Tritium Handling in Nuclear Fusion

Presented by Hugh Boniface to

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Canadian Nuclear Laboratories | Laboratoires Nucléaires Canadiens

Topics

- Introduction
- Tritium in a Fusion Machine
- Tritium control issues
- Advances in Technologies for tritium control
- Tritium R&D at CNL

Why Tritium?

- <u>D-T fusion:</u>

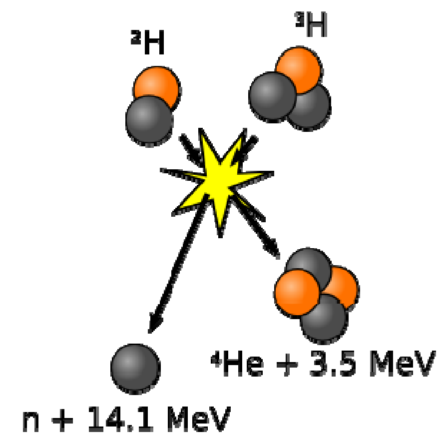
  $D + T \rightarrow He + n + \text{energy}$

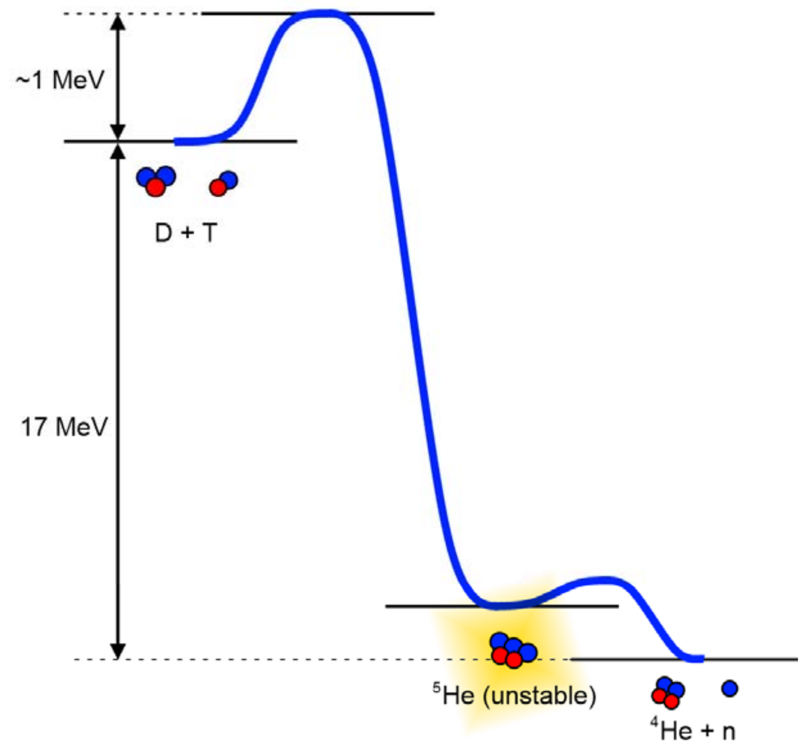
- lower energy barrier: 1 MeV
- High energy yield:

  17.7 MeV/atom

  $= 1.7 \times 10^{12}$ J/mol(T)

- Neutrons can breed more Tritium

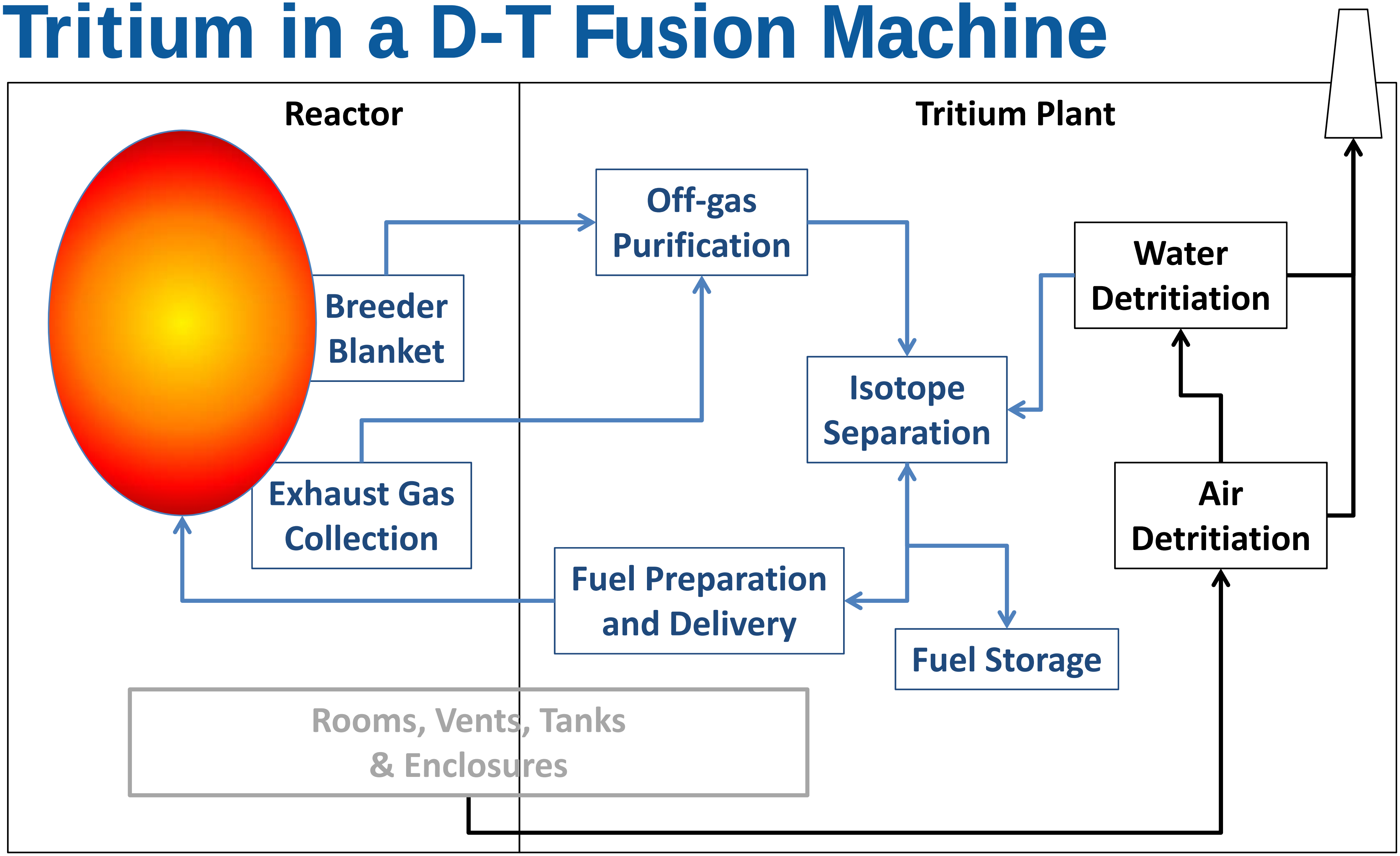




Tritium Properties

- Mass: 6.032 g/mol (T_2)
- Gas at normal T, P
- BP: 25 K (-248°C) at 1 atm.
- Half-life: 12.3 years (beta-decay, 5.7 keV)
- Pure T_2: 10,000 Ci/g, 35 μW/Ci decay heat
- Dose: 1 mSv from 0.1 mL of 15 Ci/L water (internal only, beta particle 5 μm range in water)

