Conceptual Basis of Radiation Detriment and Its Calculation Methodology

Introducing Publication 152

Webinar 9 December 2022

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Scope and Objective

Part of the review of the System of Radiological Protection

- Revisit historical development of radiation detriment
- Scrutinise the calculation methodology
- Detail the calculation procedure in P103
- Identify room for improvement

Chapters of P152

1. Introduction
2. Historical development
3. Calculation of radiation detriment
4. Sensitivity of radiation detriment calculation
5. Potential evolution
6. Summary and conclusions

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Concept of Detriment

- First introduced in P22 (1973)
- Defined as the expectation of harm in an exposed group
- Considers the probability and severity of effects
- Redefined as multi-dimensional concept in P60 (1991)
- Detriment as a single index → Radiation detriment

Caveat

- Not precisely represent risks for any particular individual
- Applicable to low-dose and/or low-dose-rate exposures
- Not a projection of the absolute number of cases
- Intended for inferring health impact for RP purposes

Historical Development

P26 (1977): Risk factor

- Probability of fatal cancer
- Probability of severe hereditary effects for the first two generations

P27 (1977) and P45 (1985): Index of harm

- Years of healthy life lost per 1000 worker-years at risk

P60 (1991): Weighted number of cases

- Cancer (mortality-based)
- Serious hereditary effects in all future generations

P103 (2007): Weighted number of cases

- Cancer (incidence-based)
- Heritable diseases for the first two generations

Procedure for Calculating Radiation Detriment

	Nominal risk calculation	Severity adjustment
Steps	1. Calculation of lifetime excess cancer risk 2. Transfer of risk estimates across populations 3. Application of a dose and dose-rate effectiveness factor (DDREF) 4. Integration of the risk of heritable effects 5. Averaging over populations and sexes	6. Adjustment for lethality 7. Adjustment for quality of life 8. Adjustment for years of life lost
Inputs	• Baseline rates • Cancer risk models • Cancer-free survival • Age-distribution of populations	• Lethality fraction • Minimum weight for non-lethal cancers • Years of cancer-free life lost
	Dependent on radiation dose	**Independent of radiation exposure**

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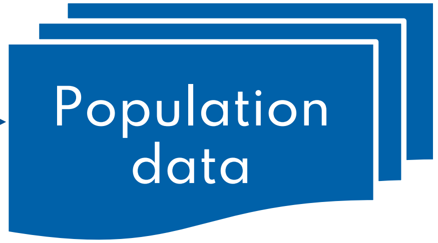
Reference Population

Selected populations with long-running cancer registries

- China (Shanghai)
- Japan (Osaka, Hiroshima and Nagasaki)
- Sweden
- UK
- US (SEER Program)

Composite reference populations

- Asian, male
- Asian, female
- Euro-American, male
- Euro-American, female



Mortality rates

Cancer incidence rates

Age-distribution of population

Cancer Risk Model

Cancer site	Information source	Dose-risk relationship
Oesophagus, Stomach, Colon, Liver, Lung, Ovary, Bladder, Other solid	LSS incidence (1958–1998)	Linear
Female breast	Pooled analysis of 8 cohorts	Linear
Thyroid	Pooled analysis of 5 cohorts	Linear
Leukaemia	LSS incidence (1950–2000)	Linear-quadratic

Input

Sex, Dose, Age at exposure, Attained age

Output

- Excess absolute risk (EAR model)
- Excess relative risk (ERR model)

