# Tritium Handling Technologies

Canadian Workshop on Fusion Energy Science and Technology

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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

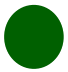
# Introduction

Tritium and Fusion: Why?

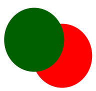
D-T fusion is attractive because:

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

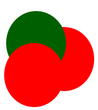
# Tritium Primer - 1



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

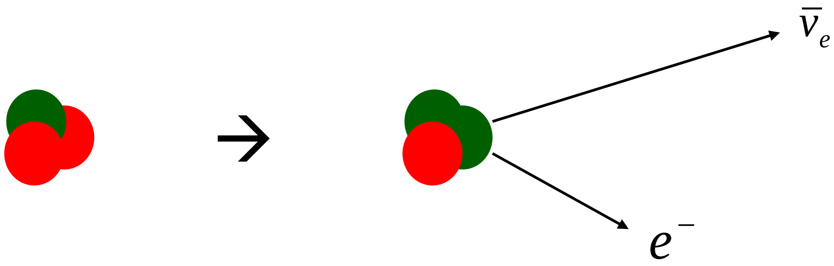


- Deuterium (heavy hydrogen)
  - One proton + one neutron
  - 1 part in 6000 on Earth



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

# Tritium Primer - 2




$$ {}_{1}^{3}H \Rightarrow {}_{2}^{3}He^{+} + e^{-} + \bar{\nu}_{e} $$

- Beta decay: 18 keV total energy,
  5.7 keV (av.) electron
- 12.3 year half-life

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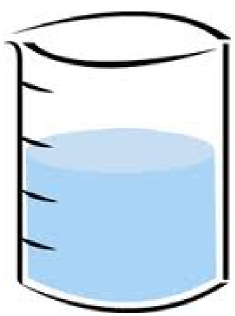
# Tritium Primer - 3

- Mass: 6.032 g/mol ($T_2$)
- Gas at normal T, P
- BP: 25 K (-248°C)

| | **Protium ($H_2$)** | **Deuterium ($D_2$)** | **Tritium ($T_2$)** |
|---|---|---|---|
| Molecular mass (g/mol) | 2.016 | 4.028 | 6.032 |
| Boiling point (K) | 20.4 | 23.7 | 25.0 |
| Melting point (K) | 14.0 | 18.7 | 20.6 |
| Critical point (K) | 33.2 | 38.4 | 40.6 |
| NMR frequency (MHz) | 100.5 | 15.36 | 104.7 |

# Tritium Primer - 4

- Tritium undergoes the same chemical reactions as protium and deuterium:
  - Burns in air/oxygen to form water ($T_2O$)
  - 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.



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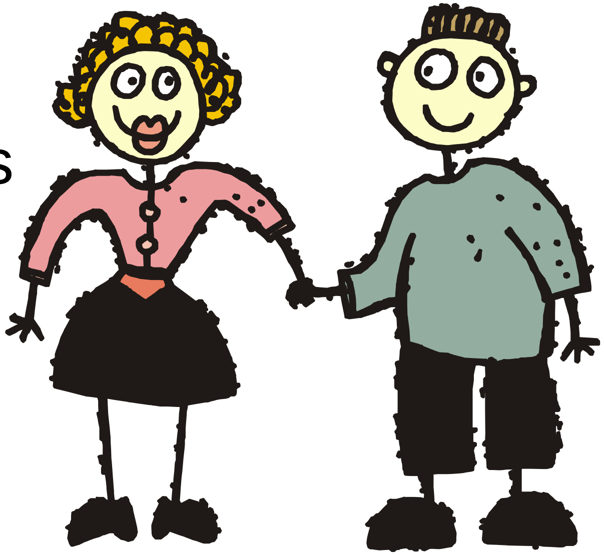
# Tritium Primer - 5

- Tritium follows hydrogen in the human body
- As for $H_2$, $T_2$ 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



