Current Approach to Radiation Quality Specification in Radiation Protection

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INTERNATIONAL COMMISSION ON RADIOLOGICAL PROTECTION

Modern radiation protection is based on the principles (ICRP Publication 26) :

- **Principle of justification:**

  No practice shall be adopted unless it produces a **net benefit**

- **Principle of optimisation**

  All exposures shall be **As Low As Reasonably Achievable**, economic and social factors taken into account

- **Principle of limitation**

  Doses to individuals shall not exceed **limits**

Assessment of radiation risks for individuals
(or groups of individuals)
is not a objective of radiation protection.

Practical Radiation Protection

The practical (**regulatory**) implementation of the principles of limitation and optimisation

requires the definition of appropriate

radiation protection quantities

including their **specific units**.

(*and the availability of methods to assess these quantities in real exposure situations*).

Effective Dose:

The concept is restricted to the <u>control of stochastic effects</u> and is based on the <u>assumptions</u> that

- **<u>at low doses</u> - the total radiation detriment to an exposed person is given by the (weighted)sum of radiation detriments to single organs**
- **organ dose equivalent is linearly correlated with detriment.**

The applicability of this quantity and its underlying concept <u>requires the use of a linear dose –risk model</u> without a threshold (<u>LNT model</u>).

EffectiveDose (ICRP 60)

Organ absorbed dose

$$E = \sum_T w_T H_T = \sum_T w_T \sum_R w_R D_{T,R} \left[Sv\right]$$

effective dose

Organ equivalent dose

tissue weighting

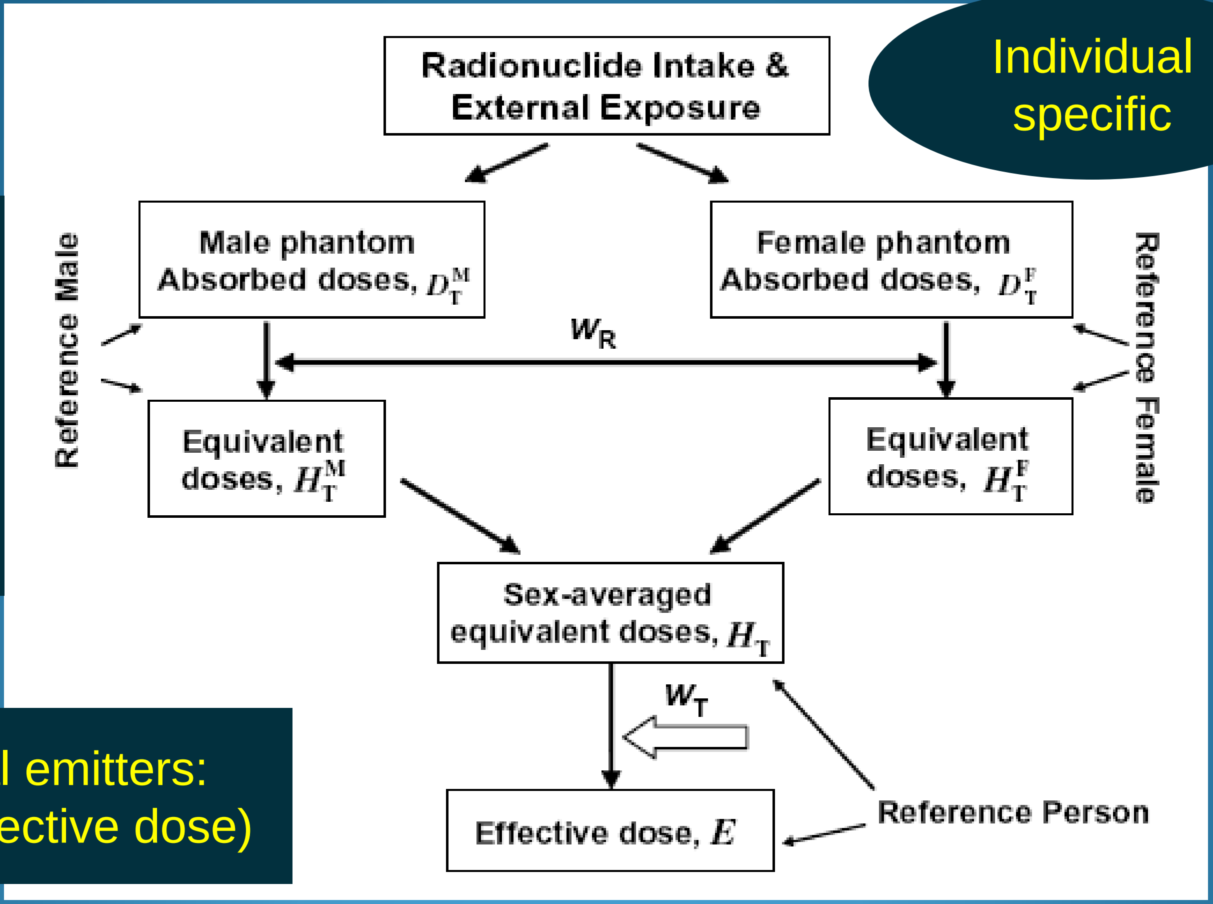
radiation (quality)weighting

The quantity enables the summation of doses from internal emitters and external radiation fields to provide a <u>single numerical value</u> for limitation and optimization.

