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X-ray imaging dosimetry challenges *Medical Physics perspective*

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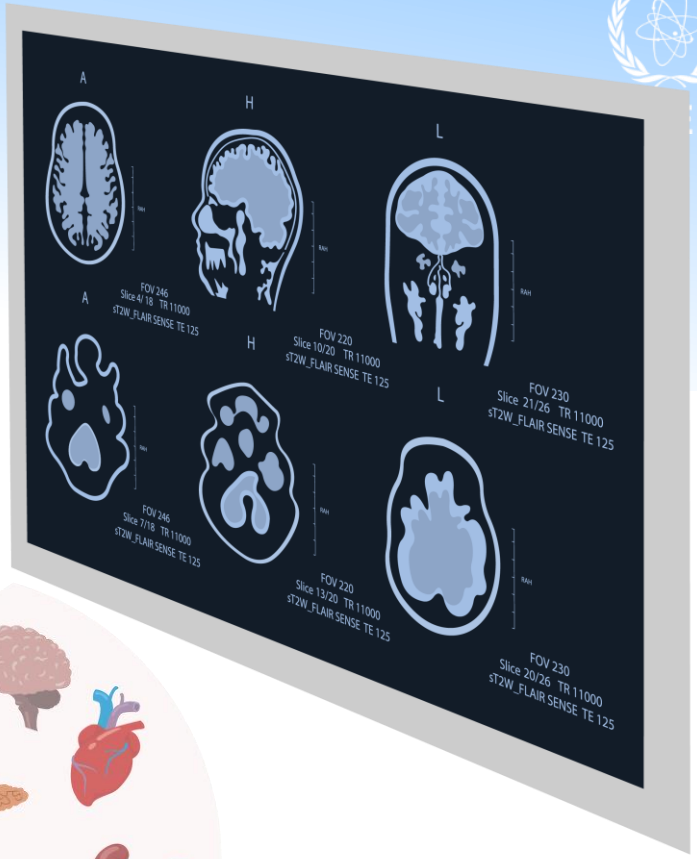
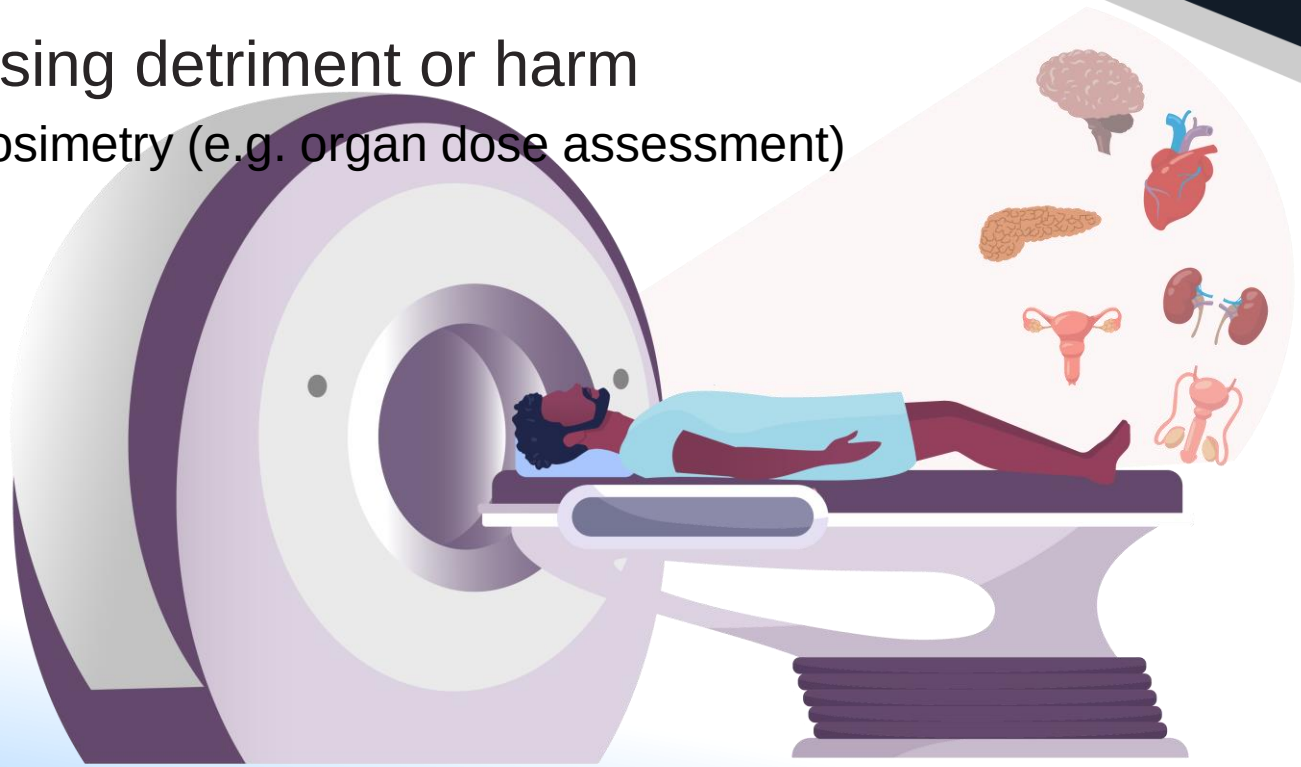
Outline

- Why dosimetry in X ray imaging?
- Role of medical physicist
- Technology in X ray imaging
  - Equipment and techniques
  - Radiation qualities and geometry
- Dosimetry methodology
- Uncertainty requirements
- Way forward

