Radiation dose & radiation Protection in SPECT/CT

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Biological Effects of Radiation

- Deterministic effects
  - Involve cell death
  - Occur above a particular radiation threshold
- Stochastic effects
  - Include radiation induced cancer
  - Randomly initiated effects, independent of a threshold exposure level
  - Increased probability of increased dosage

Radiation Units

- The biological effects is dependant upon the total energy of radiation absorbed (in joules) per unit mass (in kg) of a sensitive tissues or organs, represented by *absorbed dose in gray (Gy)*

- To compare risks of partial and whole body irradiation, a quantity *effective dose in* sievert (Sv) is used

Patient protection

- Although there are no limits recommended for the medical exposure in Kuwait or internationally. The protection of the patient is inherently included in two principles:

a) The dose in the patient must be as low as compatible with the medical purpose

b) A practice leading to a medical exposure must be clearly justified and provide a direct benefit to the patient. Protection against radiation must be optimized

Guidance levels

I. To be a reasonable indication of doses for average sized patients
II. To be established by relevant professional bodies in consultations with the authority
III. To be applied with flexibility to allow higher exposures if these are indicated by by sound clinical judgment
IV. to be revised as technology & techniques improve

ALARA

SPECT and CT use ionizing radiation and therefore when these examinations are used, the ALARA principle (radiation dose As Low As Reasonably Achievable) must be observed.

SPECT vs CT

SPECT	CT
◆ The radiation dose is affected by the biological nature of radiophmaceutical, thus wider range of organ doses received in a specific examination ◆ Much lower photon flux and higher γ-rays energy compared to x-rays	◆ In CT, absorbed dose is proportional to absorption coefficient of irradiated tissue ◆ Much higher photon flux and lower x-rays energy compared to γ-rays

Computed Tomography

- It is one of the most important radiological examinations worldwide

- The frequency of CT examinations is increasing rapidly from 2% of all radiological examinations in some countries a decade ago to 10-15 % now

Radiation dose from CT

- Radiation Exposure from CT scan depends on operator dependent factors:
  - mAs (directly proportional to radiation dose)
  - KVp (not linearly proportional to dose)
  - Pitch (inversely related to dosage)
  - Slice thickness (requires an increase in mAs)
  - Number of scans (doubling the radiation dose)
  - Scan time (faster scans lead to an increased scan area)
  - Scanning mode (step-based vs. spiral technique, single-slice vs. multi-slice)

Effective dose estimation

- $CTDI_{vol}$ CT dose index (mGy) represents an index of radiation dose to a standard phantom

- CTDI is equivalent to dose distribution integrated over the z (longitudinal) patient axis divided by the slice thickness

$$CTDI = \frac{1}{d}\int_{-\infty}^{+\infty} D(z)\,Dz$$

•D (z):radiation dose in one slice as a function of axial location

•d is the slice thickness

Effective dose estimation

- The *CTDI*vol multiplied by the length of the CT scan in cm, to yield the dose-length product(*DLP*)
- *DLP* is a measure of total radiation energy received by the patient's body
- an effective dose can be estimated using conversion factors for the relative radiosensitivity of the organs within the range of the scan

$$D = (CTDI_{vol} * L) * k = DLP * k$$

Effective dose estimation

- Some CT scanners save the *CDTI*vol and *DLP* values for a specific patient scan at the end of the examination

- If multiple CT scans of the same region of the patient was done, each scan adds to the radiation dose and risk

- *CTDI*vol from a single CT scan covering one SPECT bed position is

Effective doses in CT and radiographic examinations

CT examination	Effective dose (mSv)	Radiographic examination	Effective dose (mSv)
Head	**2**	Skull	**0.07**
Chest	**8**	Chest PA	**0.02**
Abdomen	**10-20**	Abdomen	**1.0**
Pelvis	**10-20**	Pelvis	**0.7**
		Ba swallow	**1.5**
		Ba enema	**7**

