Radiation effects, dosimetry and protection



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Quantitation of radiation effects: dosimetry

Absorbed dose: energy delivered to unit mass of medium, unit: Grey (Gy); 1 Gy=1 J/kg

Ionization is biologically harmful

Cells can be seriously impaired, depending on:

 (i) tissue exposed (proliferative cells are most sensitive)

(ii) absorbed dose
(iii) type of radiation
(iv) dose rate (longer time enables reccuperation)

Radiation impairs cells by ionizing vital mollecules, as DNA (direct effect), and by chemically altering intracellular water (indiret effect), giving rise to free radicals: H i OH.

Indirect effects are much more common and thus more important.

Radiation effects can be hereditary or somatic

Hereditary effects are due to impairment of reproductive cells, do not affect the person exposed, but her (his) offspring

Somatic effects affect only the person exposed to radiation

Biological radiation effects are also classified as stochastic (randomly occuring) and non-stochastic (regularly occuring)

Stochastic effects are due to mutation of cells. They have no threshold, i.e. may appear after minor exposure, however, with less probability than after large exposure (large absorbed dose). When they do apper, their seriousness does not depend on exposure. Non-stochastic effects follow large exposure,

inducing death of cells or permanent dammage, disabling cell division. They do have treshold (minor exposure cannot kill cells!) and their seriosness increase with absorbed dose. All non-stochastic effects are somatic (dead cells cannot play role in reproduction!)

Biological impairments of ionizing radiation, aside from absorbed dose (energy delivered), depend on type of radiation (mode of energy delivering)

Neutrons and alpha particles ionize very densely, producing more commonly the irreparable, multiple impairments of macromolecules than gamma rays or beta particles

Equivalent dose

Equivalent dose = QAbsorbed dose

Q is **quality factor**. For alpha particles, it equals 20, for neutrons from 5 to 20 (depending on energy), and for beta particles, X and gamma photons- 1

The unit for equivalent dose is Sievert (Sv)

► Old unit is **rem**

1 rem = 0.01 Sv

We are most irradiated by natural radioactivity sources

We are all constantly in the low intensity field of ionizing radiation from various sources (including our own tissues!). This is background radiation

Mostly, the radiation sources are natural

Minor degree of irradiation is due to artificial sources

95% of irradiation from artificial sources is due to medical diagnostics (radiotherapeutic exposure is not taken into account)

AVERAGE ANNUAL RADIATION EXPOSURE OF POPULATION

Natural sources : 80% • external sources cosmic rays around 0.3 mSv - 12.4% **Artificial sources: 20%** Medical purposes (therapy excluded) • N-tests radioactive fallouts • nuclear devices radioactive waste proffesional exposure various sources Total: <u>2.5 mSv</u>/person

around 2 mSv/person • *internal sources* ⁴⁰K, ²³⁸U, ²³³Th, ²²⁰Ra i ²²²Ra around 1.7 mSv - 67.6 %

around 0.5 mSv/person around 0.47 mSv - 18.5 %

oko 0.03 mSv - 1.5 %

Effective equivalent dose

Sensitivity to radiation exposure (radiosensitivity) is different in different tissues; to account for the part of body irradiated, to each body part one assigns the weight factor (wT) according to its specific radiosensitivity (the sum of all those factors equals 1):

 effective equivalent dose (Sv) =
 = Σ specific factor x equivalent dose; summing is over body parts irradiated

Specific organ radiosensitivities

	each W _T	group W _T
skin, bone surface	0,01	0,02
bile, liver, breast, esophagus, thyroid, other organs (except those below)	0,05	0,30
bone marrow, colon, lungs, stomach	0,12	0,48
gonads	0,20	0,20
total		1,0

Internal dosimetry

Assessment of absorbed doses due to radionuclides introduced into the body intentionally (diagnostics, therapy) or accidentally.