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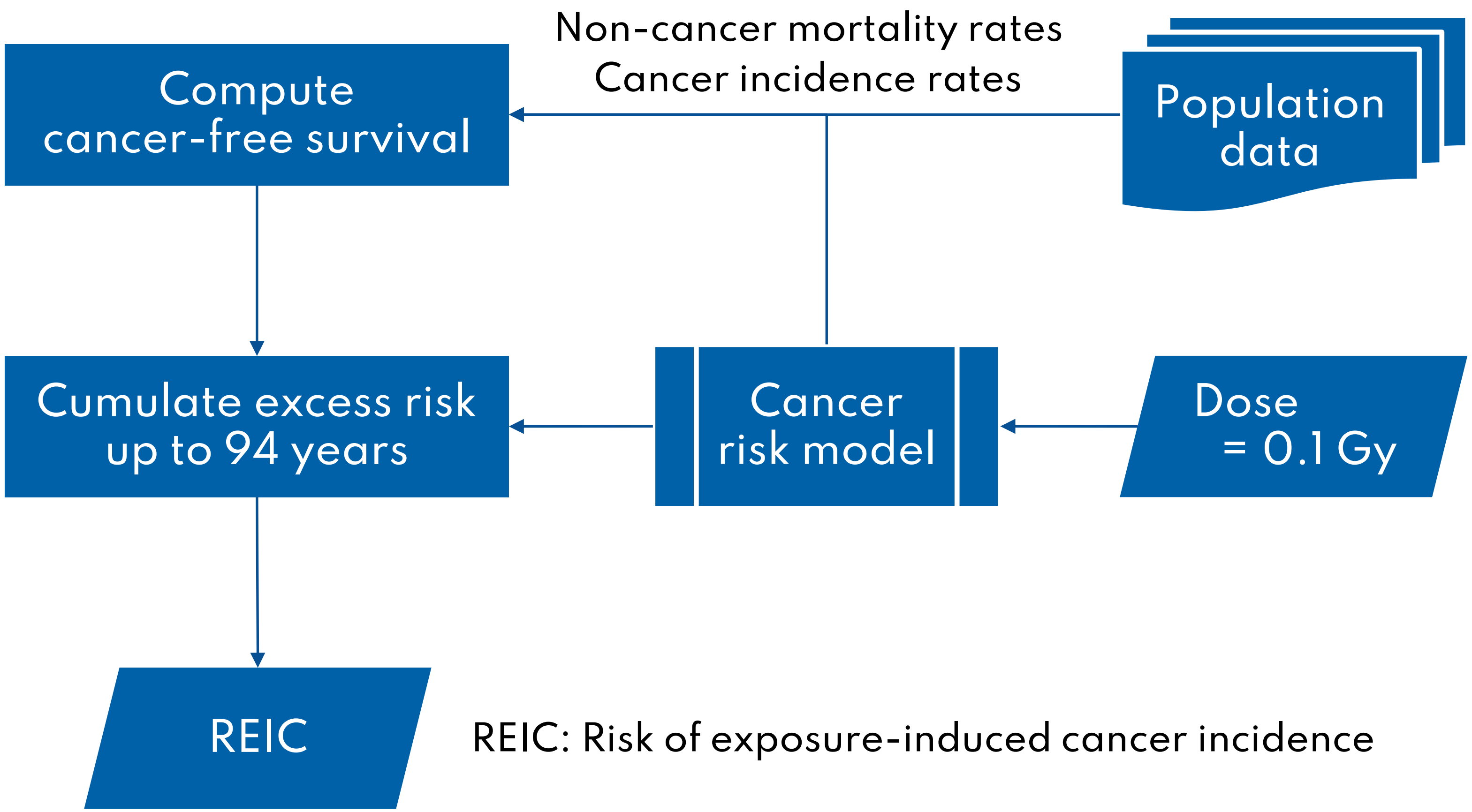
