

Radiation Units

Activity, absorbed dose and biologic dose

An applied pathology and medical-imaging lecture

Activity

Ci / Bq

Absorbed dose

Dr Abu Suraih Sakhri

MBBS, MD (Pathology)

www.abusuraisakhri.com

Biologic weighting

Sv / mSv

What the units must tell us

Identify whether a number describes radionuclide activity, deposited energy or radiation-weighted dose.

Convert correctly among Ci/Bq, Gy/cGy/rad and Sv/mSv/rem.

Explain why a reported absorbed dose cannot always be read as an effective dose.

Interpret common medical, environmental and radiation-protection examples.

Radiation measurement answers three different questions

SOURCE

How frequently do nuclear transformations occur?

Curie (Ci), becquerel (Bq)

TARGET

How much energy is absorbed per unit mass?

Gray (Gy), centigray (cGy)

BIOLOGIC WEIGHTING

How is radiation type and tissue distribution accounted for?

Sievert (Sv), millisievert (mSv)

A single word—“dose”—can conceal the quantity

Ambiguous

“The radiation dose was 5.”

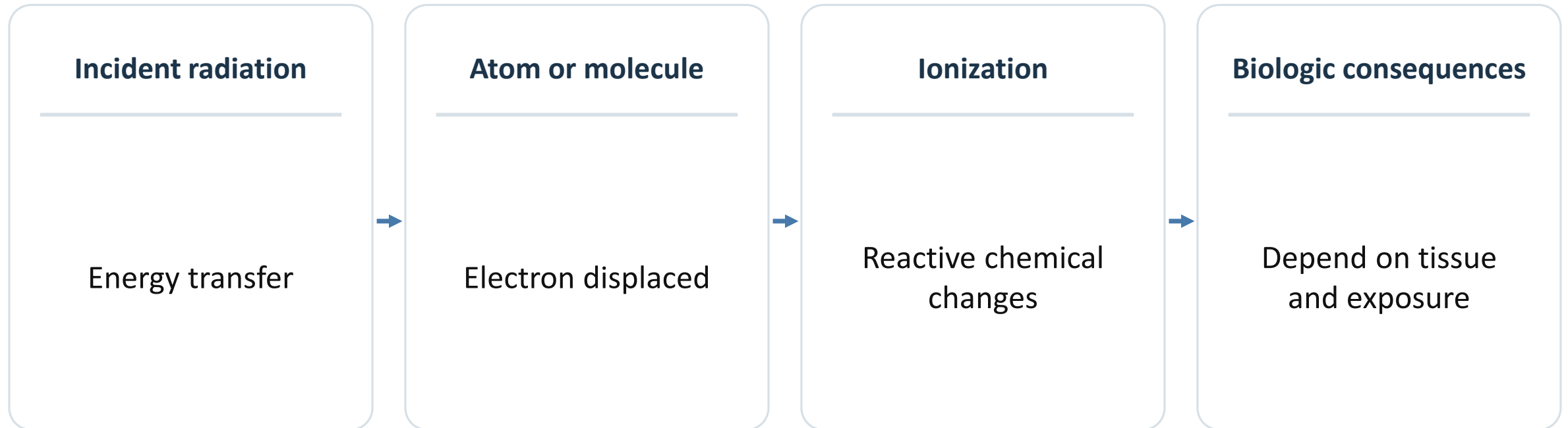
No unit, target tissue, radiation type or measurement context.

Informative

“The organ absorbed dose was 5 mGy.”

Quantity and unit identify deposited energy per mass.

Ionizing radiation removes bound electrons



Not every type of radiation is ionizing

Nonionizing

Insufficient photon/particle energy to eject tightly bound electrons.

Examples: Infrared, microwave and ultraviolet radiation.

