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Some notions and units in radioepidemiology and radiation protection
A structured list for the epidemiologist

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Radiation risk assessment is a vast field in which different disciplines participate: physics, experimental biology, medicine, epidemiology, and radiation protection. Each of these disciplines has developed its terminology according to its needs. When reading the literature the uninitiated can barely differentiate between results of epidemiological research and risk definitions for the purpose of radiation protection. It is of paramount importance to discriminate between measured risks and projected risks.
The mentioned difficulties are partly due to the loose use of terminologies. As a first aid for understanding, this annotated list intends to clarify the delineations between physics, radiation biology, epidemiology, and radiation protection. In developing this list we have profited from glossaries and definitions in the literature[1–7].

1. Some notions used in radiation biology and protection

Dosimetry: assessment of absorbed dose

The word "dosimetry" is being used in different senses, spanning from measurement in physics to dosimetric argumentations in risk estimation. Regarding the radiation burden from environmental radioactivity, Fry[8] has epitomized the difficulties of dose estimation in the paradox: "The quantity we cannot measure is the one that we require: dose". In the following, different uses of "dosimetry" have been arranged in the order of their decreasing accuracy in quantifying dose:

in radiotherapy, X-ray-diagnostics, and nuclear medicine
  measured in phantoms or patients, or calculated;
personal dosimetry (usually occupational)
  dosemeters (e.g. thermoluminescence) for external radiation;
  determination of doses from incorporated radionuclides;
"individual" reconstruction
  for atomic bomb survivors;
  retrospective reconstruction in phantoms, e.g. breast doses after fluoroscopy;
  estimated by biokinetic (and morphometric) models for radionuclides;
collective reconstruction for individuals
  radioactivity in mines (location and duration of work);
  domestic radon exposure;
collective dose estimation for radiation protection purposes
  radioactivity in food, calculated on metabolic average models (ICRP);
collective dose estimation in epidemiology (without dosimetry)
  regions with nuclear tests or fallout;
  risks by occupation.

LET: linear energy transfer
Average amount of energy lost per unit track length (keV/μm).

RBE: relative biological effectiveness: D_r/D_{test}
Ratio of absorbed doses giving the same effect in a biological system (e.g. same number of transformation foci in cultured cells).
Obtained by experiment, and dependent on biological system, dose etc.
D_r = absorbed dose of reference radiation, low-LET (generally 250 kV X-ray).

Q: quality factor
A LET-dependent factor by which absorbed doses of different LETs are multiplied to obtain a "corrected" dose (dose equivalent) which corresponds more closely to the dose of X- or low energy gamma rays producing the same biological effect,
e.g. $Q = 20$ for alpha-radiation;
$Q = 1$ for 250 kV X-rays.

Qs are set for radiation protection purposes,
are only defined for stochastic effects,
do not take into account the dose and dose rate reduction.
ICRP plans to replace them by radiation weighting factors w_R.

DDREF: Dose and dose rate reduction factor
"A factor by which the effect caused by a specific dose changes at low doses/dose rates as compared to high doses/dose rates".
Only applicable to low-LET radiation.

Relatively lower effects of low doses have been shown in most experimental systems. Measured DDREFs have been observed in the range between 1 (no reduction!) and 10.
Dose/dose rate reduction has also been suggested by human epidemiology,
e.g. human leukemia according to BEIR V[3],
lung cancer after fluoroscopies[9].
The DDREF is taken into account in risk estimations based on linear-quadratic models.

ICRP 1990[5] intends to introduce a general DDREF of 2 into radiation protection.

2. Physical units

Radioactivity
Becquerel 1 Bq = 1 decay/sec
Curie 1 Ci = 3.7×10^{10} Bq

The intake of radioactivity has to be known for estimating internal doses. The relation to dose depends, in addition, on the mode of decay (α, β, γ), energy of decay, physical half-life, and metabolism of the radioactive nuclide.

Kinetic energy released in material (Kerma, K)
1 Gy (Gray) = 1 J/kg (Joule/kilogram) = 100 rad
Kinetic energy transferred to charged particles by uncharged particles (neutrons, high energy photons) per unit mass. Used in the epidemiology of atomic bomb survivors.