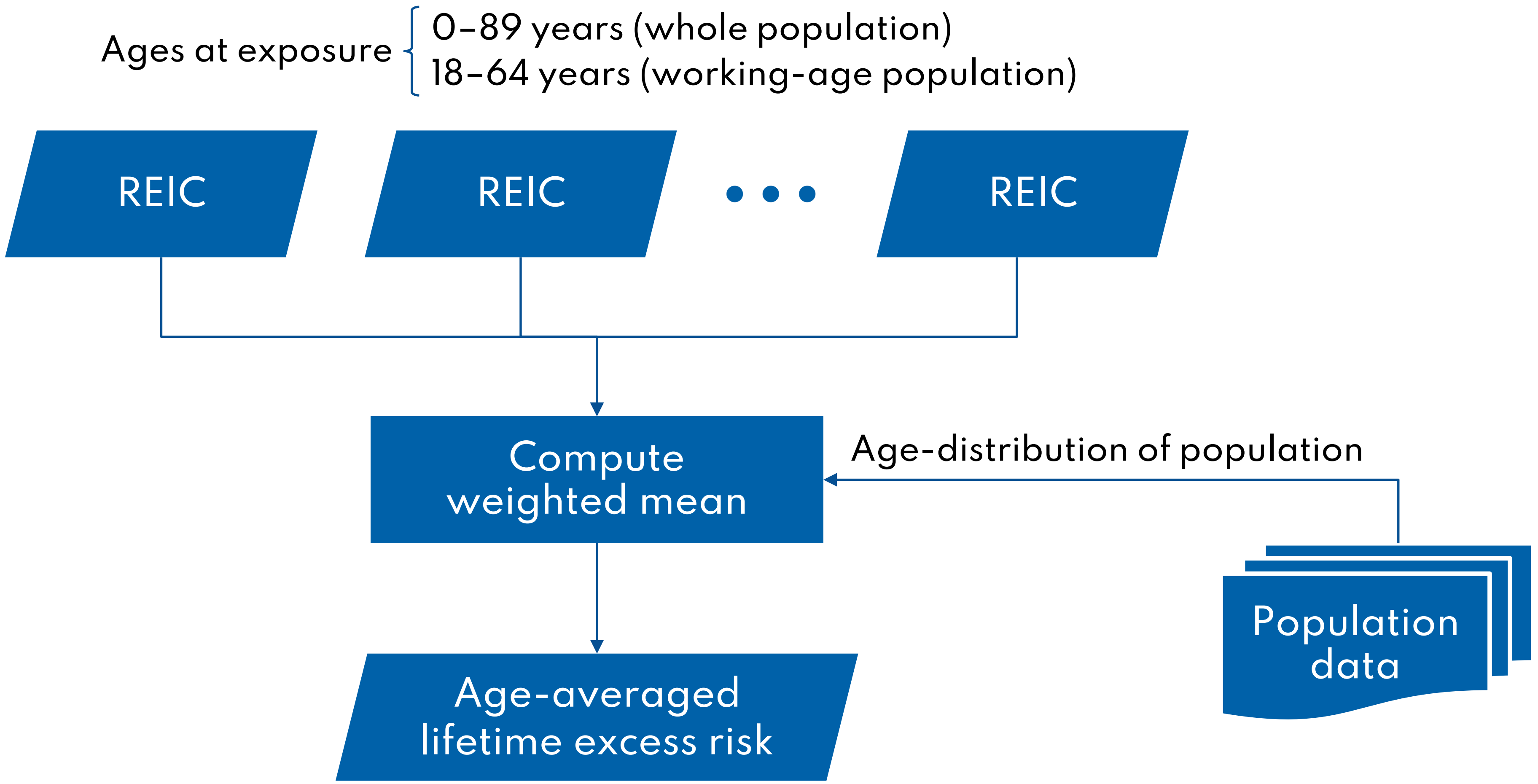
Calculation of Lifetime Excess Risk



