Basic principles of intervention to protect the public in a nuclear accident

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Objective

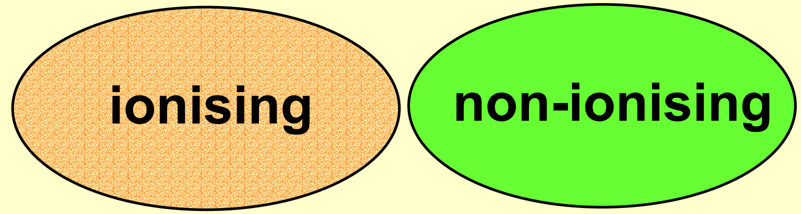
To acquaint those facilitators not familiar with radiation protection with basic information on radiation protection principles, health risks related to exposure to radiation and potential protective actions in an emergency situation

Content

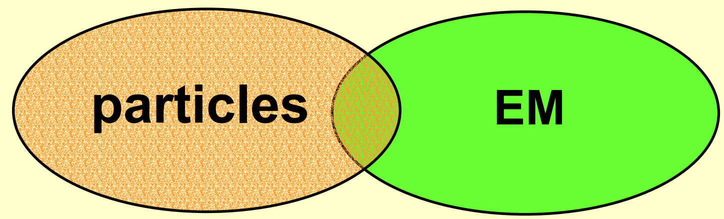
1. Basics of radiation and its health effects
2. Basics of radiation protection
3. More details about interventions
4. Factors having influence on countermeasures in nuclear emergencies

Division of radiation into groups

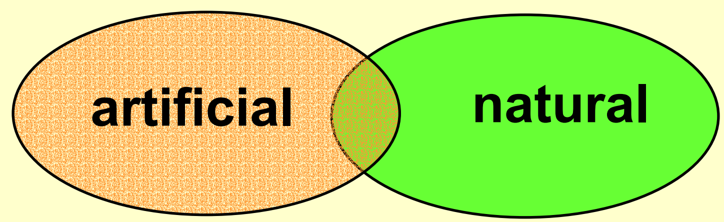
- **Ionising/non-ionising**
  - distinct borderline in energy



- **Particle/electromagnetic**
  - can overlap
  - photons, $E = mc^2 = hf = hc/\lambda$



- **Natural/artificial**
  - can overlap (technically enhanced exposure to natural radiation)



Ionising and non-ionising radiation

- **Ionising radiation**
  - **interacts with matter thereby depositing energy (~30 eV) sufficient to ionise or excite an atom (~ 15 eV) and, in consequence, to alter (biological) molecules and structures;**
  - **can be**
    - electromagnetic radiation = photons (X or γ -rays),
    - uncharged particles (e.g. neutrons),
    - charged particles (electrons/positrons, protons, α -particles, heavy nuclei) with sufficient kinetic energy to directly cause ionisations.