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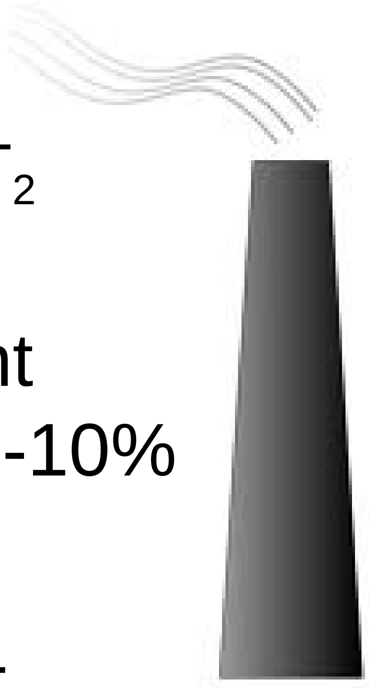
# Tritium Facts - 1

- Primary concern is radio-toxicity
  - ~10 day half-life in human body (as water)
  - $T_2O$ is about 10,000 times more toxic than $T_2$
  - ~1 mSv dose from 0.1 mL of 15 Ci/kg water
- $T_2$ is converted to $T_2O$ in the environment (slowly in air, quickly in soil), so $T_2$ has 5-10% of effect of $T_2O$ local to release
- Canadian drinking water limit: 7000 Bq/L (190 pCi/mL), about ten times US limit.



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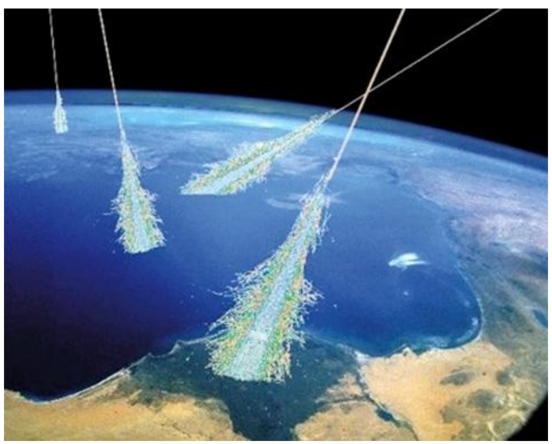
# Tritium Facts - 2

- 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)



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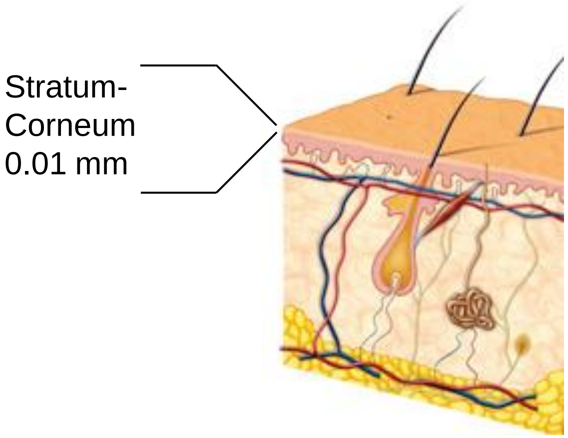
# Tritium Facts - 3