Organ doses in CT

- Breast dose in thorax CT may be as much as 30-50 mGy, even though breasts are not the target of imaging procedure

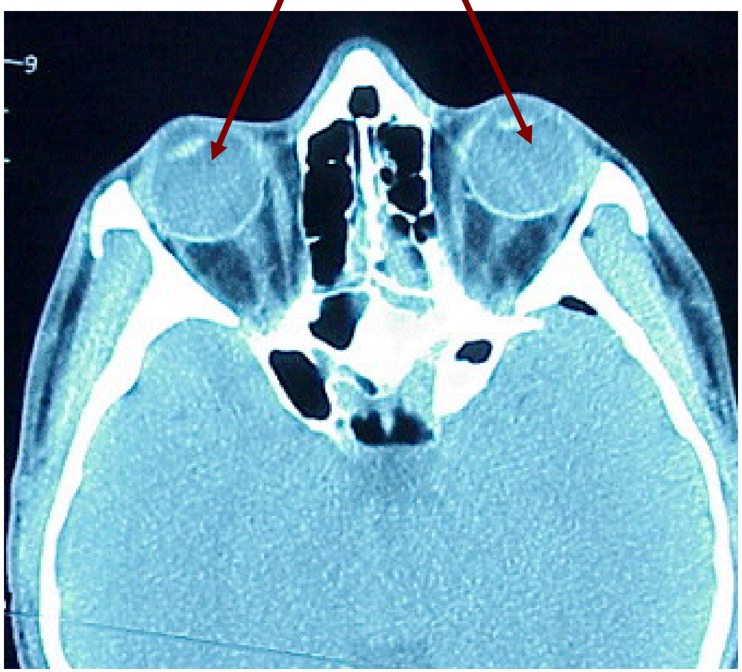
- Eye lens dose in brain CT
- Thyroid in brain or in thorax CT
- Gonads in pelvic CT

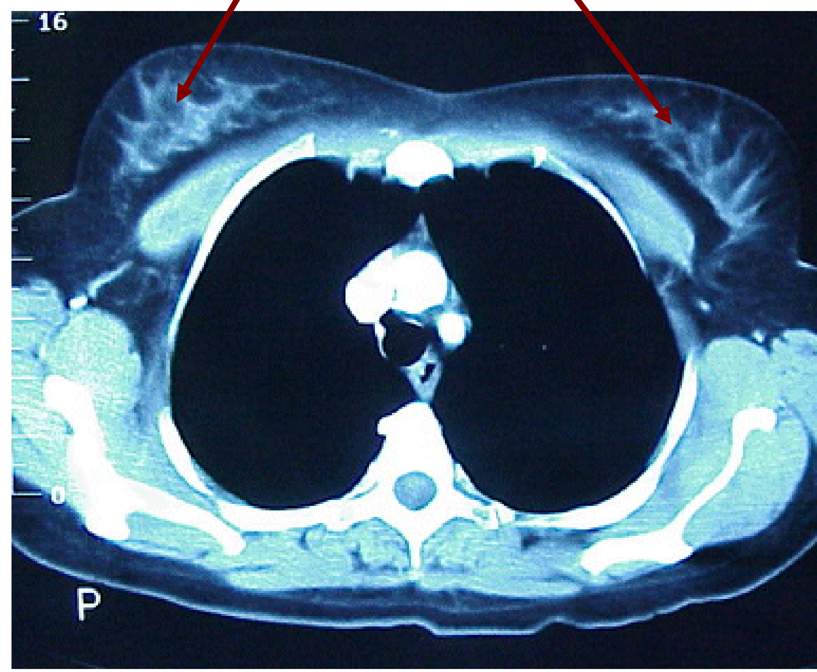
} Receive high doses

Tissues in the field although they are not the area of interest for the procedure

Eye lens

Breast tissue





Typical doses in mGy during CT in adults (Shrimpton et al. 1991)

