estimation of risk to embryo/ fetus
- Assessment of individual patient risk

❶ Why we need to know patient dose?

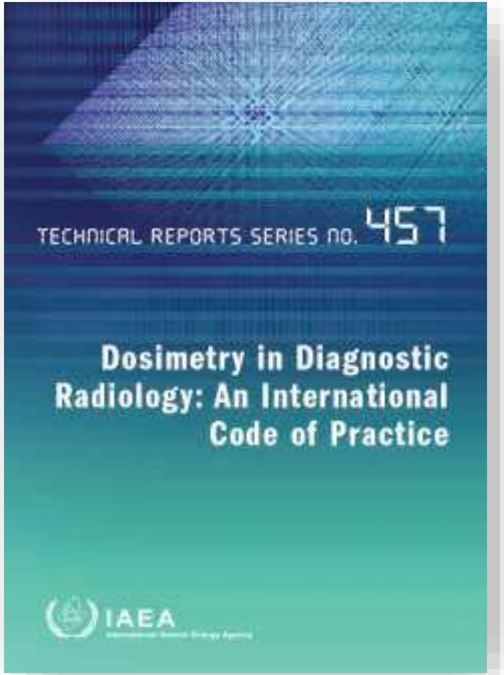
❷ Modality specific dose metrics

❸ Patient specific metrics

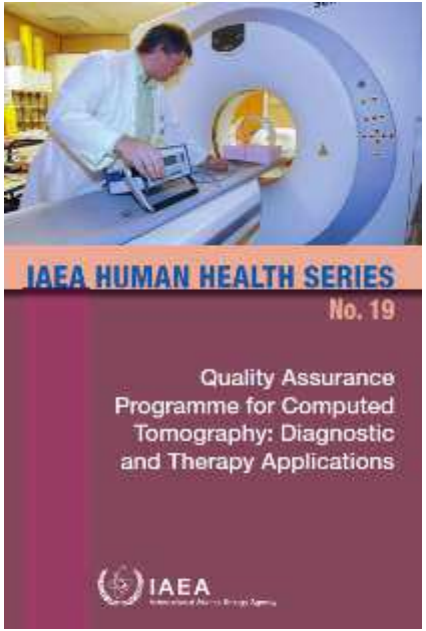
Modality specific metrics

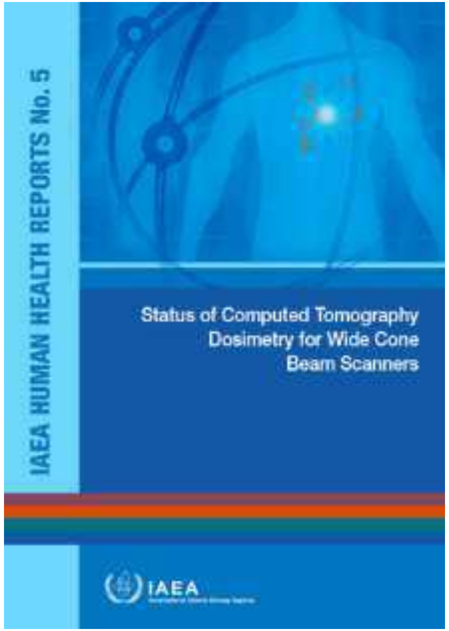
ICRU Report 74. Patient Dosimetry for X-Rays used in Medical Imaging. ICRU, 2005.

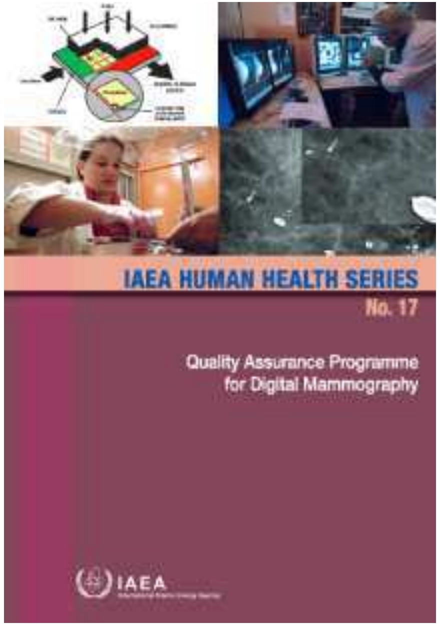
IAEA. Dosimetry in Diagnostic Radiology. An International Code of Practice. TRS 457, 2007



Modality specific metrics



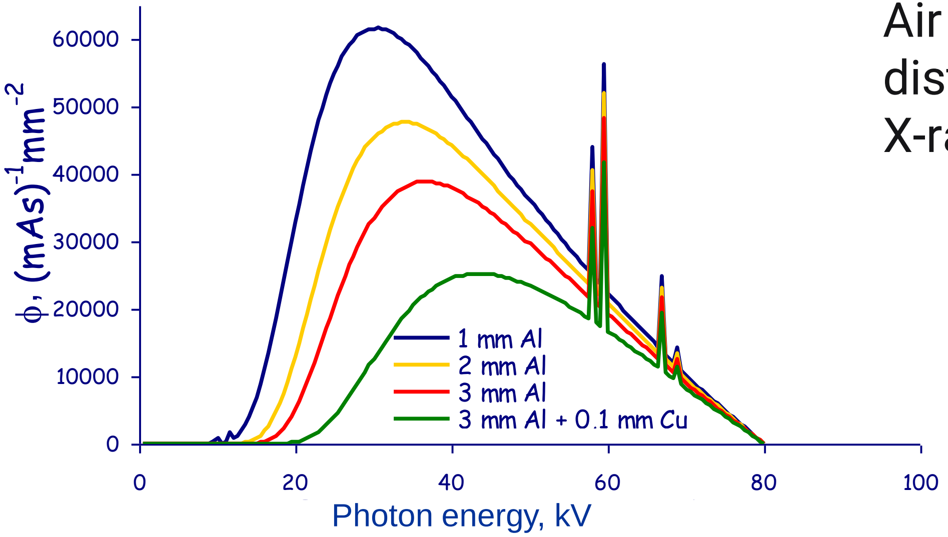


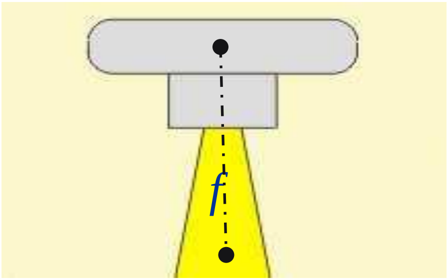


The measurements are a responsibility of qualified medical physicists

X-ray beam

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





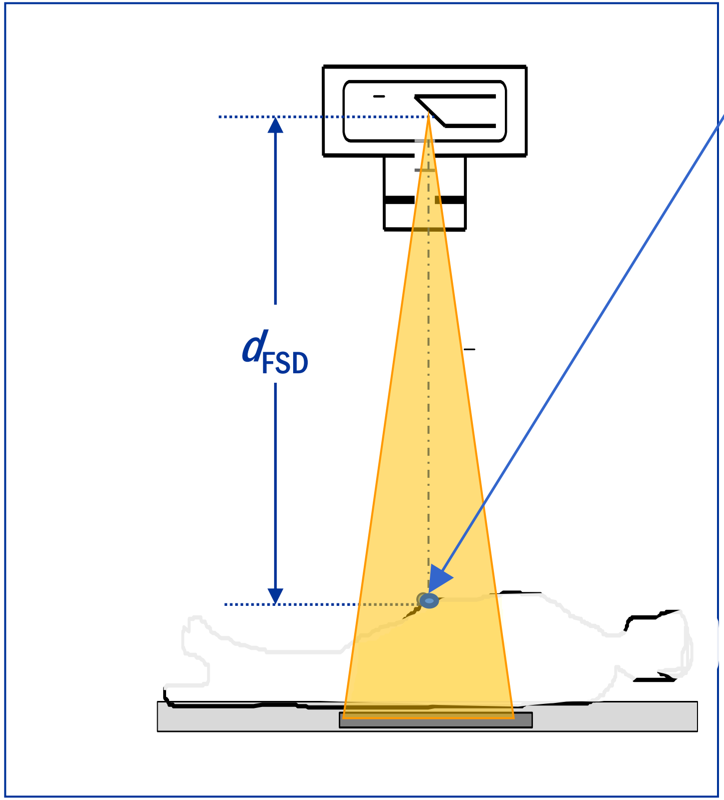
Air kerma at distance f from X-ray focus:

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

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

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

Dose quantities: Radiography

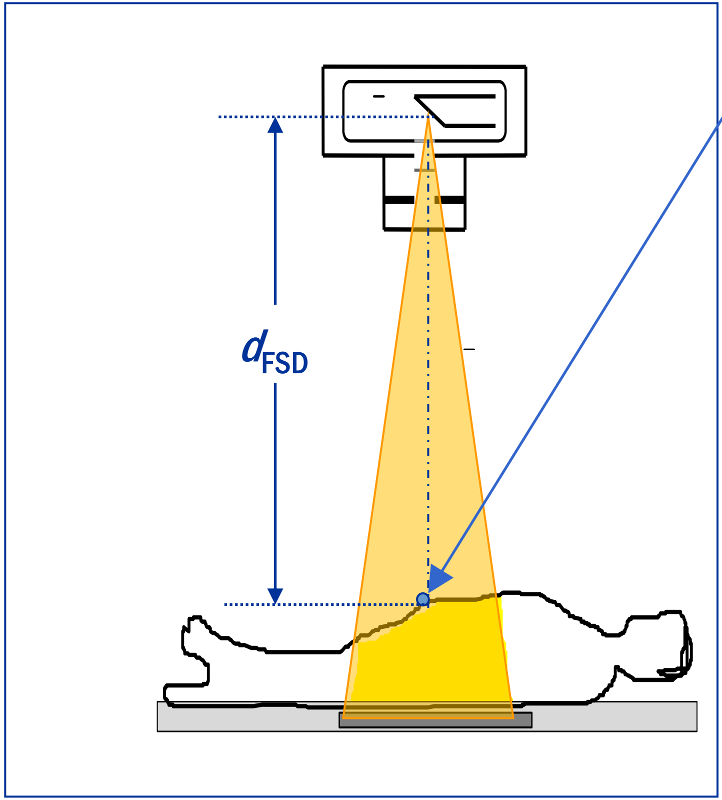


Incident air kerma, K_i

Unit: Gy

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

Dose quantities: Radiography



Entrance surface air kerma, K_e

Unit: Gy

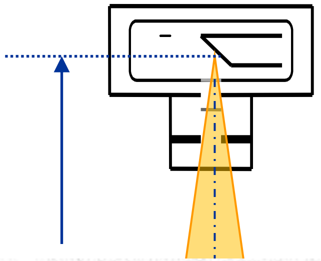
Also known as

Entrance surface dose, ESD

$$ESD \approx K_e$$

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

Dose quantities: Radiography



Entrance surface air kerma, K_e

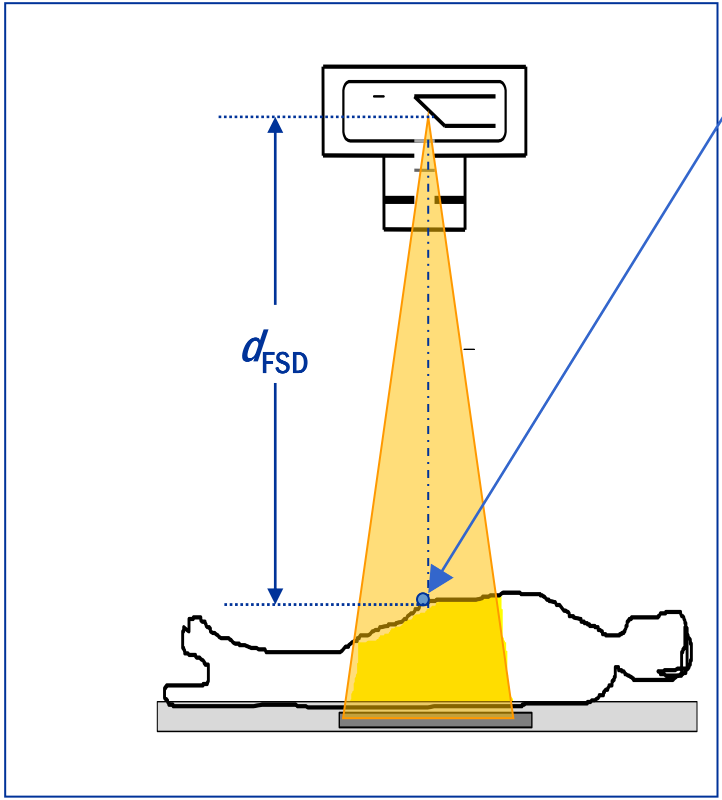
Unit: Gy

$$K_e = K_i . B$$

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

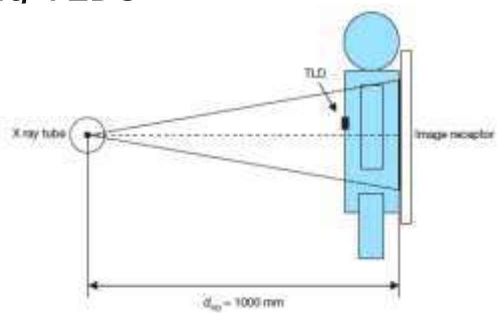
Dose quantities: Radiography



Entrance surface air kerma, K_e

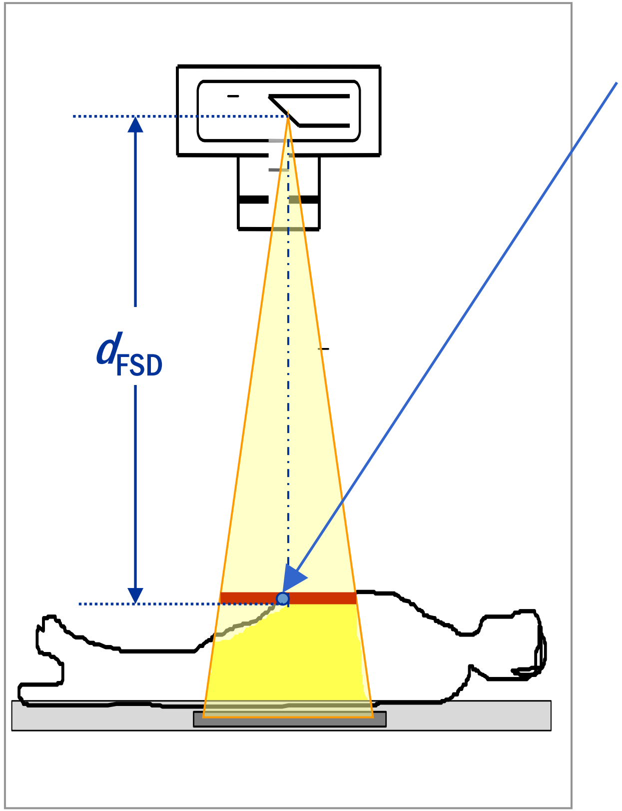
Method 1: Measurements using phantom

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 = const

$P_{KA} = K.A$

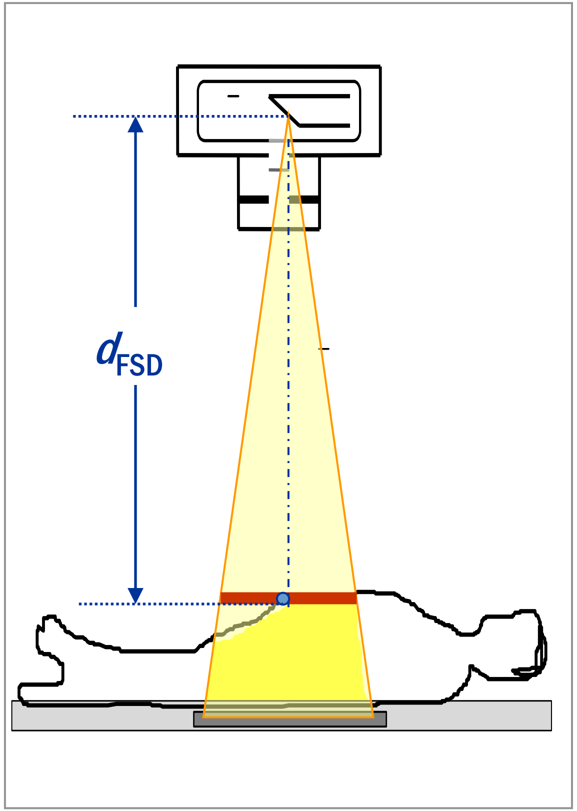
Also known as Dose Area Product, DAP

Unit: Gy·m^2

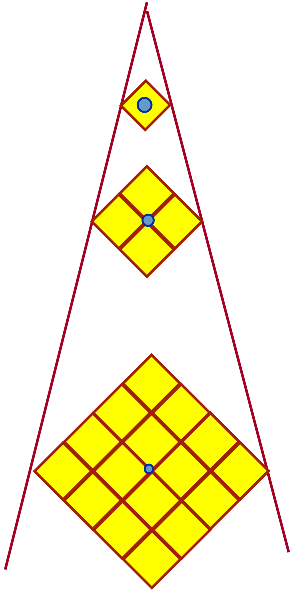
Practical units:

