Joint ICTP/IAEA Advanced School on Dosimetry in Diagnostic Radiology and its Clinical Implementation

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Introduction to Radiological Dosimetry

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Diagnostic Radiology: in the beginning...

- German physicist -Roentgen, 1885
- Discovered an "invisible light" or ray capable of passing through heavy paper
- This ‘X-ray’ would pass through most substances casting shadows of solid objects on pieces of film
- X-rays would pass through the tissue of humans leaving the bones and metals visible
- Used clinically in US from 1896
Annual X-ray examinations in Britain per thousand population (excluding mass surveys)

- Barclay, 1949
- MRC, 1956
- Adrian, 1960
- Matthews, 1969
- NRPB R104
- NRPB R201
Global X-ray figures

- In 2000: 360 examinations / 1000 people

- 75% examinations in countries with Healthcare Level I
- 1% examinations in countries with Healthcare Level III & IV
Developments in diagnostic radiology

- Screen-film radiography
- Fluoroscopy
- Computed tomography
- Digital fluorography
- Computed radiography
- Direct digital radiography
Screen-film radiography

- Projection radiography
- Fixed X-ray beam
- Attenuated through patient
- Detected by screens $\Rightarrow$ light photons
- Light detected by film $\Rightarrow$ image (2D)
- Films can be displayed / transported / stored
Developments in diagnostic radiology

- Screen-film radiography
- Fluoroscopy
- Computed tomography
- Digital fluorography
- Computed radiography
- Direct digital radiography
Fluoroscopy

- Allows real-time imaging
- Often uses contrast media for functional imaging
- Uses image intensifier
- Displays images on TV screen
- Can take ‘snapshot’ images for storage
- Specialist applications (cardiology, gastrointestinal etc.)
Developments in diagnostic radiology

- Screen-film radiography
- Fluoroscopy
- Computed tomography
- Digital fluorography
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- Direct digital radiography
Computed Tomography

- Rotating fan beam of X-rays & detectors
- Computer reconstructs cross-sectional images (3D)
- Single slice $\Rightarrow$ multi slice
- Axial scanning $\Rightarrow$ helical scanning
- Real time imaging
Developments in diagnostic radiology

- Screen-film radiography
- Fluoroscopy
- Computed tomography
- Digital fluorography
- Computed radiography
- Direct digital radiography
Digital techniques

- Computed radiography (CR) – film replaced with storage phosphor plate
- Direct digital radiography (DDR) – active matrix detector converts directly to digital signal
- Interventional radiology now possible
- Improved image quality – What’s happened to doses?

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Radiation effects on humans

• Severe injury and death was an occupational hazard with early radiation workers

• Approx 300 fatalities in early workers
  (names on Hamburg monument)

• Becquerel developed tumours

• Marie Curie died of leukemia at 67
1. Stochastic effects

- Probability of effect occurring is proportional to dose (no threshold)

- Evidence: Japanese survivors, early radiologists, uranium miners, radium dial painters

- The stochastic effect of interest is carcinogenesis
Stochastic effects

- Probability of effect vs. Dose

100%

- natural incidence
- reduced probability because of e.g. cell kill
Radiation effects on humans

2. Deterministic effects

- No effect below a threshold dose
- Above threshold, severity of effect increases with dose

Carcinogenesis & deterministic effects are somatic effects – they affect the irradiated individual
## Typical threshold doses for deterministic effects

<table>
<thead>
<tr>
<th>Tissue &amp; Effect</th>
<th>Threshold dose (brief exp) Gy</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Testes</strong></td>
<td></td>
</tr>
<tr>
<td>Temporary sterility</td>
<td>0.15</td>
</tr>
<tr>
<td>Permanent sterility</td>
<td>3.5</td>
</tr>
<tr>
<td><strong>Ovaries</strong></td>
<td></td>
</tr>
<tr>
<td>Sterility</td>
<td>2.5</td>
</tr>
<tr>
<td><strong>Lens</strong></td>
<td></td>
</tr>
<tr>
<td>Opacities</td>
<td>0.5</td>
</tr>
<tr>
<td>Cataracts</td>
<td>2.0</td>
</tr>
<tr>
<td><strong>Bone marrow</strong></td>
<td></td>
</tr>
<tr>
<td>Depression of haematopoiesis</td>
<td>0.5</td>
</tr>
<tr>
<td><strong>Skin</strong></td>
<td></td>
</tr>
<tr>
<td>Erythema</td>
<td>2</td>
</tr>
<tr>
<td>Temporary epilation</td>
<td>3</td>
</tr>
</tbody>
</table>
Deterministic effects