Determination of Effective Dose: Reference Values

Individual specific

Transport Calculations and Biokinetic and Dosimetric Models



(For internal emitters: committed effective dose)

Weighting factors

- **Radiation weighting factors, w_R**

  Are intended to take account of differences in biological effectiveness of different types and energies of ionizing radiation

- **Tissue weighting factors**, w_T

  Sex-and age averaged, relative contribution of individual tissues to total detriment of stochastic effects for low-LET irradiations:

⇨ **all $w_T < 1$ and $\sum w_T = 1$**

Selection of values for all weighting factors by ICRP is based on scientific knowledge.

Tissue weighting factors

ICRP 60	0.01	bone surface, skin
(1991)	0.05	bladder, breast, liver, oesophagus, thyroid, remainder
	0.12	bone marrow, colon, lung, stomach
	0.2	gonads
ICRP 103	0.01	bone surface, skin, brain, salivary glands
(2007)	0.04	bladder, liver, oesophagus, thyroid
	0.08	gonads
	0.12	bone marrow, colon, lung, stomach, breast, remainder

Radiation weighting factors (ICRP 103)

Radiation		w_R
Photons		1
Electrons and muons		1
Neutrons		Modified continuous function
Protons and charged pions	5 ➡	2
Alpha particles, heavy ions and fission products		20

All values for wR relate to the radiation incident on the body

or emitted from incorporated radionuclides.

Note: apart from the continuous function for neutrons wR assumes only 3 different values!

Weighting Factors

It should be noted that the concepts behind the two types of weighting factors are very different:

- **Radiation weighting factors, with values between 1 and 25, are based on RBE evaluations and judgement with the assumption that the stochastic effects of a given type of radiation can be <u>scaled</u> to those of a low-LET reference radiation.**

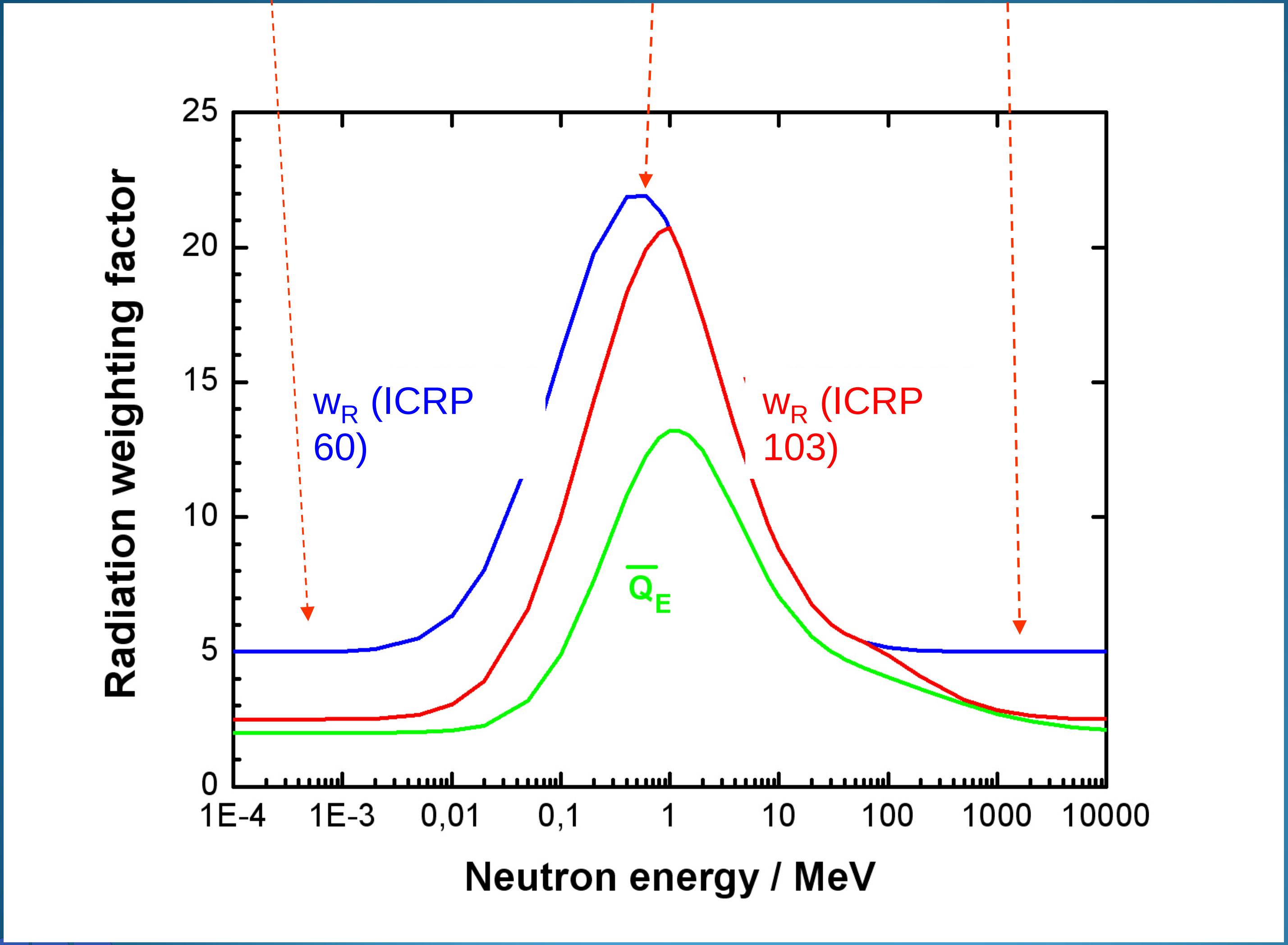
- **Tissue weighting factors are based on relative detriment factors for different organs and are used to evaluate an weighted average of equivalent doses.**

Radiation weighting factor for neutrons

Secondary γ-radiation

Animal experiments

Q(*L*)



$$\bar{Q}_E = \frac{H_E}{\Sigma w_T D_T}$$

Effective dose equivalent
(ICRP 26, 1977)

Before the 1990 recommendations of the ICRP(Report 60), all dose-equivalent quantities were defined in terms of the quality factor, *Q(L),* that was applied to the absorbed dose at a point. The quality factor weighted absorbed dose was called the dose equivalent.