1 μGy.m^2 = 1 cGy.cm^2

Dose quantities: Radiography and fluoroscopy



Air kerma-area product, P_{KA}



Kerma (dose) ~ $(1/f)^2$

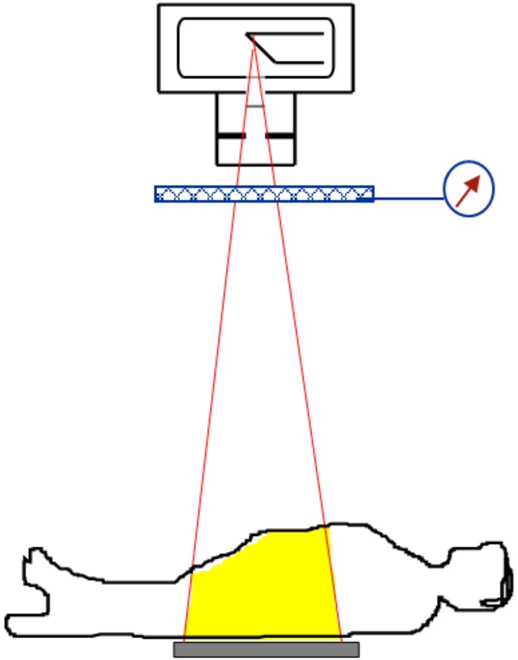
Field area ~ f^2

⇓

KAP is independent on distance from focus

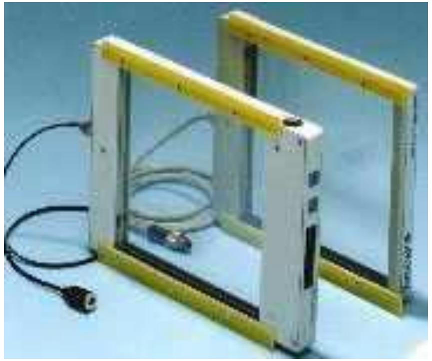
(neglecting attenuation in air, extra-focal and scatter radiation)

Dose quantities: Radiography and fluoroscopy



Air kerma-area product, P_{KA}

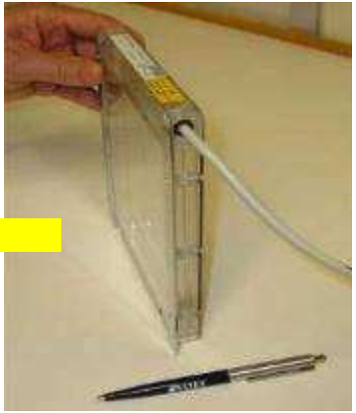
In-beam measurement with a large-size transparent ion chamber



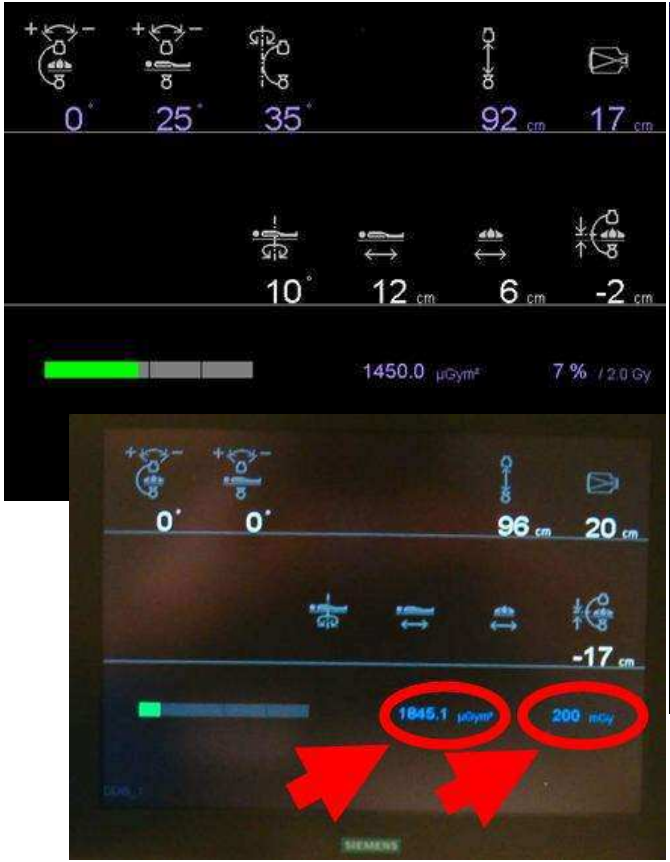
Measurement uncertainty 20 - 25 %
at the 95% confidence level

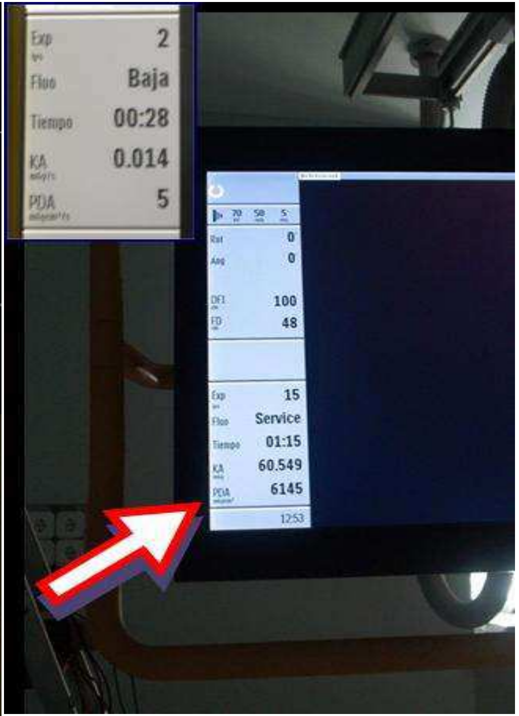
Dose quantities: Radiography and fluoroscopy

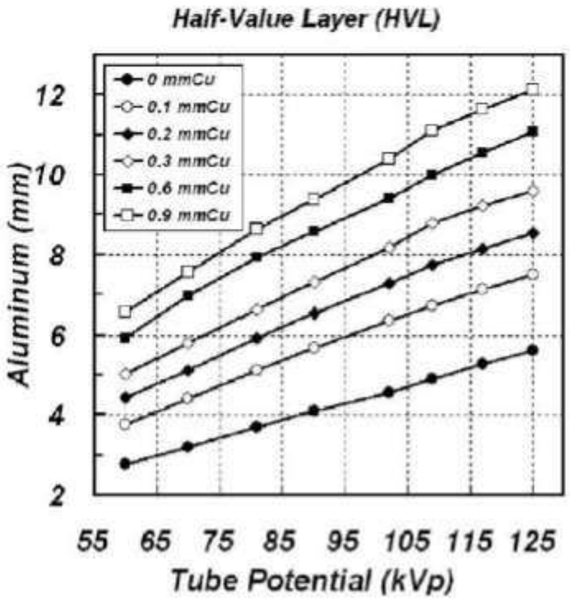
Air kerma-area product , P_{KA}



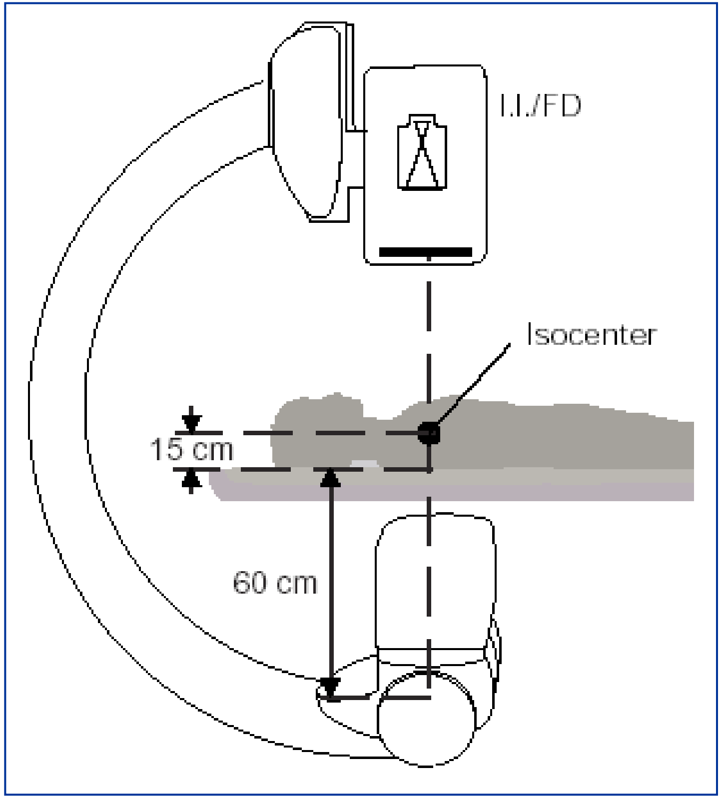
Dose quantities: Fluoroscopy





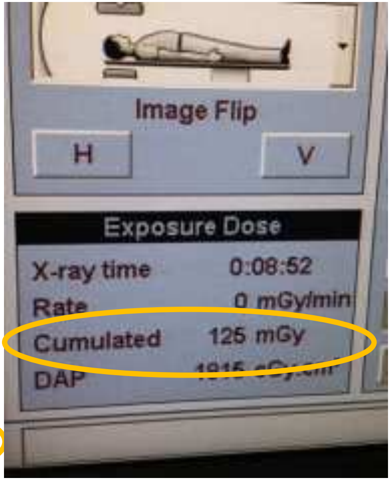


Dose quantities: Fluoroscopy

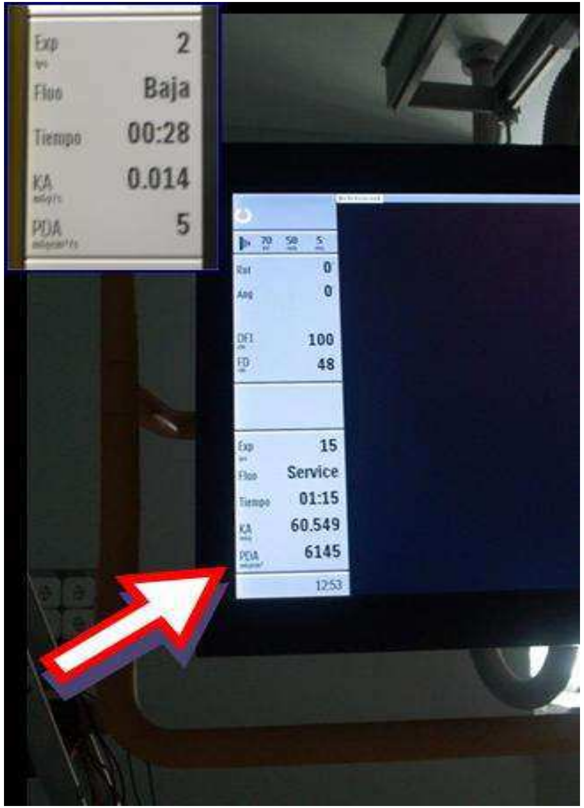


Air kerma at the interventional reference point, $CK_{a,r}$

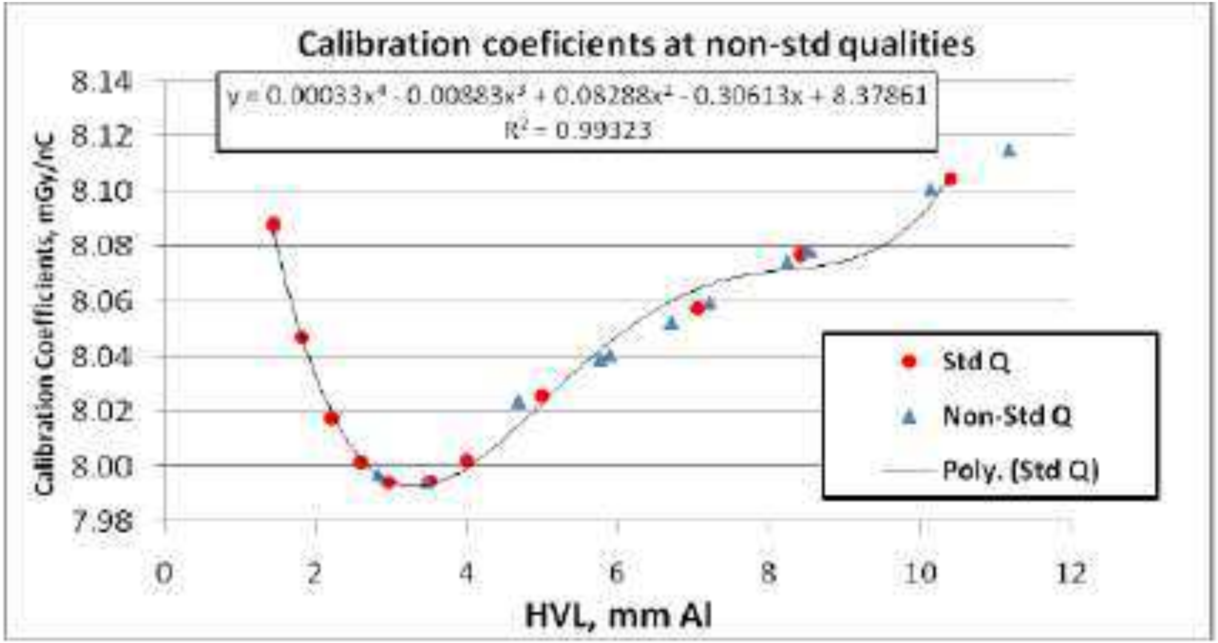
Unit: mGy (Cumulative dose)