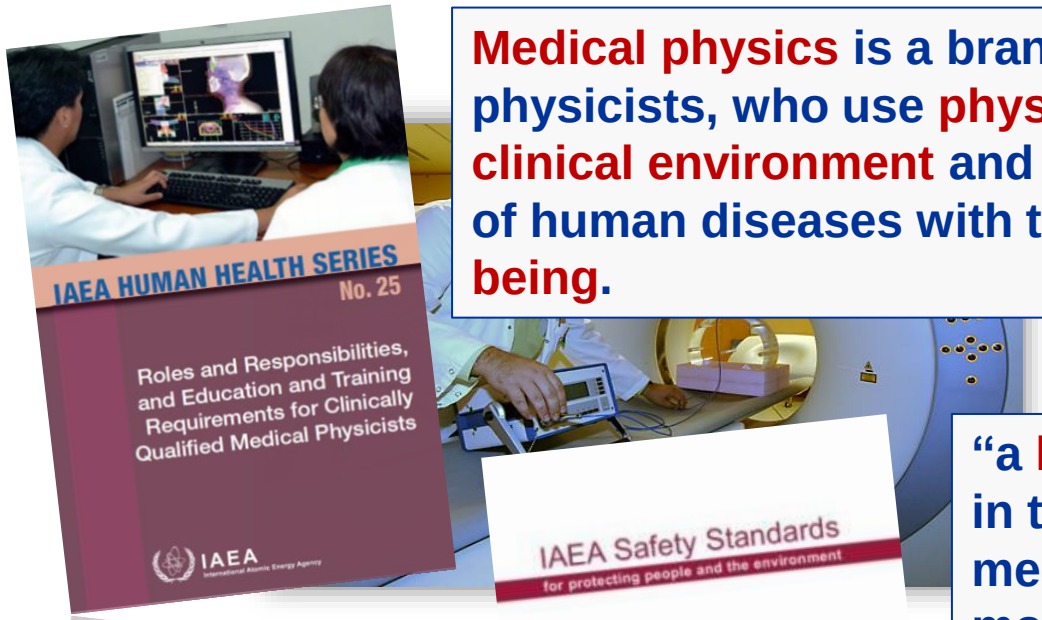
Why dosimetry in X ray imaging?

- To set and check standards of good practice
  - Performance testing of the imaging equipment (e.g. quality control tests)
  - Optimization of procedures (e.g. managing high local skin doses, DRL)
- To assist in assessing detriment or harm
  - Patient specific dosimetry (e.g. organ dose assessment)





Medical Physics

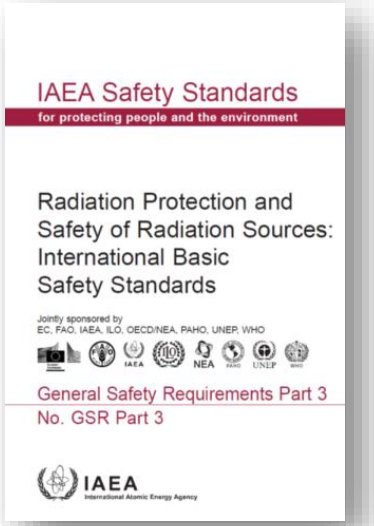


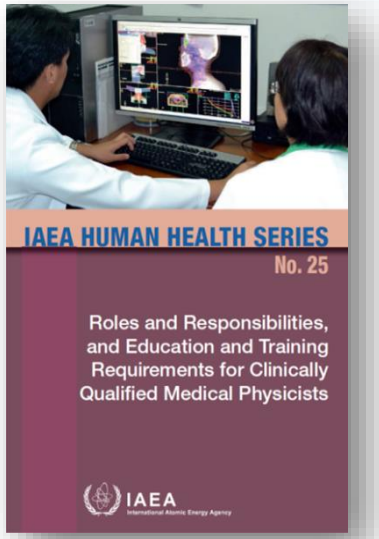
Medical physics is a branch of applied physics, pursued by medical physicists, who use **physics principles, methods and techniques** in practice, in the **clinical environment** and in research, for the prevention, diagnosis and treatment of human diseases with the specific goal of **improving human health and well-being**.

"a health professional, with specialist education and training in the concepts and techniques of applying physics in medicine, and competent to practise independently in one or more of the subfields (specialties) of medical physics."

1. **Diagnostic and interventional radiology (radiology physics)**
2. Radionuclide procedures (nuclear medicine physics)
3. Radiation therapy physics
4. Medical health physics (radiation protection in medicine)

Roles and responsibilities of medical physicist



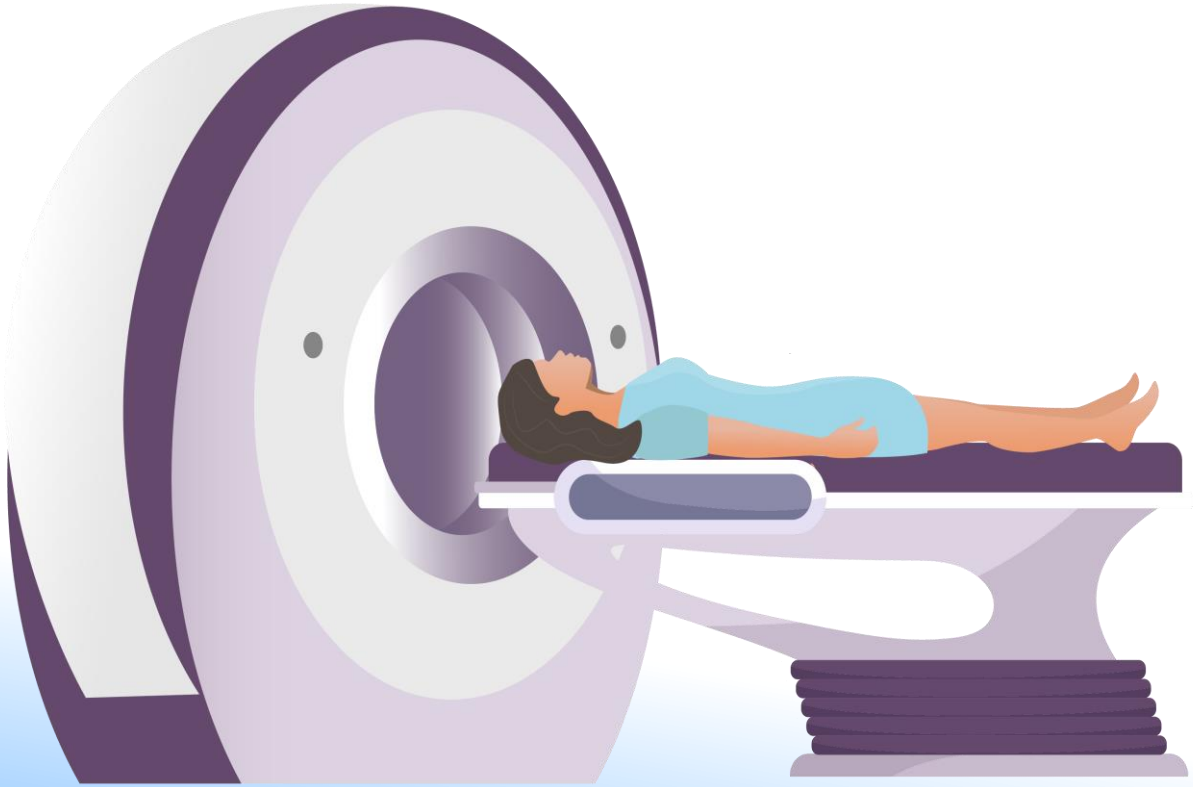


- Calibration
  - Medical radiological equipment
  - Dosimetry instrumentation
- Quality Assurance
- Dosimetry of patients