Averaging dose equivalent over an organ or a tissue, T, provided the

mean organ or tissue dose equivalent, H_T.

The tissue weighted sum of organ and tissue dose equivalents was called *effective dose equivalent,* H_E

Effective dose

ICRP 60 introduced in 1990 a new approach to take account of radiation quality, i.e. the differences in the effects of different types of radiation.

First the absorbed dose is averaged over organ and tissues, T, and this mean absorbed dose is weighted for radiation quality in terms of a radiation weighting factor, w_R, for the radiation incident on the body resulting in mean organ or tissue equivalent doses

Note: ICRU defined operational quantities (ambient and personal dose equivalent) used for radiation monitoring of exposure to external radiation (tfor assess effective dose) still use Q(L).

Mean organ doses

Organ equivalent dose (ICRP 60, 1990)

$$H_{\mathrm{T}}^{\mathrm{M}} = w_R \cdot D_{\mathrm{T}}^{\mathrm{M}} \qquad H_{\mathrm{T}}^{\mathrm{F}} = w_R \cdot D_{\mathrm{T}}^{\mathrm{F}}$$

Organ dose equivalent (ICRP 26, 1977)

$$\overline{H}_{\mathrm{T}}^{\mathrm{M}} = \overline{Q} \cdot D_{\mathrm{T}}^{\mathrm{M}} = \frac{1}{m^{\mathrm{M}}} \int_m \int_L Q(L) \cdot D(L) \mathrm{d}L \mathrm{d}m$$

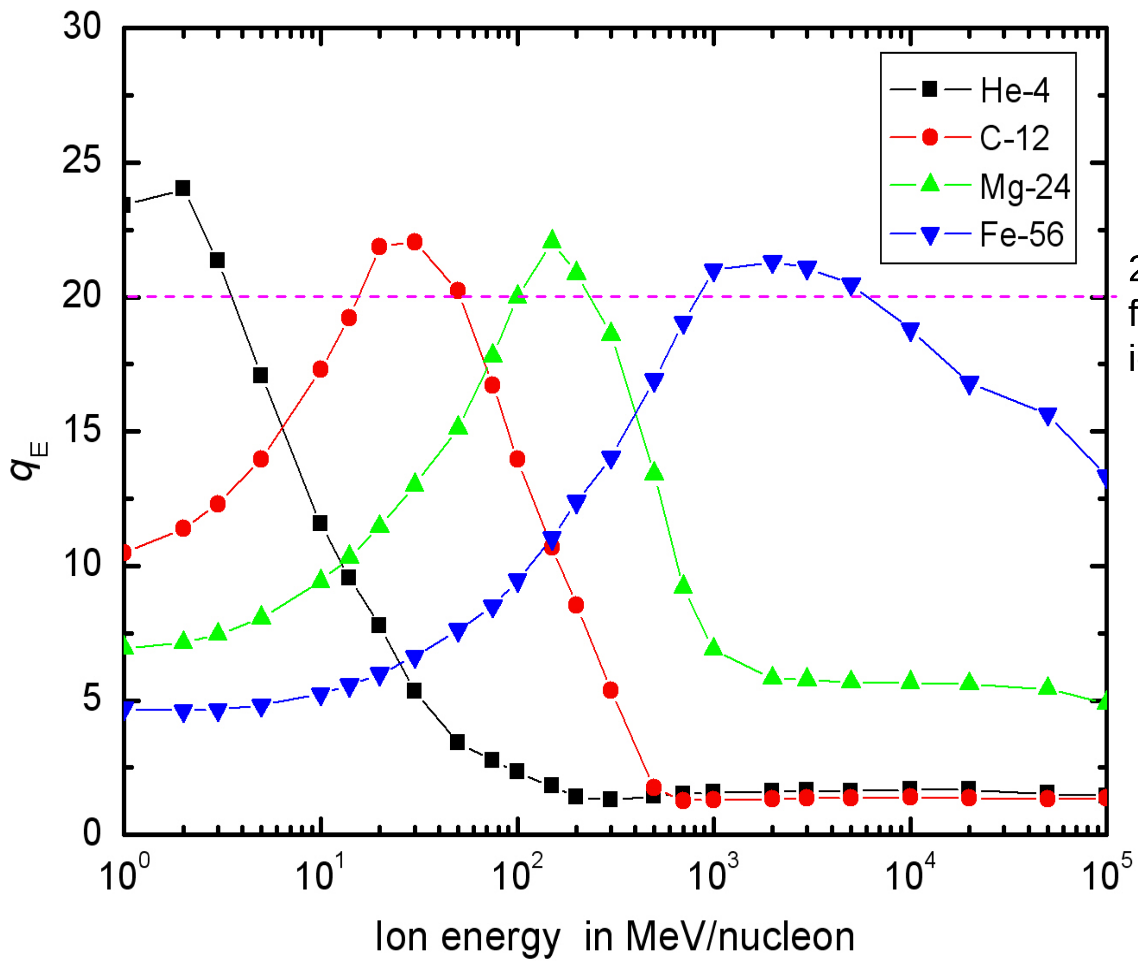
$$\overline{H}_{\mathrm{T}}^{\mathrm{F}} = \overline{Q} \cdot D_{\mathrm{T}}^{\mathrm{F}} = \frac{1}{m^{\mathrm{F}}} \int_m \int_L Q(L) \cdot D(L) \mathrm{d}L \mathrm{d}m$$

Why did ICRP change concept?

