HelmholtzZentrum münchen
German Research Center for Environmental Health

The ICRP Radiation Protection Framework

ARDENT Workshop
Schwarzenbruck

September 30th, 2014

Prof. W. Rühm

Institute for Radiation Protection

Helmholtz Zentrum München, German Research Center for Environmental Health

HELMHOLTZ | ASSOCIATION

INTERNATIONAL COMMISSION ON RADIOLOGICAL PROTECTION

- Founded in 1928

- Provides independent recommendations and guidance on radiological protection for the public benefit

- Considers advances in scientific knowledge, evolving social values, and practical experience

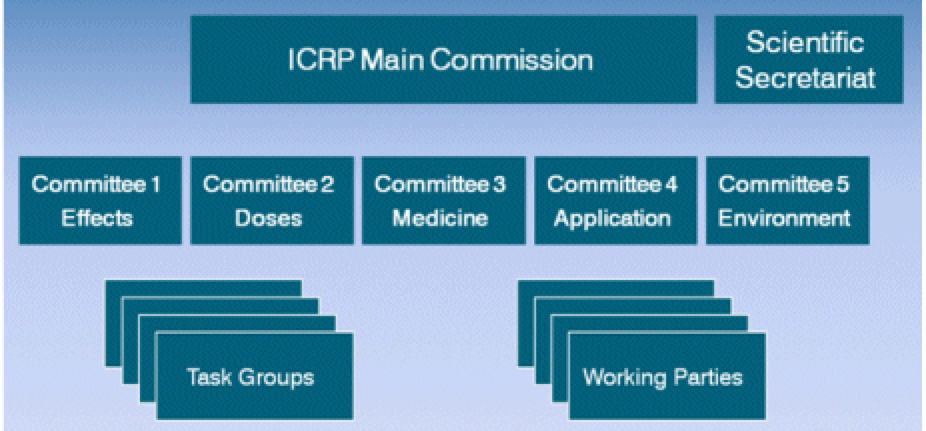
- Does not formulate standards, regulations, and codes of practice (this is the responsibility of other national and international organisations)

- **Objective: to contribute to an appropriate level of protection against the detrimental effects of ionising radiation exposure without unduly limiting the benefits associated with the use of radiation.**

Membership
- More than 200 volunteer members from over 30 countries on 6 continents
- Selected on the basis of recognised competence and experience,
- For four year terms.

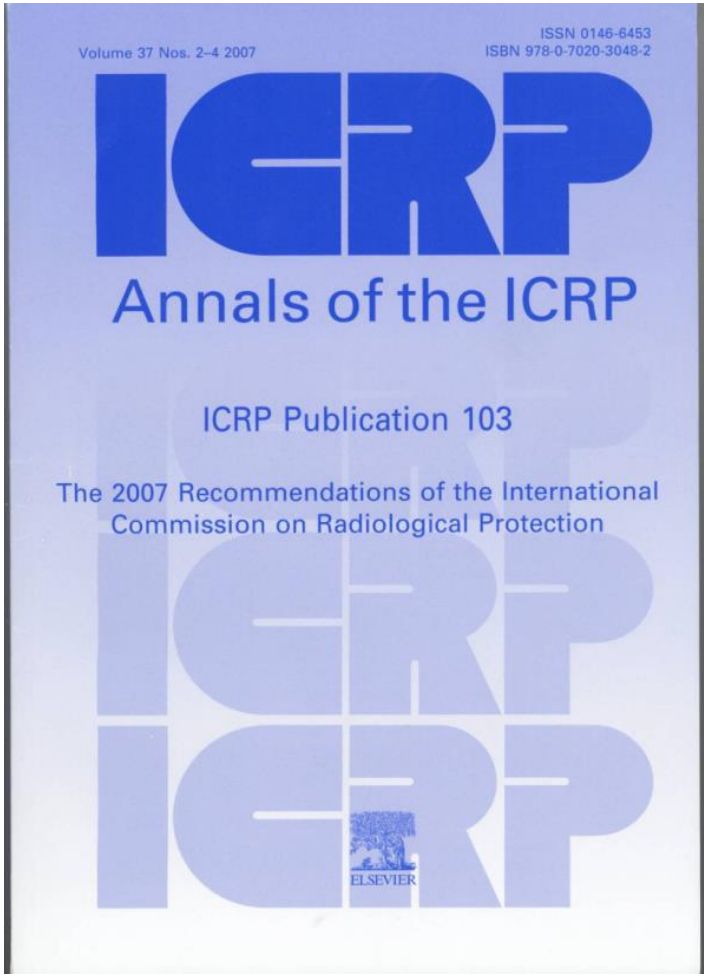
Observers
- ICRP invites observers to its Committees from the following organisations: EC, IARC, IAEA, ICRU, IEC, ILO, IOS, IRPA, NEA of OECD, UNSCEAR, WHO