Installation design
Technical specification
Acceptance and commissioning of equipment
Calibration and verification of measurement instruments
Technical supervision of equipment
Operation and maintenance
Quality management of the physical and technical aspects in DR, NM and RT
Radiation dosimetry of radiation sources and patients
Radiation safety and protection of patients, staff and the general public
Optimization of the physical aspects of procedures
Clinical computing and networking
Research and development

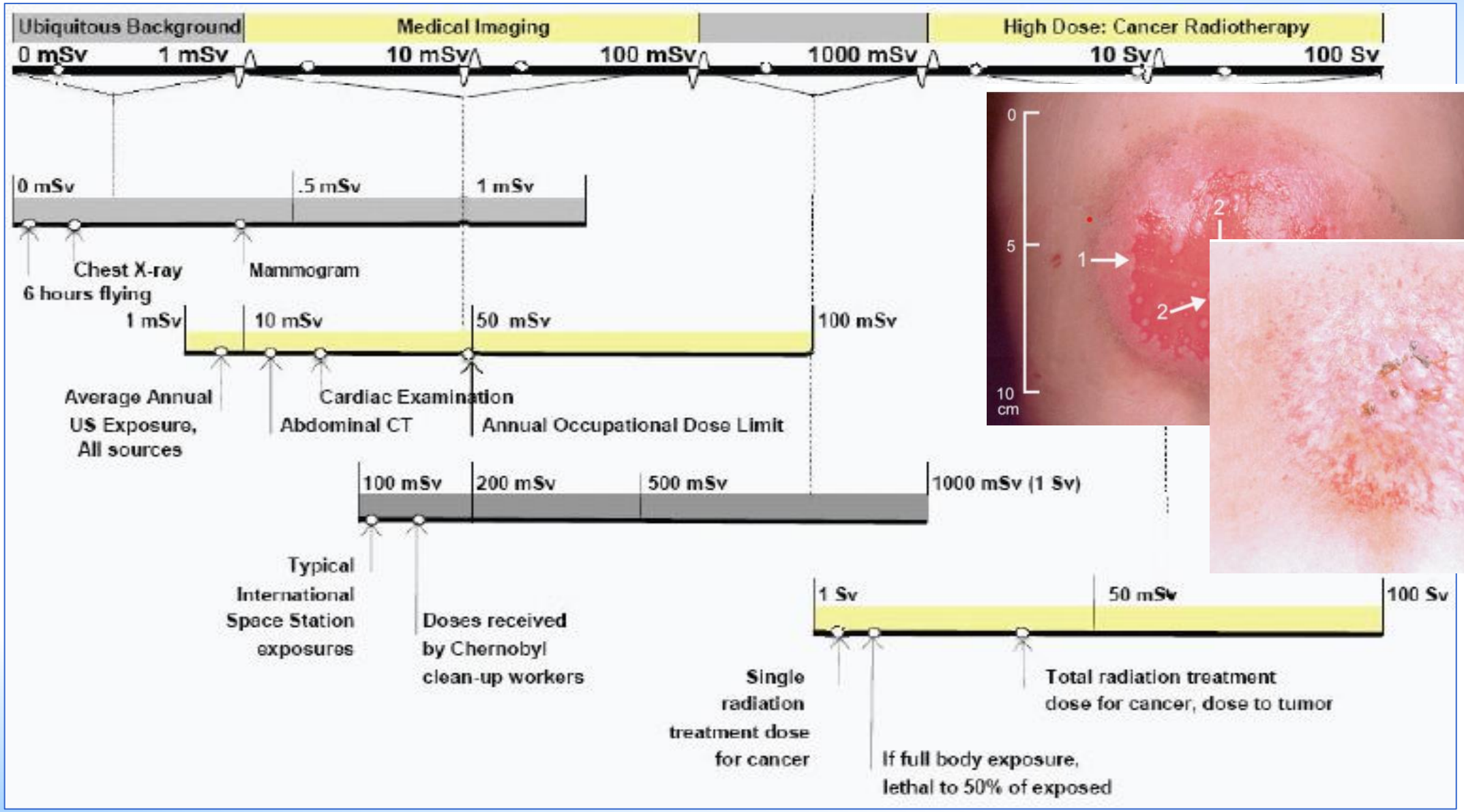
X ray imaging procedures

Diagnostic and interventional radiology



- (Image) quality, FOM (image quality vs dose)
- Diverse
- Not standardized compared to laboratory procedures
- The amount of radiation used is affected by procedure complexity, patient's characteristics and disease severity
  - Wide distribution of patient doses, even for same procedures/anatomical region