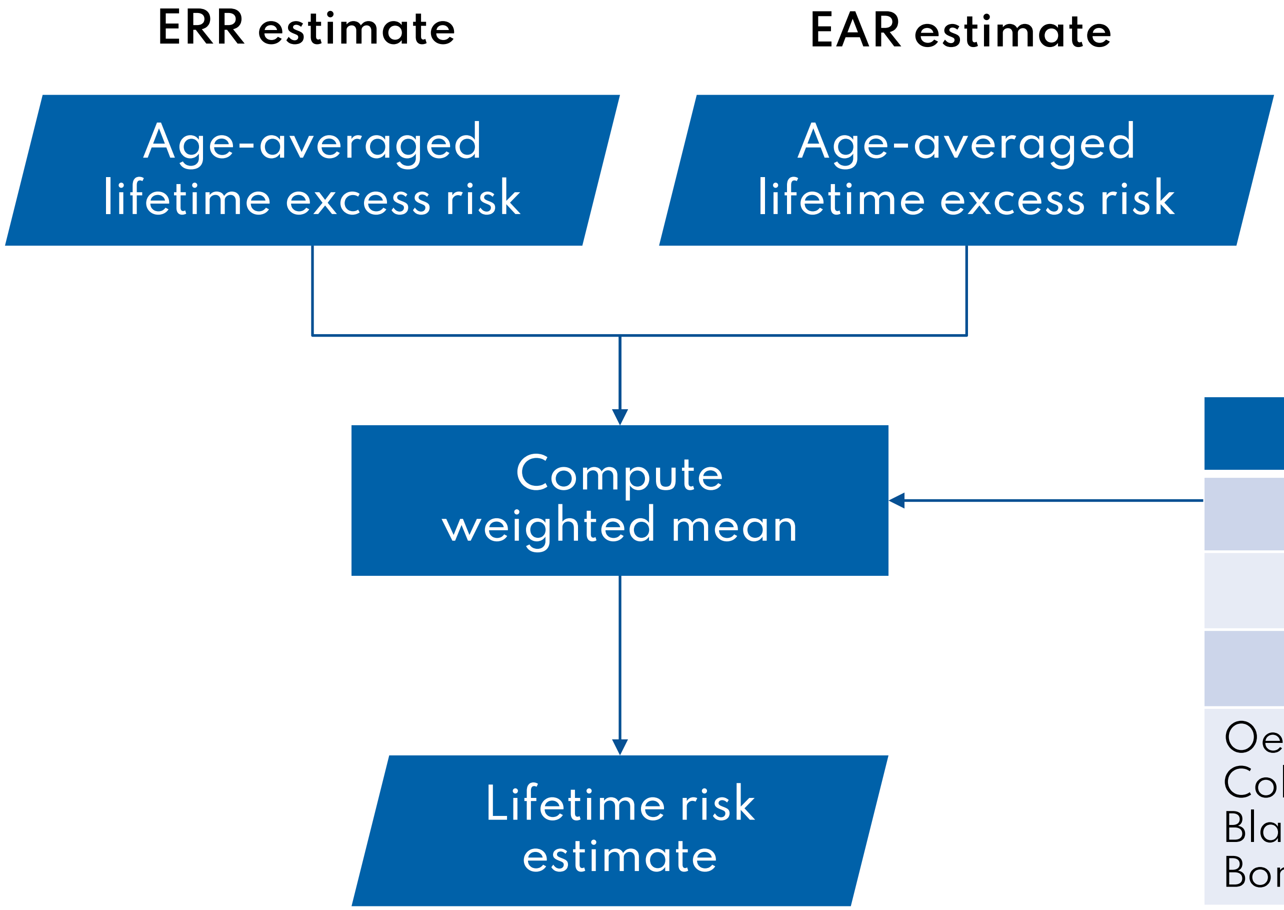
Calculation Conditions

Cancer site	Population	Risk model	Age at exposure
Oesophagus Stomach Colon Liver Lung Breast Ovary Bladder Thyroid Other solid Leukaemia	Asian male Asian female Euro-American male Euro-American female	EAR model ERR model	0 1 ⋮ 89

Averaging Across Ages



Transfer of Risk Estimates



Cancer site	**ERR**	**EAR**
Lung	30%	70%
Breast	0	100%
Thyroid	100%	0
Oesophagus, Stomach, Colon, Liver, Ovary, Bladder, Other solid, Bone marrow	50%	50%

Dose and Dose-Rate Effectiveness Factor

... the Commission finds no compelling reason to change its 1990 recommendations of a DDREF of 2 ... This risk reduction factor of 2 is used by the Commission to derive the nominal risk coefficients for all cancers ...

(P103, para.73)

↓

Lifetime risk estimates were halved (except leukaemia)

