Medical images obtained with Non ionizing radiation

Ionization Radiation and Risk

- Ionizing electromagnetic radiation: $f > 3x10^{15}$Hz i.e., UV, X and gamma. At these frequencies photon energies ($E = hf$) are high enough to ionise water molecules
- Ions lead to the formation of FREE RADICALS (H, OH) and highly chemically reactive compounds (e.g., H_2O_2) which bring about changes in biologically important molecules e.g., DNA leading to undesirable biological effects such as carcinogenesis.
- Radiation doses lead to *real* risks - patient does not feel anything but the damage has been done, some of the patient's cells have been changed!!!
- The higher the amount of x-ray energy absorbed by the body we say the higher is the radiation 'dose' - more free radicals etc are produced and the higher the risk (probability) of biological effects

Doses: Units and Risk

- Unit of dose is the Sievert (Sv). Doses in x-ray imaging practice are of the order of mSv.
- Typical Doses: intra-oral less than 0.01mSv, Chest X-ray: 0.1 mSv, CT mandible up to 1.2mSv, CT maxilla up to 3.3 mSv, Fluoroscopy: 5 mSv, Body CT Scan: 10 mSv, Interventional radiology – tens to hundreds of mSv
- A certain risk is associated with each mSv e.g., a risk of 50 per million per mSv for carcinogenesis

Radiolog. study	dose in mSv	Carcinogen risk	Number of cancer cases *if each* member of the EU is examined
Chest X-Ray	0.1	1 in 200,000	3700
Fluoro.	5	1 in 4000	185,000
CT scan	10	1 in 2000	370,000
Intervent. radiology	50	1 in 400	1,850,000

Image Quality and Patient Dose

In general the better the image quality required the higher the dose! Too low amount of radiation - insufficient image quality, inaccurate diagnosis; too high - unnecessary patient dose and therefore risk.

ICRP Principles

- JUSTIFICATION - Since every image carries risk before taking the image we must ask ourselves 'Is it *justified*?
  - Is the x-ray image really necessary for diagnosis? (check with *referral criteria*)
  - Is the benefit to the patient higher than the risk?
  - Can we use previously taken images?
  - Can we use MRI or USI which are non-ionizing?
- OPTIMISATION: we must produce an image of *just sufficient quality for an accurate diagnosis whilst avoiding unnecessary patient dose*
  - avoid repeats!
  - use imaging devices which have the required performance indicators
  - use device use protocols which produce images with just sufficient image quality for accurate diagnosis
- Dose LIMITATION: measure patient doses regularly and check that they do not exceed recommended levels (diagnostic reference levels)

ICRP = International Commission for Radiation Protection

Justification : Example Referral Criteria when Imaging the Thorax

http://ec.europa.eu/energy/nuclear/radioprotection/publication/doc/118_en.pdf

F. Thoracic system			
Non-specific chest pain **F1**	*CXR (I)*	Not indicated initially (C)	Conditions such as Tietze's disease show no abnormality on CXR. Main purpose is reassurance.
Chest trauma **F2**	*CXR (I)*	Not indicated routinely (C)	Showing a rib fracture after minor trauma does not alter management ***(see Trauma Section K).***
Pre-employment or screening medicals **F3**	*CXR (I)*	Not indicated	Not justified except in a few high-risk categories (e.g. at risk immigrants with no recent CXR). Some have to be done for occupational (e.g. divers) or emigration purposes (UK category 2).
Pre-operative **F4**	*CXR (I)*	Not indicated routinely (B)	Exceptions before cardio-pulmonary surgery, likely admission to ITU, suspected malignancy or possible TB. Anaesthetists may also request CXRs for dyspnoeic patients, those with known cardiac disease and the very elderly. Many patients with cardio respiratory disease have recent CXR available; a repeat CXR is then not usually needed.
Upper respiratory-tract infection **F5**	*CXR (I)*	Not indicated routinely (C)	

(A) randomised controlled trials, meta-analyses, systematic reviews, (B) experimental or observational studies, (C) advice relies on expert opinion and has the endorsement of respected authorities.

Proper Perspective Regarding Risk from Ionizing Radiation

- Imaging with ionising radiation is one of the most powerful tools in the doctor's 'toolbox'. Proper diagnosis is not possible without it.
- Risks in hospital: from Physical, Chemical and Biological agents.
- Physical agents: mechanical, electrical, magnetic, optical, ionising radiation
- Ionising radiation is one of the least hazardous
- However since millions of images are taken yearly the risk for the population as a whole ('collective dose') becomes high.
- Moreover medical doses are increasing with 'better safe than sorry' medicine and the ease of use of modern imaging devices (e.g., spiral CT compared to conventional CT, digital XRI compared to film XRI).
- This is why EU produced a directive regarding patient radiation protection (97/43/EURATOM).

Outline of Rest of Lecture

- Biological hazards from ionizing radiation
- Target anatomy / pathology and Image Quality Outcomes
- Performance indicators of XRI devices and image quality
- Optimization of patient doses in XRI
- CT scanning
- Dental radiology
- Interventional radiology as these are techniques which carry the highest risk
- Radiation detectors and their uses

- *The slides with PINK background contain knowledge obligatory for the exam!!!!*

Risks from Ionizing Radiation

Effects of Radiation on Cells

- Radiation bioeffects initiate at the cellular level
- Cells are most radiosensitive during mitosis (cell division)
- Effects of radiation on cells:
  - Cell death prior to or after mitosis (not so important except in certain very high dose procedures when so many cells die that the whole tissue suffers e.g., interventional radiology)
  - Delayed or prolonged mitosis
  - Abnormal mitosis followed by repair
  - Abnormal mitosis followed by replication - *this is usually the major problem in medical imaging – leads to carcinogenesis, mutagenesis*

Radiosensitivity of Cells

- Law of Bergonie and Tribondeau: radiosensitivity of cells is proportional to rate of cell division (mitotic frequency) and inversely prop. to the level of cell specialisation (also known as cell ‘differentiation’).
  - High sensitivity: bone marrow, spermatogonia, granulosa cells surrounding the ovum
  - Medium sensitivity: liver, thyroid, connective tissue, vascular endothelium
  - Low sensitivity: nerve cells
- The younger the patient the more radiosensitive because of the high rate of cell division and incomplete differentiation, more care required in paediatrics (children 3 times more radiosensitive than adults)
- The unborn child is the most sensitive

Quantifying the relative radiosensitivity for carcinogenesis and mutagenesis of various tissues: Tissue Weighting Factors

Tissue or organ	Tissue weighting factors, w_T
Gonads	0,20
Bone marrow (red)	0,12
Colon	0,12
Lung	0,12
Stomach	0,12
Bladder	0,05
Breast	0,05
Liver	0,05
Oesophagus	0,05
Thyroid	0,05
Skin	0,01
Bone surface	0,01
Remainder	0,05 (**) (***)

(**) For the purposes of calculation, the remainder is composed of the following additional tissues and organs: adrenals, brain, upper large intestine, small intestine, kidney, muscle, pancreas, spleen, thymus and uterus. The list includes organs which

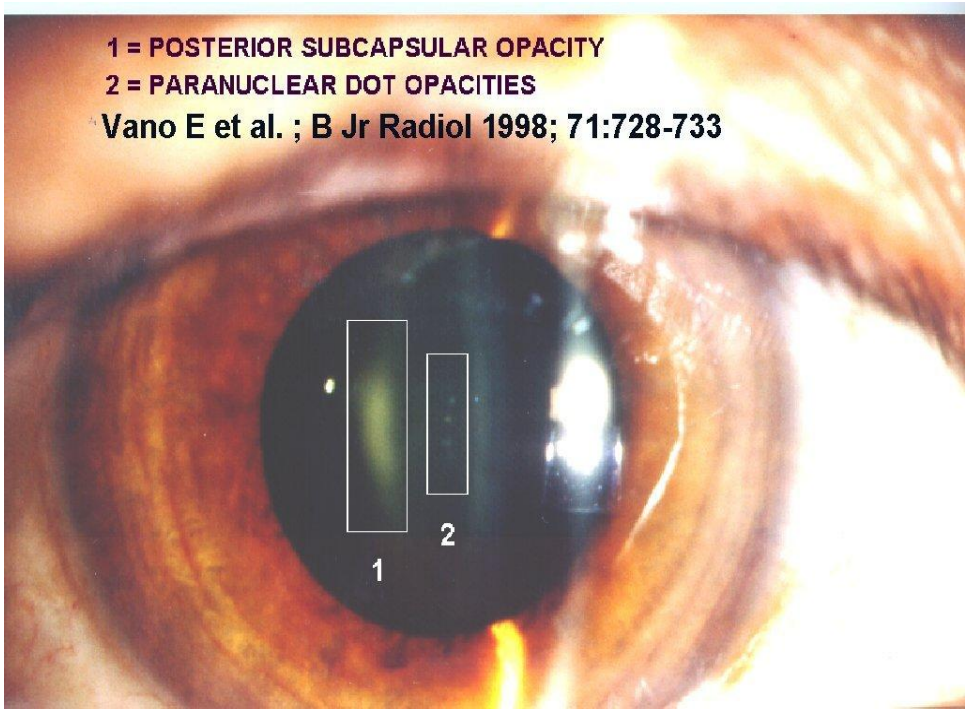
(Ref. 96/29/Euratom)

Some Ionizing Radiation Hazards

- Carcinogenesis
- Mutagenesis (change in a gene in gametes)
- Eye-lens cataracts
- Skin injuries
- Effects on conceptus when irradiated in the uterus (e.g., death, brain damage, childhood cancer)