Tritium in a D-T Fusion Machine



Tritium Fuel Cycle

- Storage: Immediate, short-term, permanent
- Delivery: Set D:T, package, inject
- Recovery: Extract from exhaust, purify
- Isotope separation and recycle
- Tritium Make-up: Breeding, extraction

Ventilation & Off-gas Recovery

- Capture T from known release points and all ventilation air from active areas
- Various other tritiated fluids collected
- Convert everything to water
- Separate out tritium and transfer to a pure hydrogen stream (catalytic exchange)
- Send tritium/hydrogen to Isotope separation system

Accounting and Inventory Control

- Analytical & radiation protection services
- Inventory measurement and control
- Emissions measurement and reporting

Fusion Power Plant Tritium Perspective

- 1000 MW_e plant: ~300 kg T_2 per year
- Likely target in-process inventory 0.1-1 kg T_2
- Likely emission target 0.1-1 g per year

Fact:

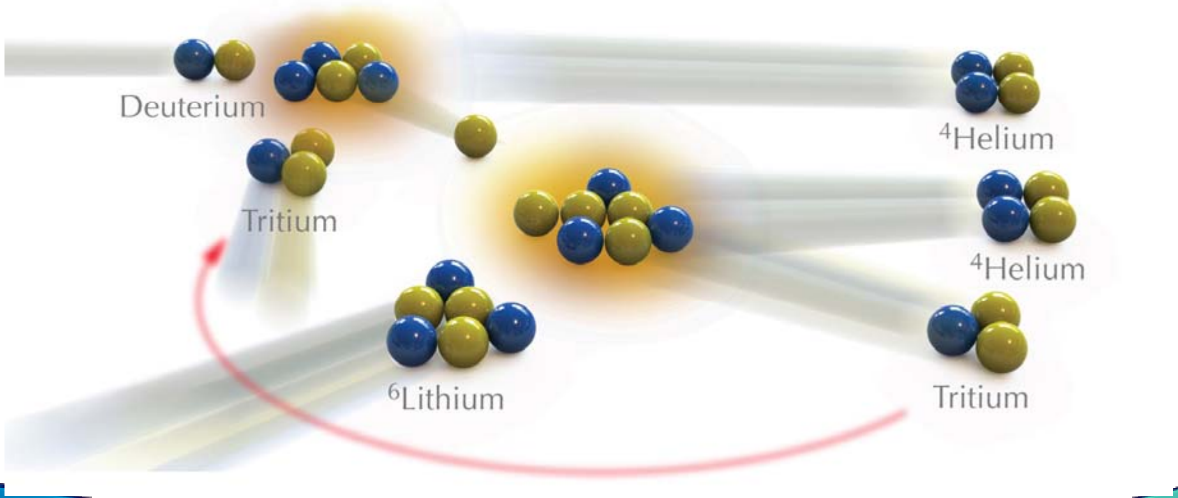
for every 1 kg T_2 inventory, nearly 400 L of ^3He is produced per year

Tritium Control Issues: Recovery

- Tritium is hydrogen – very mobile and reactive
  - readily adsorbed on surfaces and absorbed into materials – replace with H
  - reacts with oxygen and carbon forming water and hydrocarbons
  - readily leaks or diffuses/permeates out
- Purification after recovery

Tritium Control Issues: Breeding

- Ensure tritium remains in breeder material until it can be extracted – tritium barrier materials needed
- Remove tritium effectively from breeder material – separation of tritium and recycling breeder material



Tritium Control Issues: Isotope Separation

- Separating all three isotopes cannot be done in one step. The process needs to:
  - effectively remove H free of T
  - have low inventory of T.
- TCAP is attractive as an alternative to distillation because low inventory, but not as mature technology

Tritium Control Issues: Emissions

- Recovery of 100% of tritium lost from process systems
- Discharge of liquid waste and exhaust gases meet strict environmental standards – requires very high efficiency of tritium removal

CNL Technologies for Tritium Control

- Processes for effective removal of tritium from moist air and water (major technologies at CNL)
- High-temperature metals with low tritium permeability (experiment and model)
- Processes for efficient isotope separation (experiment and process models)

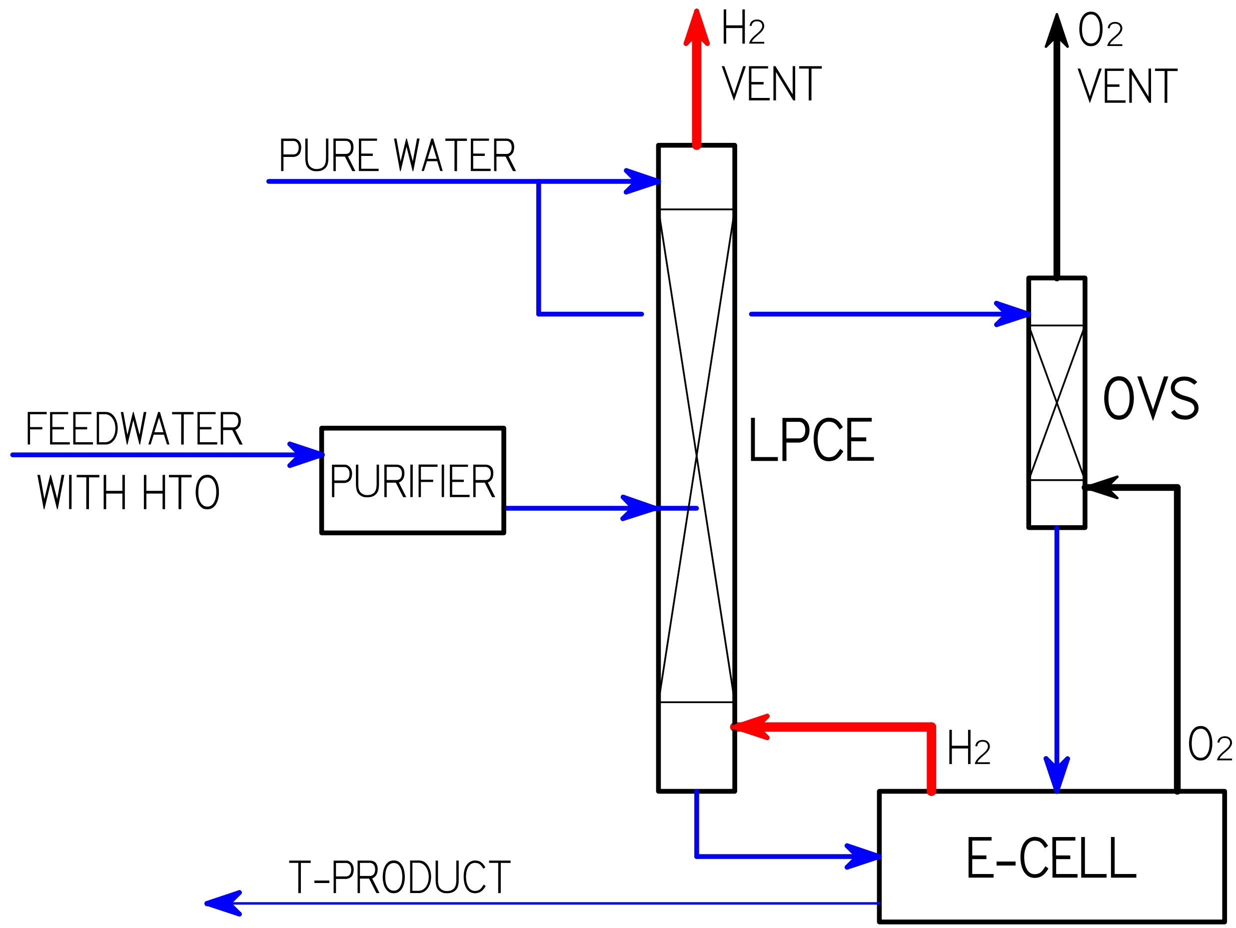
CNL Tritium Removal Technology

- Combined Electrolysis and Catalytic Exchange (CECE) Expertise:
  - Catalyst for hydrogen isotope exchange
  - Electrolysis for tritium compatibility
  - Process design and modeling
- Current R&D:
  - Tritium removal design: high detritiation factor
  - PEM-cell electrolyser for high tritium conc

