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CENTRE D'ÉTUDE SUR L'ÉVALUATION DE LA PROTECTION DANS LE DOMAINE NUCLÉAIRE

# Radiation detriment: evolution of its estimation and its role in the RP system

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# Introduction

- Radiation health detriment: introduced in 1973 by the International Commission on Radiological Protection (ICRP) in its Publication 22 and adopted in its general recommendations in 1977 (Publication 26)
- Defined as:

  *« The total harm to health experienced by an exposed group and its descendants as a result of the group's exposure to a radiation source. » (ICRP Pub. 103)*

- Directly derived from the LNT model
- A key role in the implementation of the ICRP radiation protection system: justification, optimisation and limitation principles

# Objectives

- Explain the scientific and ethical foundations of the health detriment
- Give an historical perspective of its construction from ICRP Publication 26 to 103
- Put into perspective with other occupational or public fatal risk
- Discuss its application and the issues at stake

# Content

- Introduction of the concept in the 70's
- Evolution of the detriment in ICRP Publication 60
- Recent evolution in ICRP Publication 103
- Discussion on its application
- Concluding remarks

# Introduction of the concept in the 70's

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- Radiation protection aims to deal with acute and serious late effects

- Difficulties to evaluate the late effects occurring with low frequency and after exposure of large groups

- For the sake of protection, adoption of the *"conservative hypothesis of a linear relationship between biological risks and the amount of dose down to the lowest dose levels" (ICRP Pub 22)*

# Adoption of the precautionary principle: An old story!

- **ICRP Publication 9 (1965):**
  - Lack of knowledge (threshold?) on radiation induced stochastic effects below 1 Gy
  - Prudent assumption: any increase in exposure induces an increase in terms of risk
  - Expectation from ICRP to develop a dose-effect relationship to be used in the justification of the practices and the dose limitation
  - Request for introducing rationality based on risk quantification

# ICRP Publication 9

- *"The mechanism of the induction by radiation of leukaemia and other types of malignancy is not known.*
- *Such induction has so far been clearly established after doses of more than 100 rads, but it is unknown whether a threshold dose exists below which no malignancy is produced. [...]*
- *As the existence of a threshold dose is unknown, it has been assumed that even the smallest doses involve a proportionately small risk of induction of malignancies. [...]*
- *The Commission is aware that the assumptions of no threshold and of complete additivity of all doses may be incorrect, but is satisfied that they are unlikely to lead to the underestimation of risks"*

*ICRP Publication 9 § 7, 1965*

# Introduction of the concept of detriment (1)

- Necessity to balance risks and benefits
- Introduction of the concept of detriment to judge the efforts to be put on protection:
- *"(a) the detriment resulting from exposures to radiation can be made less important than the benefits to individuals and to society from activities which result in the exposures; and*
- *(b) any further reductions in detriment become less important than the effort that would be required to accomplish such reductions."*

ICRP Publication 22 § 4, 1973

# Introduction of the concept of detriment (2)

- First definition in 1973 of the Detriment (G)
- “The "detriment" in a population is defined as the mathematical concept "expectation" of the harm incurred from a radiation dose, taking into account not only the probabilities of each type of deleterious effect but the severity of the effects as well. Thus if $p_i$ is the probability of suffering the effect *i*, the severity of which is expressed by a weighting factor $g_i$, then the detriment *G* in a group composed of *P* persons is

$$G = P \Sigma_i \, p_i g_i.$$”

