Risk management in radiation protection

- Strategy based on balance of risks and benefits
- ICRP – internationally recommended system of radiological protection
- Three basic principles
  - Justification – net benefit to society
  - Optimization – ALARA
  - Dose limitations

Risk assessment

1. Identify the hazards
2. Decide who might be harmed and how
3. Evaluate the risks and decide on precautions
4. Record the outcome and implement
5. Review your assessment and update if necessary
## Risk assessment of the workplace

### When?
- Prior to the start of a new work practice with source(s) of ionising radiation
- Before significantly altered work with sources of radiation

### Purpose?
- Evaluate the possibility of exposure to worker and members of the public
- Identify the nature and extent of any radiation hazard that might arise from the intended use of the source, or from an accident or occurrence that can be foreseen

### Outcome
- Identify the areas where protective measures should be implemented to reduce exposure to radiation
- Drafting of good radiation protection and safety procedures
Medical workplaces with radiation risks

The “usual suspects”: diagnostic imaging departments
X-rays in radiology department, cathlab and operating theaters

Radioactive tracers in nuclear medicine

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Medical workplaces with radiation risks

The “usual suspects”: radiotherapeutic treatments

- medical accelerator
- HDR and PDR brachytherapy
- radionuclide therapy
Medical workplaces with radiation risks

But also: production of radiopharmaceuticals within the cyclotron facility and GMP cleanrooms

And radioactive waste management, decommissioning of old radiation devices,…

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Step 1: identify the hazards

- **Exposure to external radiation** arising from
  - close proximity to
  - limited shielding of
  - prolonged exposure to a source
  In addition to normal operation consider non-routine operations such as alignment/adjustment and maintenance of equipment.

- **Internal radiation exposure** through ingestion, inhalation, inoculation or skin absorption. This could occur as a direct result of poor containment, the potential for contamination, or inadequate ventilation controls (e.g. fume cupboards).

- **Exposure of workers** involved in handling and disposing of any radioactive waste (including excretions from the radionuclide therapy patient).

- Radioprotection in medical facility is part of integrated risk management (patient safety, mechanical safety, infection control,…)
Step 2: who might be harmed and how

WHO?

• Occupational exposed personnel who handles the radioactive sources/radiation equipment

• Medical personnel that comes in contact with the patient who receives radionuclide therapy

• Technical personnel who does the maintenance of the radiation equipment/ventilation system in the controlled area with possibility of airborne radioactive contamination

• Personnel that carries out the radioactive waste management, internal transport of the radioactive source

• Persons who aid the radionuclide therapy patient (family members, …)
Step 2: identify who might be harmed and how

HOW?

Outline the practice/experiment: describe the radiation procedure, amounts of activity, duration, frequency, location.

Dose Estimation: prediction of the possible dose assuming that the radiation protection controls are successfully implemented.

• External doses can be estimated by:
  – measurement of similar operations using a radiation monitor, for example from indicative dose rate measurements (uSv/hr)
  – calculation: at distances from sources of relevant activity and summated for typical time spent per year.
  – reference to indicative information (scientific literature,...).

In the case of machine sources of radiation a survey may be required to establish dose rates in the vicinity under various operating conditions, including maintenance and adjustment etc.
Estimation of exposure: dose measurement

Area monitoring

Personnel monitoring

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Estimation of exposure: dose calculation

**Fluorine - 18**

- Half life: 1.83 hours
- Specific activity: $3.52 \times 10^2 \text{ Bq.g}^{-1}$

### Main emissions (MeV)

<table>
<thead>
<tr>
<th>Emission Type</th>
<th>Energy (MeV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gamma or X</td>
<td>0.66, 0.26</td>
</tr>
<tr>
<td>Beta (E_max)</td>
<td>0.80</td>
</tr>
<tr>
<td>Electron</td>
<td>0.80</td>
</tr>
<tr>
<td>Alpha</td>
<td>0.07</td>
</tr>
</tbody>
</table>

### Exemption levels

<table>
<thead>
<tr>
<th>Quantity (Bq)</th>
<th>Concentration (Bq.g$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1E-06</td>
<td>1E-01</td>
</tr>
</tbody>
</table>

### Transport (Tbq)

- IAEA STI A1 value: 1E-06
- IAEA STI A2 value: 1E-04

### External Exposure

- Point source (30 cm):
  - Beta, electrons (skin dose): $1.20 \times 10^{-1}$
  - Gamma, X rays (deep tissue dose): $1.81 \times 10^{-3}$

- Infinite plane source:
  - Beta, electrons (skin dose): $3.0 \times 10^{-2}$
  - Gamma, X rays (deep tissue dose): $5.43 \times 10^{-3}$

- 10 ml glass vial:
  - Contact with 50 ml glass beaker: $1.59 \times 10^{-4}$
  - Contact with 5 ml plastic syringe: $2.89 \times 10^{-5}$