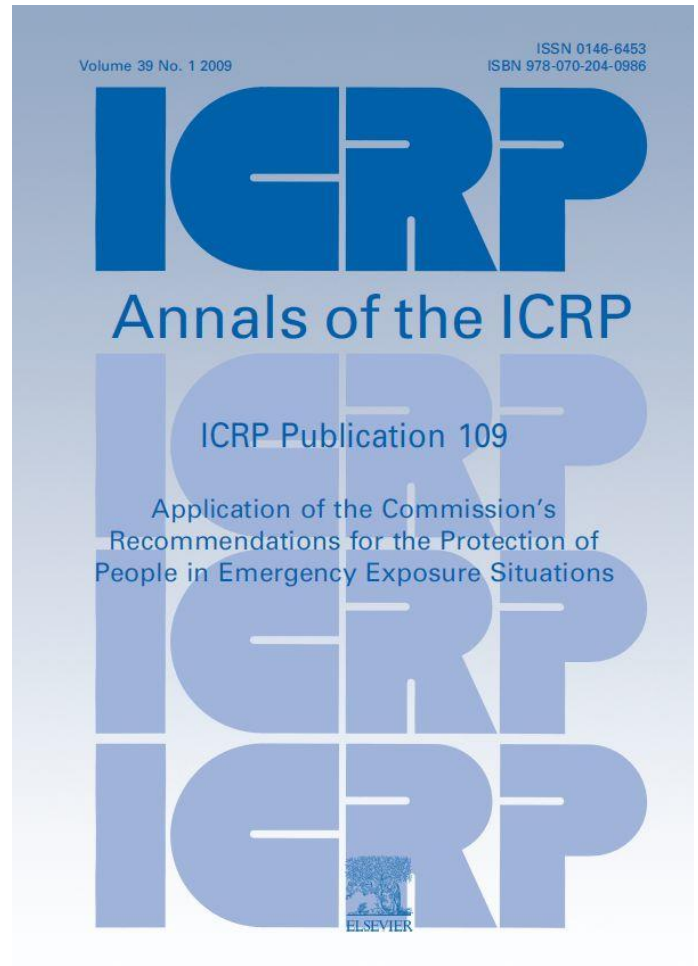
Structure

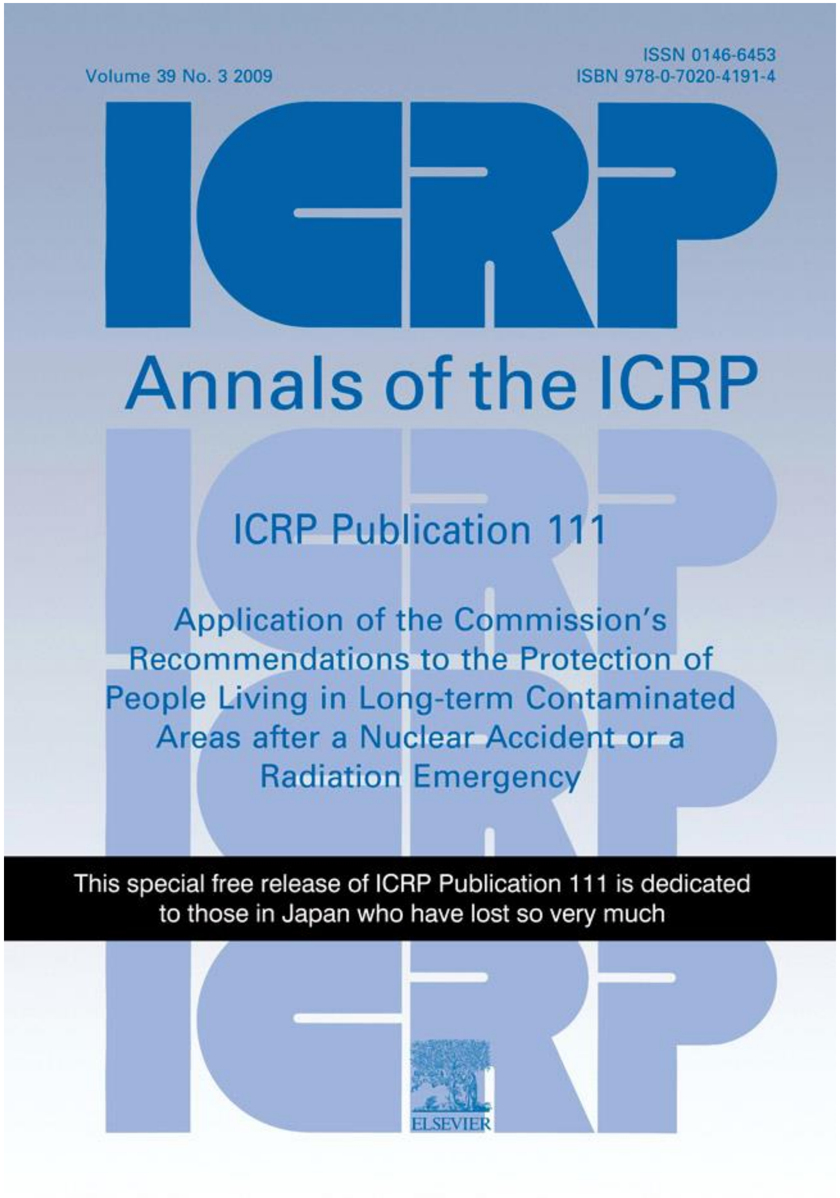


- **Main Commission** (Chair: C. Cousins)
- **Scientific Secretariat:** C. Clement
- **Committee 1: Radiation Effects** (Chair: W Morgan; Secretary: W Rühm)
  Assesses knowledge on radiation risk relevant for radiological protection
- **Committee 2: Dosimetry** (Chair: H Menzel; Secretary: J Harrison)
  Develops reference models and data, including dose coefficients
- **Committee 3: Medical Exposures** (Chairs: E Vano, JM Cosset; Secretary: M Rehani)
  Develops recommendations to protect patients, staff, and the public
- **Committee 4: Application of Recommend.** (Chairs: J Lochard, W Weiß; Secretary: J Lecomte)
  Develops principles and recommendations on radiological protection
- **Committee 5: Protection of Environment** (Chairs: J Pentreath, C Larsson; Secr.: A Real)
  Develops reference data, and guidance on protection of the environment.

Example: Major radioactive releases after the Fukuhshima accident – Guidelines by the ICRP







ICRP Publication 111

Application of the Commission's Recommendations to the Protection of People Living in Long-term Contaminated Areas after a Nuclear Accident or a Radiaiton Emergency

„This special free release of ICRP Publication 111 is dedicated to those in Japan who have lost so very much"