Ionizing

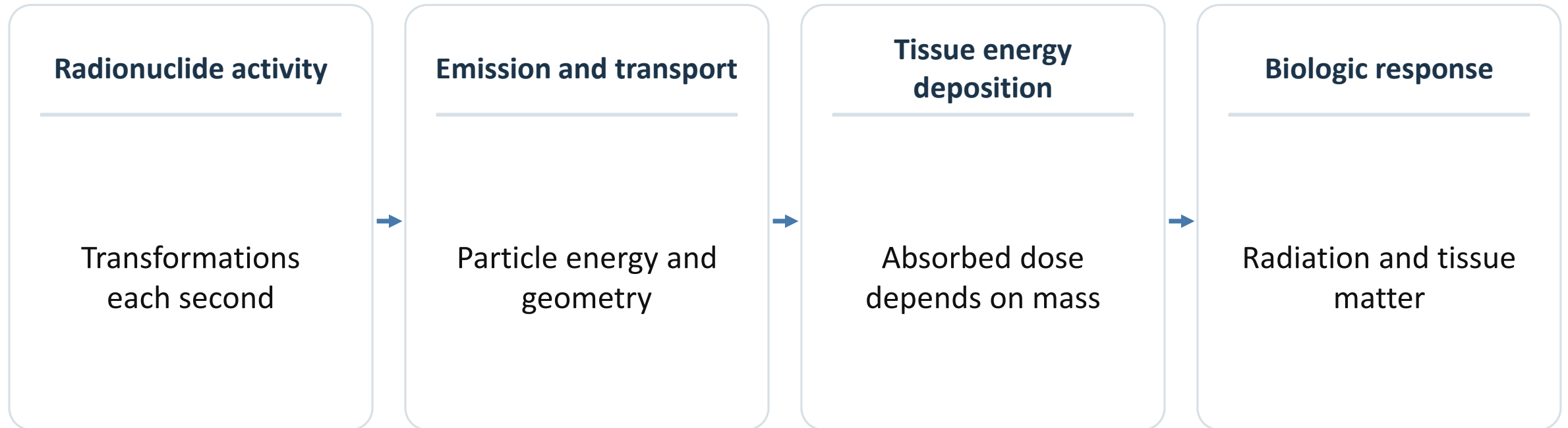
Sufficient energy to remove electrons and create ionization.

Examples: X-rays, gamma rays, alpha, beta and neutrons.

Radiation may be photons or particles

Category	Examples	Relevant distinction
Electromagnetic	X-rays; gamma rays	Penetrating photons; radiation weighting factor 1
Charged particles	Alpha; beta	Different ionization densities and penetration
Uncharged particles	Neutrons	Radiation weighting depends on neutron energy

The same source can generate different tissue doses



Curie measures radionuclide activity

1 Ci

3.7×10^{10} nuclear disintegrations per second

Activity is a property of the radioactive source—not a patient dose.

Activity is a rate, not a stored energy

A radionuclide has a probability of nuclear transformation over time.

Activity counts transformations per second in the source.

Decay may release radiation that does not reach or deposit energy in tissue.

Activity alone does not specify radiation energy, geometry or exposure duration.

Becquerel is the SI unit of activity

1 Bq = 1 nuclear transformation per second

$$1 \text{ Ci} = 3.7 \times 10^{10} \text{ Bq}$$

The SI definition expresses rate directly in reciprocal seconds.

Use prefixes to scale activity

Notation	Equivalent activity	Interpretation
1 kBq	10^3 Bq	One thousand transformations per second
1 MBq	10^6 Bq	One million transformations per second
1 GBq	10^9 Bq	One billion transformations per second

Activity conversion: 0.20 Ci

GIVEN / SETUP

$$0.20 \text{ Ci} \times 3.7 \times 10^{10} \text{ Bq/Ci}$$

RESULT

$$7.4 \times 10^9 \text{ Bq} = 7.4 \text{ GBq}$$

This is an activity conversion; It does not calculate absorbed dose.

Disintegrations do not equal absorbed joules

What activity supplies

How many nuclear transformations occur per unit time.

Bq and Ci

What dose requires

Energy deposited in a specified mass of tissue.

Gy and cGy

A dose calculation needs exposure context

Radionuclide / beam

Radiation type and
emission energies

1

Transport

Distance, shielding
and anatomy

2

Deposition

Energy reaching
target tissue

3

Target mass

Energy divided by
tissue mass

4

Two patients beside the same source

The source activity is unchanged. One patient is closer and remains exposed longer.