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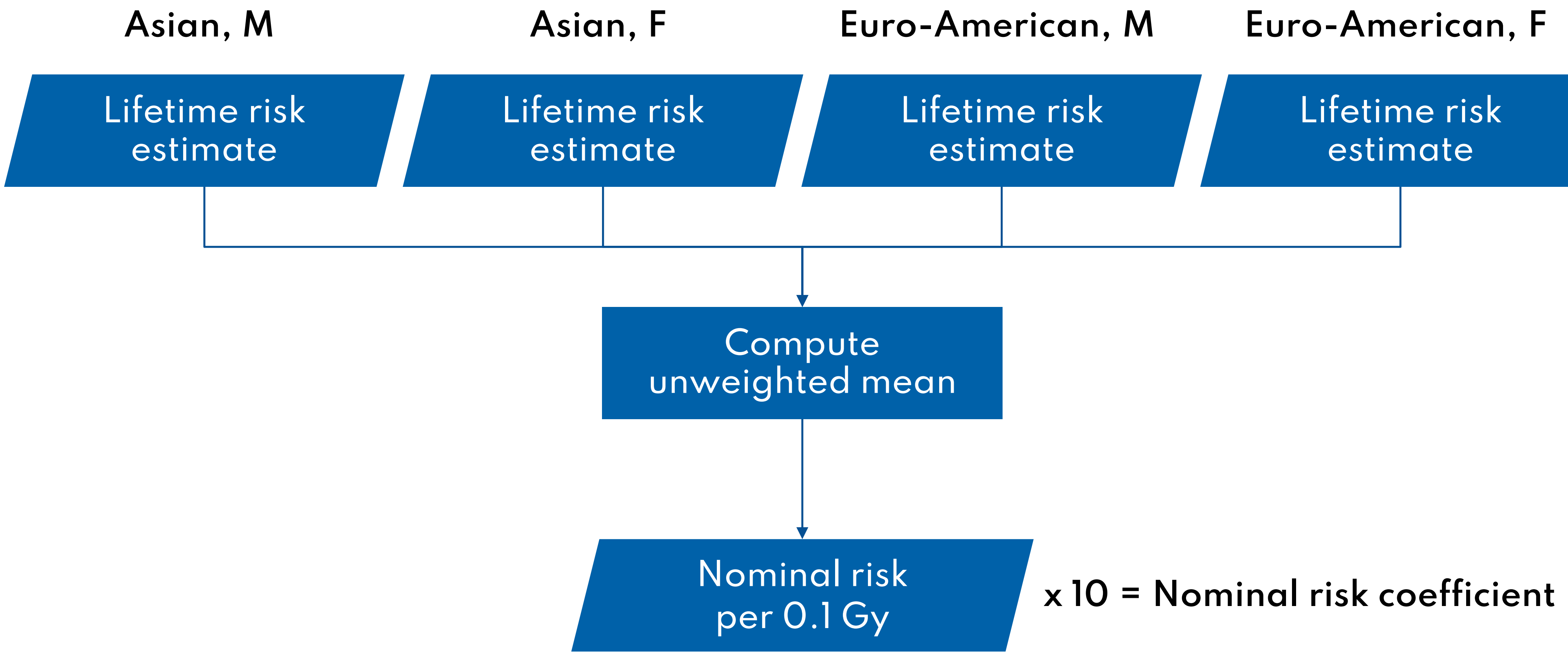
Averaging Across Populations and Sexes



Separately Estimated Components

- **Bone cancer**

  Nominal risk estimate in P60 (1991) was used.

- **Skin cancer**

  Nominal risk estimate in P59 (1992) was used.

- **Heritable effects**

  The risk for the first two generations was estimated based on UNSCEAR 2001 report.

Clarification and Correction

Risk model

- Leukaemia: mathematical expression provided
- Breast cancer: corrected

Lifetime risk calculation

- Minimum latency period: 5 years
- Ages at exposure: 0–89 years
- REIC up to age 94 years for an exposure to 0.1 Gy

Averaging

- Age-distribution of each reference population provided
- ERR:EAR weights for leukaemia → 50:50%

