Radiation Safety Training
Session 4: Handling Tritium Safely

Tritium-decay beta-energy distribution

Outgassing rate ($\mu$Ci/h/100 cm$^2$) = $7 \times 10^{-6}$ surface activity$^{0.74}$ (DPM/100 cm$^2$)

1/100 monolayer/h (each particle labeled with a T atom)

ICRP limit for handling tritiated surfaces

Contact for 2000 h leads to 5-rem whole-body dose

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There are three isotopes of hydrogen: isotopes are elements with the same number of protons but differing number of neutrons

- **Protium (\(^{1}\text{H}\))**
  - recognized as a distinct substance by Cavendish in 1766
  - makes up 90% of the atoms or \(\frac{3}{4}\) of the mass of the universe

- **Deuterium (\(^{2}\text{H}\) (D))**
  - discovered by Urey in 1932

- **Tritium (\(^{3}\text{H}\) (T))**
  - discovered by Oliphant, Harteck, and Rutherford in 1934
  - radioactivity discovered by Alverez and Cornog in 1939

<table>
<thead>
<tr>
<th>Name</th>
<th>Symbol</th>
<th>Abundance (%)</th>
<th>Mass</th>
</tr>
</thead>
<tbody>
<tr>
<td>Protium</td>
<td>H</td>
<td>99.9851</td>
<td>1.007825</td>
</tr>
<tr>
<td>Deuterium</td>
<td>D</td>
<td>0.0115</td>
<td>2.014102</td>
</tr>
<tr>
<td>Tritium</td>
<td>T</td>
<td></td>
<td>3.016049</td>
</tr>
</tbody>
</table>
Terms and units used in conjunction with radiation

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

- **Ionizing radiation**
  - atoms are typically neutral, but a few eV of energy can eject an orbital electron to leave a charged atom behind
  - radiation with enough energy to ionize matter is called “ionizing radiation”

- There are two types of ionizing radiation
  - particulate (alpha, neutrons, beta)
  - electromagnetic (gamma, x rays)

- **Activity**
  - the *rate* at which atoms disintegrate (dps, DPM)
    - 1 disintegration/s = 1 Becquerel (Bq)
    - 1 Ci = $3.7 \times 10^{10}$ disintegrations/s (Bq)
Half-life and dose are measures of activity

• **Half-life** \( (\tau_{1/2}) \)
  
  – the time required for half of a given amount of radionuclide \( (A_0) \) to decay
    
    \[
    A = A_0 \exp \left(-0.693 \frac{t}{\tau_{1/2}}\right) \quad (t \text{ is in years})
    \]
  
  – each material has a unique half-life
  
  – the half-life \( (\tau_{1/2}) \) for tritium is 12.3 years
  
  – if we start with 10 Ci we will have
    
    - 5 Ci in 12.3 years

• **Absorbed dose** \( (D) \)
  
  – *absorbed dose* is a measure of the amount of energy *deposited*
  
  – “rad” (= 0.01 J of radiation energy/kg of absorbing matter)
    
    is the unit of absorbed dose
Dose equivalent measures the effect of absorbed dose from different types of radiation in human tissue

- Dose equivalent (H) (rem, mrem)
  - the amount of biological damage resulting from the absorbed dose depends on the type of radiation
  - the “quality factor” (Q) relates absorbed dose to dose equivalent

\[
H = D \times Q
\]

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<thead>
<tr>
<th></th>
<th>Q</th>
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<tbody>
<tr>
<td>Gamma, x rays</td>
<td>1</td>
</tr>
<tr>
<td>Beta radiation</td>
<td>1</td>
</tr>
</tbody>
</table>

- for tritium decay the quality factor is 1: rad and rem are equivalent
Tritium decays to helium by releasing an energetic electron: \( T \rightarrow ^3\text{He}^+ + \beta^- + \bar{\nu} \)

- **Half-life:** 12.3232 y (1 year = 365.24 days)
  decay constant \( \lambda = 1.782 \times 10^{-9} \text{ s}^{-1} \)
- **Tritium converts to helium at:**
  ~0.015% per day; 0.46% per month; 5.6% change per year
- **End point energy:** 18.6 keV
- **Mean energy:** 5.7 keV
- **Specific activities:**
  | 1 cc (STP\(^\dagger\)) \( T_2 \) | = 2.588 Ci |
  | 1 ppm | = 2.588 Ci/m\(^3\) |
  | 1 gram of \( T_2 \) | = 9615 Ci |
  | 1 mole of \( T_2 \) | = 58020 Ci |

- **\( \beta \) decay energy\(^\dagger\dagger\):** 33.7 \( \mu \text{W/Ci} \); 0.324 W/g

\(^\dagger\)STP: Standard temperature (0ºC) and pressure (101.325 kPa)
\(^\dagger\dagger\)\( \beta \)-heat output based on the mean energy of 5.685 keV
The range of tritium-decay electrons in matter is small

- Decay electrons lose a few eV per encounter (on average) by ionization and excitation of the host lattice electrons

- For tritium-decay electrons
  - Range \(~2.36 \times 10^{-5} \ A Z/\rho\) cm for 5.7 keV betas
  - \(~2.89 \times 10^{-4} \ A Z/\rho\) cm for 18.6 keV betas
  - where \(A =\) molecular weight (g/mol); \(Z =\) number of electrons per host atom; \(\rho =\) host density (g/cc)