May we infer identical absorbed doses?

No. Dose also depends on exposure geometry, time, attenuation and absorbed energy.

Gray quantifies energy absorbed per unit mass

1 Gy

1 joule absorbed per kilogram of material

Gy is a physical absorbed-dose quantity; It does not itself encode radiation quality.

Absorbed dose is energy divided by mass

$$D = \varepsilon / m$$

$$[\text{J}] / [\text{kg}] = \text{Gy}$$

The symbol ε denotes the energy imparted; D denotes mean absorbed dose.

Why the denominator matters

1 joule in 1 kilogram

$$D = 1 \text{ J} / 1 \text{ kg} = 1 \text{ Gy}$$

Reference case

1 joule in 0.1 kilogram

$$D = 1 \text{ J} / 0.1 \text{ kg} = 10 \text{ Gy}$$

Same deposited energy; Tenfold smaller mass

Robbins expresses gray using ergs

$$1 \text{ Gy} = 10^4 \text{ erg per gram}$$

$$1 \text{ erg} = 10^{-7} \text{ J}$$

The energy unit changes; The underlying physical quantity does not.

Centigray is one hundredth of a gray

1 cGy

0.01 Gy = 100 erg/g

The centi- prefix means 10^{-2} , as it does in other SI units.

Practice: Centigray to gray

GIVEN / SETUP

$$250 \text{ cGy} \div 100$$

RESULT

$$2.50 \text{ Gy}$$

Convert units without changing the physical absorbed dose.

The historical absorbed-dose unit is the rad

$$\mathbf{1\ rad = 0.01\ Gy}$$

$$\mathbf{100\ rad = 1\ Gy = 100\ cGy}$$

The rad and gray quantify the same physical quantity with different unit scales.

Important correction to the extracted textbook text

The supplied Robbins Markdown states “1 cGy ... Equivalent to 100 Rad.”

The correct identity is $1 \text{ cGy} = 1 \text{ rad}$; $100 \text{ rad} = 1 \text{ Gy}$.

This follows from the textbook's own $1 \text{ Gy} = 10^4 \text{ erg/g}$ and $1 \text{ cGy} = 100 \text{ erg/g}$.

Do not confuse rad with roentgen

Rad

Absorbed dose in matter.

1 rad = 0.01 Gy; Normally lower-case unit symbol rad.

R (roentgen)

Historical exposure in air.

Not the abbreviation for absorbed-dose rad.

Legacy to SI unit map

Physical quantity	Legacy unit	SI unit	Unit relation
Source activity	curie (Ci)	becquerel (Bq)	$1 \text{ Ci} = 3.7 \times 10^{10} \text{ Bq}$
Absorbed dose	rad	gray (Gy)	$100 \text{ rad} = 1 \text{ Gy}$
Equivalent dose	rem	sievert (Sv)	$100 \text{ rem} = 1 \text{ Sv}$
Exposure in air	roentgen (R)	C/kg	$1 \text{ R} = 2.58 \times 10^{-4} \text{ C/kg}$

Absorbed dose in clinical radiotherapy

Prescribed physical dose is ordinarily expressed in Gy or cGy.

Dose is assigned to a target volume and the relevant normal tissues.

Tissue volume and dose distribution matter, not simply the largest displayed number.

Do not treat a radiotherapy Gy value as a whole-body effective dose in Sv.

A dose value must identify its target

PATIENT / TISSUE

Which anatomic volume absorbed the energy?

Organ, marrow, tumor or whole body

SPATIAL PATTERN

Uniform or highly localized deposition?

Organ average versus dose-volume distribution

DELIVERY

How rapidly and in how many exposures?

