Radiation detriment calculation methodology: review of current non-radiation-related parameters and perspectives

Ludovic Vaillant[1], Michiaki Kai[2], Michael Hauptmann[3]

[1] Nuclear Protection Evaluation Centre (CEPN), Fontenay-aux-Roses, France (Ludovic.vaillant@cepn.asso.fr)
[2] Oita University of Nursing and Health Sciences, Oita City, Japan (kai@oita-nhs.ac.jp)
[3] Institute of Biostatistics and Registry Research, Brandenburg Medical School Theodor Fontane, Neuruppin, Germany (michael.hauptmann@mhb-fontane.de)

Health effects associated with ionising radiation exposure are classified into two categories: harmful tissue reactions and stochastic effects. The impact of stochastic effects is reflected by the radiation detriment, whose calculation is based on the sum of lifetime risk from several cancers weighted by the severity of these cancers, and integrates the possibility of heritable effects. The detriment concept was elaborated in ICRP Publication 60 (ICRP, 1991) and revised in ICRP Publication 103 (ICRP, 2007).

Detriment calculation methodology

Calculation methodology and perspectives on the evolution of radiation detriment have been reviewed recently by ICRP Task Group 102 on Detriment Calculation Methodology. The TG performed an in-depth review of detriment calculation as presented in ICRP Publication 103, detailing each step of detriment calculation, associated parameters, models and hypothesis. The TG also identifies ways for potential improvement of the calculation methodology with regards to the development of the future ICRP General Recommendations.

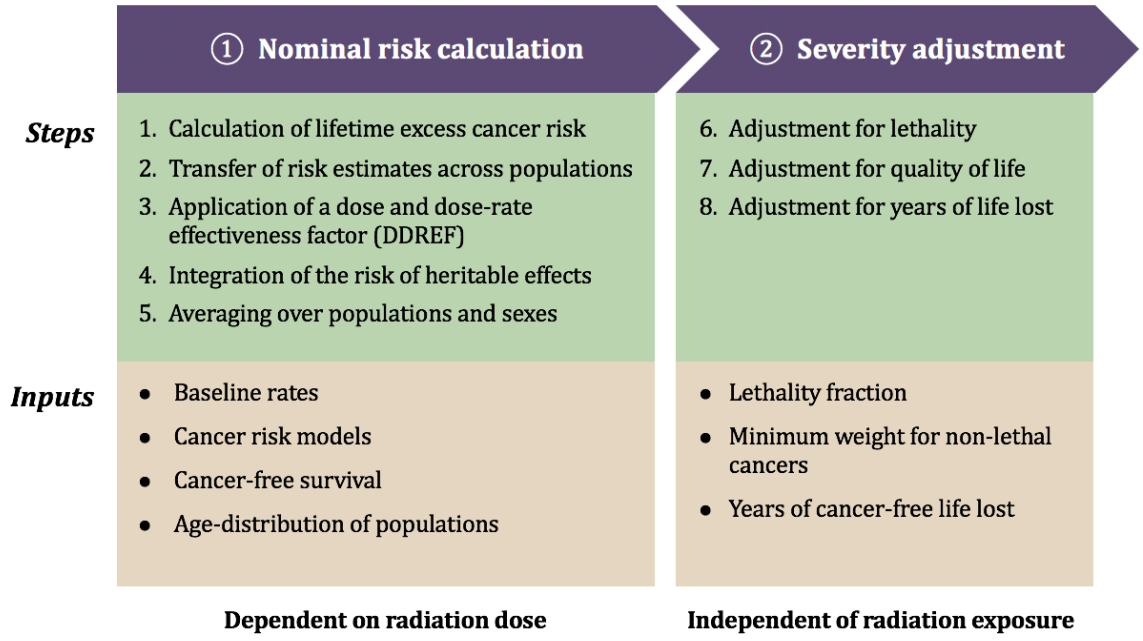

Figure 1. Detriment calculation methodology: an overview of the different steps

Detriment calculation is a 2 step process as detailed in Figure 1 (Clero et al, 2019). Step 2, severity adjustment, allows to derive organ/tissue detriment starting from nominal risk coefficients.

