Méthode d'estimation du détriment radiologique

Laurier D, pour le Task Group 102

GT CIPR

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Mandate of TG

- **Reproduction and documentation of the detriment calculation in Publication 103**
- **Identification of potential improvements in the detriment calculation procedure**

Solid basis for future recommendations

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Objectives

History of detriment in the ICRP

Steps in the calculation of radiation detriment

Sensitivity of detriment calculation

Potential evolutions

History of detriment in the ICRP

ICRP *Publication 22 (1973)*

First introduction of the detriment concept

ICRP *Publication 26 (1977)*

'*The Commission has introduced the concept of detriment to identify, and where possible to quantify, all the deleterious effects. In general, the detriment in a population is defined as the* ***mathematical "expectation" of the harm incurred from an exposure to radiation, taking into account not only the probability of each type of deleterious effect, but also the severity of the effect***'

- Denominated as the *'Risk Factor'*
- Expressed as the likelihood of **fatal cancers** and **serious hereditary abnormalities**
- Considering gonads (including both cancer mortality and hereditary effects in the 2 first generations), red bone narrow, bone, lung, thyroid, breast and 'other tissues'

History of detriment in the ICRP

ICRP *Publication 27 (1977)*

- Objective of '***comparing the safety of different industries*** *including those involving radiation exposure, taking account of the fact that the types of injury or induced diseases, and their severity and relative frequencies, might differ completely in different occupations*'
- Introduction of the '***Index of Harm***' for ionising radiation taking into account fatal cancers as well as non-fatal cancers and associated **years of life lost**

ICRP *Publications 45 (1985)*

- Assessment of the index of harm based on more comprehensive data
- Use of **lethality** data of different types of cancer to estimate the induction rates and severity of the non-fatal (curable) component
- Consideration of skin cancers

History of detriment in the ICRP

ICRP *Publication 60 (1991)*

- Purposes of the detriment calculation:
  - To assess the consequences of continued or cumulative exposures in order to **recommend dose limits**
  - To compare the consequences of different distributions of equivalent dose within the body and thence to **select a set of tissue weighting factors**
  - To provide a basis for **assessing the valuation of a unit of effective dose** for use, for example, in the **optimisation of protection** within a practice
- Calculation of the lifetime probabilities of fatal cancer in organs for a nominal world population of all ages ('**nominal risks**'), based on a weighted average of ERR an EAR models
- Application of a **DDREF of 2** for the calculation of nominal risks for solid cancers
- Consideration of bladder, colon, liver, oesophagus, stomach cancers
- In addition to 'nominal risks', consideration of **expected life lost** (for fatal cancers) and of the morbidity resulting from **non-fatal cancers**
- Risk of **serious hereditary disease in all future generations** descended from the irradiated individual

Detriment calculation in ICRP Pub 103

	① Nominal risks	② Detriment
Steps	**1.** **C**alculation of lifetime attributable risk **2.** **T**ransfer of risk estimates across population **3.** **A**pplication of a dose and dose-rate effectiveness factor (DDREF) **4.** **S**ex-averaging **5.** **I**ntegration of heritable effects	**6.** **A**djustment for lethality **7.** **A**djustment for quality of life **8.** **A**djustment for years of life lost
Inputs	✓ Baseline rates ✓ Survival function ✓ Cancer risk models ✓ Age distribution of the population	✓ Lethality fractions ✓ Quality of life factor ✓ Relative duration of life lost
	Step related to radiation	**Step not related to radiation**

Steps to nominal risks

1 Calculation of lifetime risk

- **Lifetime risk estimate: Radiation Excess Induced Cancer (REIC)**
  an approximation to Lifetime Attributable Risk (LAR) replacing $S(a|e)$ with $S(a|e,d)$

$$REIC_c(e,d) = \int_{a=e+L}^{\infty} [\mu_c(a|e,d) - \mu_c(a)] S(a|e,d) da$$

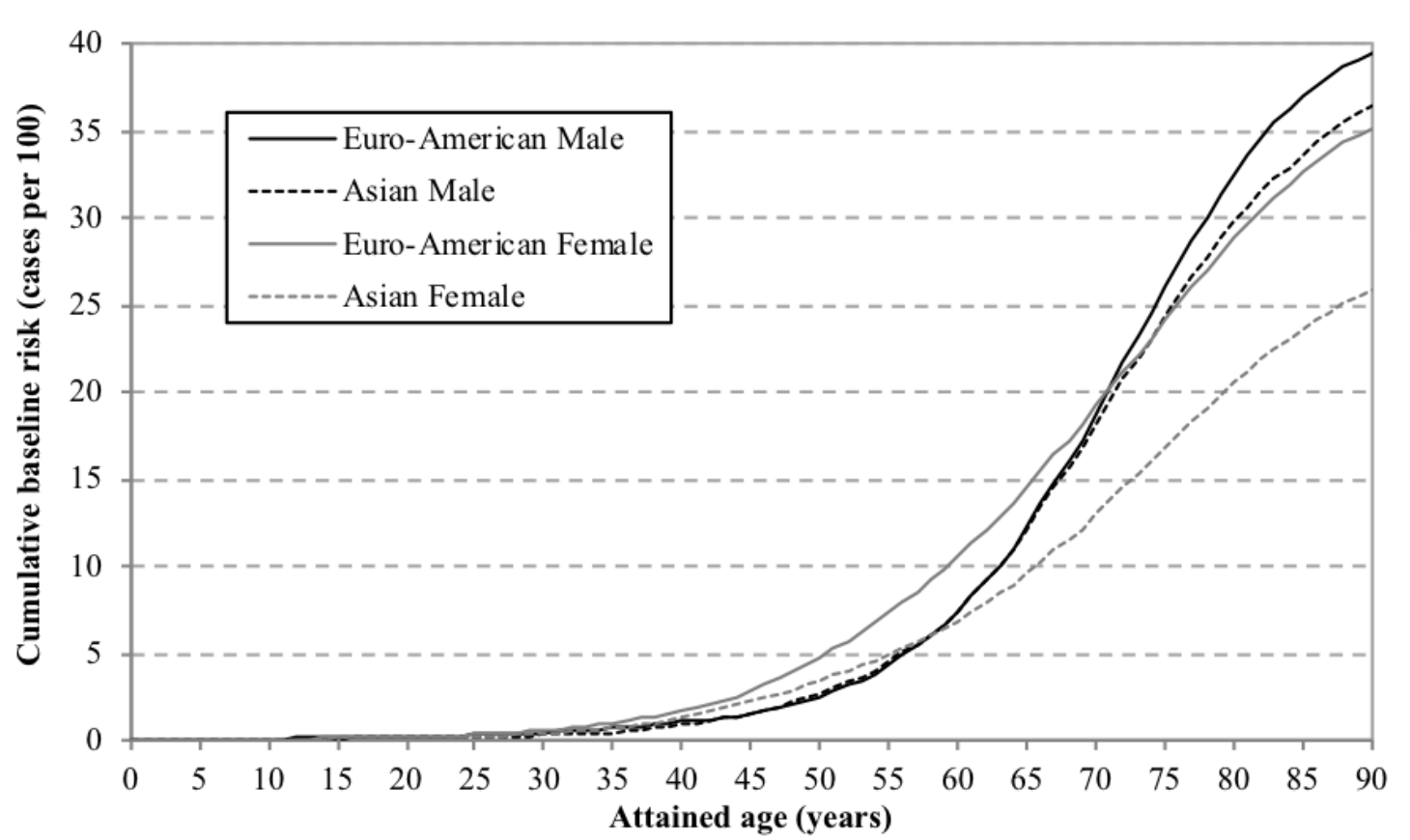
where:
$\mu_c(a)$ = annual risk of incidence from cancer c at age a
$\mu_c(a|e,d)$ = annual risk of incidence from cancer c at age a given exposure d at age e
$S(a|e,d)$ = probability of the individual surviving to age a given exposure d at age e
L = latency period