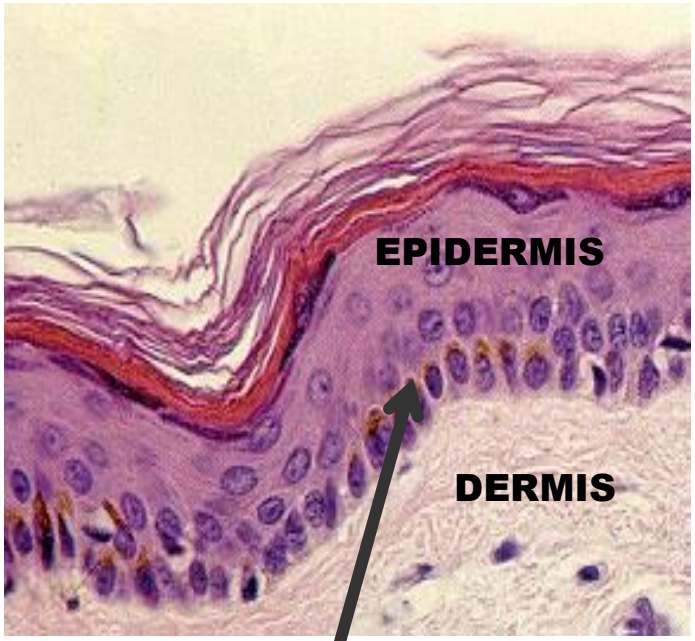
Radiation Effects: Eyes

- Eye lens is highly radiosensitive, moreover, it is surrounded by highly radiosensitive cuboid cells.
- lens opacities (cataracts)



Radiation Effects on Skin

Histology of the skin

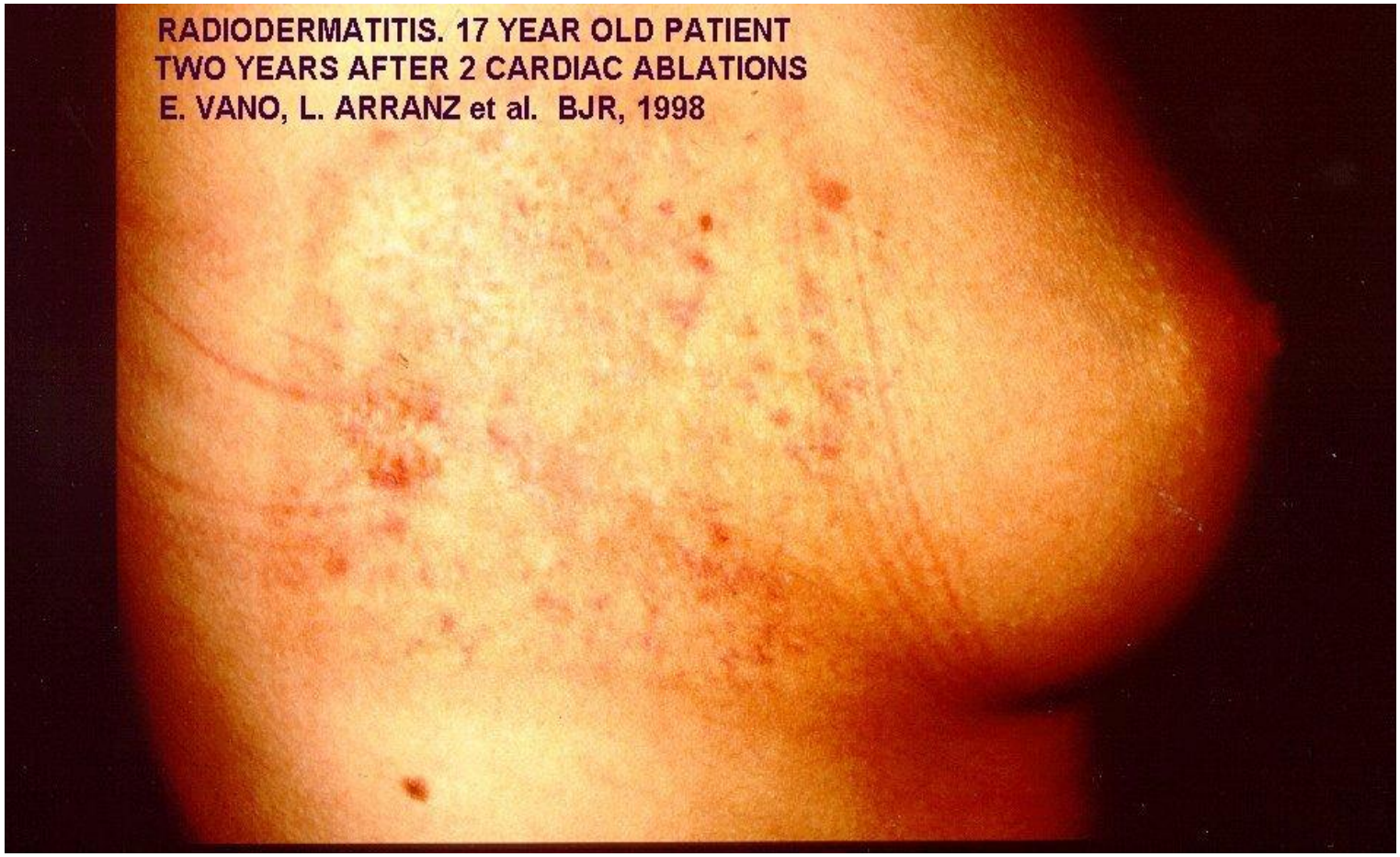


From "Atlas de Histologia...". J. Boya

Basal stratum cells, highly mitotic, (most radiosensitive)

- Erythema (reddening of skin): 1 to 24 hours after irradiation
- Alopecia (hair loss): reversible; irreversible at high doses.
- Pigmentation: Reversible, appears 8 days after irradiation.
- Dry or moist desquamation (skin peeling)
- Delayed effects: teleangiectasia (small red viens and arteries showing on skin), fibrosis (loss of skin elasticity).

Increasing radiation

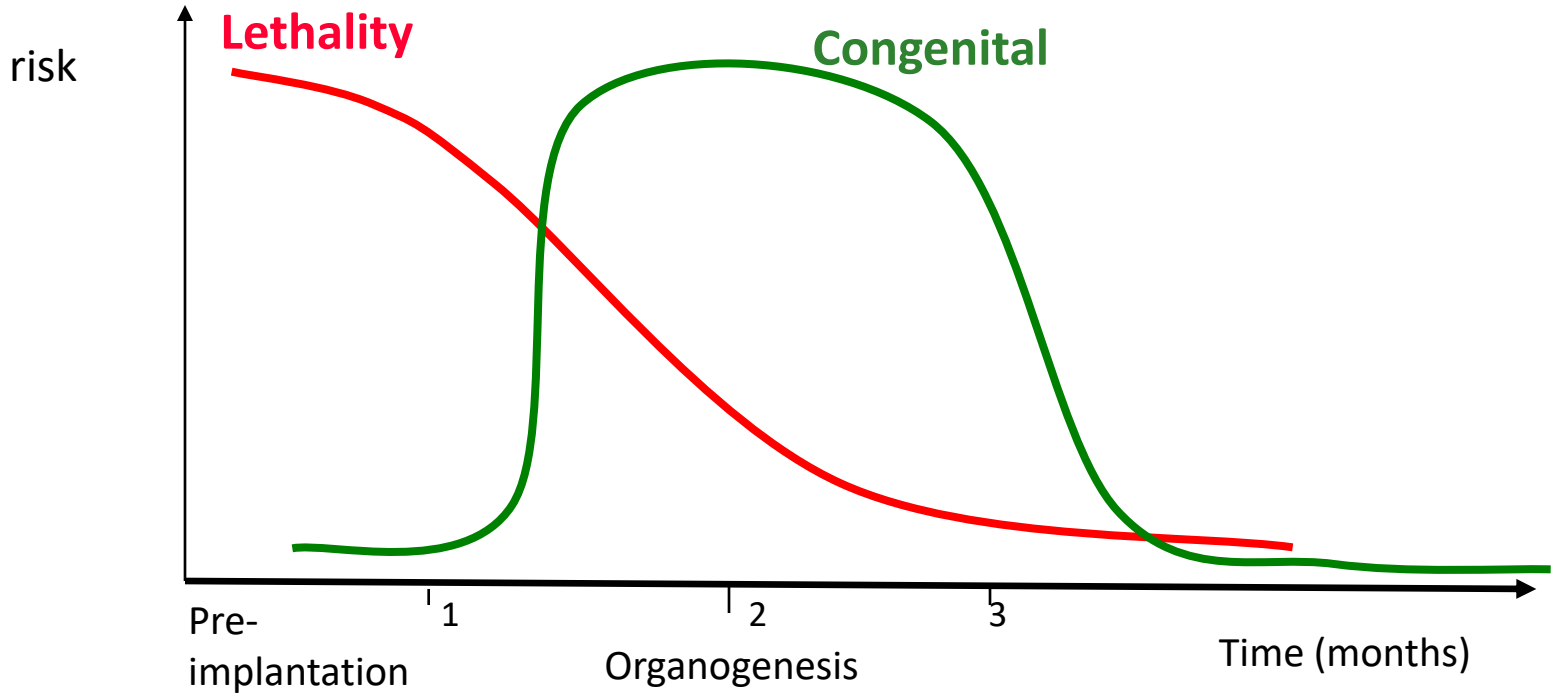


(dermatitis = inflammation (pain, heat, redness) of the skin caused by an outside agent

ablation = removal of tissue by cutting, microwave radiation etc)

The Pregnant patient : Effects on Conceptus

There are 3 kinds of effects: **lethality (i.e., death)**, **congenital abnormalities (e.g., Down Syndrome)** and **delayed effects** (e.g., childhood cancer and hereditary effects noticed long after birth).

