

Cost of Life Saved in Radiological Protection

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- **ICRP – the International Commission on Radiological Protection**
- **The system of radiological protection**
Justification – optimisation of protection – application of limits
- **The importance, or otherwise, of the cost of life-saving**
CBA – non-parametric methods – common sense – collective dose matrix
Dose and risk constraints on optimisation
- **Some problematic issues**



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ICRP



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ICRP: Produces Recommendations

- Established in 1928

- Objectives

prevent deterministic harm

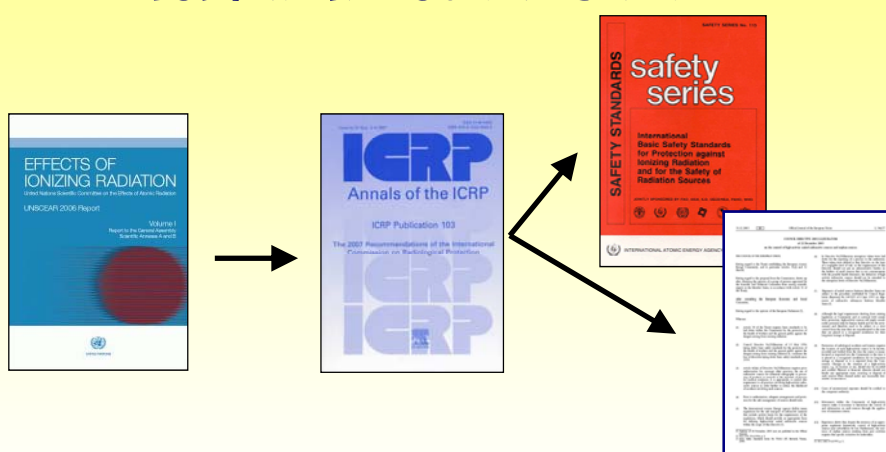
‘minimise’ stochastic harm – doses as low as reasonably achievable



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ICRP in The Cosmic Scheme



UNSCEAR Reports
on doses and effects

Science

ICRP
Recommendations

Policy

UN, EU Basic
Safety Standards

Regulations



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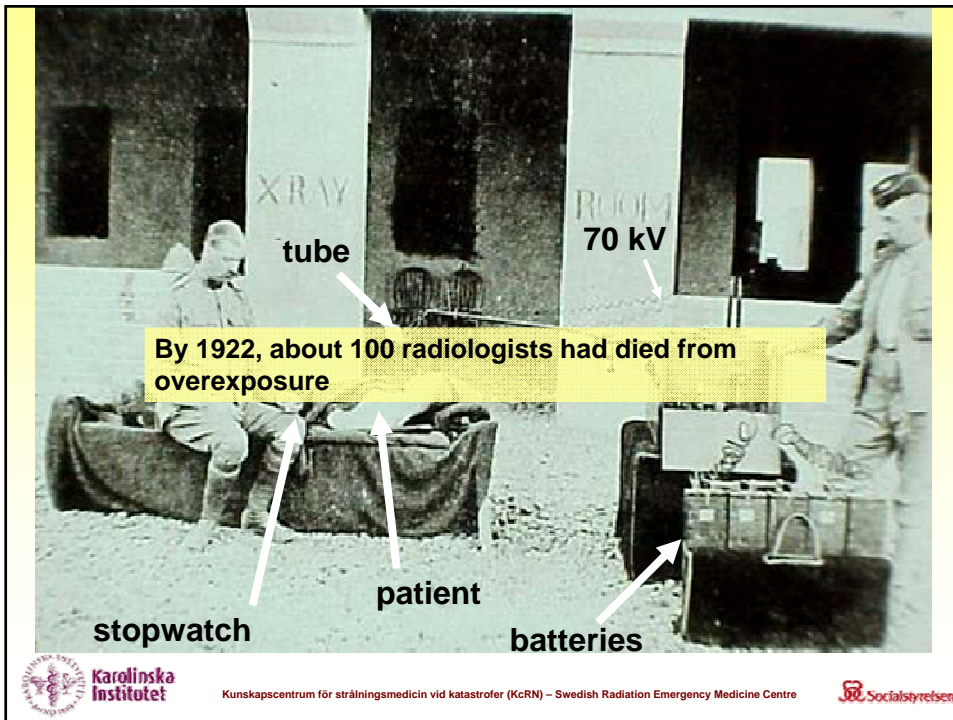