- ~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· and $O_2$

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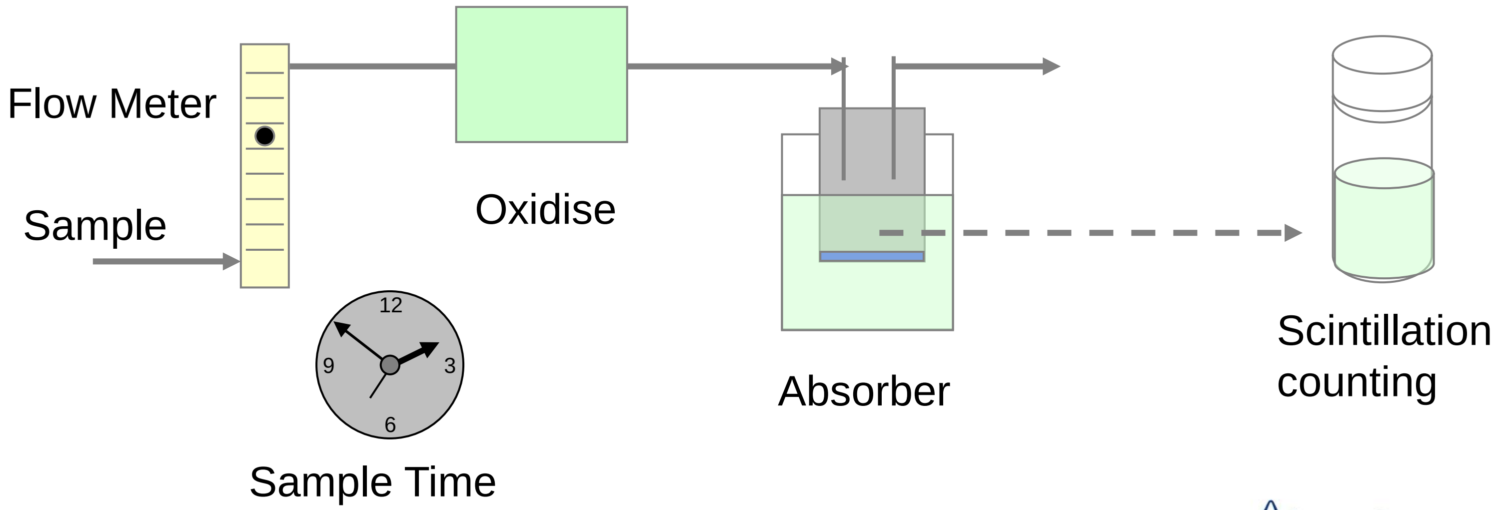
# Tritium Measurement - 1

- Low or high concentrations:
  - Sample
  - Convert all to water
  - Add scintillation cocktail and count

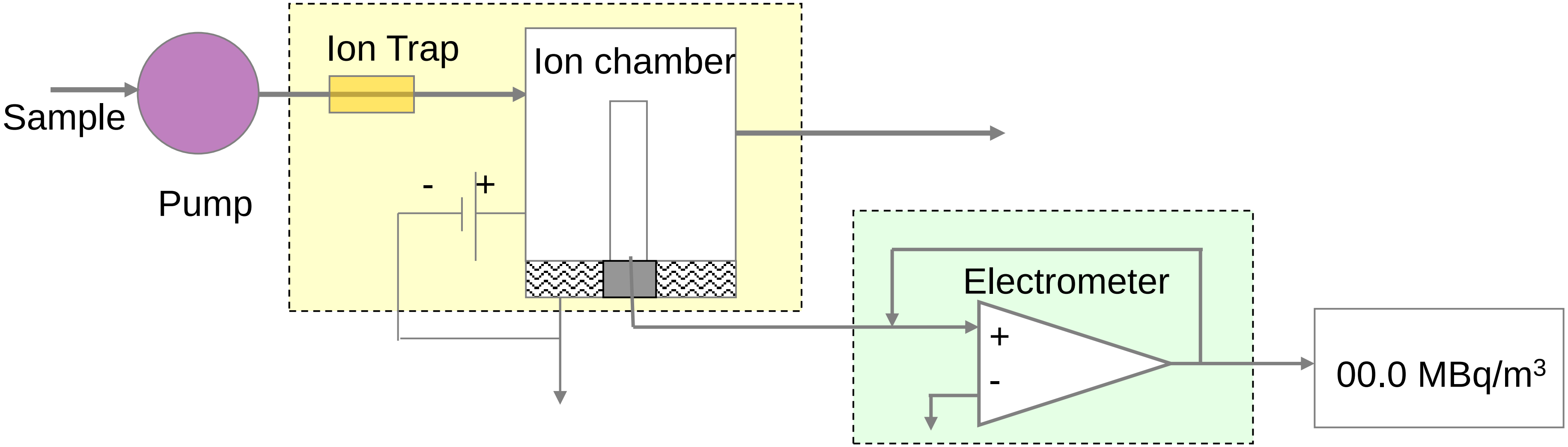
(Typical sensitivity: <1 Bq/L, count for hours)