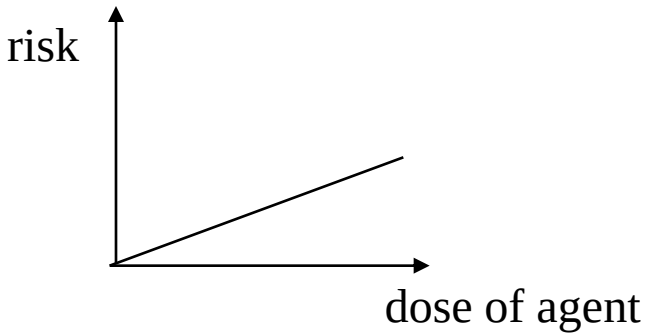


Protection of the Conceptus

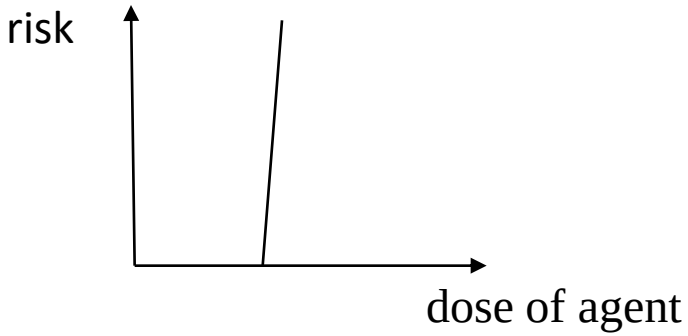
- Women of child bearing age: protection of a possible conceptus when X-ray imaging the region from the knees to the diaphragm
- Ask pregnancy question, pregnancy test, 10 day rule, 28 day rule
- Except for certain very high dose procedures imaging can be done normally with some added precautions

Characteristics of Biological Effects

- **Acute** (effects occur short-term e.g., skin peeling after interventional radiology) vs. **Late** (effects occur long-term e.g., carcinogenesis)
- **Deterministic** (existence of a threshold dose, risk zero below threshold e.g., cataracts, skin injuries, brain damage in conceptus) vs. **Stochastic** (no threshold, dose and risk proportional, risk never zero e.g., carcinogenesis, mutagenesis)



stochastic effects



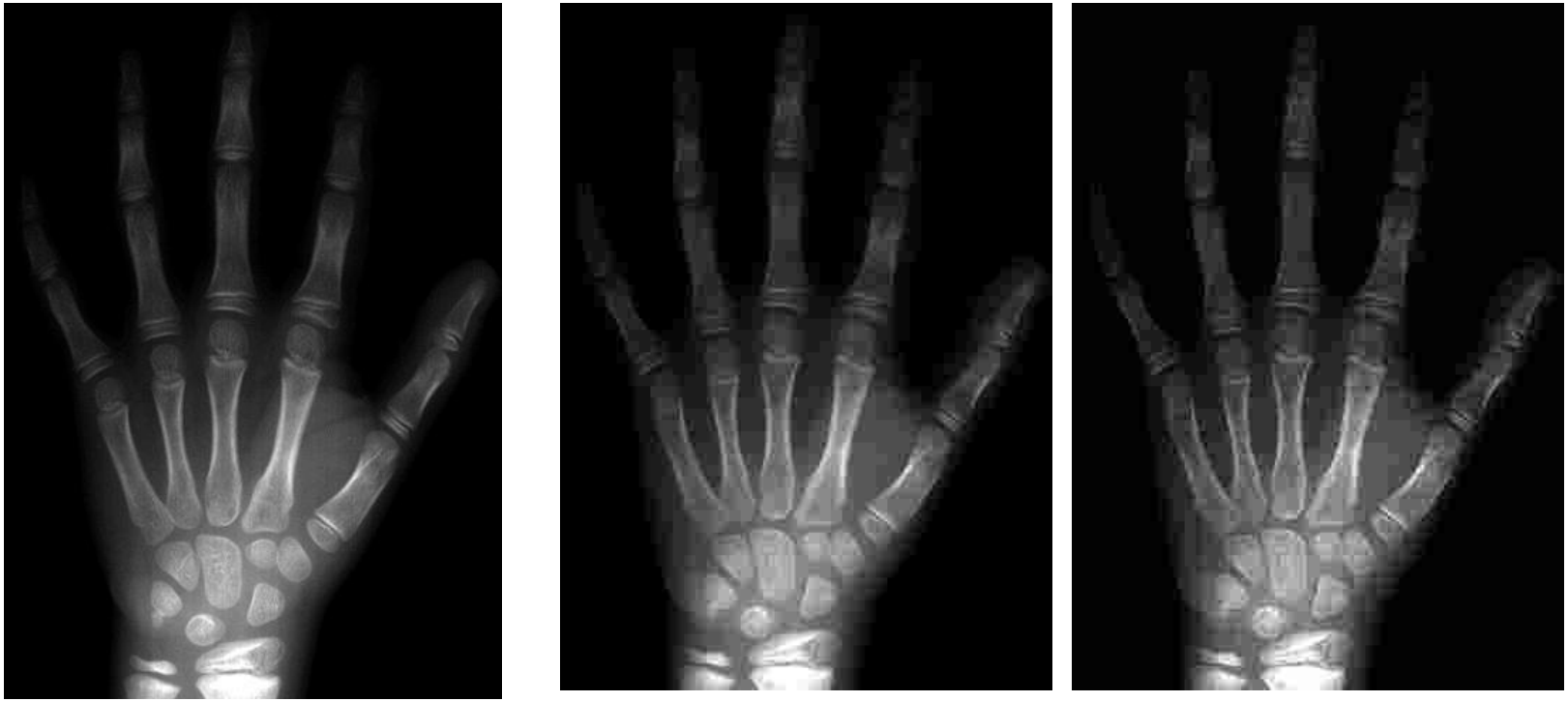
deterministic effects

Target Anatomy / Pathology and Image Quality Outcomes

Some Terminology

- Target anatomy / pathology: what is present *inside the patient* that I want to visualize in the image?
- Target Image Quality Outcomes: what qualities must *the image have* in order for me to be able to see the target anatomy and pathology clearly enough to make an accurate diagnosis

X-ray of Child's Wrist

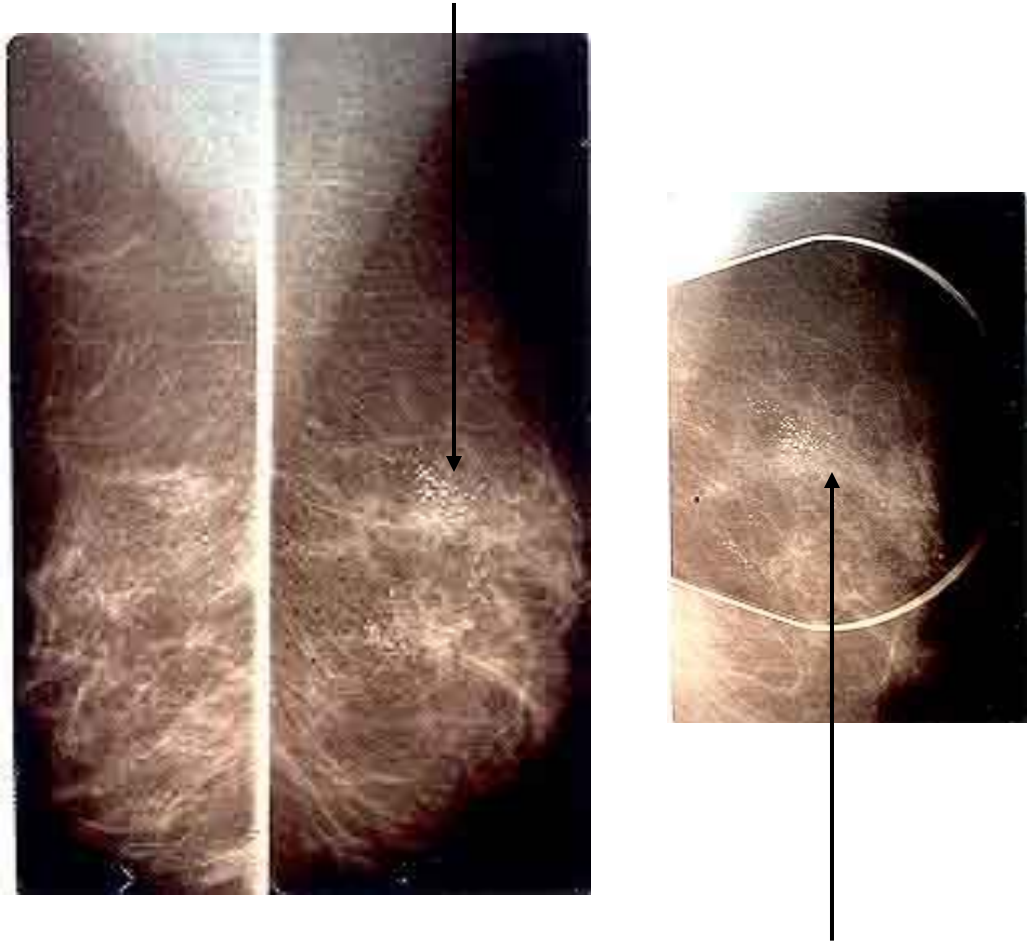


Target anatomy / pathology: measure gaps between the carpal bones of the wrist (in an adult, the average space less than 2mm)