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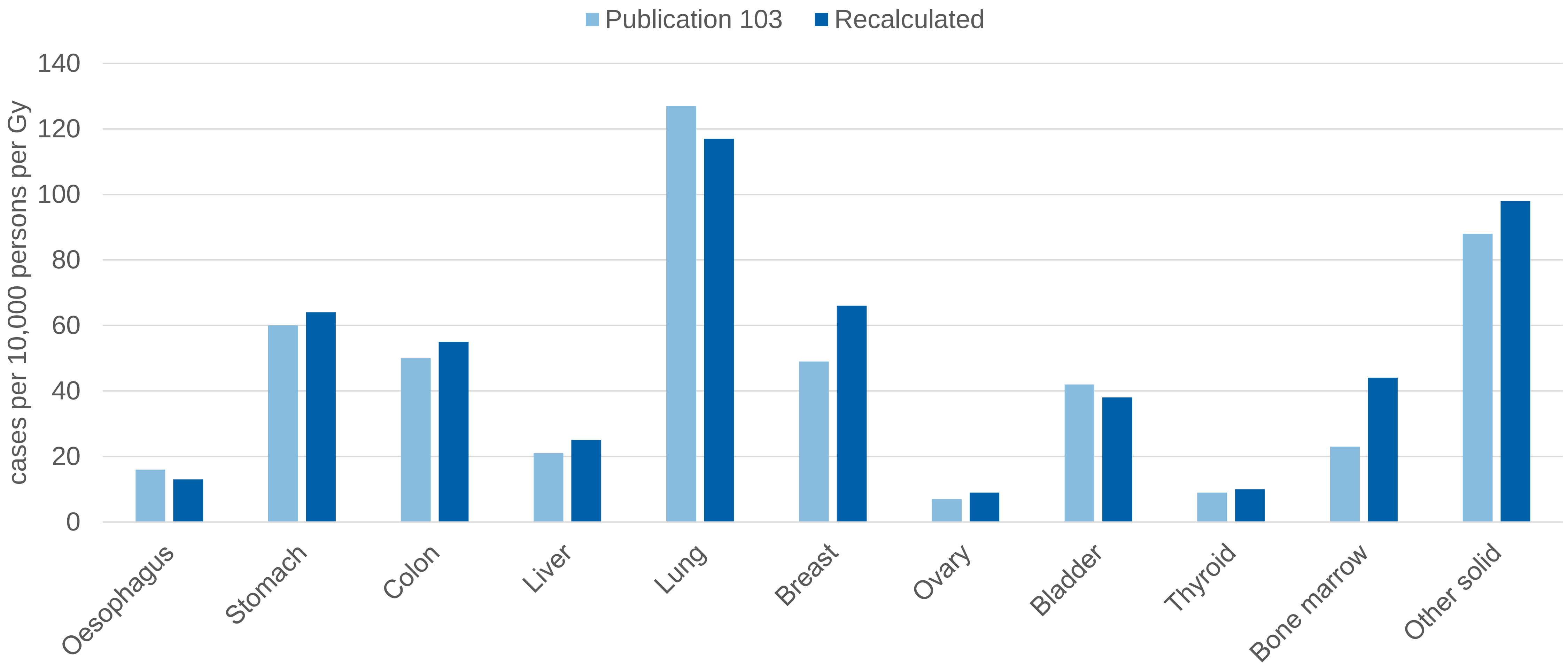
Nominal Risk Coefficients for Workers



Impact of Miscalculation

- The impact of the errors on the overall nominal risk is limited.
- The errors do not affect tissue weighting factors.
- Correction of errors does not change the conclusion of P103.

… the approximated overall fatal risk coefficient of 5% per Sv on which current international radiation safety standards are based continues to be appropriate for the purposes of radiological protection.

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Miscalculations have no implications for operation of the System of Radiological Protection.