Absorbed dose (D)
1 Gy = 1 J/kg = 100 rad
The mean energy imparted by ionizing radiation to an irradiated medium, per unit mass.

In atomic bomb survivors related to kerma by organ-specific transmission factors ([3], p. 195).

Working level month (WLM)
A quantity generally used in epidemiological studies of miners.
1 WLM = 1 working month (170 h)
in 1 working level of radon daughters.
1 WL (working level) = any combination of short-lived Rn-daughters in equilibrium in 1 liter of air that results in the ultimate release of 1.3×10^5 MeV alpha energy[1,2,6].
WLMs cannot directly be converted into absorbed doses which also depend on:
characteristics of inhaled air aerosol,
breathing pattern,
characteristics of lung (mucus thickness and clearance, morphometric models of target cells),
duration of exposure (domestic vs. work).

3. "Biological units"

not measured; defined only for radiation protection purposes, for low doses or low dose rates.

Dose equivalent (H)
Sv (Sievert) 1 Sv = 100 rem
D × Q. Sv has the dimension J/kg.
Absorbed dose multiplied by the quality factor,
used for organ doses or whole body doses.
The term "equivalent" indicates that equivalence between the effects of high- and low-LET radiation has been introduced by the use of Q.

100 rems defined before 1977 are not necessarily equal to 1 Sv today.

Effective dose equivalent (H_E)
Sv (Sievert) 1 Sv = 100 rem
Weighted sum of the dose equivalents for the different organs/tissues, providing a single summary value which corresponds to a theoretical dose delivered to the whole body conferring the same risk; used as weighted index of harm for radiation protection purposes.

Weighting factors for the different organs/tissues have been defined by ICRP in 1977[4] based on epidemiologic and biological data for cancer and genetic effects. They have been revised by ICRP 1990[5].
Conventions on incurred risk are thus built in twofold:
- Q or w_R;
- tissue weighting factors w_T.

ICRP 1990 also uses a new terminology: Effective dose (E)

4. Two types of risk assessment: observed vs. projected

observed risks
risk estimates from epidemiologic studies, calculated as:
relative risk
RR at 1 Gray *or*
excess risk per Gray (RR at 1 Gray minus one);
absolute excess risk per Gray and person-years,
usually given as excess cases/10.000 PYGy (person-years × Gray)

"lifetime risk" (projected risks)
estimation of numbers of cancers due to radiation over the whole life span:
dependent
– *on* observed risks, *but also*
– *on* risk estimation model
– absolute, time constant
– relative (time constant or time dependent);

- *on* baseline cancer rates in source population
  (i.e. the general population to which the study collective(s) belong from which the observed radiogenic cancers have emerged);
- *on* characteristics of population to which risk-projection is done
  - age-composition
  - life-table (baseline general mortality by age)
  - age-specific baseline cancer mortality rates

A discussion of the methodologies involved in calculating projected risks is given by S. Darby et al.[10].

Summary

An annotated list of some notions and units used in radioepidemiology is presented, with special emphasis on differentiating between the realms of radiation physics, radiation biology, radioepidemiology and radiation protection.

Résumé

Quelques concepts et unités utilisés en radio-épidémiologie et dans la radio-protection
Cet article présente une liste commentée de quelques concepts et unités d'usage courant en radio-épidémiologie; une attention particulière est accordée au sens propre des termes dans les disciplines concernées, telles la physique des radiations, la biologie des radiations, la radio-épidémiologie, la protection contre les radiations.

Zusammenfassung

Begriffe und Einheiten in Strahlenbiologie, -epidemiologie und -schutz
Diese kommentierte Liste einiger Begriffe und Masszahlen soll das Sich-Einlesen in Arbeiten aus Strahlenepidemiologie und Strahlenschutz erleichtern, indem Bedeutung und Begriffsbereich der verwendeten Begriffe aus den Disziplinen Strahlenphysik, -biologie, -epidemiologie und -schutz kurz charakterisiert werden.

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