



# *Tritium Activities at Chalk River, Canadian Nuclear Laboratories*

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Canadian Nuclear Laboratories Ltd.

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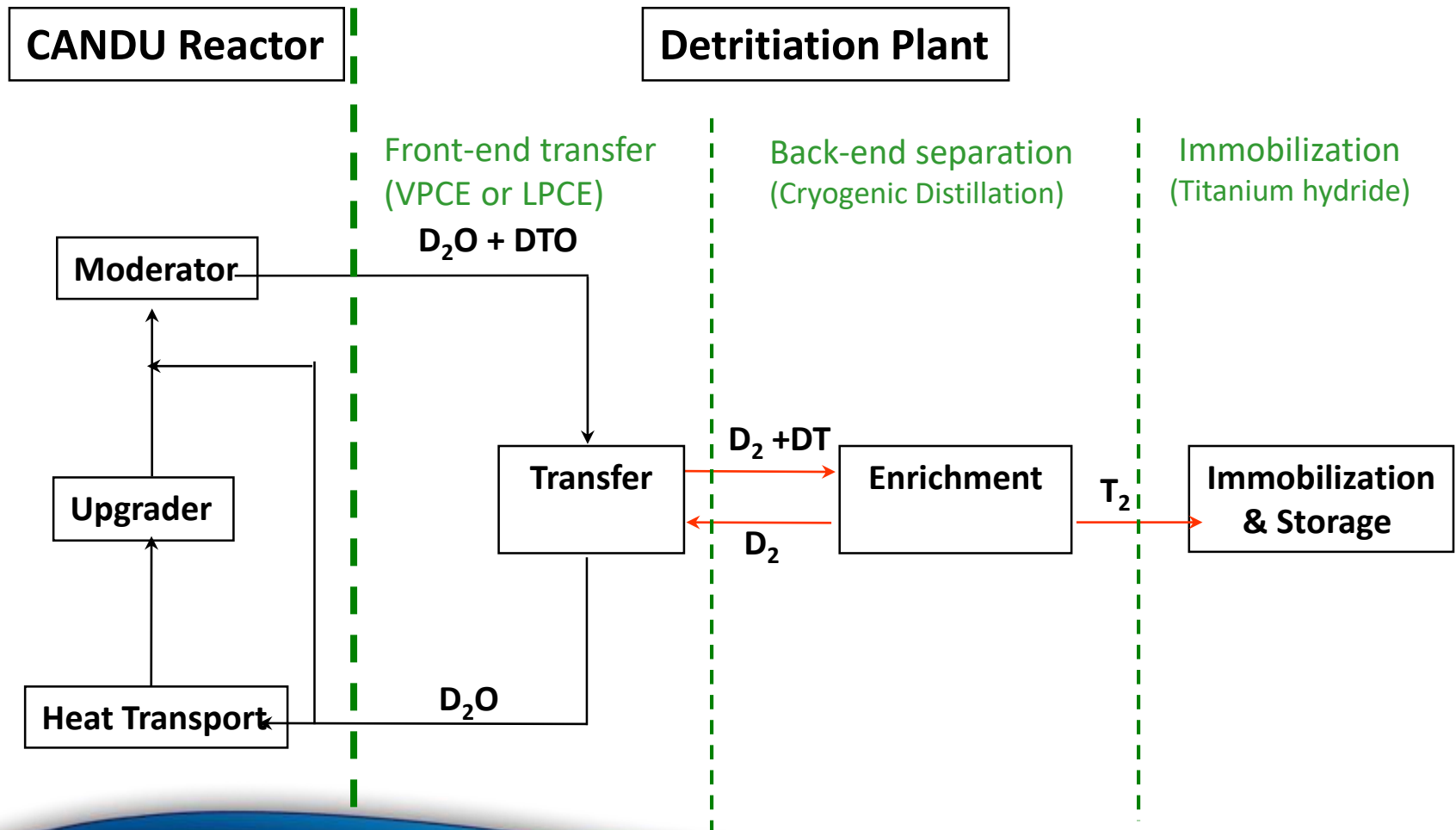
# Canada & Tritium