Detriment calculation

1 Calculation of lifetime risk

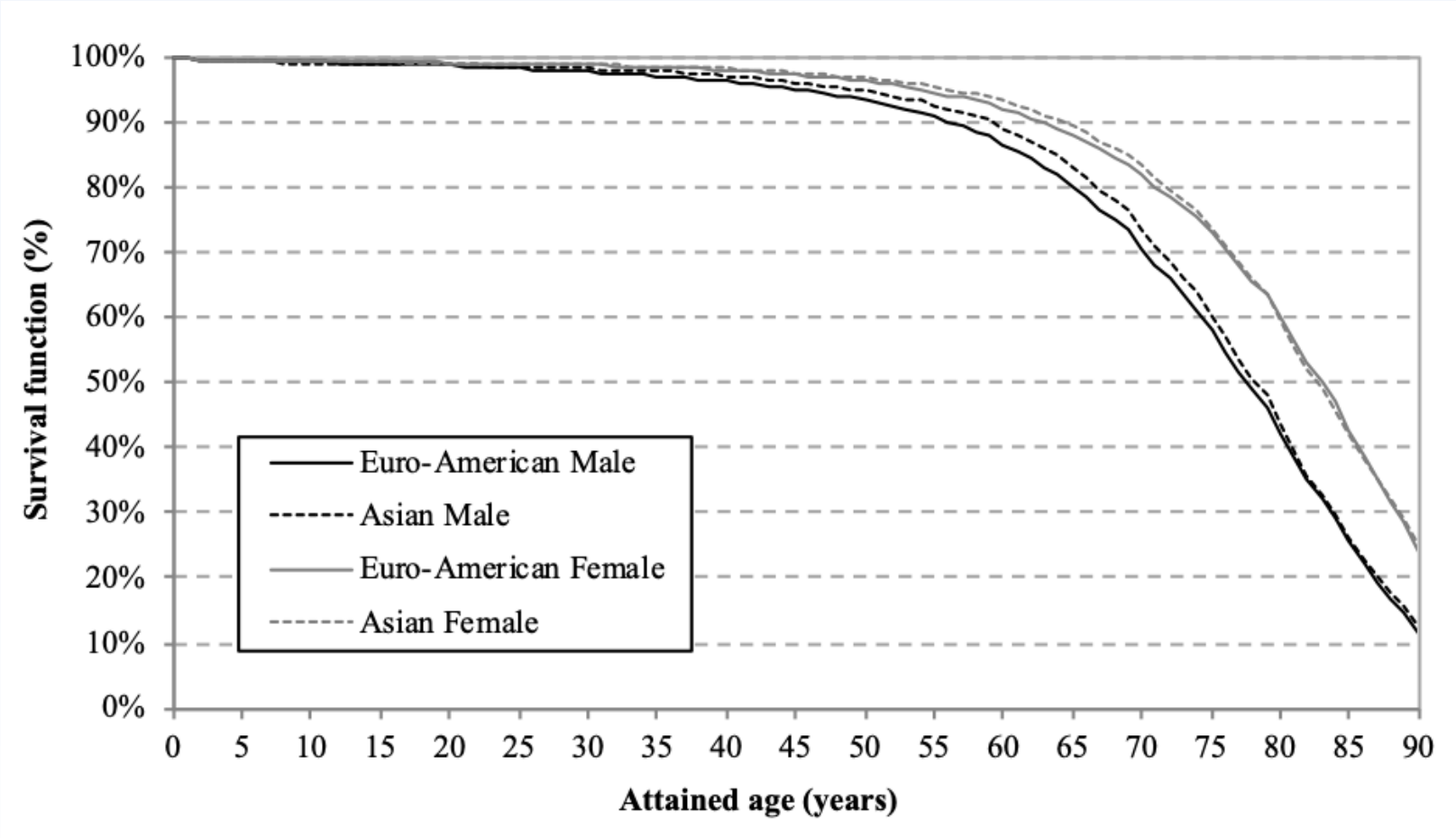
- For 13 specific cancer types, based on risk models derived from the Japanese cohort of A-bomb survivors (except bone and skin cancers)
- Calculated for males/females and Asian/Euro-American composite populations
- Cumulated risk up to attained age 89 years (90^{th} anniversary)
- Exposure scenario: acute exposure to 0.1 Gy for each year of age
  - Age at exposure 0-84 years for whole population
  - Age at exposure 18-64 years for adult workers
- Age-averaged using weights based on the age distribution of the four reference populations