ICRP Publication 22 § 21, 1973

# First risk quantification in ICRP Publication 26 in 1977

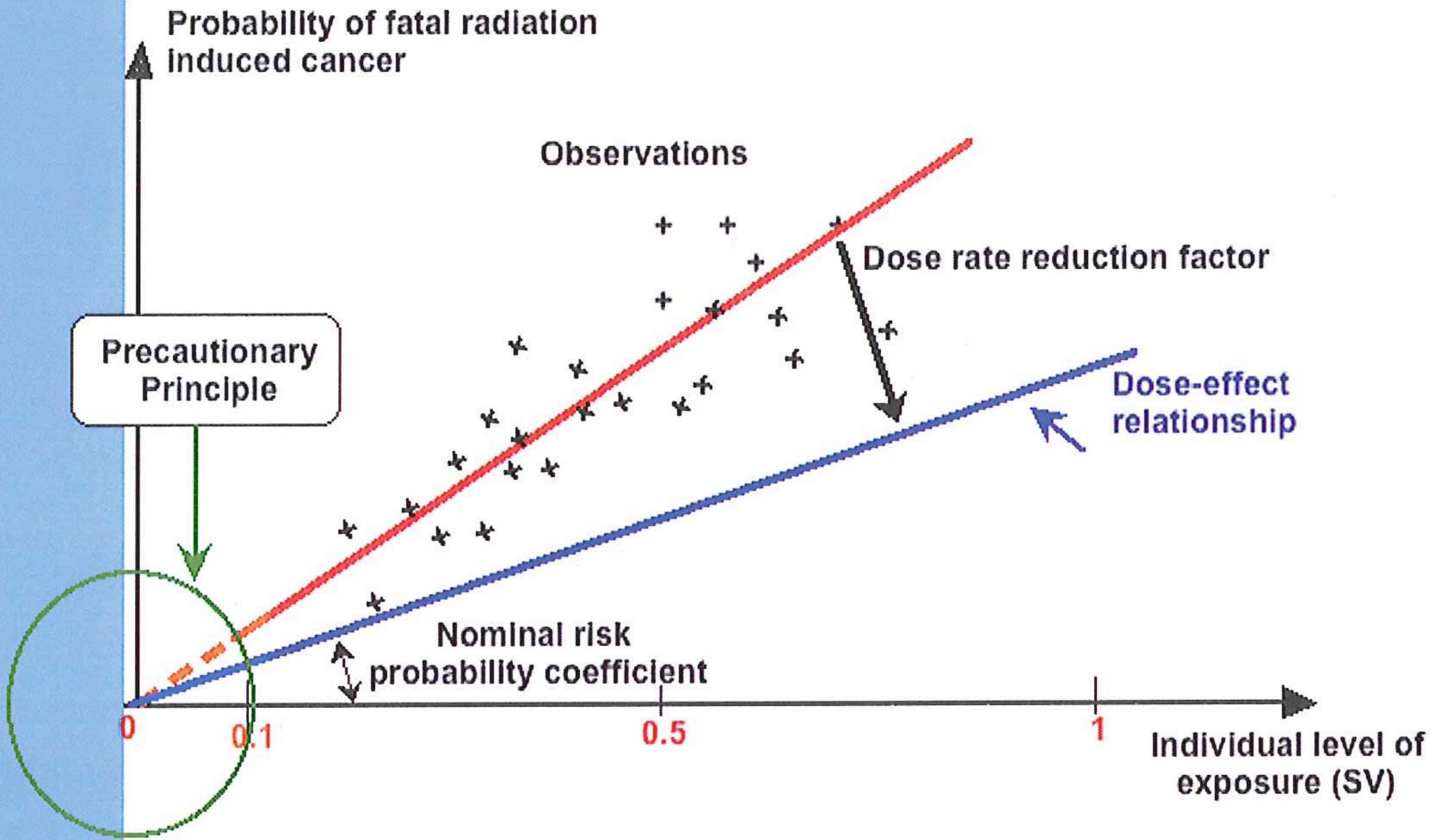
- Willingness to have a risk indicator, simple and robust:

  "dose equivalent" (*expressed in Sv* )

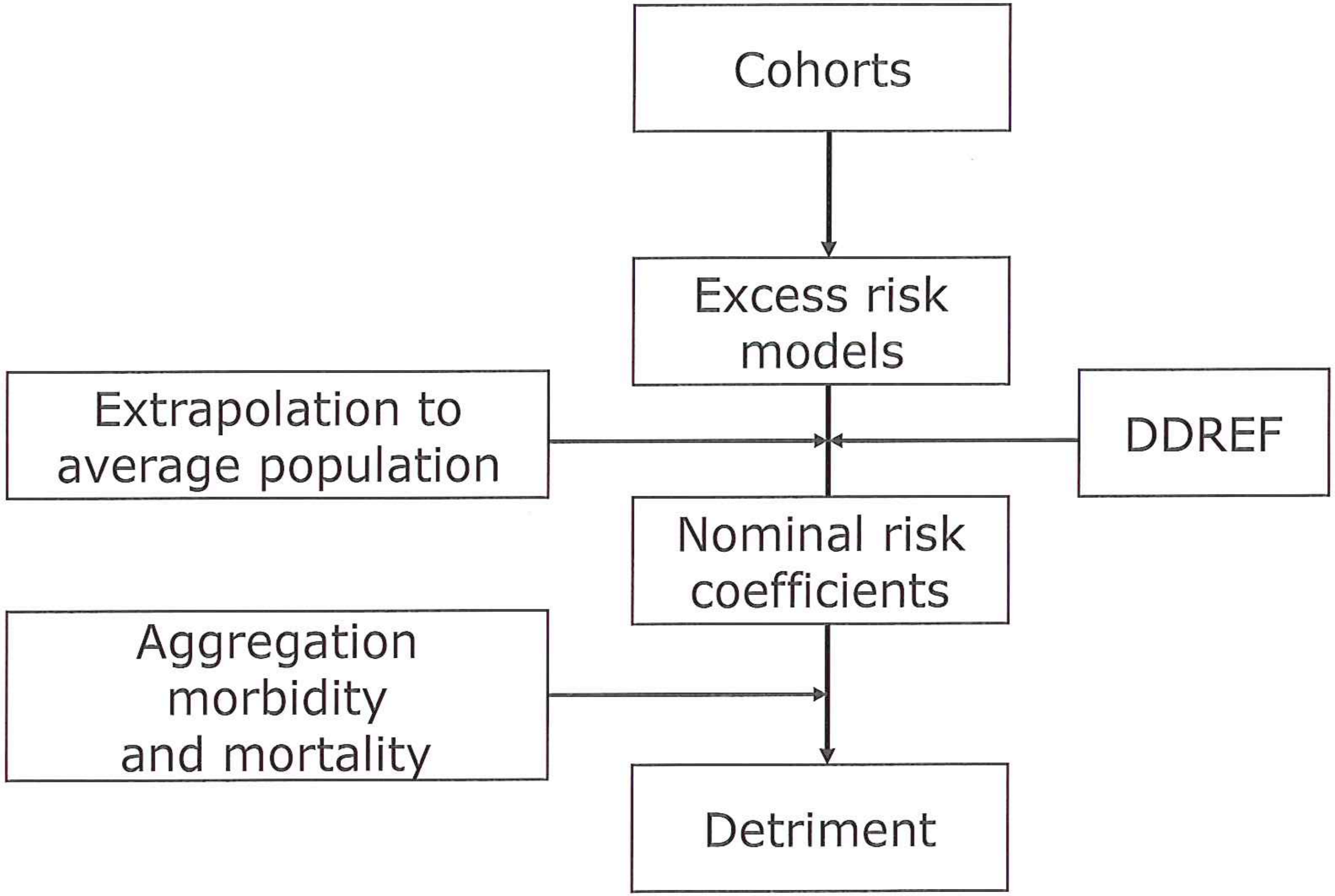
- Corresponding to the absorbed dose weighted by modifying factors to take into account the quality of radiation

