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Effective Dose and its Limitations

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Effective dose and its limitation in medical exposure

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- Effective dose (E)
- News from ICRP 103 (2007)
- The use of E
  - Collective dose
  - E limitation in medical exposure

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The Basis of the System of Protection

- The ICRP (Report 103, 2007) has established a formal system of radiological protection aimed for a feasible and structured approach to protection.
- The system is based on:
  - Reference anatomical and physiological models of man
    - **To assess doses**
  - Molecular and cellular studies
    - **To assess hazards**
  - Animal experiments; epidemiology
    - **To assess probability of detriment**

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Effective dose

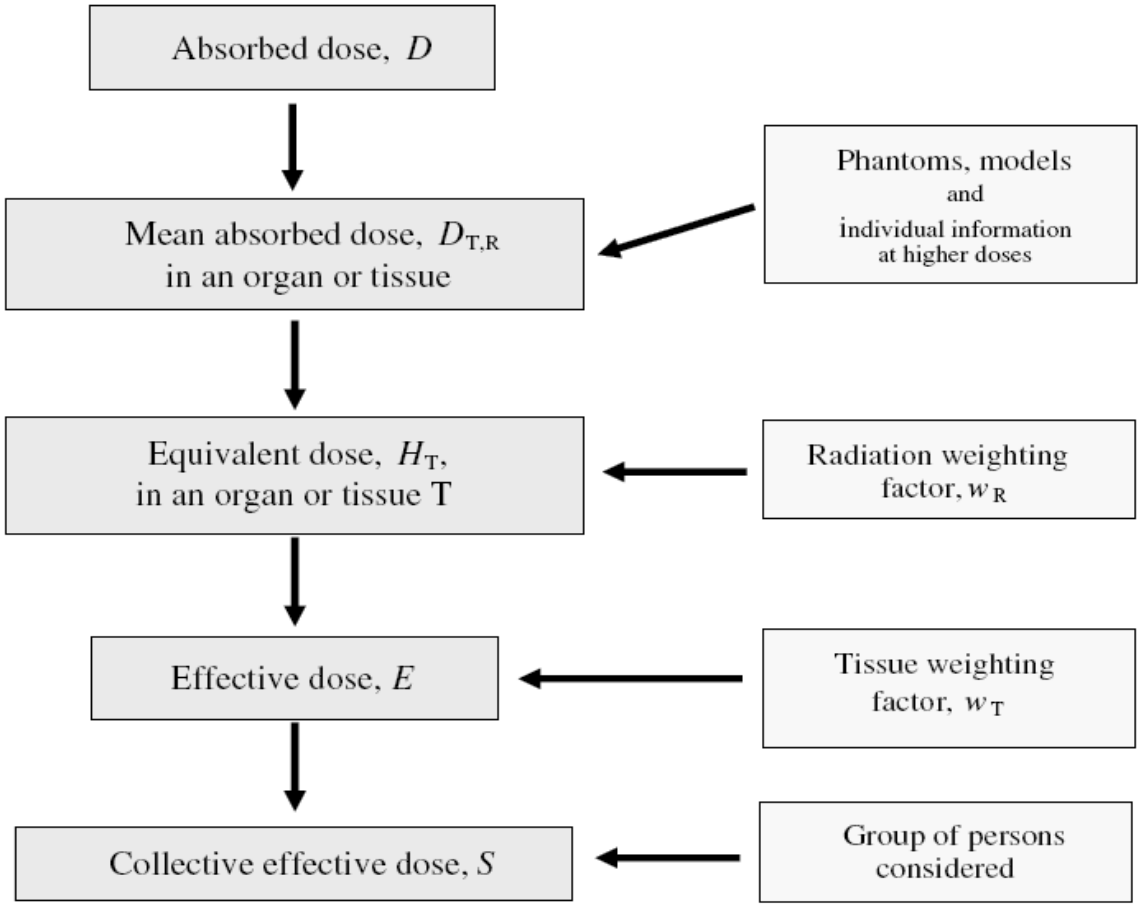

Fig. B.1. System of dose quantities for use in radiological protection.