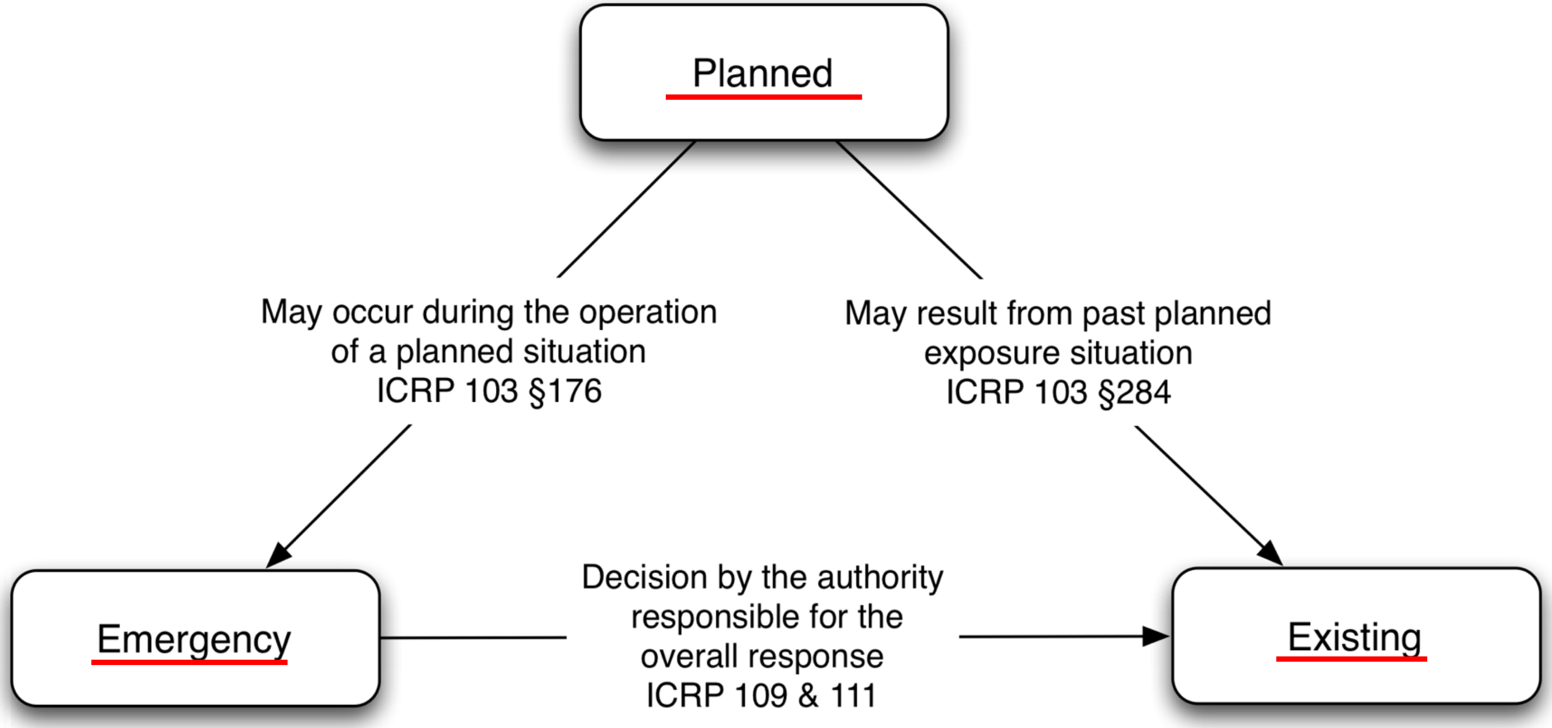
www.icrp.org

Recent Publications	Title
ICRP Publication 122	Radiological Protection in Geological Disposal of Long-lived Solid Radioactive Waste
ICRP Publication 121	Radiological Protection in Paediatric Diagnostic and Interventional Radiology
ICRP Publication 120	Radiological Protection in Cardiology
ICRP Publication 119	Compendium of Dose Coefficients based on ICRP Publication 60
ICRP Publication 117	Radiological Protection in Fluoroscopically Guided Procedures outside the Imaging Department
ICRP Publication 116	Conversion Coefficients for Radiological Protection Quantities for External Radiation Exposures
ICRP Publication 115	Lung Cancer Risk from Radon and Progeny and Statement on Radon
ICRP Publication 114	Environmental Protection: Transfer Parameters for Reference Animals and Plants
ICRP Publication 113	Education and Training in Radiological Protection for Diagnostic and Interventional Procedures
ICRU Report 84 (prepared jointly with ICRP)	Reference Data for the Validation of Doses from Cosmic-Radiation Exposure of Aircraft Crew

ICRP 103 - Three types of exposure situations

- **Planned exposure situations:**
  - planned introduction and operation of radiation sources
- **Emergency exposure situations:**
  - unexpected situation e.g. during operation of a planned situation
  - malicious event such as e.g. **nuclear accident**
  - require urgent attention
- **Existing exposure situations:**
  - already exist when a decision on control has to be taken, e.g.
    - exposure to radon in houses,
    - air crew exposure to cosmic radiation
    - exposure to naturally occuring radioactive material (NORM),
    - exposure from **past events and accidents**

Transitions between exposure situations



(Courtesy: J. Lochard, ICRP C4)

ICRP 103 - Three key principles of radiological protection

1) Principle of Justification:

„Any decision that alters the radiation exposure situation should do more good than harm“ – *source-related*

2) Principle of Optimisation of Protection

„The likelihood of incurring exposure, the number of people exposed, and the magnitude of their individual doses should all be kept **a**s **l**ow **a**s **r**easonably **a**chievable, taking into account economic and societal factors“ – *source-related* („ALARA“)

3) Principle of Application of Dose Limits:

„The total dose to any individual from regulated sources in planned exposure situations other than medical exposure of patients should not exceed the appropriate limits specified by the Commission“ – *individual-related*

Note: Principles 1 and 2 apply for all exposure situations, while principle 3 applies for planned exposure situations only

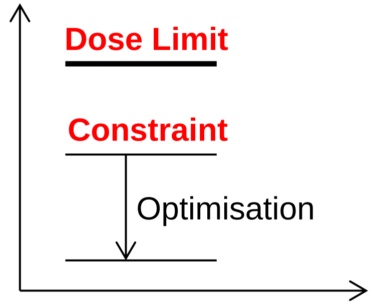
Process of Optimisation – Application of Dose Constraints and Reference Levels

Dose Limits:
- Only for planned exposure situations
- Occupational exposure: effective dose of 20 mSv/y averaged over 5 years
- Public exposure: effective dose of 1 mSv/y (averaged over 5 years)

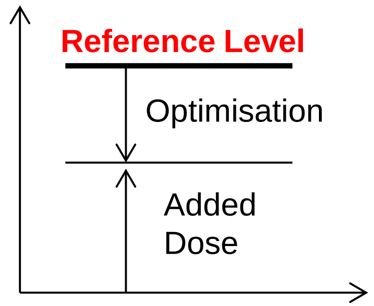
Dose constraint:
- For planned exposure situations
- Prospective restriction on individual dose from a source
- Always lower than dose limit

Reference level:
- For emergency and existing exposure situations
- Dose above which exposure is inappropriate
- Below which optimisation should be implemented
- Depends on prevailing circumstances

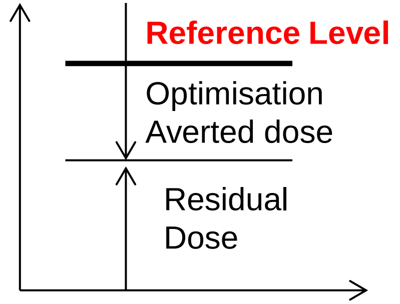
Planned Exposure



Emergency Exposure



Exisiting Exposure



Protection of the Public in case of a Nuclear Accident

- **Emergency exposure situation**

  in the range of **20–100 mSv/year**

- **Existing exposure situation**

  In the **lower part of the 1–20 mSv/year** range

  with the ultimate goal to reduce and maintain exposures **below 1 mSv/year**

Reference levels may vary depending on the scale of the accident and the local circumstances