- Allowing to consider a proportionality between small increments of dose equivalent and the additional detriment to health

# Assessment of radiological risk at low doses and low dose rates



# Construction of the detriment concept



# Risk factors - ICRP Publication 26

| Tissue, organ | Type of effects - Risk factor of fatal effects | |
|---|---|---|
| Gonads | Serious hereditary effects: | $4.10^{-3}$ $Sv^{-1}$ |
| Red bone marrow | Leukaemia: | $2.10^{-3}$ $Sv^{-1}$ |
| Bone | Bone cancer: | $5.10^{-4}$ $Sv^{-1}$ |
| Lung | Lung cancer: | $2.10^{-3}$ $Sv^{-1}$ |
| Thyroïd | Thyroïd cancer: | $5.10^{-4}$ $Sv^{-1}$ |
| Breast | Breast cancer: | $2.5.10^{-3}$ $Sv^{-1}$ |
| Others | Cancer: | $5.10^{-3}$ $Sv^{-1}$ |

# Derived tissue weighting factors: $w_T$

| Tissue, organ | $w_T$ |
|---|---|
| Gonads | 0.25 |
| Red bone marrow | 0.12 |
| Bone | 0.03 |
| Lung | 0.12 |
| Thyroïd | 0.03 |
| Breast | 0.15 |
| Others | 0.30 |

# First evaluation of the radiation health detriment

- For radiation protection purposes, ICRP adopted in its Publication 26 for whole body exposures:
  - Mortality risk factor for radiation-induced cancers: about $10^{-2}$ $Sv^{-1}$ (average for both sexes and all ages)
  - Average risk factor for hereditary effects (expressed in the first two generations): $4.10^{-3}$ $Sv^{-1}$
- No significant differences for adopting separate values for workers and general public

# General principles in ICRP Publication 26 in 1977

- ***Risk-based approach*** for the recommendations:

  (*a*) *no practice shall be adopted unless its introduction produces a positive net benefit;*

  (*b*) *all exposures shall be kept as low as reasonably achievable, economic and social factors being taken into account;*

  *and*

  (*c*) *the dose equivalent to individuals shall not exceed the limits recommended for the appropriate circumstances by the Commission.*

  ICRP Publication 26, § 12, 1977

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# Calculation of dose limit for occupational exposure (1)

- Judgement of the acceptability of the level of risk in radiation work by comparing it with that for other occupations recognised as having high standard of safety:
  - Average annual mortality due to occupational hazards lower than $10^{-4}$ per year
- Taking into account the distribution of individual exposures, it is assumed that:
  - *"...where the Commission's system of dose limitation has been applied, the resultant annual average dose equivalent is no greater than one-tenth of the annual limit."*

    *(ICRP, Pub 22, § 99)*

# Calculation of dose limit for occupational exposure (2)

- Adoption of an annual dose limit of 50 mSv for occupational exposure
- Assuming to result in an average annual exposure of 5 mSv
- Corresponding to a risk of $5.10^{-5}$ per year for fatal cancers and $2.10^{-5}$ for hereditary effects

## Calculation of dose limit for public exposure

- Assumption that acceptability of risk is an order of magnitude lower for fatal risk to the general public
  - Risk in the range of $10^{-6}$ to $10^{-5}$ per year

- Based on the detriment of $10^{-2}$ $Sv^{-1}$, the restriction on the lifetime dose would correspond to 1 mSv per year

- Adoption of an annual dose limit of 5 mSv for pubic exposure, assuming to result in average dose equivalents of less than 0.5 mSv

# Evolution of the detriment in ICRP Publication 60

# Evolution of knowledge and new approach

- Reassessment of the risk according to the evolution of the scientific knowledge on the follow-up of Hiroshima and Nagasaki survivors

- Integration of morbidity and year-of-life lost in the calculation of the health detriment, reflecting public health concerns in society

- Revision of dose limits on the basis of the model of tolerability of risk – ***Risk-informed approach***

# Evolution of risk estimates for fatal cancer - DDREF 2

| | Fatal probability coefficient ($10^{-4}$ $Sv^{-1}$) | |
|---|---|---|
| | ICRP (Pub 26) | ICRP (Pub 60) |
| Bladder | - | 30 |
| Bone marrow | 20 | 50 |
| Bone surface | 5 | 5 |
| Breast | 25 | 20 |
| Colon | - | 85 |
| Liver | - | 15 |
| Lung | 20 | 85 |
| Oesophagus | - | 30 |
| Ovary | - | 10 |
| Skin | - | 2 |
| Stomach | - | 110 |
| Thyroid | 5 | 8 |
| Remainder | 50 | 50 |
| **Total** | **125** | **500** |

# Components of the health detriment in ICRP Publication 60

- Occurrence of fatal cancer (F, derived from epidemiological studies)

- Years of life lost associated with the occurrence of a fatal cancer (l/lm) *(with l: life expectancy with fatal cancer and lm: average life expectancy)*