Examination	Eyes	Thyroid	Breast	Uterus	Ovaries	Testes
Head	**50**	**1.9**	**0.03**	*	*	*
Cervical spine	**0.62**	**44**	**0.09**	*	*	*
Thoracic spine	**0.04**	**0.46**	**28**	**0.02**	**0.02**	*
Chest	**0.14**	**2.3**	**21**	**0.06**	**0.08**	*
Abdomen	*	**0.05**	**0.72**	**8.0**	**8.0**	**0.7**
L. spine	*	**0.01**	**0.13**	**2.4**	**2.7**	**0.06**
Pelvis	*	*	**0.03**	**26**	**23**	**1.7**

The symbol * indicates that dose is < 0.005 mGy

Spiral CT (more or less dose?)

- It depends on the choice of factors
- It is possible to perform a spiral CT with lower radiation dose than slice-by-slice CT, however in practice the patient gets higher dose due to the factors chosen (scan volume, mAs, pitch, slice width)
- An increase by 10-30% may occur with multi-slice detector array

CT parameters

- 0.7-sec rotation time, 8 × 2.5-mm collimation, 120 kV, and 10 mA

(*CTDI*)=1.0 mGy

- 4.0-sec rotation time, 4 × 5.0-mm collimation, 140 kV, and 10 mA

(*CTDI*)=2.4 mGy

Low dose CT

- High currents improve image quality but also increase the radiation dose to the patient

- A reduced mAs is the most practical means of lowering dosage due to direct proportion between mAs and dose

Low dose CT

- A low dose CT with 40 mA delivers 2- 8 mSv.
- GE Hawkeye use a much lower tube current 2 mA, thus radiation added to SPECT in SPECT/CT is 0.5 mSv
- Limiting the scanned volume will reduce dose

Hardware developments to reduce patient radiation exposure

- X-ray filtering
  - Filtering to remove low energy photons which are commonly attenuated in the body and don’t contribute to image
  - Beam-shaping filters reduce dosage by minimizing radiation to thinner portions of the body
- Milliampere-second modulation
  - CT manufacturers are making move to automatically adjust mAs based on patient size

Safety measures

- Draw attention of users to select separate protocols for paediatric patients
- CT examination should **not be repeated** without clinical justification and should be limited to the area of interest
- CT examination of chest in young girls and young females needs to be justified in view of high breast dose

CT for SPECT attenuation correction

- Most dedicated CT protocols are high dose compared to doses adequate for SPECT AC
- For SPECT/CT, sensible selection of the CT parameters can reduce the overall patient dose by over 50% without compromising diagnostic information.

- attenuation-corrected SPECT/CT images obtained by using a low current (10 mA) with those obtained by using a standard current (140 mA) at CT
- There was no significant difference between the counts on $SPECT_{CT10}$ and $SPECT_{CT140}$ ($P = .95$)
- a low-current CT scan is sufficient for attenuation correction.

(Utsunomiya et al, *November 2005 Radiology, 237, 662-669)*

Radiation dose from SPECT

- Doses of SPECT examinations are typically much lower than PET or CT
- 10 mCi 18F-FDG delivers radiation dose of ~11mSv to a patient
- Diagnostic CT delivers 10 to 20 mSv (high quality CT)

Radiation dose from SPECT

- The dose absorbed by the patient for any radiopharmaceutical depends on:
  - Type of decay
  - Radiation energy
  - Radionuclide half-life (physical half-life)
  - Clearance from the body (Biological half-life)
  - Kinetics of distribution in the body

Measurement of Effective Dose

The sum of weighted equivalent dose over all organs or tissues in an individual is termed the *effective dose* (E)=

$$E = \sum_T W_T \times D_T$$

ICRP Publication 60: w_T of the gonads (0.2), followed by the bone marrow, colon, lung, and stomach (each 0.12)

Typical effective doses from diagnostic medical exposures in the 1990s (U.K.).