X ray imaging procedures: dose magnitude



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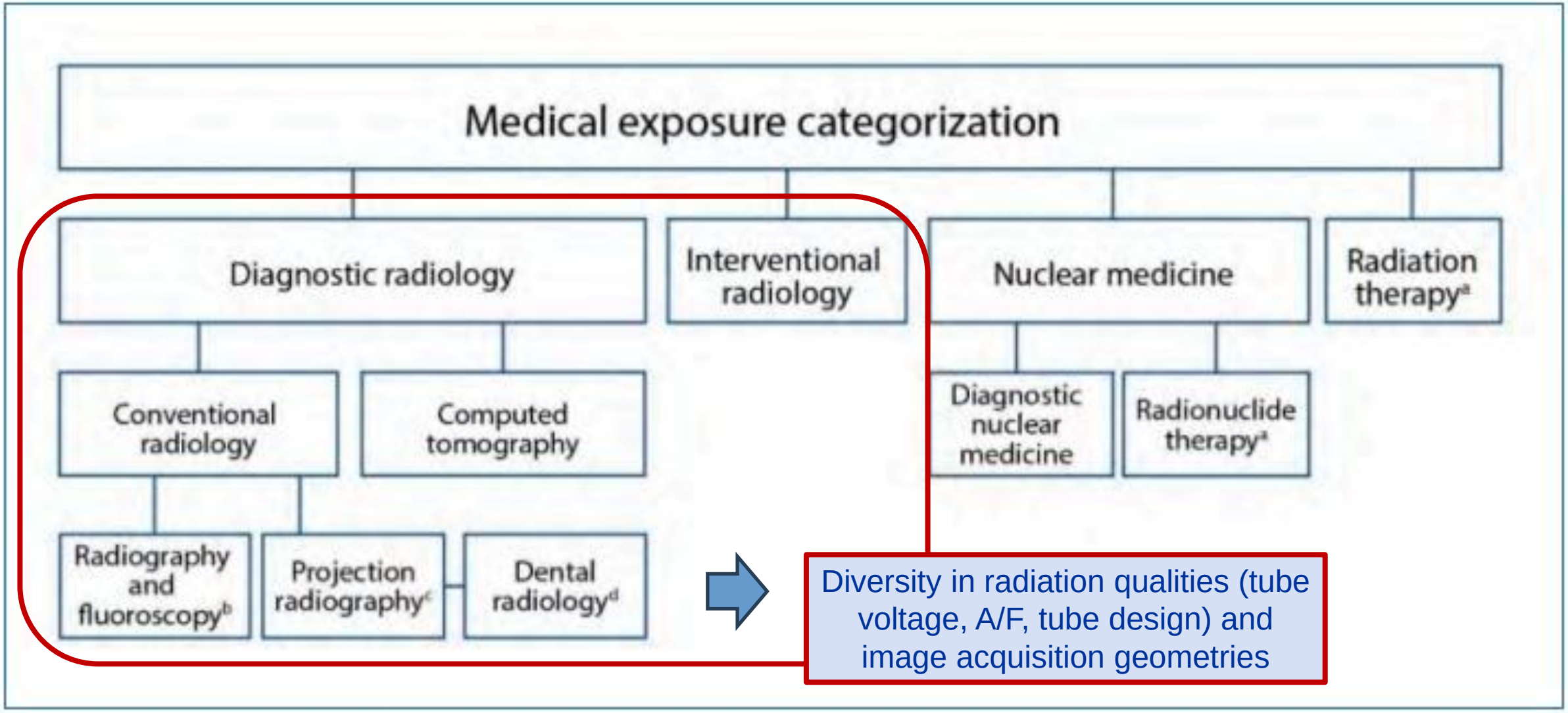
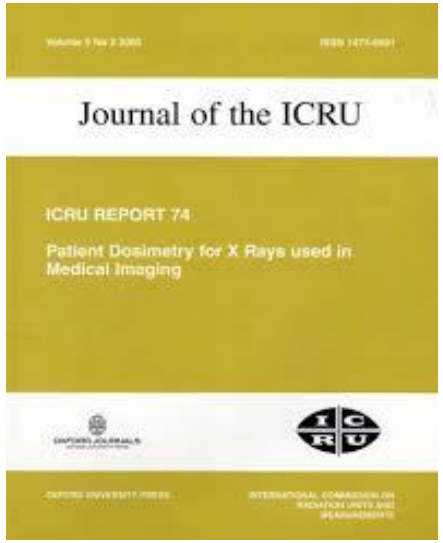
https://nap.nationalacademies.org/read/13263/chapter/15

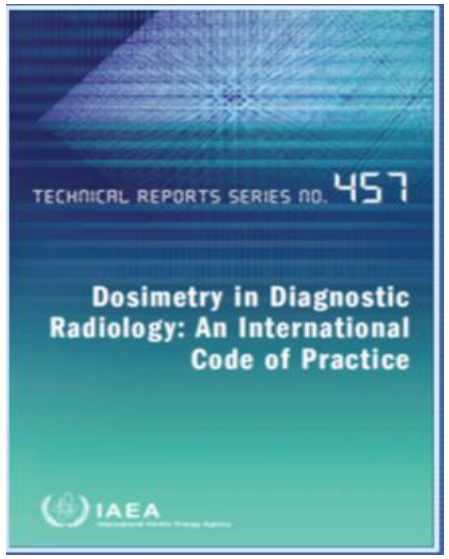
X ray imaging procedures: types



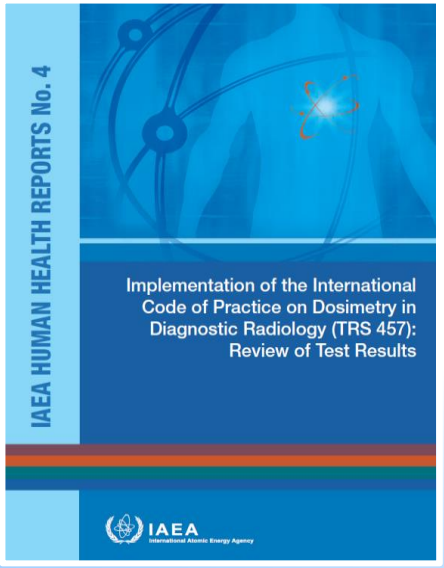
UNSECAR 2020/21

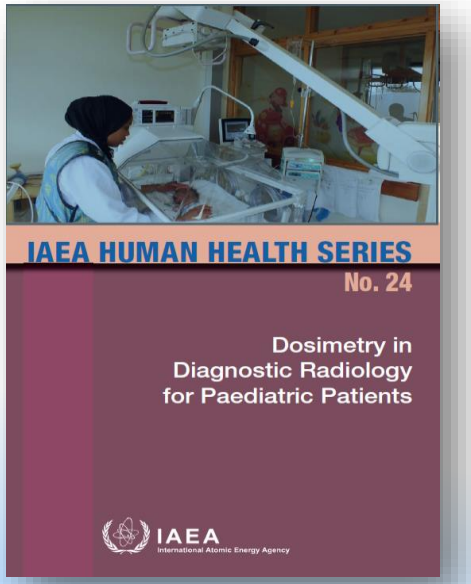
Dosimetry methodology





- Different imaging modalities
- Application specific dosimetry quantities
- Different dosimeters
- Phantom measurements*
- Measurements with patients
- Analysis, dose assessment
- Uncertainties





*Phantoms
Repeatable, standardized and fast QA tests
For comparisons between different systems
Using clinical settings and AEC

Dosimetry formalism

Air kerma

$$K = M \cdot N_{K,Q_0} \cdot k_Q \cdot k_{T,p} \cdot \prod_i k_i$$

Clinical conditions

K represents a generic term for one of the dosimetric quantities *K*i, *K*e, P_{KA}, P_{KL} …

Quantity name	Symbol	Field of application
Incident air kerma	$K_{a,i}$	Radiography and fluoroscopy
Incident air kerma rate	$\dot{K}_{a,i}$	Fluoroscopy
Entrance surface air kerma	$K_{a,e}$	Radiography and fluoroscopy
Entrance surface air kerma rate	$\dot{K}_{a,e}$	Fluoroscopy
Air kerma–area-product	P_{KA}	Radiography and fluoroscopy
Air kerma–area-product rate	$\dot{P}_{KA}$	Radiography and fluoroscopy
Air kerma–length product	P_{KL}	CT
CT air kerma index	C_K	CT