- Personal dosimetry vs. application of results for 'average' human.
- Methods: actual measurements or model-based calculations
- The results may not be accurate due to many unknowns

Given the absorbed doses (and the dose rate!) there is large uncertainty in individual (patho)physilogical (clinical) response (wanted or unwnated)

- Absorbed doses are estimated separately for particle (alpha and beta) and non-particle (X and gamma) radiation;
- In most cases both are present and the results are added.
- Distinguish: organ equivalent dose(s) and total body effective equivalent dose.
- It is important to report/note:
- 1. effective equivalent (body) dose
- 2. dose to target organ (organ aimed at diagnostically or therapeutically)
- 3. dose to critical organ (highest dose)
- 4. dose to gonads, bone marrow and eye lenses

Dose determinants

Equivalent dose (body parts) and effective equivalent dose (whole body) per unit of radioactivity introduced depend on:

1. biochemical properties of radiotracer and its components (radioindicator + tracer)

2. physical properties of radioindicator (modes, energies and tempo of decay)

3. admission route, stability of indicator-tracer binding, uniformity of radiotracer disribution (patient specific)

1. and 2. determine effective half-lives in various body parts

Particles

Basic assumption: only target organs are affected since all energy is locally absorbed.

energy absorbed = average energy of a particle x total number of dissintegrations ('cummulative activity')

Cummulative activity equals the product of organ specific mean life of a compaund and activity that entered the organ (organ uptake x total activity introduced)

In convenient units, the later translates to:

Dose (Gy) = 14 x mean particle energy (MeV) x cummulated activity (MBq/day)/ organ mass (g) Equivalent organ dose (Sv) = Dose (Gy) x Q

Organ mass is usually assessed with aid of diagnostic imaging

Cummulated activity can be assessed by follow-up of radiation intensity emanating from an organ (sequential extern measurements of count-rates)

X and y radiation

Other organs, aside from target organ are affected, depending on proximity to target organ and photon energy (energies).

Complex calculations are required; the shapes of targets and sources (the same organ is irradiation source for other organs as well as their target) and their relative positions are taken into account.

Except in case of pure gamma emitters, the dose due to nonparticle radiation is only a small part of total dose (the rest is due to particles). ^{99m}ITc

Absorbed doses in common procedures

Procedure	Radiotracer	Activity	Dose in critical organ (Gy) ^a	Dose in gonads (mGy)
Brain scintigraphy	pertechnetate	500 MBq (~ 15 mCi)	Intestines, 0.02	4
Liver scintigraphy	sulphor colloid	150 MBq (~ 4 mCi)	Liver, 0.02	0.85
Lung scintigraphy	macroaggregate	100 MBq (~ 3 mCi)	Lungs, 0.009	0.3
Bone scintigraphy	pyrophosphate	500 MBq (~ 15 mCi)	Bladder, 0.06	4
Renography	hyppuric acid	Bq (~ 200 μCi)	Bladder, 0.02	0.2
Thyroid function	sodium iodide	300 kBq (~ 8 μCi)	Thyroid, 0.08	0.6
Thyroid scintigraphy	pertechnetate	150 MBq (~ 4 mCi)	Intestines, 0.01	0.8

^a critical organ has the largest absorbed dose

Whole body counters

In case of accidental intake of radioactive material the unwanted radiation exposure can be assessed by whole body counter: gamma counter large enough to accomodate a whole person inside of it.

The devices aid in determing the type and quantity of radionculides introduced. These dana enable assessment of absorbed doses and expected clinical course.

> Pure alpha and β emitters can not be detected.

The deviices are very sensitive, but have low spatial resolution.

Risks of radiation exposure in nuclear medicine

There are no serious non-stohastic effects of radiation due to nuclear medicine diagnostic procedures (effective doses mostly in range 0.5-5 mSv; exception is test of accumulation of I-131)

Probablitiies of stohasic effects of lowdose exposures to radiation

Lethal malignoma	5 x 10 ⁻² Sv ⁻¹ (1 in 20)
Curable malignoma	1 x 10 ⁻² Sv ⁻¹ (1 in 100)
Serious inherited disease in offspring	1,3 x 10 ⁻² Sv ⁻¹ (1 in 77)

All numbers are per 1 Sv of effective low dose, on a single occassion, uniformly accross the body, in case of an avearge world inhabitant.