Target image quality outcome: SHARP outlines

Mammography

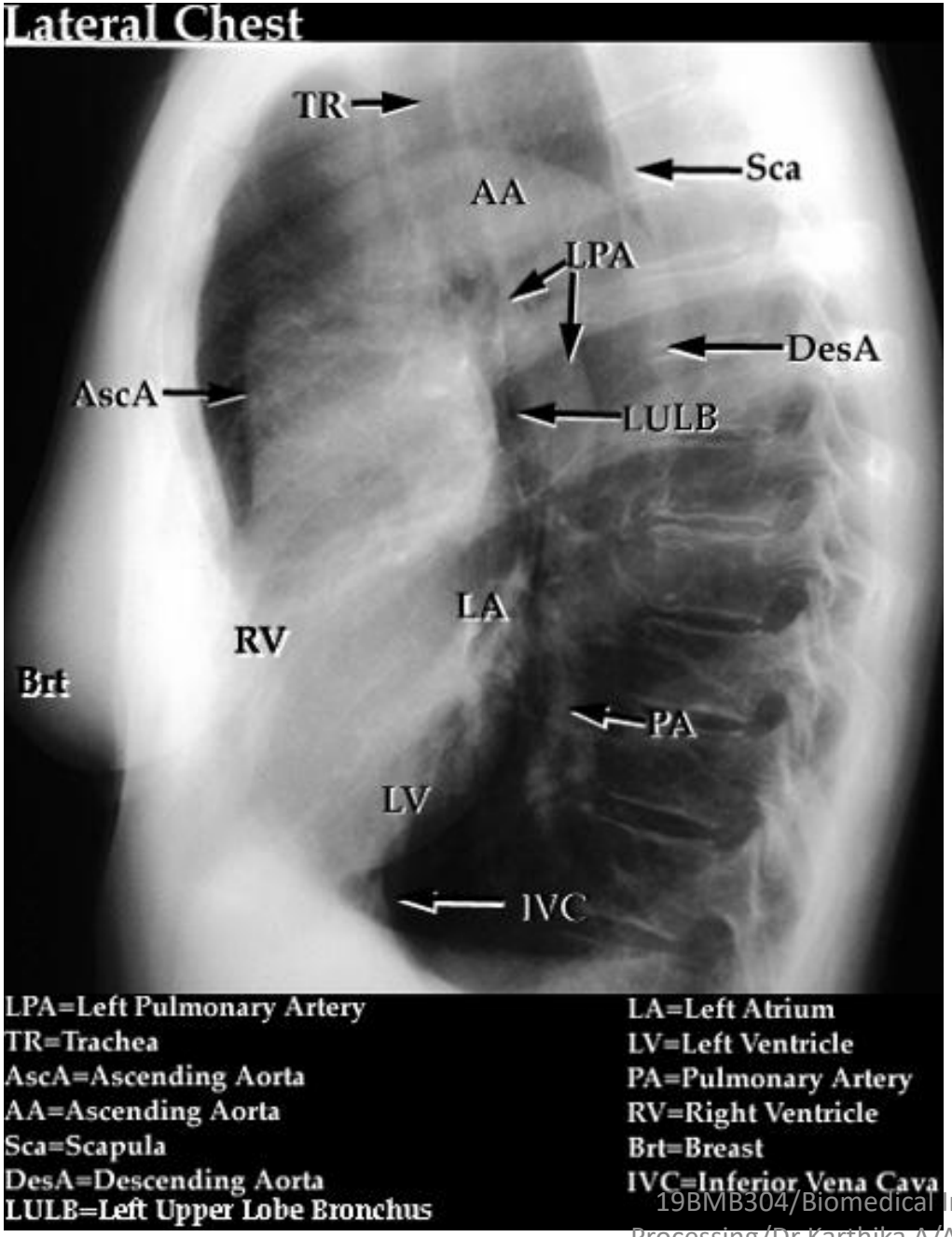
Micro-calcifications



magnified view of micro-calcifications

Target anatomy / pathology: microcalcifications in female breast

Target image quality outcome: high CONSPICUITY of very small objects



Lateral Chest X-Ray

Target anatomy / pathology: To distinguish between Ascending Aorta (AA) and Left pulmonary artery (LPA) in a lateral chest x-ray.

Target image quality outcome: High IMAGE CONTRAST (differences in grey scale level between images of different tissues)

Target anatomy / pathology	Target Image Quality Outcomes
Gaps between carpal bones in a child's wrist	SHARP outlines
To distinguish between Ascending Aorta (AA) and Left pulmonary artery (LPA) in a lateral chest x-ray.	High IMAGE CONTRAST
Mammography: detect microcalcifications in female breast	High CONSPICUITY of very small objects
Distinguish close multiple bone fractures	Separate images of close objects
Check for enlarged heart	accurate organ / tissue shapes, sizes and positions – no distortion
Detect all fractures in a bone	same image quality over the whole image

Performance Indicators of XRI Devices and Image Quality

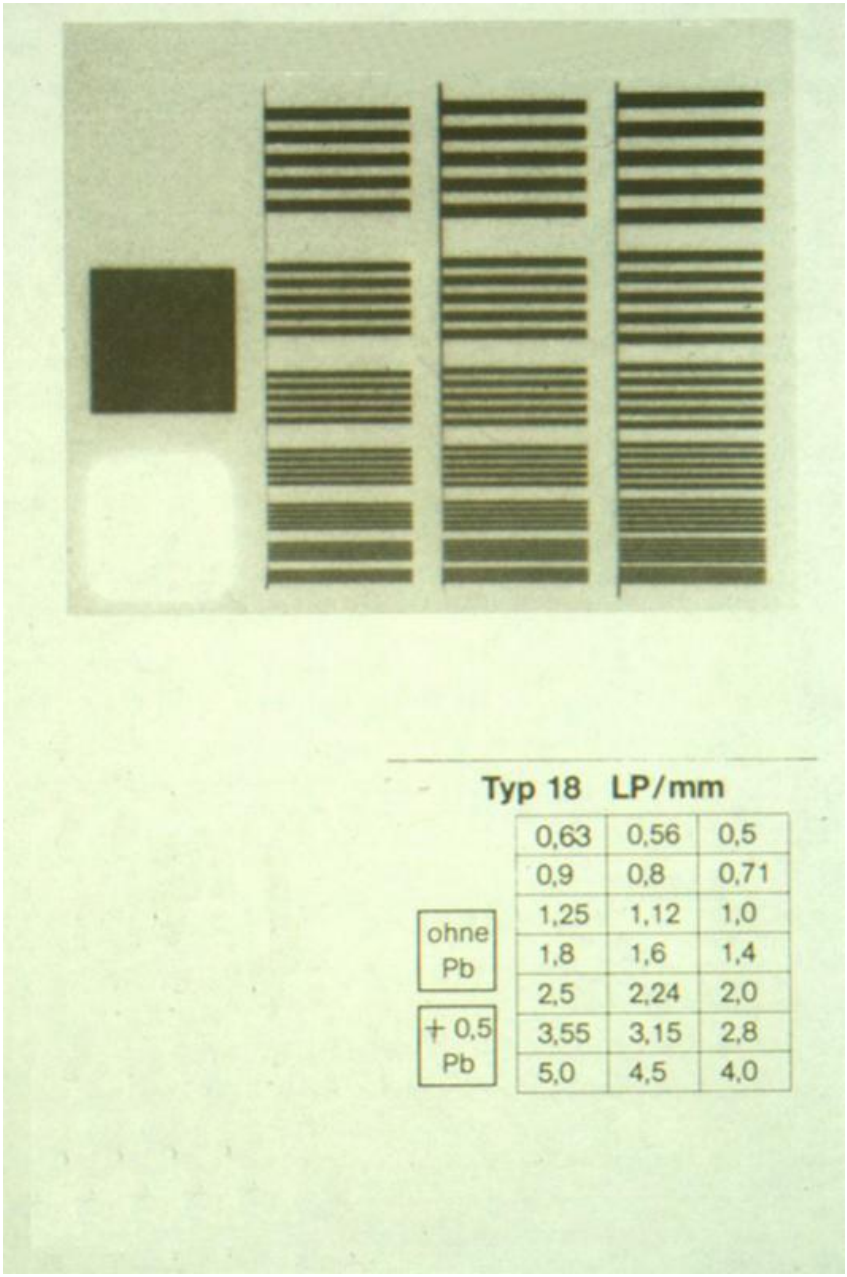
Performance Indicators for Image quality

- Definition: A device performance indicator is:
  - a physical specification of a medical device measured with a suitable test object
  - provides an indication of how good a device is.
- Important performance indicators for XRI devices are:
  - Limiting spatial resolution (LSR)
  - Contrast resolution (CR)
  - Signal-to-noise-ratio (SNR)
  - Geometric accuracy
  - Uniformity

N.B. 'Performance Standards' for medical devices are recommended values of performance indicators

Limiting Spatial Resolution (LSR)

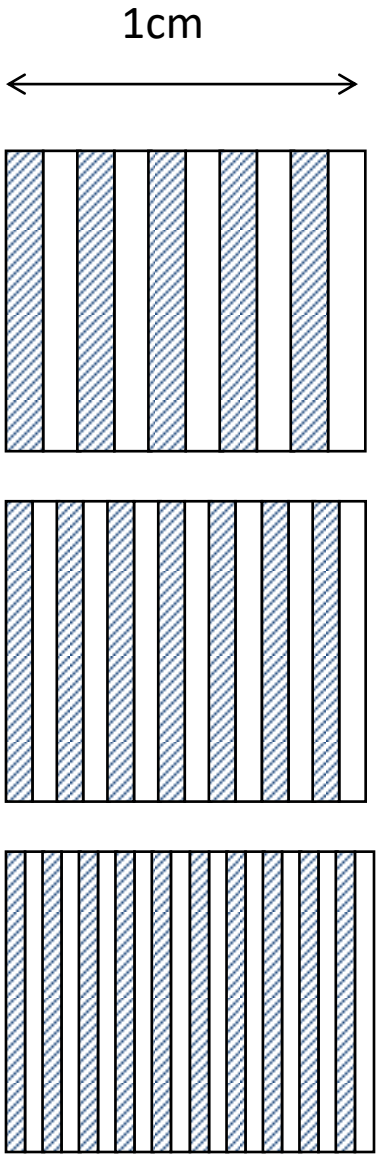
- Put LSR test-object on the X-ray table and expose.
- The LSR is the max spatial frequency which can be seen clearly.