Dose rate and fractionation

Gray does not alone predict tissue injury

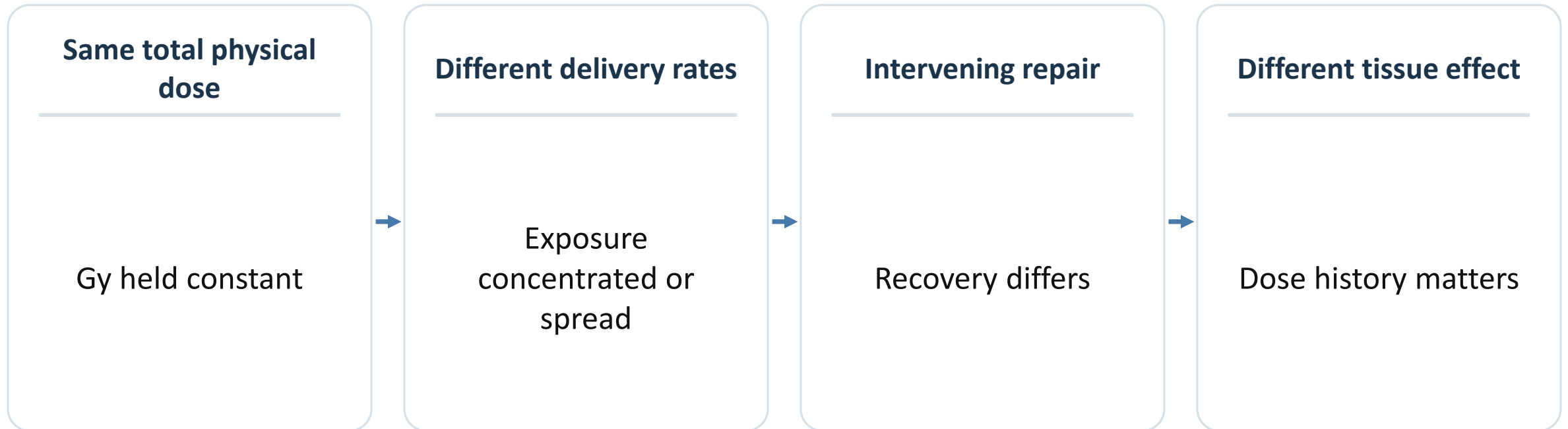
Radiation quality modifies damage at an equivalent absorbed dose.

Cell proliferative activity alters susceptibility to DNA damage.

Field size, dose rate, oxygenation and repair influence outcome.

Gy is essential but insufficient for full biologic interpretation.

Dose rate changes the opportunity for repair



Fractionation is not merely arithmetic

Single exposure

All prescribed physical dose delivered without planned recovery interval.

Limited time for inter-fraction repair.

Fractionated exposure

Physical dose delivered in separated fractions.

Normal-cell recovery can reduce cumulative injury.

Field size changes clinical consequences

Localized field

A relatively high local absorbed dose may be tolerated with shielding.

Limited volume exposed.

Large field / total body

Even a lower widespread dose can injure multiple vulnerable systems.

Widespread tissue exposure.