- Morbidity associated with the occurrence of a non-fatal cancer (2-k) *(with k being the lethality fraction)*

- Serious hereditary effects

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# Expression of the health detriment in ICRP Publication 60

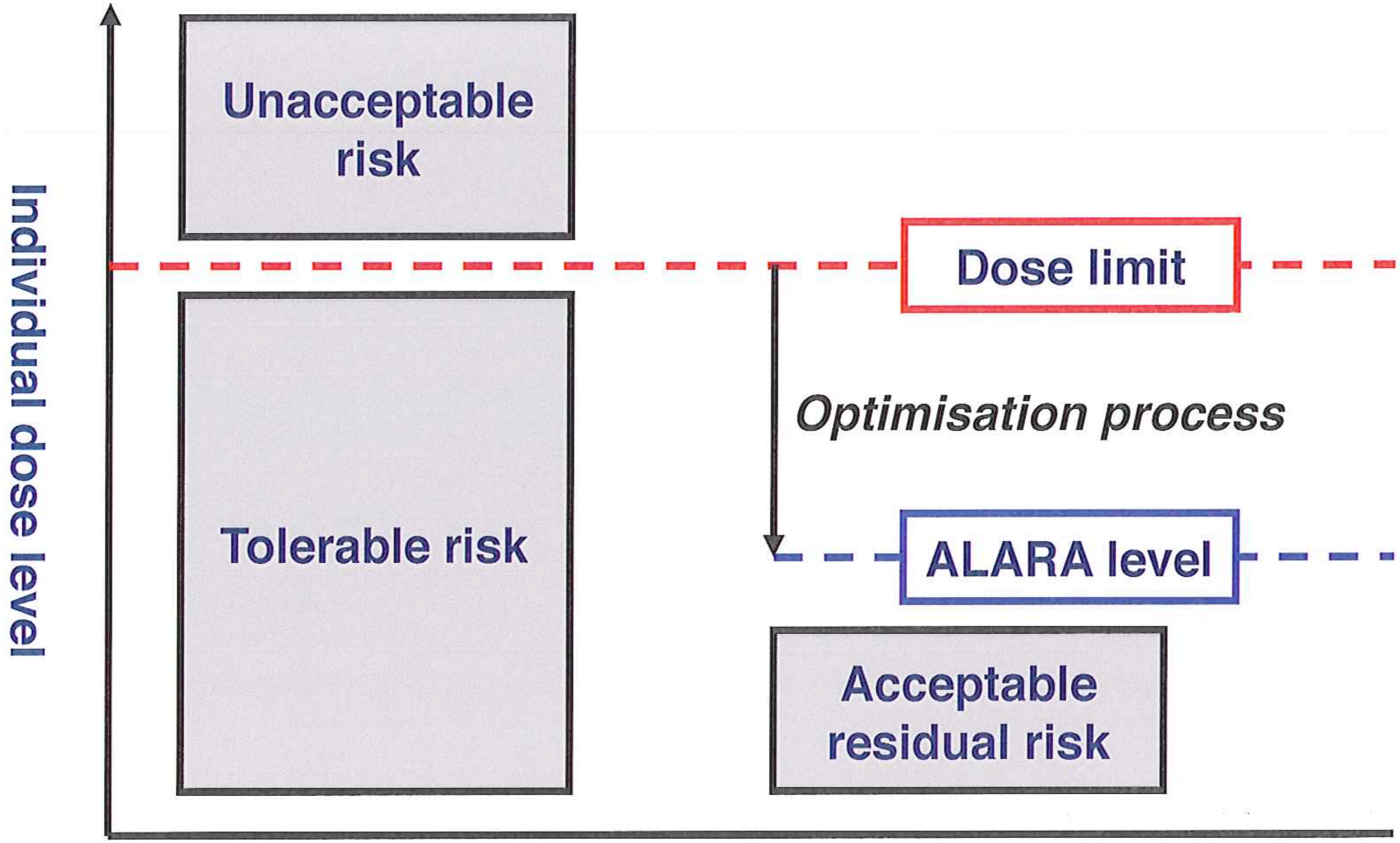
- *"if in a given tissue there are F fatal cancers, the total number of cancers is F/k.*
- *The number of non-fatal cancer is then (1-k) F/k*
- *and the total weighted detriment is (F + k((1-k)F/k) or F(2-k)".*

*ICRP Publication 60, § B117*

# Calculation of the health detriment ICRP Pub. 60

| | F ($10^4$ p.Sv) | Severe genetic effects ($10^4$ p.Sv) | Relative length of life lost l/lm | Relative non-fatal contribution | Detriment |
|---|---|---|---|---|---|
| Bladder | 30 | | 0.65 | 1.50 | 29.4 |
| Bone marrow | 50 | | 2.06 | 1.01 | 104.0 |
| Bone surface | 5 | | 1.00 | 1.30 | 6.5 |
| Breast | 20 | | 1.21 | 1.50 | 36.4 |
| Colon | 85 | | 0.83 | 1.45 | 102.7 |
| Liver | 15 | | 1.00 | 1.05 | 15.8 |
| Lung | 85 | | 0.90 | 1.05 | 80.3 |
| Oesophagus | 30 | | 0.77 | 1.05 | 24.2 |
| Ovary | 10 | | 1.12 | 1.30 | 14.6 |
| Skin | 2 | | 1.00 | 2.00 | 4.0 |
| Stomach | 110 | | 0.83 | 1.10 | 100.0 |
| Thyroid | 8 | | 1.00 | 1.90 | 15.2 |
| Remainder | 50 | | 0.91 | 1.29 | 58.9 |
| Gonads | | 100 | 1.33 | - | 133.3 |
| **Total** | **500** | | | | **725.3** |