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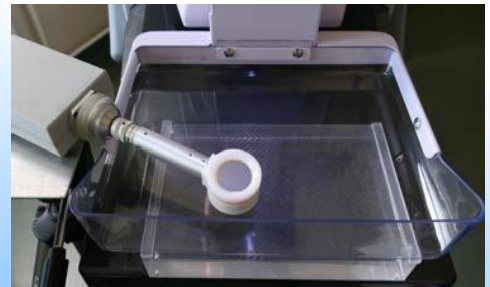
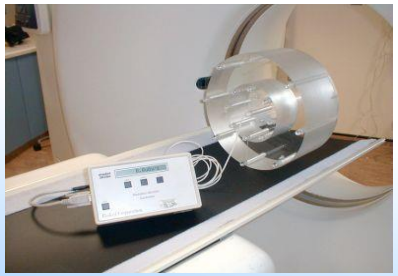
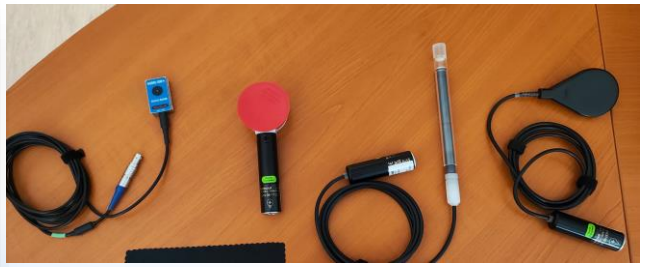
Instrumentation in diagnostic radiology

Dosimeters :
equipment for the measurement of air kerma, air kerma length, air kerma area and/or air kerma rate.

kVp-meters :
equipment for the measurement of tube high voltage invasively or non-invasively.

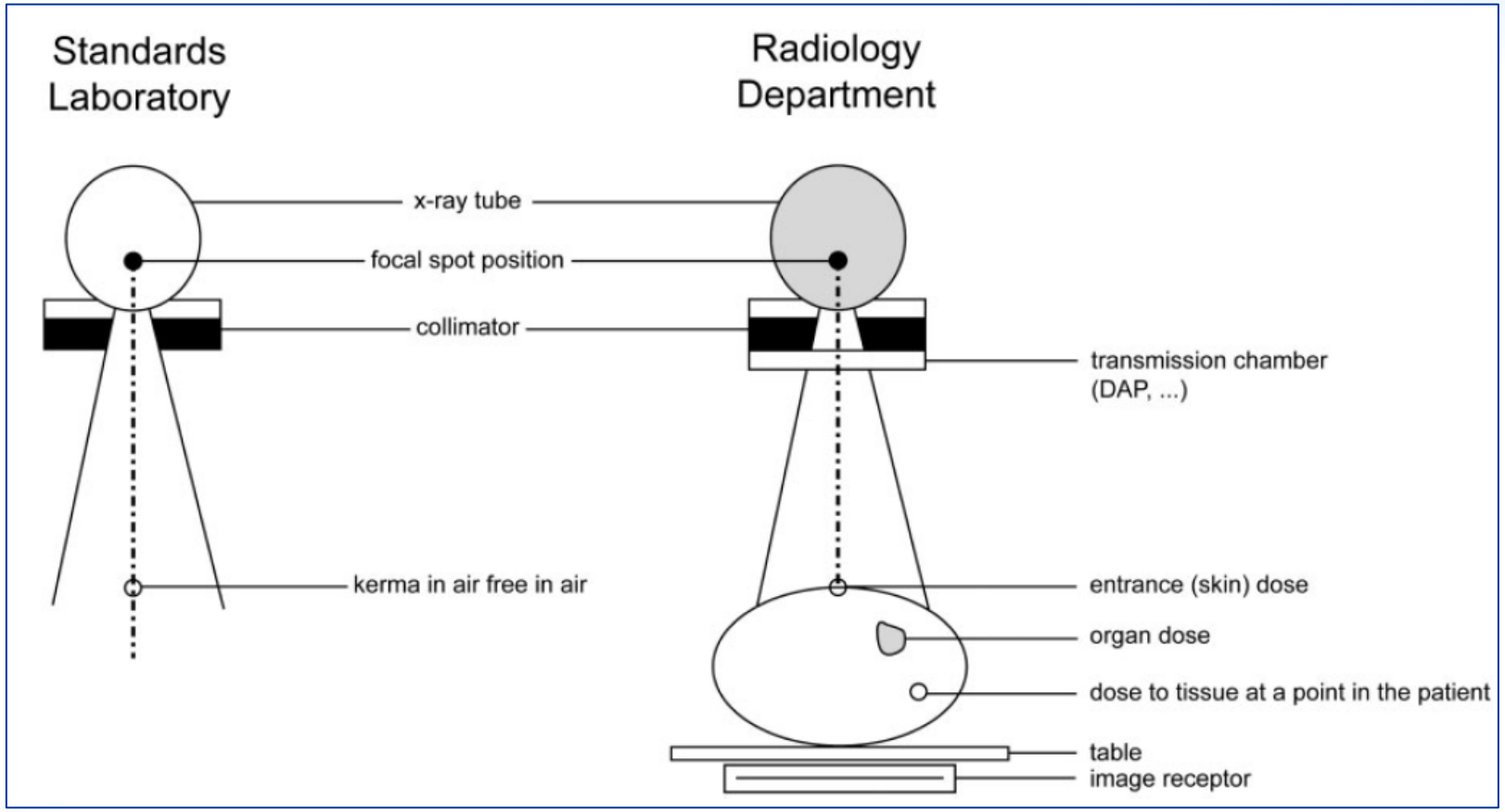
Timers, mAs-meters, etc equipment for the measurement other parameters of exposure parameters, like exposure time (ms), tube current time exposure product (mAs), etc