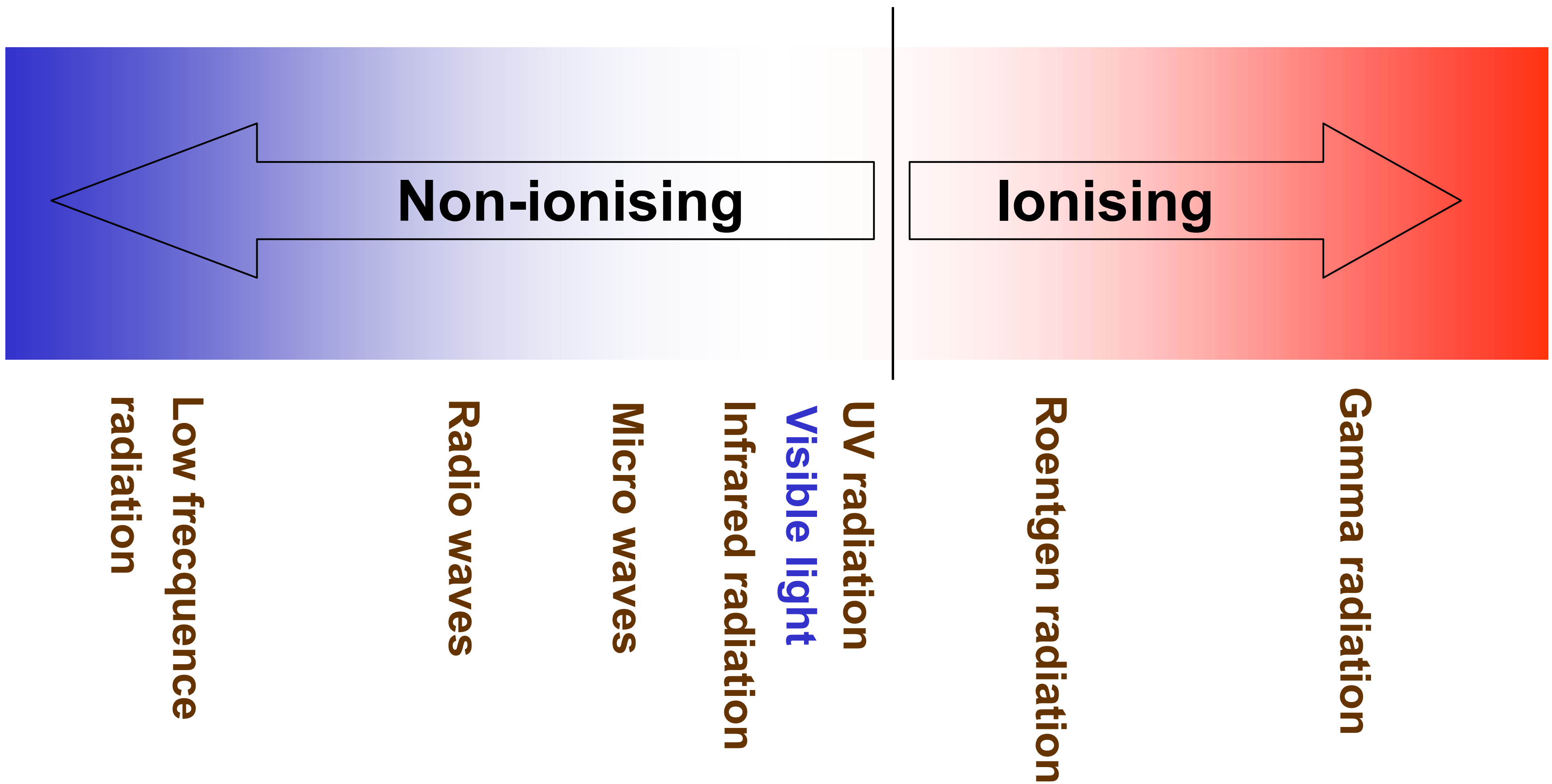
- **Non-ionising radiation**
  - **unable to ionise a target atom or molecule (e.g. visible light)**

Particle and electromagnetic radiation

- **Particle radiation can be;**
  - electrons, positrons, protons, neutrons, α -particles, etc.
  - normally they are always able to ionise the target atoms or molecules

- **Electromagnetic radiation;**
  - is combined electric and magnetic field and can be presented also as
  - photons moving with the speed of light
  - can be ionising or non-ionising

Electromagnetic radiation



Natural and artificial radiation

- **Natural radiation;**
  - originates from the outer space (cosmic radiation) or from naturally occurring radionuclides in the ground
  - can be particle radiation and electromagnetic radiation
  - can be ionising or non-ionising

- **Artificial radiation;**
  - is always man-made radiation
  - can be particle or electromagnetic radiation
  - can be ionising or non-ionising

Modes of radioactive decay

- **Beta decay:** A nuclear neutron is converted to a proton increasing the atomic number Z by one and emitting an electron.
- **Positron decay:** A nuclear proton is converted to a neutron reducing the atomic number by one resulting either in the emission of a positron which then is annihilated giving rise to two oppositely directed photons, or in the capture of an orbital electron.
- **Alpha decay:** An alpha particle is emitted reducing both atomic number and neutron number by two; this occurs mainly in heavy elements (>=Pb)
- **Nuclear fission:** Heavy nuclei (>=Th) are split in two, about equal, fragments with the emission, among others, of neutrons.

Unit of radioactivity

- The unit of radioactivity is the Bq (becquerel)
  1Bq = one radioactive decay/second.

Note:

- One Bq is a small amount of radioactivity.
- Air in homes contains an average of 50 Bq/m^3 of radioactivite radon.
- The human body contains about 4.2 kBq (~60 Bq/kg) of ^{40}K.
- Amounts of 100 -1000 MBq of ^{99m}Tc are given for diagnostics.
- About 3 GBq ($3x10^9$ Bq) of ^{131}I are administered for the therapy of thyroid cancer,
- The Chernobyl accident released about 40 PBq ($40 x10^{15}$ Bq) of radioactive caesium isotopes.