The overall radiation detriment is calculated as an unweighted sum of the 14 tissue/organ specific detriments.

The result is shown in Table 1 (in terms of the number of cases per 10,000 persons per Sv). Radiological detriment represents a theoretical estimate of the severity-adjusted number of excess cases per unit dose of radiation. Sv is used to express the radiation dose since the radiation detriment is intended for the purpose of radiological protection at low doses and low dose rates.

Table 1. Construction of radiation detriment from nominal risk coefficients for the whole population (ICRP, 2007)

Organ/tissue	Nominal risk coefficient[a]	Lethality fraction	Min weight for non-fatal cancers	Non-fatal case weight	Relative cancer free life lost	Radiation detriment[b]	Relative radiation 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	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	1.000

[a] Cases per 10,000 persons per Gy.

[b] Cases per 10,000 persons per Sv.

Radiation detriment calculations: severity adjustment aspects

For each organ/tissue, the radiation detriment $\mathbf{D_T}$ is calculated as

$$\mathbf{D_T = R_T[k + q(1 - k)] \times l}$$

$\boldsymbol{R_T}$ is the nominal risk coefficient for tissue/organ T. Since the nominal risk coefficient for an organ/tissue is calculated based on the excess incidence, the lethality fraction ***k*** is applied to take account of cancer severity.

Lethality fractions are derived as judgement-based values reflecting the impact of medical treatment for cancers by site. In Publication 60 (ICRP, 1991), the choice of the values was based on the analysis of two sets of data from the US SEER program: 5-year survival rates by cancer site for 1980-1985 and 20-year survival rates for 1950–1970 (US DHHS, 1989). ***k*** values were updated in Publication 103 (ICRP, 2007) based on SEER data for 1994–1999 (5-year survival) and 1979–1999 (20-year survival). The same values were applied to males and females.

l reflects the relative years of cancer-free life lost, with a value of less than 1 for cancers occurring late in life (e.g. 0.71 for bladder cancer or 0.80 for lung cancer) and more than 1 for those occurring early in life (e.g. 1.63 for bone marrow or 1.29 for thyroid and breast cancers).

$\boldsymbol{q}$ is the quality of life factor, expressed as $\boldsymbol{q} = \boldsymbol{q}_{\mathbf{min}} + \boldsymbol{k}(\mathbf{1} - \boldsymbol{q}_{\mathbf{min}})$where ***k*** is the lethality fraction and $\boldsymbol{q}_{\mathbf{min}}$ is a factor representing the minimum weight for non-lethal cancers. $\boldsymbol{q}_{\mathbf{min}}$ is a judgment-based parameter. The value of $\boldsymbol{q}_{\mathbf{min}}$ is equal to 0.1 except for the skin and thyroid. The $\boldsymbol{q}_{\mathbf{min}}$ adjustment has an impact upon radiation detriment calculations in proportion to the fraction of cancers that are non-lethal. Accordingly, highly lethal cancers such as lung and stomach cancer are less affected by $\boldsymbol{q}_{\mathbf{min}}$ compared to less lethal cancers such as breast or thyroid. No $\boldsymbol{q}_{\mathbf{min}}$ adjustment is used for skin cancer because radiogenic skin cancers (i.e. non-melanoma skin cancers) are almost exclusively of the basal cell type, which is usually associated with very little pain, suffering or treatment sequelae. For thyroid cancer, $\boldsymbol{q}_{\mathbf{min}}$ is set to 0.2.

Consideration for the update of radiation detriment methodology

The Commission recognized that the radiation detriment calculation methodology needs to be revised (Clement et al., 2021).

Update of numerical parameters

The current methodology should be updated to reflect the evolution of scientific knowledge of risks (nominal risk calculation) and expert judgement concerning lethality, quality of life, and years of life lost (severity adjustment). As an example, recent data from SEER indicates that 5-year relative survival for breast cancer has continuously increased since the 1980s (https://seer.cancer.gov/statfacts/html/breast.html). The same trend is observed for lung and bronchus and stomach cancer (Figure 1).