# Risk acceptability model



# A multi-attribute approach for the selection of dose limits

| Effective dose ($mSv.y^{-1}$) | 10 | 20 | 30 | 50 | *50 (Pub.26)* |
|---|---|---|---|---|---|
| Approximate lifetime dose (Sv) | 0.5 | 1.0 | 1.4 | 2.4 | *2.4* |
| Probability of attributable death (%) | 1.8 | 3.6 | 5.3 | 8.6 | *2.9* |
| Weighted contribution from non fatal cancers (%) | 0.4 | 0.7 | 1.1 | 1.7 | - |
| Weighted contribution from hereditary effects (%) | 0.4 | 0.7 | 1.1 | 1.7 | *1.2* |
| Aggregated detriment (%) | 2.5 | 5 | 7.5 | 12 | |
| Time lost due to an attributable death given that it occurs (y) | 13 | 13 | 13 | 13 | *10 - 15* |
| Mean lost of life expectancy at age 18 years (y) | 0.2 | 0.5 | 0.7 | 1.1 | *0.3 – 0.5* |

*ICRP Publication 60, Table 5. Attributes of detriment due to exposure of the working population*

# Recent evolution

# in ICRP Publication 103

# Importance of incidence data and risk-informed approach

- Evolutions of scientific knowledge on cancer incidence lead to base the calculation of the health detriment on incidence
- Significant reduction of the part of severe hereditary effects in the health detriment
- Introduction of reference levels as guideline for managing the different exposure situations with risk considerations

# New formula to calculate the health detriment

**Publication 60** Cancer mortality-based

$$(2-k) \bullet F \bullet (l/\bar{l})$$

**Publication 103** Cancer incidence-based

$$D_T = (k_T R_{I,T} + q_T(1-k_T)R_{I,T})I_T$$

$$q_T = q_{min} + k_T(1-q_{min})$$

$q_{min} \rightarrow 0.1$

# Calculation of the health detriment ICRP Pub. 103

| | Detriment ($10^{-4}$ $Sv^{-1}$) ICRP Pub. 103 | Detriment ($10^{-4}$ $Sv^{-1}$) ICRP Pub 60 |
|---|---|---|
| Bladder | 16.7 | 29.4 |
| Bone marrow | 61.5 | 104.0 |
| Bone surface | 5.1 | 6.5 |
| Breast | 79.8 | 36.4 |
| Colon | 47.9 | 102.7 |
| Liver | 26.6 | 15.8 |
| Lung | 90.3 | 80.3 |
| Oesophagus | 13.1 | 24.2 |
| Ovary | 9.9 | 14.6 |
| Skin | 4.0 | 4.0 |
| Stomach | 67.7 | 100.0 |
| Thyroid | 12.7 | 15.2 |
| Other solid | 113.5 | 58.9 |
| Gonads | **25.4** | **133.3** |
| **Total** | **574.3** | **725.3** |

# Evolution of the quantification of the health detriment

*Probability of occurrence of a fatal cancer - $10^{-2}$ per Sv (Detriment indicator: aggregated indicator expressed in equivalent of fatal effects)*

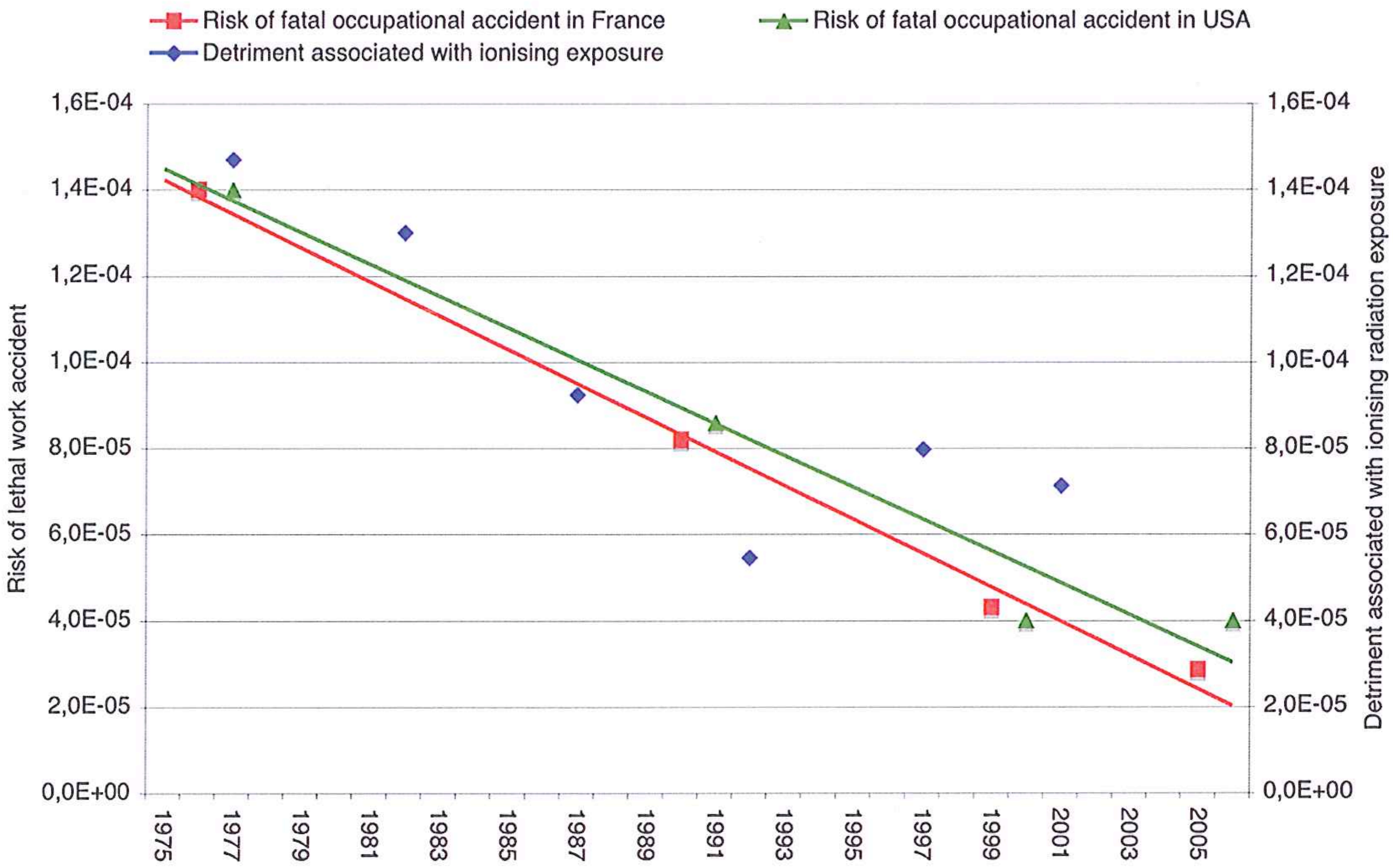
| | **1977** | **1990** | **2007** |
|---|---|---|---|
| Adults | 1.25 | 5.6 | 4.2 |
| Whole population | | 7.3 | 5.7 |