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<thead>
<tr>
<th>Medium</th>
<th>Range ((\mu m))</th>
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<tbody>
<tr>
<td></td>
<td>5.7 keV</td>
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<tr>
<td>Air (1 atm)</td>
<td>0.35 (cm)</td>
</tr>
<tr>
<td>Water</td>
<td>0.40</td>
</tr>
<tr>
<td>SS</td>
<td>0.05</td>
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Surface reactions encourage isotopic mixing in the presence of tritium

- If the three hydrogen isotopes are present in a system the molecules will dissociate and recombine to form several isotopic combinations

- Elemental: $\text{H}_2$, HD, HT, $\text{D}_2$, DT, $\text{T}_2$
  
  Water: $\text{H}_2\text{O}$, HDO, HTO, $\text{D}_2\text{O}$, DTO, $\text{T}_2\text{O}$
  
  Organic: $\text{CH}_4$, CH$_3$D, CH$_3$T, HCOOT, TCOOH
Tritium gas interacts with all materials in some way

- Ceramics and glass
  - T\textsubscript{2} solubility in ceramics is low. βs can disrupt the local Si-O-Si bonds to transform them to Si-OT and Si-T bonds. Mechanical strength deteriorates after tens of years of exposure
  - glass behave like ceramics. Solubility is higher in glass and the mechanical deterioration is faster (of the order of years)
  - both ceramics and glass become progressively more brittle with time and more likely to shatter under impact

- Non-hydride forming metals
  - T-atom solubility in metals is much lower than glass
  - βs disrupt metal bonds but they re-constitute

- T interaction with non-hydride forming metals is not a problem except when abnormally high atom concentrations occur within the metal lattice
Organic material should be avoided when possible if tritium is present

- Tritium is **highly soluble** in organic materials
  - large voids
  - remains as molecules

- Plastics and organic O rings (Viton, neoprene) are permeable to tritium gas and vapor

- Teflon is a halogenated organic. It decomposes on contact with tritium and should be avoided.

- $T_2$ mixes with pump oils to form volatile tritiated organic vapors
  - the mechanical properties of polymeric materials degrade within **days to months** depending on the dissolved tritium concentration

Use metallic seals above 1 Ci/m$^3$
Tritium is an internal, whole body, exposure hazard only

• Control of external exposure hazards (ALARA)
  – minimize time
  – maximize distance
  – maximize shielding

• Control of internal exposure hazards
  – breathing contaminated air
  – ingestion (eating, drinking, licking...)
  – absorption through skin
  – absorption through open wounds
There are several exposure pathways for tritium

- Airborne tritium comprises several forms: HT, DTO, CH$_3$T

- Surfaces exposed to tritium
  - promptly release HT and DT and then
  - slowly release DTO, HTO, and CH$_3$T over extended periods

- Tritiated water presents a dual hazard
  - HTO vapor and skin absorption
  - HTO is $10^4$ times more hazardous than HT

- Tritiated particulate reside in the lungs and exchanges with water in the body. Tritiated particulates are as hazardous as HTO
Radiological data for tritium: urinalysis is the definitive method to measure the degree of an exposure

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<tbody>
<tr>
<td>Whole body dose for radiation worker (mrem/a)</td>
<td>5000†</td>
</tr>
<tr>
<td>Annual limit on intake (mCi)</td>
<td>80</td>
</tr>
<tr>
<td>Airborne limit in radiological area (μCi/m³)</td>
<td>20</td>
</tr>
<tr>
<td>Surface contamination (DPM/100 cm²)</td>
<td>1000</td>
</tr>
<tr>
<td>Biological half-life (days)</td>
<td>10</td>
</tr>
</tbody>
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80 mCi
2000 hrs at 20 μCi/m³
5000 mrem

†U.S. Nuclear Regulatory Commission guideline for atomic workers
Dry smear paper measures the **removable** fraction of tritium on a surface

- **Excellent health physics tool**
  - directly related to the amount picked up by an individual
  - simple to use
  - destructive

- Provides an order of magnitude accuracy
  - results vary with individuals, material surveyed and times smeared

- **Not** useful to estimate the total tritium inventory of a material

- LLE uses the 8-h “wait period” to assess the effectiveness of a decontamination

- Activity after the $n^{th}$ smear will be
  $$ A_n = A_0 (1 - \varepsilon)^n $$
  $\varepsilon$ is the fraction removed, typically $\sim 10\%$
Chronic outgassing from tritiated surfaces leads to the spread of contamination; local ventilation reduces cross-contamination.

- Tritium contaminated surfaces present three concerns:
  - respiratory dose
  - contact dose
  - cross-contamination

Outgassing species are “sticky”

Outgas rate ($\mu$Ci/h/100 cm²) = $7 \times 10^{-6}$ surface activity$^{0.74}$ (DPM/100 cm²)

Contact for 2000 h leads to 5-rem whole-body dose

ICRP limit for handling tritiated surfaces

400-mCi cryo DT shot

1/100 monolayer/h (each particle labeled with a T atom)
Tritium is released when water vapor in the air exchanges with tritiated water bound on a surface.

- Activity release decreases as the surface layers closest to air become tritium deficient.
- HTO is the dominant outgassing species.
- Tritium release after a long time is determined by “T” diffusion up to the surface from the bulk.

A controlled air purge reduces personnel exposure.
The degree of surface contamination depends on the exposure duration and the tritium partial pressure.

Decontaminate after an exposure as soon as reasonably possible.
Surfactants in an ultrasonic bath promote effective and rapid decontamination of a surface.

Surfactant accelerates the tritium-removal rate.

Water-soaked sample washed in 5% surfactant/water, 145 μCi removed

5% surfactant soak, 160 μCi removed

2.5% surfactant soak, 62 μCi removed

Water-soak, 19 μCi removed