Cumulative baseline rates by sex and region



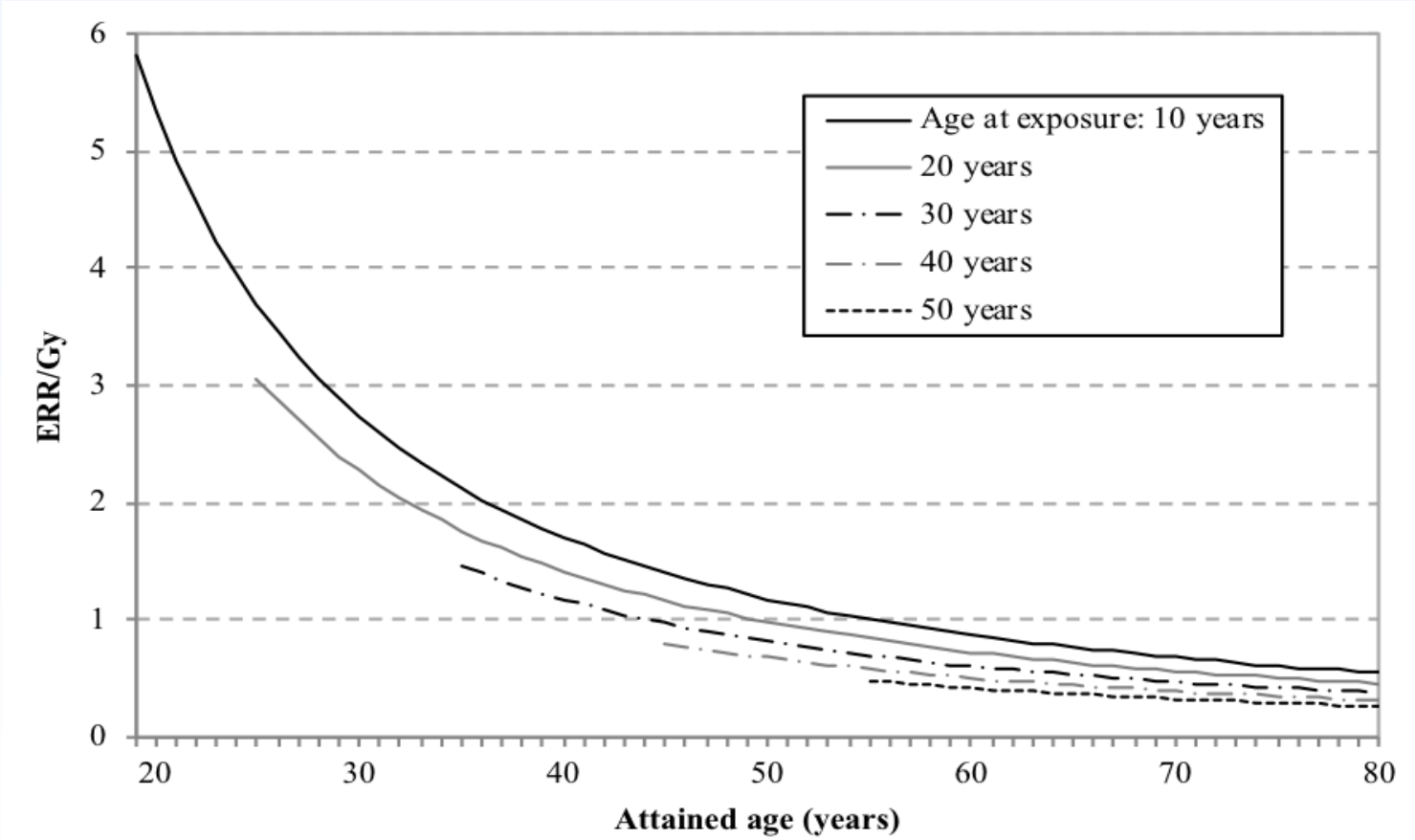
Cumulative baseline risk for all solid cancer incidence in reference populations.