The reason given for replacing the quality factor, i.e. the *Q-L* relationship, with w_R values in the definition of the organ-equivalent doses (replacing organ dose equivalent) and the effective dose (replacing effective dose equivalent) was that the ICRP Commission believed:

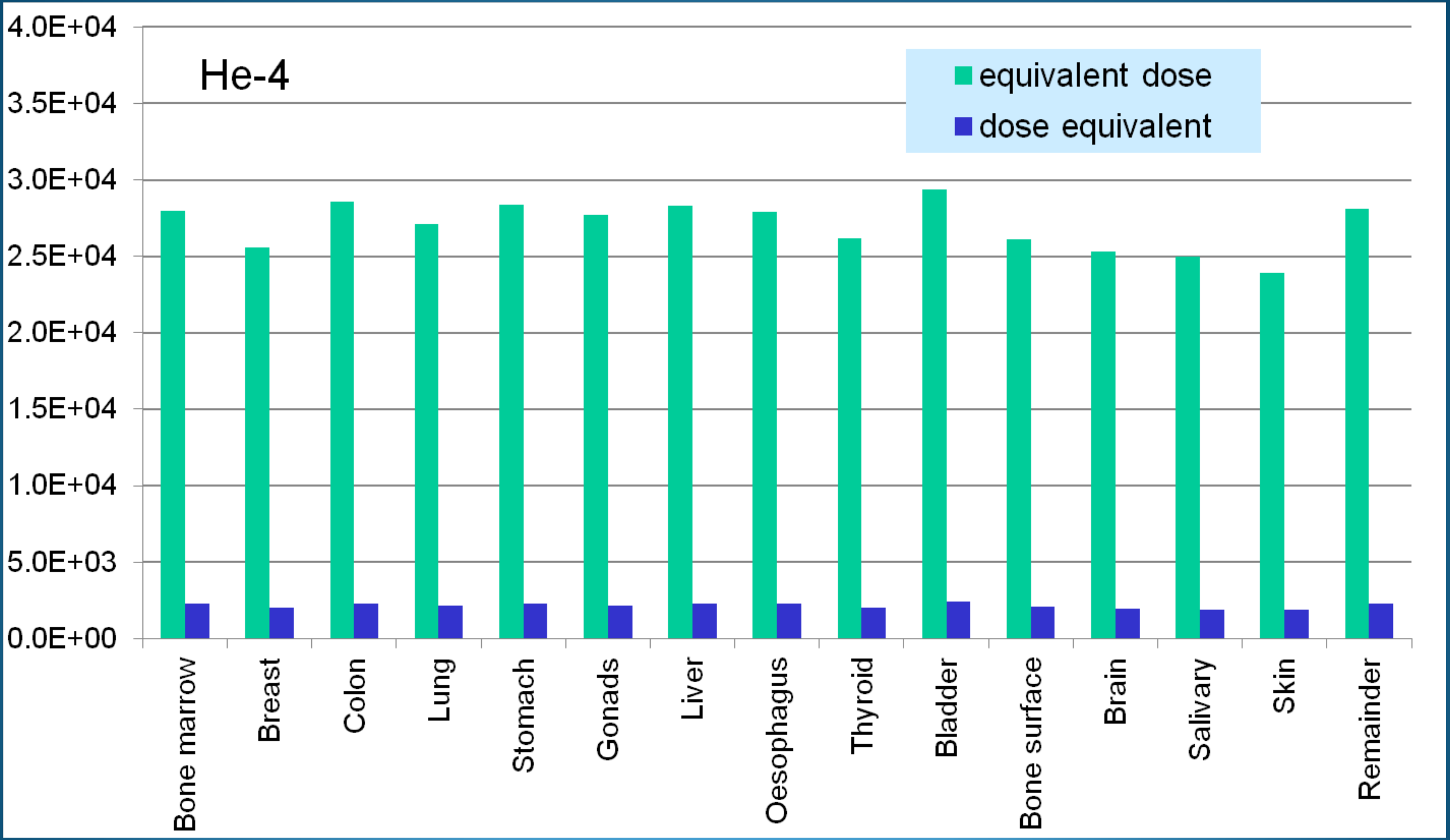
'that the detail and precision inherent in using a formal Q-L relationship to modify absorbed dose to reflect the higher probability of detriment resulting from exposure to radiation components with high LET is not justified because of the uncertainties in the radiological information'.

Human body averaged mean quality factors (Q_E) ISO exposure (data from Sato et al.)