# Tritium Measurement - 2

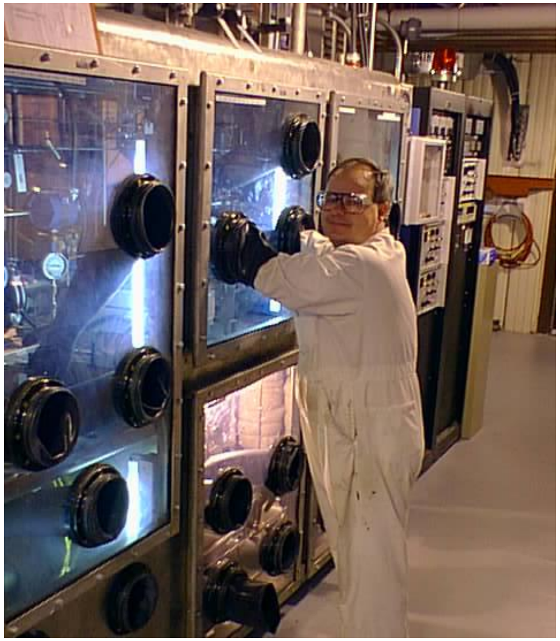
- High concentrations:
  - Draw sample
  - Convert all to gas
  - Measure radiation (ion chamber)

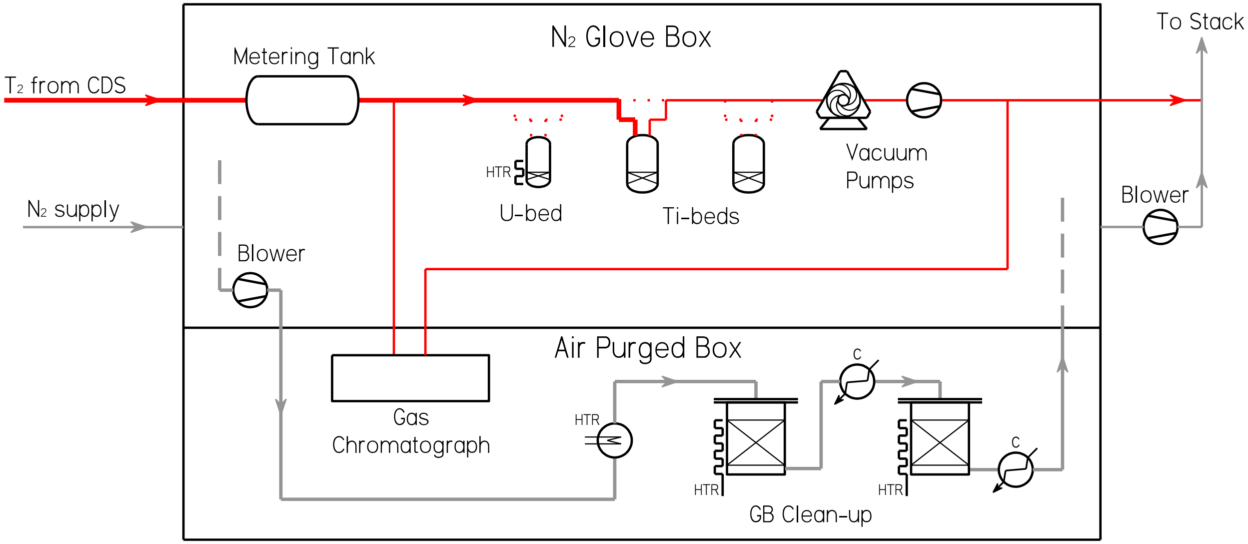
(Typical sensitivity: 40 kBq/m$^3$ with1L chamber)



