Physics eReference: Units and safety of nuclear radiation

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A. Summary of radioactivity units [Ref. 1]

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 Coulomb (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		Function of neutron energy	
Tissue, W_T		Bone marrow (red), colon, lung, stomach, breast	0.12 (each)	Total for a body =
		Gonads	0.08 (each)	

		Bladder, liver, esophagus, thyroid	0.04 (each)	1
		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 (胃腸) tract (GI) damaged, death within days	
5 Sv		Bone marrow failure, death within 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.
20 mSv per year			Maximum annual effective dose for a person employed in radiation work
15-20 mSv per year	Cigarette smoking (1 pack per day)		
6.9 mSv (1 time)	CT scan		
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. Safety of Food – effective dose coefficient, i.e. the value in mSv corresponding to 1 Bq

	Effective dose coefficients (Baby)	Effective dose coefficients (Adult)
Iodine 131	0.00014	0.000016
Cesium 137	0.000021	0.000013
Plutonium 239	0.0042	0.00025

E. Examples

Example 1 A survey meter is configured to show nuclear radiation intensity in Roentgen (R), but in many cases, reading in Sv is more concerned for the assessment of safety. If it is known that one gram of soft tissue absorbs 96 ergs of energy to produce an exposure of 1 R (valid for γ-radiation with energies in the range of 0.1 - 3 MeV), explain why [Ref. 1]

(a) rad and R are approximately interchangeable;

(b) hence, show that 1 R is approximately 0.01 Sv.

Solution

(a) γ-ray of 96 ergs ($\approx$ 100 ergs) is absorbed by 1 gram of soft tissue to give 1 R.
On the other hand, absorption of 100 ergs radiation energy by 1 gram of material is defined as 1 rad.
Hence 1 rad $\approx$ 1 R.

(b) For γ-ray with $W_R = 1$, 1 rad is exactly equal to 1 rem. Further, 1 rem = 0.01 Sv. Hence 1 R $\approx$ 0.01 Sv.

Example 2 A radiation detector shows a reading of 0.02 mR hr^{-1} in the lab without any radioactive source. How does it compare with the average background radiation?

Solution

0.02 mR hr^{-1} $\approx$ 0.02×0.01 mSv hr^{-1} = 0.2 μSv hr^{-1} = 1.75 mSv per year. It is around the average background radiation of 2.65 - 2.75 mSv per year.

Example 3 A radiation detector placed close to a lantern mantle specimen shows a reading of 2.5 mR hr^{-1}. Estimate the potential danger.

Solution

2.5 mR hr^{-1} = 0.025 mSv hr^{-1}. If one holds the mantle with bare hand, 40 hrs is required for the accumulated dosage to reach the maximum annual tolerable exposure of 1 mSv; or 800 hrs to reach the maximum annual tolerable exposure of 20 mV for a person employed in radiation work. The situation is safe because the risk is greatly reduced by keeping a distance from the source, and the tissue weighting factor is low. However, one must not swallow or inhale any detachment from the mantle; do not touch it with bare hands; and wash hands after using it.

Example 4

Spinach contains 10000 Bq/kg iodine-131. An adult eats spinach 20 g per day. Estimate the value of 1-year effective dose.

Solution

One-year effective dose = 10000 Bq/kg × 0.02 kg × 365 days × 0.000016 = 1.2 mSv/year.

Example 5

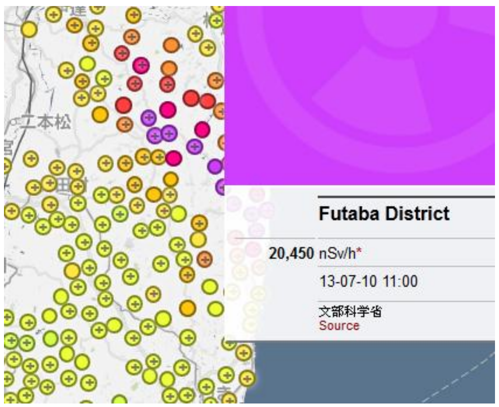
From Ref.2, find the radiation dose at (a) Futaba District and (b) Minamiaisu District in Japan on a recent day, and evaluate the risk of travelling in these two places.

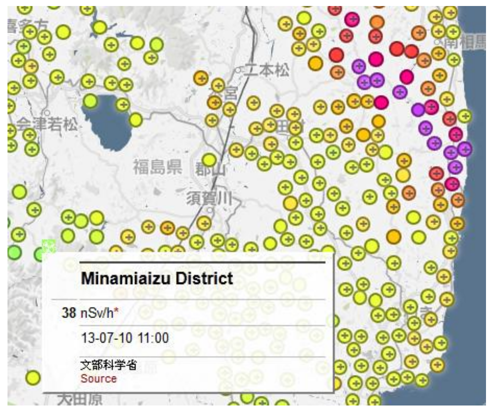
Solution

On 13 July, 2013 at 11:00 am

(a) The radiation dose detected at Futaba is 20450 nSv/hr = 0.02045 mSv/hr. A person at that location will receive the maximum annual effective dose of 1 mSv in ≈ 2 days; or the dangerous threshold of 1 Sv in ≈ 5.5 years.

(b) The radiation dose detected at Minamiaisu District is 38 nSv/hr = 3.8×10^{-5} mSv/hr = 0.33 mSv/year. It is lower than the maximum annual effective dose of 1 mSv, and hence the risk to health from radiation is very low.





Example 6 From Ref. 3, it is known that Hong Kong adopts the international standards in the Guidelines Levels for Radionuclides in Food following Accidental Nuclear Contamination, laid down by the Codex Alimentarius Commission, in testing the radiation levels of food. The most relevant radionuclides include I-131 (100 Bq/kg), Cs-134 and Cs-137 (1,000 Bq/kg). Please evaluate how these criteria are associated with the risk of radiation to health.

Solutions Answer

Foods are detected to contain Cs-137, Radiation intensity 1000 Bq/kg. Radiation dose =1000 Bq/kg × 0.000013 = 0.013 mSv. If daily consumption of the foods is 0.5 kg, effective doses per year = 0.013 mSv × 0.5 kg × 365 = 2.37 mSv per year, which is still within the acceptable range.

References

1. An excellent document describing radiation units and their conversions. "Radiation Safety Guide, Appendix E: Roentgens, RADs, REMs, and other Units", Princeton University, http://web.princeton.edu/sites/ehs/radsafeguide/rsg_app_d.htm.
2. A website showing real-time radiation levels at different places in Japan, http://jciv.iidj.net/map/.
3. The Centre for Food Safety of HKSAR, http://www.cfs.gov.hk/tc_chi/programme/programme_rafs/programme_rafs_fc_01_30_Q&A_3.html .

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