Survival function by sex and region



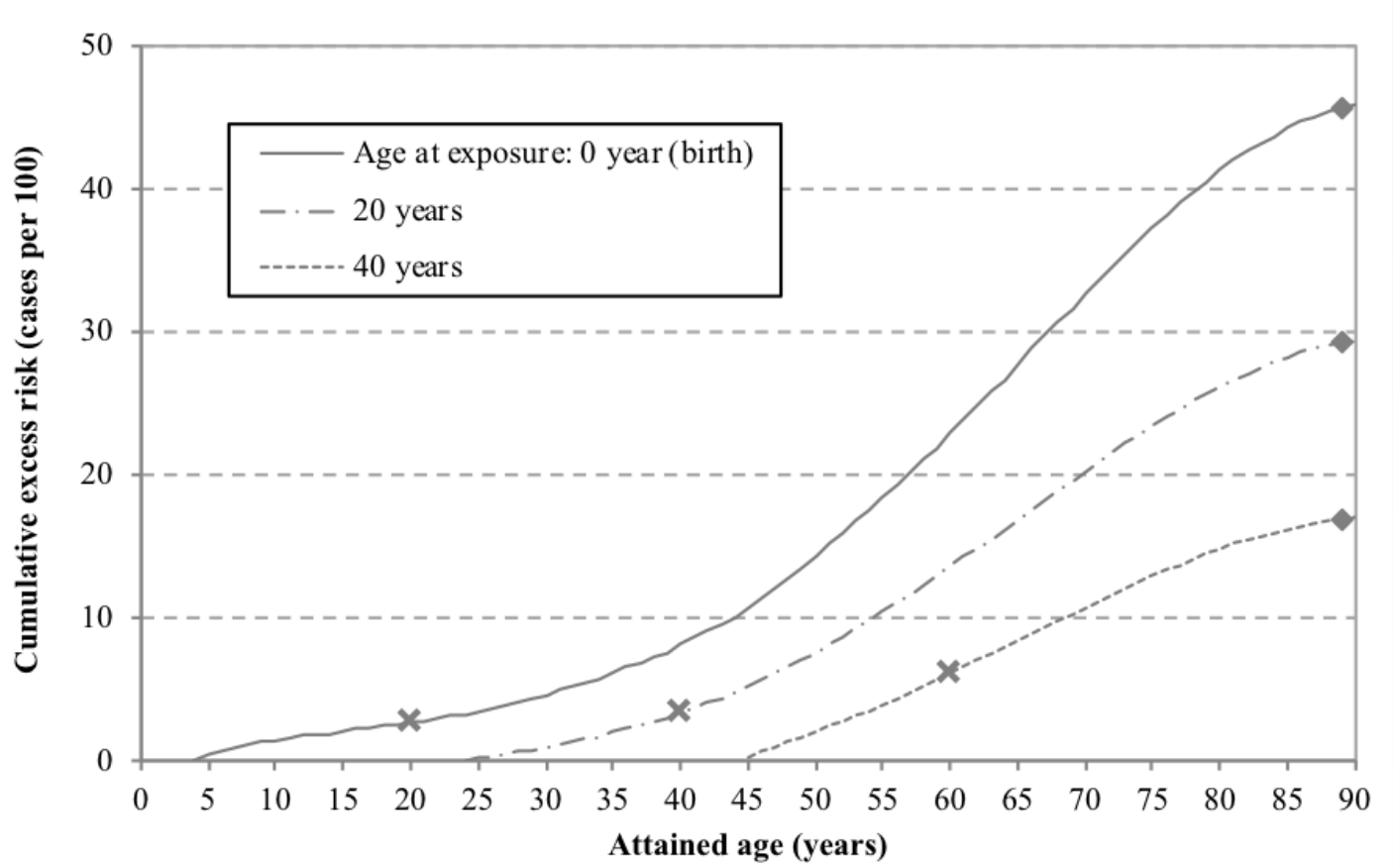
Survival function of reference populations.

Variation of ERR with age



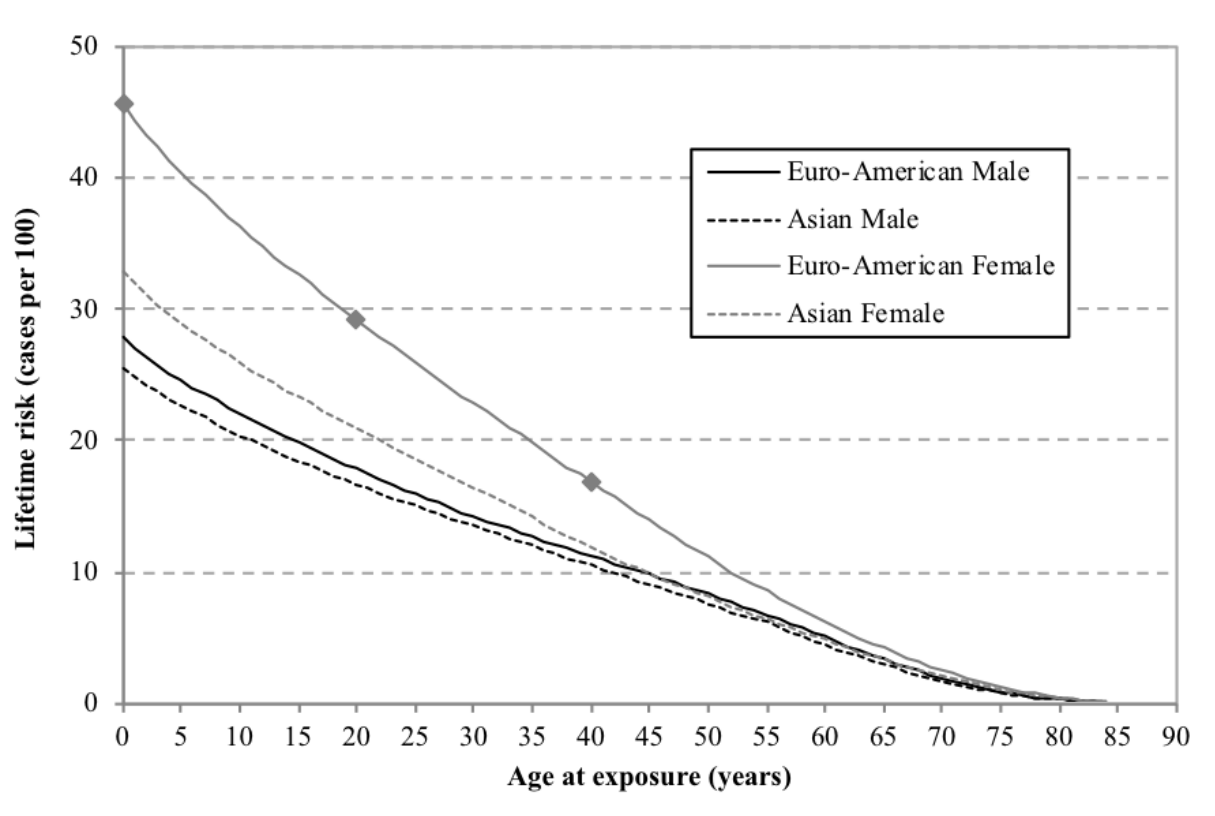
Modification of the ERR for all solid cancers
by age at exposure and attained age.

Calculation of cumulative excess risk



Cumulative excess risk for all solid cancers in Euro-American females by age at exposure, using an ERR-based model.