Dose quantities: Fluoroscopy

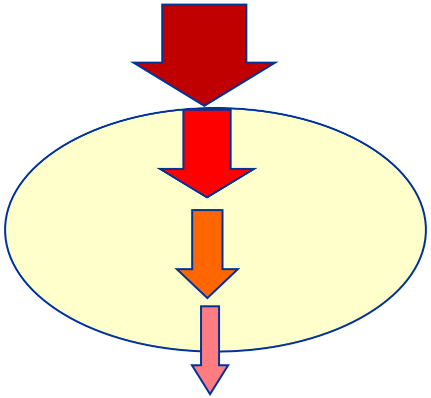


$K_{a,r}$ is calculated as $K_{a,r} = P_{KA} / A$



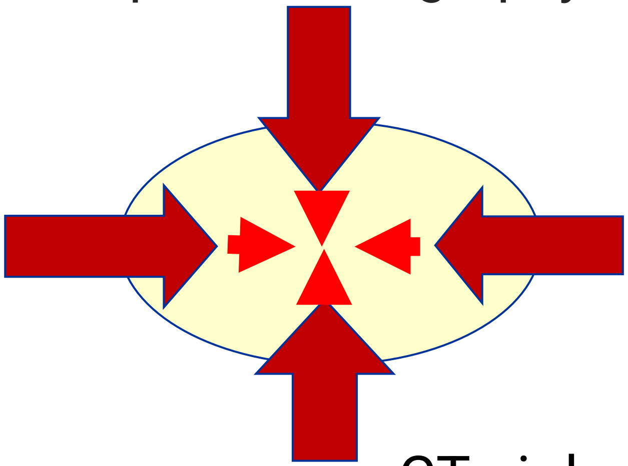
Dose quantities: Computed tomography

Radiography



Entrance surface air kerma

Computed tomography



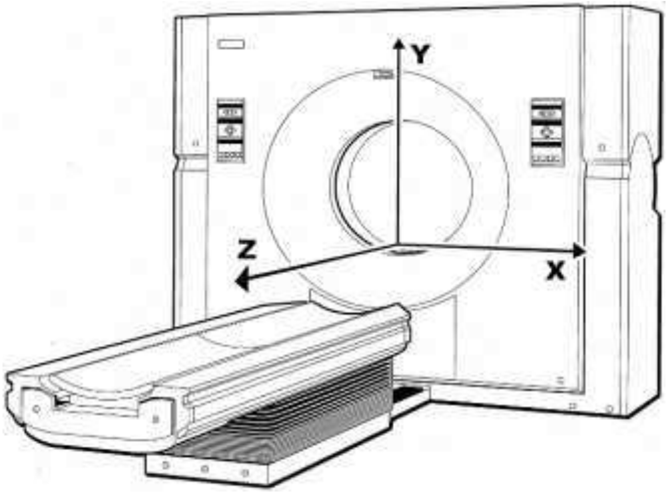
CT air kerma index

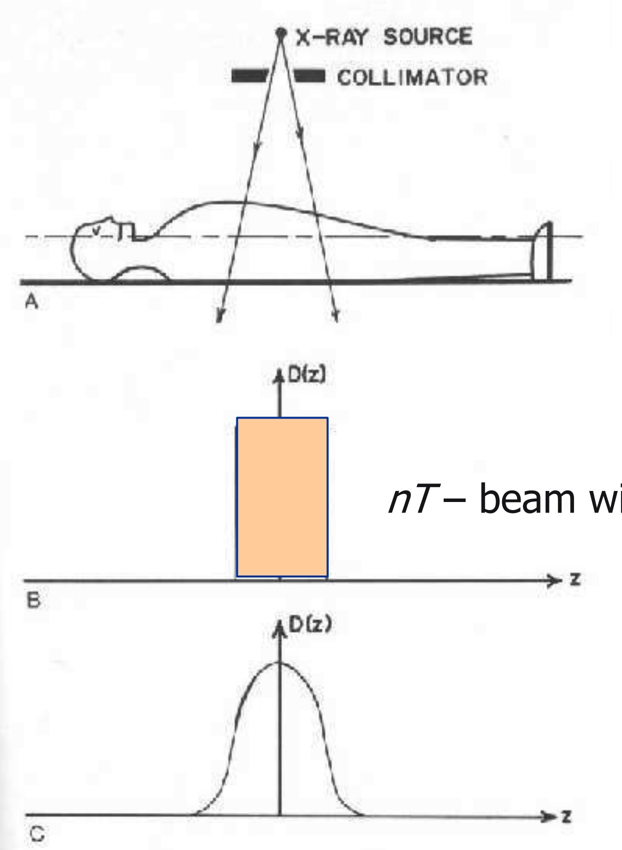
Dose quantities: Computed tomography

CT air kerma index *C*

Unit: Gy

$$C = \frac{1}{nT} \cdot^{+} K(z).dz$$





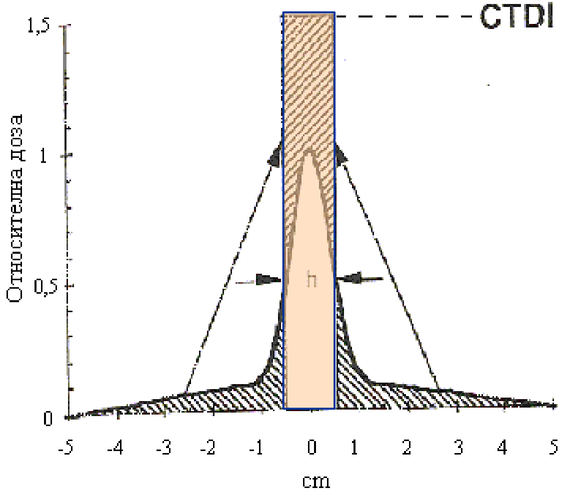
nT – beam width

Dose quantities: Computed tomography

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

Unit: Gy

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



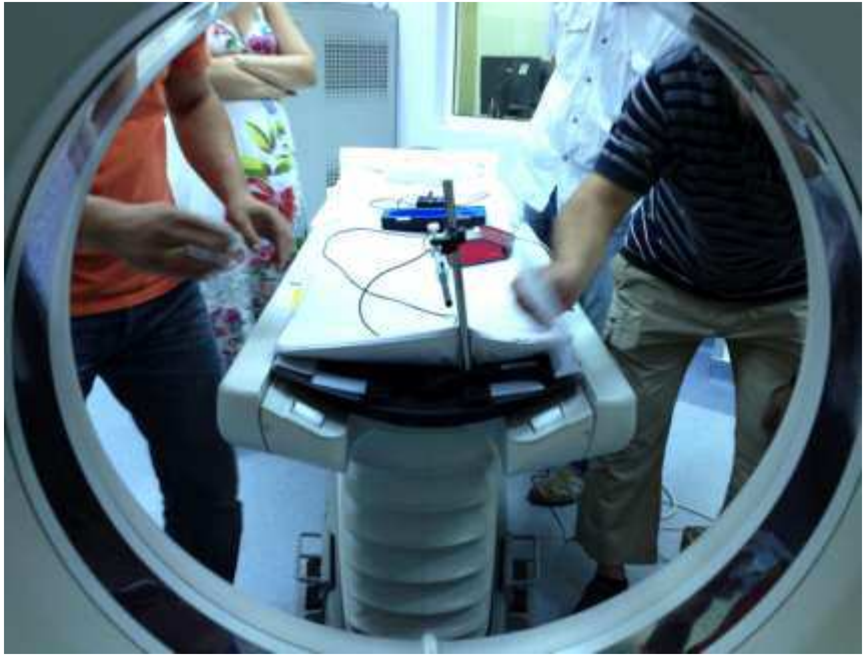
Measured with ion chamber with a lenght 100 mm

- 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}

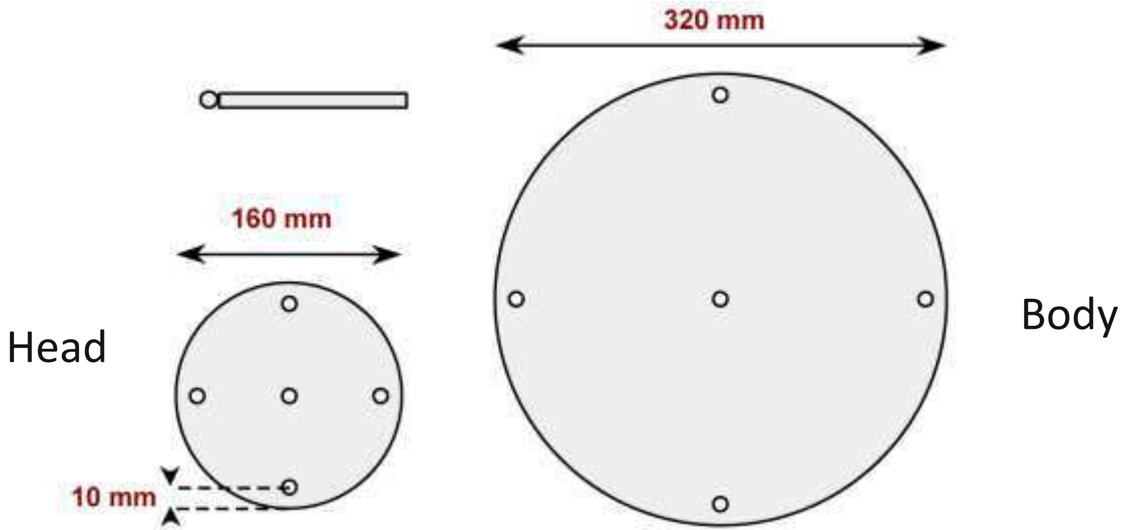
Measurements in a standard phantom

Body

Head

Dose quantities: Computed tomography

Standard CT phantom



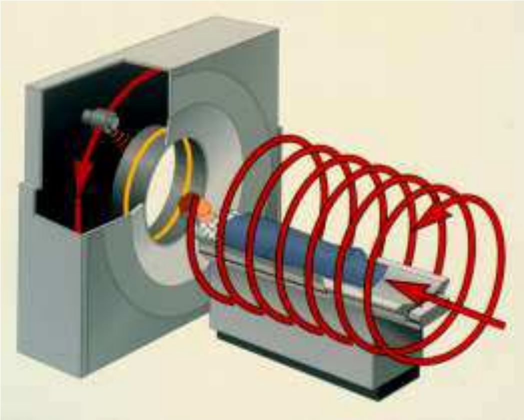
Weighted CTDI$_w$

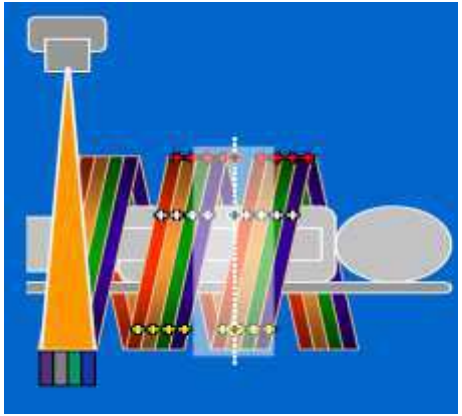
$$C_w = \frac{1}{3}(C_{100,PMMA,c} + 2C_{100,PMMA,p})$$

$C_{100,PMMA,,c}$ – in central hole

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

Dose quantities: Computed tomography





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

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

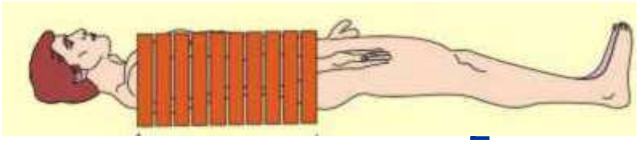
$$p = \frac{l}{NT}$$

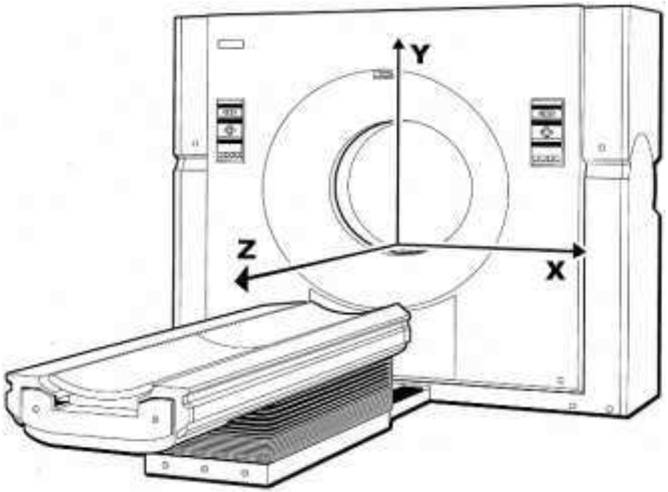
p is pitch factor

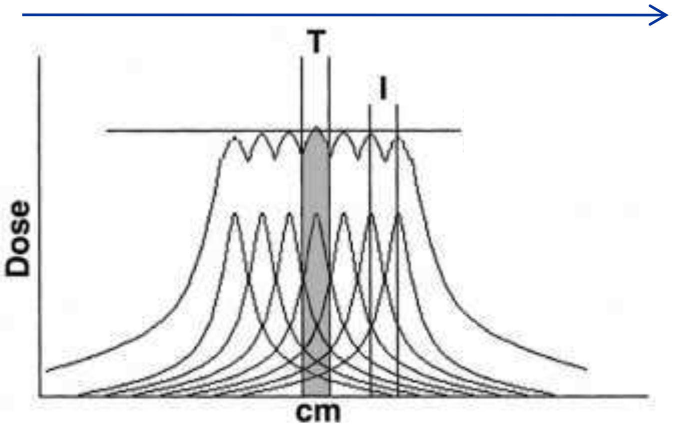
Dose quantities: Computed tomography

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

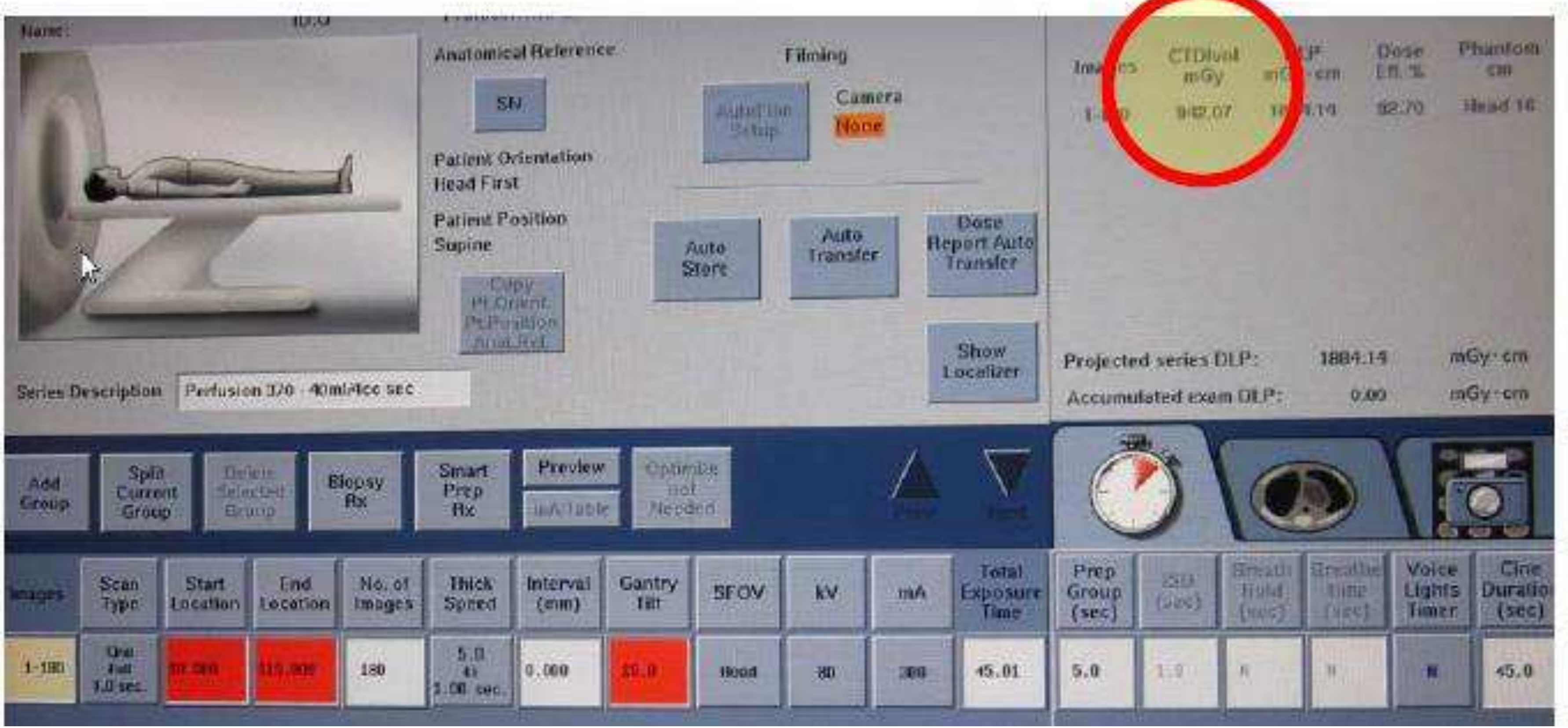
$$DLP = CTDI_{vol} \times (Exposure\_length)$$







Dose quantities: Computed tomography



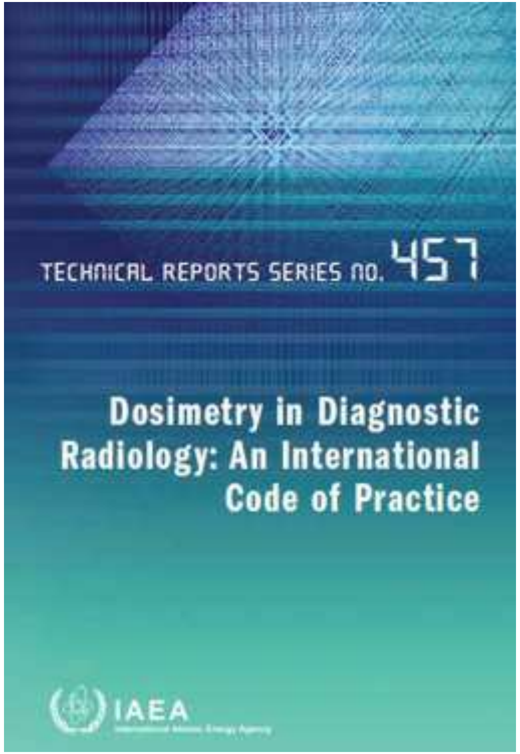
Dose quantities: Computed tomography

Exam Description: QA CT3

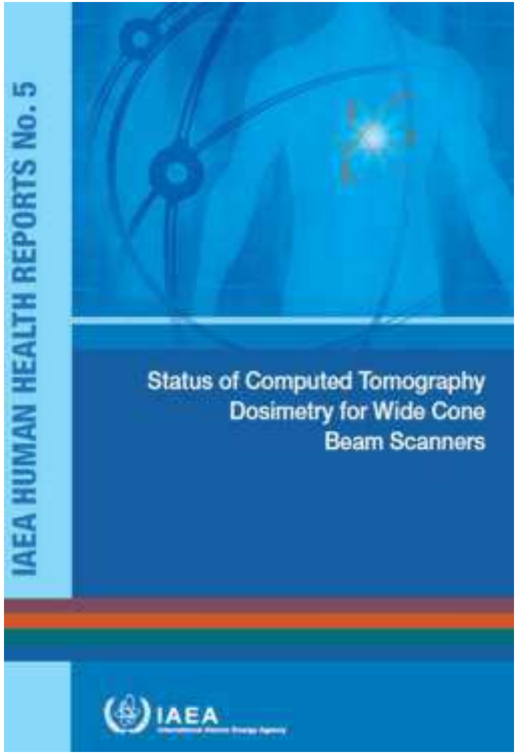
Dose Report

Series	Type	Scan Range (mm)	CTDIvol (mGy)	DLP (mGy-cm)	Phantom cm
1	Axial	S0.000-S0.000	64.38	64.38	Head 16
1	Axial	S35.000-S35.000	64.38	64.38	Head 16
1	Axial	S50.000-S50.000	64.38	64.38	Head 16
			Total Exam DLP:	193.14	

