Radiation Safety Training
for General Radiation Workers

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The sources and effects of radiation are well known, and understanding them is essential to ensure safety.

Radiation is a natural phenomena and mitigating the hazards and risks associated with it are straightforward (not unlike dealing with the hazards and risks of everyday life, e.g., crossing the street, driving a car, flying in an airplane, etc.).

Neutron, high-energy betas, x rays, and γ rays are released from fixed radiation sources at LLE.

Tritium represents a diffuse radiation source.

LLE’s Radiation Safety Program ensures personnel safety and protection of the environment.
Terms and units used to describe radiation

• Radioactive nuclide
  – unstable nuclide that tries to achieve a more-stable configuration by emitting energy (particles or e/m radiation)

• Ionizing radiation
  – radiation with enough energy to ionize matter

• Half-life
  – the time required for half of a given amount of radionuclide to decay

• Activity
  – the rate at which radioactive nuclides disintegrate (dps, DPM)
    - 1 disintegration/s = 1 Becquerel (Bq)
    - 1 Ci = $3.7 \times 10^{10}$ disintegrations/s (Bq)

• Activation
  – radioactivity induced in a material when ionizing radiation interacts with that material (mrem/h)

• Contamination
  – removable radioactive material present on a surface or in the bulk (DPM/100cm$^2$)
<table>
<thead>
<tr>
<th>Type</th>
<th>Mass</th>
<th>Charge</th>
<th>Energy (MeV)</th>
<th>Skin</th>
<th>Aluminum Plastic</th>
<th>Lead Concrete</th>
<th>Concrete Paraffin</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alpha</td>
<td>4</td>
<td>+2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Beta</td>
<td>~1/1835</td>
<td>±1</td>
<td>0.057 1.4</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Neutron</td>
<td>1</td>
<td>0</td>
<td>2–14</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gamma</td>
<td>0</td>
<td>0</td>
<td>0.4–2.8</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>X rays</td>
<td>0</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Half thickness (cm)</td>
<td>0.3 0.6</td>
<td>0.3–2 3–8 5–8 4–10</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Terms and units used to describe radiation safety

- **(Absorbed) dose (D)**
  - the amount of energy imparted by ionizing radiation to matter
  - “rad” is the unit of absorbed dose

- **Quality factor (QF)**
  - a weighting factor to account for the biological effectiveness of differing radiation
    
    \[
    QF = \begin{cases} 
    1 & \text{for beta, x rays, and gamma rays} \\
    20 & \text{for alpha particles} \\
    3 \text{ to } 10 & \text{for neutrons}
    \end{cases}
    \]

- **Dose equivalent (H)**
  - the amount of biological damage caused by ionizing radiation
  - “rem” is the unit of dose equivalent
    
    \[
    H = D \times QF
    \]
Radiation exposure limits and natural sources

- Radiation exposure is limited by law in the workplace to the following:
  - radiation worker exposure limit: 5000 mrem/year
  - general public exposure limit: 100 mrem/year

- Natural radiation sources and average annual dose equivalent levels for individuals are as follows:

<table>
<thead>
<tr>
<th>Source</th>
<th>mrem/year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cosmic rays (outer space)</td>
<td>27–96</td>
</tr>
<tr>
<td>Terrestrial (rocks, soil)</td>
<td>28–100</td>
</tr>
<tr>
<td>Human body (elements in the body)</td>
<td>40</td>
</tr>
<tr>
<td>Radon</td>
<td>~200</td>
</tr>
</tbody>
</table>

Typical exposure for an individual living in the U.S. is 310 mrem/year.
Doses to individuals living at higher elevations can approach 800 to 1000 mrem per year

Half of the dose received by the population of the U.S. is due to nuclear medicine.

Effects of large acute exposures

<table>
<thead>
<tr>
<th>Dose (rem)</th>
<th>Effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>No clinical effects</td>
</tr>
<tr>
<td>50</td>
<td>Minor blood chemistry changes</td>
</tr>
<tr>
<td>500</td>
<td>Radiation sickness within 4 h, over 50% death rate</td>
</tr>
</tbody>
</table>
The aim of radiation protection is to reduce exposure to As Low As Reasonably Achievable levels (the ALARA principle) for fixed activated materials.

**MINIMIZE TIME**

\[ H = \text{Dose rate} \times \text{time} \]

At LLE, time = number of target shots

**MAXIMIZE DISTANCE**

Closed access during shots

**MAXIMIZE SHIELDING**

- Provide shielding
  - energetic betas → aluminum, plastic
  - x rays, γ rays → lead, concrete
  - neutrons → concrete, paraffin
Additional radiation protection measures

- **Use of personal protective equipment**
  - Beta/gamma/x ray detector, portable T monitor, gloves, overcoats

- **Wearing personal monitors**
  - film badges/ring dosimeters (when handling activated materials)
  - urinalysis when handling more than 100 mCi

- **Periodic surveys of**
  - the neutron activation of structural materials
  - the surface contamination in tritium-handling areas