Rapidly dividing tissues are more vulnerable

DNA injury

Ionization / free radicals

Replication

Damage tested during division

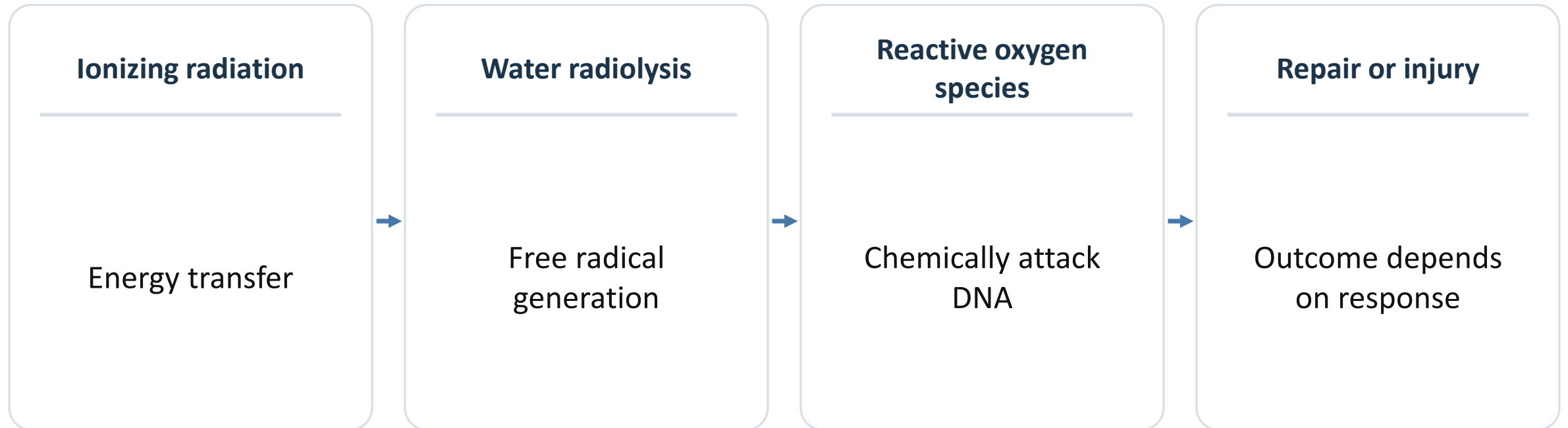
Cell loss

Marrow and mucosa especially vulnerable

Clinical effect

Depends on field and time

Radiation can damage DNA indirectly



High LET tracks concentrate ionization

Photons

More sparsely ionizing interactions along their tracks.

Radiation weighting factor = 1.

Alpha particles

Dense local energy deposition along short tracks.

Radiation weighting factor = 20.

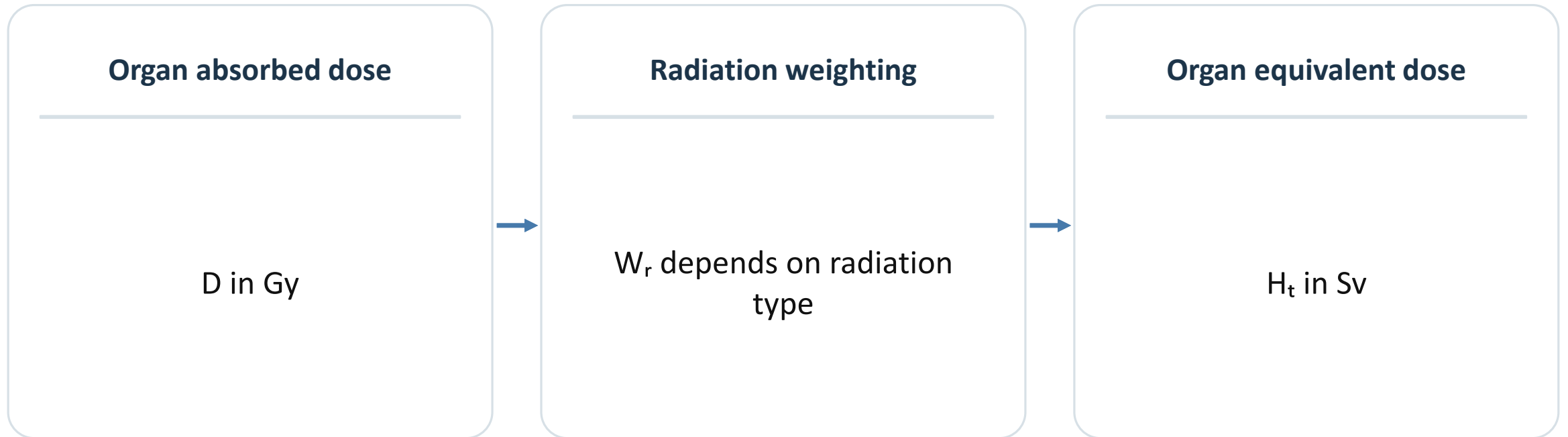
Sievert is a radiation-protection dose unit

1 Sv

A radiation-weighted quantity for biologic detriment

The name Sv is used for equivalent dose and effective dose; The quantities differ.