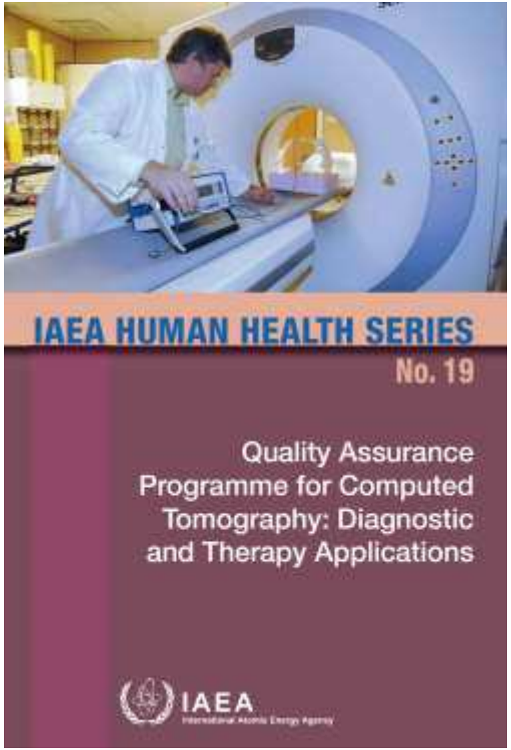
Dose quantities: Computed tomography



2007



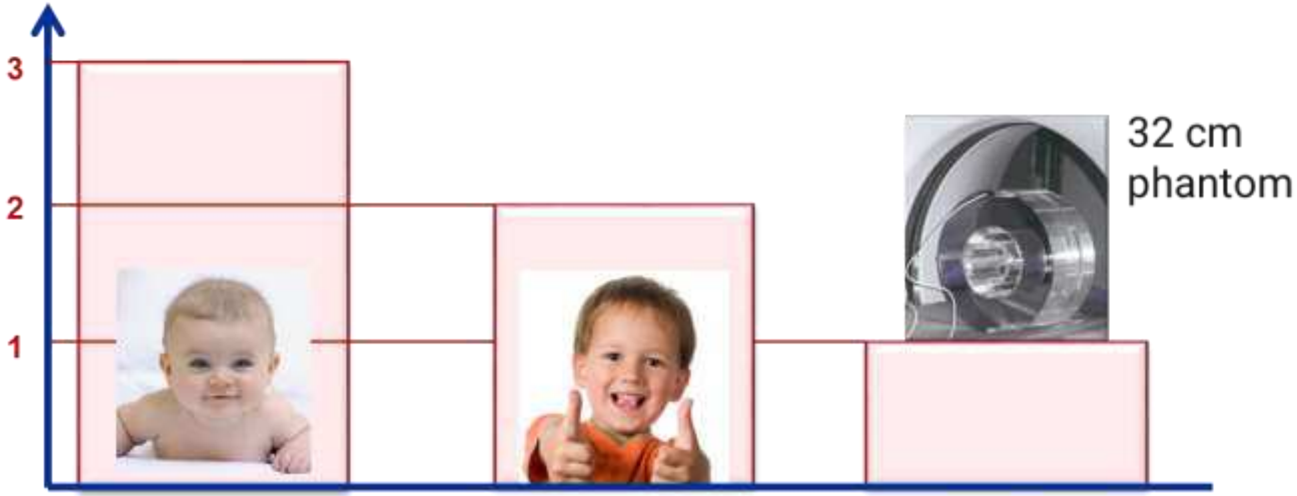
2011



2012

Dose quantities: Computed tomography

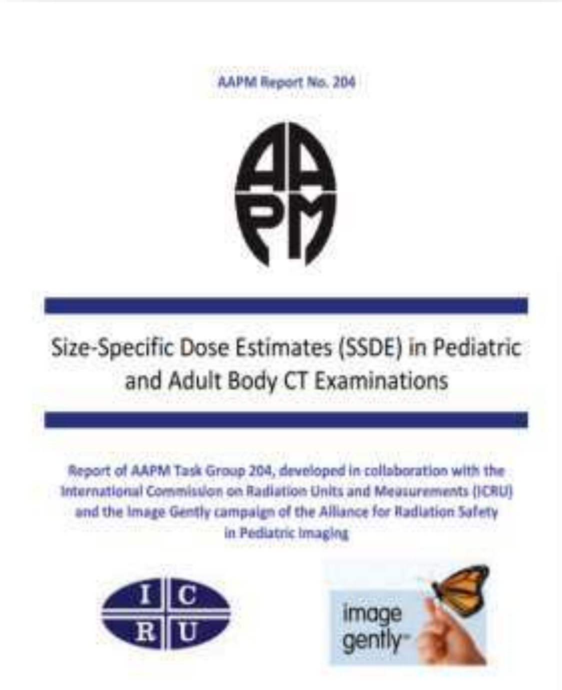
- CTDI ≠ patient dose
- For the same protocol (set of exposure parameters) for an adult and a child ⇨ the same CTDI



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

Dose quantities: Computed tomography

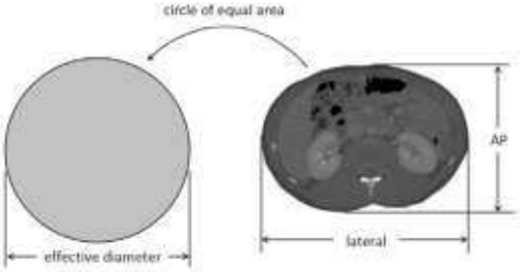
Size-specific dose estimate (SSDE)

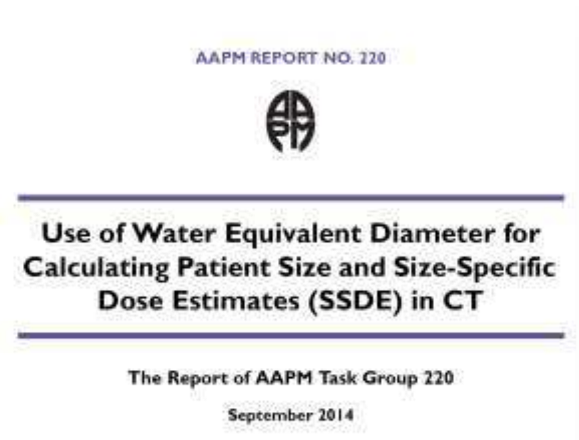

AAPM Report No. 204

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

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

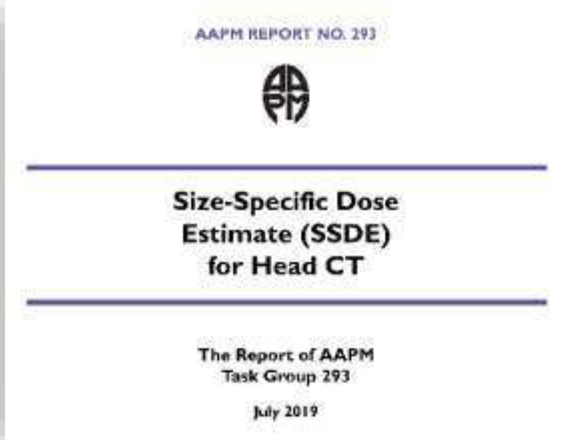



AAPM REPORT NO. 220

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

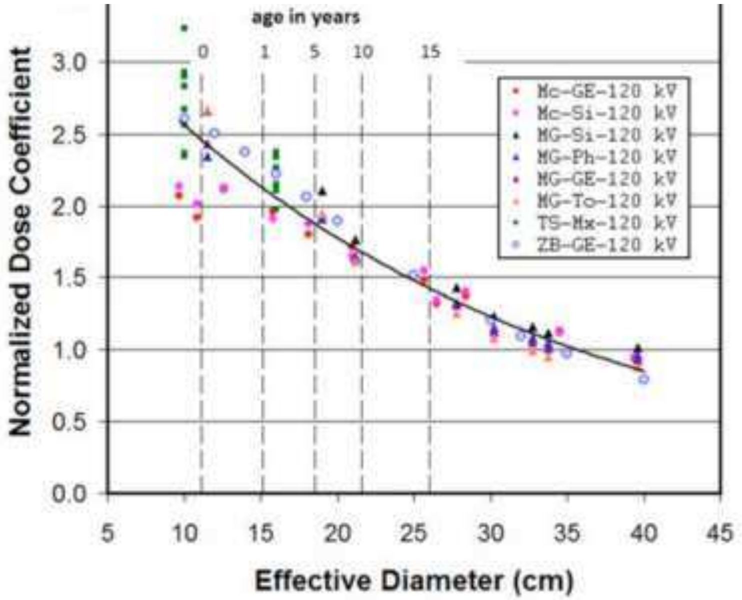
The Report of AAPM Task Group 293

July 2019

Dose quantities: Computed tomography

Size-specific dose estimate (SSDE)

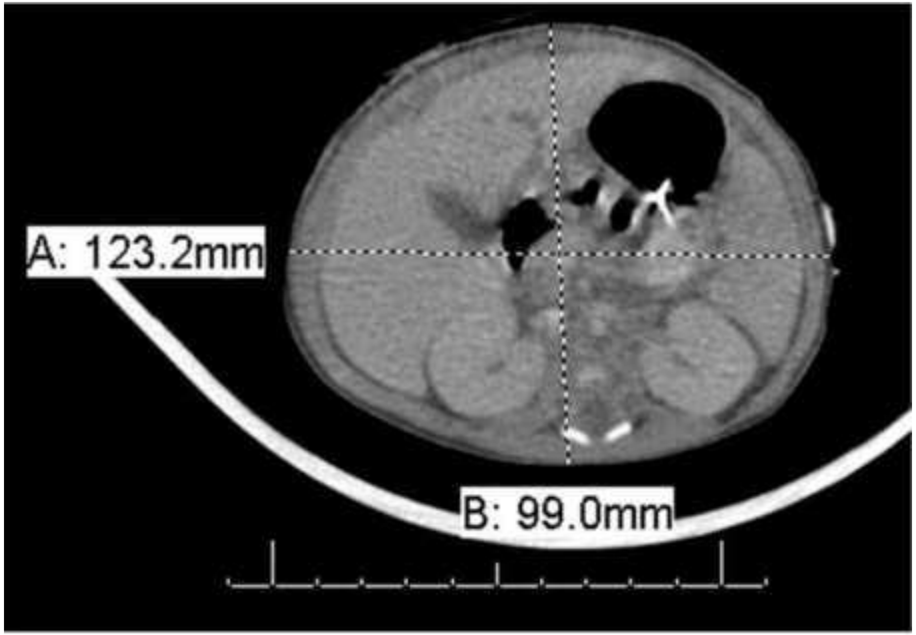
$$size\ specific\ dose\ estimate = SSDE = f_{size}^{32X} \times CTDI_{vol}^{32}$$



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	082
42	0.79
43	0.76
44	0.74
45	0.71

Dose quantities: Computed tomography

Size-specific dose estimate (SSDE)



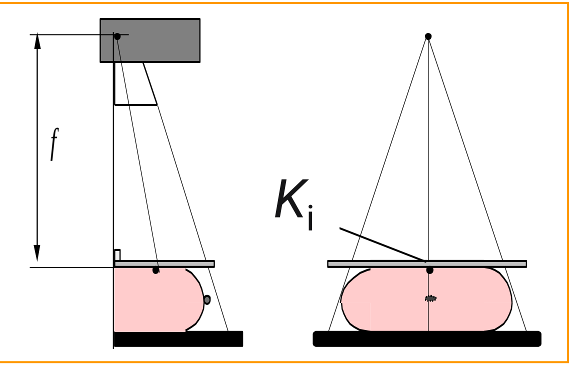
5.40 mGy = CTDIvol (32 cm phantom)

Example: Effective diameter 11 см

f = 2.5

SSDE = 5.4 x 2.5 = 13 mGy

Dose quantities: Mammography



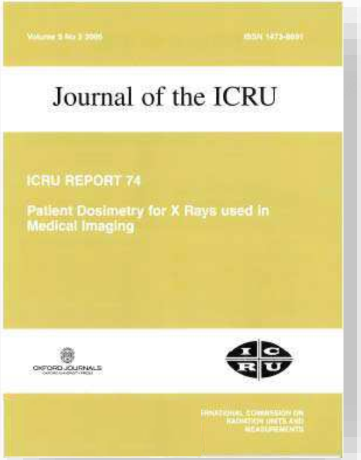
- Incident air kerma, K_i

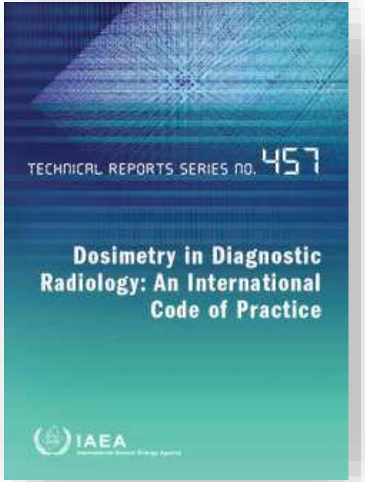
  the air kerma from the incident beam on the central x-ray beam axis at the skin entrance plane, backscatter excluded

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

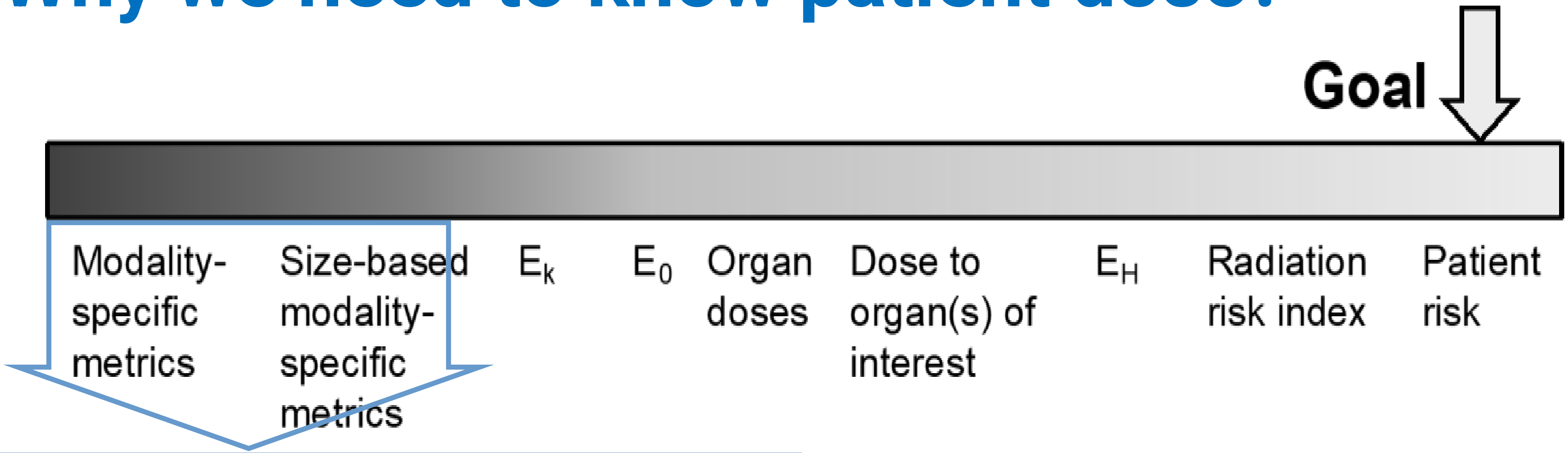
Modality specific metrics

Modality	Dose quantity	Dose unit
Plain radiography, including dental	Entrance surface air kerma, K_e Kerma-area product, P_{KA}	mGy $\mu Gy.m^2$
Mammography	Incident air kerma, K_i Mean glandular dose, MGD	mGy mGy
Fluoroscopy & fluoroscopy guided interventional procedures	Kerma-area product, P_{KA} Cumulative air kerma at the interventional reference point	$Gy.cm^2$ mGy
Computed tomography	CT air kerma index, C Air kerma-length product, L_{KP}	mGy mGy.cm





Why we need to know patient dose?