- *Tritium management in CANDU reactors*
- *Ensure worker doses remain ALARA*
  - *Tritium is a significant contributor to occupational dose*
    - *In particular, maintenance dose*
  - *Minimize operating and maintenance costs*
- *Ensure emissions remain ALARA*
  - *Emissions are low at existing plants (<0.1% DEL)*
- *Management strategies reflect station-specific issues, e.g.:*
  - *Installed equipment*
  - *Emission limits*
  - *Plant life, etc.*
- *CFFTP (Canadian Fusion Fuel Technologies Program) in 1980's*



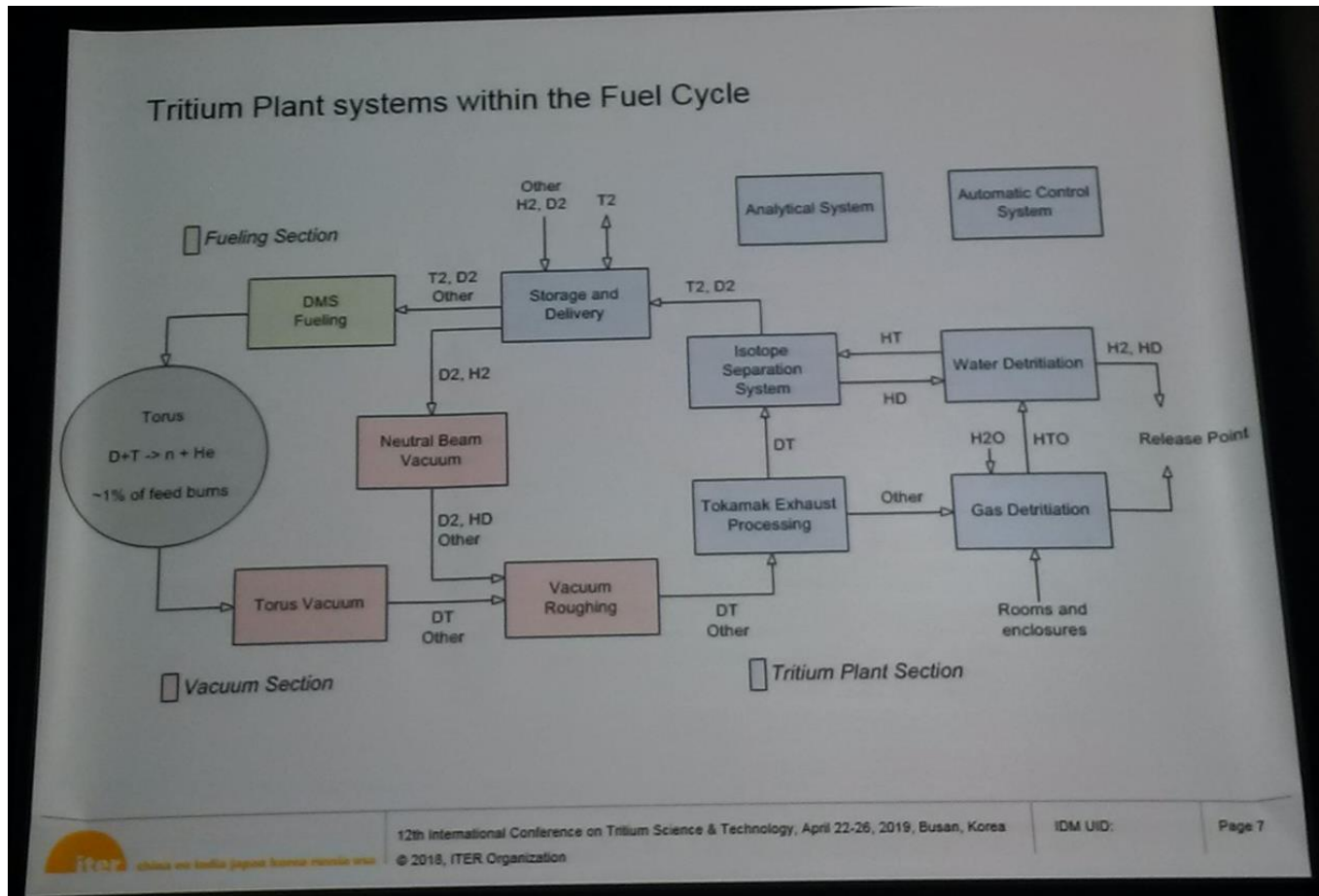
# CANDU Reactor Heavy Water Tritium Management