20 = w_R for heavy ions

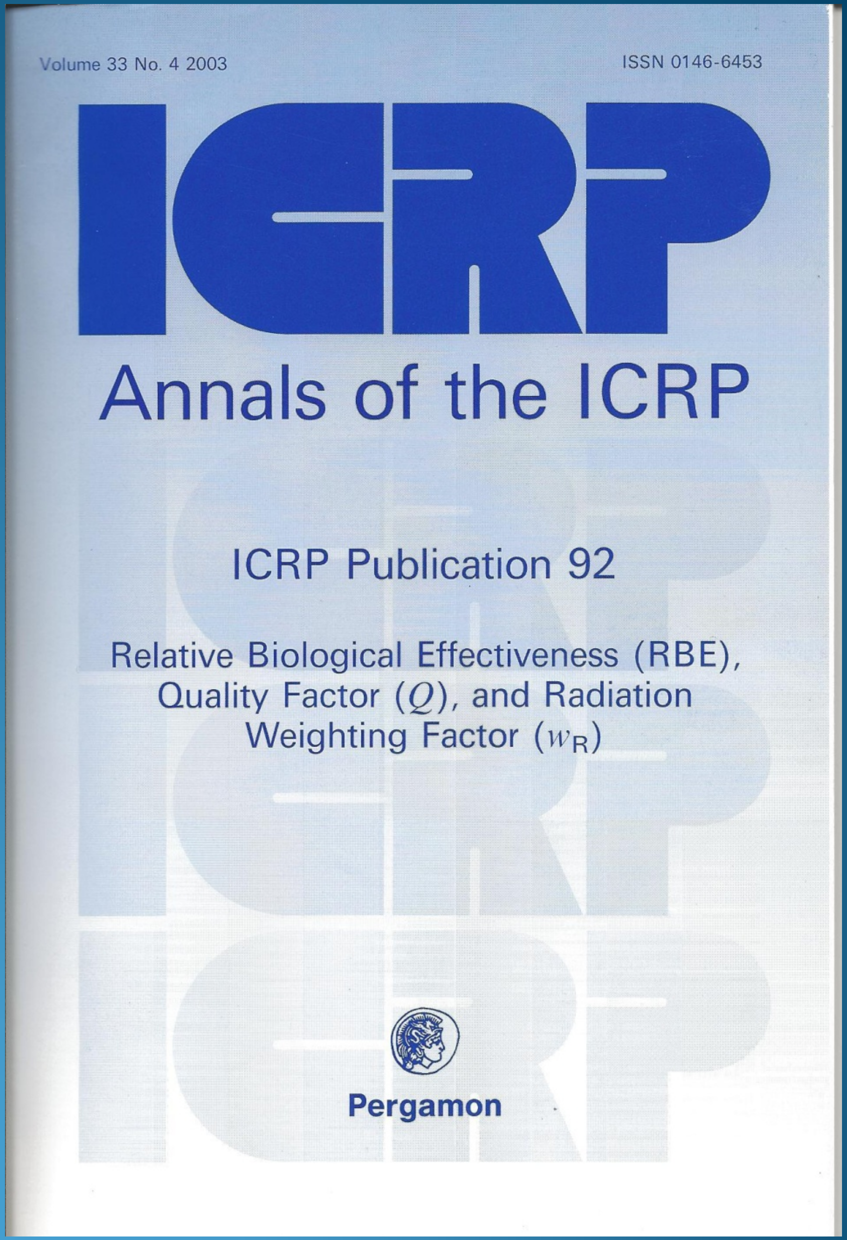
Organ equivalent dose, H_T, and organ dose equivalent from the GCR He-4 component (ISO exposure)



Taken from Sato et al

Review Reports on Radiation Quality In Radiation Protection

NCRP Report 104 (1990)
The Relative Biological Effectiveness Of Radiations of Different Quality



Radiation Quality Parameters

Quantification of radiation quality

- The general approach to quantify radiation quality in radiation protection is to multiply absorbed doses (in an organ or tissue)with weighting or quality factors.
- This requires on one side suitable physical parameters describing the energy deposition pattern.
- On the other side relevant radiobiological (and epidemiological) data are required.
- RBE data used in the evaluation of quality factors come mainly from cell radiobiology and to a lesser extent from cancer induction and life shortening studies (mainly on mice).

RBE, quality factor and radiation weighting factor

RBE a broad range of values obtained in radiobiological experiments for a given radiation depending on the biological endpoint considered, the dose and dose rate, <u>the reference radiation</u> and the experimental conditions

***Q*(*L*)** radiation quality specification defined in terms of LET (distribution) of the radiation at the point of interest. Nominal value used at low doses which are derived from various radiobiological experiments on cells at (not always very)low doses.