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)

1	2015-03-28	Thoracic spine	PA	Male	22	482	68	115	Yes	Large	24	30	68	56	0.102	1 - fully	13	0.10	1.829
[illegible]	[illegible]	Thoracic spine	PA	Female	29	163	62	115	Yes	Large	24	30	66	32	0.058	1 - fully	22	0.09	1.146
3	2015-03-28	Thoracic spine	PA	Male	40	168	55	115	Yes	Large	24	30	71.5	56	0.102	1 - fully	20	0.11	2.413
4	2015-03-28	Thoracic spine	PA	Female	30	170	69	115	Yes	Large	24	30	66	28	0.051	1 - fully	23	0.09	1.018
5	2015-03-28	Thoracic spine	PA	Female	25	163	72	115	Yes	Large	24	30	66	28	0.051	1 - fully	24	0.09	1.040
6	2015-03-28	Thoracic spine	PA	Female	33	173	65	115	Yes	Large	24	30	71.5	56	0.102	1 - fully	22	0.11	2.489
7	2015-03-28	Thoracic spine	PA	Male	55	164	70	115	Yes	Large	24	30	71.5	56	0.102	1 - fully	23	0.11	2.568
8	2015-03-28	Thoracic spine	PA	Female	40	165	62	115	Yes	Large	24	30	66	28	0.051	1 - fully	22	0.09	1.000
9	2015-03-31	Thoracic spine	PA	Female	78	150	56	115	Yes	Large	24	30	65	28	0.051	1 - fully	22	0.08	0.954
10	2015-03-31	Thoracic spine	PA	Male	29	155	65	115	Yes	Large	24	30	71	56	0.102	1 - fully	23	0.11	2.511
11	2015-03-31	Thoracic spine	PA	Male	39	165	75	115	Yes	Large	24	30	70	56	0.102	1 - fully	24	0.10	2.470
12	2015-03-31	Thoracic spine	PA	Female	27	168	69	115	Yes	Large	24	30	70	56	0.102	1 - fully	23	0.10	2.407
13	2015-03-31	Thoracic spine	PA	Male	26	171	74	115	Yes	Large	24	30	71	56	0.102	1 - fully	23	0.11	2.531
14	2015-03-31	Thoracic spine	PA	Male	24	170	76	115	Yes	Large	24	30	66	28	0.051	1 - fully	24	0.09	1.044
15	2015-04-03	Thoracic spine	PA	Female	50	160	73	115	Yes	Large	24	30	66	40	0.073	1 - fully	24	0.09	1.499
16	2015-04-03	Thoracic spine	PA	Male	65	170	75	115	Yes	Large	24	30	71	56	0.102	1 - fully	24	0.11	2.544
17	2015-04-03	Thoracic spine	PA	Male	68	168	65	115	Yes	Large	24	30	66	40	0.073	1 - fully	22	0.09	1.438
18	2015-04-03	Thoracic spine	PA	Female	27	165	63	115	Yes	Large	24	43	66	36	0.065	1 - fully	22	0.09	1.290
19	2015-04-03	Thoracic spine	PA	Female	57	166	90	115	Yes	Large	35	43	71.5	56	0.102	1 - fully	26	0.11	2.742
20	2015-04-03	Thoracic spine	PA	Male	33	173	76	115	Yes	Large	35	43	70	56	0.102	1 - fully	24	0.10	2.448
Average						181.45	69	115					68.5	45.2	0.082		22.529		1.8891
Standard deviation						70.972	7.9802	0					2.5547	12.722	0.023		2.4757		0.6916
Minimum						150	55	115					65	28	0.051		13.406		0.9538
Maximum						482	90	115					71.5	56	0.102		26.28		2.7423
Median						167	69	115					69	56	0.102		22.993		2.1181

Range (Min-Max):
(0.01 – 0.10) Gy.cm^2
Median = 0.1 Gy.cm^2

Modality specific dose metrics

- Used to estimate typical dose values

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

Room 1: Median = 0.1 $Gy.cm^2$

Room 2: Median = 0.05 $Gy.cm^2$

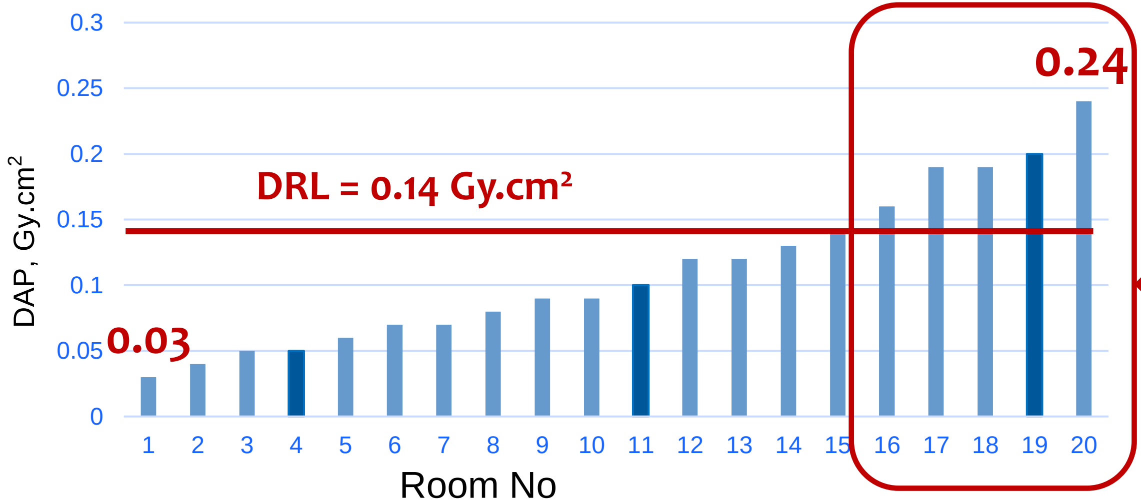
Room 2: Median = 0.2 $Gy.cm^2$

Modality specific dose metrics

- Used to establish DRLs

<u>Chest X-ray,</u> Adult patient (average weight 70 kg)

Typical DAP values in 20 X-ray rooms



Investigation and actions to reduce doses!

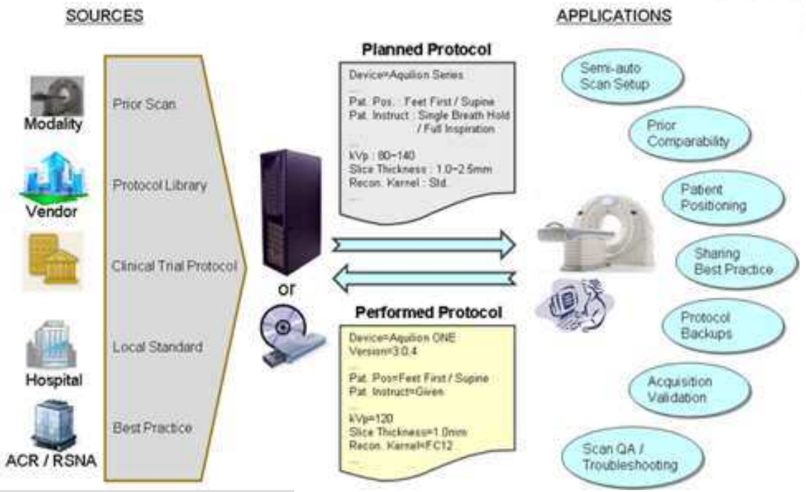
Patient exposure monitoring workflow

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
Digital Imaging and Communications in Medicine

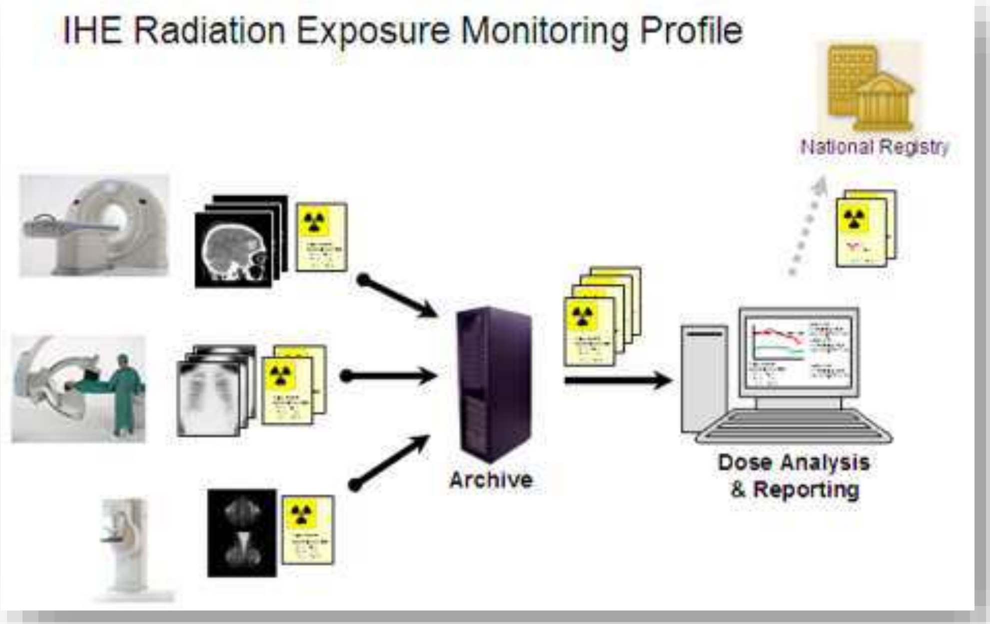
DICOM RDSR

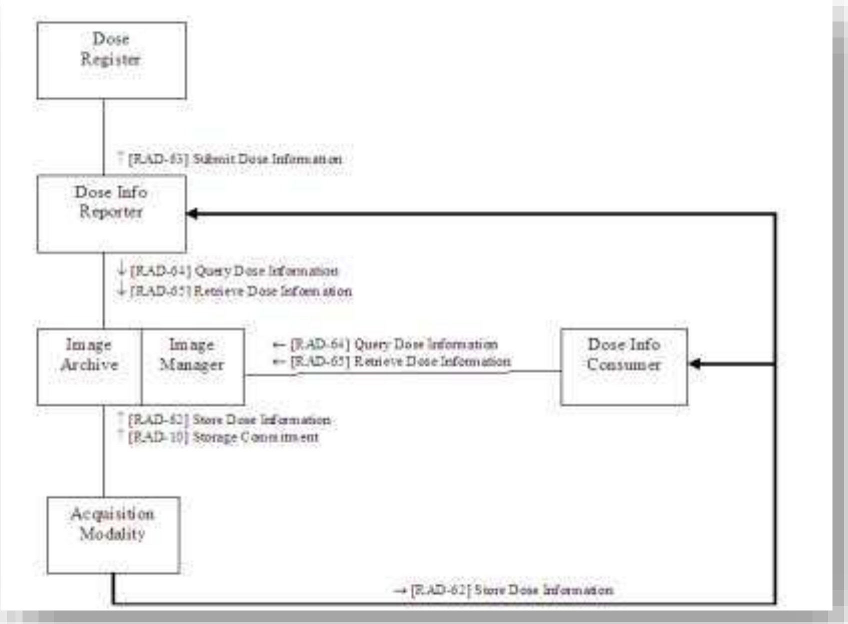
CT Acquisition Parameters	
Exposure Time	7.98s
Scanning Length	367mm
Exposed Range	350mm
Nominal Single Collimation Width	0.6mm
Nominal Total Collimation Width	19.2mm
Pitch Factor	1.2ratio
Number of X-Ray Sources	1X-Ray sources
CT X-Ray Source Parameters	
Identification of the X-Ray Source	A
KVP	120kV
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 Integrating the Healthcare Enterprise





https://www.ihe.net/

Automatic radiation exposure monitoring

- Commercial products

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 USA, 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
Guerbet LLC	Dose&Care
Imalogix	Imalogix
Infinitt Healthcare	DoseM
Medic Vision Imaging Solutions Ltd.	SafeCT
MyXrayDose Ltd	MyXrayDose
PHS Technologies Group, LLC (PACSHealth, 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

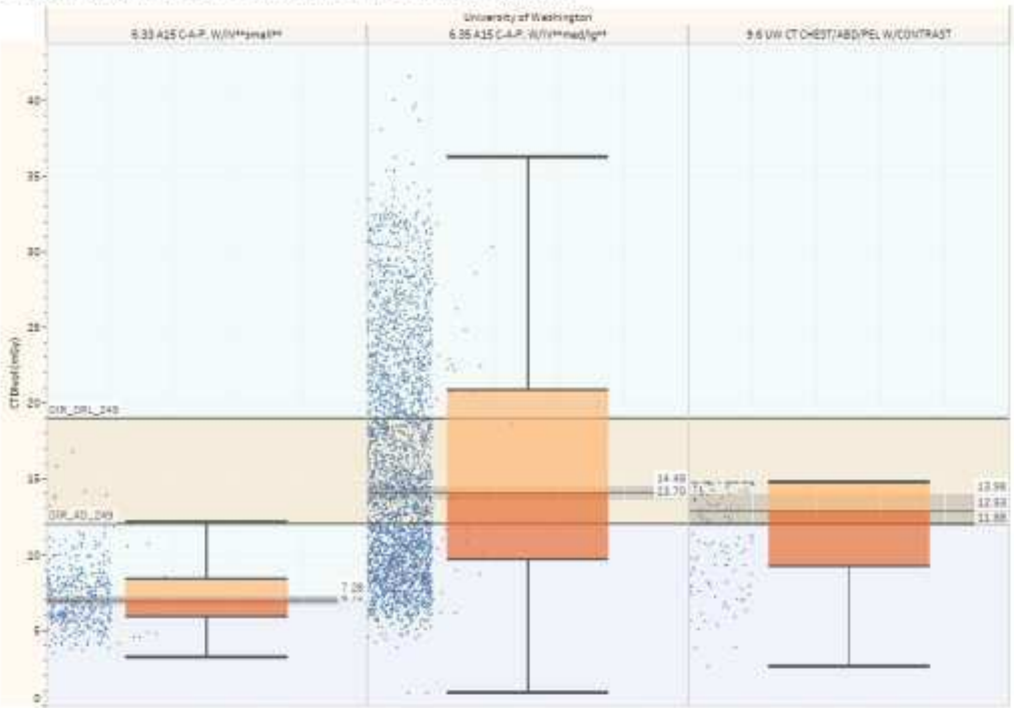
- Free software
  - OpenREM by Ed McDonagh - Python SourceCode
  - Pixelmed DoseUtility
  - CT Dose OCR by Philip Cheng at USC - ARRS Abstract
  - Generalized Radiation Observation Kit (GROK) by Graham Warden at Brigham & Women's Hospital - Source Code
  - Siemens CARE Analytics (free Windows executable)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