Equivalent dose weights radiation type



Radiation weighting factors are dimensionless

Radiation type	Radiation weighting factor (w_r)	Scope
X-rays / gamma rays	1	Photon radiation
Electrons / beta particles	1	Standard external electron radiation
Alpha particles	20	High-LET particles
Neutrons	Energy dependent	No single universal neutron factor

Equivalent dose: The formal definition

$$H_t = \sum_r (w_r \times D_{t,r})$$

Absorbed dose (Gy) × radiation weighting = equivalent dose (Sv)

For mixed radiation fields, sum each radiation-type contribution.

Worked example: X-ray dose to one organ

GIVEN / SETUP

$$2 \text{ mGy} \times w_r 1$$

RESULT

2 mSv equivalent dose to that organ

This does not establish a patient's whole-body effective dose.

Worked example: Alpha dose to one organ

GIVEN / SETUP

$$2 \text{ mGy} \times w_r 20$$

RESULT

40 mSv equivalent dose to that organ

The physical absorbed dose remains 2 mGy in both examples.

RBE and protection weighting are not synonyms

Relative biologic effectiveness (RBE)

Experimental ratio tied to a specified biological endpoint.

Can depend on radiation, endpoint, dose and context.

Radiation weighting factor (w_r)

Standardized factor adopted for radiological protection.

Based on RBE evidence; Not an individual tissue response measurement.

Use mSv and mGy with the correct qualifier

MGy

Physical absorbed dose in a specified tissue.

A measured or modeled energy-per-mass quantity.

MSv

Equivalent dose to an organ OR effective dose.

The surrounding words identify which quantity is reported.

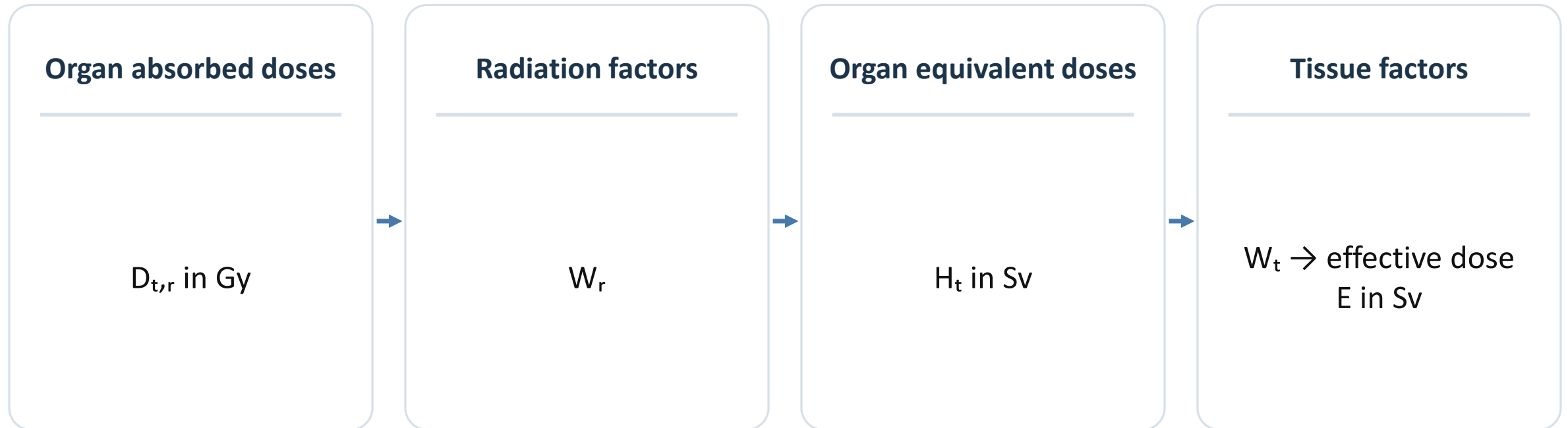
Rem is the historical equivalent-dose unit

$$1 \text{ rem} = 0.01 \text{ Sv}$$

$$1 \text{ Sv} = 100 \text{ rem}$$

Never convert rem to rad without specifying radiation weighting.

Effective dose additionally weights tissues



A tissue factor represents detriment weighting

Different organs contribute differently to aggregate stochastic radiation detriment.

ICRP assigns tissue weighting factors (w_t) in a reference-person framework.

Weighting is applied after radiation type has been accounted for.