# Discussion on the application of the detriment

# A useful tool

- Health detriment as a key indicator for the radiation protection system:
  - Introduction of equivalences between different types of radiation exposures
  - Fixation of dose limits and reference levels according to the tolerability of risk
  - Contribution to the selection of protection options in the ALARA approach

# Evolution of risk associated with occupational exposures



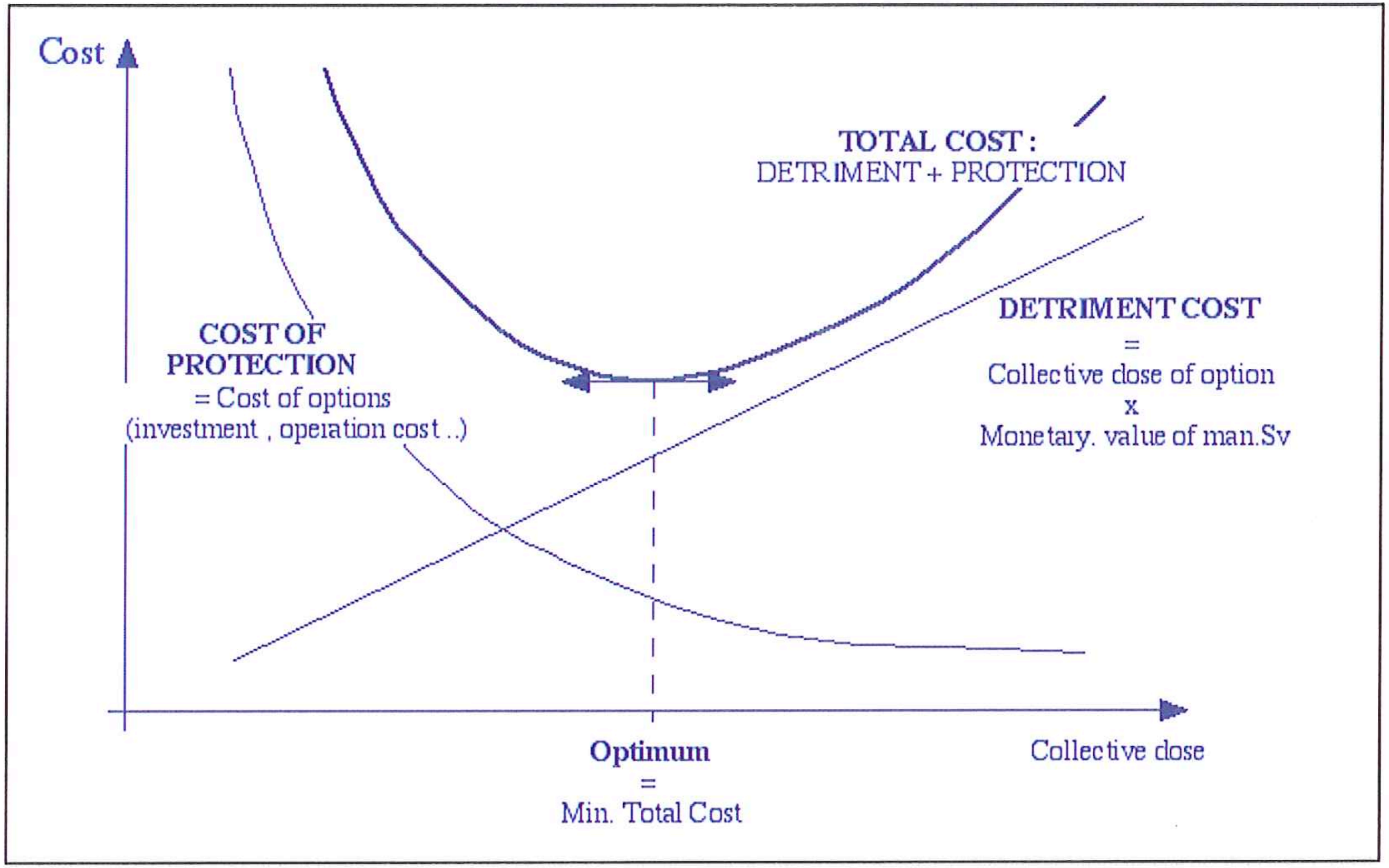
# Comparison with occupational risk due to exposure to chemical substances