Severity or probability of effect vs. Dose

well-defined threshold
3. Genetic damage

- chromosome damage – breakage followed by faulty repair
  no convincing evidence

Problems of genetic risk assessment

- only gonad exposure is relevant
- mutations may be recessive
- mutations may be unstable
Relative contributions to UK population dose

- Radon (50.00%)
- Medical (14.00%)
- Cosmic (12.00%)
- Internal (10.00%)
- Gamma (13.50%)
- Fallout / occupational (0.50%)
Per caput doses from medical irradiation

- USA: 3 mSv
- UK: 0.4 mSv
<table>
<thead>
<tr>
<th>Examination</th>
<th>% Frequency</th>
<th>% Collective dose</th>
</tr>
</thead>
<tbody>
<tr>
<td>Computed tomography</td>
<td>2.0</td>
<td>20</td>
</tr>
<tr>
<td>Lumbar spine</td>
<td>3.3</td>
<td>15</td>
</tr>
<tr>
<td>Barium enema</td>
<td>0.9</td>
<td>14</td>
</tr>
<tr>
<td>Barium meal</td>
<td>1.6</td>
<td>13</td>
</tr>
<tr>
<td>Intravenous urography</td>
<td>1.3</td>
<td>11</td>
</tr>
<tr>
<td>Abdomen</td>
<td>2.9</td>
<td>8</td>
</tr>
<tr>
<td>Pelvis</td>
<td>2.9</td>
<td>6</td>
</tr>
<tr>
<td>Chest</td>
<td>24</td>
<td>2</td>
</tr>
<tr>
<td>Limbs &amp; joints</td>
<td>25</td>
<td>1.5</td>
</tr>
<tr>
<td>Skull</td>
<td>5.6</td>
<td>1.5</td>
</tr>
<tr>
<td>Thoracic spine</td>
<td>0.9</td>
<td>1</td>
</tr>
<tr>
<td>Dental</td>
<td>25</td>
<td>1</td>
</tr>
</tbody>
</table>
Typical dose levels

- Projection radiography: 1-20 mGy
- CT: 10-100 mGy
- Fluoroscopy dose rates: 0.02-0.2 Gy/min
Quality assurance

• Diagnostic image quality required with as low as dose as possible
• Framework provided by WHO & BSS
• Includes
  • Measurement of physical X-ray parameters
  • Image quality assessment
  • Dose assessment
• BSS requires guidance levels for achievable doses
• EU requires diagnostic reference levels
Two good reasons for dosimetry in x-ray diagnostics

• A tool for setting up and control of standards of a good practice
  • Quantities should be easy to measure

• A tool for estimation of radiation detriment and injury
  • Quantities should have a direct link to potential risk from the exposure
Two pillars of dosimetry in diagnostics

• Clinical needs
  • Correct diagnosis is the main goal of any x-ray examination
  • Need to protect a patient
  • Balancing between necessary dose and quality of image (important role of medical physicists)

• International system of measurements
  • Mechanism for consistency in radiation dosimetry (role of SSDLs)
Historical problems of dosimetry in x-ray diagnostics

- General radiography
  - Backscattered radiation included or not?
  - Absorbed dose or air kerma?
  - Material in which the measured quantity is specified (air, PMMA, water, tissue)
  - Same symbols used for different quantities (ESD)?
  - Different names used for the same quantity
- Similar problems occur for other modalities

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ICRU and IAEA documents

- Patient dosimetry for x rays used in medical imaging
  - ICRU Report 74, published in 2005

- Dosimetry in diagnostic radiology: an international code of practice
  - IAEA Technical Reports Series No 457, 2007