The System of Radiological Protection



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Early ICRP Recommendations

- **At first: Occupational exposures in medicine**

Avoid deterministic harm

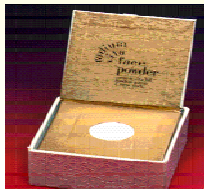
1928: Working hours limited (~1000 mSv)

1934: ~500 mSv

- **Then: All occupational exposures**

1950: ~150 mSv

Spirit of the time: Radiation good, safe thresholds, no environmental concerns



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However, Things Changed

Accelerators

Reactors

**Fallout from weapons testing
'The Lucky Dragon'**

1950: IXRPC re-named 'ICRP'

**1955: Excess leukaemia observed
in Hiroshima, Nagasaki survivors**

**Radiation – a concern for
members of the public**



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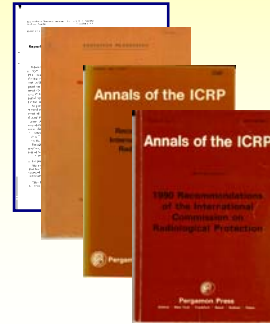


Further ICRP Recommendations

- **Then: All human exposures**
*Avoid deterministic and **minimise stochastic** harm*
1956/59: Publ. 1, 50 mSv workers; 5 mSv public
1966: Publ. 9, reduce doses if readily achievable
1977: Publ. 26, ...if reasonably achievable
1990: Publ. 60: 20 mSv, 1 mSv

System of protection developed:

- **Justification**
More benefit than detriment
- **Optimisation of protection**
Doses As Low As Reasonably Achievable
- **Application of dose limits**



Optimisation in Publication 26 (1977)

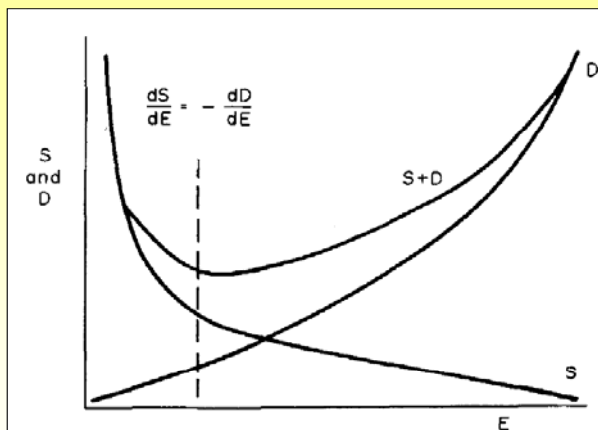


FIG. 1. Differential cost-benefit analysis.

E = a variable reflecting the exposure, possibly in man-rems,
 S = total cost of achieving a value of E ,
 D = total cost of detriment associated with a value of E .

Optimisation in Publication 26 (1977)

- **Cost of protection**
How much does it cost to remove 20 man.Sievert?
- **Cost of detriment**
How much does it cost to be exposed to 20 man.Sv
= How much does it cost to lose 1 statistical life
- **Optimum = lowest sum of the two costs**
Always below dose limit
Taking account of social & economic factors



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Assessing The Marginal Cost of Life-Saving

- **The minimum level: production loss**
Up to ~1 MUSD
- **The stakeholder choice: willingness to pay**
Claimed WTP: can be ~10 MUSD
Actual WTP: can be ~5 MUSD
- **The maximum level: per caput allocable funds**
In the order of ~100 MUSD?