Variation of lifetime excess risk with age at exposure



Lifetime excess risk at 89 years for all solid cancers, using an ERR-based model.

Detriment calculation

2 Transfer of risk estimates across populations

- ERR:EAR weights

  0:100 % assigned for breast

  30:70 % for lung

  100:0 % for thyroid and skin

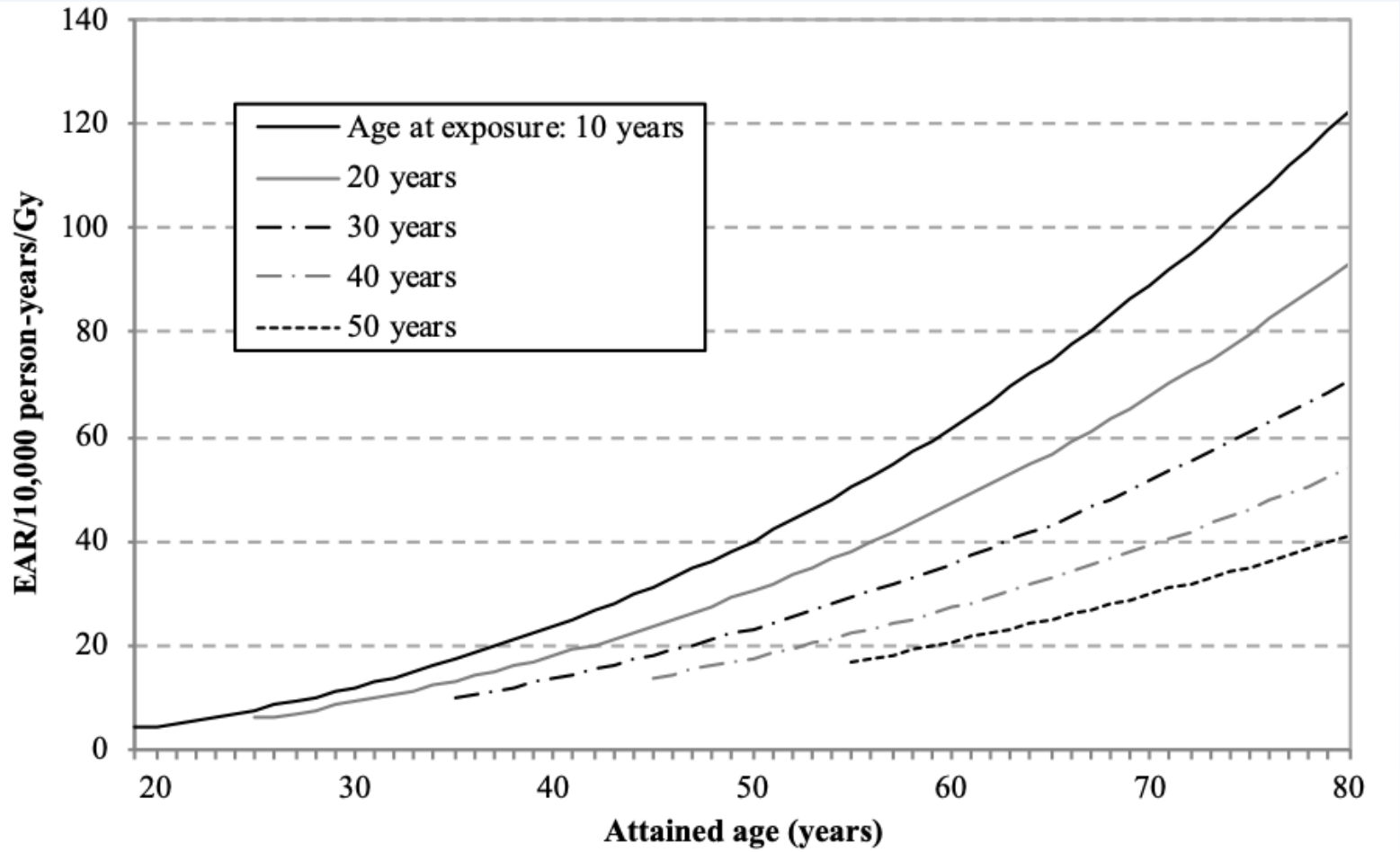
  50:50 % for all others (including bone marrow)

Illustration de la variabilité des taux de cancer de base

Taux de mortalité standardisés pour 100 000 / an (OMS 1988)

	Lung (M+F)	Breast (F)	Stomach (M+F)
United States	53	32	6
Japan	25	8	41
United Kingdom	57	42	16
France	32	27	10

Variation of EAR with age



Modification of the EAR for all solid cancers
by age at exposure and attained age.

Detriment calculation

2 Transfer of risk estimates across populations

- ERR:EAR weights

  0:100 % assigned for breast — 100:0 % for thyroid and skin

  30:70 % for lung — 50:50 % for all others (including bone marrow)

3 Application of a dose and dose-rate effectiveness factor (DDREF)

- Lifetime risk estimates adjusted downward by a factor of 2 to account for a DDREF
  Except for leukaemia, where the linear-quadratic model accounts for the DDREF
- Same DDREF applies to males and females, general population and workers

Detriment calculation

① Nominal risks → ② Detriment

2 Transfer of risk estimates across populations

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4 Sex-averaging

- Unweighted average of male and female estimates
- For sex-specific cancers (ovary, breast), average calculated considering risk among males = zero

5 Integration of heritable effects

- Based on experimental results (Unscear 2001)
- Risk of genetic diseases associated with gonadal dose estimated to be about 20 cases per 10,000 people per Sv

Detriment calculation

Nominal risk for the whole population (cases per 10 000 per Sv)

(from Tables A.4.1 and A.4.5, ICRP Publication 103, 2007)

Tissue	Nominal risk coefficient
	R
Oesophagus	**15**
Stomach	**79**
Colon	**65**
Liver	**30**
Lung	**114**
Bone	**7**
Skin	**1000**
Breast	**112**
Ovary	**11**
Bladder	**43**
Thyroid	**33**
Bone marrow	**42**
Other solid cancers	**144**
Gonads (heritable)	**20**
Total	**1715**