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Detriment Risk Estimation

- ICRP 60:
  - mainly based on cancer mortality
  - hereditary effects over all following generations
- ICRP 103:
  - based on cancer incidence for which data have been published in recent years for the atomic bomb survivors in Japan
  - hereditary diseases based on the first two generations after radiation exposure
- These changes of methodology for the estimation of detriment lead to **lower detriment adjusted risk coefficients** than in the previous recommendations.
- The difference is small for the total cancer risk but larger for the hereditary risk.

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Radiation weighting Factors (w_R)

- For the determination of E, the absorbed dose of a radiation R in tissue or organ T is multiplied by the w_R value to give the equivalent dose HT.
- A single w_R value for photons is retained, although the findings of some in vitro studies (RBE increase with decreasing photon energy).
  - For protons the w_R value is reduced from 5 to 2.
  - The w_R values for alpha particles, heavy ions and fission fragments remain the same: 20.
  - For neutrons, recommended to use a continuous function (ICRP 92) with a max value of 20 at 1 MeV.

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Tissue weighting factors (w_T)

- New radiation detriment values and **tissue weighting factors (w_T)** have been proposed
- The most significant changes from Publication 60 relate to:
  - breast
  - gonads
  - remainder tissues.
- w_T changes are:
  - Breast: 0.05 → 0.12
  - Gonads: 0.20 → 0.08
  - Remainder tissues: 0.05 → 0.12 -- using a new additive system

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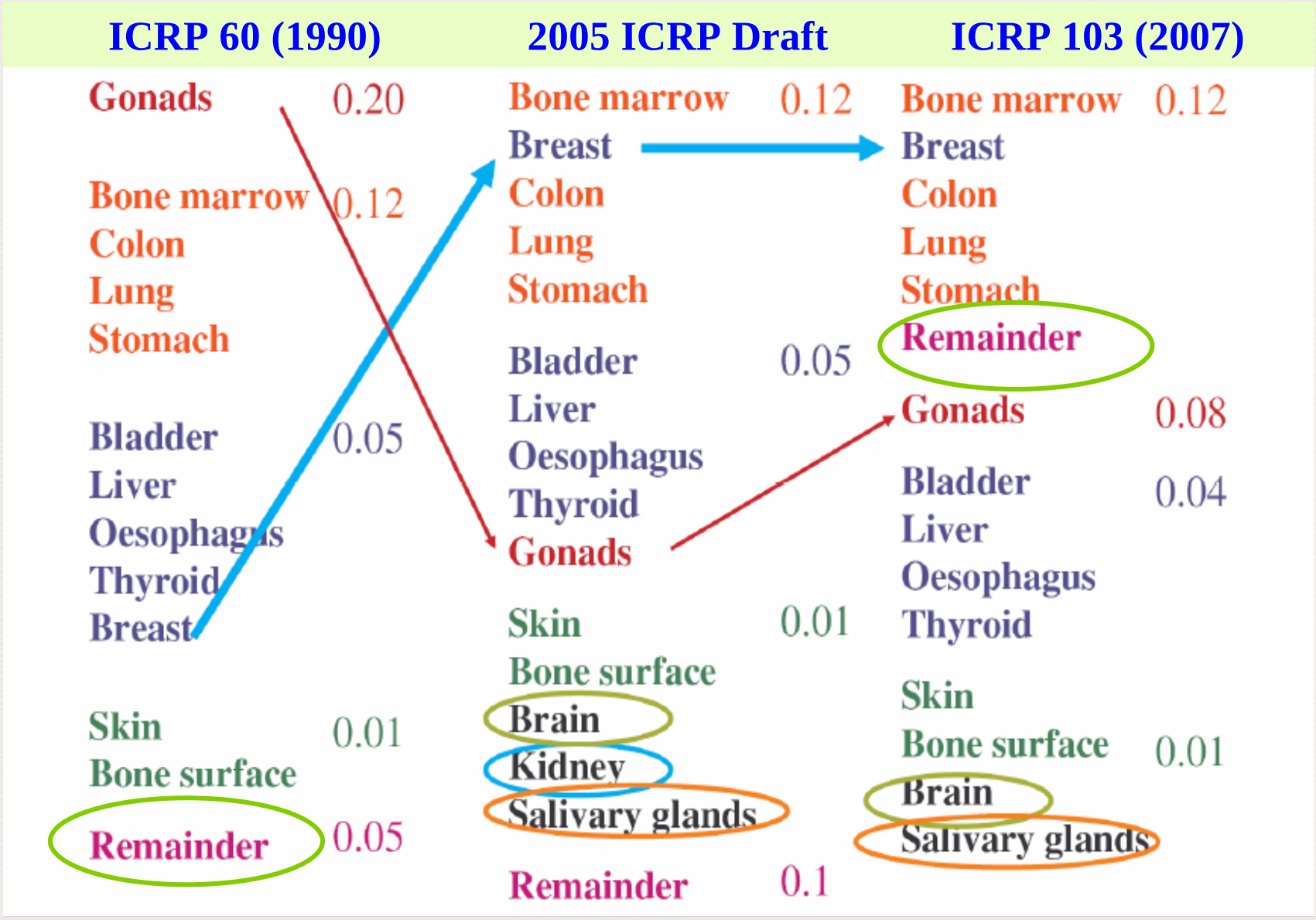
Tissue Weighting Factors, w_T