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Typical Marginal Cost of Life-Saving

- **Recommended, Swedish Radiation Protection Authority 1997**
Up to ~4 MUSD
- **Licensee willingness to pay**
Nuclear industry: Up to ~10 MUSD
Medical sector: Unspecified, but much less
- **Road traffic safety authority 2007**
Up to ~4 MUSD



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Optimisation in Publication 37 (1983)

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COST-BENEFIT ANALYSIS IN THE OPTIMIZATION OF RADIATION PROTECTION

where R_0 is the maximum effective dose-equivalent rate, which would be incurred by a hypothetical receptor located in contact with the external face of an initial minimum thickness shield for practical shielding design. R_0 can be taken to be the maximum dose-equivalent rate at the point of occupancy being considered outside the shielding—in any case, ($R_0 \ll R_1$).

$R_0(w)$ is the shielding dose building factor;

μ is the dose attenuation coefficient;

w is the thickness of the extra shield;

$R_0(w) e^{-\mu w}$ is, therefore, the maximum effective dose-equivalent rate against the face of the extra shield;

ρ_j is the ratio between the average effective dose-equivalent rate, to which individuals in a group j of people are exposed, and the maximum effective dose-equivalent rate;

t is the lifetime of the installation;

f_j is the occupancy time factor of a group j of exposed people; it denotes the fraction of time during which individuals in group j are exposed to radiation from the source;

$L_j \rho_j R_0(w) e^{-\mu w}$ denotes the average effective dose equivalent incurred by members of the group j as a result of the construction of the extra shield, and

N_j is the number of people in the group.

(A.9) The objective function can then be formulated as:

$$U = \mu R_0(w) e^{-\mu w} \sum_j N_j f_j \rho_j + X_p M$$

which should be minimized with respect to thickness.

(A.10) The optimum thickness can be determined by differentiating the objective function with respect to w and setting it equal to zero:

$$\mu R_0 \sum_j N_j f_j \rho_j e^{-\mu w} \left(\frac{dR_0(w)}{dw} - \mu R_0(w) \right) = X_p M = 0$$

Therefore, the optimum dose reduction factor of a simple wall-type shielding of a selected material will be obtained when:

$$e^{-\mu w} = \frac{X_p M}{\mu R_0 \sum_j N_j f_j \rho_j \left(\frac{dR_0(w)}{dw} - \mu R_0(w) \right)}$$

The above equation provides a solution for a value of w , assessing the optimum extra thickness, w_o , that is to be added to the initial shield thickness.

(A.11) It could also have been assumed that the individual dose distribution varies through the optimization process. This might occur if the shield thickness could change substantially as a result of optimization, thus modifying operational parameters as a result of different working practices through a thicker or thinner shield. The problem could conceptually be solved by assuming that the ratio, ρ , between average and maximum dose rates will be a function of the

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REPORT OF COMMITTEE A

shield thickness, w . In that case, the objective function introduced in para. A.9 will be as follows:

$$U = \mu R_0(w) e^{-\mu w} \sum_j N_j f_j \rho_j + X_p M$$

Therefore, the optimum dose reduction factor will be:

$$e^{-\mu w} = \frac{X_p M}{\mu R_0 \sum_j N_j f_j \rho_j \left(\frac{dR_0(w)}{dw} - \mu R_0(w) \right)}$$

ANNEX A₁

Numerical Example of Optimization of Radiation Protection by the Design of a Simple Shield

(A.1) A numerical example of optimization of a simple shield in a "hot" corridor of a laboratory is presented. It is assumed that the shield material is standard concrete and that its installed cost is 100 \$ m⁻². The value of μ is assumed to be 10⁻³ (man Sv)⁻¹. The gamma-radiation energy is about 0.7 MeV, so that the effective attenuation coefficient is ~14 m⁻¹. The value of ρ is assumed to be 10⁻². The total time of exposure (i.e. the lifetime of the installation times the occupancy factor) is taken to be 30 years. The number of people working is assumed to be one worker per 14 square metres of shield surface. The maximum effective dose-equivalent rate without extra shielding, R_0 , is taken to be 0.05 Sv y⁻¹ (5 mSv y⁻¹).