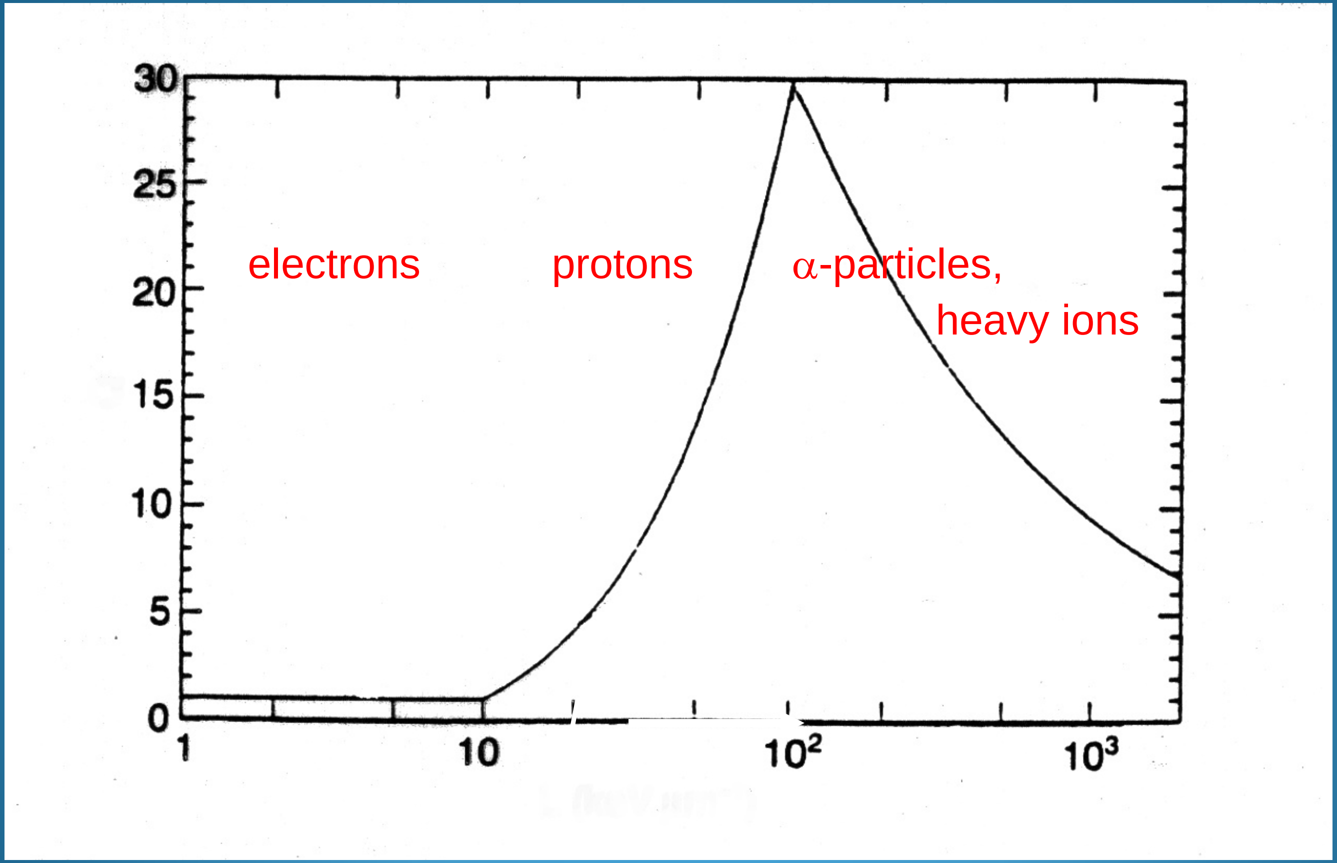
w_R a single, selected value depending only on the type (for neutrons also energy) of radiation incident on the human body..

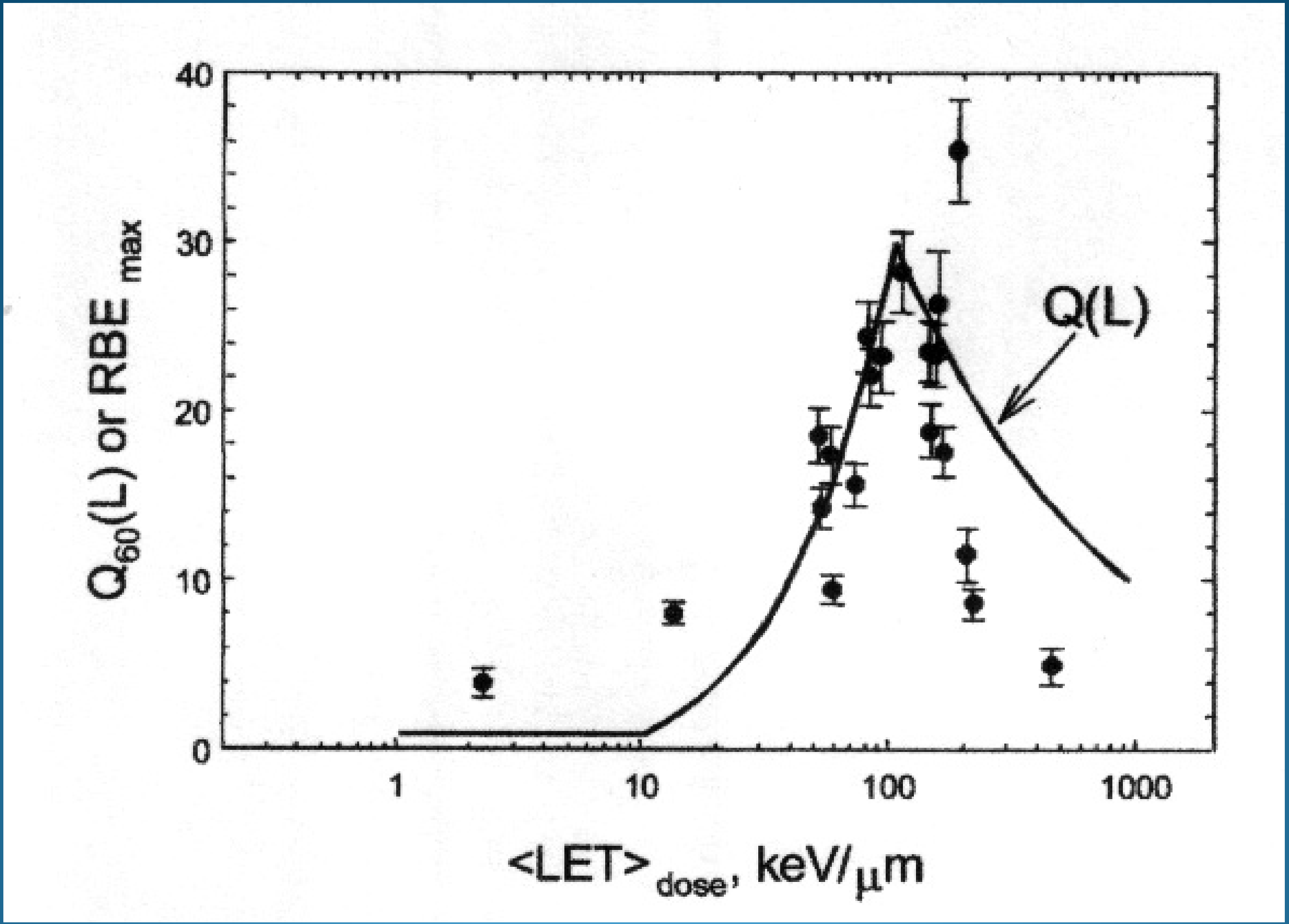
Quality factor Q(*L*)