Diagnostic procedure	effective dose (mSv)
X-ray examinations:	
Limbs and joints (except hip)	< 0.01
Chest (single PA film)	0.02
Skull	0.07
Thoracic spine	0.7
Lumbar spine	1.3
Hip	0.3
Pelvis	0.7
Abdomen	1.0
IVU	2.5
Barium swallow	1.5
Barium meal	3
Barium follow thrugh	3
Barium enema	7
CT head	2.3
CT chest	8
CT abdomen or pelvis	10

Diagnostic procedure	effective dose (mSv)
Radionuclide studies:	
Lung ventilation (Xe-133)	0.3
Lung perfusion (Tc-99m)	1
Kidney (Tc-99m)	1
Thyroid (Tc-99m)	1
Bone (Tc-99m)	4
Cardiac gated study (Tc-99m)	6
PET head (F-18 FDG)	5
MPI (MIBI)st/re	11.5
Tl-201 (viability)	22
Dual isotope(Tc+Tl) MPI	29
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Annual natural background	2.5

Data from the National Radiation Protection Board in the U.K.

Radiation safety: SPECT/CT

- The dramatic increase in the use of SPECT/CT techniques has given rise to concern regarding the level of radiation exposure of both healthcare staff and patients

- For the patient, a sensible choice of the parameters used in the CT scan can significantly reduce radiation dose, without any compromise in the quality of the diagnostic information

Radiation safety: SPECT/CT

- The SPECT room requires shielding both because of activity in the patient as well as scattered X-rays from the CT
- The shielding of SPECT/CT facilities presents special challenges because of the diverse radiation and sources involved.

Factors to be considered in shielding

- The radionuclide and its physical properties (ie half-life and the abundances and energies of emitted radiations)
- Administered activity
- Radiopharmaceutical kinetics (uptake & excretion)
- Scan duration
- CT scan parameters
- The workload, that is, the number of patients scanned per week
- any existing structural and instrument shielding

Design-goal limits

- For occupationally exposed individuals, the Maximum Permissible Dose (MPD) is 50 mSv per year & equals to a point of interest within a restricted or a controlled area (an area to which access is limited to protect individuals against risk of radiation exposure)

- 5 mSv (1/10th of the 50 mSv per year MPD) or 0.1 mSv per week is commonly used as the design goal for restricted or controlled areas.

Design-goal limits

- For the general public:the MPD is 1mSv per year equals to the MPD for a person at a reference point within an unrestricted area (an area to which access is neither limited nor controlled)