**Lifetime risk associated with chemical substance exposure**

| Substances $(mg/m^3)^{-1}$ | Cancer | URE (INERIS) | Occupational limit $(\mu g/m^3)^{-1}$ (INRS) | Lifetime risk (INRS) |
|---|---|---|---|---|
| Arsenic | Respiratory | $4{,}3.10^{-3}$ | 200 | $1.21.10^{-1}$ |
| Chrome VI | Lung | $1{,}2.10^{-2}$ | 50 | $8.44.10^{-2}$ |
| Nickel (dust) | Lung | $2{,}4.10^{-4}$ | 1 000 | $3.37.10^{-2}$ |
| Cadmium | Lung, prostate | $1{,}8.10^{-3}$ | 50 | $1.26.10^{-2}$ |
| Benzene | Leukaemia | $7{,}8.10^{-6}$ | 3 250 | $3.57.10^{-3}$ |

- *Examples of risk derived from French data for 45 y of occupational exposure at the limit value*
- *For ionising radiation, 45 y of exposure at 20 mSv = $3.8 . 10^{-2}$*

# Cost/benefit analysis



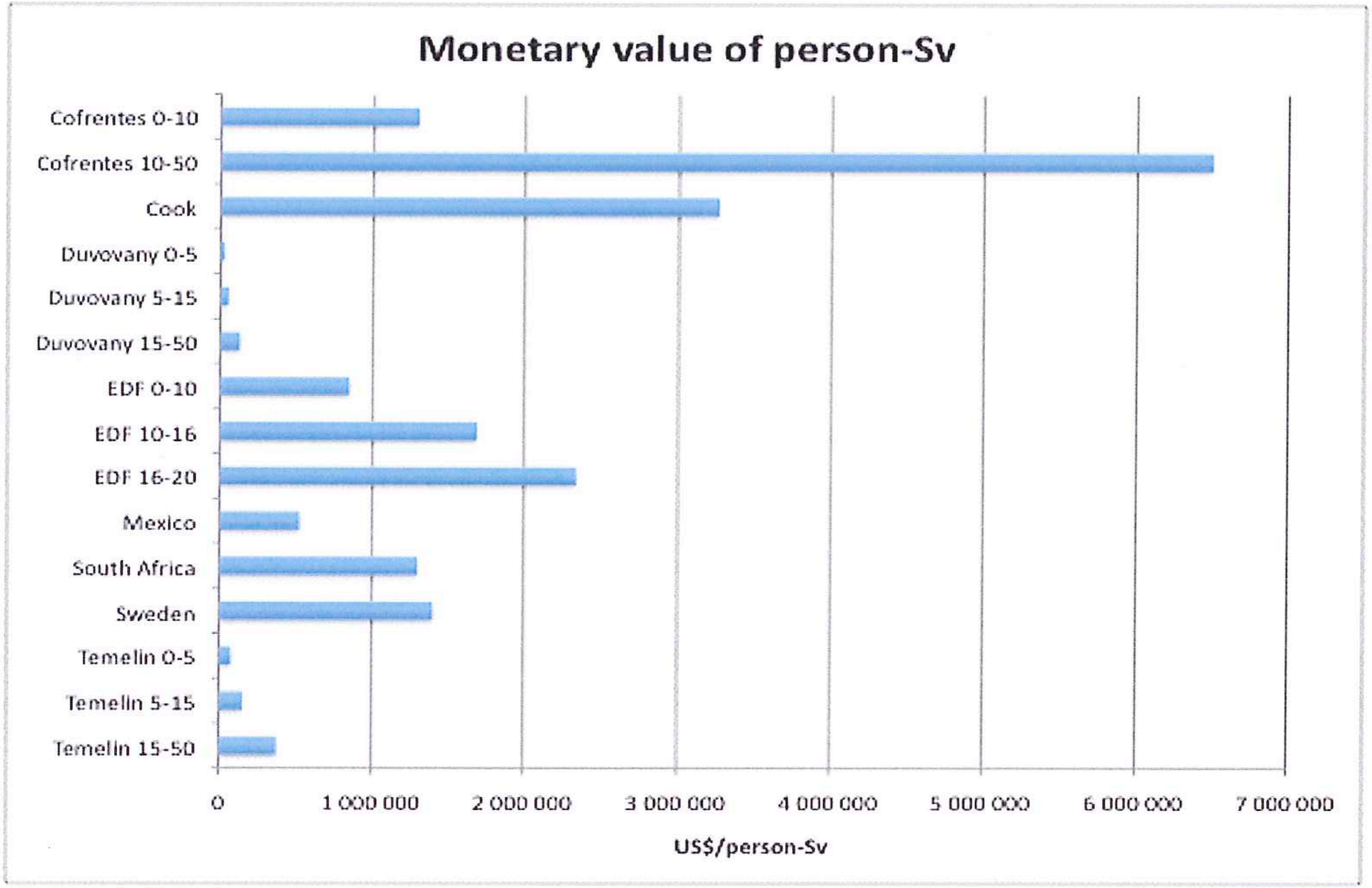
# The monetary value of the person-sievert

