Physics eReference Units and safety of nuclear radiation

A. Summary of radioactivity units

Definition	**SI unit**	**cgs unit (obsolete)**
Activity, A , Number of disintegrations per second	1 becquerel (Bq) ≡ 1 disintegrations s^{-1}	1 curie (Ci) ≡ $37x10^{9}$ disintegrations s^{-1}
Conversion	1 Bq ≡ 2.7 $x10^{-11}$ Ci	1 Ci ≡ $37x10^{9}$ Bq
Ionizing radiation exposure The amount of radiation required to generate unit charge in unit mass (SI unit) or unit volume (cgs unit) of dry air at STP	1 C kg^{-1} of air	1 roentgen (R) ≡ 1 esu cm^{-3} of air
Conversion	1 C kg^{-1} = 3876 R	1 R = 2.58 $x10^{-4}$ C kg^{-1}
Radiation (absorbed) dose, D Radiation energy absorbed / unit mass	1 gray (Gy) ≡ 1 J kg^{-1}	1 rad (rad) ≡ 100 ergs g^{-1}
Conversion	1 Gy = 100 rad	1 rad = 0.01 Gy
Equivalent dose $D \times W_R = H$, where W_R is the radiation type weight factor	1 sievert (Sv) ≡ 1 J kg^{-1}	1 rem (rem) ≡ 100 ergs g^{-1}
Conversion (for β- or γ-radiation)	1 Sv = 100 rem	1 rem = 0.01 Sv
Effective dose Weighted average of equivalent dose = $\Sigma_i D_i \times W_{Ri} \times W_{Ti}$ = $\Sigma_i H_i \times W_{Ti}$, where W_{Ti} is the tissue/organ weighting factor	in Sv	in rem

B. Summary of weighting factors

Weighting factor	**Radiation type**	**Tissue / organ**		
Radiation type, W_R	γ-ray (photons) , β-ray (electrons), muons		1	
	Protons, charged pions		2	
	α-ray, fission fragments, heavy ions		20	
	Neutrons		A function of neutron energy	
Tissue, W_T		Bone marrow (red), colon, lung, stomach, breast, remainder tissues	0.12 (each)	Total for a body = 1
		Gonads	0.08 (each)	
		Bladder, liver, esophagus , thyroid	0.04 (each)	
		Skin, bone surface, salivary, glands, skin	0.01 (each)	

C. Radiological protection and Safety

Effective dose	Event	Effects	Remarks
20 Sv	Sudden, accidental, unwanted exposure	Central nervous system (CNS) damaged, death within hrs	fatal
10 Sv		Gastrointestinal tract (GI) damaged, death with days	
5 Sv		Bone marrow failure, death with weeks	
1 Sv		Blood count depression	may recover
0.1 Sv = 100 mSv per year			Risks are very low for dose values below. No observable harmful effects on humans.
15-20 mSv per year	Cigarette smoking (1 pack per day)		
20 mSv per year			Maximum annual effective dose for a person employed in radiation work
2-3 mSv per year	Annual effective dose from background, including: 0.25-0.35 mSv (cosmic ray) 0.4 mSv (food) 2 mSv (radon in household)		
1 mSv per year			Maximum annual effective dose for a public member
0.4 mSv	X-ray diagnosis		
0.01 mSv	1000 mile flight trip		

D. Examples

Example 1 There is a survey meter in a lab configured to show nuclear radiation intensity in the unit of Roentgen (R). However, it is more concerned to get reading in Sv. It is known that (i) one gram of air absorbs 87 ergs of energy, and (ii) one gram of soft tissue absorbs 96 ergs of energy to produces an exposure of one R. This is valid for γ-radiation with energies from 0.1 MeV to 3 MeV.

(a) Explain why rad and R are interchangeable.

(b) Propose an approximate conversion relationship between R and Sv.

Solution

(a) γ-ray of 96 ergs $\approx$ 100 ergs makes 1 gram of issue absorbs to give 1 R. On the other hand, 1 rad of absorbed dose is defined as absorption of radiation energy of 100 ergs per gram. Hence 1 rad and 1 R are interchangeable.

(b) 1 rad = 1 rem (for γ-ray with $W_R = 1$) = 0.01 Sv. Hence 1 R $\approx$ 0.01 Sv. For example, a reading of 2 R is converted into 20 mSv.

Note: 1 R is absorption of 258 μC kg^{-1}. There are 2.58×10^{-4} C/electron charge = 2.58×10^{-4} / e ionized air molecules. Ionization energy of an air molecule = 34 eV. Ionization energy absorbed in 1 kg of material is $(2.58 \times 10^{-4}$ /e) x (34 e) (J kg^{-1}) = 0.00877 (J kg^{-1}) = 87.7 erg g^{-1}.

Example 2 The radiation background in our lab is 0.02 mR hr^{-1}. Compare the value with the annual upper limit.

Solution

Background radiation is 0.02 mR hr^{-1} $\approx$ 0.02×0.01 mSv hr^{-1} = 0.2 μSv hr^{-1} = 1.75 mSv annually $\approx$ the average background (2.65 - 2.75 mSv per year); larger than the upper limit of 1 mSv annually.

Example 3 The reading shown by a detector placed almost in touch with a lantern mantle specimen is 2.5 mR hr^{-1}. Estimate the potential danger.

Solution

The radiation dose is 2.5 mR hr^{-1} = 0.025 mSv hr^{-1}. If one holds the source with his/her bare hand, it takes 40 hrs to reach the exposure of 1 mSv (for a pubic member in 1 year); 800 hrs to reach the threshold of 20 mSv (for a related worker in 1 year), even longer by keeping a farther distance, or tissue weighting factor is taken into account.

Importantly, one must avoid swallow or inhale any detachment (may contain radioactive powder e.g. thorium dioxide) from the mantle. Never touch it with bare hands. Wash hands after using it.