Operational radiation protection
Irradiation and contamination
First part

EXTERNAL EXPOSURE
Outline

I. Protection against irradiation
   1. Source selection
   2. Reduce exposure time
   3. Increase the distance
   4. Proper positioning of a shielding

II. Measuring external exposure
   I. Personal dosimetry
   II. Ambiante dosimetry
External exposure

An individual located near a source of radiation is subject to external exposure.

External exposure is essentially caused by gamma radiation. External exposure from alpha radiation can be overlooked.
External exposure

\[ H = A \cdot h \cdot \frac{1}{r^2} \cdot T \cdot t \]

- **h**: Quantity for external exposure, this is a dose constant indicating the dose per unit of intensity of the source. \([(\text{mSv/h})/\text{GBq}] \text{ at 1 m}\)
- **T**: Transmission factor of radiation through a screen placed between the source and the individual.
- **r**: Distance between the individual and the radiation source [m]
- **t**: Duration of exposure [h]
- **A**: Activity of the source [GBq]
- **H**: Dose [mSv/h]
External exposure

h -> Annex 3 of the Radiological Protection Ordinance

<table>
<thead>
<tr>
<th>Nuclide</th>
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<th>Type of decay/radiation</th>
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<th>$\epsilon_{\text{ing}}$ Sv/Bq</th>
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<th>$h_{0.07}$ (mSv/h)/GBq at 10 cm</th>
<th>$h_{0.07}$ (mSv/h)/ (kBq/cm$^2$)</th>
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<th>Guidance values</th>
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Guidance values:
- CA: Bq/m$^3$
- CS: Bq/cm$^2$
External exposure

"H" = "A" \cdot "h" \cdot \frac{1}{"r^{2}"} \cdot "T" \cdot t

« source » « time » « distance » « shielding »

Rules of protection against external exposure

- Source selection
- Reduce exposure time
- Increase the distance
- Proper positioning of shielding
Source selection

Act on the characteristics of the emitted radiation ($h$)

$$H = A \cdot h \cdot \frac{1}{r^2} \cdot T \cdot t$$

Act on the intensity of the source ($A$)

Use the least penetrating radiation possible which is compatible with the application goal.

Ex: Iodine-125 (35 keV $\gamma$ radiation) rather than Iodine-131 (360 keV $\gamma$ radiation) for biological marking

Reduce the intensity of the source

Ex: Immediate storage of the parent solution following a dilution for use in chemistry or biology
Reduce exposure time

The shorter the exposure time, the smaller the dose.

⇒ Work planning:
  ▪ practice of the operation without the source
  ▪ reduce any useless gestures, dead time and unexpected occurrences.

⇒ Limit the number of person working with the source
Exercises

1) Estimate the annual dose for a person working 10 h per week at 1 m from a 500 kBq source of Cesium-137 (control source).

2) What is the maximum working time at 10 cm from 200 MBq source of F-18 which would limit the dose at 100 µSv?
Increase the distance

Dose rate evolves as the inverse of the square of the distance to the source
Increase the distance

Dose rate evolves as the inverse of the square of the distance to the source

\[
\frac{H_1}{H_2} = \left(\frac{r_2}{r_1}\right)^2
\]

Especially important at the first few centimeters:

Ex: 10 cm distance rather than 1 mm distance reduces the dose rate by a factor of 10000.

⇒ Use tweezers whenever possible!
⇒ Use telemanipulators
Exercises

1) Calculate, for a surface dose, the benefit linked to using tweezers (handle length: 20 cm) to hold a flask of Technetium-99m.

2) If the operation using the tweezers in the previous exercise lasts 1 minute, calculate the duration of the manual manipulation if we want to maintain the same dose.
Proper positioning of a shielding
Proper positioning of a shielding

- α Radiation: Layer of the epidermis (70 µm) made up of dead skin cells, Sheet of paper
- β Radiation: 1 cm of water, 1 cm-thick plastic screen
- γ Radiation: Lead, Concrete
Proper positioning of a shielding

Radiation transmission of concrete for various radionuclides ($\rho = 2.35$ g/cm$^3$)
Proper positioning of a shielding

Radiation transmission of lead for various radionuclides ($\rho = 11.35 \text{ g/cm}^3$)
Proper positioning of a shielding
Exercises

1) Compare at equal transmission (1%) the thickness of lead to be used for an area where a source of Cobalt-60 or Iridium-192 is used.