- Corresponds to the probability to have a radiation-induced health effect multiplied by the monetary value attributed to that health-effect
- Health effect expressed as a number of years of life lost
- Corresponds to what the utility is willing to pay to avoid 1 unit of collective dose
- Predefined value, usually set by the operator

# Example of calculation (Data from France 1999)

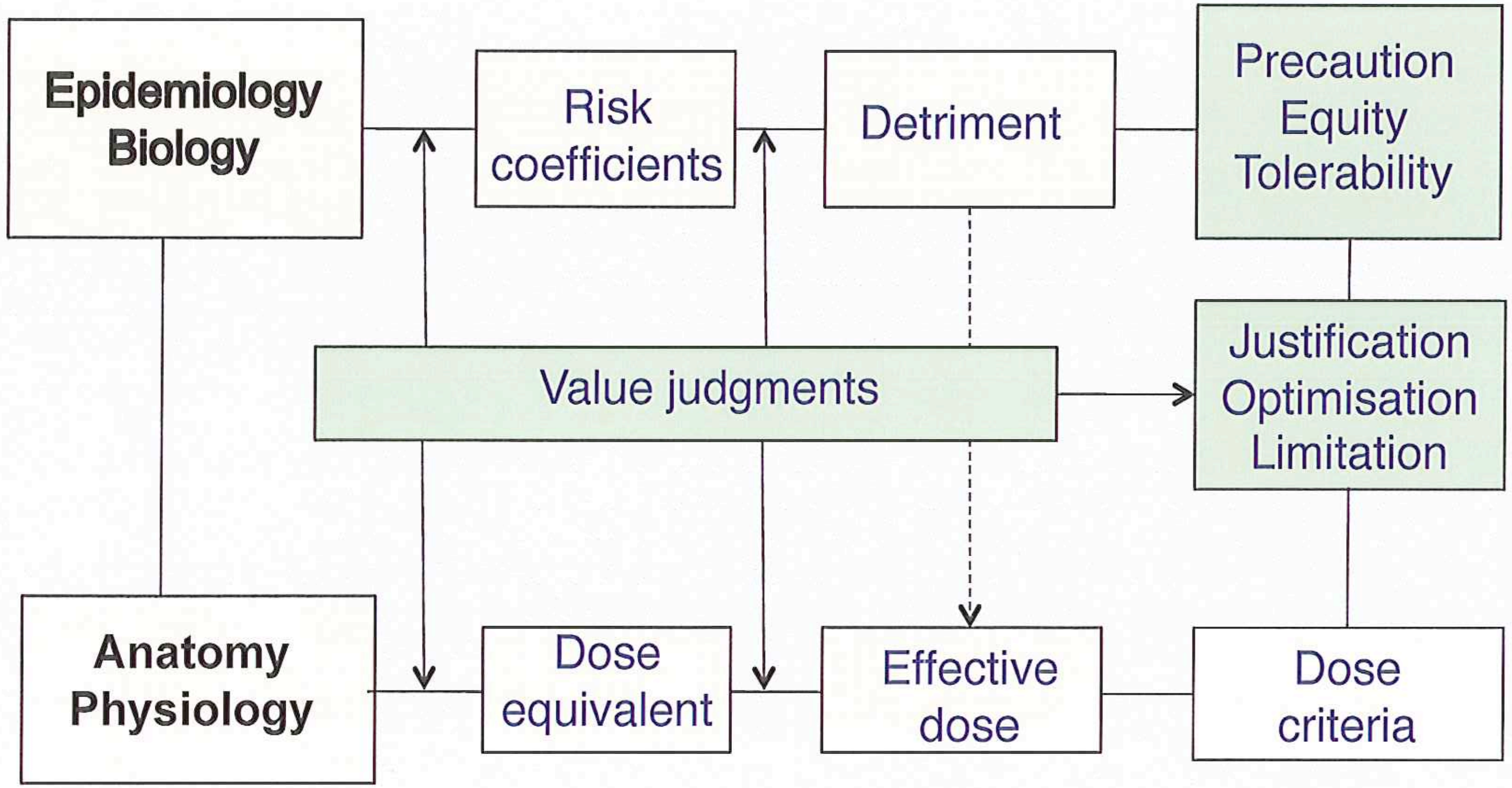
| | |
|---|---|
| Gross national product per inhabitant | 21 k€ |
| Number of years of life lost per radioinduced health effect | 16 years |
| **Monetary value of a radiation-induced health effect** | **16 x 21 = 0.34 M€** |
| Probability of health effect occurence (value) | 5.6 x $10^{-2}$/Sv |
| **Monetary value of radiation-induced health effects corresponding to 1 person-sievert** | **0.34 x 5.6 x $10^{-2}$ = 19 k€ / pers.Sv** |

# Example of monetary values adopted by utilities
# Data from ISOE



# Concluding remarks

# The key elements of the radiation protection system



# Meaning of the health detriment

- An average indicator
- Dedicated to risk management
- Based on available and current scientific knowledge
- Including values judgements
- Evolving with time to take into account new knowledge and values