Establishing DRLs and typical doses

- National/ regional dose registries

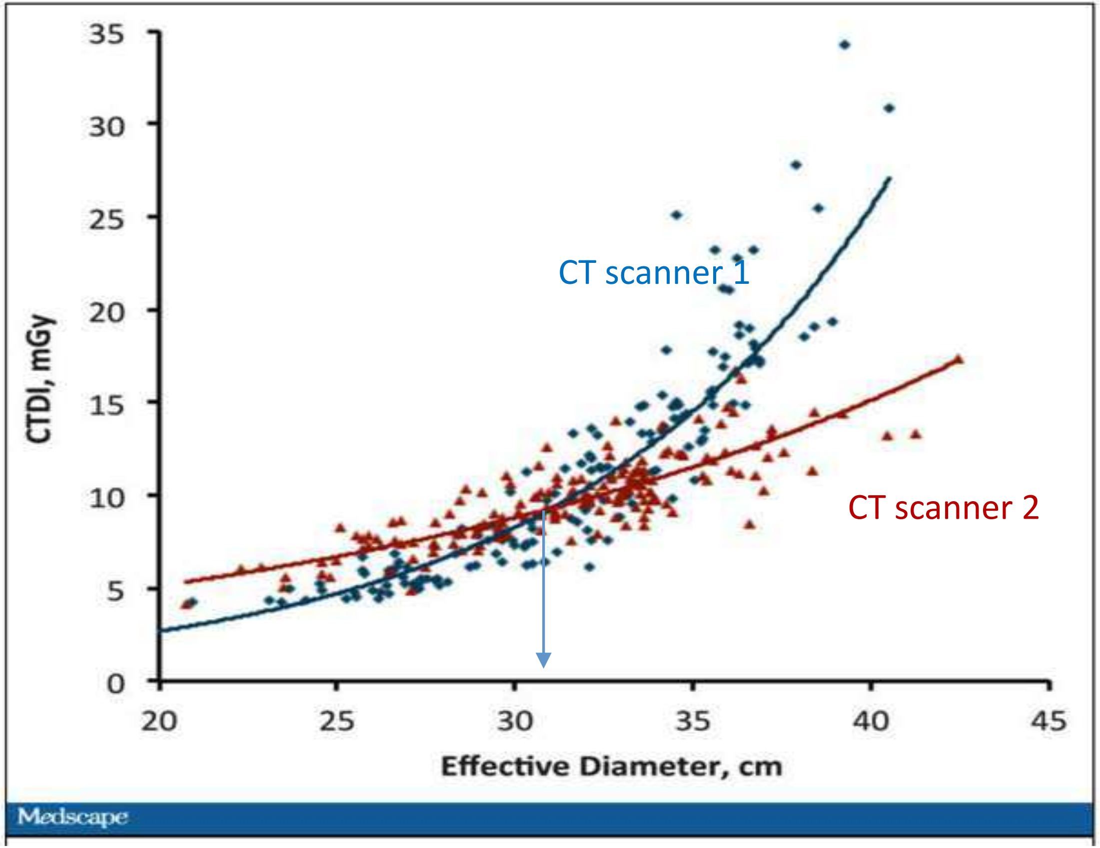
Analysis: Benchmarking against DRLs

CTDIvol Facility RPID249: RAD ORDER CT CHST ABD PELVIS W IVCON



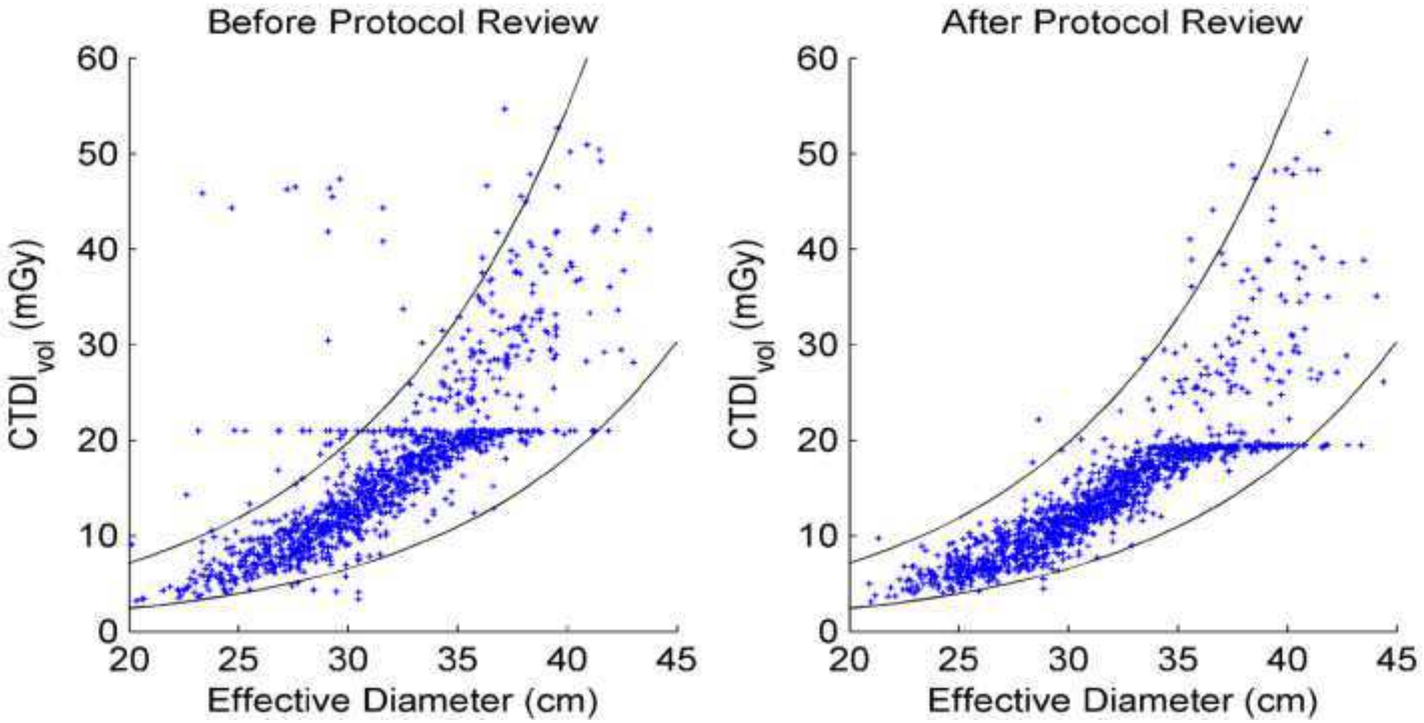
Courtesy K. Kanal

Analysis: Inter-system variability



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

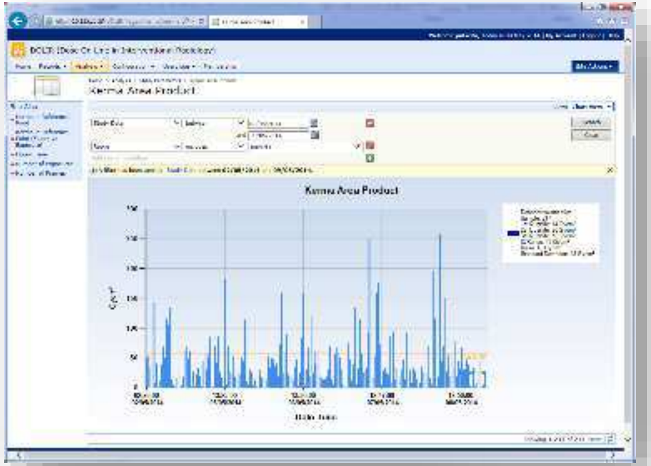
Analysis: Identifying and investigating over-exposure and under-exposure



Courtesy E. Samei, DUMC

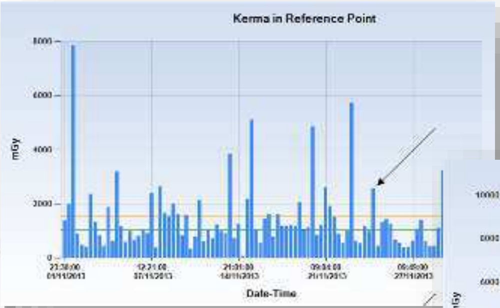
Dose monitoring in interventional radiology

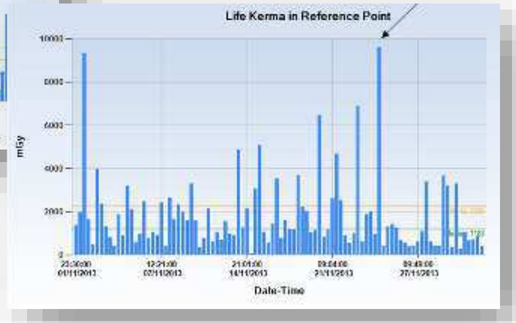
Madrid: DOLIR (Dose On Line for Interventional Radiology)

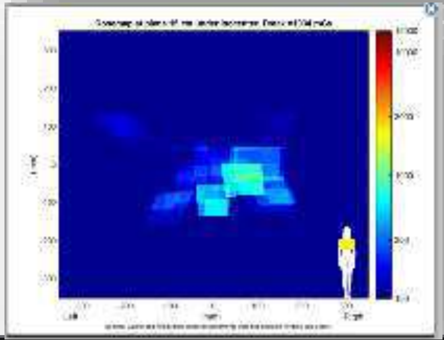


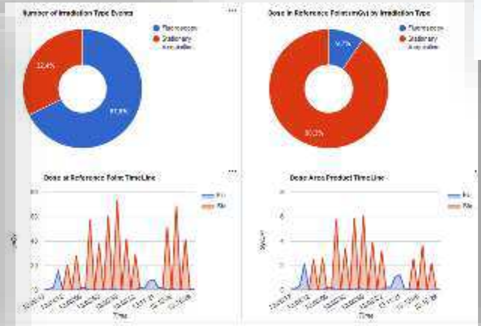
“Life KAP” and “Life CAK” – cumulative doses values of all the procedures performed **on the same patient**

Clinical **follow-up protocol** for patients with CAK and Life CAK values > 5 Gy









Courtesy E. Vano & R. Sanczes

❶ Why we need to know patient dose?

❷ Modality specific dose metrics

❸ Patient specific metrics

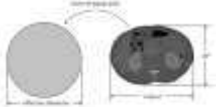
Dose metrics

Goal

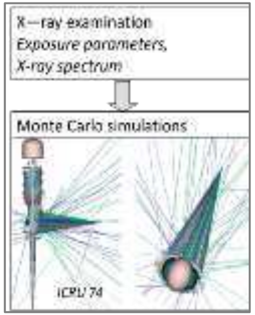
Modality-specific metrics

Size-specific metrics

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



Organ doses



Effective dose

$$E = \sum_T w_T H_T$$

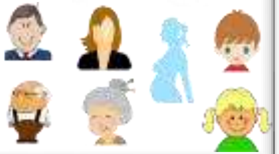
Radiation risk index

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

Lat+AP Dim (cm)	Effective Dia (cm)	Conversion Factor
16	7.7	2.79
18	8.7	2.69
20	9.7	2.59
22	10.7	2.50
24	11.7	2.41
26	12.7	2.32
28	13.7	2.24
30	14.7	2.16
32	15.7	2.08
34	16.7	2.01
36	17.6	1.94
38	18.6	1.87
40	19.6	1.80
42	20.6	1.74
44	21.6	1.67
46	22.6	1.62
48	23.6	1.56
50	24.6	1.50
52	25.6	1.45
54	26.6	1.40
56	27.6	1.35
58	28.6	1.30
60	29.6	1.25
62	30.5	1.21
64	31.5	1.16
66	32.5	1.12
68	33.5	1.08

Table 1B

Lateral Dim (cm)	Effective Dia (cm)	Conversion Factor
8	9.2	2.65
9	9.7	2.60
10	10.2	2.55
11	10.7	2.50
12	11.3	2.45
13	11.8	2.40
14	12.4	2.35
15	13.1	2.29
16	13.7	2.24
17	14.3	2.19
18	15.0	2.13
19	15.7	2.08
20	16.4	2.03
21	17.2	1.97
22	17.9	1.92
23	18.7	1.86
24	19.5	1.81
25	20.3	1.76
26	21.1	1.70
27	22.0	1.65
28	22.9	1.60
29	23.8	1.55
30	24.7	1.50
31	25.6	1.45
32	26.6	1.40
33	27.6	1.35
34	28.6	1.30

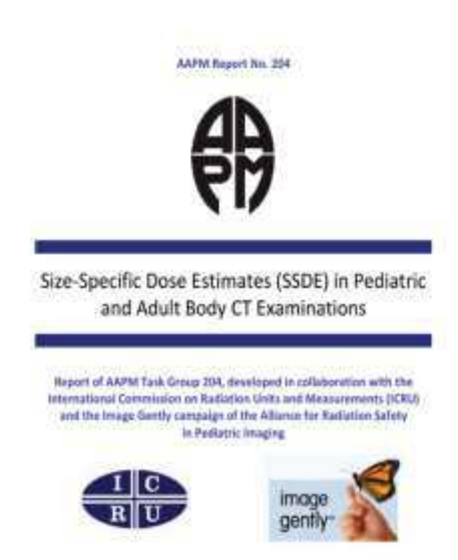
Table 1C

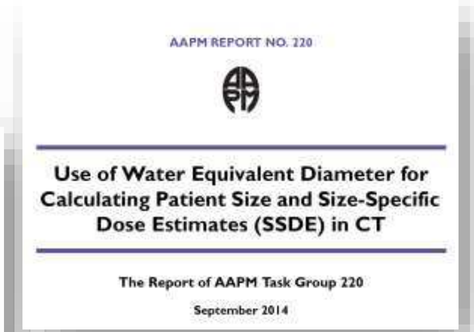
AP Dim (cm)	Effective Dia (cm)	Conversion Factor
8	8.8	2.68
9	10.2	2.55
10	11.6	2.42
11	13.0	2.30
12	14.4	2.18
13	15.7	2.08
14	17.0	1.98
15	18.3	1.89
16	19.6	1.81
17	20.8	1.73
18	22.0	1.65
19	23.2	1.58
20	24.3	1.52
21	25.5	1.45
22	26.6	1.40
23	27.6	1.34
24	28.7	1.29
25	29.7	1.25
26	30.7	1.20
27	31.8	1.16
28	32.6	1.12
29	33.5	1.08
30	34.4	1.05
31	35.2	1.02
32	36.0	0.99
33	36.8	0.96
34	37.6	0.93

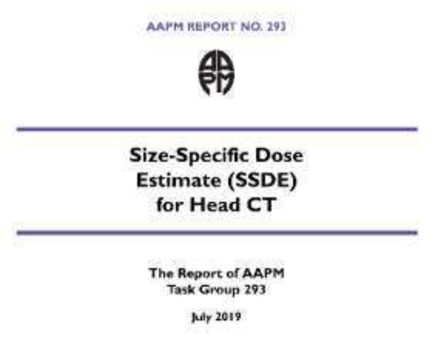
Table 1D

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

AAPM Report 204: Size-Specific Dose Estimates (SSDE) in Pediatric and Adult CT Examinations Page 10







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)

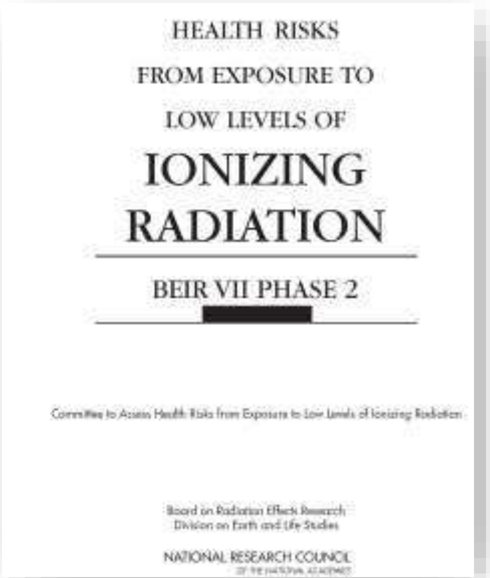
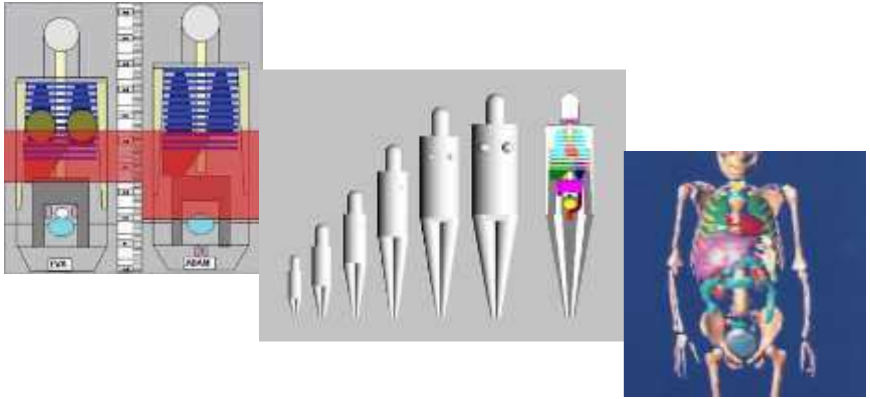


TABLE 12D-2 Lifetime Attributable Risk of Cancer Mortality[a]

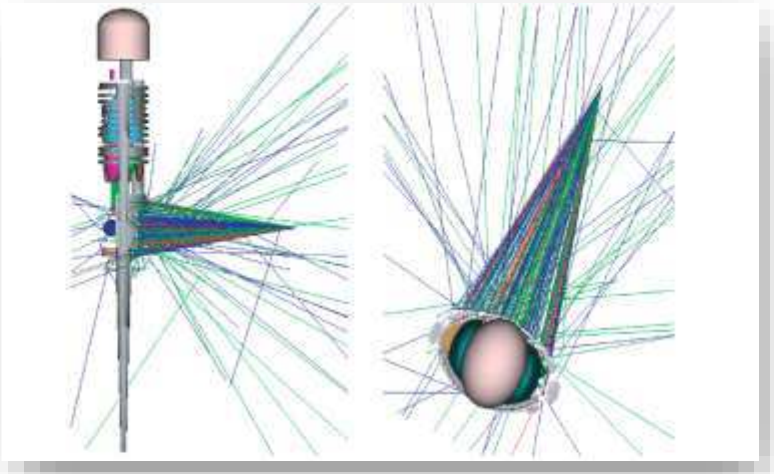
	Age at Exposure (years)										
Cancer Site	0	5	10	15	20	30	40	50	60	70	80
Males											
Stomach	41	34	30	25	21	16	15	13	11	8	4
Colon	163	139	117	99	84	61	60	57	49	36	21
Liver	44	37	31	27	23	16	16	14	12	8	4
Lung	318	264	219	182	151	107	107	104	93	71	42
Prostate	17	15	12	10	9	7	6	7	7	7	5
Bladder	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	533	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
Females											
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:



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

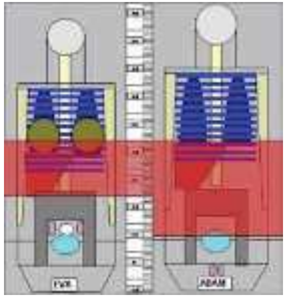


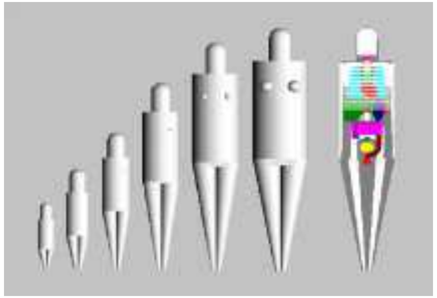
Source: ICRU 74

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

Organ doses

Simplistic geometrical phantoms uniform irradiation fields





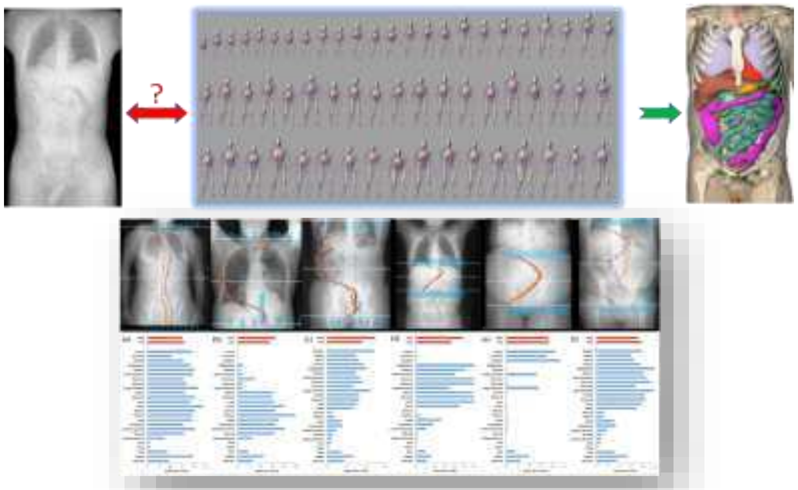
- Generic attributes of the patient (size)
- Large uncertainties in reported organ doses estimates
- Conversion coefficients from a modality-specific quantity to organ doses (tabulated or software-based)