These factors are not direct predictions for a particular patient.

Effective dose is a weighted sum

$$E = \sum_t (w_t \times H_t)$$

Equivalent dose by organ × tissue factor → whole-body detriment-related metric

E is principally a radiological-protection quantity; It is not an observed lesion.

ICRP tissue weighting is not uniform

Illustrative tissue	ICRP 103 w_t	Interpretation
Red bone marrow	0.12	Larger contribution to reference stochastic detriment
Thyroid	0.04	Smaller contribution than marrow
Skin	0.01	Smaller contribution than marrow

Example: Localized thyroid photon exposure

GIVEN / SETUP

$$10 \text{ mGy thyroid} \times w_r 1 \times w_t 0.04$$

RESULT

0.4 mSv contribution to effective dose

Hypothetical simplified case: All other organ contributions set to zero.

Equivalent and effective dose are distinct

Equivalent dose, H_t

Refers to a specified tissue or organ.

Weights absorbed dose by radiation type.

Effective dose, E

Reference-person aggregate across tissues.

Also weights tissue contributions to stochastic detriment.

Medical-imaging reports often quote effective dose

Diagnostic radiography and CT summaries commonly use mSv for effective dose.

This is not interchangeable with absorbed dose to skin, marrow or an imaged organ.

Imaging geometry and organ exposure distribution affect effective-dose estimates.

Effective dose is useful for broad procedure comparisons, not individual cancer-risk prediction.

The “1 mSv = 1 mGy” shortcut has a limit

For photons, $w_r = 1$: 1 mGy organ absorbed dose corresponds numerically to 1 mSv organ equivalent dose.

This does NOT imply 1 mGy to one organ equals 1 mSv whole-body effective dose.

The mSv unit alone does not tell us whether H_t or E is intended.

Local dose and population metric are not substitutes

Local absorbed dose (Gy)

Useful for assessing energy deposited in tumor and normal tissue.

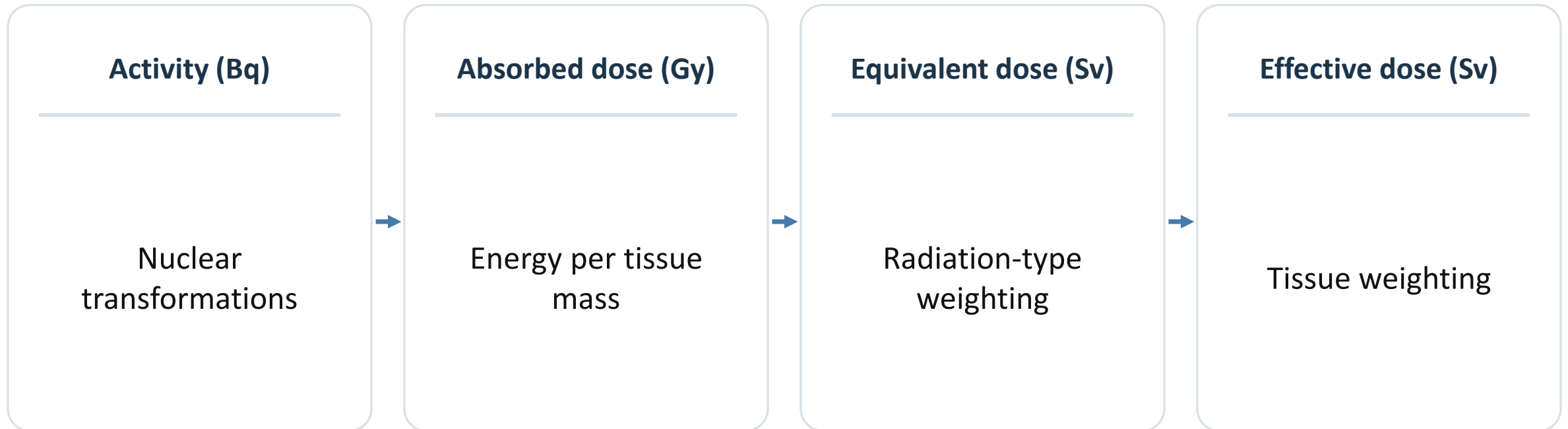
Depends on spatial distribution and tissue reactions.

