Mostly harmless:

Who in the Universe needs dosimetry?

Ulrike Ankerhold
Ionising radiation: brief historical review

1895: discovery of X-rays (‘Röntgenstrahlung’) by Wilhelm C. Röntgen (first Nobel prize for physics, 1901)

1896: discovery of radioactivity by Antoine H. Becquerel (1903: Nobel prize together with Marie and Pierre Curie)

1912: discovery of cosmic radiation by Victor F. Hess (Nobel prize, 1936)

1932: discovery of the neutron (neutron radiation) by James Chadwick (Nobel prize, 1935)
Ionising radiation – General

Characteristics of ionising radiation:

• photon radiation (X-rays, gamma rays), particle radiation (electron radiation, neutron radiation, ion radiation, muons, positrons, ….)

• invisible and not directly detectable by human senses

• exposure to ionising radiation causes damage to living tissue and can result in mutation, radiation sickness, cancer or death.

• it can be helpful, but it can also be harmful!
Dosimetry: brief historical review

What are the measuring quantities and the units?
How can the “intensity” of ionising radiation be measured?

Definition of the “intensity” of ionising radiation or dose:

1925: International Congress of Radiology (the precursor of the International Commission on Radiation Units and Measurements (ICRU) )

main topics: measuring quantities, units and standard measuring instruments for X-rays

H. Behnken (Physikalisches-Technische Reichsanstalt, PTR) presented the German proposal for a dose definition
Dosimetry – General

**Dosimetry** is the measurement and/or calculation of the dose in matter and tissue resulting from the exposure to ionising radiation.

**What are the measuring quantities and the units?**

**Absorbed dose** is a measure of the energy deposited in a medium per unit mass.

**Unit:** J/kg (joules per kilogram)

**How can the “intensity” of ionising radiation be measured?**

**Measuring principle:**

The amount of charge produced in a detector (consisting of air, silicon, etc.) is proportional to the absorbed dose, which is proportional to the irradiated energy by ionising radiation.
Fields of dosimetry

Dosimetry for external radiation

Radiation protection dosimetry
(unit: Sv (Sievert))

Environmental dosimetry

Dosimetry for the medical application of ionising radiation
(unit: Gy (Gray))

Dosimetry for diagnostic radiology

Dosimetry for radiation therapy

Dosimetry for the medical application of ionising radiation
Fields of dosimetry

Dosimetry for external radiation

Radiation protection dosimetry (unit: Sv (Sievert))

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Dosimetry for occupationally exposed workers

Dosimetry for the medical application of ionising radiation (unit: Gy (Gray))

Dosimetry for diagnostic radiology

Dosimetry for radiation therapy
Radiation protection dosimetry

Dosimetry for monitoring to ensure the compliance of the legal dose limits and, therefore, to protect the health of the general public and the occupationally exposed workers.

But: equal doses of different types or energies of radiation cause different amounts of damage to living tissue.

Solution: radiobiological weighted absorbed dose in tissue; the biological effectiveness is taken into account by the use of a dimensionless quality factor measuring quantity: dose equivalent $H$

unit: 1 Sv (Sievert) = 1 J/kg.

Rolf Sievert, Swedish physicist, 1896 - 1966
Environmental dosimetry

Natural ionising radiation sources:
- cosmic radiation:
  muons, neutron, electrons, gamma radiation
- terrestrial radiation:
  gamma radiation from natural radioactivity from rocks, soil,..
- Radon in air

→ composite radiation field

Artificial (not natural) ionising radiation:

Legal dose limit for the general public in Germany: 1 mSv/a

Duration of stay outdoor (daily): 5 h

BMU – annual report 2009
Environmental dosimetry

**Purpose:** monitoring to ensure the compliance of the legal dose limit of 1 mSv/a for the general public

**Challenge:** dose of natural ionising radiation is in the same order of magnitude as the legal dose limit
distinction between “natural” dose and “artificial” dose
Dosimetry for occupationally exposed workers

Purpose: monitoring to ensure the compliance of the legal dose limits for occupationally exposed workers in Germany: about 370,000 people
Dosimetry for occupationally exposed workers

Work places of occupationally exposed employees in Germany

- Medicine: 69.1%
- Industry: 20.6%
- Aircraft: 9.8%
- Others: 0.5%

nach Bundesamt für Strahlenschutz 2009
### Dosimetry for occupationally exposed workers