Tissue	w_T	$\sum w_T$
Bone-marrow, breast, colon, lung, stomach, remainder tissues *(14)*	0.12	0.72
Gonads	0.08	0.08
Bladder, oesophagus, liver, thyroid	0.04	0.16
Bone surface, brain, salivary glands, skin	0.01	0.04

•Remainder tissues: Adrenals, Extrathoracic (ET) region, Gall bladder, Heart, Kidneys, Lymphatic nodes, Muscle, Oral mucosa, Pancreas, Prostate (M), Small intestine, Spleen, Thymus, Uterus/cervix (F).

Changes in Tissue Weighting Factors



Nominal Probability Coefficients (% Sv^{-1})

Exposed population	Cancer		Heriditary effects		Total	
	1990	2007	1990	2007	1990	2007
Whole	6.0	5.5	1.3	0.2	7.3	5.7
Adult	4.8	4.1	0.8	0.1	5.6	4.2

L.E. Holm, 2007

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Sex-averaging

- ICRP has not set sex-specific dose limits despite the fact that the carcinogenic risk (cancer incidence) for women is 1.7 higher than for males.
- Sex-specific dose limits would make regulations for radiological protection more complicated and could lead to discrimination at workplaces
- ICRP has concluded that the dose limits have been set in such a dose range that women are also well protected
- Therefore, the $\mathbf{w_T}$ values have been sex-averaged

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E calculation: sex-averaging

- Sex-averaging to be considered for the calculation of **E**
- New mathematical phantoms have been developed for male and female body
- Organ doses will be estimated in a sex-specific way and these sex-specific organ doses will be sex-averaged for the calculation of **E**:

$$E = \sum w_T \left[\frac{H_T^M + H_T^F}{2} \right]$$

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E calculation: remainder tissues

- w_T for the remainder tissues: 0.12.
- New proposal in which the weighting of remainder tissues (14, 13 in each sex) is treated.

- The sum of the organ doses is divided by 13

$$H_{\mathrm{rem}}^{\mathrm{M}} = \frac{1}{13}\sum_{\mathrm{T}}^{13} H_{\mathrm{T}}^{\mathrm{M}} \qquad H_{\mathrm{rem}}^{\mathrm{F}} = \frac{1}{13}\sum_{\mathrm{T}}^{13} H_{\mathrm{T}}^{\mathrm{F}}.$$

- and then the male and female remainder doses are sex-averaged.

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E calculation: remainder tissues

- The number of tissues included in remainder could be increased if necessary.
- The system preserves additivity in effective doses.
- This is judged to be an appropriate simplification of the scheme of Publication 60 in which the w_T for the remainder is divided among the five remainder tissues which receive the highest dose, i.e., a non-additive system.