Effective dose (Sv)

Useful for broad radiation-protection comparisons.

Reference model of stochastic detriment; Not a treatment-planning prescription.

The measurement chain has distinct transitions



Choose a unit by asking what is quantified

Source

Transformations
per second → Bq /
Ci

Tissue energy

Deposited joules
per kilogram → Gy
/ cGy

Radiation quality

Organ weighted
dose → Sv / mSv

Overall detriment

Tissue-weighted
effective dose → Sv
/ mSv

Consolidated radiation-unit comparison

Quantity	SI unit	What is being quantified
Activity	Bq	Radionuclide transformations per second
Absorbed dose	Gy	Deposited energy per kilogram
Equivalent dose	Sv	Absorbed dose weighted by radiation type
Effective dose	Sv	Equivalent doses weighted across tissues

Case: A radioisotope is labeled “5 MBq”

The isotope vial bears an activity label of 5 MBq.

Can that number tell you the organ dose in mGy?

No. It specifies transformations per second; Patient dosimetry also needs the nuclide, uptake, time and energy deposition.

Case: A treatment field records 250 cGy

The treatment sheet gives a local absorbed dose of 250 cGy.

Express this dose in Gy and rad.

$250 \text{ cGy} = 2.5 \text{ Gy} = 250 \text{ rad}$; All express the same physical dose.

Case: A legacy chart records 175 rad

An older radiotherapy record specifies 175 rad.

What absorbed dose is represented in SI units?

$$175 \text{ rad} \times 0.01 \text{ Gy/rad} = 1.75 \text{ Gy} = 175 \text{ cGy}.$$

Case: A photon organ dose is 2 mGy

Photons deposit 2 mGy in a defined organ, with radiation factor $w_r = 1$.

State the equivalent dose and whether this equals the effective dose.

Organ $H_t = 2$ mSv. E cannot be concluded without organ distribution and tissue weighting.

Case: Alpha and photon doses in one organ

GIVEN / SETUP

$$(1 \text{ mGy alpha} \times 20) + (2 \text{ mGy photons} \times 1)$$

RESULT

22 mSv organ equivalent dose

The absorbed-dose total is 3 mGy, which is not 22 mGy.

Case: Same effective dose, different organ doses

Two different imaging examinations are summarized by the same effective dose in mSv.

Do they necessarily give identical absorbed dose to each organ?

No. A common weighted aggregate can arise from different organ-dose distributions.

Dose magnitude and time cannot be conflated

Dose

An accumulated physical quantity.

Examples: 2 Gy, 5 mSv effective dose.

Dose rate

How quickly dose accumulates.

Examples: Gy/h, mSv/h; The rate needs time integration.

Five recurrent errors in radiation-dose reading

Calling activity (Ci or Bq) the patient absorbed dose.

Confusing rad with roentgen (R).

Reading Gy as though it included radiation or tissue weighting.

Interchanging organ equivalent dose and effective dose because both use Sv.

Applying the photon $\text{mGy} \leftrightarrow \text{mSv}$ numerical shortcut to all imaging situations.

Unit literacy supports defensible clinical interpretation

START WITH THE QUANTITY

Activity, absorbed, equivalent
or effective?

Never infer meaning from a number
alone.

PRESERVE THE TARGET

Source, organ, field or
reference person?

Specify anatomy and exposure
geometry.

STATE THE LIMIT

What the metric does not
establish

A single unit never describes the full
biologic response.

Selected sources for further reading

Robbins, Cotran & Kumar: Pathologic Basis of Disease, 11th ed., Chapter 9, “Radiation Units” and adjacent ionizing-radiation sections.

International Commission on Radiological Protection. ICRP Publication 103: The 2007 Recommendations.

ICRP Publication 92: RBE, Quality Factor, and Radiation Weighting Factor; ICRP Publication 147: Use of Dose Quantities.

International Atomic Energy Agency: radiation-dose and unit conversion guidance (including Gy, rad, Sv, rem, Ci, Bq).