- **Procedures**
Four radiation sources need to be managed at LLE

- **DT fusion**—prompt neutron radiation
  - maximum credible yield shot of $3 \times 10^{15}$ neutrons yield 516 rem at the surface of the OMEGA target chamber (radius = 1.6 m)
  - maximum neutron yield on OMEGA EP is $\sim 10^{12}$ neutrons

- **Activated structures**—short-term gamma radiation
  - neutrons interact with OMEGA
  - protons interact with film pack on OMEGA EP

- **Tritium**—contaminate equipment
  - surface contamination
  - airborne releases \( \text{long-term diffuse radiation} \)

- **Fast-electron** deceleration in high-Z materials in OMEGA EP—prompt, high-energy x rays
Response to activated materials and radioactive sources depends on the activity level

- **Activated material:** >0.1 mrem/h on contact
  - tag, log in Radiation Material Log book
  - enter date, activity level, where stored
  - store in pre-approved locations
  - release when activity drops below 0.1 mrem/h on contact
  - work in pre-approved work space
  - mark work space with “Caution–Radioactive Material” sign
  - must be qualified *and* badged Rad Worker
Your response to a radiation area is determined by the strength of the source

- **Radiation area:** source ≥5 mrem/h at 30 cm
  - work in a pre-approved radiation area
  - isolate the area with one entry point
  - post “Caution–Radiation Area” signs around the perimeter
  - Rad worker must be badged
  - controlled access
  - pre-approved work scope
  - limited stay time

- **High-radiation area:** >100 mrem/h at 30 cm
  - set barrier at 5 mrem/h
  - post a “Caution–High Radiation Area” sign
  - no access to the area without Radiation Safety Officer approval
Tritium is a *diffuse* radiation source. The ALARA principle requires: ventilation and decontamination for tritium

- **Ventilation**
  - tritium gas (DT, DTO) diffuses from the point of origin to the extremities of a room in a few minutes
  - draw air away from worker with an elephant trunk
  - work in a ventilated environment

- **Decontamination**
  - surfaces exposed to tritium gas will *slowly release* DTO (and HCOOH) over an extended period
  - scrub surfaces with water/surfactant mixtures
  - ultrasonic baths
  - humid air
Surface contamination, airborne, and annual limit on intake tritium limits and basis

- **Surface contamination**
  - Limit: 1,000 DPM/100 cm²
  - Basis: Control of radioactive material, **NOT** exposure

- **Airborne limit**
  - Limit for radiation workers: 20 μCi/m³
    - Basis: Exposure to this level for 2000 h/yr gives a dose of 5 rem
  - Limit for general public: 0.1 μCi/m³
    - Basis: Continuous exposure to this level will give an individual one half of their yearly limit of 100 mrem

- **Annual limit on intake (ALI):**
  - Limit: 80 mCi
    - Basis: 5 rem
# Limits and responses to tritium contamination on surfaces

<table>
<thead>
<tr>
<th>DPM</th>
<th>Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;1000</td>
<td>- none</td>
</tr>
<tr>
<td>( &gt;10^3 )</td>
<td>- establish Controlled Surface Contamination Area (CSCA)</td>
</tr>
<tr>
<td></td>
<td>- decontaminate the component/area</td>
</tr>
<tr>
<td></td>
<td>- two surveys taken 8 h apart to verify that a component is not contaminated</td>
</tr>
<tr>
<td>( &gt;10^3 ) Pre-defined CSCA’s Internal surfaces of TIM’s, TC, and moving cryostat transport carts (MCTC’s)</td>
<td>- decontaminate using air purges or pump/vent cycles to reduce “puff”</td>
</tr>
<tr>
<td></td>
<td>- monitor breathable air with portable tritium detector</td>
</tr>
</tbody>
</table>
Controlled surface-contamination areas are used to limit the spread of contamination

- Establish a CSCA when
  - the activity of an area or surface >1000 DPM/100 cm²
  - work on components with activities >1000 DPM/100 cm² is required

- Establish a barrier and a controlled entry point
  - if particles suspected, use step off mat and floor cover

- Post a warning: “Controlled Surface Contamination Area–Do Not Enter”

- Survey the work area and equipment before clearing the CSCA
  - if >1000 DPM/100 cm², clean, re-survey the area 8 h later

- For work on components with activities >1000 DPM/100 cm²
  - sample airborne activity around the item before transfer
  - transfer material into and out of CSCA in sealed containment
Handling radioactive materials at LLE requires Radiation Safety Officer (RSO) approval

- Receipt
  - discuss with RSO first
  - arrange through Radiation Safety Unit (RSU)

**Do NOT transport any radioactive material in personal vehicle**
**Do NOT ship any radioactive materials person-to-person**

- Usage
  - discuss application with RSO first
  - use in approved/properly identified work location
  - secure source in pre-assigned storage facility when not in use

**All radioactive material/waste is ALWAYS disposed through the RSU.**
Bioassays are required anytime there is a potential exposure to tritium or contaminated equipment

- A target chamber entry
- Handling gaseous DT targets
- Handling/packaging water from regeneration systems
- Exposure to an airborne release $> 20 \mu$Ci/m$^3$
- Maintenance of highly contaminated equipment ($>10^5$ DPM/100 cm$^2$)
  - tritium recovery systems, tritium handling systems, carts, and gloveboxes
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