(concept introduced by “RBE” Committee in 1963)

L*, *LET **[keV/μm]** **unrestricted linear energy transfer** by a charged **particle in water (not in tissue!)**

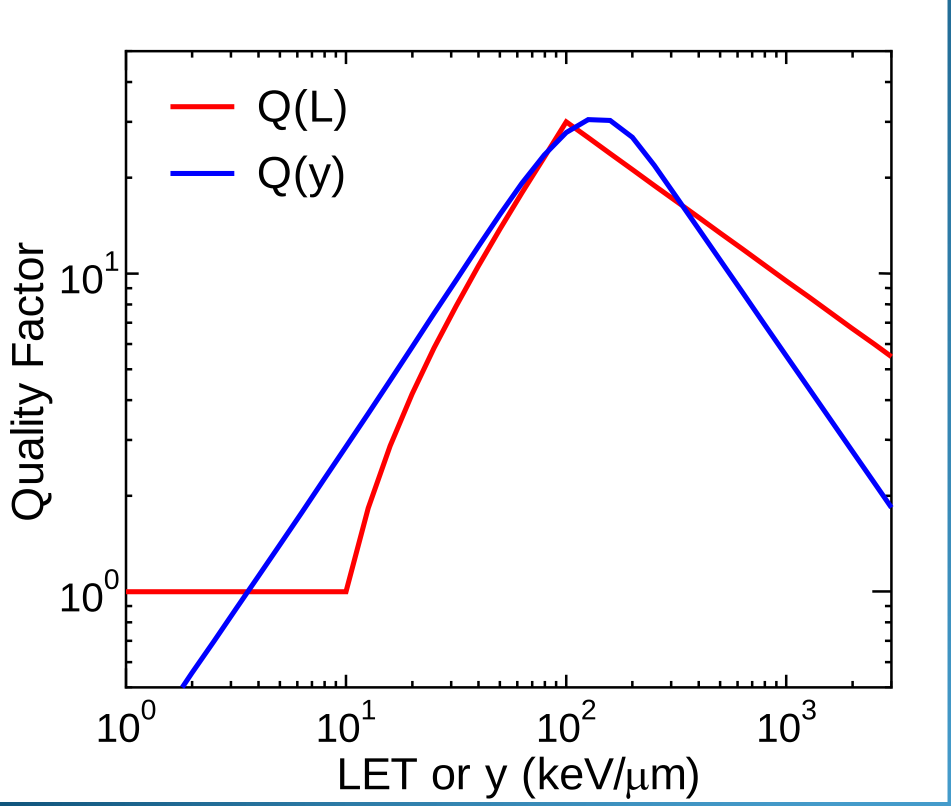
Q(L) point quantity, currently used only for operational quantities. Values mainly based onsingle cell experiments and judgement

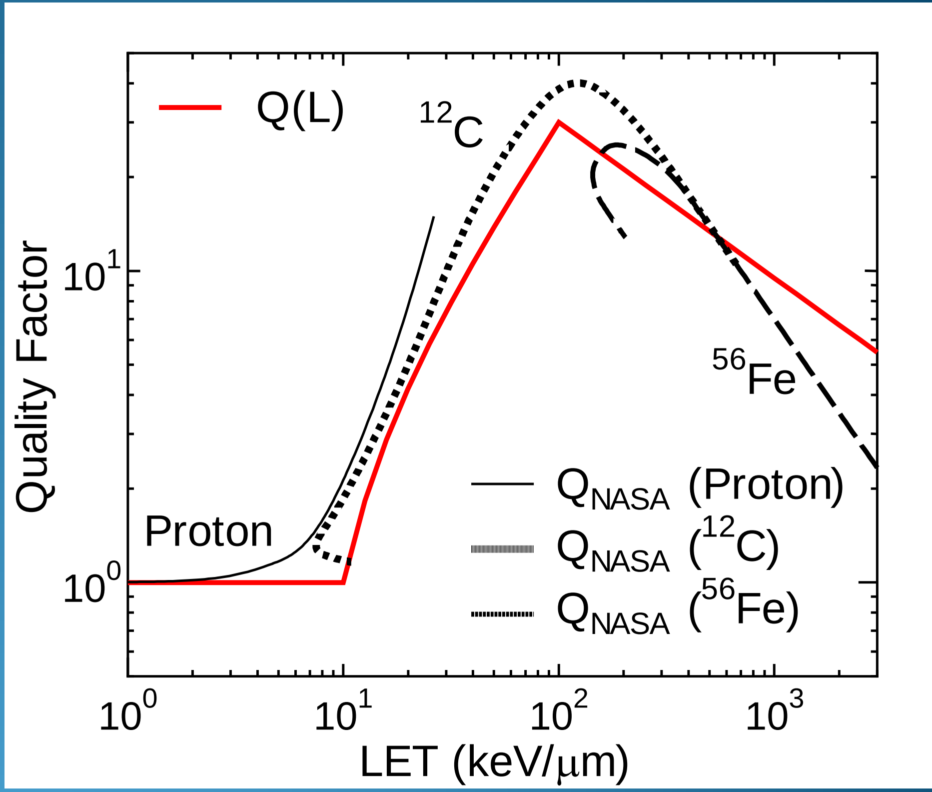




LET dependance of radiation quality factor , *Q*, (ICRP 60) and of RBE$_{max}$ for total chromosomal exchanges (Cucinotta et al., Rad. Res. 170, 127-138 (2008))