Some radiation protection quantities

- Activity (A), activity concentration (C):
  - Bq (becquerel), Bq/kg, Bq/l
  - 1 Bq = 1 radioactive decay per second
- Absorbed dose:
  - indicates how much energy is absorbed from radiation into target matter, unit is Gy (gray)
- Equivalent dose:
  - takes into account the type of radiation, unit is Sv (sievert)
- Effective dose:
  - takes into account the organ or tissue where radiation is absorbed, unit is Sv (sievert)

Dose quantities of radiation protection

Absorbed dose $D = \frac{d\bar{\varepsilon}}{dm}$ (gray Gy =J/kg) the energy absorbed per unit mass

Equivalent dose $H_{TR} = \sum_R W_R D_{TR}$ (sievert Sv) the sum of absorbed doses in tissue or organ T due radiations R. The radiation weighting factor W_R accounts for the relative harmfulness of different types of radiations.

Effective dose $E = \Sigma W_T H_T = \Sigma W_T \Sigma W_R D_{TR}$ (sievert Sv) the sum of the weighted equivalent doses D_{TR} in all tissues or organs T. The tissue weighting factor W_T accounts for the relative sensitivity of different tissues.

Radiation Weighting Factors W_R

Type and Energy Range	Radiation weighting factor
Photons all energies	1
Electrons, muons all energies	1
Neutrons, energy < 10 keV	5
10-100 keV	10
100 keV- 2 MeV	20
2- 20 MeV	10
> 20 MeV	5
Protons other than recoil >2 MeV	5
Alpha particles, fission fragments, heavy nuclei	20

Example:
An *Absorbed Dose* of 1 Gy from X-rays plus 0.1 Gy from 1 MeV neutrons yields an Equivalent Dose of 1x1 + 0.1x20 = 3 Sv

Tissue Weighting Factors W_T

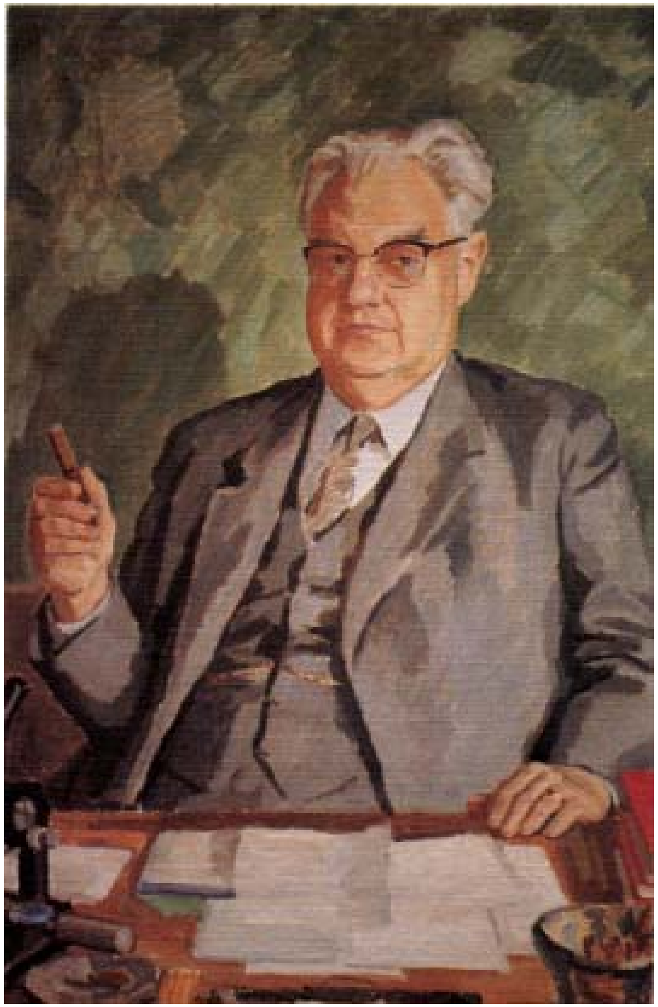
Organ/tissue	Weighting factor
Gonads	0.20
Bone marrow (red)	0.12
Colon	0.12
Lung	0.12
Stomach	0.12
Bladder	0.05
Breast	0.05
Liver	0.05
Esophagus	0.05
Thyroid	0.05
Skin	0.01
Bone surface	0.01
Remainder	0.05
Total	1.00

Example:
An *equivalent dose* of 1Sv to the stomach and of 2 Sv to the colon yields an *effective dose* of
$1 \times 0.12 + 2 \times 0.12 = 0.36$ Sv

What is Sv (sievert), mSv (millisieveret) and manSv ?