(A.2) Under the above assumption and using the expression in para. A.7, an optimum dose reduction factor can be obtained:

$$e^{-\mu w} = \frac{X_p M}{\mu R_0 \sum_j N_j f_j \rho_j}$$

$$= \frac{10^2 \$ \text{ m}^{-2} \cdot 15 \text{ m}^2 \text{ man}^{-1}}{10^3 (\text{man Sv})^{-1} \cdot 14 \text{ m}^{-1} \cdot 5 \cdot 10^{-2} \text{ Sv y}^{-1} \cdot 0.1 \cdot 20 \text{ y}}$$

Thus, $e^{-\mu w} = 0.1$

Therefore, the optimum dose reduction factor becomes 10⁻¹. This means that in this example it is worthwhile, as a design objective, to reduce the limit dose rate (i.e. that ensuring compliance with the dose limits) by a factor of ten.



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Optimisation in Publication 37 (1983)

- **Cost-benefit analysis** (worked examples)

CBA is not the only quantitative method

Optimisation is not just the quantitative information



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Collective Dose: Logical, But Is It Right?

**Equates
many small doses to
few large doses...**

**Are 500 road traffic
casualties just as bad as
500 victims of one
plane crash?**



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The Importance, or Otherwise, of The Cost of Life-Saving



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Optimisation in Publication 55 (1990)

- **Optimisation = decision aiding**
- **‘Have I done all that I reasonably can’**
Safety culture
- **Different quantitative methods**
Differential CBA (explicit cost of life-saving)
Multi-attribute utility analysis (implicit cost of life-saving)
Multi-criteria outranking analysis (-''-)



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Optimisation in Publication 60 (1991)

- **Practices: ALARA, but restricted by dose constraints**
 - Occupational: Dose constraints often = dose in well-managed operations*
 - Public: Dose constraints must allow for other sources*
 - Potential exposures: Apply risk constraints*
- **Interventions**
 - Justify: The benefit of each protective action must exceed its disadvantages*
 - Optimise: Choose method, scale, duration that maximises the benefit*
 - Time of withdrawal is also part of the optimisation*



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Optimisation in Publication 101b (2006)

- **Broadening the process**
 - Invite stakeholders*
- **Apply to all exposure situation, in the same way**
- **Consider equity, safety culture**
- **Consider collective & individual dose distributions**

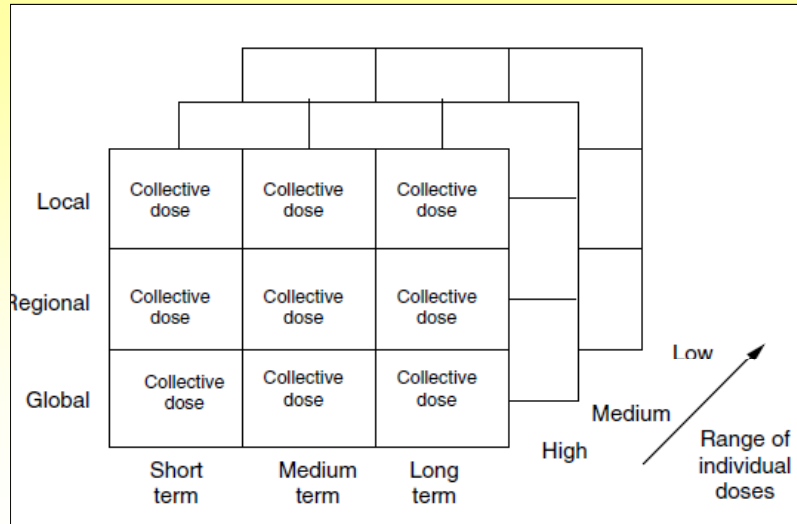


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Optimisation in Publication 101b (2006)