J. Lochard (2012) Protection of people living in long-term contaminated areas after a nuclear accident: the guidance of ICRP Publication 111.
J. Radiol. Prot. 32 (2012) N95–N99 doi:10.1088/0952-4746/32/1/N95

ICRP Dose Concepts

- **Absorbed dose**: Energy deposited per unit mass

  $D = dE/dm$ SI Unit: J/kg   ICRP special name: Gy

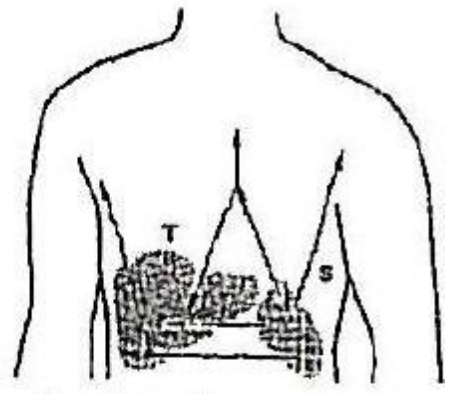
  Calculate D for tissue T and radiation R using human phantom: $D_{T,R}$

- **Equivalent dose in organ or tissue**: multiplication with radiation weighting factors

  $$H_T = \sum_R w_R \cdot D_{T,R}$$ SI Unit: J/kg   ICRP special name: Sv

Radiation Type	w_R
Photons	1
Electrons, muons	1
Protons, charged pions	2
Alphas, fission fragments, heavy ions	20
Neutrons	function with max. value 20

Internal Exposure - Use of ICRP reference phantoms



Energy deposition per unit mass in target organT (D(T)) by nuclear disintegrations in source organ S	Number of nuclear disintegrations per unit time in source organ S (activity) as a function of time $A_S(t)$

$$D(T<S) = SEE(T<S) \times A_S(t)$$

$$D(T) = \sum_S D(T<S)$$

Required information to assess SEE values (specific effective energy)

- probability, that radiation emitted in S is absorbed in T

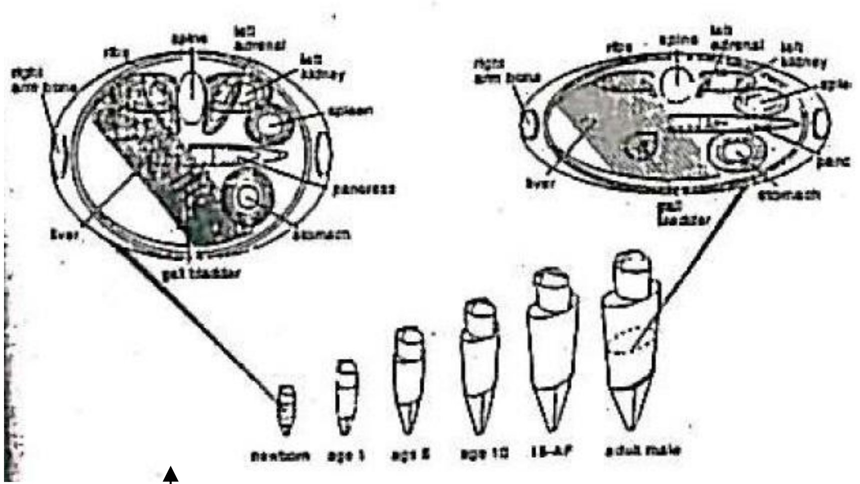
- mass of target organ T

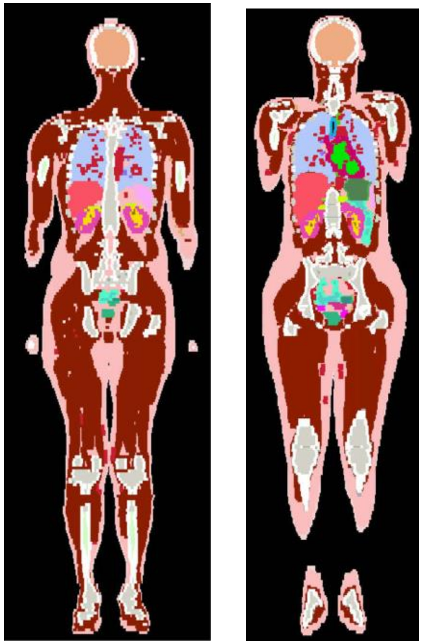
> Simulation of radiation transport in organism by means of Monte Carlo techniques

> Use of anthropomorphic phantoms of human body

  - Mathematical phantoms (old)

  - Voxel phantoms (new)





Example: Table of SEE-values for ^{137}Cs (Source: D. Nosske, BfS)

For adults, male, Unit: Sv/decay

	Brain	Breasts	Kidneys	Liver	Lung Tiss	Muscle	Thyroid
Brain	3.88E-14	2.53E-17	3.45E-18	1.09E-17	5.81E-17	1.09E-16	6.15E-16
Breasts	2.53E-17	1.30E-13	1.24E-16	3.25E-16	9.73E-16	2.07E-16	1.66E-16
Kidneys	3.45E-18	1.24E-16	1.50E-13	1.13E-15	2.97E-16	4.18E-16	3.46E-17
Liver	1.09E-17	3.25E-16	1.13E-15	3.01E-14	7.66E-16	3.18E-16	5.58E-17
Lng_Tissue	5.81E-17	9.73E-16	2.97E-16	7.67E-16	4.44E-14	3.83E-16	3.70E-16
Muscle	1.09E-16	2.07E-16	4.18E-16	3.18E-16	3.83E-16	1.89E-15	4.84E-16
Ovaries	7.54E-19	2.83E-17	3.21E-16	1.83E-16	4.37E-17	5.80E-16	5.30E-18
Pancreas	9.00E-18	2.99E-16	1.96E-15	1.39E-15	6.70E-16	5.04E-16	5.28E-17
R_Marrow	3.89E-16	2.78E-16	7.41E-16	3.86E-16	4.90E-16	4.03E-16	3.42E-16
Skin	2.16E-16	3.74E-16	2.07E-16	1.89E-16	1.96E-16	2.84E-16	2.18E-16
Spleen	1.16E-17	2.30E-16	2.64E-15	3.12E-16	6.45E-16	4.29E-16	5.01E-17
Testes	1.64E-19	0.00E+00	3.47E-17	2.04E-17	6.72E-18	4.41E-16	1.13E-18
Thymus	6.21E-17	1.19E-15	1.07E-16	2.64E-16	1.13E-15	4.48E-16	6.48E-16
Thyroid	6.15E-16	1.66E-16	3.46E-17	5.58E-17	3.70E-16	4.84E-16	2.14E-12
Uterus	6.99E-19	3.20E-17	2.99E-16	1.57E-16	3.49E-17	5.76E-16	4.99E-18