# Tritium Handling - 1

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



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# Tritium Handling - 2

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

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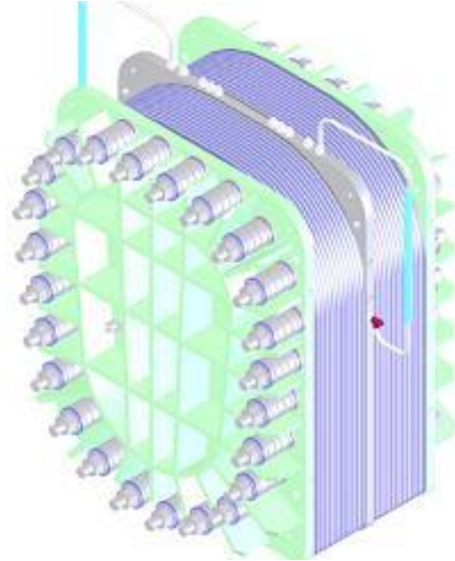
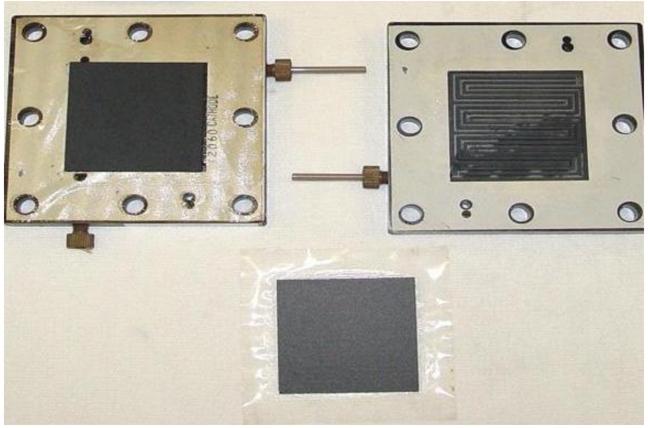
# Tritium Processing - 1

- 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

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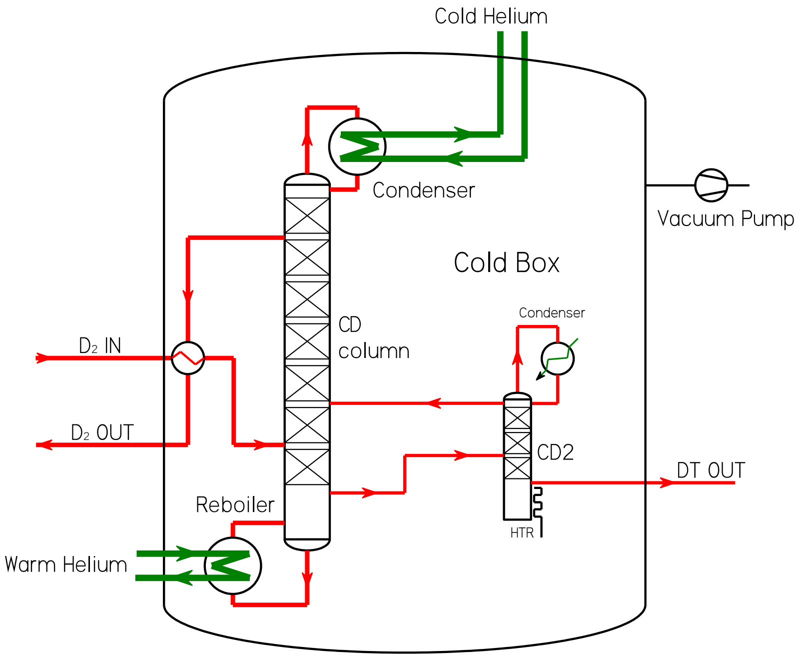
# Tritium Processing - 2

- 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)