Modality	Radiography	Fluoroscopy	CT	X ray breast imaging
Subtypes	Stationary (CR, DR) Mobile	Stationary R/F Mobile C-arm Interventional radiology/cardiology CBCT Dedicated urology X ray units, etc	CT (EID, PC)	Mammography: 2D, DMT, CEM, biopsy
Features	**50-150 kV** Planar imaging (35 cm x 43 cm) AEC **One shot event (~ms exposure time)** **High dose rate**	50-150 kV Multiple acquisition modes (cine) **Dose rate ranges** **Pulsed beams (from a few to 30 pps)** **AEC/ABC** **Dynamic, change of geometry and exposure parameters**	80-140 kV **Rotational geometry** TCM	**25-50 kV** Diverse A/F combinations AEC (advanced)
Dosimetry quantities	Incident air kerma Entrance surface air kerma Air kerma area product	Entrance surface air kerma rate Air kerma area product Cumulative air kerma	CT air kerma index Air kerma–length product	Incident air kerma Entrance surface air kerma MGD/AGD (output, HVL)
Dosimeters	IC chambers (cylindrical, pp, spherical) KAP meters Solid state (XMM, TLD)	IC chambers (cylindrical, pp, spherical) KAP meters Solid state (XMM, TLD)	Pencil type ionization chamber Solid state (dose profilers)	IC chambers with thin windows Semiconductor based detectors appropriate for mammo measurements (matching A/F combination)
Methods	Phantoms: Incident air kerma (calculated) Patients: ESAK determined from the incident air kerma with the application of the BSF or derived from measured KAP	Phantoms: ESAK rate Patients: KAP measures or computed **DICOM: KAP, Cumulative air kerma**	Standardized, phantoms (10/16/32 cm), SSDE Free in air Partial irradiation **DICOM: CTDI, DLP** **Modifications for wide beams**	Phantoms Patients **DICOM: air kerma, AGD/MGD**
Typical uncertainty (k=2)	(10-25) %	(10-25) %	(10-20)%	(8-14)%

Dosimetric quantities



Application specific dosimetry quantities

Conversion coefficient for tissue and organ dose assessment

Quantities for risk assessment

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Radiation risk related quantities

Organ dose

Table 5.2. Important features of sources of dose-conversion coefficients for medical x-ray imaging.

Type of examination	No. of views	No. of organs	No. of spectra	Normalization quantity	Phantom	Reference[a]
General radiology	54	8	17	$K_{a,i}$	MIRD hermaphrodite	CDRH 89-8031 (Rosenstein, 1988)
	40	16	3[b]	$K_{a,i}$	ADAM EVA	GSF 11/90 (Drexler *et al.*, 1990)
	68	26	40	$K_{a,e}$, P_{KA}	Cristy hermaphrodite	NRPB-SR262 (Hart *et al.*, 1994b)
	[c]	24	[c]	$K_{a,i}$, P_{KA}	Cristy hermaphrodite[c]	Tapiovaara *et al.* (1997)
Mammography	6	1	14	$K_{a,i}$	Reference	CDRH 85-8239 (Rosenstein *et al.*, 1985)
	1	1	90	$K_{a,i}$	Breasts	Dance (1990, 2000)
	1	1	10	$K_{a,i}$		Wu *et al.* (1991a, 1994)
	1	1	17	$K_{a,i}$		Jansen *et al.* (1994)
Fluoroscopy: Upper GI tract	12	12	3	$K_{a,i}$	ADAM EVA	CDRH 92-8282 (Rosenstein *et al.*, 1992)
Coronary Arteries		20[d]	6	$K_{a,i}$	ADAM EVA	CDRH 95-8289 (Stern *et al.*, 1995b)
Fluoroscopy	[c]	24	[c]	$K_{a,i}$, P_{KA}	Cristy hermaphrodite[c]	Tapiovaara *et al.* (1997)
Pediatric radiography	20	6	3	$K_{a,I}$	0, 1, 5 years hermaphrodite	BRH 79-8079 (Rosenstein *et al.*, 1979)
	20	26	72	$K_{a,i}$, P_{KA}	0,1,5,10,15 years hermaphrodite	NRPB-R279 (Hart *et al.*, 1996a) NRPB-SR279 (Hart *et al.*, 1996b)
	5/6	16/11	1[b]	$K_{a,i}$	Voxel baby Voxel child	Zankl *et al.* (1988) Zankl *et al.* (1989)
Radiography/ Fluoroscopy	[c]	24	[c]	$K_{a,i}$, P_{KA}	Christy hermaphrodite[c]	Tapiovaara *et al.* (1997)
CT adult	208 slices	23	23	C_K[e]	Cristy hermaphrodite	NRPB-R250 (Jones and Shrimpton, 1991) NRPB-SR250 (Jones and Shrimpton, 1993)
	104 slices	22	3	C_K	ADAM EVA	GSF 30/91 (Zankl *et al.*, 1991)
CT Pediatric	45 slices	35	2	C_K	Voxel baby	GSF 30/93 (Zankl *et al.*, 1993)
	66 slices	37	2	C_K	Voxel child	

Effective dose

- Restricted to comparison
- Not designed to estimate the risk for incidence of effects for a particular individual patient
- Not accurately reflect the differences in the age dependency
- Partial irradiation of organs

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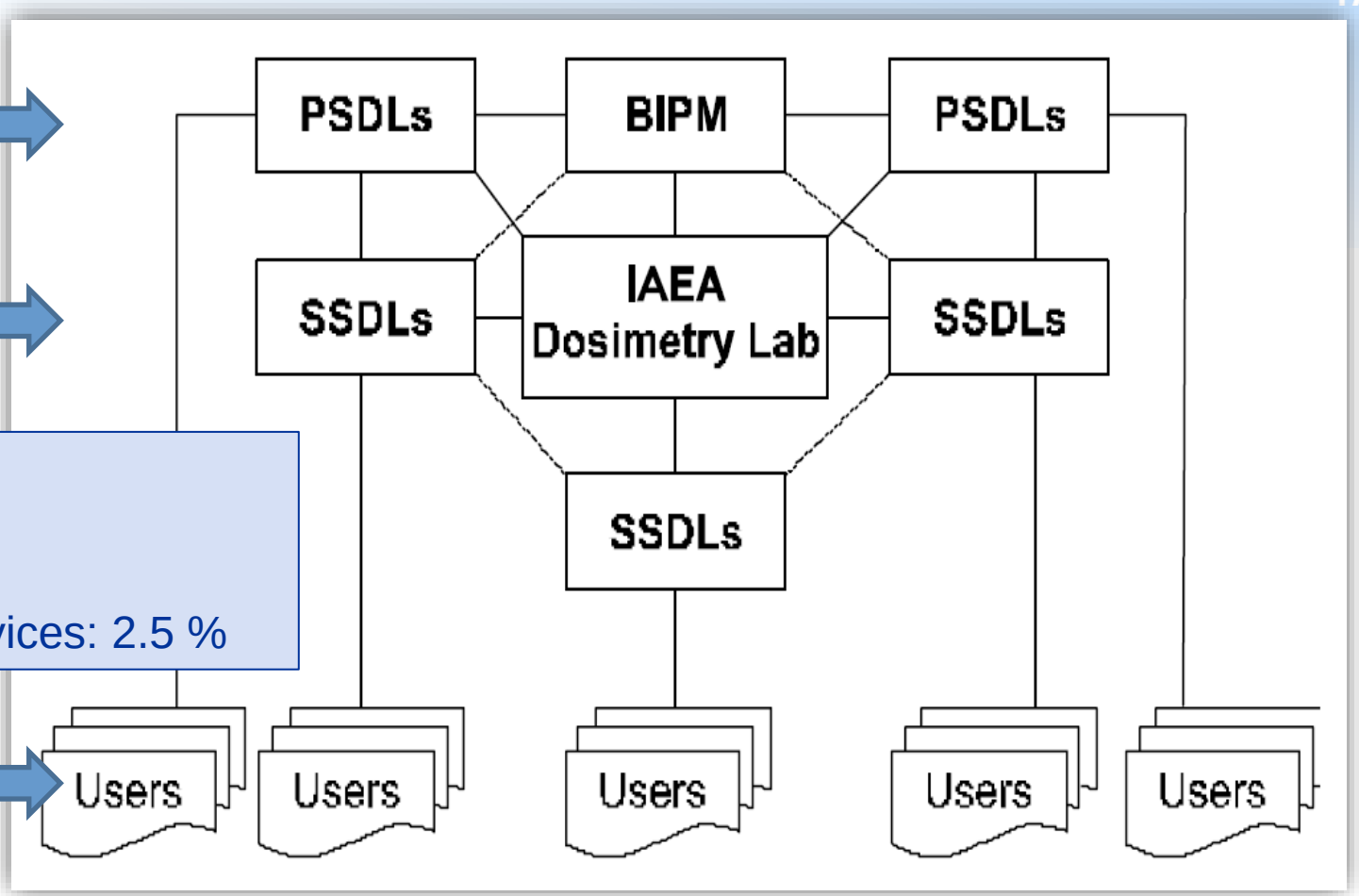
Uncertainty