2) In order to reduce the dose rate by a factor of 100 a I-131 source must be shielded with a thickness of approximately:
   - 0.6 cm of lead
   - 6 cm of lead
   - 6 cm of concrete
   - 60 cm of concrete
Outline

I. Protection against irradiation
   1. Source selection
   2. Time, exposure duration
   3. Distance from the source
   4. Shielding

II. Measuring external exposure
   I. Personal dosimetry
   II. Ambiante dosimetry
Personal dosimetry

**Dosimeter** to measure the dose \([\mu\text{Sv}]\).

- Passive individual Dosimeter
  - Monthly reading

- Active individual Dosimeter
  - Immediate reading and alarm

- Ring Dosimeter
Ambient dosimetry

**Ambient dose rate meter** to measure the dose rate $[\mu\text{Sv/h}]$. 

**Portable measuring device**
Permanently available in the laboratory and can be used when needed.

**Stationary monitors**
Generally equipped with an alarm. Data can be recorded if necessary.
Exercise

True or False

When working with $\gamma$ emitters:

- The Automess can be used to control the ambient dose rate.

- The active individual dosimeter can be used to know instantaneously the dose received while working.

- The passive individual dosimeter and the active individual dosimeter have the same utility.
Second part

INTERNAL EXPOSURE
Outline

I. Protection against contamination
   1. Source selection
   2. Protection through structures
   3. Means of personal protection
   4. Protection through working methods

II. Decontamination
   I. Guiding value
   II. Measuring surface contamination
   III. Decontamination techniques
Internal exposure occurs following a contamination. The radiation source is present inside the organism.
Internal exposure

The risk of contamination linked to radioactive substances directly depends on their physical state:

- Gas and aerosol
- Liquid
- Solid
# Source selection

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Optimization</th>
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<tbody>
<tr>
<td>Type of emitter and radiation energy</td>
<td>Less dangerous radiation and the lowest energy</td>
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<tr>
<td>Activity of the source</td>
<td>Minimum activity compatible with the planned application</td>
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<tr>
<td>Half-life</td>
<td>Shortest half-life compatible with the planned application</td>
</tr>
<tr>
<td>Chemical forms</td>
<td>Chemical forms which are the most quickly eliminated by the body</td>
</tr>
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Protection through structures
Protection through structures

**LA – Authorization limit**

Authorization limit is the activity of a substance above which an authorization/licence is needed to handle it as an open source.

LA leads, by inhalation of the substance, to a committed effective dose of 5 mSv.

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Protection through structures

Goal of the working area: **Confine the radioactive substance**

<table>
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<th>Type</th>
<th>Maximum activity</th>
</tr>
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<tbody>
<tr>
<td>Normal</td>
<td>$1 , \text{L}_\text{A}$</td>
</tr>
<tr>
<td>Type C</td>
<td>$100 , \text{L}_\text{A}$</td>
</tr>
<tr>
<td>Type B</td>
<td>$10,000 , \text{L}_\text{A}$</td>
</tr>
<tr>
<td>Type A</td>
<td>$&gt; 10,000 , \text{L}_\text{A}$, in accordance with authorization</td>
</tr>
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</table>
Protection through structures

Ordinance on the use of open sources of radiation

Ordonnance sur l'utilisation des sources radioactives non scellées

du 21 novembre 1997 (Erat le 1er janvier 2013)

Le Département fédéral de l'Intérieur,
vu les art. 58, al. 4, 61, al. 1 et 3, 62, 69, al. 5, 75, al. 2, 77 et 87, al. 3, de l'ordonnance du 22 juin 1994 sur la radioprotection (ORaP),
arrêté:

Chapitre premier: Dispositions générales

Art. 1 Champ d'application
1 La présente ordonnance s'applique à l'utilisation, soumise à autorisation, de sources radioactives non scellées.
2 Des dérogations aux dispositions de la présente ordonnance sont admises lors d'interventions d'ordre médical en cas d'accident majeur ou de guerre, pour autant que les doses de rayonnement ne dépassent pas les valeurs fixées aux art. 35 à 37 ORaP; le cas échéant, l'art. 40 ORaP est applicable. Le médecin responsable décide des mesures à prendre.

Art. 2 Définitions
Les définitions dans l'annexe 1 ORaP et dans l'annexe 1 de la présente ordonnance sont applicables.

Art. 3 Limitation des doses individuelles
1 Les lieux et les secteurs de travail prévus pour l'utilisation de sources radioactives non scellées doivent être construits et organisés de manière à limiter et à optimiser les doses individuelles.
2 S'il y a plusieurs sources radioactives au même endroit, on prendra en considération le débit de dose de chacune d'elles, de façon à respecter les valeurs directrices mentionnées dans l'annexe 2.