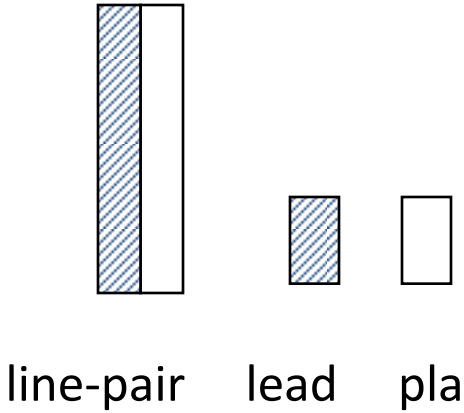


Typ 18 LP/mm

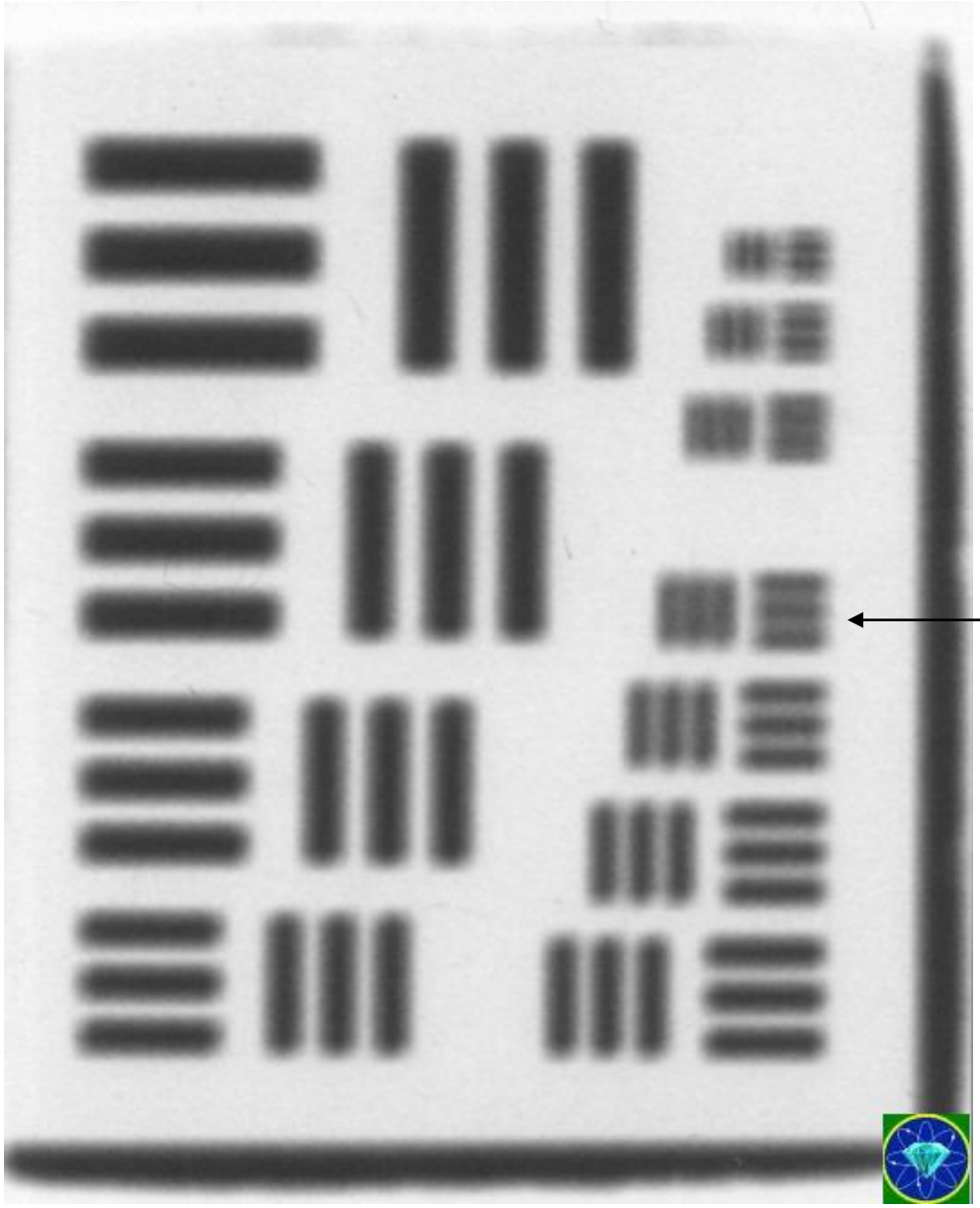
	0,63	0,56	0,5
	0,9	0,8	0,71
ohne Pb	1,25	1,12	1,0
	1,8	1,6	1,4
	2,5	2,24	2,0
+ 0,5 Pb	3,55	3,15	2,8
	5,0	4,5	4,0

Spatial Frequency Test Objects



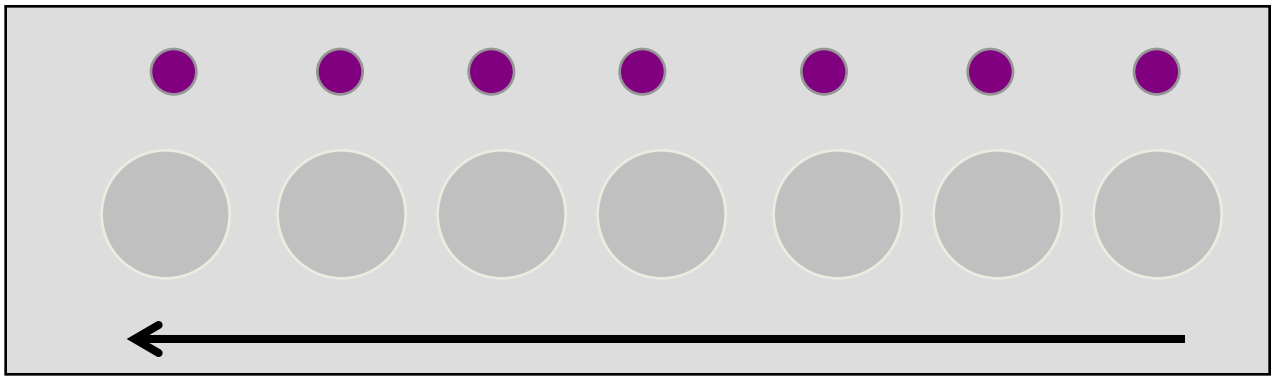


SPATIAL FREQUENCY = number of line-pairs per cm


LSR

Contrast Resolution (CR)