These data illustrate the changes over time, particularly during the last 20-30 years, and outline the need for an update of k values (among other parameters such as Year of Life Lost per cancer site) which were used in Publication 103[1] (in Publication 103 '*sex-specific, all-stage relative survival statistics from the US SEER programme for 1994–1999 (5-year survival) and 1979–1999 (20-year survival) were averaged to compute overall relative survival rates for different cancer sites*').

[1] Lethality fraction k used for radiation detriment calculation is based on a combination of 5 and 20-year survival values. 5-year survival percentage are provided here as an illustration for the need for updating values.

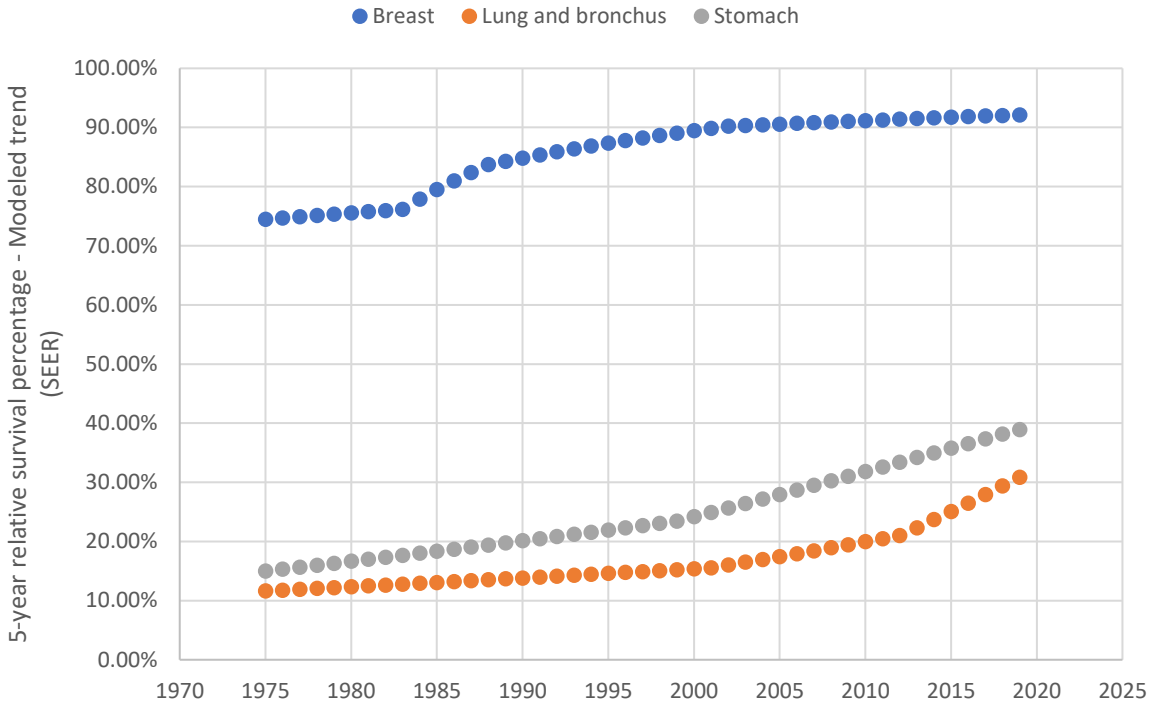

Figure 1. **5-year relative survival percentages (modeled trend) for breast cancer, lung and bronchus cancer and stomach cancer (SEER)**

In addition to ***k*** values, Years of Life Lost (YLL) per cancer site should be updated as well in order to adjust ***l*** values used for relative detriment calculation.

Update of the current approach for severity adjustment

While there is a need for updating numerical values which are required to implement detriment methodology calculations as described in Publication 103, the Commission will also give consideration to alternative ways to calculate the detriment as an expression of harm. In particular, the use of disability-adjusted life years (DALY) as a measure of radiation-induced harm will be examined.