Art. 4 Grandeurs de surveillance
Les valeurs directrices mentionnées dans l'annexe 2 servent de grandeurs de surveillance à utiliser dans la pratique pour le contrôle des mesures prises en matière de radioprotection.
Protection through structures

Type C laboratory
Protection through structures

Type B laboratory
Exercices

1) Which type of working area is required to handle 10 MBq of an open radioactive source of Sr-90?

2) Which type of working area is required to handle 300 MBq of an open radioactive source of P-32?

3) True or false:
   Type B laboratory:
   - The exit must be equipped with a hand and foot monitor.
   - All structures (doors and walls) must be shielded.
   - Is only used for handling sealed sources.
Means of personal protection

Goal: **Confine the user**
Means of personal protection
Protection through working methods

Basic rules:

Do not smoke, drink or eat in a laboratory where open sources are located;

Always use gloves when handling the source;

Take all necessary precautions to avoid cuts or other injuries;

Never use a pipette with the mouth.
Protection through working methods

**Contamination monitoring:**

Frequently monitor hand contamination;

Periodically monitor (and when finished with any work) surface contamination of working areas, shoes and clothing;

Never allow a contamination to sit about, wash hands as frequently as necessary;

Monitor the contamination of any object leaving the working area.
Protection through working methods

**Sources manipulation**

Avoid working near the stock of a radioactive substance: put it away as soon as you’ve taken what you need for working;

Conduct any handling above a basin which can gather the substance if it disperses;

Prepare special containers for radioactive waste;

Label all radioactive products.

**Accident**

Prepare response measures in the event of a contamination;

In case of an accident, react calmly and carefully, avoid spreading the contamination, call upon the radiation protection officer.
Outline

I. Protection against contamination
   1. Source selection
   2. Protection through structures
   3. Means of personal protection
   4. Protection through working methods

II. Decontamination
   I. Guiding value
   II. Measuring surface contamination
   III. Decontamination techniques
Guiding value

**CS – Surface contamination**

The guiding value for surface contamination is the accepted limit value outside controlled zones.

Maximum allowable residual contamination:

1 CS outside controlled zones;

10 CS inside controlled zones.

Measuring surface contamination

Measuring instrument:

Surface contamination monitor
Measuring surface contamination

Direct method:
Measuring surface contamination

Indirect method

Indication of the level of contamination using wipe test

- Surfaces that cannot be easily controlled
- High level background
- Low energy β emitters (H-3)

Or
Decontamination techniques

Decontamination of surfaces
- Standard cleaning;
- Chemical methods or electrochemical procedures (water, acids, bases, oxidants, reducers, etc);
- Physical procedures (aspiration, abrasion, ultrasound, etc).

- wash-dry-measure-rewash-etc
- Decontaminate as soon as possible

Decontamination of people
- Wash with mild soap, rinse with water
- If contamination of the eyes, ears or mouth -> Physician
Exercice

1) Calculate the waiting time so that a surface contamination of 200 Bq/cm² of I-125 decays below the legal guideline value for uncontrolled areas.
Limits and guiding values

For radiation protection needs, two secondary activity limits and two guiding values were established:

- Exemption limit, LE
- Authorization limit, LA

- Guiding value for air contamination, CA
- Guiding value for surface contamination, CS.
Below the exemption limit, the ordinance is no longer applicable.

Ingestion of 1 kg of a substance with a specific activity corresponding to LE leads to a committed effective dose of 10 μSv.
LA – Authorization limit

Authorization limit is the activity of a substance above which an authorization/licence is needed to handle it as an open source.

LA leads, by inhalation of the substance, to a committed effective dose of 5 mSv.
The parameter CA is defined so that one person, working the entire year* in a contaminated room at the guiding value, receives a committed effective dose equal to the annual dose limit for professionals (20 mSv).

* 40 hours per week / 50 weeks per year; breathing 1,2 m³/h

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<th>Période</th>
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<td>1 E+04</td>
<td>30</td>
</tr>
</tbody>
</table>

**Ordonnance sur la radioprotection ORaP (annexe3)**

**Grandeurs d’appréciation**

<table>
<thead>
<tr>
<th>$h_{10}$ (mSv/h)/GBq à 1 m de distance</th>
<th>$h_{0.07}$ (mSv/h)/GBq à 10 cm de distance</th>
<th>$h_{0.07}$ (mSv/h)/ (kBq/cm²)</th>
<th>LE Bq/kg ou LE_{a0}, Bq</th>
</tr>
</thead>
</table>

**Limites d’exemption**

<table>
<thead>
<tr>
<th>CA Bq/m²</th>
<th>CS Bq/cm²</th>
<th>Nucléide de filiation instable</th>
</tr>
</thead>
</table>
The guiding value for surface contamination is the accepted limit value outside controlled zones.