## Source Reduction



# Tritium Handling Requirements

## CANDU Vs Fusion (ITER)



From presentation at Tritium 2019, Busan, South Korea



# *Tritium Facility at CRL Before 2019 April 01*



*Argon Glove Box for Tritium Handling*



# *Tritium Facility at CRL Since 2019 April 01*



# *New Tritium Laboratory - Features*

- Licensed inventory Limits:
  - 1 MCi Tritium (facility use) & 2.5 MCi Tritium (storage)
- Inert atmosphere glove boxes (IAGB)
  - Tritium dispensing
  - Tritium in gaseous & liquid forms
- Air-purged glove boxes
  - Maintenance tasks & Experimental studies
- Fumehoods
  - Gas standards Preparation Rig
  - Experimental studies
- Tritium counting room



# *Tritium Areas of Interest - Commercial*

## *National & International shipments*



### • Tritium dispensing of high purity tritium – **Transportation of Dangerous Goods (TDG) Program**



- Maximum ~100 kCi per shipment, typically ~25 kCi
- Tritium gas standards supply and assay
- Tritium loading on substrates
  - Targets
  - Carriers

### **CNL Radioactive Material (RAM) Shipment Process**



# Tritium R&D Activities

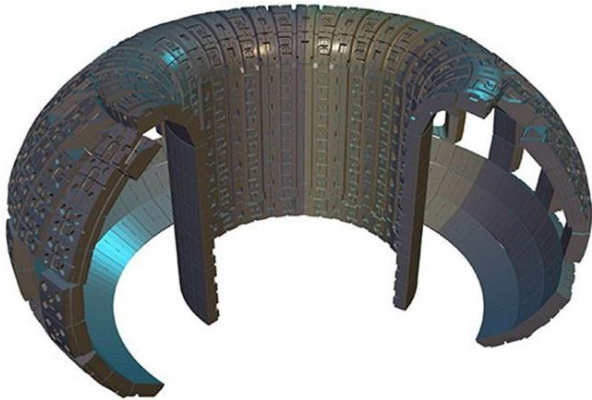
- **In the Facility**
  - Development of  $T_2$  Compatible Electrolysers for Tritium Service
  - Material Selection from Tritium Permeation Studies
  - He-3 Recovery
  - Tritium Concentrator Development- Thermal Cycling Absorption Process (TCAP)
  - Tritium Targets
  - Tritium as a Power Source – Beta batteries
  - Tritium Handling Course/Training
- **Heavy/Light Water Detritiation**
  - Process Engineering
  - Project Management
  - Catalyst & Component supply
  - Commissioning
- **Hydrogen/Tritium Safety**
  - Low Temperature Catalytic  $H_2/O_2$  Recombiners
  - Stoichiometric  $H_2/O_2$  Catalytic Recombiners