- sievert is a measure for harmful health effects of ionising radiation
- it gives a probability of getting a cancer from exposure to radiation
- one Sv as an effective dose corresponds a risk of 0.05 (5%) for getting a fatal cancer
- millisievert (mSv) is 0.001 Sv
- manSv is a unit for collective dose in a population group (sum of doses of all exposed individuals)

Sievert is a big unit !



Professor Rolf Sievert
1898 - 1996

How to get 1 mSv effective dose?

- by ingesting 80 000 Bq of Cs-137 with food and drink
- by living one year in a house where radon concentration is 60 Bq/m^3

If you get a radiation dose of 1 mSv in a year, you have 0,005 % probability to get a fatal cancer during your life

Biological grounds for philosophy of radiation protection

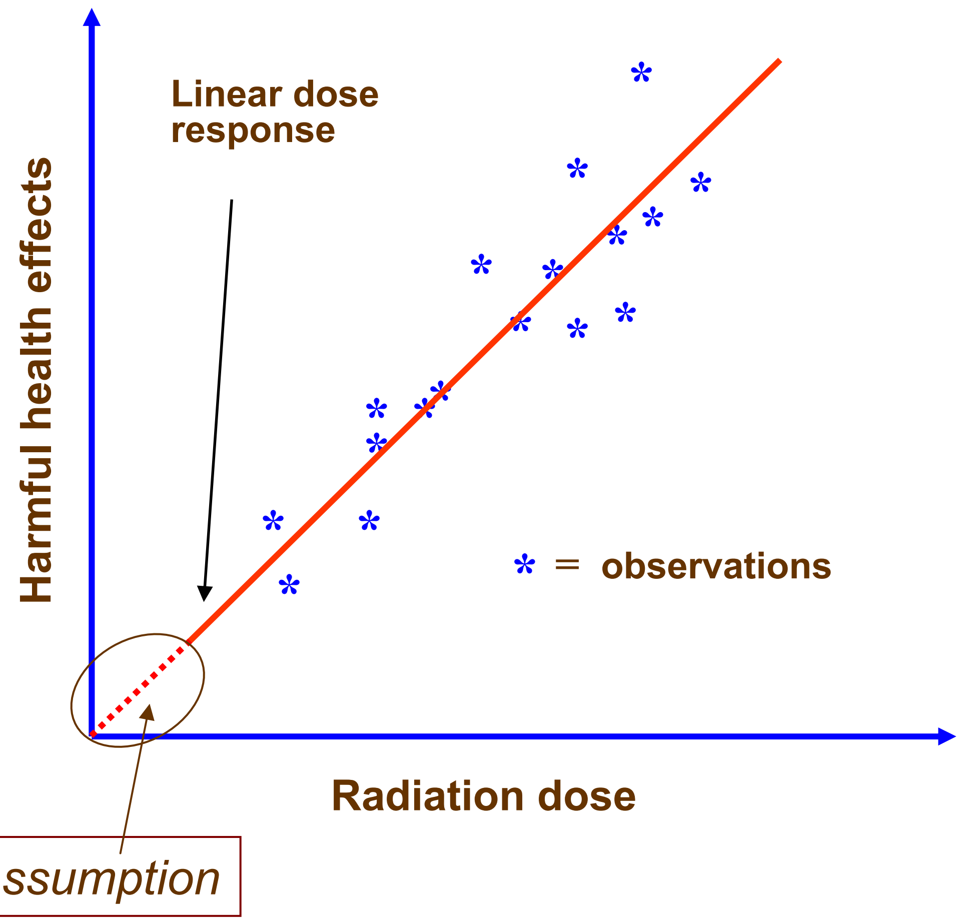
Ionising radiation has two kinds of harmful effects to human health:

- **Deterministic health effects**
  - can occur only at high radiation doses
  - are always based on cell killing
  - detriment is proportional to the amount of cell killings
  - threshold doses, below which no detriment effects
  - doses are giving in absorbed dose (Gy)
- **Stochastic health effects**
  - can occur also at low doses
  - are always based on changes in the genome (DNA molecule)
  - detriment is fully stochastic
  - detriment increases with dose (linear dose-response relationship, no threshold doses)
  - cancer is the most important detriment
  - doses are giving in equivalent dose or effective dose (Sv)
  - risk for fatal cancer is 5% per Sv

Stochastic health effects
Linear Non-Threshold model (LNT)

Stochastic (= coincidental) health effects:

- no threshold doses
- linear response
- dose inside an organ can be presented as a mean dose of the organ
- doses received in different times can be summed
- doses received from different sources can be summed
- cancer and hereditary effects



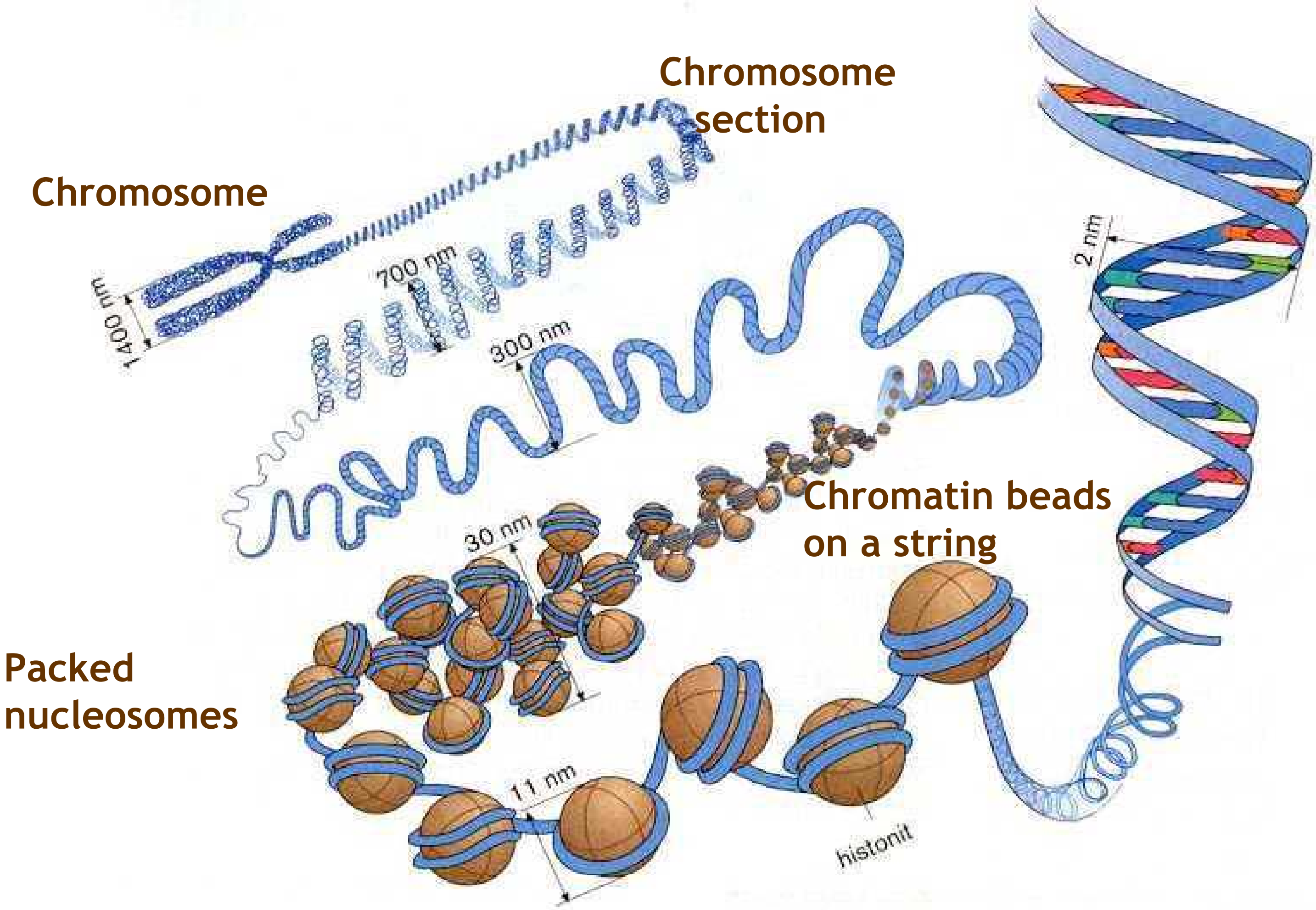
DNA, gene, chromosome

DNA = genetic code

gene = funtional unit

chromosome = structural unit

Damage at different levels



Source: Ulmanen I, Tenhunen J, Ylänen J, Valste J, Viitanen P: Biologia. Geeni. 4. painos , WSOY, 2000

Collective dose and number of cancers

- If some population group receives a collective dose of 1000 manSv, 50 cancer deaths due to exposure to radiation can be expected to occur