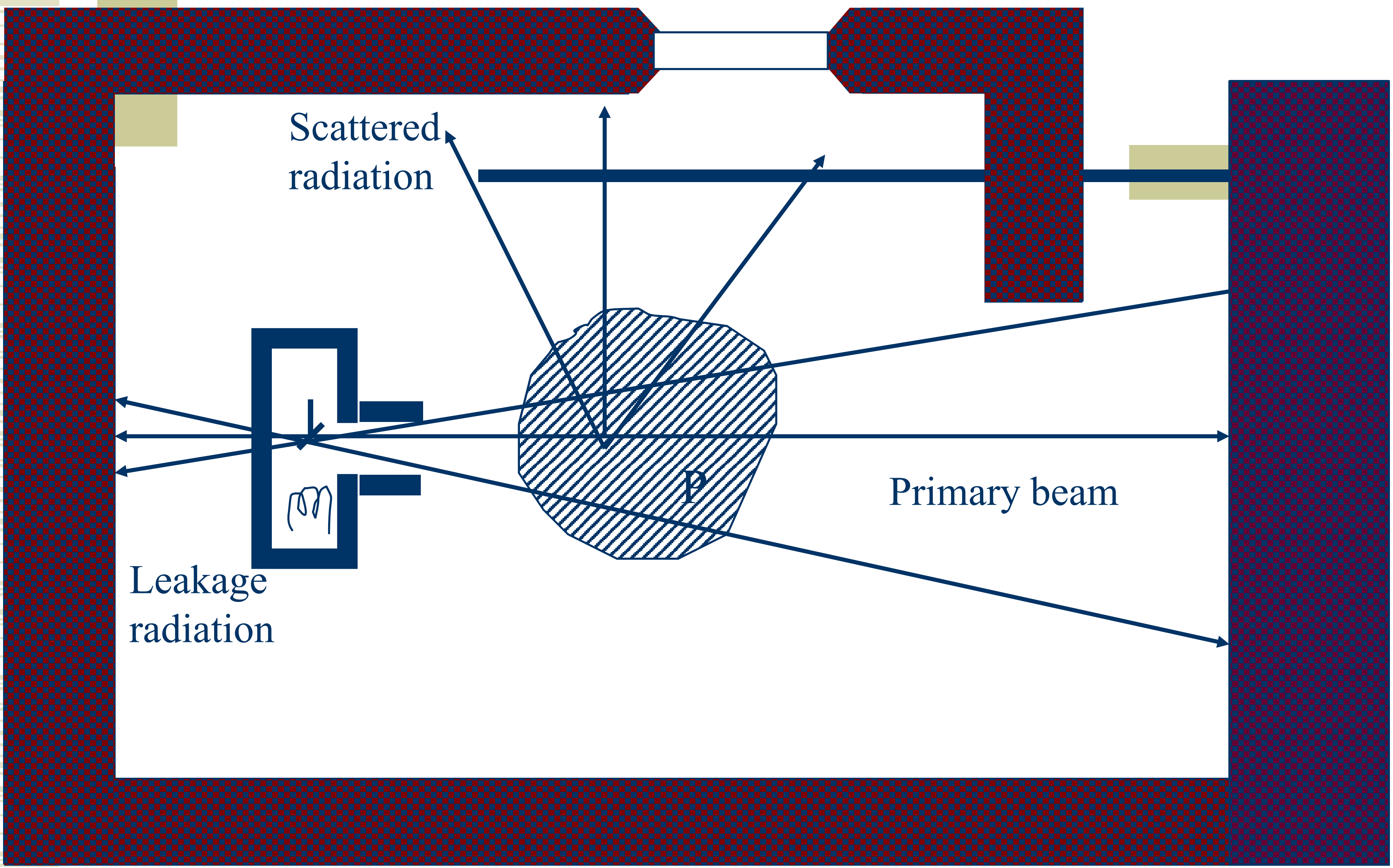
- The 1 mSv per year (0.02 mSv per week) is generally a reasonable shielding design goal for unrestricted areas

Design-goal limits

Regardless of modality, the objective of a shielding calculation is to determine the thickness of the barrier (lead shielding) that is sufficient to reduce the dose at the designated reference point in an occupied area to a value less than or equal to the weekly shielding design goal.

Design-goal limits

- The required barrier thickness corresponds to the value of the broad-beam transmission function B(x) yielding the design-goal dose limit
- B(x)= (the ratio of the dose behind a barrier of thickness x to the dose at the same location with no intervening barrier)


Scattered
radiation
P
Primary beam
Leakage
radiation

Lead shielding with up to 12mm for PET/CT scanner rooms, & ~ 18mm lead for uptake rooms

only 3mm lead or less for a CT scanner alone)

SPECT/CT facilities will not require shielding beyond that dictated by the CT scanner

Important considerations

- For pediatric patients, adequate attenuation correction can be obtained with very-low-dose CT (80 kVp, 5 mAs, 1.5:1 pitch), this leads to a 100-fold dose reduction relative to diagnostic CT.
- For adults undergoing CT with 5 mAs and 1.5:1 pitch, the tube voltage needs to be increased to 120 kVp to prevent under-correction of attenuation.