<table>
<thead>
<tr>
<th>Nucléide</th>
<th>Période</th>
<th>Type de désintégration</th>
<th>$\varepsilon_{\text{inh}}$ Sv/Bq</th>
<th>$\varepsilon_{\text{inh}}$ SV/Bq</th>
<th>$h_{00}$ (mSv/h)/GBq à 1 m de distance</th>
<th>$h_{007}$ (mSv/h)/GBq à 10 cm de distance</th>
<th>$h_{007}$ (mSv/h)/kEql/cm$^2$</th>
<th>$\text{LE Bq/kg ou LE}_{\text{eq}}$ Bq</th>
<th>$\text{LA Eq}$</th>
<th>$\text{Valeurs directrices}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>H-3</td>
<td>12.35 a</td>
<td>$\beta^-$</td>
<td>4.1 E-11</td>
<td>4.2 E-11</td>
<td>&lt;0.001</td>
<td>&lt;1</td>
<td>&lt;0.1</td>
<td>2 E+05</td>
<td>1 E+08</td>
<td>2 E+05</td>
</tr>
<tr>
<td>H-3, HTO</td>
<td>12.35 a</td>
<td>$\beta^-$</td>
<td>1.8 E-11</td>
<td>1.8 E-11</td>
<td>&lt;0.001</td>
<td>&lt;1</td>
<td>&lt;0.1</td>
<td>6 E+05</td>
<td>3 E+08</td>
<td>5 E+05</td>
</tr>
<tr>
<td>H-3, gaz [7]</td>
<td>12.35 a</td>
<td>$\beta^-$</td>
<td>1.8 E-15</td>
<td></td>
<td>&lt;0.001</td>
<td>&lt;1</td>
<td>&lt;0.1</td>
<td>3 E+12</td>
<td>5 E+09</td>
<td>3 E+09</td>
</tr>
<tr>
<td>Be-7</td>
<td>53.3 d</td>
<td>$\gamma$</td>
<td>4.6 E-11</td>
<td>2.8 E-11</td>
<td>0.008</td>
<td>&lt;1</td>
<td>0.1</td>
<td>4 E+05</td>
<td>1 E+08</td>
<td>1 E+05</td>
</tr>
<tr>
<td>Be-10</td>
<td>1.6 E6 a</td>
<td>$\beta^-$</td>
<td>1.9 E-08</td>
<td>1.1 E-09</td>
<td>&lt;0.001</td>
<td>2000</td>
<td>1.6</td>
<td>9 E+03</td>
<td>3 E+05</td>
<td>9 E+01</td>
</tr>
<tr>
<td>C-11</td>
<td>20.38 m</td>
<td>$\beta^-$</td>
<td>3.2 E-12</td>
<td>2.4 E-11</td>
<td>0.160</td>
<td>1000</td>
<td>1.7</td>
<td>4 E+05</td>
<td>7 E+07</td>
<td>7 E+04</td>
</tr>
<tr>
<td>C-11 monoxide</td>
<td>20.38 m</td>
<td>$\beta^-$</td>
<td>1.2 E-12</td>
<td>1.2 E-12</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C-11 dioxide</td>
<td>20.38 m</td>
<td>$\beta^-$</td>
<td>2.2 E-12</td>
<td>2.2 E-12</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C-14</td>
<td>5730 a</td>
<td>$\beta^-$</td>
<td>5.8 E-10</td>
<td>3.8 E-10</td>
<td>&lt;0.001</td>
<td>200</td>
<td>0.3</td>
<td>2 E+04</td>
<td>9 E+06</td>
<td>1 E+04</td>
</tr>
</tbody>
</table>

**Ordonnance sur la radioprotection ORaP (annexe3)**
Controlled areas are:

- areas with air contamination > 1/20 CA
- areas with surface contamination > CS
- areas where one can receive a dose > 1 mSv / year for external irradiation
- areas declared as controlled zone by authorities

Laboratories type C, B or A are **Controlled Areas**
Protection through structures

ORaP, Chap.5, section 1, art 58

- Controlled areas are **defined by the holder of the authorization**
- Controlled areas **must be labeled**
- The holder of the authorization must **control the access** and the limited stay of people in the zone.
Protection through structures

Labelling of controlled areas concerning open radioactive sources

+ Information about necessary protective clothing as well as protection measures to take.
Protection through structures

Labelling of controlled areas concerning **sealed radioactive source**

+ The ambient dose rate in mSv per hour in the working area, if this is considered judicious.
Protection through structures

Labelling of controlled areas concerning X-ray generators, accelerators, ...

- Type of installation
- Type of radiation
- Dose rate, mSv.h-1