Water Detritiation (CECE)

- Feed is part-way up LPCE
- Some natural water fed at top
- Discharge is tritium-free hydrogen and water vapor
- Tritium is concentrated in water or gas drawn from the electrolysis cell

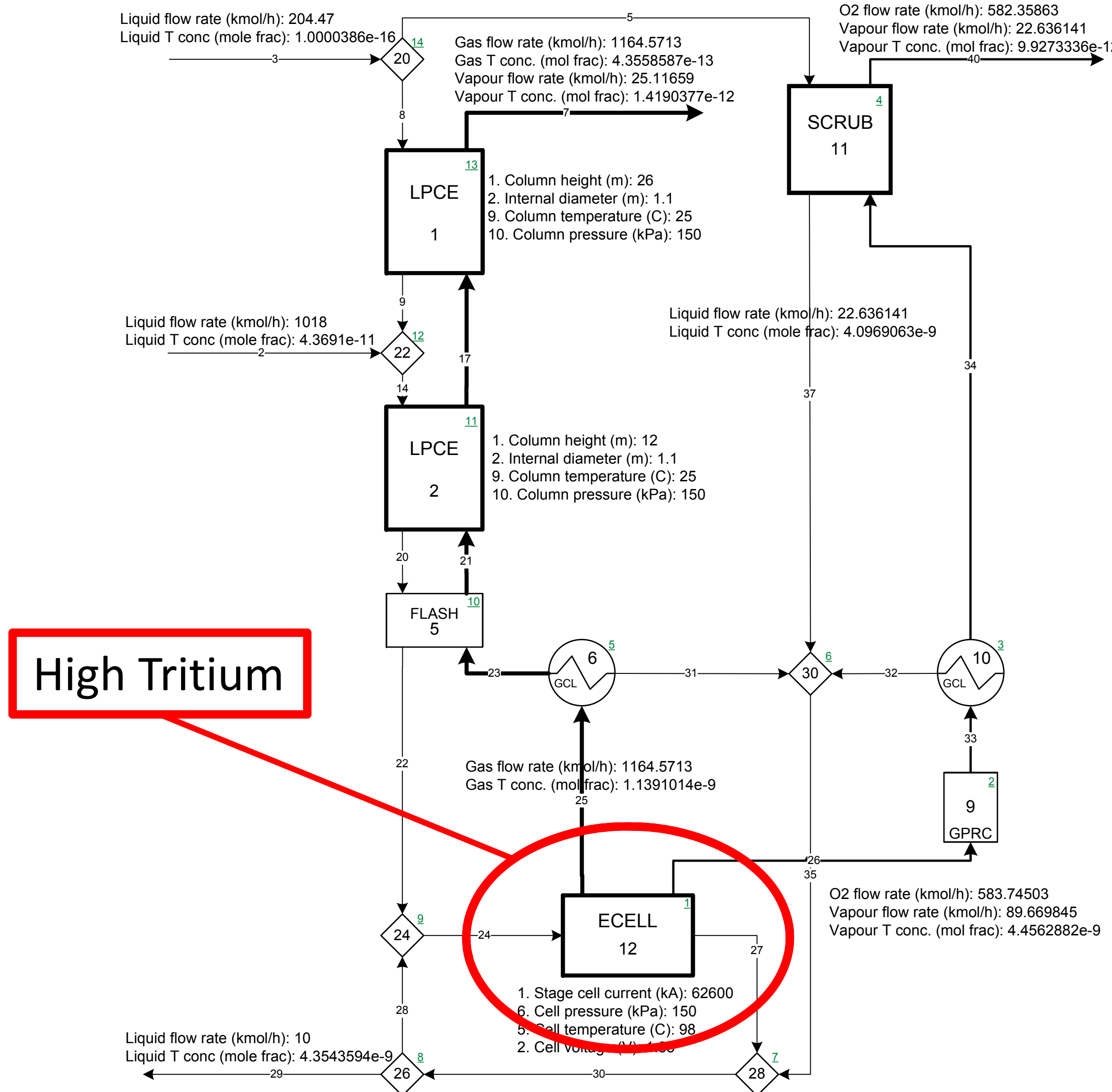
$$HT_{(g)} + H_2O_{(l)} \rightleftharpoons H_{2(g)} + HTO_{(l)}$$



$$2H_2O_{(l)} \rightleftharpoons 2H_{2(g)} + O_{2(g)}$$

CECE Design for High Detritiation Factor

- Modeling CECE:
  - Include 3 isotopes
  - T from D vs T from H
  - Latest CNL catalyst
- Optimize:
  - Tritium reduction factor: 10^6 - 10^8

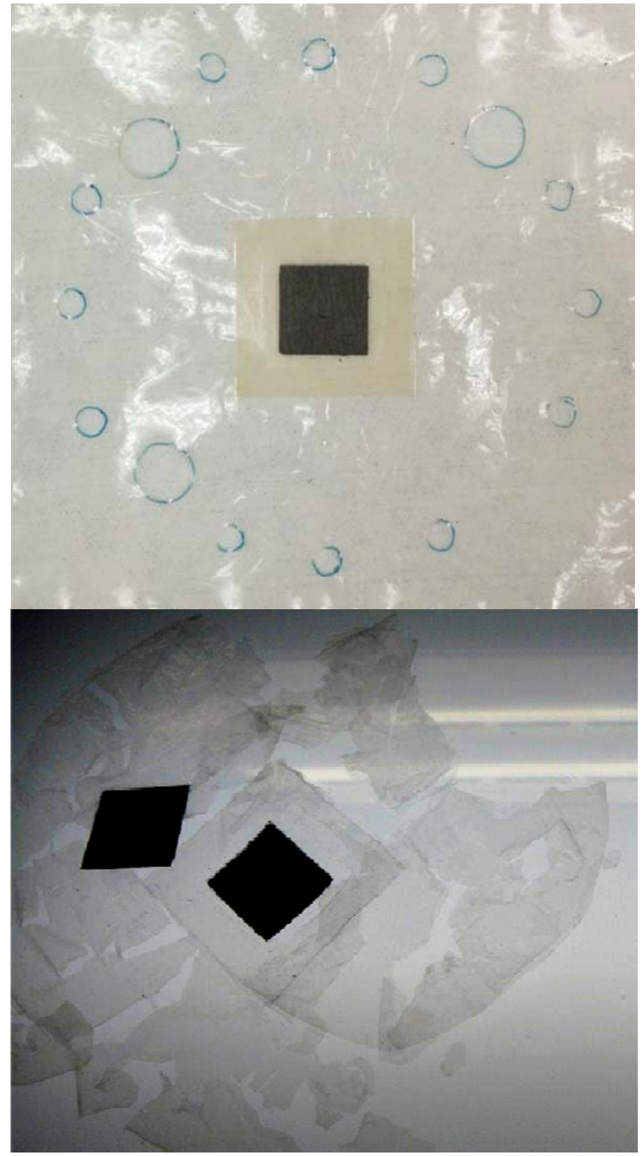


Cell Materials Development for High-T

- Program at CNL:
  - Review current electrolysis cell technology – concentrating on Proton-Exchange Membranes
  - Manufacture T-resistant materials
  - Test membranes in γ radiation (easy)
  - Test membranes in high tritium (difficult)
  - Determine effects on cell performance

T-resistant Membrane Development

- Initial exposure to γ radiation (Gamma-cell)
- Compare exposure to tritium (β) at 1000 Ci/L
- Test properties and performance.