1%

2%

5%



Air kerma: ± 2.7 %
Air kerma length product: ± 3.0 %
Air kerma area product: ± 15 %
Non-invasive tube voltage measuring devices: 2.5 %

?

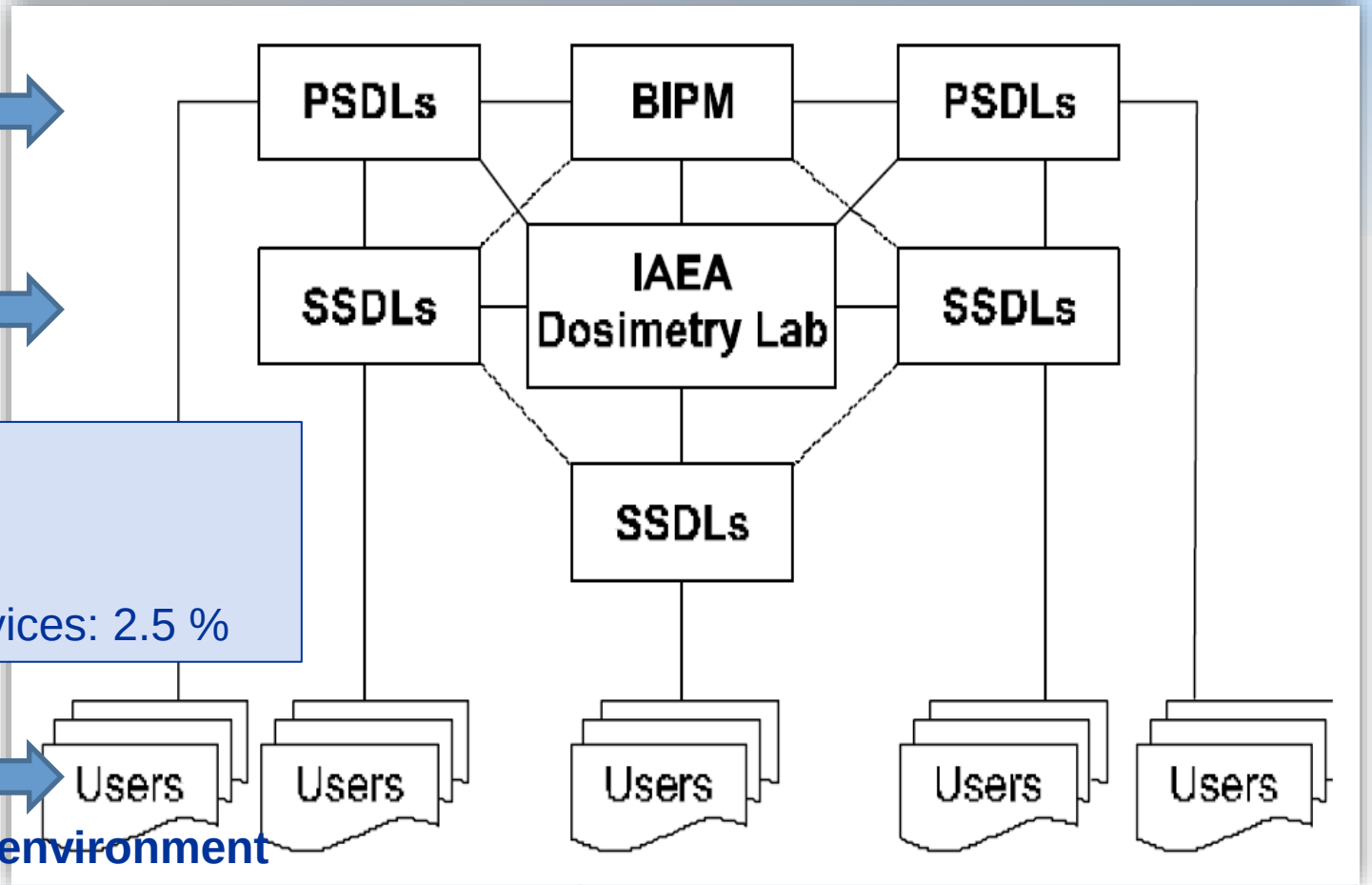
Organ dose assessment (e.g. skin dose) *k=2*

Uncertainty

1%

2%

5%



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Non-invasive tube voltage measuring devices: 2.5 %