ICRP 1991-1992

UNSCEAR 2001

Risk models derived from the A-Bomb survivors cohort (LSS) based on a follow-up from 1958 through 1998

Detriment calculation

6 Adjustment for lethality (k)

- Nominal risks converted to fatal risks by multiplying by the lethality fractions
- Highly lethal cancers received a greater weight (k = 0.95 for liver and 0.89 for lung) than those that seldom cause death (k = 0.002 for skin and 0.07 for thyroid)

7 Adjustment for quality of life (q)

- Thought to reflect pain, suffering, and any adverse effects of cancer treatment
- Factor q_{min} applied to the non-lethal fraction of cancers
  (q_{min} = 0.1 for most cancer sites, 0 for skin cancer, 0.2 for thyroid cancer)

8 Adjustment for years of life lost (l)

- Thought to reflect differences in the age distribution of cancer types
- Less than 1 for cancers occurring late in life (l = 0.71 for bladder, 0.80 for lung)
- More than 1 for cancers occurring early in life (l = 1.63 for leukemia, 1.29 for thyroid / breast)
- Fixed to 1 for skin and 1.32 for gonads

Detriment calculation

Nominal risk and detriment for the general population (cases per 10 000 per Sv)

(from Tables A.4.1 and A.4.5, ICRP Publication 103, 2007)

Tissue	**Nominal risk coefficient**	Lethality fraction	Min weight for non-fatal cancers	Non-fatal case weight	Relative cancer free life lost	**Detriment**	Relative detriment
	R	k	q_{min}	q	l	D	
Oesophagus	**15**	0.93	0.1	0.935	0.87	**13.1**	0.023
Stomach	**79**	0.83	0.1	0.846	0.88	**67.7**	0.118
Colon	**65**	0.48	0.1	0.530	0.97	**47.9**	0.083
Liver	**30**	0.95	0.1	0.959	0.88	**26.6**	0.046
Lung	**114**	0.89	0.1	0.901	0.80	**90.3**	0.157
Bone	**7**	0.45	0.1	0.505	1.00	**5.1**	0.009
Skin	**1000**	0.002	0.0	0.002	1.00	**4.0**	0.007
Breast	**112**	0.29	0.1	0.365	1.29	**79.8**	0.139
Ovary	**11**	0.57	0.1	0.609	1.12	**9.9**	0.017
Bladder	**43**	0.29	0.1	0.357	0.71	**16.7**	0.029
Thyroid	**33**	0.07	0.2	0.253	1.29	**12.7**	0.022
Bone marrow	**42**	0.67	0.1	0.702	1.63	**61.5**	0.107
Other solid cancers	**144**	0.49	0.1	0.541	1.03	**113.5**	0.198
Gonads (heritable)	**20**	0.80	0.1	0.820	1.32	**25.4**	0.044
Total	**1715**					**574.2**	1

$$D = [(R \times k) + (R \times (1 - k) \times q)] \times l$$

$$q = (1 - q_{min}) \times k + q_{min}$$

Detriment calculation

① Nominal risks → ② Detriment

Nominal risk and detriment for workers (cases per 10 000 per Sv)

(from Tables A.4.1 and A.4.5, ICRP Publication 103, 2007)

Organ/tissue	Nominal risk coefficient	Lethality fraction	Min weight for non-fatal cancers	Non-fatal case weight	Relative cancer free life lost	Detriment	Relative detriment
	R^*	k	q_{min}	q	l	D^*	
Adult workers (age 18–64 years at exposure)							
Oesophagus	16	0.93	0.1	0.935	0.91	14.2	0.034
Stomach	60	0.83	0.1	0.846	0.89	51.8	0.123
Colon	50	0.48	0.1	0.530	1.13	43.0	0.102
Liver	21	0.95	0.1	0.959	0.93	19.7	0.047
Lung	127	0.89	0.1	0.901	0.96	120.7	0.286
Bone	5	0.45	0.1	0.505	1.00	3.4	0.008
Skin[c]	670	0.002	0.0	0.002	1.00	2.7	0.006
Breast	49	0.29	0.1	0.365	1.20	32.6	0.077
Ovary	7	0.57	0.1	0.609	1.16	6.6	0.016
Bladder	42	0.29	0.1	0.357	0.85	19.3	0.046
Thyroid	9	0.07	0.2	0.253	1.19	3.4	0.008
Bone marrow[d]	23	0.67	0.1	0.702	1.17	23.9	0.057
Other solid[e]	88	0.49	0.1	0.541	0.97	65.4	0.155
Gonads (heritable)	12	0.80	0.1	0.820	1.32	15.3	0.036
Total	**1179**					**422**	1.000

Radiation-induced detriment

Detriment-adjusted nominal risk coefficients (10^{-2} Sv^{-1}) for stochastic effects after exposure to radiation at low dose rate

Exposed population	Cancer	Heritable effects	Total
Whole	5,5	0,2	5,7
Adult	4,1	0,1	4,2

(from Table 1, ICRP Publication 103, 2007)

Field of application

- Average individual (averaged on gender, age at exposure, region)
- Doses below 0.2 Gy or dose rates less than 0.1 Gy per hour at ≥ 0.2 Gy
- To be used only for the purposes of radiological protection

w_T

Tissue weighting factors used for each organ/tissue category in *Publication 103* (ICRP, 2007)

Organ/tissue	Relative detriment		w_T
	Whole population	Adult workers	
Oesophagus	0.023	0.034	0.04
Stomach	0.118	0.123	0.12
Colon	0.083	0.102	0.12
Liver	0.046	0.047	0.04
Lung	0.157	0.286	0.12
Bone	0.009	0.008	0.01
Skin	0.007	0.006	0.01
Breast	0.139	0.077	0.12
Ovary	0.017	0.016	
Bladder	0.029	0.046	0.04
Thyroid	0.022	0.008	0.04
Bone marrow	0.107	0.057	0.12
Other solid*	0.198	0.155	0.12
Gonads (heritable)	0.044	0.036	0.08
Brain	–	–	0.01
Salivary glands	–	–	0.01
Total	1.000	1.000	1.00