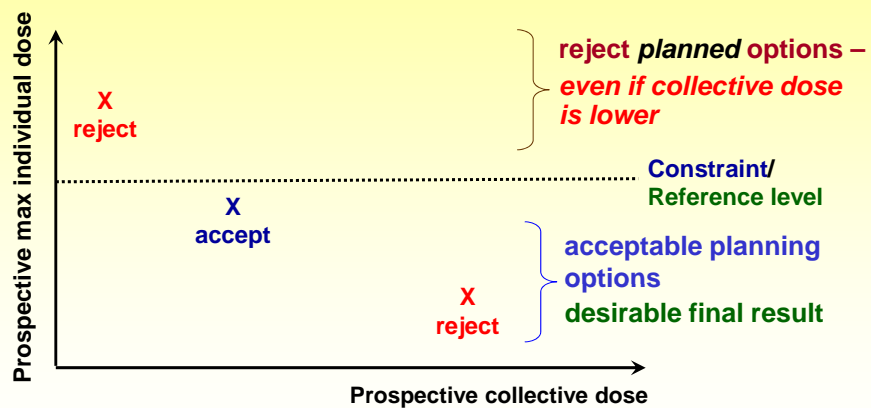
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Optimisation in Publication 103 (2007)

Planned / Emergency / Existing exposure situations



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The Principles of Protection

- **Justification**
More benefit than detriment
- **Optimisation of protection**
*Dose and risk as low as reasonably achievable –
but with constraints to:*
 - *increase equity, and*
 - *consider multiple sources*
- **Application of dose limits**
Except medical exposure of patients



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Some Problematic Issues



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Optimised Protection, Huge Absolute Cost

- **Radon mitigation might cost 3 kUSD, save 1/50 statistical life**
- **Cost of a saved life: 0.2 MUSD**
Only ~1/10 of highest recommended cost
- **A lot of money**
For individual home-owners (1 month salary after tax)
For society (if 100 000 homes, 20 000 MUSD)



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Trivial Cost, Protection Not Optimised

- **Shielding of waiting rooms at dental clinics**
An extra plasterboard = 50 USD
- **Not much money**
1 h work for an individual dentist
7500 dentists in Sweden = 0.4 MUSD for society
- **Not much effect**
Maybe 1/50 000 life saved
Cost per saved life 10 MUSD



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Potential Exposures

- **Workplace accidents**
Number of people affected is small
Detriment = health risk to those directly exposed
- **Large disasters**
Number of people affected can be large
Detriment also includes contaminated land, food restrictions, etc
- **Exposures in the far future, e.g. from waste repositories**
Considerable uncertainties
Dose calculations useful to compare protection options but not to project detriment



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Assessment of Potential Exposures

- **Everybody is responsible for safety, incl. security**
Particularly important to remember outside the nuclear fuel cycle
- **Risk constraints: guide optimisation of protection against risk (probability of death) =**
*Prob (accident) * Prob (death | accident dose)*
- **ICRP continues to recommend established generic constraints:**
Potential exposure of workers: $2 \cdot 10^{-4}$ per year
Potential exposure of the public: $1 \cdot 10^{-5}$ per year



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What Is The Size of The Risk?

ICRP Nominal Probability Coefficients (% Sv⁻¹)

Exposed population	Cancer		Heritable effects		Total detriment	
	Publ 60	2007	Publ 60	2007	Publ 60	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



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What Is The Size of The Risk?

ICRP Nominal Probability Coefficients (% Sv⁻¹)

**For practical protection purposes,
the overall risk coefficient of ~5%
is still appropriate**



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Does ICRP Over- Or *Under*estimate Risk?



So What Was The Take-home Message?

- **Optimisation is the most important aspect of protection**
Cost of life-saving is an input variable to CBA
CBA is just one of many quantitative methods
Qualitative methods may be more relevant
- **Typical marginal cost of life-saving: ~5 MUSD**
- **Optimised protection does not always mean sensible**
Radon: Optimised protection but huge absolute cost
Shielding: Sometimes, low absolute cost but little protection value
- **Potential exposures & risk constraints need attention**