Hydrogen-water Isotope exchange

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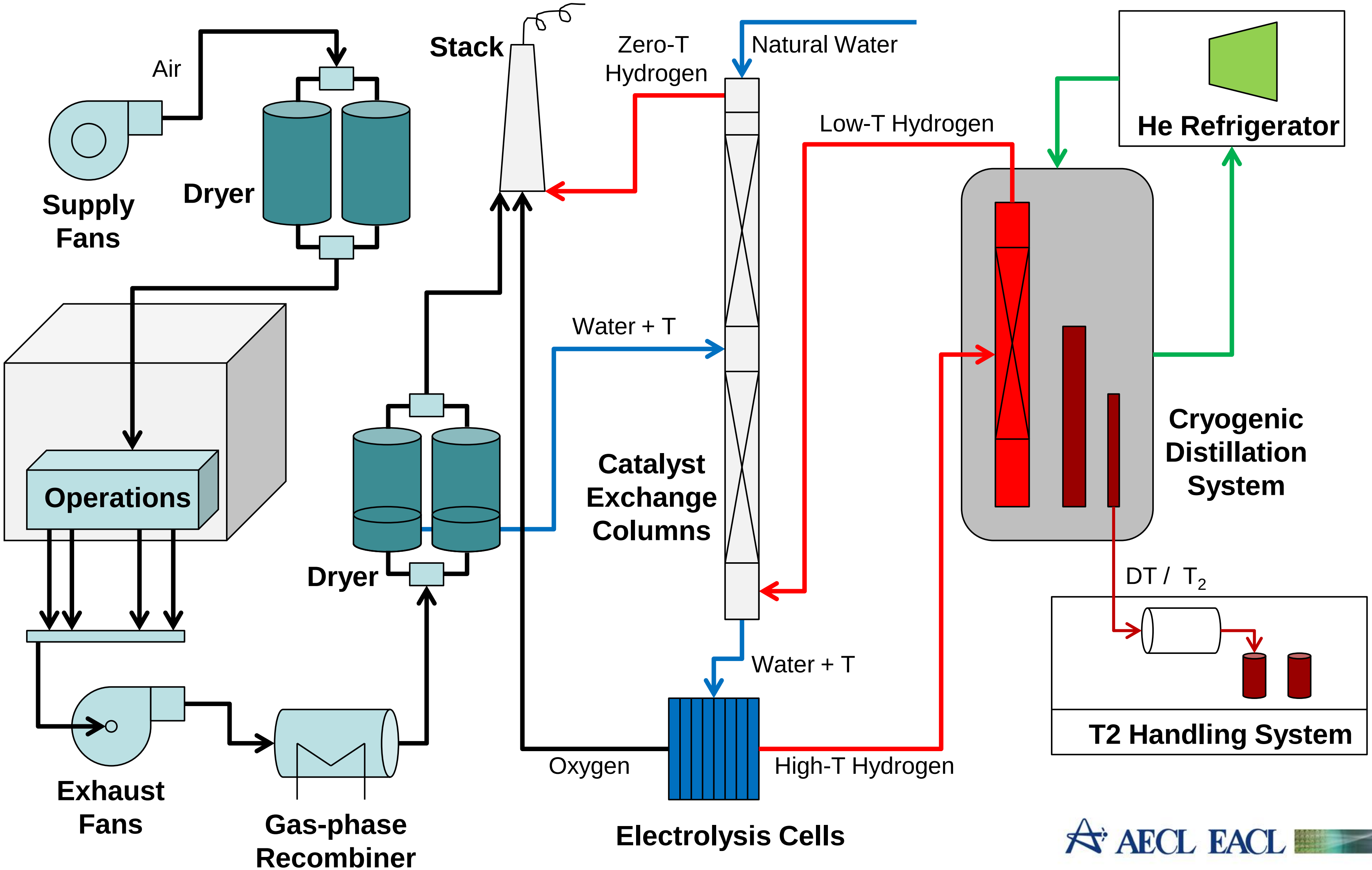
# Tritium Processing Cycle

- 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

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# Tritium Technology in Canada - 1

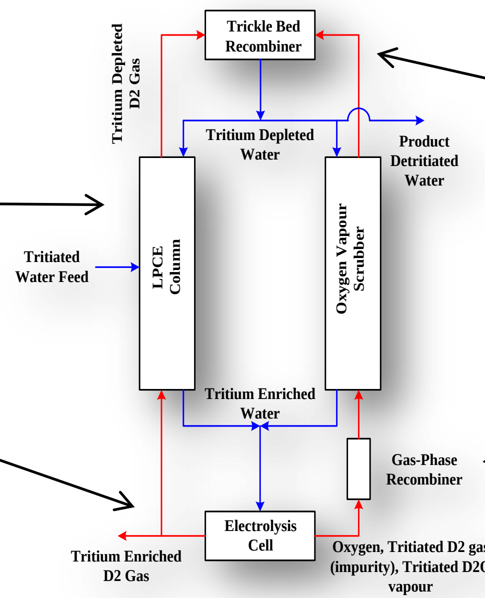
AECL’s Chalk River Laboratory is the major centre for tritium expertise in Canada with:

- 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

# Tritium Technology in Canada - 2

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

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