Quality Factor Comparison





Taken from Sato, T. et al.,
Comparison of mean quality factors for astronauts calculated using the Q-functions proposed by ICRP, ICRU, and NASA, **Adv. Space Res. (2013)**

Q_{NASA} is based on the track structure Parameter $Z^2/ß^2$

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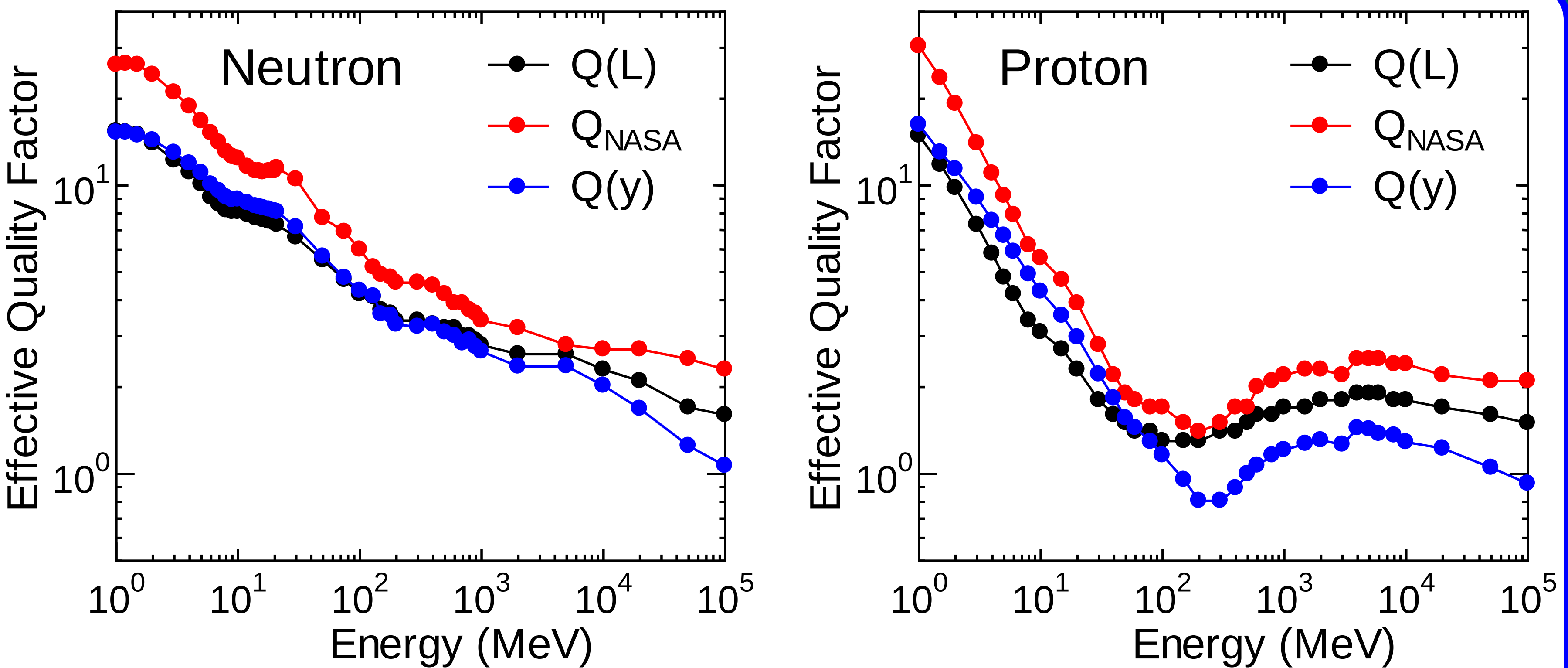
Comparison of Effective Quality Factors



Effective Quality Factors for Male based on Q(L), Q_{NASA} and Q(y) (ICRU 40)

- ✓ Low Energy : Q(L) ≤ Q(y) < Q_{NASA}
- ✓ High Energy : Q(y) < Q(L) < Q_{NASA}

Taken from Sato et al

- ✓ Q_{NASA} is larger than the others for lighter particles
- ✓ Q(y) < 1 for low LET particles such as high-energy protons

Concluding Remarks

- **In the ICRP concept for radiation protection, differences in radiation quality are taken into account in a very simplified way.**

  (Note however, for the application in the regulatory context, radiation weighting factors have no uncertainty!)
- **This is justified by the conservative approach taken in radiation protection and explained by the paucity and considerable uncertainties of radiobiological data of relevance, for the assessment of RBE values for stochastic effects in humans.**

Concluding Remarks

- Different radiation quality parameters provide comparable results, except for high energy ions.

- The ICRP approach of using weighted organ absorbed doses appears adequate for the purpose of risk limitation and optimization for many exposure situations. Exceptions include exposure to incorporated radionuclides emitting short-ranged radiation (e.g. Tritium, Auger emitters) and cosmic i.e. high-energy radiation .

Concluding Remarks

There is an obvious need for improvement of radiobiological knowledge and epidemiological data for the scientific basis of radiation protection, i.e. the management and control of stochastic effect including appropriate specification of radiation quality.

THANK YOU

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