* Remainder tissues (14 in total): adrenals, extra-thoracic region, gall bladder, heart, kidneys, lymphatic nodes, muscle, oral mucosa, pancreas, prostate, small intestine, spleen, thymus, uterus/cervix

Clarified Points

- Leukaemia risk was estimated using a 50:50% ERR:EAR transfer model (details of the models were not available).
- The lifetime risk was cumulated over an age range of 0–89 years (90 years of life) for the whole population, and 18–89 years (72 years of life) for adult workers.
- To estimate a lifetime risk per Gy, REIC at 0.1 Gy was calculated and multiplied by 10.
- The age-averaged lifetime risk was calculated as a weighted mean of the lifetime risk estimated for each age-at-exposure, the weight being calculated using the age distribution derived from the four reference populations.

Potential Evolution

Input information

Variation with sex and age

Exposure scenario

Inclusion of non-cancer effects

Transparency and comprehensibility

Potential Evolution: input information

Reference population data

- Two reference populations :
  - Asian (composite rates from Shanghai (China), Osaka, Hiroshima and Nagasaki (Japan))
  - Euro-American (composite rates from Sweden, United Kingdom and the Surveillance, Epidemiology and End Results (SEER) program of the US National Cancer Institute)

- Baseline rates correspond to the period 1993–1997

Potential Evolution: input information

Cancer risk models

- Risk models for 10 organs were derived from the LSS based on a follow-up from 1958 through 1998 (Preston et al 2007)
- Risk model for leukemia also derived from the LSS but equations no more available
- Nominal risks for bone cancer and non-melanoma skin cancer were taken from *Pub 60* and *59* (1991, 1992),
- No specific risk models for the brain and salivary glands.
- Risk models derived essentially from the LSS without incorporating findings from other sources.

Potential Evolution: input information

Cancer severity parameters

- Lethality fractions per cancer site have been provided as judgment-based values derived from U.S. population data for the 1980–1985 and 1950–1970 periods (U.S. DHHS, 1989). The same lethality fraction values were used for males and females, the general population and workers.
- Relative estimates of years of life lost were calculated from values used in *Publication 60* (ICRP, 1991).
- Adjustment for quality of life of cancer patients was based on the use of very approximate judgment-based values.

- More elaborated approaches such as disability-adjusted life years (DALY) are today available to estimate and characterise the quality of life for many different cancer types.

Potential Evolution: input information

Heritable effects

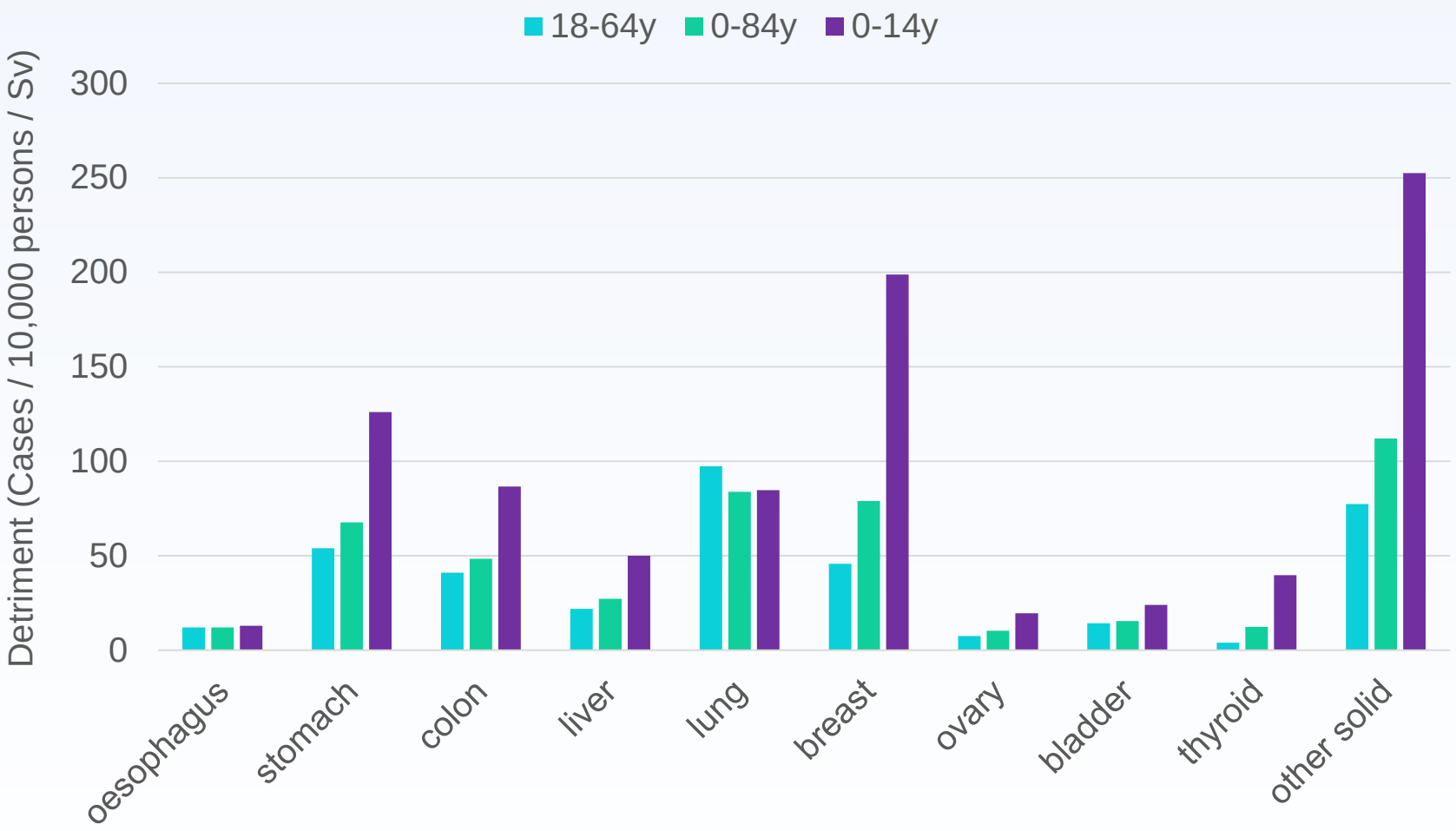
- Integration of heritable effects based on the risk estimate in the UNSCEAR 2001
- Considered genetic risks include Mendelian diseases, congenital abnormalities and multifactorial chronic diseases expressed up to the second generation.
- Heritable effects are introduced in the detriment as an add-in to the nominal risk due to cancer