Required information to calculate $A_S(t)$

- activity as a function of time in all parts of the human body

  > biokinetics: > compartment models

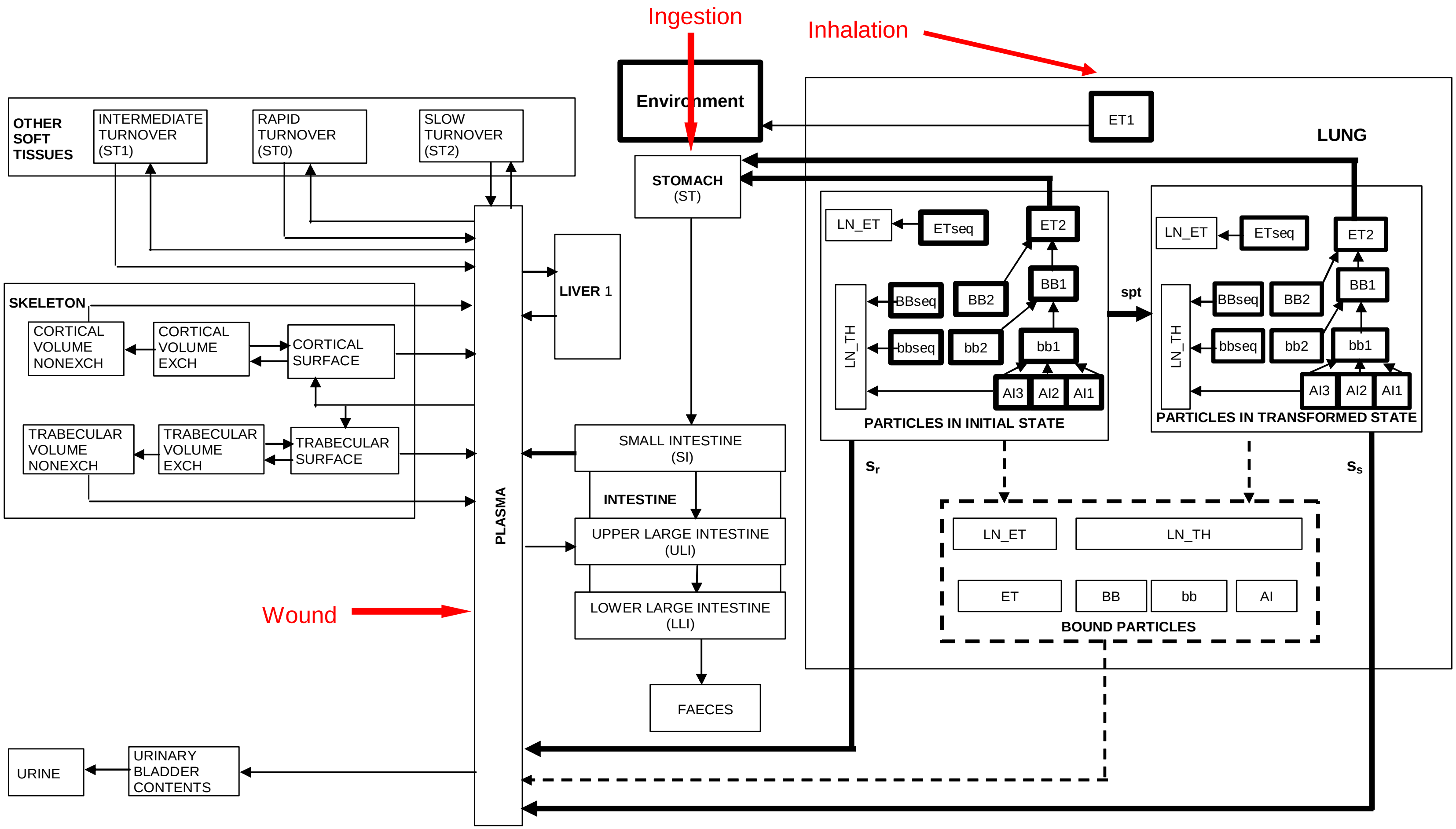
- Assumptions:
  - activity does not influence biokinetics
  - biokinetics can be described by means of exponential functions

- depends on radionuclide

- may depend on age

Biokinetic model of ICRP

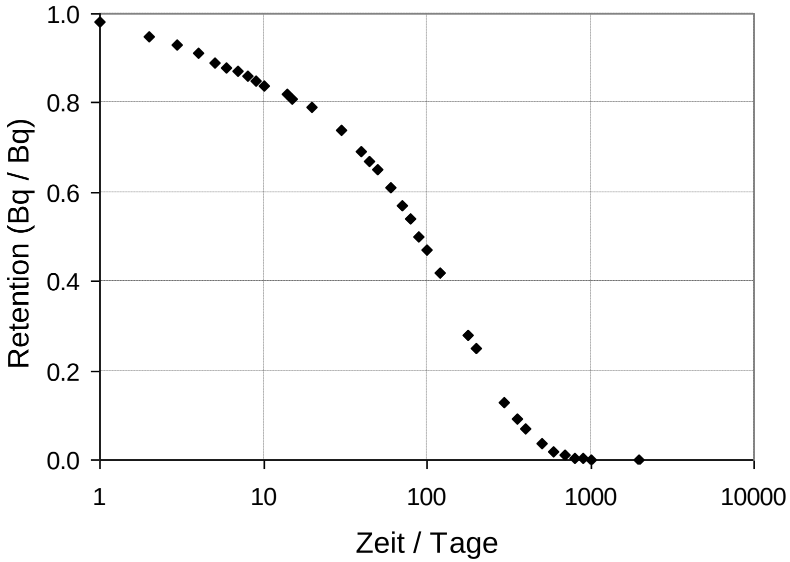
Complicated example: ^{226}Ra



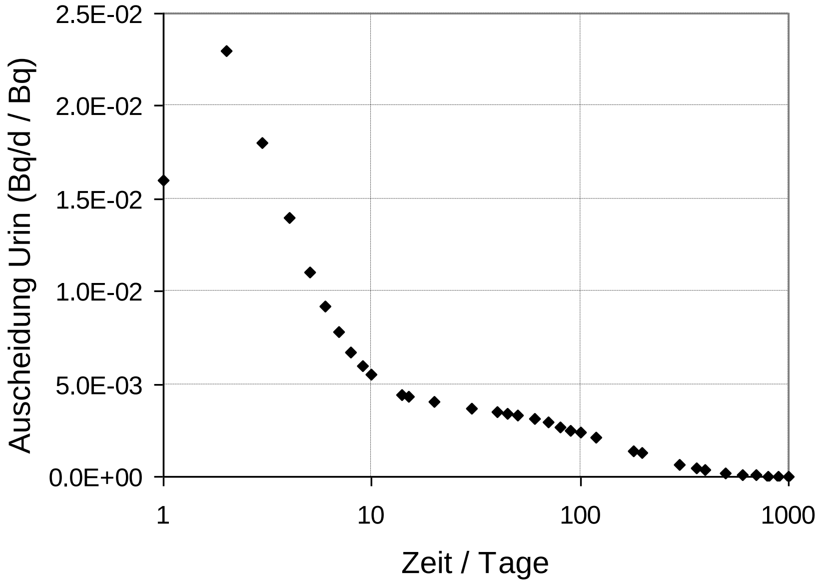
Use of biokinetic models to calculate activity in various organs and excretion as a function of time