Patient-specific organ dosimetry

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

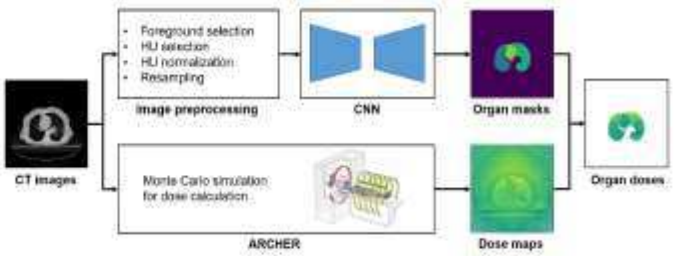
Organ doses

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]

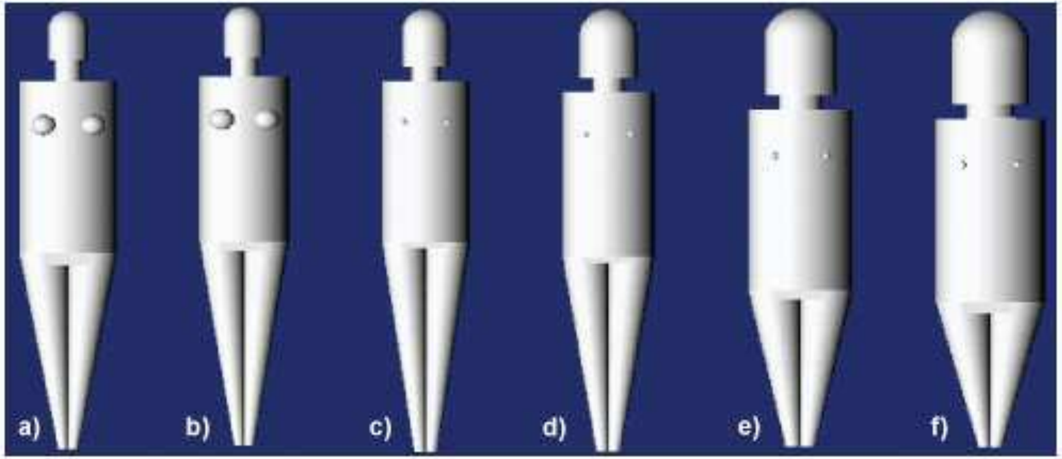
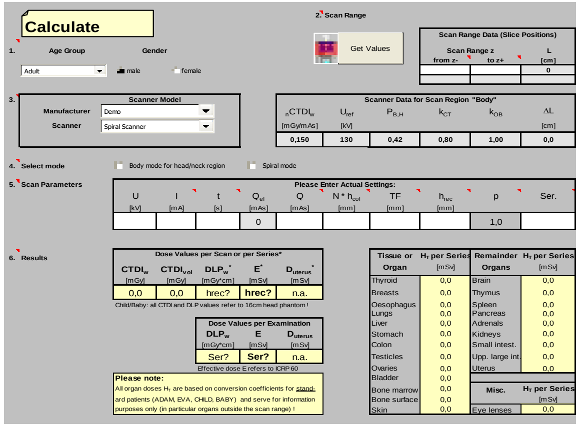


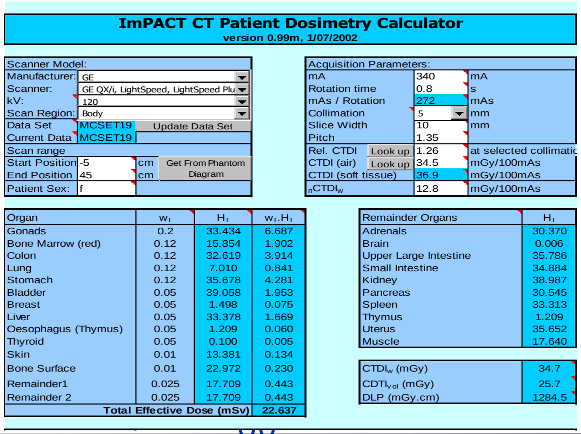
Figure 2: Anterior views of the basic phantom models in PCXMC, scaled to have identical heights. (a) Adult phantom 178.6 cm/73.2 kg, (b) 15-year old phantom 168.1 cm/56.3 kg, (c) 10-year old phantom 139.8 cm/32.4 kg, (d) 5-year old phantom 109.1 cm/19.0 kg, (e) 1-year old phantom 74.4 cm/9.2 kg (f) new-born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

Organ doses – software products

CT-Expo
[www.sascrad.com]

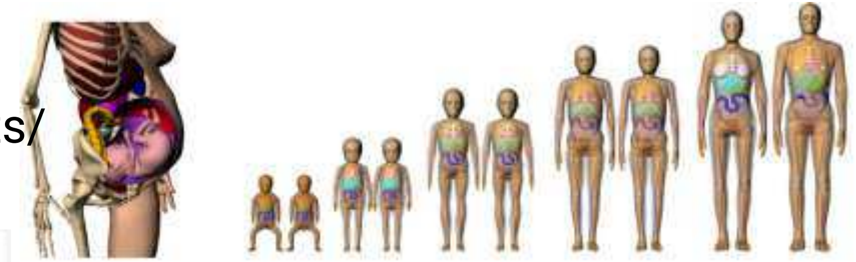


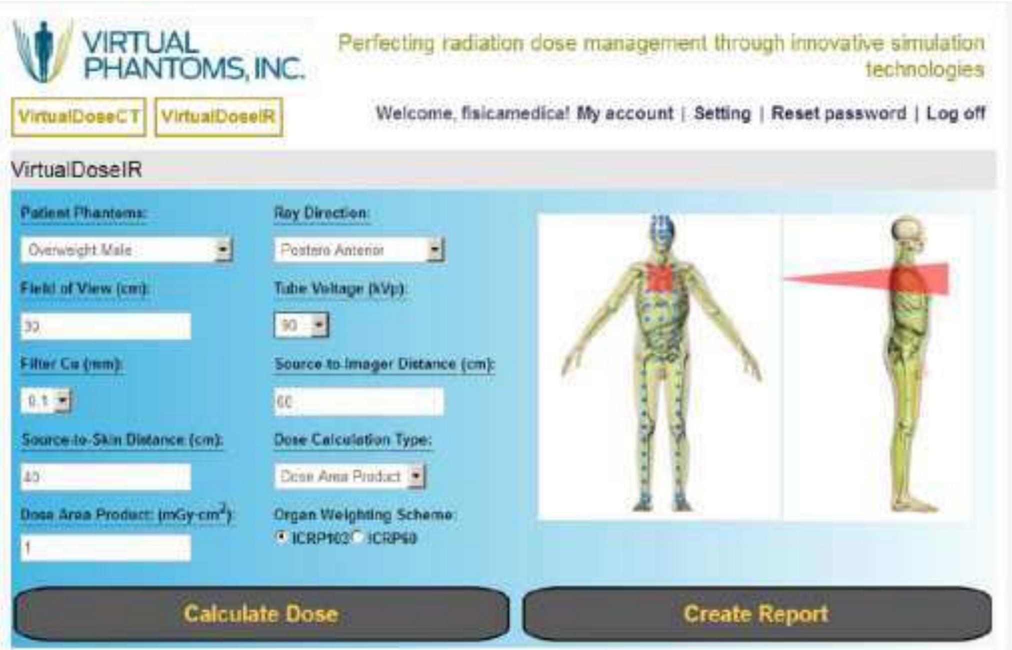
ImPACT
CT Patient Dosimetry Calculator
(www.impactscan.org)



Organ doses – software products

Virtual Dose (Virtual Phantoms, inc)
http://www.virtualphantoms.com/our-products/





Modules for
- CT
- Interventional procedures

Organ doses – software products

- XCATdose за 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 (±)
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.

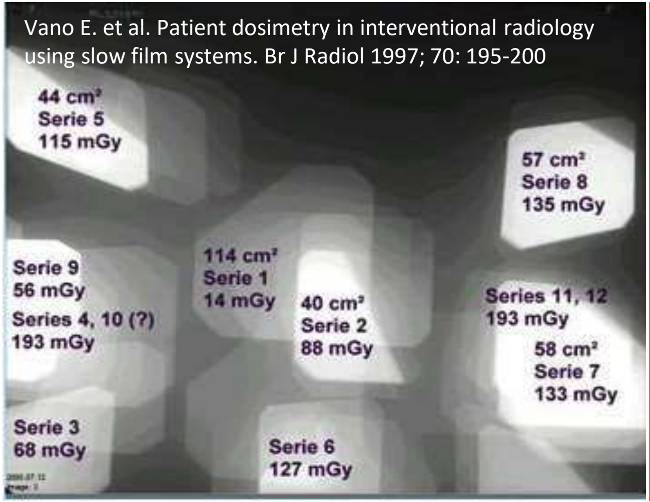
Organ doses to organs of interest

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

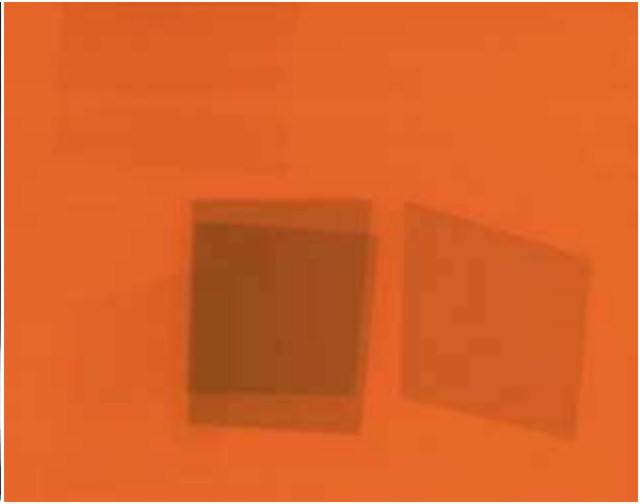
Skin dose in fluoroscopy

- Skin dose (mGy)

TLD



Therapy film
Kodak X-Omat V



Gafchromic film

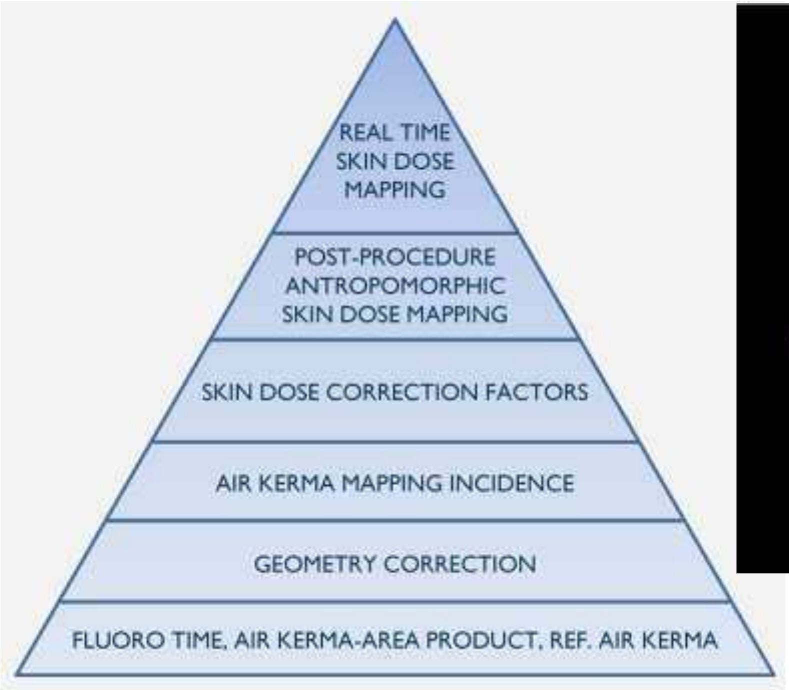
Skin dose in fluoroscopy

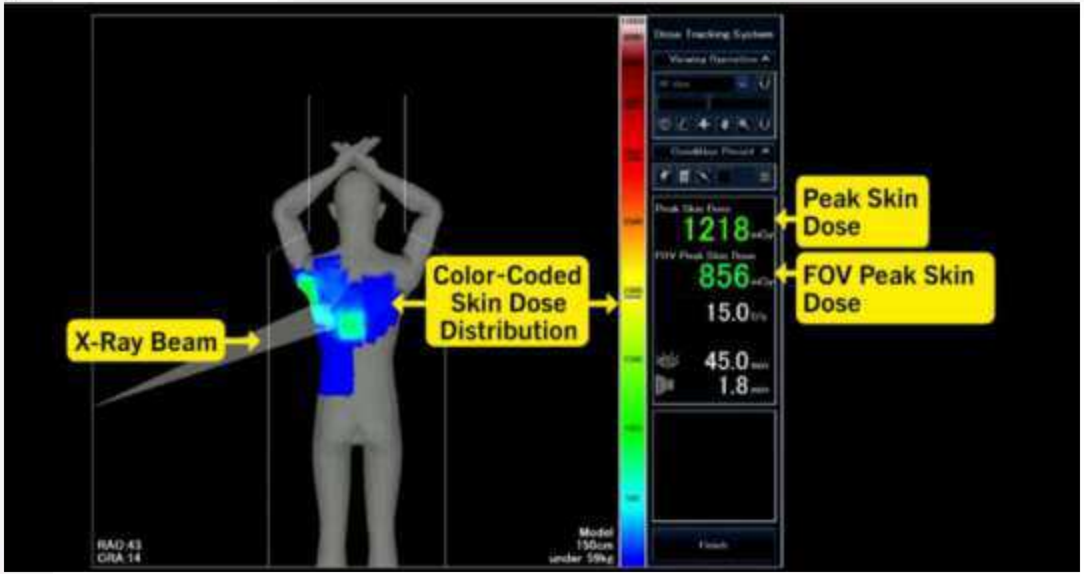
$$Skin\ dose = K_{a,r} \times CF \times Att \times BSF \times \left(\frac{d_{ref}}{d_{perp}}\right)^2 \times f_{skin}$$

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. Pasciak[2]





Courtesy A. Trianni

Skin dose calculation and reporting


CONCERT

VERIDIC

EJP-CONCERT

European Joint Programme for the Integration of Radiation Protection Research

D 9.141 - Standards for digital dose reporting

Lead Author: Françoise Malchair

With contributions from: Jérémie Dabin, Marine Deleu, Carlo Maccia, Marta Sans Merce

- 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.

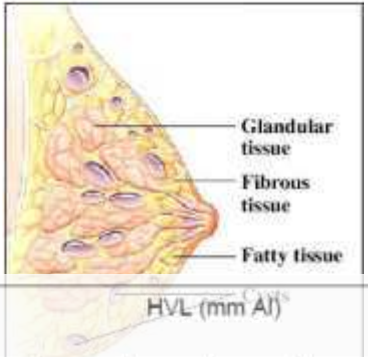
- ±25% agreement with measurements on phantoms for 10 SDC products
- ±43% and ±76% agreement for 2 products validated on patients
- No software validated for vendor-independent transportability

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

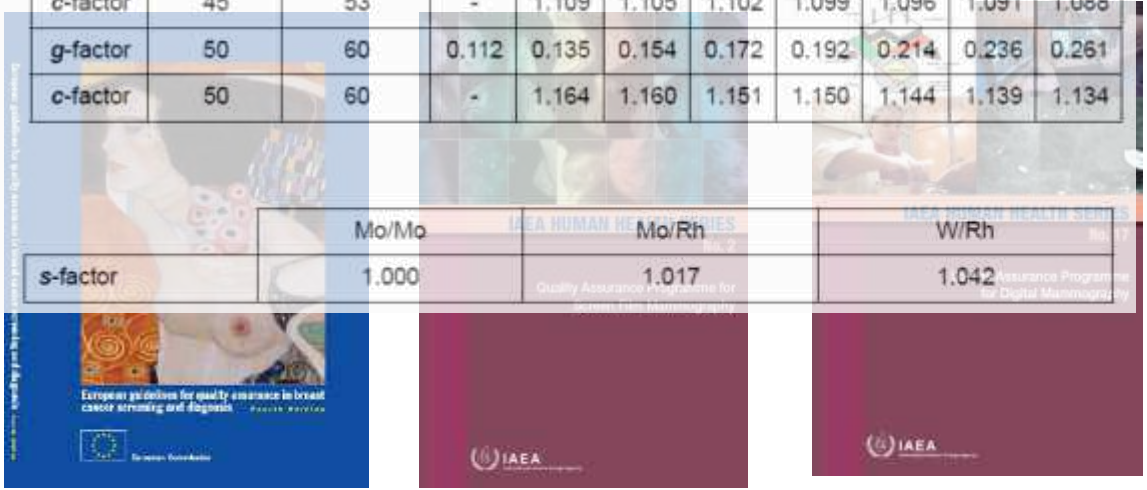


$D_g = K_i \, . \, g \, . \, c \, . \, s$

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)							
			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