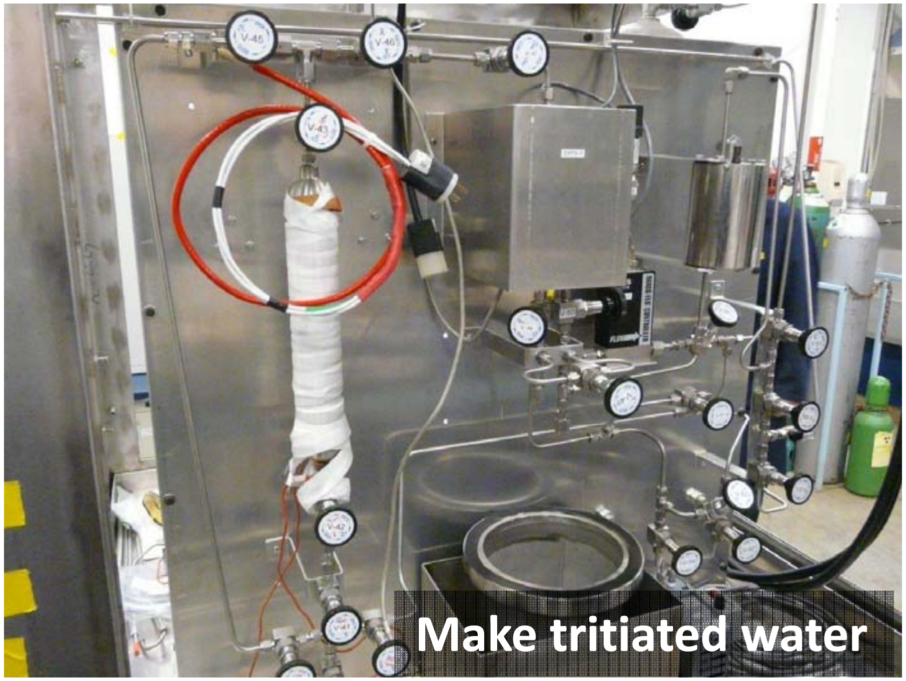
T-resistant Membrane Development

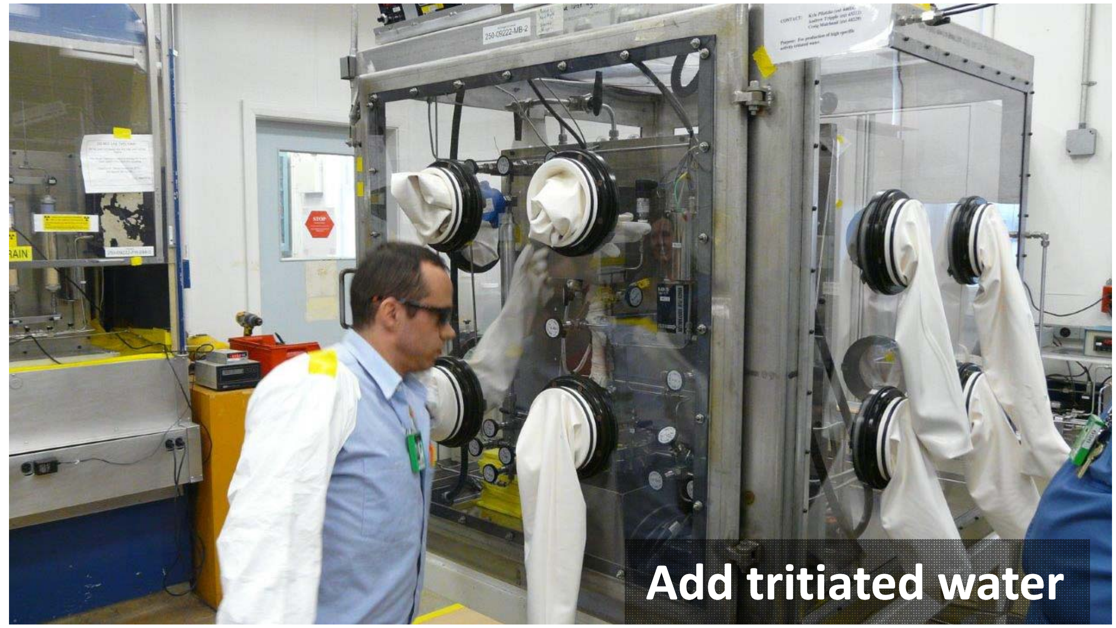
- Gamma-cell (^{60}Co) irradiation is simple:
  - Put samples in cell
  - Wait
  - Remove samples (no residual contamination)

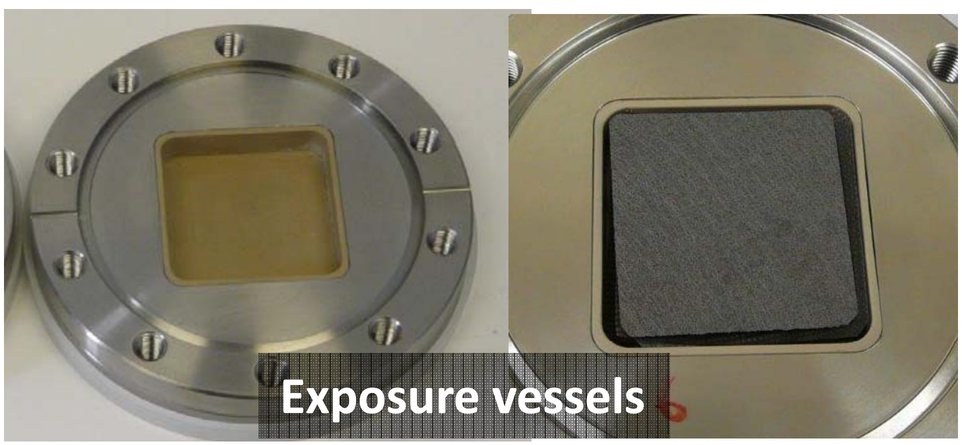
T-resistant Membrane Development

- Exposure to high-conc. tritium is not so simple:
  - Set up safe enclosures
  - Make tritiated water
  - Make leak-proof sample vessels
  - Add tritiated water to samples and wait
  - Remove tritiated water
  - De-tritiate samples (not totally successful)