Simple example: acute incorporation via ingestion of 1 Bq ^{137}Cs

Retention

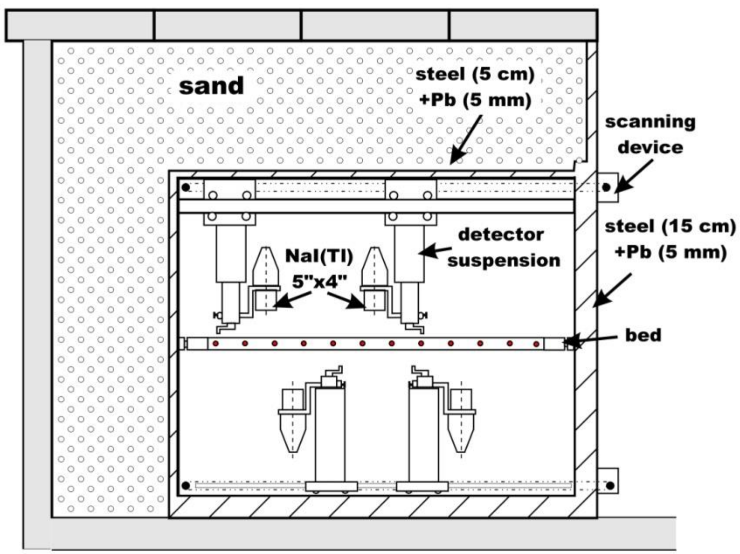


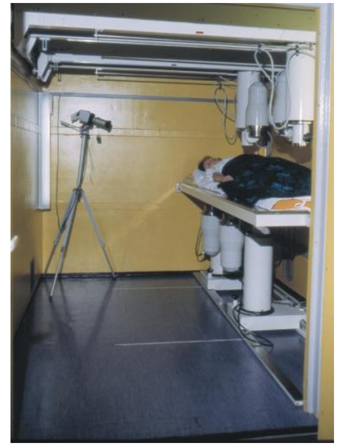
Excretion, urine



In-vivo Measurement Technique: ISS – Whole Body Counter

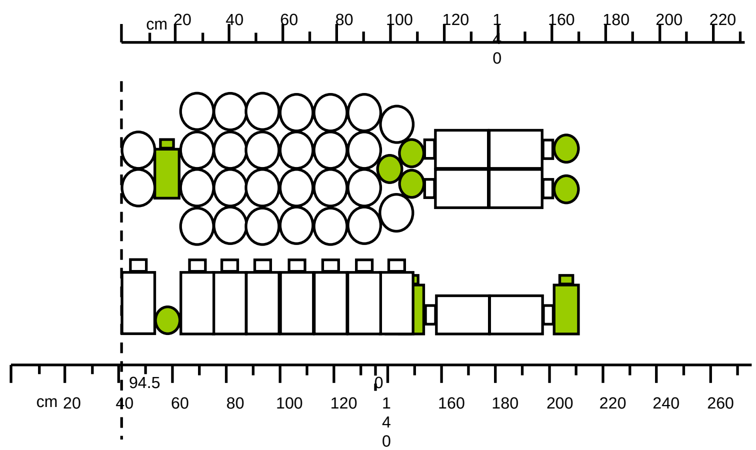
- 4 NaJ - counters
- **detection of gamma radiation**
- of radionuclides that are *homogeneously* distributed
- in shielding chamber (10 t sand, 31 t steel + lead)