### Contamination

- Skin dose (mSv h$^{-1}$):
  - Uniform deposit: $1.99 \times 10^{-6}$
  - Uniform drop: $7.68 \times 10^{-1}$

### Detection

- Recommended probes:
  - Alpha probe
  - Beta, Gamma, X rays probe

### Derived limits (Bq.cm$^{-2}$)

<table>
<thead>
<tr>
<th>Probe Type</th>
<th>Derived limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beta</td>
<td>$2 \times 10^2$</td>
</tr>
<tr>
<td>Alpha</td>
<td>$1 \times 10^5$</td>
</tr>
</tbody>
</table>

### Shielding (mm)

- Glass:
  - 0.9
- Plastic:
  - 1.7
- Lead:
  - 10
- Sheet:
  - 0.4

### Internal Exposure for Workers

**Committed effective dose per unit intake (Sv.Bq$^{-1}$)**

<table>
<thead>
<tr>
<th>Mode of Intake</th>
<th>Effective Dose</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ingestion</td>
<td>$1 \times 10^2$</td>
</tr>
<tr>
<td>Inhalation</td>
<td>$4.96 \times 10^{-1}$</td>
</tr>
</tbody>
</table>

### Maximum recommended activities

- Subject to external exposure requirements which may be more restrictive.

<table>
<thead>
<tr>
<th>Physicochemical State</th>
<th>Volatility factor (s)</th>
<th>Supervised area</th>
<th>Controlled area</th>
</tr>
</thead>
<tbody>
<tr>
<td>All compounds</td>
<td>0.01</td>
<td>Enter</td>
<td>Enter</td>
</tr>
<tr>
<td>Highest dose organ</td>
<td>Liver</td>
<td>30 mSv AU ingestion: $4.1 \times 10^2$ (lbs) 20 mSv AU inhalation: $2.2 \times 10^2$ (lbs)</td>
<td></td>
</tr>
</tbody>
</table>

**Maximum recommended activities in low level or intermediate level laboratories (Bq)**

- Subject to external exposure requirements which may be more restrictive.
Step 2: who might be harmed and how

HOW?

Dose Estimation:

- **Internal doses** can be received through inhalation of volatile radioactive emissions, absorption through the skin (accidental spillage or contaminated surfaces) or by ingestion.
  - The procedure should be evaluated to identify those steps and **identify the controls to be applied to restrict** this.
  - An indication of the potential for internal hazard can be gained from **comparison of the ALI (Annual Limit on Intake)** for the isotope with the quantity to be handled.
Control of Exposure
Description of the steps taken to control radiation exposure, both external and internal:

- **Physical precautions:**
  - Designation and suitability of the workplace
  - Access restriction
  - Containment
  - Shielding
  - Safety features

- **Procedural precautions:**
  - design of procedure: work procedure, procedure describing the safety features, incident procedure, training of the work practices involved, of the safety measures being taken
  - competence of personnel: education on new techniques, optimization,…

Step 3: Evaluate the risks
Decide on precautions
Access restriction – Containment - Shielding
Step 4: Record the outcome + implement

- The methods to reduce or eliminate exposure will need to be incorporated into the local rules and/or experimental protocols.
  
  **Logbooks: inventory on contamination monitoring, storage of sources,…**

- The radiation worker(s) concerned should receive information, instruction and training in the risks of the work and the safe conduct of this.

  **Records of training should be maintained**

- Effective supervision to confirm procedures/safety measures are operating correctly
  
  **Keeping records of the regular control of safety features installed**
  
  **Installation of a warning system in case of faulty equipment with a safety function**
  
  **Permanent radiation monitoring in high risk areas**

Implement your radioprotection plan on the work floor while following the clinical goals.
Step 5: Review your assessment
Update if necessary

Examples that would require a review of the risk assessment

- The introduction of a new radioactive source of a much larger activity, or a source emitting a different type or quality of radiation
- The introduction of new work practices which require new radioactive sources or irradiating apparatus e.g. in radiotherapy, nuclear medicine
- The introduction of unsealed sources in an area where only sealed sources have previously been used
- Work station modifications, including engineering controls and safety features
- Changes to processes or methods of work.
Risk assessment making high activity Y-90 radionuclide therapy agents

**Step 1:** Y-90 is a high energetic beta-emitter. It is used for RNT purposes, so at high activities (GBq) and in liquid form.