(Shimada, 2015) investigates the use of DALY as a measure of radiation risk. An advantage over the ICRP detriment is that DALY can sum the risk of fatal and non-fatal cancer using a well-developed methodology based on available data. The DALY is widely used in public health and environmental risk assessment ,whereas the ICRP detriment is only used for radiological protection. Another characteristic is that DALY is expressed by a unit of year and more understandable than the detriment as a severity-adjusted probability. Also, (Shimada, 2015) indicates that *'DALY is a practical tool that can compare many types of diseases encountered in public health*. […] *DALY may be a promising risk measure for effective radiation protection.'*

WHO[2] assesses the overall burden of disease by using the DALY concept which they describe as a time-based measure that combines years of life lost due to premature mortality (YLL) and years of life lost due to time lived in states of less than full health, or years of healthy life lost due to disability (YLD). One DALY represents the loss of the equivalent of one year of full health. Using DALYs, the burden of diseases that cause premature death but little disability (such as drowning or measles) can be compared to that of diseases that do not cause death but do cause disability (such as cataract causing blindness).

[2] https://www.who.int/data/gho/indicator-metadata-registry/imr-details/158

DALY is a measure of overall disease burden, expressed as the number of healthy years lost due to premature death and disability by disease. Mortality and morbidity are combined into a single metric. The basic formula of DALY is expressed as:

$$\mathrm{DALY} = \mathrm{YLL} + \mathrm{YLD} = \mathrm{N_m} \times \mathrm{LE} + \mathrm{N_i} \times \mathrm{DW} \times \mathrm{YD}$$

With

DALY	Disability adjusted life year (year)
YLL	Years of life lost due to premature mortality (year)
YLD	Years lived with disability (year)
N_m	Number of deaths (person)
LE	Standard life expectancy at age of death (year/person)
N_i	Number of incident cases (person)
DW	Disability weight
YD	Mean years of disability (year/person)

The concept of DALY can be used as a way to express radiation detriment starting from nominal risk coefficients. Adequate values for DALY per cancer site could be based on the Institute for Health Metrics and Evaluation (IHME) data (https://vizhub.healthdata.org/gbd-compare/). The IHME database provides, for a large set of pathologies, DALY values per sex, population and class of age.

Using a simple set of average DALY values (Huijbregts et al, 2005), Table 2 provides a crude preliminary assessment of radiological detriment using DALY as a measure of harm. The following assumptions are made:

- Skin cancer incidence is not considered,
- An average value of 11.5 DALY was considered for bone and other solid cancer categories,
- Heritable effects are associated with 43.1 DALY which is the median value for congenital anomaly in (Huijbregts et al, 2005).

Calculations show that radiation detriment is approximately equal to 9,900 DALY per 10,000 person per Sv, or D ~ 1 DALY per person per Sv.

These results are preliminary and used here as an illustration of an alternative approach for radiation detriment calculation methodology based on the concept of DALY. This should not be considered as an official ICRP recommendation or result. Future detailed work will be undertaken by the Commission in this field in the coming years.

Table 2. Expression of radiation detriment in DALY

Organ/tissue	Nominal risk coefficient[a]	$DALY_T$	Radiation detriment[b]	Relative radiation detriment
Oesophagus	15	17.9	269	0.023
Stomach	79	13.6	1074	0.118
Colon	65	8.8	572	0.083
Liver	30	22.5	675	0.046
Lung	114	16.5	1881	0.157
Bone	7	11.5	81	0.009
Breast	112	7.6	851	0.139
Ovary	11	13.3	146	0.017
Bladder	43	5	215	0.029
Thyroid	33	13.35	441	0.022
Bone marrow	42	28.3	1189	0.107
Other solid	144	11.5	1656	0.198
Gonads (heritable)	20	43.1	862	0.044
Total	715		9911	1.000

[a] Cases per 10,000 persons per Gy

[b] DALY per 10,000 persons per Sv

The use of DALY as a risk metric to express radiation detriment shows several potential advantages:

- Transparency and clarity of the approach and methodology,
- Potential for comparison of radiological risk with other risk in complex situations,
- Inclusion of non-cancer effects in radiation detriment calculation,
- Consideration of subgroups (sex, age, ethnicity) with heterogeneous burden from cancer.

Future work

This paper outlines the way to move forward with regard to the update of severity adjustment aspects of radiation detriment calculation. The first step is updating parameter values based on available data while keeping the same methodology. The second step involves the investigation of alternative methodologies to express radiation detriment. The use of the DALY concept, developed by WHO, will be further examined (among other approaches) by the Commission.

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