Calibration: bottle pantom with known activity

70 kg 170cm

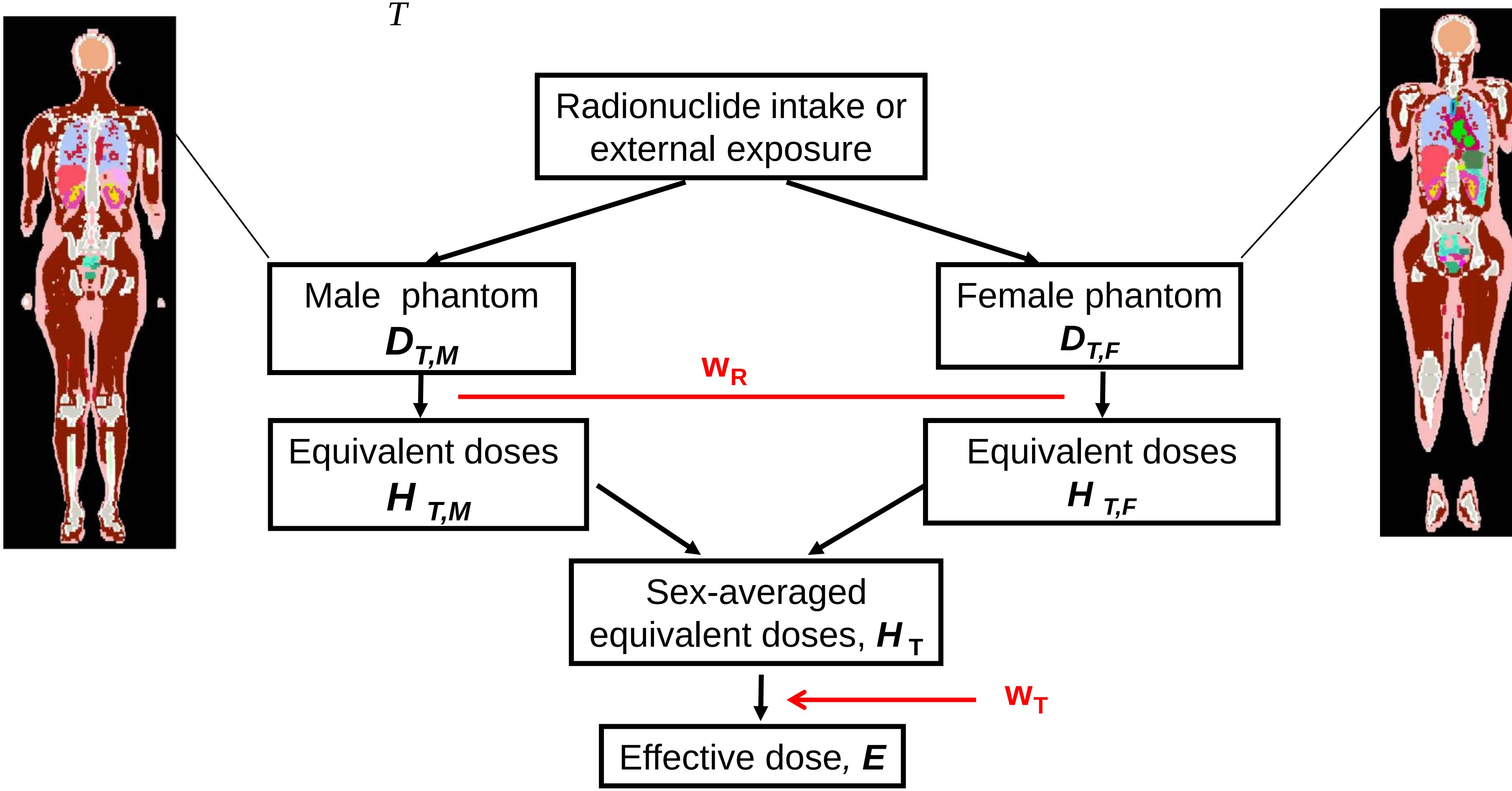


Pictures:
Courtesy
D. Berg, GSF

- **Effective dose**: multiplication with tissue weighting factors

$$E = \sum_T w_T \cdot H_T$$

SI Unit: J/kg   ICRP special name: Sv

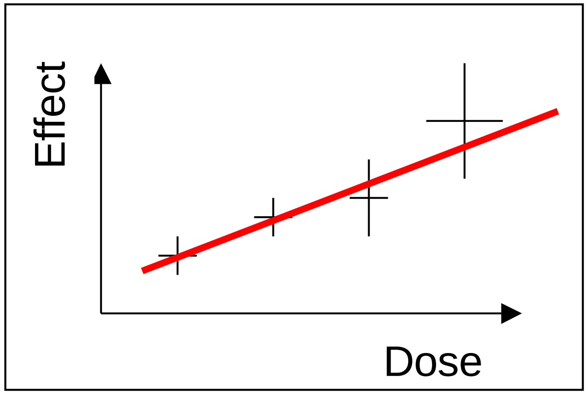


ICRP Tissue Weighting Factors: Based on Data on Radiation-induced *Late* Effects among the A-bomb Survivors

Principle (simplified)

e.g. solid cancers, leukaemia
as a function of age, sex, organ, …

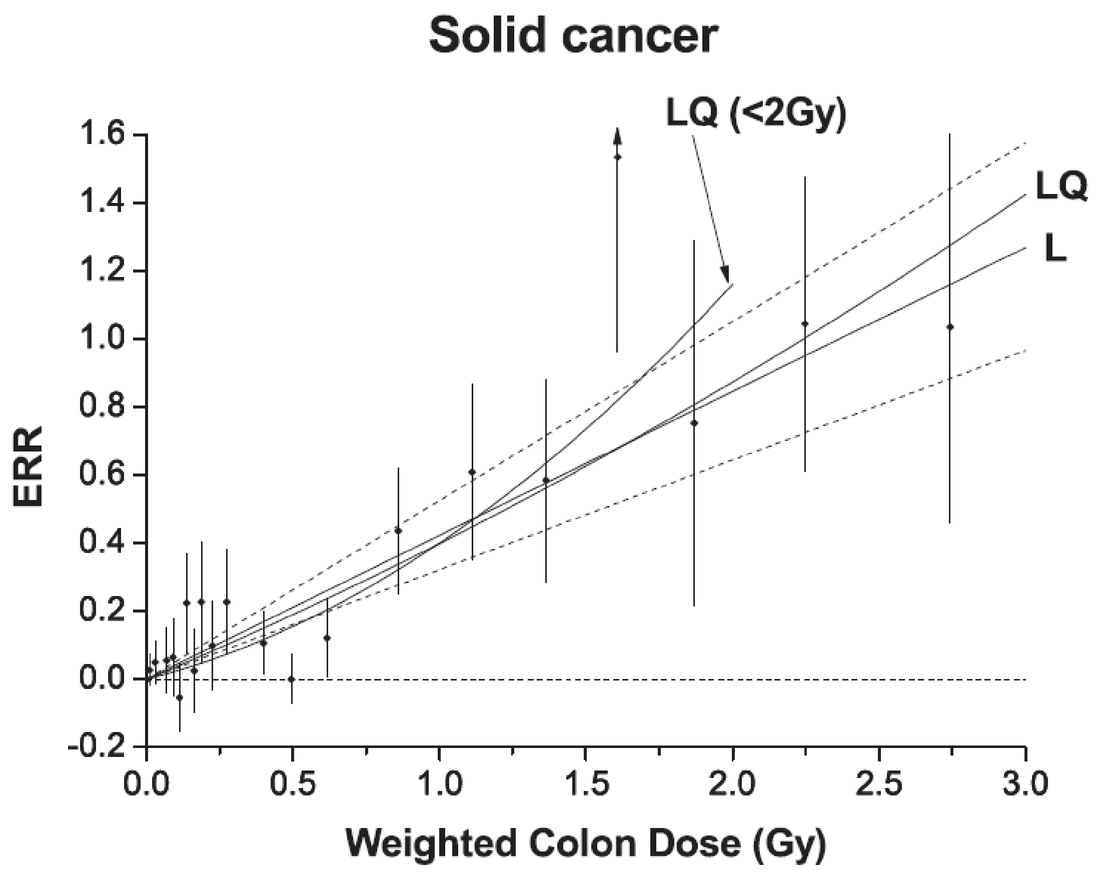
Done by the Radiation Effects Research Foundation (RERF) in Hiroshima and Nagasaki