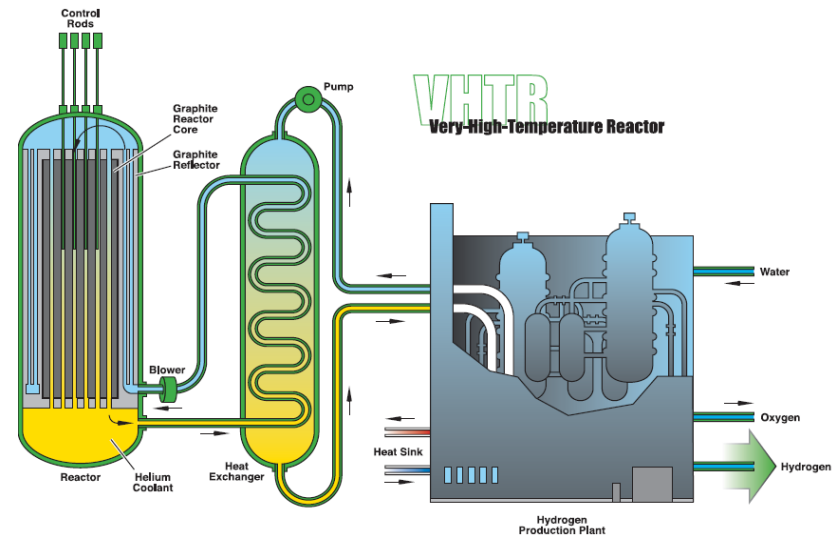
# Tritium Permeation in Structural Materials

## Fusion & GEN IV Reactors

### Fusion Reactor



- Structural Materials are exposed to high concentrations of tritium and high temperatures (600 to 800 °C)
- Tritium permeation contributes to:
  - Loss of fusion fuel
  - Environmental emissions
  - Worker dose

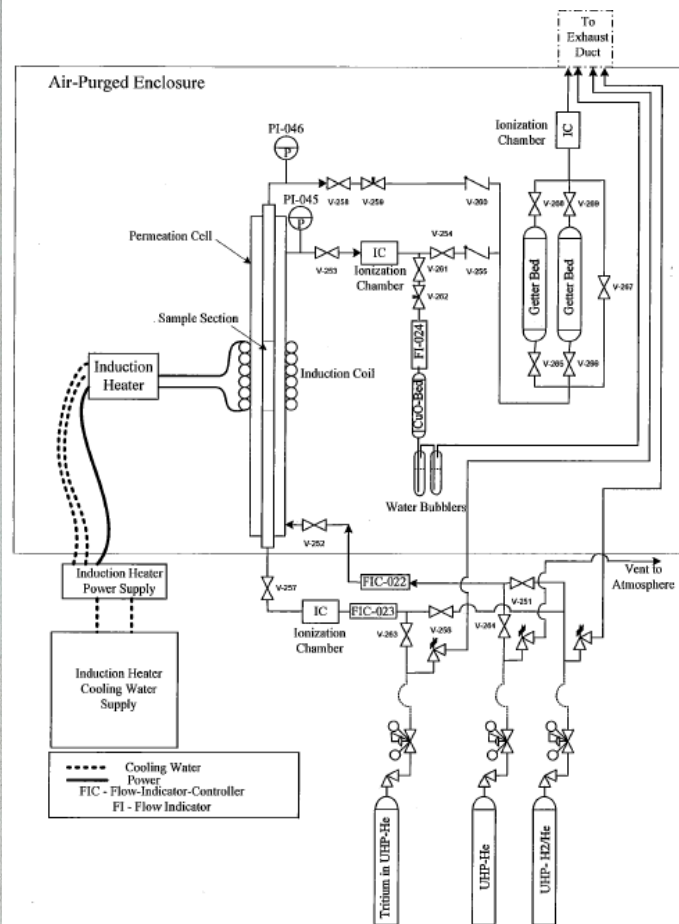


- Tritium generated in the reactor core can accumulate in the primary coolant loop
- Tritium permeates through the IHX to the secondary coolant loop, which carries the heat to the hydrogen production process
- Primary coolant temperatures are 800 to 950°C