Tritium exposure



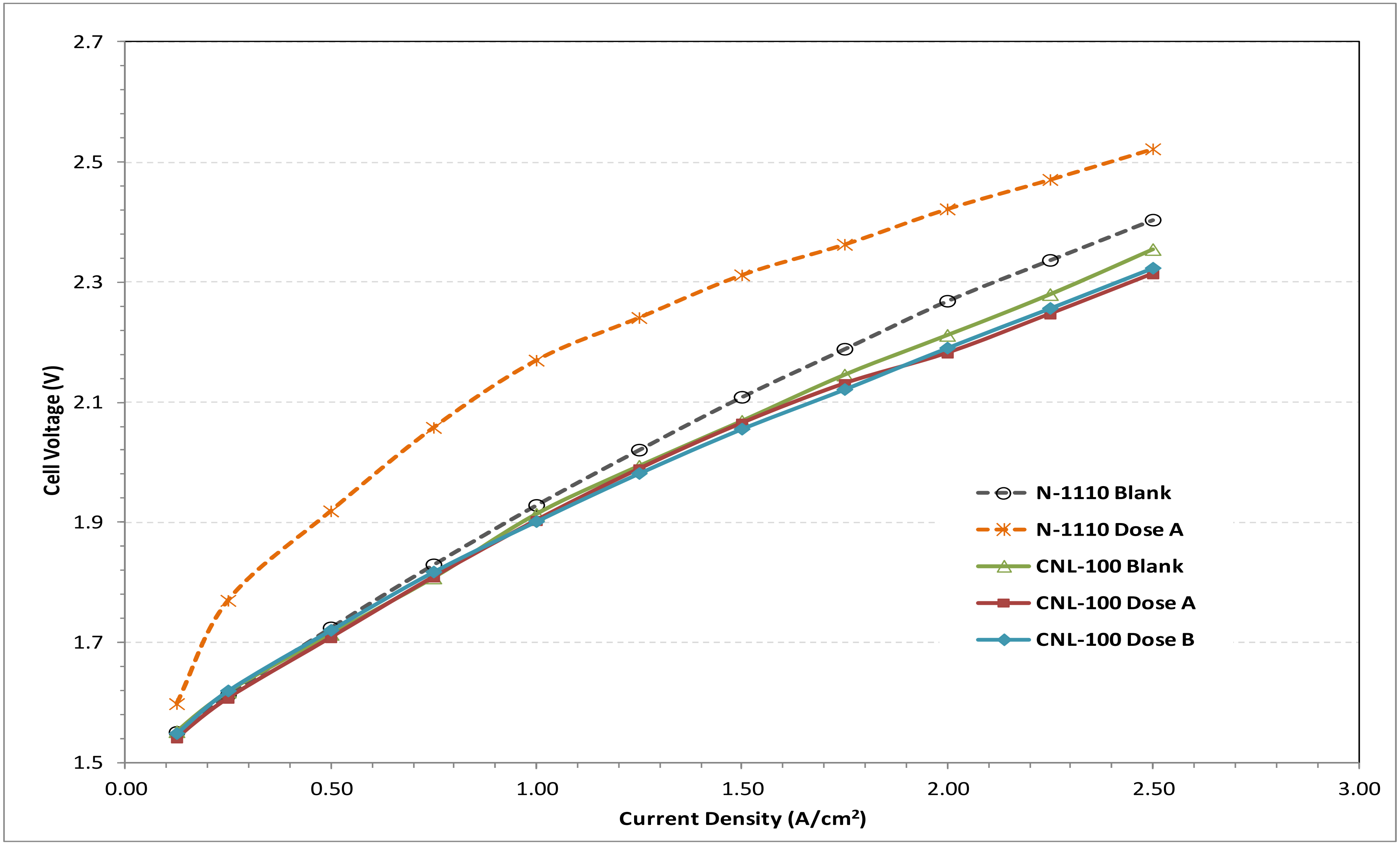




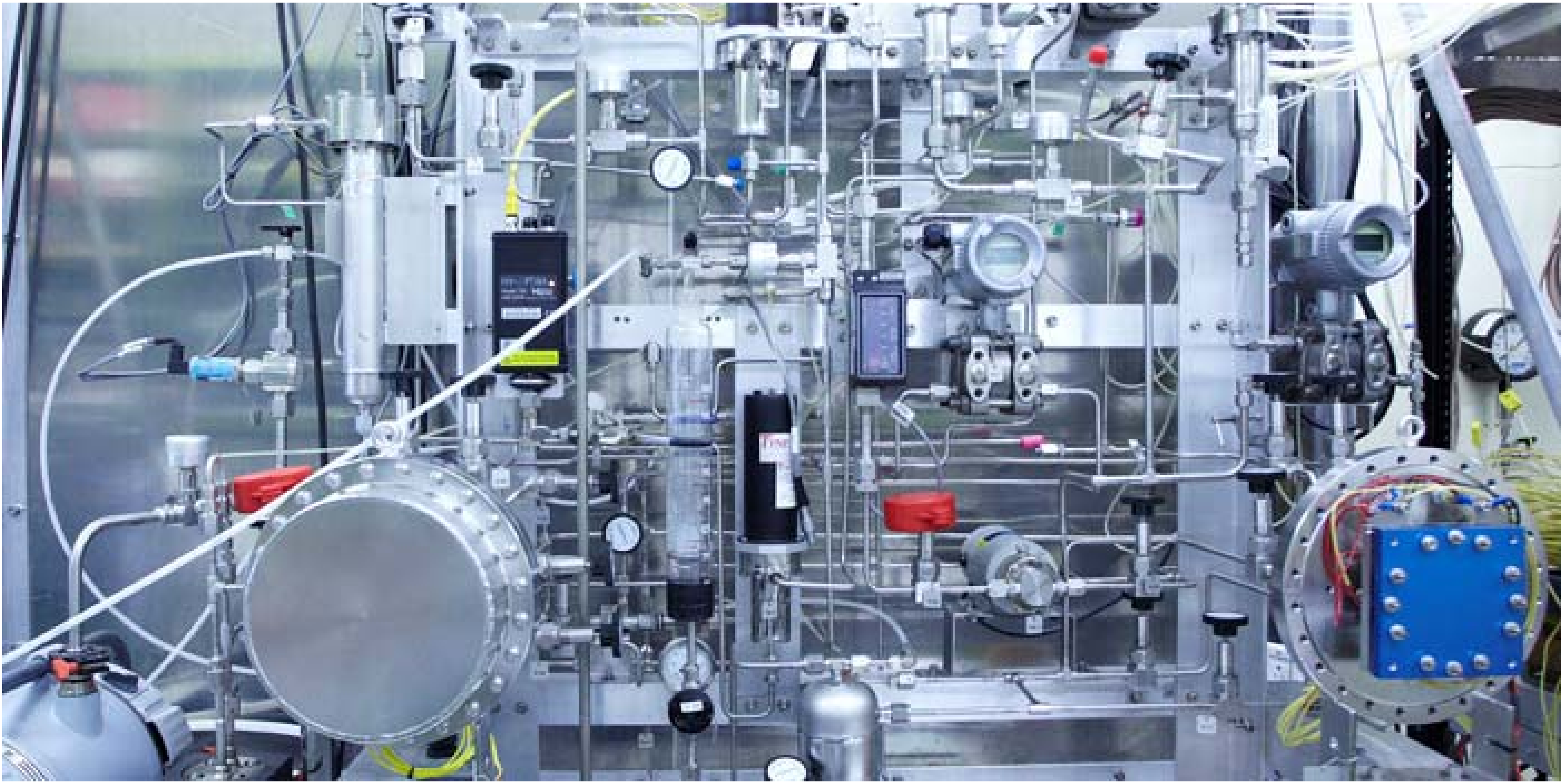
T-resistant Membrane Development

- Observations:
  - Tritium radiation (β) more damaging than γ
  - Materials became harder and more brittle
  - Chemical structure changed
  - Ionic conductivity loss significant
  - Cell voltage increased
  - CNL-100 material less affected by tritium than standard N-1110 commercial material