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Determination of effective dose

- The quantities *equivalent dose and effective dose* are not measurable in practice, so they should be related to measurable physical quantities.
- For occupational exposures, their values are determined by radiation monitoring using *operational quantities (ICRU.)*
- For the calculation of conversion coefficients for external exposure, *computational phantoms* are used for dose assessment in various radiation fields.
- For the calculation of dose coefficients from intakes of radionuclides, biokinetic models for radionuclides, reference physiological data, and computational phantoms are used

Reference Phantoms

- Reference computational phantoms of the *adult Reference Male* and *Reference Female* for the calculation of H_T for organs and tissues
  - The phantoms are based on medical tomographic images (Zankl et al., 2005).They are made up of 3D volume pixels (ICRP 89, 2002).
- These models are used to compute the mean absorbed dose, D_T, in an organ or tissue T, from reference radiation fields external to the body and from decay of radionuclides after incorporation.
- They are used for calculations of *dose conversion coefficients* for external radiation fields and *dose coefficients for the intake* of radionuclides (Annex B).

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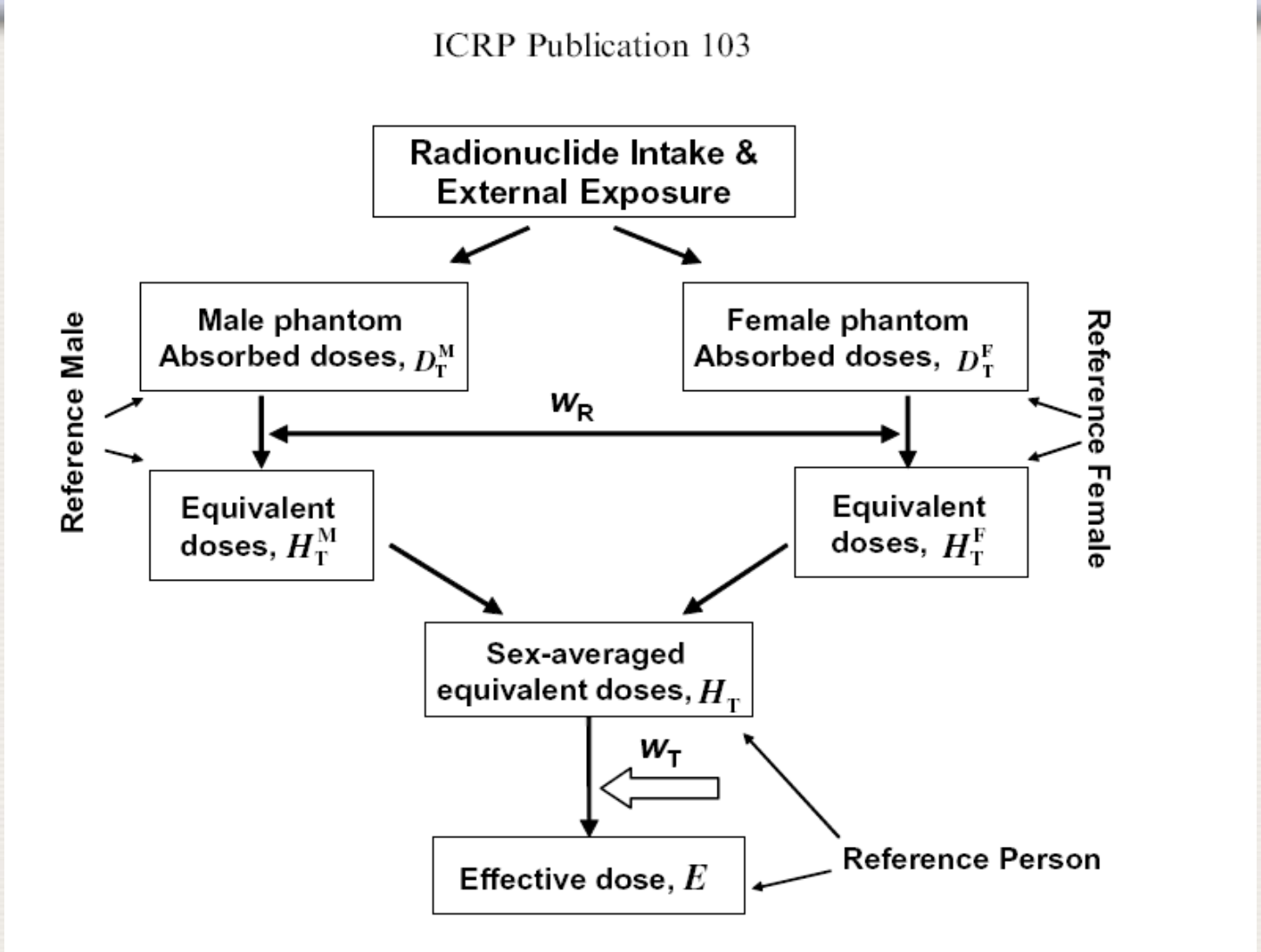
Determination of Effective Dose



Uncertainties

- In the evaluation of radiation doses, models are necessary to simulate
  - *the geometry of the external exposure*
  - *the human anatomy.*
- The Commission is aware of the uncertainty or lack of precision in radiation dose models and efforts are undertaken to critically evaluate and to reduce them wherever possible.