Radiation Protection Measures

- **Time**
- **Distance**
- **Shielding**

Time

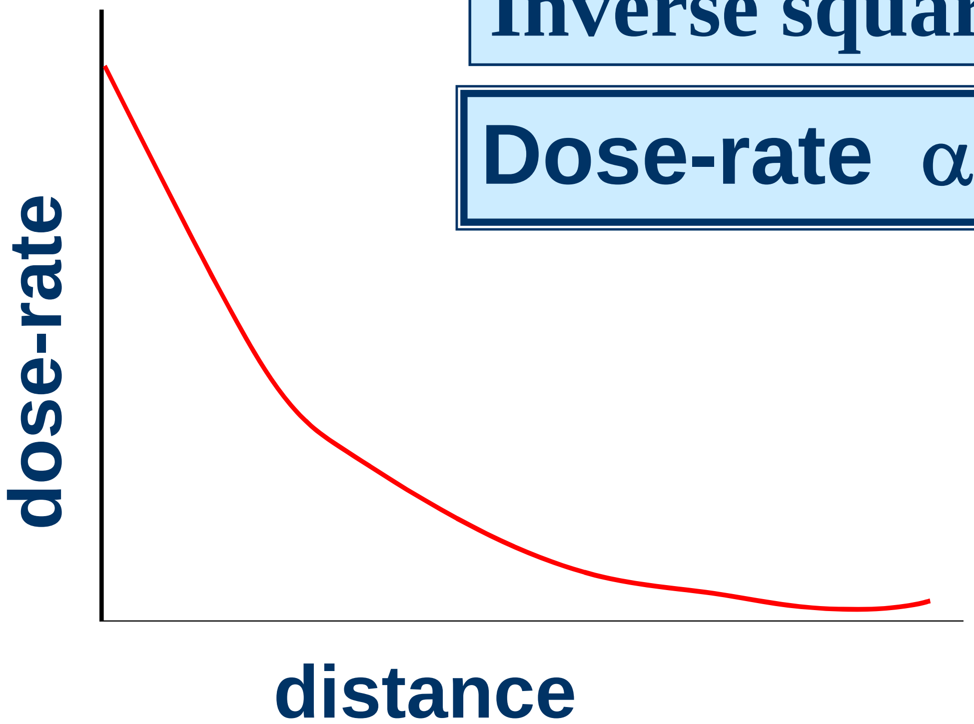
Dose is proportional to the time exposed