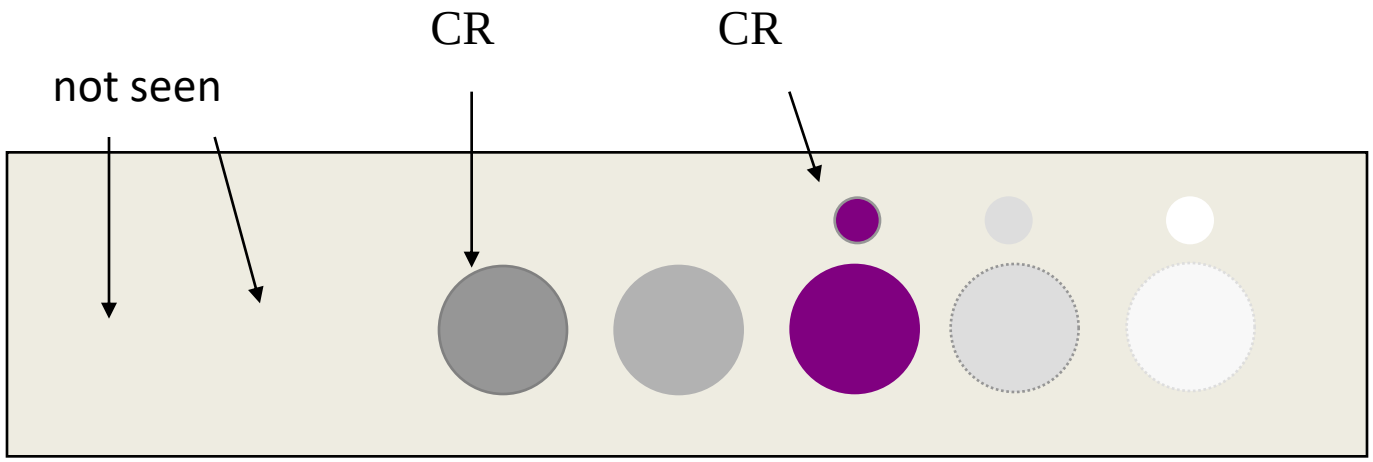
CR test-object

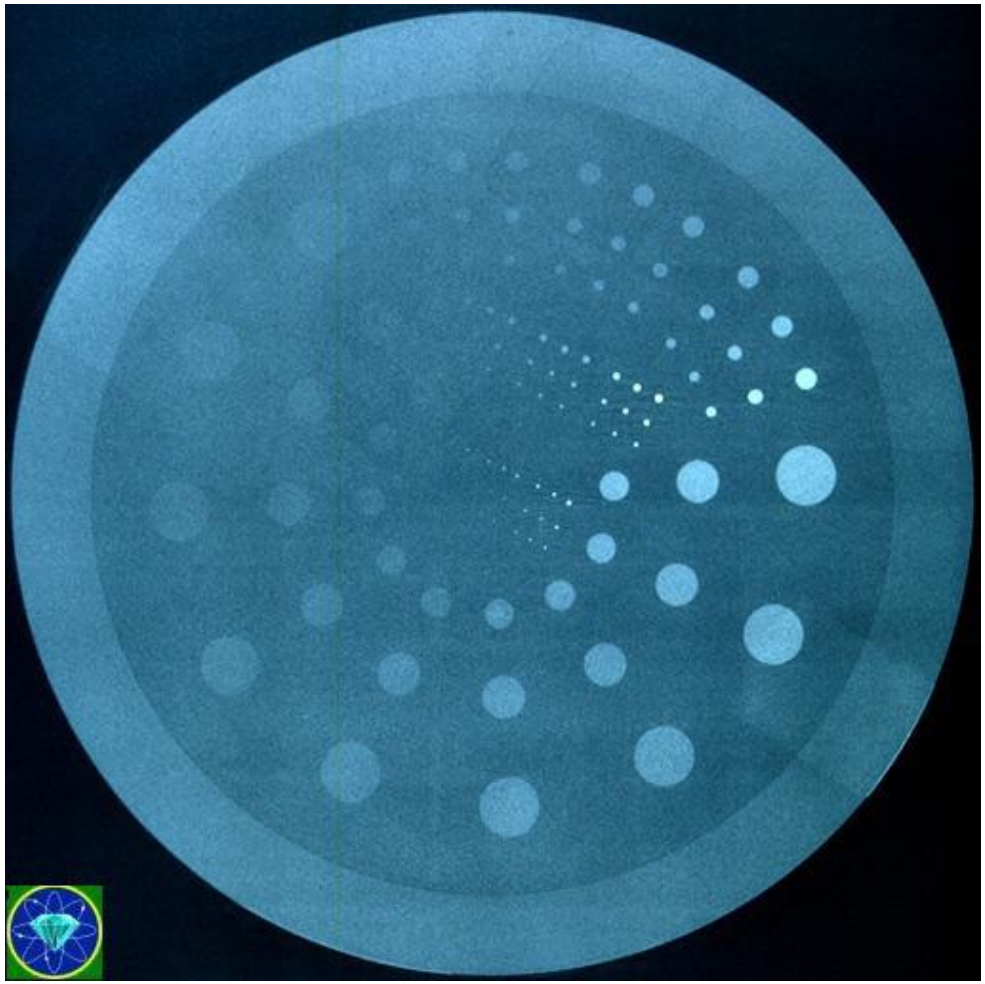


Disks of materials with decreasing test-object contrast (i.e., difference in attenuation coefficient from that of the surrounding material)

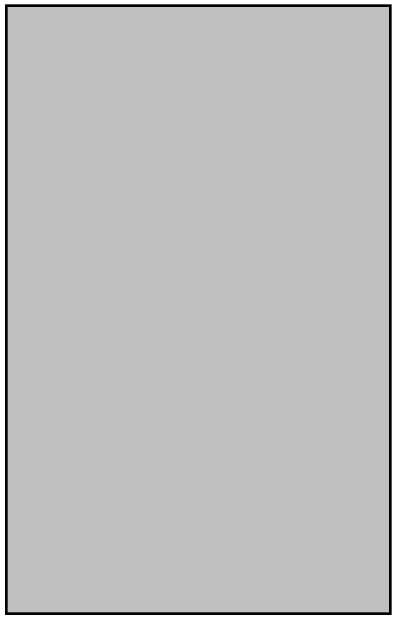
Contrast Resolution

- The CR is the lowest test-object contrast that you can see in the image of the test-object.
- Note that CR depends on the size of the discs



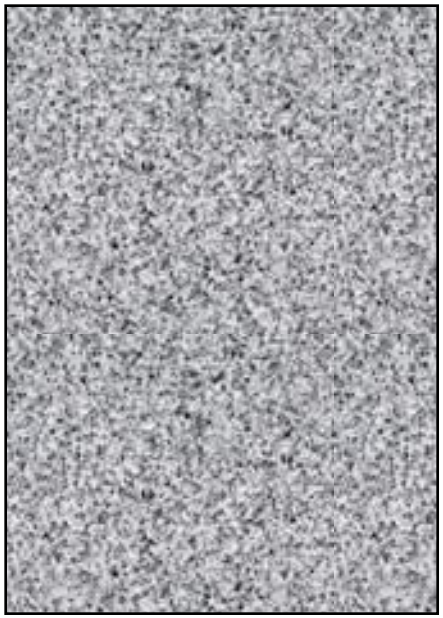


Signal-to-Noise Ratio (SNR)



Ideal x-ray tube and sensor: zero noise

In practice: Low noise



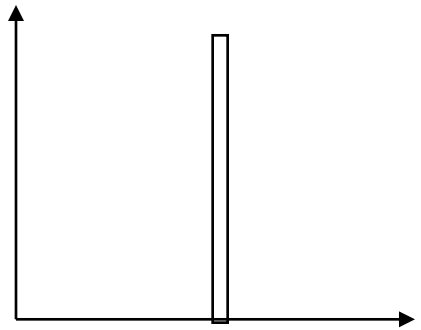
In practice: High noise

Test object: uniform thin sheet of copper

Noise occurs because of the random variability in x-ray energy fluence (energy per unit area) across the beam and detection sensitivity across x-ray sensor.

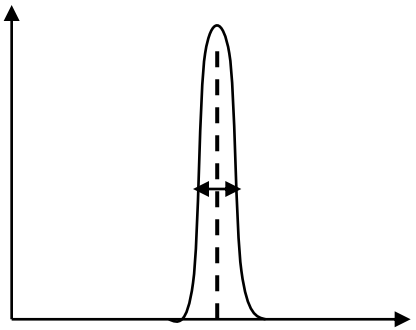
Measuring SNR

- Plot a histogram.
- SNR = mean / standard deviation

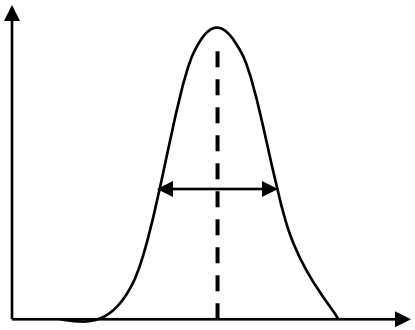


Ideal x-ray tube and detector: zero noise, zero SD

Very high SNR

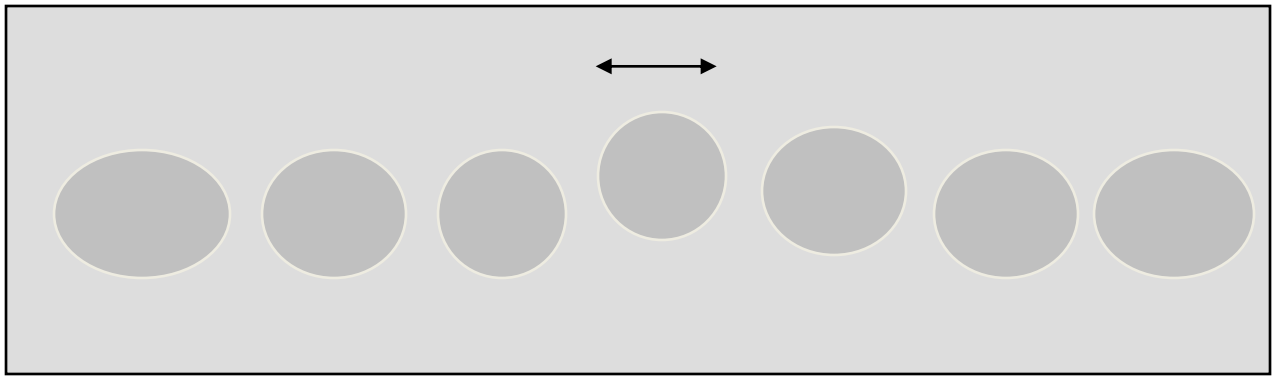


low noise, small SD
High SNR



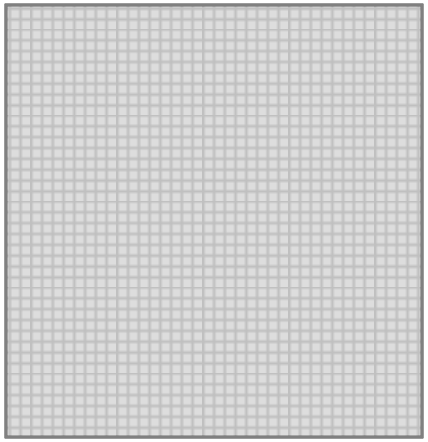
high noise, high SD Low SNR

Geometric Accuracy

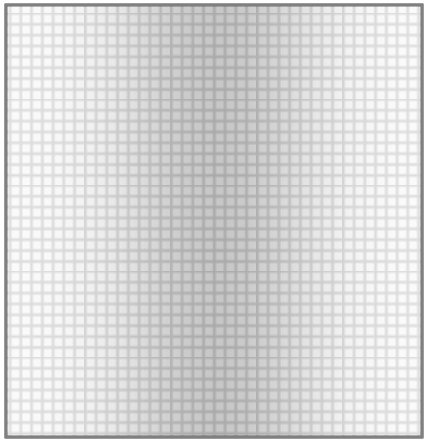


To measure geometric accuracy: measure diameters and positions of images and compare with actual diameters and positions of discs in CR test object.

Uniformity



high uniformity



low uniformity

Checked by imaging a metal gauze and looking for areas where the image is different (darker, less sharp) than the rest of the image.

Use of Device Performance Indicators in Imaging

Target anatomy / pathology	Target Image Quality Outcomes	Imaging Device Performance Indicator of Major Importance
Gaps between carpal bones in a child's wrist	SHARP outlines	High spatial resolution
Distinguish between ascending aorta (AA) and left pulmonary artery (LPA) in a lateral chest x-ray	High IMAGE CONTRAST	High contrast resolution
Mammography: microcalcifications in female breast	High CONSPICUITY of very small objects	High SNR
Distinguish close multiple bone fractures	Separate images of close objects	High spatial resolution
Check for enlarged heart	accurate organ / tissue shapes, sizes and positions – no distortion	High geometric accuracy
Detect all fractures in a bone	constant image quality over the whole image	High uniformity

General Comments

- You must always choose a device which has the performance indicator that would maximise visualisation of the particular anatomy / pathology under study.
- Attempts to improve one performance indicator might lead to a degradation of another so one must be careful and check which performance indicator is the most important.
- Attempts at improvement of performance indicators often leads to a higher patient dose (therefore one must ask whether the increased value of the performance indicator is really necessary for improved diagnostic accuracy)
- Device use protocols must be designed so that these performance indicators are not degraded.