Uncertainties

- For regulatory purposes, the dosimetric models and parameter values that the Commission recommends are **reference values,** fixed by convention and therefore not subject to uncertainty.

- Despite changes in dosimetric modelling, as well as differences in the computation of effective dose, previous assessments of equivalent dose or effective dose should be considered adequate.

- In general, the **Commission does not recommend re-computation of existing values** with the new models and parameters.

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The Use of Effective Dose (E)

- **E** is a risk-related quantity and should only be used in the low-dose range (not for the assessment of the possibility of tissue reactions !).

- Primary use:
  - to demonstrate compliance with dose limits
  - in regulation, for prospective planning of radioprotection

- Not for:
  - detailed retrospective dose and risk assessments after exposure of individuals
  - epidemiological studies, neither in accidents.

  - In the last cases: organ doses are needed !

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Effective Dose in Medical Exposure

- The relevant quantity for planning the exposure of patients and risk-benefit assessments is the **equivalent dose or the absorbed dose to irradiated tissues.**
- The assessment and interpretation of **E** is very problematic when organs and tissues receive only partial exposure or a very heterogeneous exposure (x-ray diagnostics).
- The use of **E** for assessing the exposure of patients has severe limitations that must be considered.
- **E can be of value for comparing doses from**
  - ***different diagnostic procedures***
  - ***similar procedures in different hospitals and countries***
  - ***different technologies for the same medical examination.***

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B.5.7. Medical exposures of patients

- (B 221) Medical exposures of patients to external radiation are commonly concerned with only limited parts of the body and it is important that medical professionals are fully aware of the doses to normal tissue in the irradiated fields.
- With low tissue weighting factors for skin and relatively low values for a number of other body tissues partial body exposure can result in appreciable equivalent doses to local tissues even though the corresponding effective dose may be small.

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- ICRP 103. The use of E for medical exposures of patients has important limitations:
  - as often only parts of an organ or the human body are exposed,
  - and the age distribution of patients differs from that of the general public;
  - other factors may also need to be considered.

Collective effective dose

- The collective dose is a measure of the radiation exposure in a population:
  - it is the integral of the distribution on individual doses within the population
- Collective effective dose is retained as an important and useful instrument for optimisation especially for occupational exposures
  - In the past, collective effective dose was frequently computed as the sum of radiation exposures over a wide range of doses, over long time periods and over large geographical regions
  - On this basis radiation-related detriments have been calculated.
  - Such calculations are not meaningful because large uncertainties are included with respect to the dose assessments and extrapolation procedures from high and medium radiation doses to very low doses

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Collective effective dose

- It is possible to estimate per-caput doses associated with different ‘group doses’.
- These could form a useful input to optimisation and option comparison decisionmaking.

Collective effective dose

- ICRP (2005) recommends the separation of collective doses into various components relevant for the decision making process, reflecting
  - attributes and exposure characteristics of the exposed individuals
  - time and space distributions of exposures.
- The aim is to derive a dose ‘matrix’ where the disaggregation takes account
  - of time,
  - space
  - and the characteristics of the exposed population.

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Collective Effective Dose

- The collective effective dose, **S**, is based on the assumption of the LNT model (without-a-threshold).
- On this basis it is possible to regard effective doses as additive.
- **S** is an instrument for optimisation, for comparing radiological technologies and protection procedures.
- **S** is not intended as a tool for epidemiological studies, and it is inappropriate to use it in risk projections.
- This is because the assumptions implicit in the calculation of **S** conceal large biological and statistical uncertainties.
- Specifically, the computation of cancer deaths based on **S** involving trivial exposures to large populations is not reasonable and should be avoided.