Tritium Handling Technologies

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Outline

- Introduction
- Tritium properties
  - Nuclear, Physical, Chemical, Biological
- Tritium Facts
  - Abundance, Activity, Toxicity
- Handling, measuring
  - Elemental, Water
- Processing
  - Recovery, Extraction, Enrichment, Storage/disposal
Tritium and Fusion: Why?

D-T fusion is attractive because:

• It produces a lot of energy (17.7 MeV)
• It has a relatively low activation energy
• It produces neutrons to breed more T
Tritium Primer - 1

- **Protium (normal hydrogen)**
  - One proton
  - Most abundant element

- **Deuterium (heavy hydrogen)**
  - One proton + one neutron
  - 1 part in 6000 on Earth

- **Tritium (extra heavy hydrogen)**
  - One proton + two neutrons
  - Unstable, radioactive
  - Produced by deuterium neutron capture
  - <1 in $10^{16}$ on Earth
Beta decay:

\[ {\text{^3}_1H} \rightarrow {\text{^3}_2He^+} + e^- + {\overline{\nu}_e} \]

- Beta decay: 18 keV total energy, 5.7 keV (av.) electron
- 12.3 year half-life
• Mass: 6.032 g/mol ($T_2$)
• Gas at normal T, P
• BP: 25 K (-248°C)

<table>
<thead>
<tr>
<th></th>
<th>Protium ($H_2$)</th>
<th>Deuterium ($D_2$)</th>
<th>Tritium ($T_2$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Molecular mass (g/mol)</td>
<td>2.016</td>
<td>4.028</td>
<td>6.032</td>
</tr>
<tr>
<td>Boiling point (K)</td>
<td>20.4</td>
<td>23.7</td>
<td>25.0</td>
</tr>
<tr>
<td>Melting point (K)</td>
<td>14.0</td>
<td>18.7</td>
<td>20.6</td>
</tr>
<tr>
<td>Critical point (K)</td>
<td>33.2</td>
<td>38.4</td>
<td>40.6</td>
</tr>
<tr>
<td>NMR frequency (MHz)</td>
<td>100.5</td>
<td>15.36</td>
<td>104.7</td>
</tr>
</tbody>
</table>
Tritium undergoes the same chemical reactions as protium and deuterium:

- Burns in air/oxygen to form water ($\text{T}_2\text{O}$)
- Adsorbs/dissociates on surfaces (e.g. Pt-T)
- Forms hydrides with metals (e.g. TiT$_2$)
- Forms hydrocarbons (OBT)

Because it is the same element, chemical separations of T from H, D are difficult.
Tritium Primer - 5

- Tritium follows hydrogen in the human body
- As for H\textsubscript{2}, T\textsubscript{2} gas is not significantly absorbed into the body (low solubility in fluids)
- As water:
  - It is absorbed through all membranes (lungs, skin, digestive system)
  - Follows all metabolic paths
  - Is not significantly sequestered
  - Is excreted as water etc.
- General damage to cell constituents from direct radiation and free radicals
Primary concern is radio-toxicity
- ~10 day half-life in human body (as water)
- $\text{T}_2\text{O}$ is about 10,000 times more toxic than $\text{T}_2$
- ~1 mSv dose from 0.1 mL of 15 Ci/kg water

$\text{T}_2$ is converted to $\text{T}_2\text{O}$ in the environment (slowly in air, quickly in soil), so $\text{T}_2$ has 5-10% of effect of $\text{T}_2\text{O}$ local to release

Canadian drinking water limit: 7000 Bq/L (190 pCi/mL), about ten times US limit.
• T is produced in atmosphere (cosmic rays etc. – about 200 g/a), but current inventory in troposphere and hydrosphere is mainly from H-bomb testing (about 500-600 kg released up to 1962)
• Most surface waters in Ontario have 1-10 Bq/L (0.03-0.3 pCi/mL)
Tritium Facts - 3

- ~10,000 Ci per gram of $T_2$
- 1 Ci/kg water has ~0.3 ppm T (mol)
- Get ~35 µW/Ci from decay heat (only beta)
- Beta radiation range:
  - In air – 6 mm
  - In water – 0.005 mm
- Tritiated water is corrosive from radiolysis, which produces various active compounds e.g. $H_2O_2$, $H\cdot$ and $O_2$
• Low or high concentrations:
  • Sample
  • Convert all to water
  • Add scintillation cocktail and count

(Typical sensitivity: <1 Bq/L, count for hours)
- High concentrations:
  - Draw sample
  - Convert all to gas
  - Measure radiation (ion chamber)

(Typical sensitivity: 40 kBq/m$^3$ with 1L chamber)
Tritium Handling - 1

- In elemental form:
  - Best for high concentrations (minimize toxicity)
  - Double barriers (gloveboxes)
  - Forms stable hydrides (e.g. titanium sponge)

\[ T_2 \text{ from CDS} \]
\[ N_2 \text{ supply} \]
\[ \text{Blower} \]
\[ \text{Metering Tank} \]
\[ \text{N}_2 \text{ Glove Box} \]
\[ \text{U-bed} \]
\[ \text{Ti-beds} \]
\[ \text{Vacuum Pumps} \]
\[ \text{Air Purged Box} \]
\[ \text{Gas Chromatograph} \]
\[ \text{GB Clean-up} \]
\[ \text{To Stack} \]
\[ \text{Blower} \]
Tritium Handling - 2

- In water form:
  - Best for low concentrations (simple equipment)
  - Simple barriers (PPE)
  - Readily condensed/adsorbed (e.g. mol sieves)
Tritium Processing - 1

- Chemical conversion:
  - Oxidation OBT or element to water (catalyst)
  - Reduction of water to element (e.g. electrolysis)

Trickle-bed recombiner
Gas-phase recombiner
E-cell, membranes and catalysts
- **Separation:**
  - Hydrogen-water exchange (Pt catalyst) where natural separation factor favors heavy isotope in the water
  - Distillation of hydrogen (cryogenic) or water (vacuum)
  - Adsorption of hydrogen (e.g. palladium)
Example: Tritium recovery system

- Dry air feed to tritium areas
- Collect all exhaust air
- Recombine elemental T (and OBT) to water
- Adsorb water from air, recover liquid water
- Feed water to combined electrolysis and catalytic exchange process (CECE)
- Release hydrogen free from T
- Send T in hydrogen to cryogenic distillation
- Return concentrated tritium to process or store it in U-bed.
Tritium Processing System Diagram

- Supply Fans
- Dryer
- Exhaust Fans
- Gas-phase Recombiner
- Operations
- Stack
- Zero-T Hydrogen
- Natural Water
- Low-T Hydrogen
- Cryogenic Distillation System
- He Refrigerator
- T2 Handling System
- Oxygen
- High-T Hydrogen
- Water + T
- Catalyst Exchange Columns
- Electrolysis Cells
- DT / T₂
- Air
- Natural Water
- Water + T
AECL’s Chalk River Laboratory is the major centre for tritium expertise in Canada with:

- Tritium Facility licensed for 1 million Curies
- Facilities for handling and dispensing pure tritium
- Facilities and personnel engaged in active R&D on tritium handling, measurement, use, separations, control, transport, reactions, storage and biological effects
- Tritium models
AECL’s R&D products:

- Tritium power sources
- Processes for tritium removal
- Catalysts for tritium reactions and separations
- Certified tritium standards
- Tritium-resistant materials and equipment