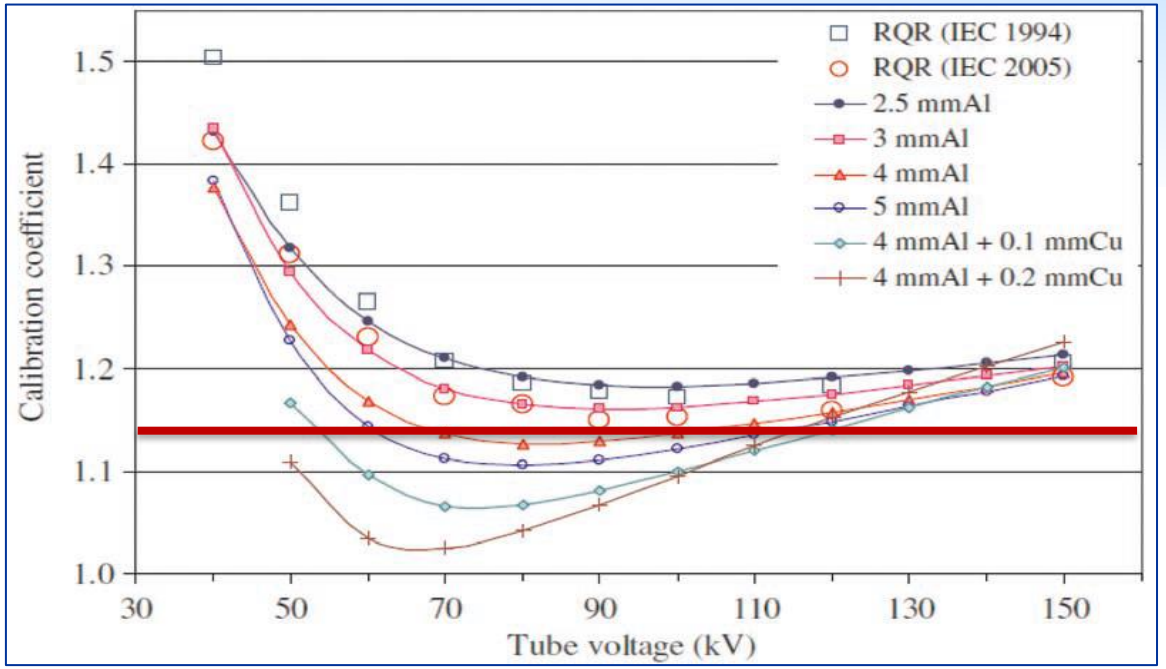
Typical/required uncertainty in clinical environment

QC	7%	AAPM (1992)
Application specific queitites	10-20 %	IAEA TRS 457
Organ dose	30-50 %	ICRU 74
Collective effective dose	75%	UNSCEAR 2020/21

k=2

Use of calibration coefficient

$$K = M \cdot N_{K,Q_0} \cdot k_Q \cdot k_{T,p} \cdot \prod_i k_i$$



$$K = M \cdot N_{K,Q_0} \cdot \cancel{k_Q \cdot k_{T,p} \cdot \prod_i k_i}$$

Use of a single calibration coefficients (e.g. >40% uncertainty)

$$K = M \cdot \cancel{N_{K,Q_0} \cdot k_Q \cdot k_{T,p} \cdot \prod_i k_i}$$

No correction applied; indication form the instrument (e.g. >50% uncertainty)

IAEA HHR 4/Toroi et al, PMB, 2008

Challenges and caveats

Access to medical physic service and interest for dosimetry

- Disbalance between requirements and use of patient dosimetry (e.g. DMS, DRL) and access to medical physics service

Dosimetry formalism

- Understanding of dosimetry formalism
- Assessment of influencing quantities (PMMA tissue equivalence, BSF, HVL mesurment)

Calibration and instrumentation vs clinical needs

- The importance of calibrating all clinical dosimetry devices in relevant radiation qualities
  - Reference dosimetry in clinical environment
  - Use of calibration coefficient and beam quality correction coefficient (large number of radiation qualities/calibration coefficients), interpolation
  - Cross-calibrations in clinically relevant beams following international guidance formalisms (meters with strong energy dependence such as KAP meters and semiconductor dosemeters)
  - Verification of online dose indices (RSDR, DMS, SDM)

Uncertainty

- Use of dosimetry results, understanding uncertainty, comparison & decision rules (e.g. DRL process)

Potential way forward

- Medical physicist are key for dosimetry in clinical environment
- Promotion of dosimetry topics in the medical physics community, stronger involvement of clinical staff
- Collaboration of metrology and medical physics community has potential to identify a balanced approach:
  - Practicality vs accuracy
  - Understanding dosimetry methods and improving accuracy of measurable quantities
  - Uncertainty assessment and interpretation of dosimetry tailored to a specific application

Potential way forward

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Letter to a radiation metrologist

From the Desk of a Clinical Medical Physicist: Seeking SSDL's Dosimetry Expertise in Radiology

As a radiology clinical medical physicist, I am deeply involved in the realm of all radiology imaging services in our hospital, whether these are in the radiology department, the catheterization laboratory, the surgery theater or the emergency unit and I constantly strive to ensure the highest standards of dosimetry for the well-being of our patients. While the IAEA Dosimetry Code of Practice 457 provides valuable guidelines and insights, I think that practical collaboration with the SSDL would be indispensable in truly realizing this objective.

To that end, I am reaching out with some questions from my side looking for your feedback on certain challenges I have and hope for your expertise and support.

- **Calibration Services**: Maintaining the precision and accuracy of our dosimetry equipment is foundational to our commitment to patient safety and care quality. While we endeavour to uphold the highest standards, the absence of a dedicated SSDL calibration facility in our vicinity presents a significant challenge. We keenly feel this gap, as it hinders our ability to regularly ascertain and validate the precision of our dosimetry instruments. Collaborating with the SSDL for calibration services would not only address this challenge but also reinforce our confidence in the data we rely on daily. My hospital as well as other hospitals have tens or hundreds of radiology equipment, so the challenge of multiple radiology modalities and a limited number of SSDLs available for consultation and calibration services needs to be addressed through some strategies. Do you have any suggestions on this?
- **Dosimetry Audits**: Continuous improvement remains central to the mission in providing exceptional patient care. Periodic audits by an SSDL can significantly elevate our practices. While we are keenly aware of the geographical challenge, owing to the absence of an SSDL facility nearby, we believe in seeking a solution. With this in mind, would the SSDL consider a collaboration that allows for remote audits or perhaps periodic visits, ensuring we align our practices with global standards?
- **Consultation**: The evolving landscape of radiology continually presents us with opportunities to integrate new technologies and methodologies. Navigating these changes while ensuring adherence to international standards can be daunting. Given the lack of an SSDL facility in close proximity, the expertise of SSDL specialists becomes even more crucial for us. What are your thoughts on this?

In closing, I am confident that a collaboration between our institution and the SSDL can lead to meaningful advancements in radiological dosimetry. Despite the challenges, our collective commitment to ensuring patient safety and adhering to the highest standards offers a solid foundation for a fruitful partnership. I am hopeful that together we can chart a path that serves both our immediate needs and sets the tone for future collaborations. Let's pave the way for a safer and more accurate medical radiology service future.

I am looking forward to receiving your response in the next SSDL Newsletter.