- In the recent years, new findings have been obtained, including epigenetic inheritance. An updated review of the scientific literature on radiation and heritable effects is recommended.

Potential Evolution: Variation with sex and age

- Age at exposure has a large impact on radiation detriment. In particular, an **exposure during childhood** brings significantly high lifetime risks for most cancer sites compared to adult exposure, which therefore results in a larger calculated detriment value than that for adult exposure.
- **In-utero exposure** not taken into account in the detriment calculation
- Differences due to sex are also notable for some tissues, with the most extreme examples of **the ovary and the breast**. It is advisable to calculate detriments for both sexes and selected ages, and they should be averaged only in the last stage to obtain a nominal value.
- The relative contribution of each cancer site to the global detriment varies considerably with sex and age. These variations are not considered in the current $\mathbf{W_T}$ set.

Impact of Age at Exposure



Potential Evolution: Exposure scenario

- The **risk of childhood exposure** is not well represented in the two existing exposure situations (whole population and adult workers). The inclusion of adults in the detriment calculation dilutes and offsets the high lifetime risks in children. Consequently, the difference in the detriment is less pronounced when the whole population and the adult workers are compared.
- With the use of DDREF, the detriment for an acute exposure averaged over the whole population is assumed to be equivalent to that for a lifelong continuous exposure of an individual. Similarly, the detriment of workers represents a constant occupational exposure throughout the working life. **Scenarios of chronic exposure** would be possible.
- It is suggested that the dose for the detriment calculation should be **0.1 Gy** to show it is intended for the low-dose, low-dose-rate exposure.

Potential Evolution: Consideration of non-cancer effects

- In recent years, evidence has accumulated that some non-cancer diseases, particularly **circulatory disease and cataract** may be induced at much lower doses than previously considered. In *Publication 118* (ICRP, 2012), the Commission proposed to classify these diseases as 'tissue reactions', with a threshold of 0.5 Gy independent of dose rate.
- The Commission has not decided to include circulatory disease and/or cataract in the calculation of detriment, but it remains an open question, which requires consideration in a broad context.
- If these effects were to be included, a detailed calculation of lifetime risk appears highly challenging.

Potential Evolution: Transparency and comprehensibility

- Calculation of radiation detriment consists of many steps in which a wide range of information is processed, including risk models, health statistics along with various other parameters. It will be increasingly important to accurately **document and publish the calculation procedure** for ensuring transparency and **traceability**. It may be desirable to develop and share an open-source code for calculating detriment.
- The detriment calculation is oriented to the assessment of the global health impact of radiation. However, the resultant values are **not easy to comprehend**, and it is difficult to compare them with other commonly-used health risk indices.
- It is desirable to improve the presentation so that the make-up of radiation detriment becomes **more comprehensible to non-specialists**. Graphical presentation of key components of detriment would give a wider, balanced perspective on health effects of radiation..

Conclusions 1

Calculation of radiation detriment

- The concept of radiation detriment was first introduced in the ICRP Publication 26 (ICRP, 1977). The methodology and scope has evolved over time to consider new scientific knowledge about the harmful health effects of radiation exposure at low doses.
- The calculation process of radiation detriment consists of two main parts. The first part is the calculation of nominal risks, which is an estimate of the lifetime risk of stochastic effects averaged over sex, age and population. The second part is the calculation of detriment in which the nominal risk is adjusted for severity. The second part is independent of radiation dose.
- Although the Annex A of *Publication 103* (ICRP, 2007) explains the data and models for the detriment calculation, the details were not fully documented and part of the calculations are difficult to reconstruct today.
- The detriment is calculated as a weighted mean of the severity-adjusted lifetime risk attributable to radiation exposure. Justification for averaging the variations with sex, age and population could be better explained.

Conclusions 2

Sensitivity of detriment

- The sensitivity analysis was not applicable to bone and skin cancer, to leukemia and to heritable effects.
- Impact of **DDREF**: the choice of DDREF value directly affects the detriment.
- Impact of **age-at-exposure**: detriment for the young age-at-exposure group (0–14 years) is higher than that for a whole population (0–84 years). The difference is more than twice as large in some cancer sites, i.e. stomach, breast, thyroid and other solid.
- Impact of the **transfer model**: varying impact of ERR-based model and EAR-based model for different cancer sites
- Impact of **Lethality**: updated data and approaches to be considered

Conclusions 3

Suggestions for future improvement

- To calculate detriment for both sexes and selected ages, and to average only in the last stage.
- To make calculations for chronic exposure scenarios.
- To update the approach based on evolution of cancer incidence and treatment and on progress in scientific understanding of radiation health effects – to update and improve reference population data and cancer severity parameters – to consider new cancer risk models (LSS and other epidemiological studies, risk models for the bone, skin, brain, salivary glands).
- To consider and justify whether or not to include non-cancer effects in radiation detriment.
- To ensure transparency and traceability of detriment calculation, and to improve understanding by non-specialists.

Agenda

Papers for scientific journal

- Historical review and calculation methodology
- Sensitivity analysis

TG Report

Final version for validation by the MC – summer 2019

Public consultation – Automn 2019

Publication - 2020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