# Tritium Permeation Experimental Setup

- Geometry similar to a tube-in-tube heat exchanger
- Key Components: ion chambers, mass flow controller, pressure transmitter, induction heater.
- Test conditions:
  - Counter-current flow
  - ~100 mCi/m<sup>3</sup> tritium in He (0.1% H<sub>2</sub>)
  - Flow: ~200 mL/min (both)
  - Pressure: ~160kPa (tube), and ~110kPa (permeate)
  - Temperature: 600 – 950 °C



# *Tritium Permeation Experimental - Past & Future*

## Materials Tested

## Proposed Materials To Test

## Proposed Coatings To Test

- 304L Stainless Steel – results comparable to literature
- Inconel 617 – results slightly above literature values
- Incoloy 800H – results slightly above literature values

- Haynes 230
- Inconel 625, 718
- Incoloy 800, 802
- Hastelloy-N, -X
- Silicon carbide
- Reduced Activation Ferritic (RAF) steels
- Reduced Activation Ferritic Martensitic (RAFM) steel
- Oxide Dispersion Strengthened (ODS) RAFM

- Metal oxides ( $\text{Al}_2\text{O}_3$ ,  $\text{Cr}_2\text{O}_3$ ,  $\text{Er}_2\text{O}_3$ ,  $\text{Y}_2\text{O}_3$ ,  $\text{ZrO}_2$ )
- Nitrides
- Carbides
- Composites of the above materials

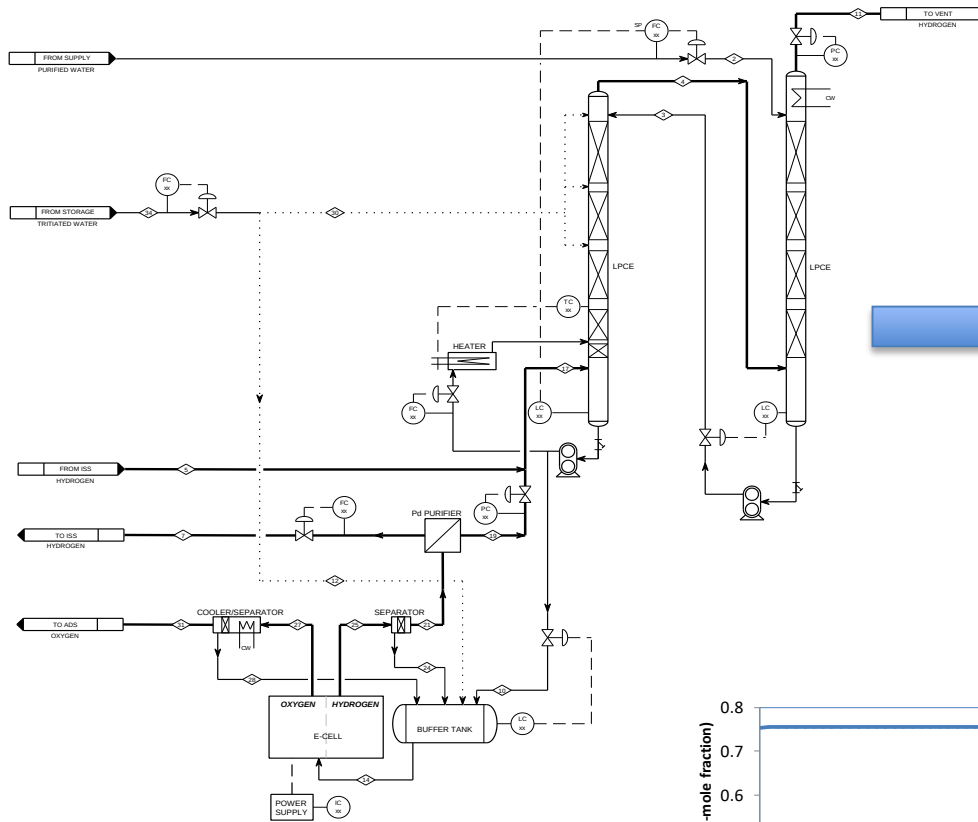
## Coating Methods

- Hot dip aluminizing followed by oxidation
- Dip coating
- Electrolytic deposition
- Sol-gel
- Metal Organic Deposition
- Chemical Vapour Deposition
- Sputtering