For High Limiting Spatial Resolution

- Devices:
  - X-ray tube: use the device with the smallest small focal spot available
  - Digital radiography: use digital plate with the highest number of pixels sensors per unit area
- Protocol:
  - choose the smallest focal spot available on your device
  - large SID
  - low OID - use patient compression if necessary
  - avoid geometric magnification if possible
  - minimise motion of patient (use low exposure time, immobilise patient, give proper instructions to patient)
  - Use zoom in digital

For High Contrast Resolution

- Devices:
  - use digital devices with high ADC bit-depth
- Protocol:
  - low kV
  - minimise scatter reaching the detector (minimise field-size, minimise thickness of irradiated part, use grids, air-gap)
  - use windowing

For High SNR

- Devices:
  - use low electronic noise detectors
- Protocol:
  - SNR is proportional to the square root of the number of photons per unit area hitting the detector. Therefore the higher the number of photons the better the SNR. Therefore use high mAs and low sensitivity detector setting (but both lead to higher patient dose).

For High Geometric Accuracy

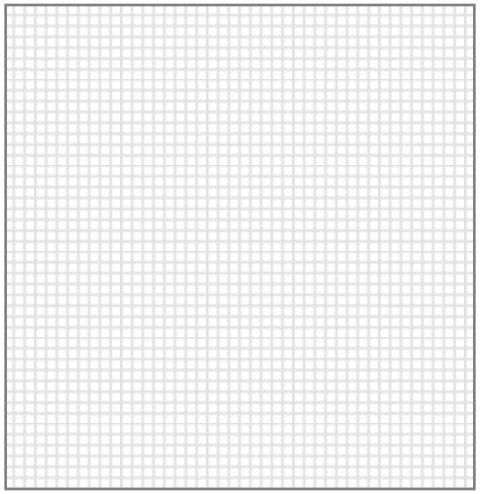
- ensure proper beam centring to reduce distortion
- ensure proper patient positioning (object of interest parallel to detector) to reduce distortion
- use large source-image distance (SID), low object-image distance (OID, including compression) to reduce magnification.

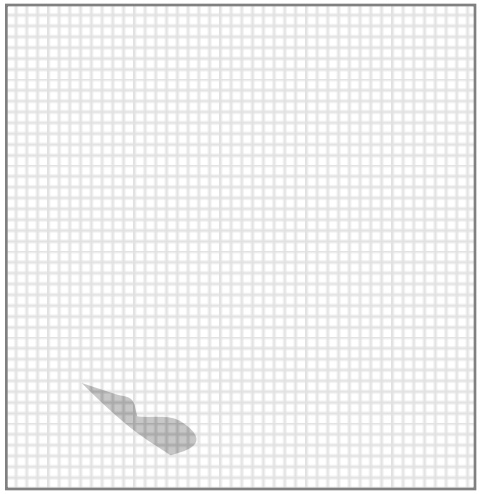
For High Uniformity

- Devices:
  - Digital: high-quality digital sensor plates and signal processors
- Protocol:
  - Use beam-shaping filters
  - Use the heel effect

Always Check for Artefacts

- Artefacts: features in the image which are not in the imaged object and which are brought about by damaged devices (or inappropriate use of a device)
- Always check for these in every test image





no artefacts

artefacts present

Optimisation of Patient Doses in XRI

For Optimisation of Dose

- Use low dose imaging devices
- Use low dose protocols
- Use DAP meter readings to monitor patient doses
- Check that doses are below the appropriate Diagnostic Reference Levels DRLs
- Ensure that the procedure is within your competence
- Regular Quality Control (QC) of devices to reduce retakes (QC = regular checking of the performance indicators to ensure that they have not deteriorated)
- Do regular reject analysis (to avoid making the same mistakes and hence avoid repeats)
- Take advice when necessary: use the services of the Medical Physics Expert (in CZ called Medical Radiological Physicist)

Use Low Dose Devices

- no grid (but CR deteriorates, avoid grid for children and small adults)
- appropriate filters (removes very low energy photons which are just absorbed by the skin)
- immobilisation devices with children, old people to reduce repeats
- Use the Automatic Exposure Device (AED)

DAP meter

DAP (Dose Area Product) meter reading is a good performance indicator for the doses given by the device

Use Low Dose Protocols

- high kV, low mAs (but lower CR)
- collimate to smallest field-size (also improves CR)
- never use SSD less than 30cm
- protect radiosensitive organs (gonads, breast, eyes, thyroid …): exclude via collimation, right projection angle, use protective apparel e.g., lead aprons, gonad shields
- right projection e.g. PA projections best for chest and skull
- use patient compression to minimise amount of tissue irradiated (improves SR, CR)
- proper patient instruction to avoid repeats

Reducing Patient Doses in CT

Current Situation

- CT high dose procedure
- CT continues to evolve rapidly
- The frequency of CT examinations is increasing rapidly from 2% of all radiological examinations in some countries a decade ago to 10-15 % now
- worldwide CT constitutes 5% of procedures yet 34% of the total dose!
- *Why increased frequency of use?* 20 years ago, a standard CT of the thorax took several minutes while today with spiral-CT similar information can be accumulated in a single breath-hold making it patient & user friendly.

Why increased dose?

- The higher the dose the better the image quality
- There is a tendency to increase the volume covered in a particular examination
- Modern helical CT has made volume scanning with no inter-slice gap much easier (easy just set pitch = 1)
- As CT permits automatic correction of the image, high exposure factors are used even when these are not required e.g., for thick or thin regions of the body
- Same exposure factors often used for children as for adults
- many radiologists believe that modern CT scanners which are very fast give lesser radiation dose, not true as mA used is higher

Radiosensitive Organs Needing Protection

- Breast dose high in CT of thorax
- Eye lens in brain CT
- Thyroid in brain and in thorax CT
- Gonads in pelvic CT

Low dose CT devices

- Real-time automatic mA modulation (patient not uniform area of cross-section)
- Partial rotation feature: e.g. 270 degree in Head CT (omitting the frontal 90^{o}) saves the eyes
- Gantry angulation to avoid high-sensitivity organs
- Infant, small patient buttons

Low dose protocols

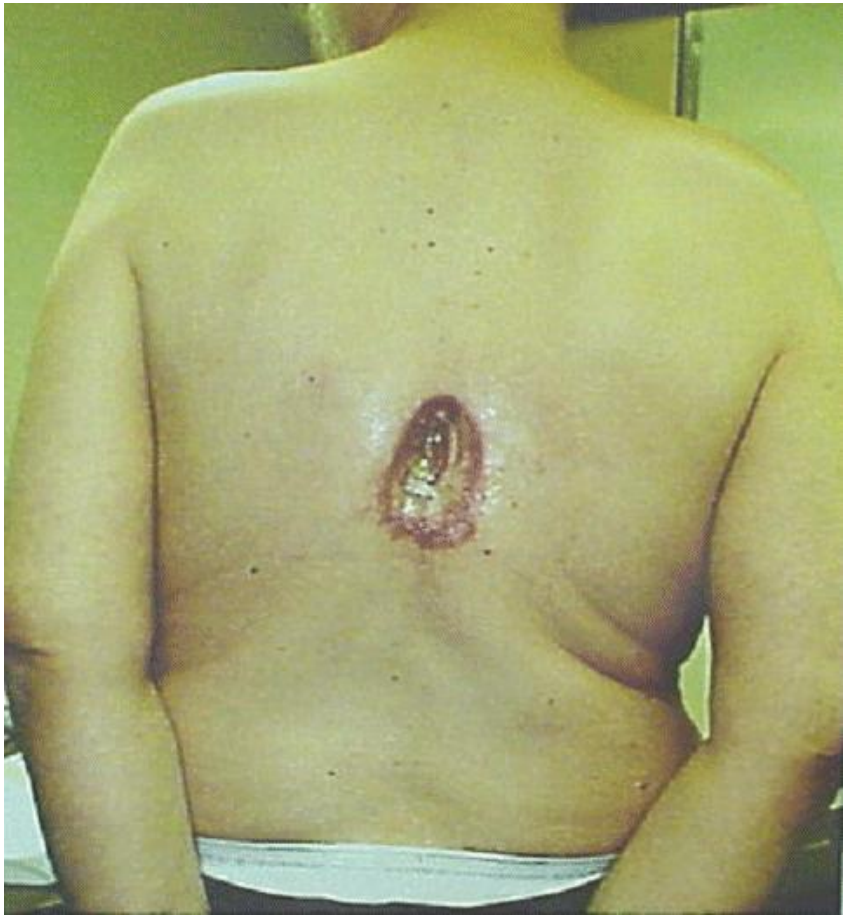
- Limit the scanned volume to what is necessary only
- Shielding of superficial organs such as thyroid, breast (special breast garments available), eye lens and gonads particularly in children and young adults.
- Spiral CT: the higher the pitch the less the dose but the lower the axial SR
- separate protocols for paediatric patients (e.g., lower mA)

Reducing Patient Doses in Interventional Radiology

RP Environment in IR

- Lengthy, complex, difficult, sometimes repeated procedures - prolonged exposure times – potential for high patient doses

Patient: Severe Skin Injury at High Doses



Example of chronic skin injury from coronary angiography and 2x angioplasties (spine exposed)

Protocol Design for Patient Protection

- Use low frame rates 50, 25, 12.5, 6 fps
- Minimise: fluoro time, use of high image quality mode
- Short intermittent exposures using pedal switch
- Read dose display (total fluoro time, number of images, cumulative DAP)
- Keep in mind that dose rates will be greater and dose accumulates faster in larger patients
- Keep the image intensifier at minimum distance from patient
- Always collimate closely to the area of interest
- Prolonged procedures: reduce dose to the irradiated skin e.g. by changing beam angulation
- Minimise use of zoom mode as it leads to higher patient doses

Units and Dose Measuring Devices

Quantities and Units for Estimating Risk

Effective Dose (units Sv):

$$E = w_T \, w_R \, D$$

w_T = *tissue weighting factor*

w_R = *radiation weighting factor*

D = ABSORBED DOSE , the amount of energy absorbed per unit mass of tissue. Units JKg^{-1} (Gray Gy). The higher the absorbed dose (energy absorbed) the higher the number of ions produced and the higher the risk.