For example a single, uniformly distributed effective dose of 3 mSv is expected to induce lethal malignoma in 1/6667 persons

Lethal effective dose (LD 30/50): 50% die within 30 days



Monkey Dog Pig Donkey Cattle Rabbit Guinea pig Mouse Hen Frog **Golden fish** Turtle Snake Drosophilia Amoeba Infusoria

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"Small" doses

Up to 200 mGy for χ and γ radiation or 50 mGy for a particles and neutrons, received acutely, on a single occasion. In practice we mostly encounter the yearly irradiation up to 20 mSv.

There are no evidences that very small doses (couple of mGy) increase the risk of malignant diseases, but, to be on the safe side, we take it for granted that stohastic effects have no treshold.

Acute effects of radiation

1. Acute local radiation lesions



Lesions confied to smaller, superficial parts of body, due to accidental exposure to external radiation, mostly during professional activities



Erythema



Edema

Develops due to vasculitis after the dose over 10 Sv



Epidermatitis

Dry: dose treshold 5 Sv (lesion of basal skin layer)

Moist: dose treshold 15 Sv, occurs after 20 days latency (plasma transudation, vesicules...)



Necrosis

Doses over 25 Sv, develops after couple of weeks or months



Alopecia

Treshold is 3-4 Sv, above 7 Sv hair loss is permanent.

Skin effects

Effect	Single Dose (Gy)	Onset Time
Epilation	3 - 7	∼18 days
Erythema	10 - 20	12 - 17 days
Pigmentation	10 - 20	
Dry Desquamation	10 - 20	30 - 70 days
Moist Desquamation That Heals	20 - 24	30 - 50 days
Telangiectasia	17 - 24	6 mo - years
Nonhealing Necrosis	> 60	months, years

2. Acute radiation syndrome

Develops after dose over 1 Sv accross whole body or its major part. Results in halt of reproductive processes, abnormal cytokine secretion and cell death

Phases of Acute Radiation Syndrome

Acute Radiation Syndrome

Components of Radiation Effects:

 Prodromal
 Hematological
 Gastrointestinal
 Neurovascular
 50 Gay

Haematological response to 1 Gy whole body exposure to ionizing radiation.

Haematological response to 3 Gy whole body exposure to ionizing radiation.

Late effects of radiation

Chronic radiodermatitis

After long-term exposure to 10 Sv (but acutely under erythema treshold).

Cataract

External exposure to 2 Gy (acute) or 15 Gy (long term)

Malignant tumors

Firm evidences only after 1 Sv; effects of doses less than 0.1 Sv uncertain (although for protection purposes we assume no treshold, since a single mutated cell may induce carcinoma). Latencyaround 8 years (leukemia) and 15-20 years (solid tumors).

Genetic effects

The effects are usually not expressed in first generation offspring

Acute or chronic- depending on dose

Deformity/retardation in newborn infants

During 8-1week of gestation the treshold is low (0.1 Sv)

Chromosome abberations

Circulating lymphocytes are most sensitive

Legal maximal tolerated yearly doses

	professionals	populaation
Effective dose	20 mSv	1 mSv
Eye lenses equivalnet dose	150 mSv	15 mSv
Skin equivalent dose	500 mSv	50 mSv

Radiation protection principles

Main principles:

There are no apriori acceptable levels: ALARA principle: As Low As Reasonably Achievable

Exposure of many persons to small radiation doses can induce the same number of genetic lesions as exposure of few persons to large doses

Reduction of external irradiation

As short as possible

As far away as possible: most efficient (inverse squared distance rule)

Use of absorbers: not always efficient

Isotope	Half- value thickness lead (mm)	Half-values thickness water(cm)
I-131 (364 keV)	2,3	6,3
Tc-99m (140 keV)	0,28	4,5

1 cm of lead reduces Tc-99m radiation to $1/10^{12}$ but only to 1/12 in case of I-131

Reduction of internal exposure

Radionuclides may enter the body by ingestion, inhalation or through skin/skin lesions.

- Measures to reduce internal contamination should be strictly followed:
- -use of protective clothing, protective gloves, lead apron, lead glasses
- -the area with risk of contamination should be marked
- -radionuclide containers should be specified in terms of type, activity and date, etc.

The end!