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Severity Adjustment

Radiation detriment

Nominal risk coefficient

$$D = R\underbrace{\big(k + q(1-k)\big)l}_{\text{Adjustment factors}}$$

Adjustment factors

k : Lethality fraction

Judgement-based value reflecting the impact of medical treatment

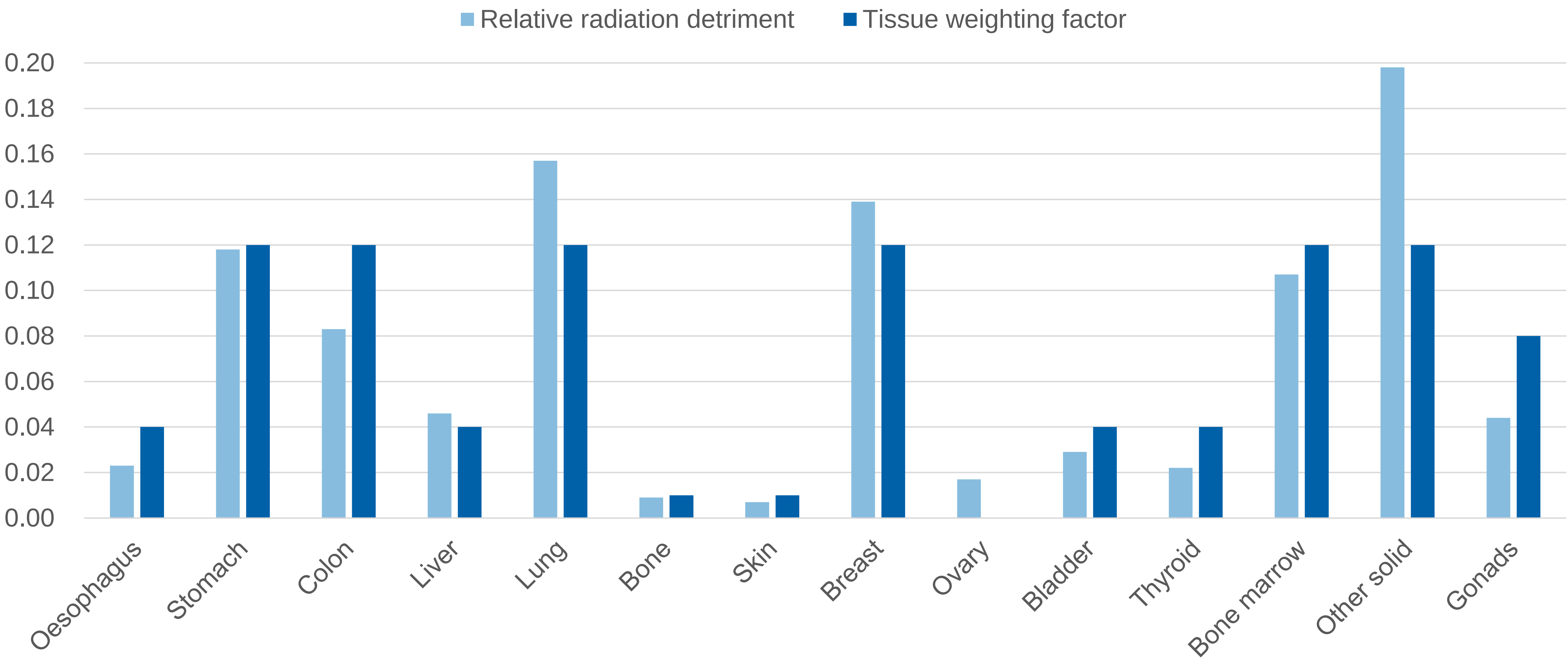
q : Quality-of-life factor

Adjustment factor for non-fatal cancers that reflects pain, suffering, and any adverse effects of cancer treatment

l : Relative years of cancer-free life lost

Based on the estimated average ages of onset for cancer sites

Relative Radiation Detriment and w_T



Determination of Tissue Weighting Factors

Organ/tissue	w_T	Reason
Lung, Breast, Stomach, Bone marrow, Colon, Remainder	0.12	Highest radiation detriments
Gonads	0.08	Heritable effects + Ovarian cancer
Bladder, Oesophagus, Liver, Thyroid	0.04	Intermediate radiation detriments
Bone, Skin	0.01	Lowest radiation detriments
Salivary glands, Brain	0.01	Greater than any other remainders

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Points of Chapters 1–3

- P152 constitutes a part of the review of the System of RP.
- Historical development of the detriment concept and its scope of application are summarised.
- Procedure of nominal risk calculation in P103 has been clarified.
- Although programming errors were found in nominal risk calculation for the working-age population, the miscalculation has no practical impact on the System of RP.

Published Papers

- Cléro E et al (2019) History of radiation detriment and its calculation methodology used in ICRP Publication 103. J Radiol Prot 39: R19–R35.
- Zhang W et al (2020) Sensitivity analysis of parameters and methodological choices used in calculation of radiation detriment for solid cancer. Int J Radiat Biol 96: 595–605.
- Ban N et al (2022) Radiation detriment calculation methodology: summary of ICRP Publication 152. J Radiol Prot 42: 023001.

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