Dose = Dose-rate x Time

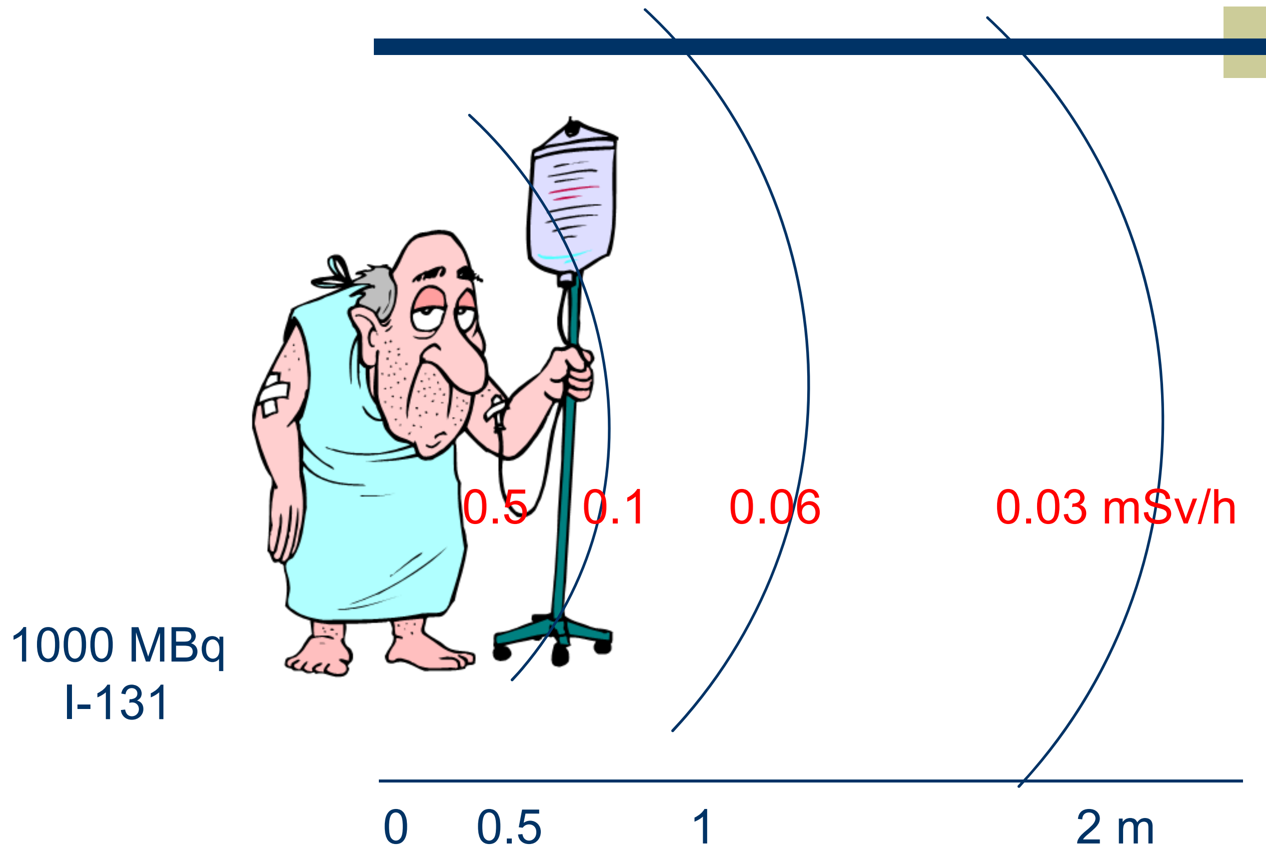
Distance

Inverse square law (ISL):