The radiation weighting factor is necessary because certain radiations are more risky than others. gamma and X (external / internal) 1, alpha (external) 0, alpha (internal) 20. The tissue weighting factor is necessary because different tissues have different *radiosensitivity*.

The effective dose is often referred to simply as the '*dose*'. Units of E are Sievert Sv (usually mSv used).

Old Quantities and Units (only used in USA now)

- 1Rad = 0.01Gy
- 1 Rem = 0.01Sv
- Quality factor = radiation weighting factor
- Roentgen (R): old measure of radiation used for X and gamma in air only

Dosimeters (dose sensors)

Types of Dosimeters used in medicine:

a) Those based on **thermoluminescent materials** e.g. lithium fluoride. The ionising radiation brings some electrons into a stable higher energy excited state. After heating, the electrons fall into the ground state. This is accompanied by emission of visible light. The intensity of this light is proportional to the dose. **All medical radiation badge personal dosimeters today are this type.** They can also be produced as rings to measure finger doses when handling radiopharmaceuticals in nuclear medicine. They can also be put on patients skin to measure patient entrance doses.

b) Those based on **semiconductors**: Ionising radiation causes movement of electrons from the valence to the conduction band in semiconductors, and increases their conductivity. Semiconductor dosimeters are occasionally encountered as miniaturised probes, which can be introduced into body cavities. They directly measure the patient's dose.

c) The **photographic methods** are based on the ability of ionising radiation to blacken photographic emulsions (films).

d) Gas ionisation methods (ionization chamber) utilise the ability of ionising radiation to produce ions in gases and increase their electrical conductivity. The charge collected is proportional to the dose, the current to the dose rate. The ions disappear by recombination and the sensor can be then re-used.

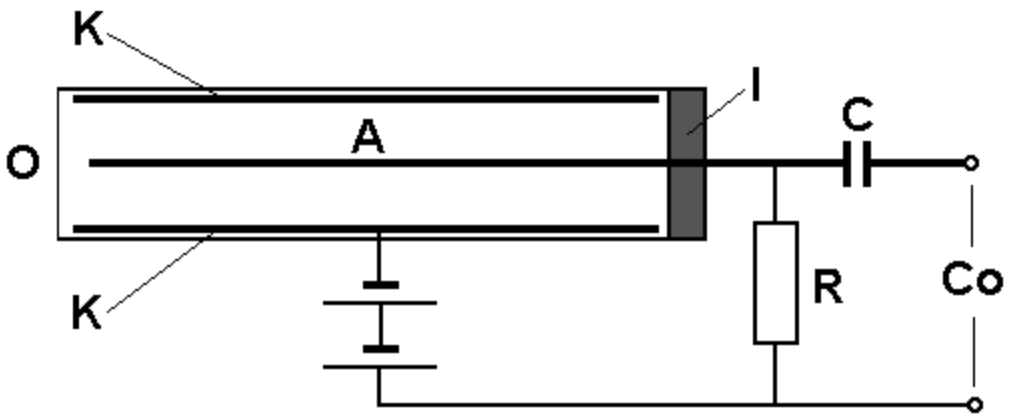
TL personal monitors

Radiation Counters

- Radiation counters are radiation detectors that can detect *individual* photons / particles and hence make it possible for these *to be counted*.
- The **Geiger-Müller counter** is based on gas ionization, however the value of voltage across the two electrodes, is such that even a single photon / particle of ionising radiation forms enough ions to be detected. The voltage between electrodes is so high that even the secondary ions can ionise neutral molecules, and the so-called **multiplication** or **avalanche effect** arises. The "avalanche" of ions hitting one of the electrodes is registered as a short voltage pulse. The number of pulses gives the number of photons / particles. However the size of the pulse is independent of the energy of the photon and therefore cannot be used as measure of that energy (it is a detector only and not a sensor).
- **Scintillation counters are optoelectronic devices** (used for example in gamma cameras) which are both detectors and sensors - they measure both the number and the energy of the individual photon / particle.

GM tube

Geiger-Müller Counter



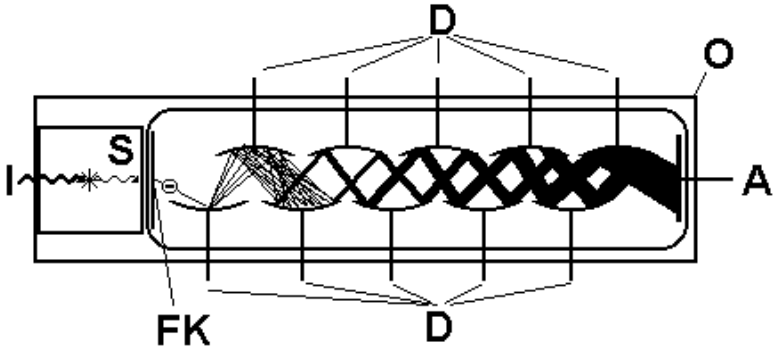
K - cylindrical cathode, A - anode central wire, O - input window, I - isolator, R - working resistor, C - condenser of the capacity coupling, Co - counter connectors.

The Geiger-Müller (GM) counter consists of a GM tube, a source of high direct voltage, and an electronic counter of impulses. The GM tube is a hollow cylinder with metallic inner surface. This metallic layer is a cathode. The central wire is the positively charged anode. The GM tube is usually filled by argon containing 10 % of the **quenching agent** (e.g. ethanol vapour). This agent stops (quenches) the ion multiplication process, and so prevents the formation of a stable electric discharge between the anode and cathode. The duration of avalanche ionisation is very short, about 5 ms. However, during this time the tube is not able to react to another particle of ionising radiation. This **dead time** is an important characteristic of GM tubes. It causes measurement error which can be corrected by calculation.

Scintillation counters

Scintillation counter consists of a scintillator, photomultiplier and an electronic part - the source of high voltage, and the pulse counter. The **scintillator** is a substance in which the **scintillation** (small flashes of visible light) occurs after the absorption of ionising radiation energy. The light originates in deexcitation and recombination processes. Sodium iodide crystals activated by traces of thallium are the most effective scintillators.

Scintillation counters



The scintillation detector.
I - ionising radiation, S - scintillator, FK - photocathode, D - dynodes, A - anode, O - light- and water-proof housing. There is depicted the origin of only one photon which liberates only one electron from the photocathode.

The scintillator is enclosed in a light-proof housing. One side of the housing is transparent, so that the originating photons can come to a **photomultiplier**, which measures low-intensity light.

The photons hit the **photocathode -** a very thin layer of a metal with low electron binding energy. They eject electrons from the cathode, which are attracted and accelerated by the closest positively charged electrode, the first **dynode**. The dynodes form an array of e.g. ten electrodes. On average, six secondary electrons are ejected by each electron impact. The secondary electrons are attracted to the next dynode, where the process is repeated. Resulting voltage pulses are counted in the electronic part of the instrument. Magnitude of this pulse is given by the energy of the ionising particle.

Websites for additional information on radiation sources and effects

European Commission (radiological protection pages): **europa.eu**

International Commission on Radiological Protection: **www.icrp.org**

World Health Organization: **www.who.int**

International Atomic Energy Agency: **www.iaea.org**

United Nations Scientific Committee on the Effects of Atomic Radiation: **www.unscear.org**

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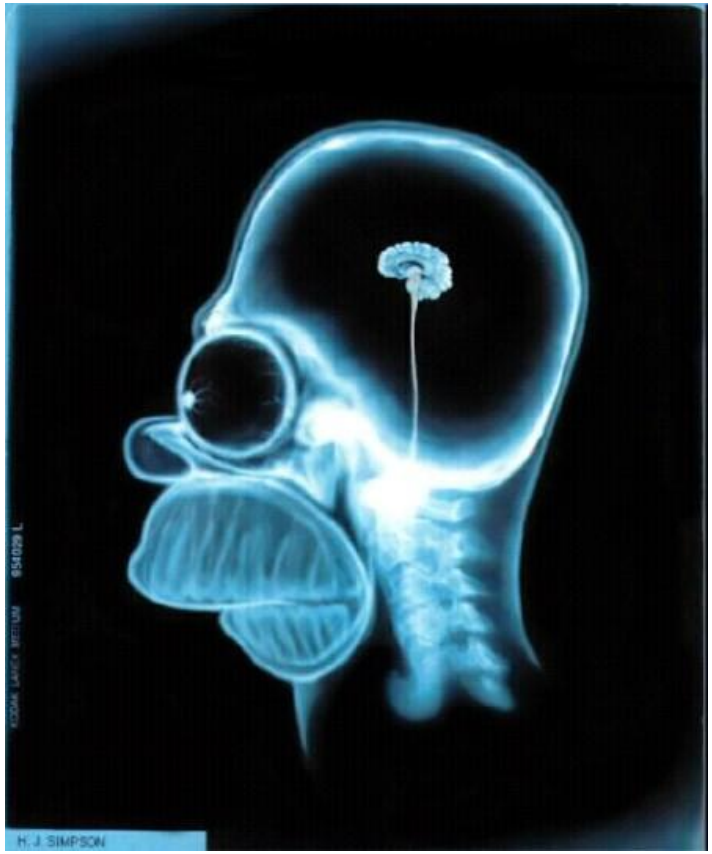

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