- “Normal” rate of cancer death is about 25%

Size of population	*Cancer deaths from:* radiation	*other reasons*
100 people	50	25
1 000 people	50	250
10 000 people	50	2 500
100 000 people	50	25 000
1000 000 people	50	250 000

Two types of activities with radiation

- **Practice:**
  – action with use of radiation or nuclear energy
  – adds the human exposure to radiation
- **Intervention:**
  – protective actions in an event of nuclear accident or radiation emergency
  – mitigation of exposure to natural radiation
  – decreases the human exposure to radiation

Differences between a practice and an intervention

Practice:

- Use of radiation
- Production of nuclear energy
- Occupational exposure to enhanced natural radiation
- Adds the human exposure to radiation
- Constraints to radiation sources
- Dose limits and constraints

Intervention:

- Countermeasures in nuclear or radiological emergencies
- Enhanced exposure to natural radiation at homes
- Decreases the human exposure to radiation
- Limits the individual freedom to act since radiation is already in the living environment
- Intervention levels

Radiation protection principles

In practice:

- Each practice should be justified
- The doses arising from practices should be kept as low as reasonably achievable
- The sum of doses should be kept below the dose limits

In intervention:

- Each protective measure should be justified
- The level of protective measures resulting in dose reduction should be optimized
- Deterministic health effects of radiation should be prevented

Objectives of intervention

- To keep radiation exposure of individuals below the thresholds for serious deterministic health effects

- To keep the stochastic health effects in all population groups as low as reasonably achievable

Principles of intervention

Justification:

- *Every countermeasure will do more good than harm, i.e. benefits of the countermeasure should be sufficient to justify the harm and costs it causes*

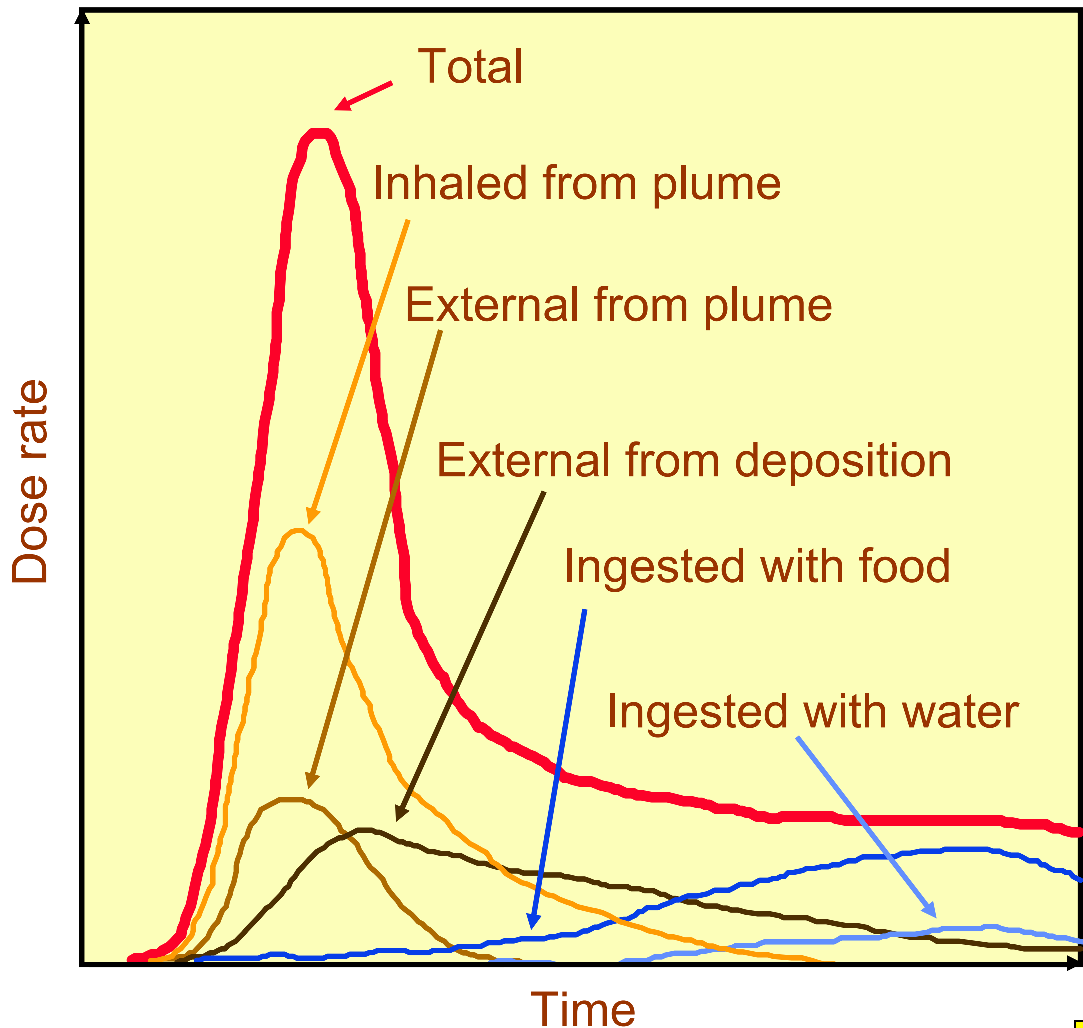
Optimization:

- *Net benefit of the countermeasure should be maximized, i.e. the form, scale, and duration of the countermeasure should be optimized*

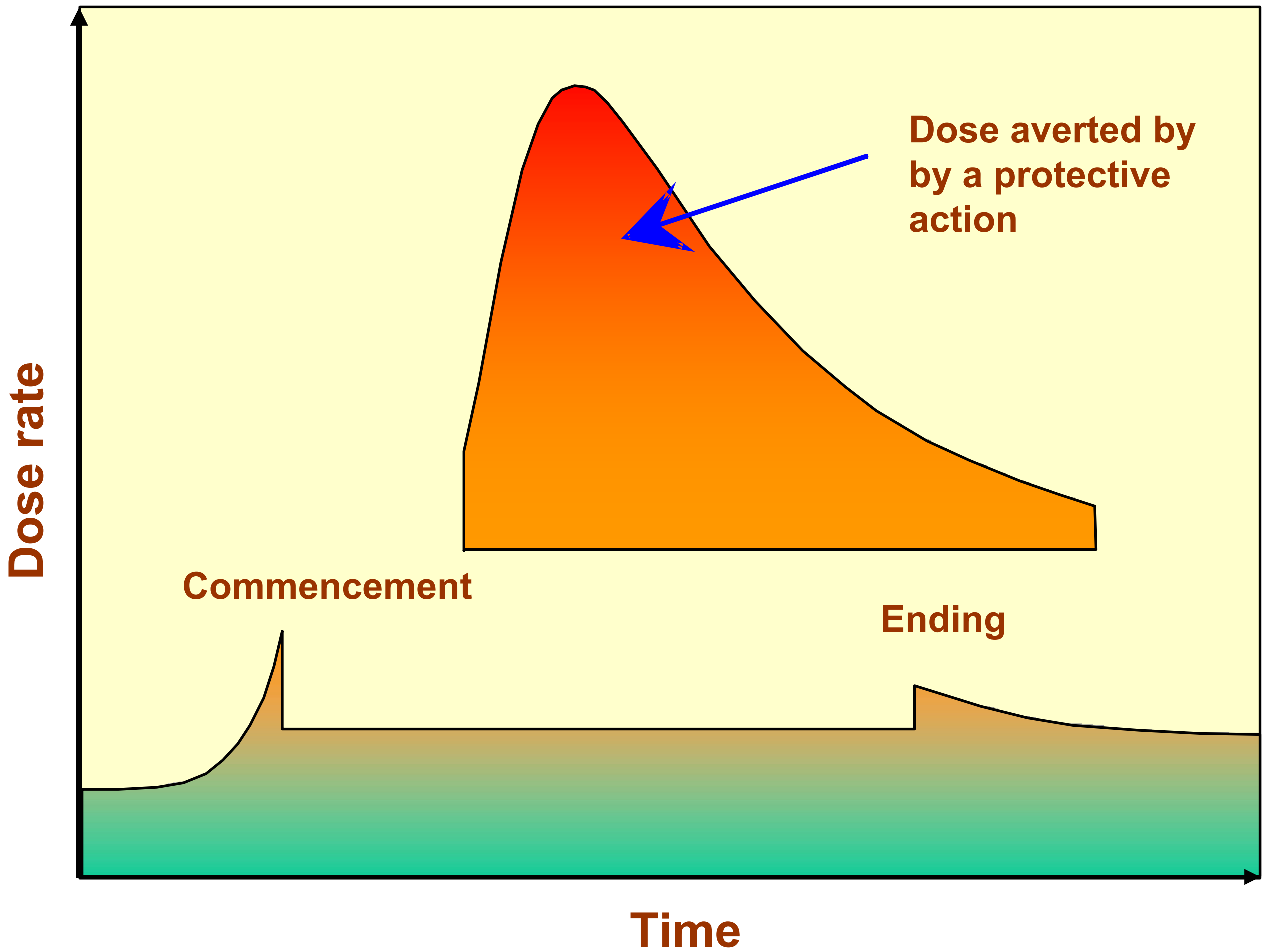
Protection of individuals:

- *Intervention levels are applied instead of dose limits*

Components of exposure to radiation in a nuclear accident situation



Averted dose is the ground of intervention



Actions to protect the public

Urgent protective actions:

- Sheltering
- Evacuation
- Iodine prophylaxis

Longer-term protective actions:

- Limitations for foodstuff consumption
- Temporary relocation
- Permanent resettlement
- Decontamination

International recommendations for generic intervention levels (as avertable doses)

Protective action	*Intervention level*
Sheltering	10 mSv/two days (effective dose
Evacuation	50 mSv / week (effective dose)
Administration of stable iodine	100 mGy (absorbed dose to thyroid)

International recommendations for generic intervention levels (as avertable doses)

Protective action	*Intervention level*
Temporary relocation	30 mSv in first month, 10 mSv in subsequent month (effective dose)
Permanent resettlement	1000 mSv in lifetime (effective dose)

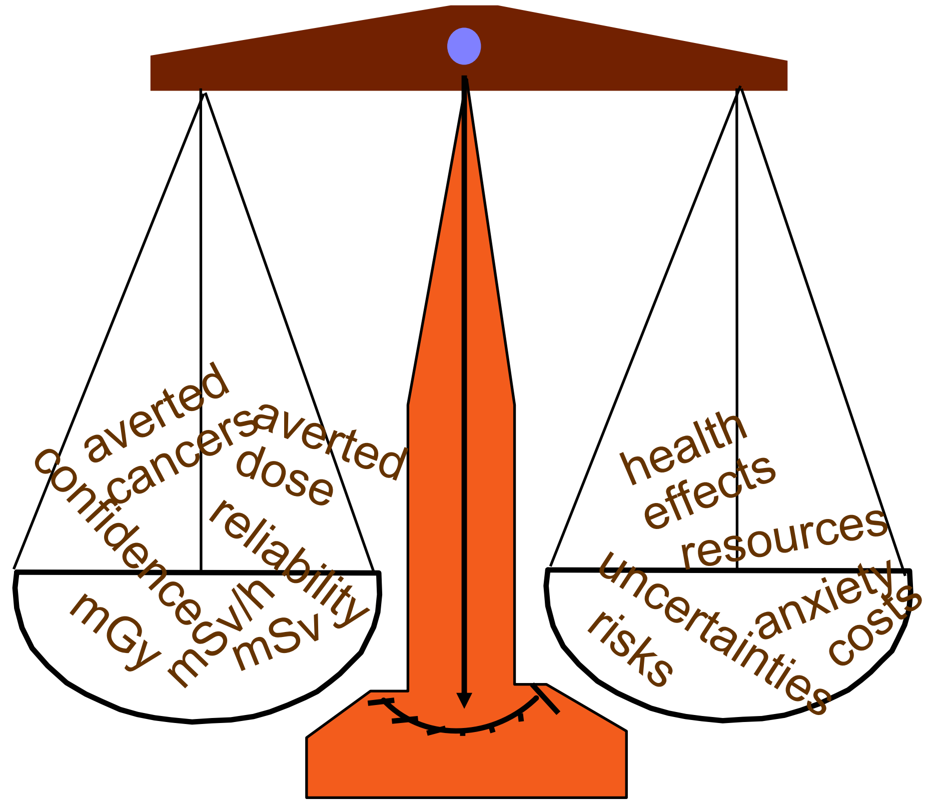
Generic reference level: >10 mSv in a year ⟶ something should be done

Factors to be taken into account in implementation of countermeasures

- Radiation doses
- Exposed populations
- Avertable radiation doses
- Costs of countermeasures
- Feasibility of countermeasures
- Anxiety of affected population
- Confidence in authorities
- Risks associated with countermeasures
- Radioactive wastes from decontamination actions
- All relevant stakeholders
- etc.

How to find the best countermeasure?

- Acquire sufficiently information about the radiation situation
- Use expertise of all relevant branches
- Assess advantages and disadvantages of the countermeasures
- Demonstrate different options to the decision makers
- Use a handy evaluation tool when demonstrating countermeasure strategies



- do more good than harm
- save as much as reasonable achievable