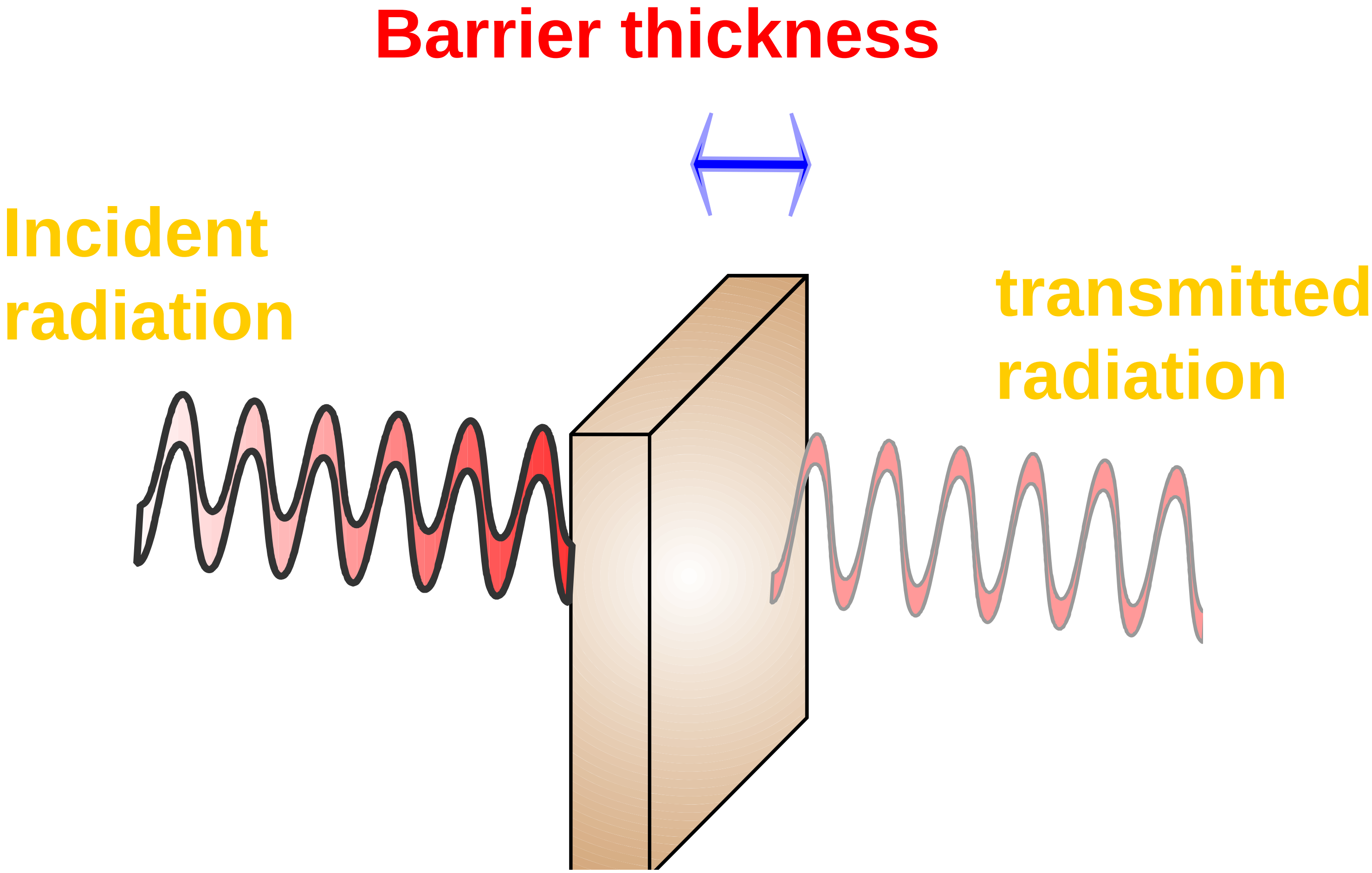
Dose-rate α $1/(\text{distance})^2$



Patient with iodine-131



Shielding


Barrier thickness
Incident radiation
transmitted radiation

Lead shield

Estimate the thickness of a lead container for 30 GBq of

Tc-99m. Dose rate at 1 m should be 2 μSv/h

Dose rate constant: 0.017 μSv/h&MBq

TVL: 0.9 mm lead

Dose rate for unshielded source: 0.017*30000 = 510 μSv/h

Reduce exposure 255 times which equals 2.4 TVL=

2.2 mm lead

Units of Absorbed Dose

Units not normalized by w_R	mGy	0.01	0.1	1	10	100	1,000	10,000
	rad=cGy	0.001	0.01	0.1	1	10	100	1,000
	Gy	0.00001	0.0001	0.001	0.01	0.1	1	10

Units of Effective Dose, Equivalent Dose, and Weighted Equivalent Dose

Units normalized by w_R	mSv	0.01	0.1	1	10	100	1,000	10,000
	rem =cSv	0.001	0.01	0.1	1	10	100	1,000
	Sv	0.00001	0.0001	0.001	0.01	0.1	1	10
# of Chest x-rays (PA)		0.5	5	50	500	5,000	50,000	500,000

- LD50: 5 Sv
- Average dose, atomic bomb survivors (RERF): 200 mSv
- Annual limit to radiation workers (10 CFR 20.1201): 50 mSv
- Dual isotope stress test: 29 mSv
- Sestamibi stress test or CTA with tube current modulation: 11 mSv
- Average US annual background radiation: 3 mSv
- Annual limit to general public from a licensed radiation operation (10 CFR 20.1301): 1 mSv
- Chest x-ray (lateral) or Dental x-rays (4 bitewing films): 0.04 mSv
- Roundtrip flight, New York-Los Angeles: 0.03 mSv
- Chest x-ray (single view, posteroanterior): 0.02 mSv

Thank you