**Step 2:** The operator handling the radiopharmaceutical.

**Step 3:** Risks are external and internal exposure. 
- **Contamination** → avoid spills and direct contact with the pharmaceutical fluid, work in a dedicated workspace (eg. Shielded LAF-cabinet) 
- **Manipulation can result in high finger dose** → use tweezers (distance principle); syringe shielding and plexi screens (shielding principle)

**Step 4:** follow-up of finger dose, write SOP

**Step 5:** optimize safety measures based on dose results
Risk assessment making high activity Y-90 radionuclide therapy agents
Risk assessment for the introduction of Ru-106 eye plaques in brachytherapy for eye tumours

Unique Plaque Design
The core of the Ru-106 Eye Applicator consists of a foil coated with Ru-106/Rh-106. This core is safely encapsulated within pure silver sheets. The silver backing acts as a radiation shield and absorbs approximately 95% of the beta radiation.
Step 1: identify the risk

- Ru-106 / Rh-106 => Pd-106: Sealed source, β-emitter (βmax: 3.5 MeV)
- Reusable up to 18 months: Needs steam sterilisation after application (max. 50 cycles)
- Produced with nominal reference dose rate of 80 mGy/min based on the shipping date. Production-related tolerances ranging from -10% to +60% are possible.
- Application time: 3 – 7 days

Risk: external exposure

High dose at the base of the tumour while sparing the organs at risk.

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Step 2: Who might be harmed and how

- Equivalent dose rate around the patient?

Assumptions: Source activity: 20 MBq, shielding: 1.5 cm tissue

Estimated equivalent dose rate due to γ-radiation:
- At 10 cm: 55 μSv h⁻¹
- At 30 cm: 15 μSv h⁻¹
- At 1 meter: 1 μSv h⁻¹

β radiation is completely absorbed by the patient.

<table>
<thead>
<tr>
<th>Handeling</th>
<th>Locatie</th>
<th>Medewerker(s)</th>
<th>Type zone</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>168.01.07.07 (bering 3)</td>
<td>Medewerker radioprotectie</td>
<td>Bewaakt</td>
</tr>
<tr>
<td>2</td>
<td>168.01.07.07 (bering 3)</td>
<td>Medisch fysisch</td>
<td>Bewaakt</td>
</tr>
<tr>
<td>3</td>
<td>168.01.07.07 (bering 3)</td>
<td>Medewerker Oka oogzien</td>
<td>Bewaakt</td>
</tr>
<tr>
<td>4</td>
<td>OKA oogziken – 168.01.07.03</td>
<td>Medewerker Sterilisatie</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>E770 - OKA oogziken</td>
<td>Oogchirurg</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>E 722</td>
<td>Verplegend personeel</td>
<td>Oogchirurg</td>
</tr>
<tr>
<td>7</td>
<td>E770 - OKA oogziken</td>
<td>Oogchirurg</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>168.01.07.07 (bering 3)</td>
<td>Medewerker Oka oogzien</td>
<td>Bewaakte</td>
</tr>
</tbody>
</table>
Step 3: Evaluate the risks + Decide on precautions

Radioactive encapsulated source:
- Provide shielding for source and workstation
- Lockable storage
- Symbol of ionizing radiation: designated area
- The necessary protective equipment is present: tweezers to manipulate source, source and sterilization container, ....
- Emergency procedure present + contact details of who to contact
- Regular leak/wipe tests to verify the integrity of the source ...

New medical application:
mandatory commissioning = approval of type of source and testing of safety devices
Quality Control (QC) =
- calibration test of the source: medical physics
- intactness encapsulated source: health physics
Step 4: Record the outcome + implement

Doserate during manipulation of the source

<table>
<thead>
<tr>
<th>Ruthenium oogapplicator</th>
<th>Holle zijde</th>
<th>Bolle zijde</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Hp(10) γ-straling</td>
<td>Hp(0.07) γ-straling</td>
</tr>
<tr>
<td>CCA (#2297) @ contact</td>
<td>22000</td>
<td>50000</td>
</tr>
<tr>
<td>CCA @ 5 cm</td>
<td>3500</td>
<td>10000</td>
</tr>
<tr>
<td>CCA @ 12 cm</td>
<td>2400</td>
<td>6200</td>
</tr>
<tr>
<td>CCA @ 30 cm</td>
<td>780</td>
<td>1600</td>
</tr>
<tr>
<td>CCA @ zijopening loodkasteel</td>
<td>100</td>
<td>150</td>
</tr>
<tr>
<td>CCA @ voor operatorscherm</td>
<td>&lt; 1</td>
<td>6</td>
</tr>
</tbody>
</table>

Dose rate during cleaning of the source

Bron ondergedompeld in potje waterige oplossing min. 5 cm hoog gevuld (bron met de bolle kant naar boven)

| CCA @ 3 cm (bij contact aan zijkant) | 52 |
| CCA @ 5 cm (waar potje wordt vastgehouden) | 40 |
| CCA @ 7 cm (vlak boven potje)       | 32 |
| CCA @ 30 cm (boven potje)          | 6  |
| CCA @ 100 cm (boven potje)         | 1  |
Step 4: Record the outcome + implement

**SOP:** integrate in the total medical workflow
Thank you

More information? niki.bergans@kuleuven.be