	Mo/Mo	Mo/Rh	W/Rh
s-factor	1.000	1.017	1.042



Dose to embryo or fetus

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


Radiology
Radiation Dose to the Conceptus from Multidetector CT during Early Gestation: A Method That Allows for Variations in Maternal Body Size and Conceptus Position[1]

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

John Damilakis
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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
    - Uncertainites due to organ dose calculations
        - phantoms, simulations
    - Change of w_T over time

$$E = \sum_T w_T H_T$$

- 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)

Effective dose assessment methods

Computed *E* using modality-specific conversion factors

$$E_k = k.F$$

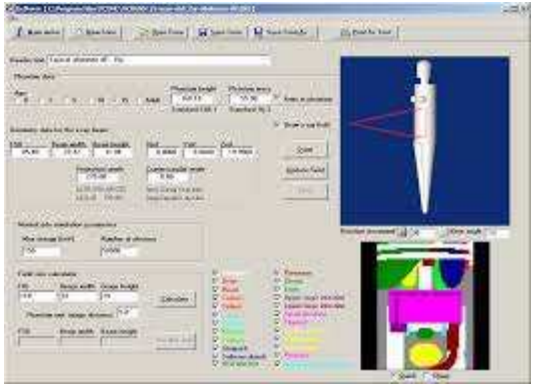
F - modality specific metrics (DLP in CT or KAP in radiography/ fluoroscopy

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

Ignores patient's habitus and irradiation field

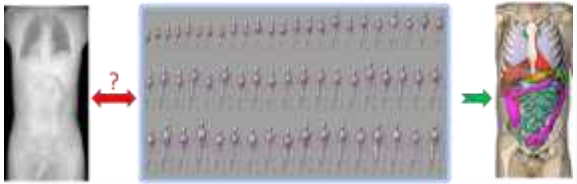
Computed *E* using a generic patient model and Monte Carlo

(e.g. PCXMC, CTExpo)



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. SSG12-05, 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)

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

- Radiation risk index

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

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

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

ICRP

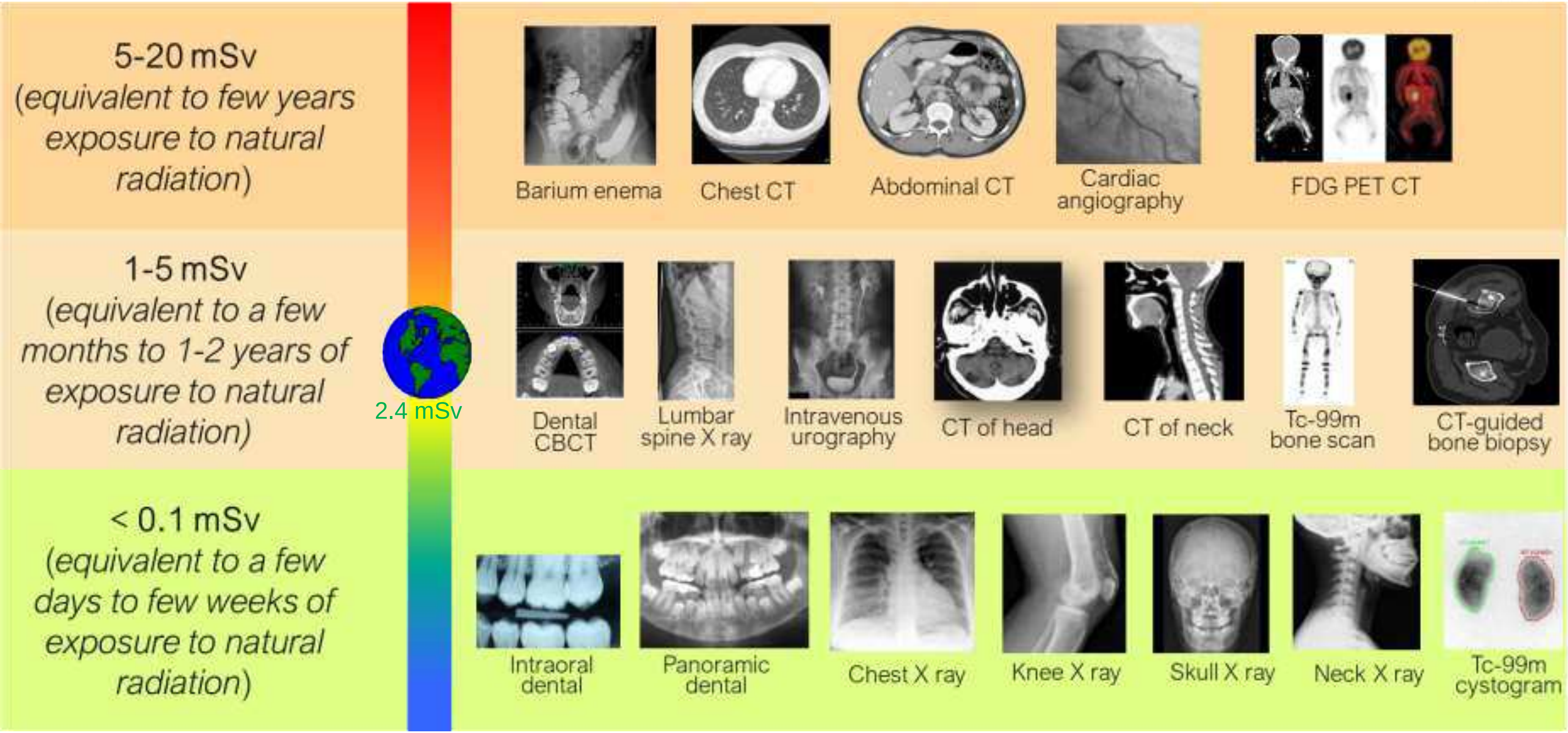
Task Group 79
The Use of Effective Dose as a Risk Related Radiological Protection Quantity

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



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

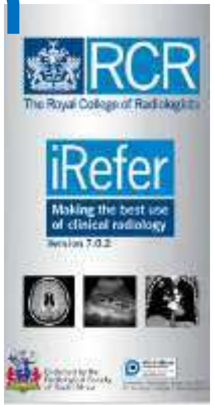
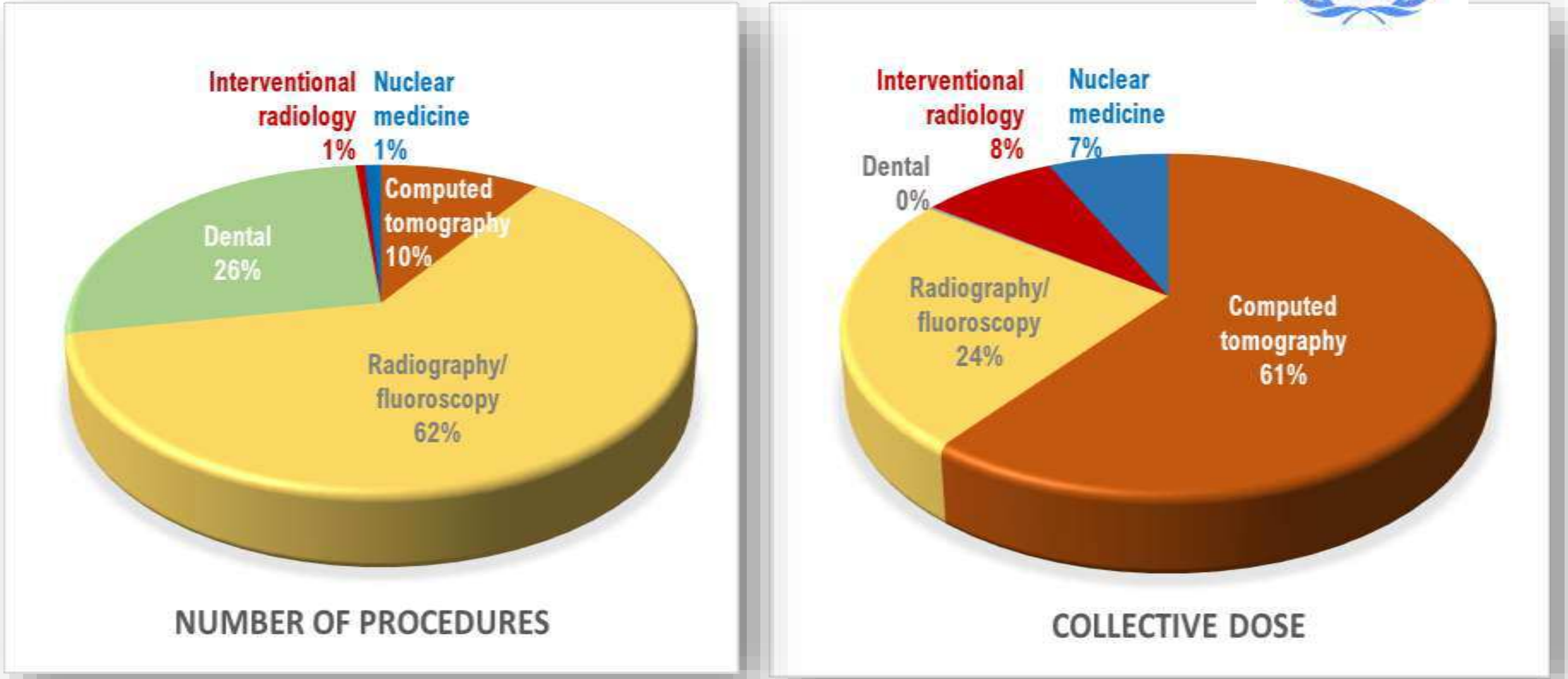


Table 3. Band classification of the typical doses of ionising radiation from common imaging procedures[23,26]

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

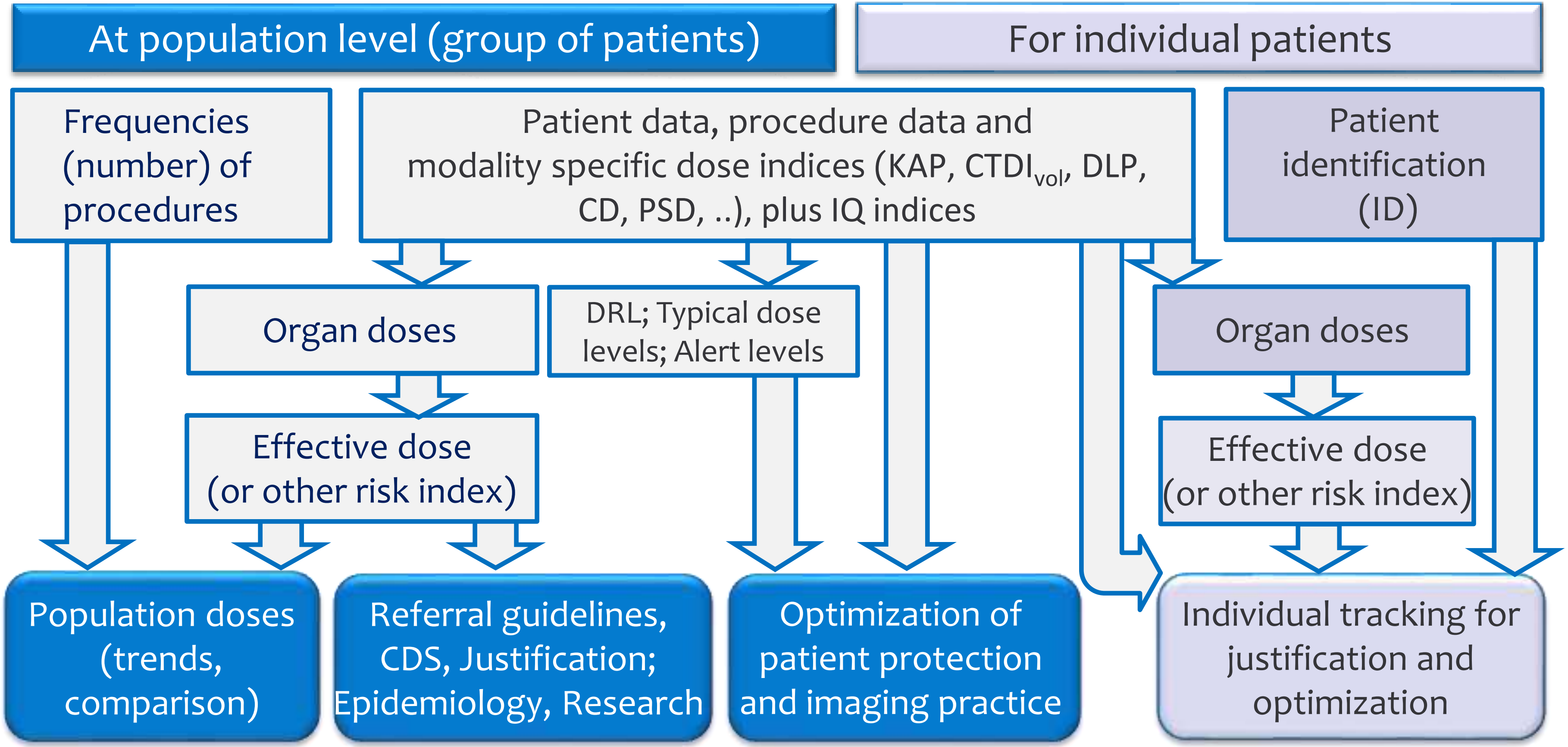
*The average annual background dose in most parts of Europe falls within the 1–5 mSv range (☢☢). Cancer risks from radiation vary considerably with age and sex, with higher risks in infants and females.[24] Cancer risk indicated in this table is averaged for adults. This should be taken in the context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



UNSCEAR, 2022

Patient exposure monitoring strategy



SAFETY REPORT SERIES No. XX

PATIENT RADIATION EXPOSURE MONITORING IN MEDICAL IMAGING

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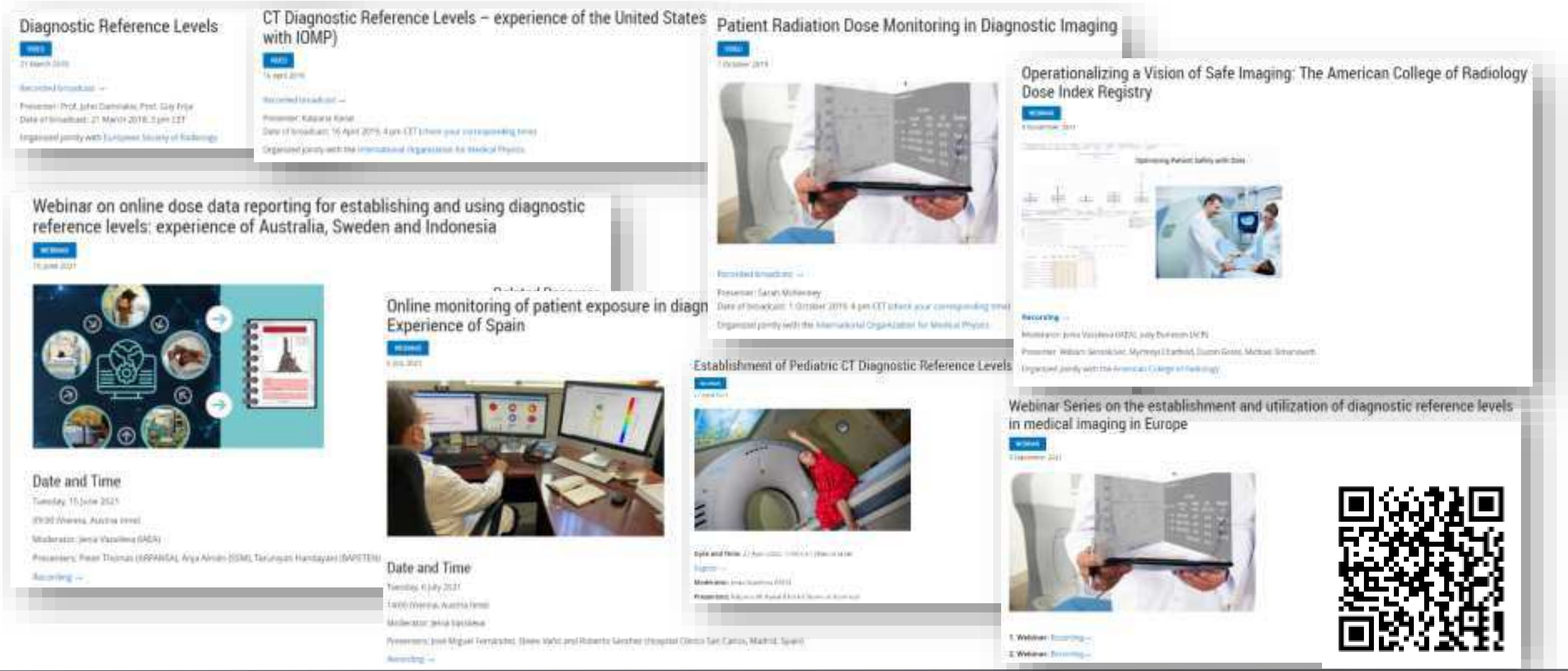
https://preprint.iaea.org/search.aspx?orig_q=patient+radiation+exposure+monitoring&src=ics

IAEA webinars related to the topic

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



IAEA eLearning course on DRLs

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Home > My courses > Diagnostic Reference Levels in Medical Imaging

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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