T-resistant Membrane Development



CECE Materials Demonstration – High-T

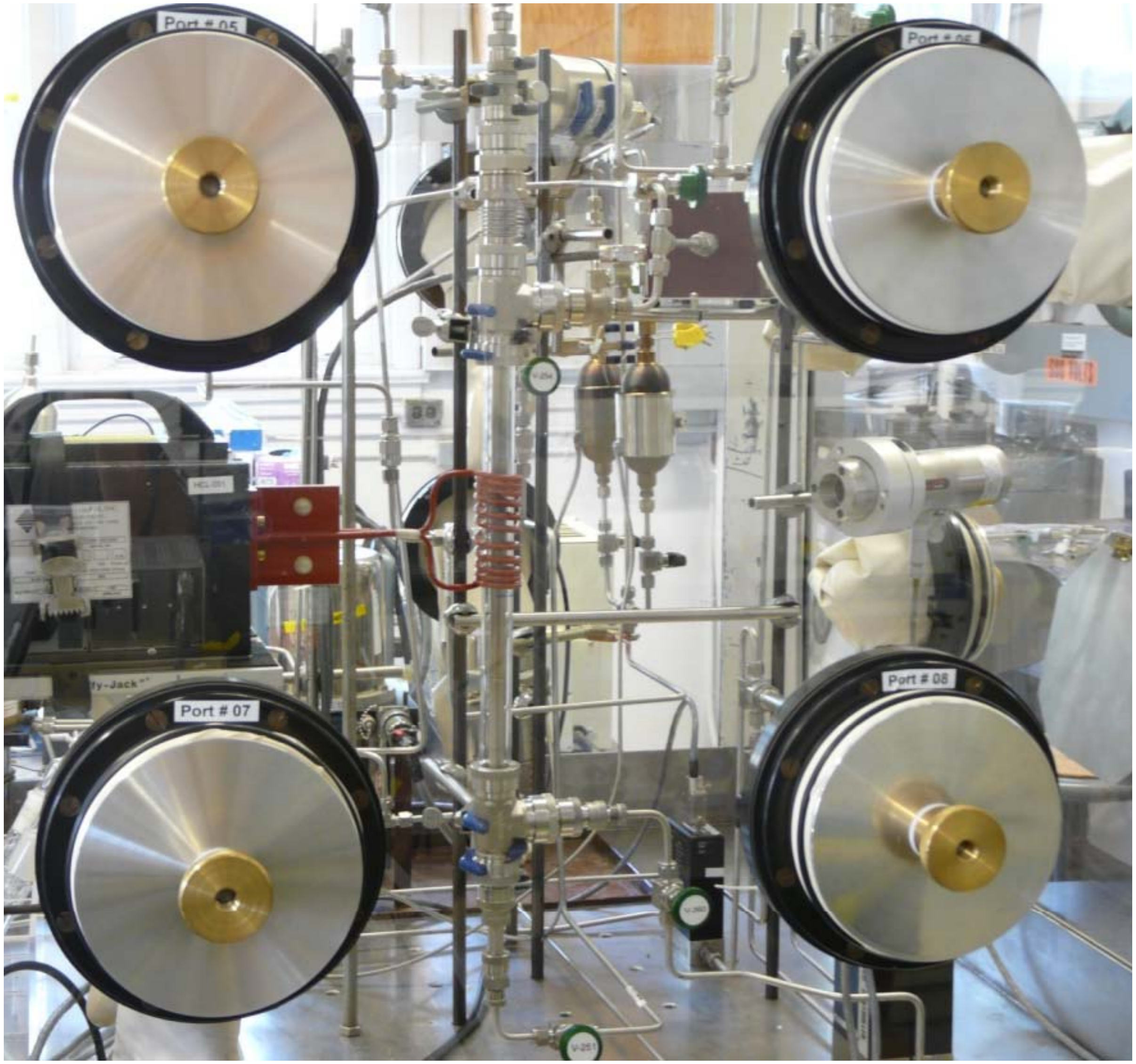


Permeation of Tritium Through Metals

- Goal: Find materials that will limit escape of tritium through high-temperature pressure boundary materials in reactors. Applies to fusion and fission.
- Program at CNL:
  - Set up a system for screening materials with tritium at well controlled conditions.
  - Model the permeation rate of existing and proposed materials