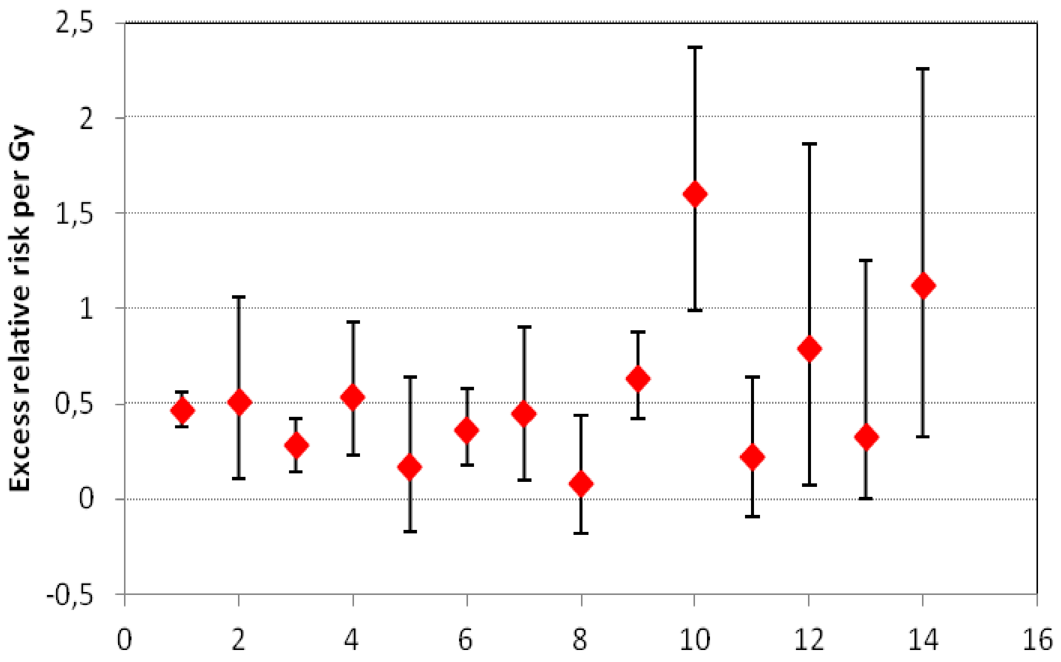
> effect per dose
> basis for risk estimates used by ICRP

y-axis:	x-axis:
Life Span Study (LSS)	**Dosimetry System 2002 DS02** (DS86)

ICRP Tissue Weighting Factors: Based on Data on Radiation-induced *Late* Effects among the A-bomb Survivors



Ozasa et al. Rad. Res. 2012 **ERR per dose ≅ 0.42 / Sv**



1 – all solid cancers; 2 – esophagus;
3 – stomach; 4 – colon;
5 – rectum; 6 – liver;
7 – gall bladder; 8 – pancreas;
9 – lung; 10 – breast;
11 – uterus; 12 – ovary;
13 – prostate; 14 – bladder

error bars represent 95% confidence intervals

→ w_T

The Dose and Doserate Reduction Factor (DDREF)

- Exposure in Hiroshima and Nagasaki: **high dose rates**

- However, in radiation protection, typical exposures are of **low dose rates**

- Based on cell (invitro) studies and animal studies, ICRP assumes **DDREF = 2**

  - ICRP 103: „… the Commission finds no compelling reason to change its 1990 recommendations of a DDREF of 2.“

  - ICRP 103: „… this continues to be a broad whole number judgement for the practical purposes of radiological protection which embodies elements of both subjective and probabilistic uncertainty. …“

- But – more recent epidemiological evidence (human data!!) challenge this concept

  - Jacob, Rühm, Walsh, Blettner, Hammer Zeeb (2009) Cancer risk for radiation workers larger than expected? Occup Environ Med 66: 798-796

>> New ICRP TG91 on DDREF: W. Rühm (chair), T. Azizova (Russia), S. Bouffler (UK), R. Shore (Japan), G. Woloschak (US)

• Gender-averaged

Risik estimates were done separately for different organs, then averaged over age and gender

ICRP 103: „ … gender-specific data are not recommended for the general purposes of radiological protection.“

• further aspects included:

• transfer of risk estimations from Japanese population to global population

• number of years of life lost different for different

• loss of quality of life different for different tumour sites

From relative detriment to tissue weighting factor

„… a policy decision that there should only be a single set of w_T values that are averaged over both genders and all ages …“

„… the Task Group feels that additional judgements need to be exercised to include subjective factors not reflected in the mathematical formulation of detriment.“

Tissue	w_T	Σw_T
Bone marrow, colon, lungs, stomach, breast, remainder	0.12	0.72
Gonads	0.08	0.08
Bladder, esophagus, liver, thyroid	0.04	0.16
Bone surface, brain, salivary gland, skin	0.01	0.04

>> Effective Dose $E = \sum_T w_T \cdot H_T$

Example: Incorporation of ^{137}Cs
Based on assumptions on biokinetics and SEE values:

- Dose conversion coefficients can be calculated
- Allow calculation of effective dose per Bq intake

Nuklid	Zufuhrpfad	Absorptions-klasse	AMAD	f1-Wert	effektive Dosis (Sv/Bq)	Teilkörper-dosis (Sv/Bq)	Organ
Cs-134	Inhalation	F	10µm	1	8,5E-09	9,3E-09	Uterus
Cs-134	Ingestion	-	-	1	1,9E-08	2,2E-08	Uterus
Cs-134	Wunde	-	-	-	2,0E-08	2,2E-08	Uterus
Cs-137	Inhalation	F	0,3µm	1	3,3E-09	3,5E-09	Ovarien
Cs-137	Inhalation	F	1µm	1	4,8E-09	5,0E-09	Ovarien
Cs-137	**Inhalation**	**F**	**5µm**	**1**	**6,7E-09**	**6,9E-09**	**Uterus**
Cs-137	Inhalation	F	10µm	1	5,9E-09	6,1E-09	Uterus
Cs-137	Ingestion	-	-	1	1,3E-08	1,4E-08	Ovarien
Cs-137	Wunde	-	-	-	1,4E-08	1,5E-08	Uterus

1 Bq intake (ingestion) >> 1.3 x 10^{-8} Sv effective dose

How do you know, how much Activity incorporated?

a) Excretion analysis

b) In-vivo measurements

- Effective dose is for ICRP reference person only!!
- It does not represent the exact dose of any individual!
- It must not be used to calculate deaths from radiation (e.g. many thousands of deaths in Europe after Chernobyl accident)
- It is useful to compare different exposure situations (external, internal)
- It is useful to quantify radiation protection measures (e.g. does it decrease once shielding at a certain workplace was improved)
- It cannot be measured!!
- >> ICRU operational dose quantities

What does the annual effective dose of 4 mSv for the German population mean?

What does an effective dose rate of 5 µSv/h at flight altitudes mean?

Thank you!