<table>
<thead>
<tr>
<th>dose</th>
<th>organ</th>
<th>dose limit for occupationally exposed workers per year</th>
</tr>
</thead>
<tbody>
<tr>
<td>effective dose</td>
<td>whole body</td>
<td>20 mSv</td>
</tr>
<tr>
<td>Equivalent dose to an organ</td>
<td>eye lens</td>
<td>150 mSv</td>
</tr>
<tr>
<td></td>
<td>hands, skin, forearm, feet, ankle</td>
<td>500 mSv</td>
</tr>
</tbody>
</table>

The dose limits are set in such a way that the probability of radiation damage is negligible.
Dosimetry for occupationally exposed workers

**Quality assurance:** type testing of radiation protection dosemeters for photon radiation (in Germany: legal task of PTB)

**Challenge:** dose measurements in composite radiation fields:
- photon radiation: X-rays (keV), …., accelerator fields (MeV), electron radiation, neutron radiation, cosmic radiation
- continuous and pulsed radiation
- wide range of dose rates

For monitoring the dose limits: individual dosimetry and area dosimetry
Fields of dosimetry

Dosimetry for external radiation

Radiation protection dosimetry (unit: Sv (Sievert))

Environmental dosimetry

Dosimetry for occupationally exposed workers

Dosimetry for the medical application of ionising radiation (unit: Gy (Gray))

Dosimetry for diagnostic radiology

Dosimetry for radiation therapy
Dosimetry for the medical application of ionising radiation

Dosimetry to ensure that the dose exposed to the patient is equal to the dose predefined by the doctor.

Characteristics:

- Administration of a dose only due to medical indication
- No legal dose limits, the doctor decides the dose to be administered
- No individual patient dosimetry
- Dosimetry that the facility (e.g. X-ray unit or accelerator) delivers the predefined dose and field (dose distribution)
- Measuring quantity: absorbed dose $D$
  - Unit: $1 \text{ Gy (Gray)} = 1 \text{ J/kg}$

Louis H. Gray, British physicist, 1905 - 1965
Dosimetry for diagnostic radiology

**Purpose:** to ensure that the patient is exposed with the predefined dose, i.e. for quality assurance of the diagnostic facilities.

Patient safety: patient dose as low as possible, but enough for an assured diagnosis.
Dosimetry for diagnostic radiology

Typical doses for X-ray examination:

- X-ray examination: – tooth: < 0.01 mGy
- CT-examination, adult (CTDI\text{vol}): – abdomen: 20 mGy
  – thorax: 12 mGy
- CT-examination, baby (CTDI\text{vol}): – abdomen: 2.5 mGy
  – thorax: 1.5 mGy
Dosimetry for diagnostic radiology

Challenge: dosimetry in sophisticated radiation fields produced by recently developed facilities for better clinical diagnostics, e.g. new generation of CT scanner, mammography units, …
Dosimetry for radiation therapy

Number of annual incidences of cancer: EU: $\approx 2.3$ million; Germany: $\approx 430,000$

Causes of death in the industrial countries
- other (suicide, dementies, accidents, …) 25.6%
- cerebrovascular disease 18.2%
- cancer 24.1%
- heart disease 32.1%

Curability of cancer
- no cure 50%
- cure through chemotherapy 2%
- cure through surgery 22%
- cure by means of radiation therapy 26%
Dosimetry for radiation therapy

Types of radiation therapy:

External radiation therapy:

Brachytherapy:
Dosimetry for radiation therapy

**Purpose:** to ensure that the tumour is exposed with the predefined dose for killing tumour cells, i.e. for quality assurance of the radiation treatment

**Characteristics:**

- **typical dose:** 20 Gy to 70 Gy depending on the tumour, exposed fractional, where the amount of dose is decided by the doctor
- **objective:** to achieve a high dose in the tumour volume and a small dose in the surrounding healthy tissue

⇒ „tumour matched“ dose distribution in the patient, e.g. by superimposing a large number of small, irregularly shaped radiation fields
Dosimetry for radiation therapy

Measuring instruments: ionisation chambers

In radiation therapy the medical physicists are responsible for the dosimetry.
Dosimetry for radiation therapy

**Challenge:** dose measurements in complex fields with small uncertainty:

- photon, electron, proton or carbon ion radiation fields
- small, irregularly shaped fields with deep dose gradients
- complex dose distribution
- dose measurement with an **uncertainty of ± 2.5 %** \((k = 1)\) in the exposed volume (requirement: ICRU report 24)

Need for a precise dose measurement
Who in the Universe needs dosimetry?

Dosimetry for external radiation

Radiation protection dosimetry

Dosimetry for the medical application of ionising radiation
Session 3: Mostly harmless

Who in the Universe needs dosimetry?

Thank you for your attention!!