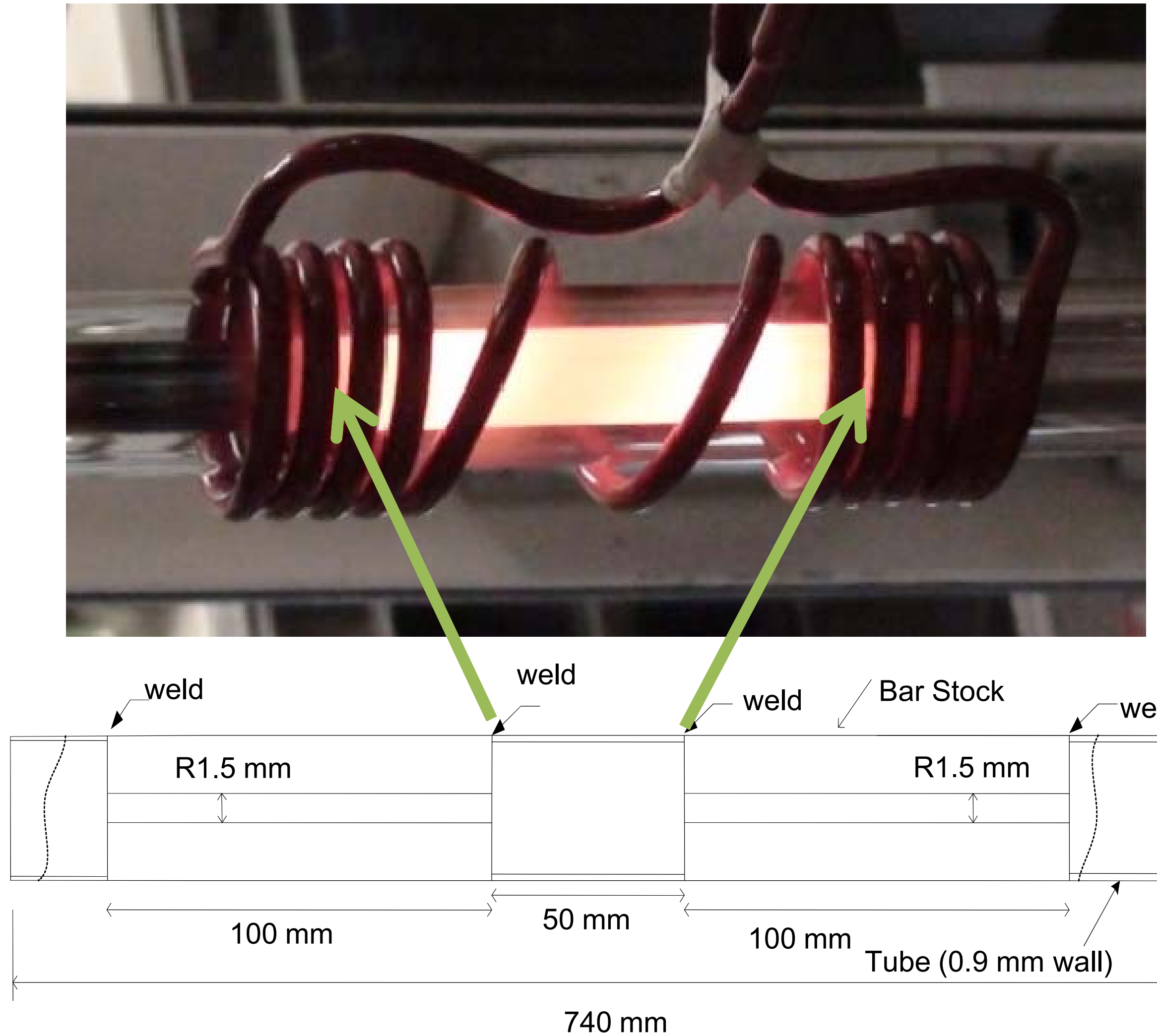
Tritium Permeation testing: Method

- Inductive heat to 1000°C (within 5°C)
- Sample:
  - 10 mm dia.
  - 50 mm lg.
- HT flow inside
- Sweep gas outside
- Measure and model tritium permeation



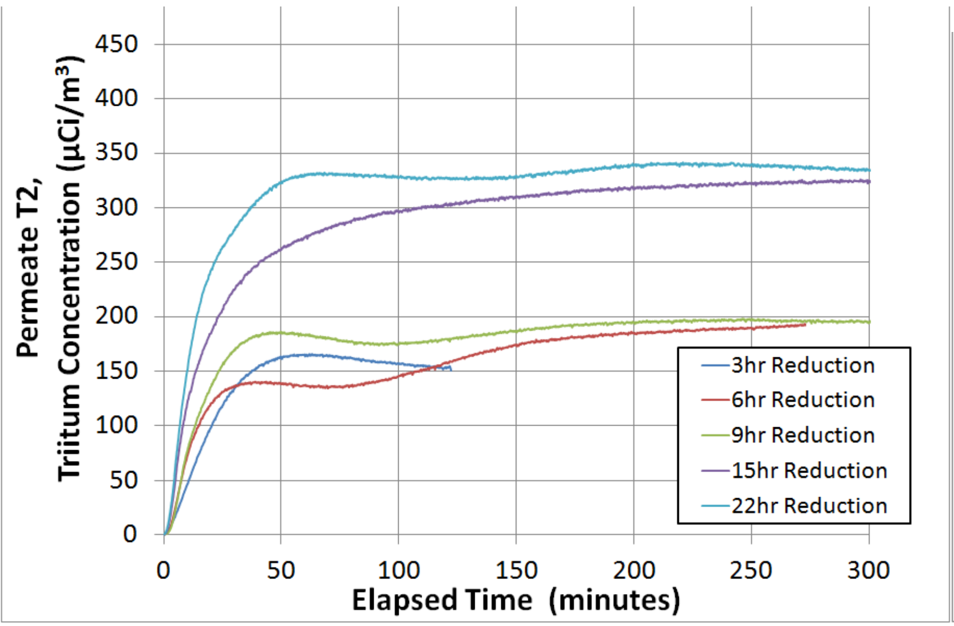
Permeation sample setup

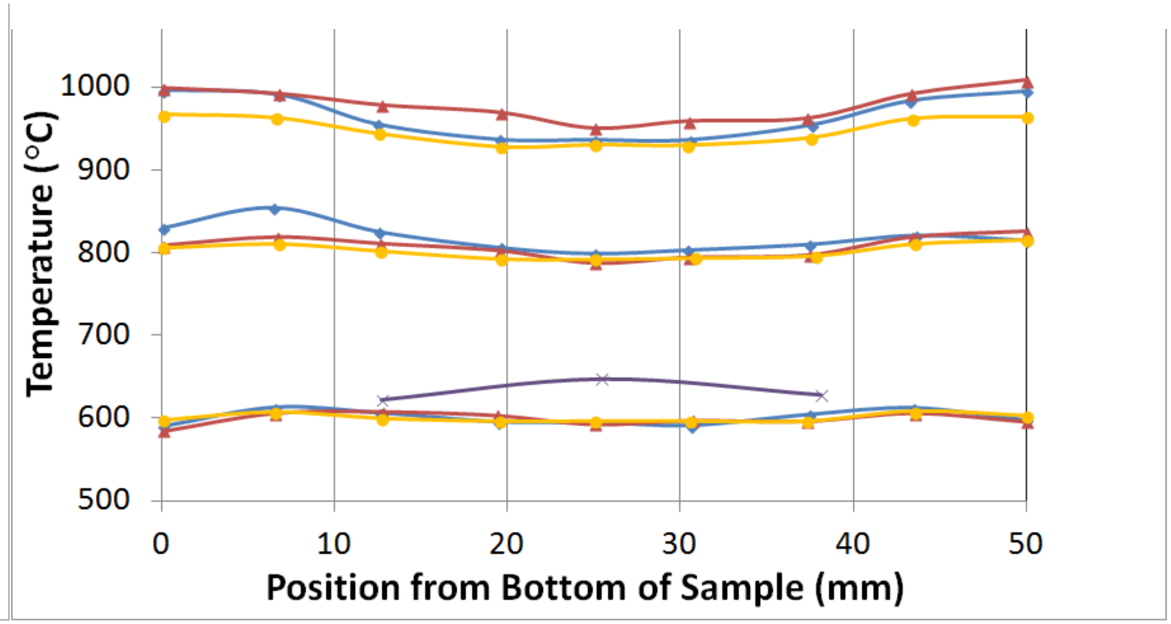
- Samples fabricated by precision welder
- Thin-wall alloy sample tube (~0.5mm) welded between thick-walled SS 304L tubes
- Initial testing:
  - Stainless Steel 304L,
  - Inconel 617, and
  - Incoloy 800H.



Tritium Permeation: Advances

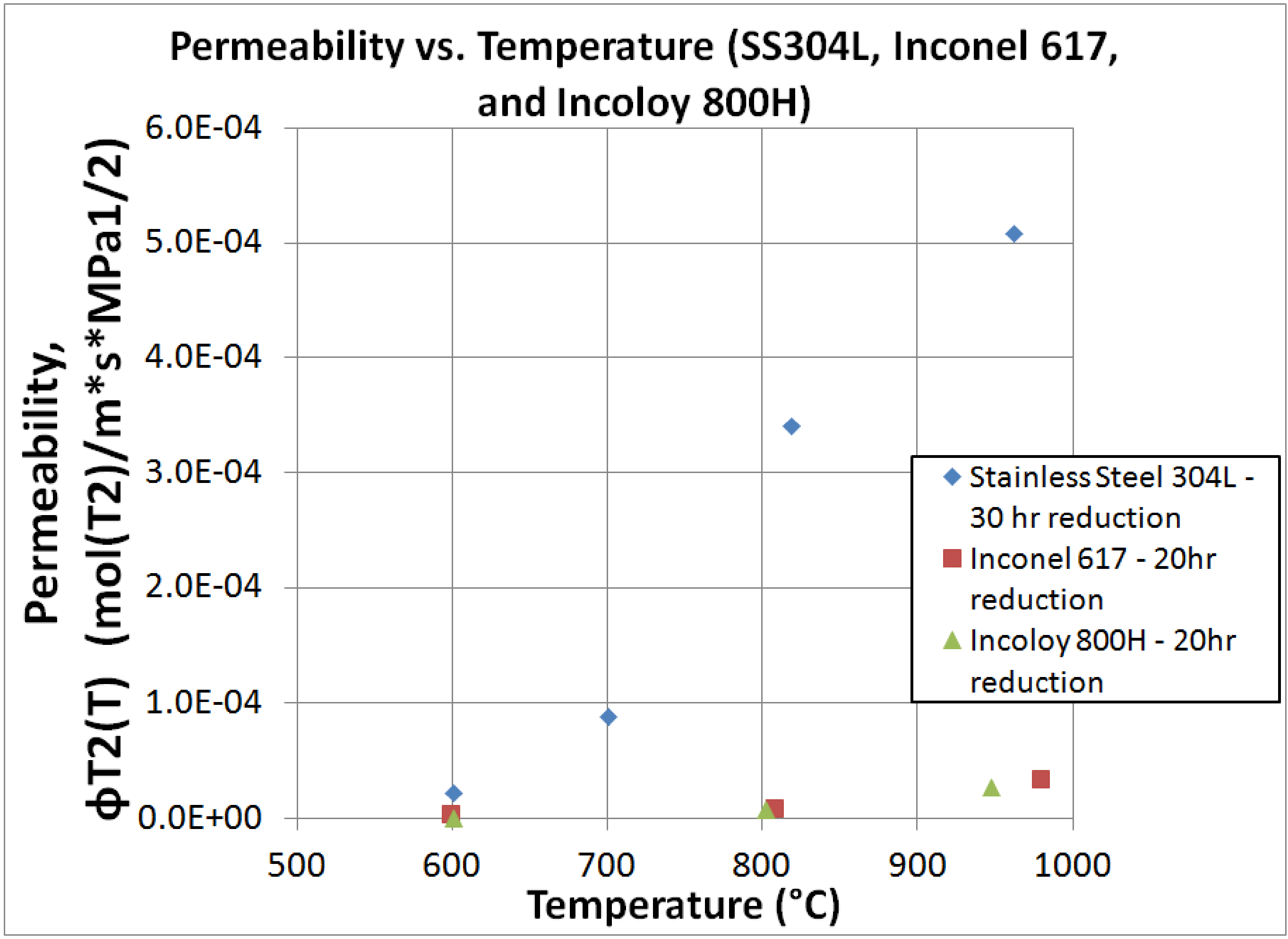
- Major experimental difficulties overcome:
  - Uniform temperature over sample
  - Removal of surface layer (oxide)





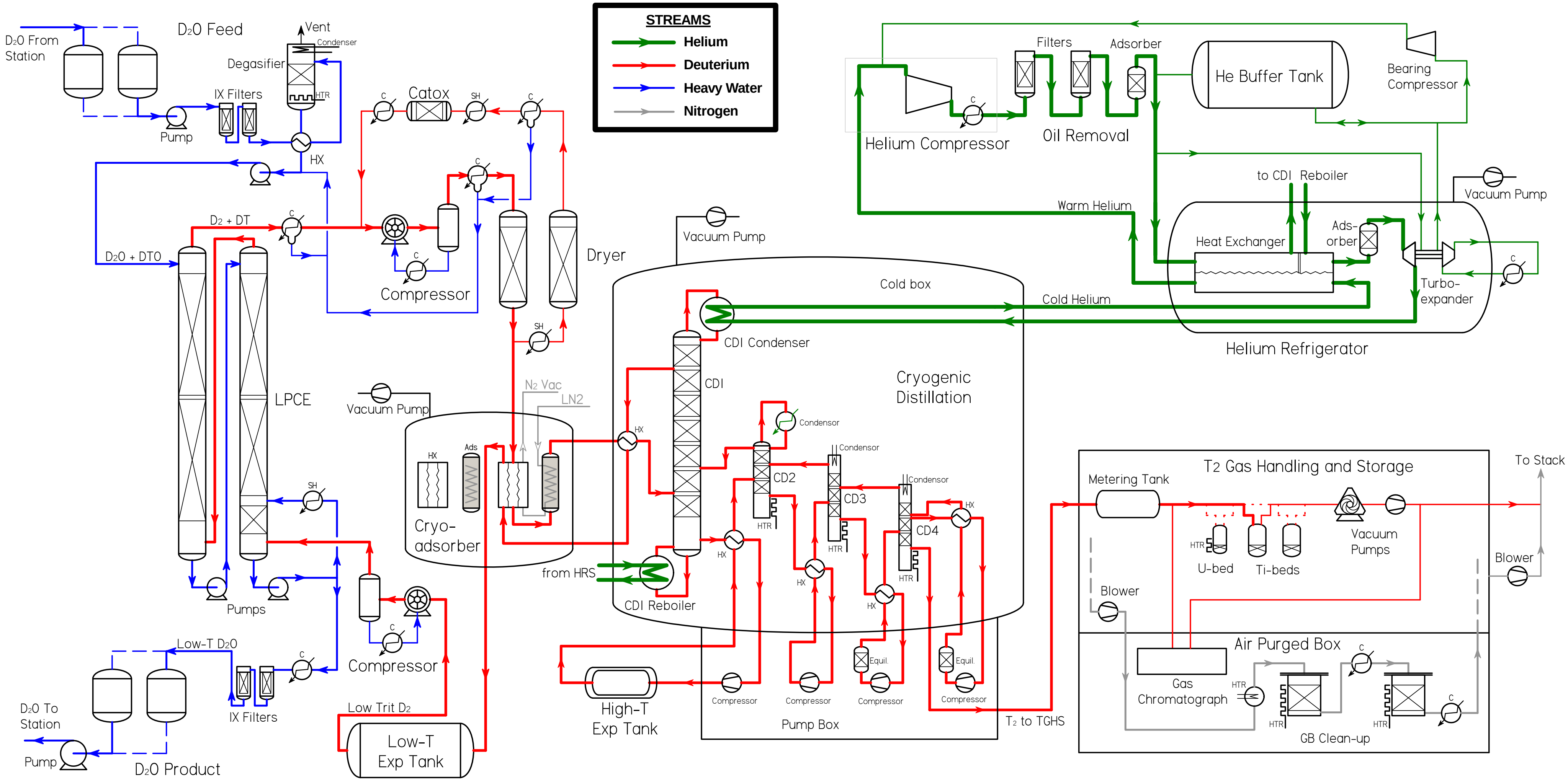
Permeation Results – Alloys as Barriers

- Two alloys show factor of about 20 reduction in permeability over 304L
- Better materials needed.



Other CNL Tritium/Fusion R&D areas

- Isotope separation:
  - Cryogenic distillation (modeling)
  - TCAP absorbent materials
- Tritium immobilization:
  - Permanent storage (stable hydrides)
- Tritium cleanup
  - Exchange with H and desorption
  - Conversion of tritium to water
- Fusion power in the Canadian economy
  - Economic modeling



Thank you -Merci