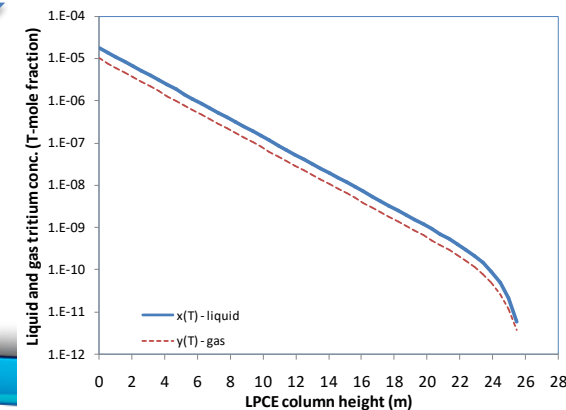
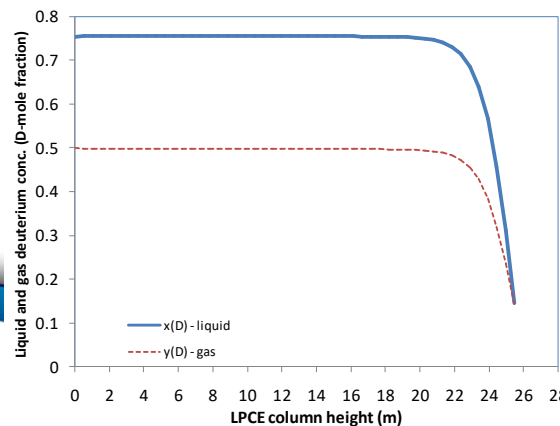
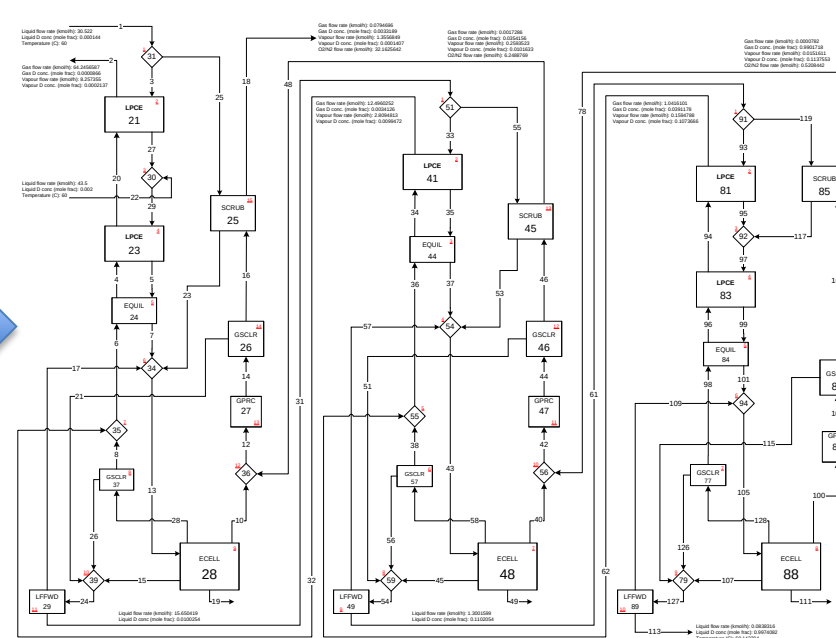


# Process Modeling Codes

## Model Flowsheet



Process Flowsheet



Model Results



# *Combined Electrolysis and Catalytic Exchange (CECE) Demonstration*

## *Heavy Water Upgrading & Detritiation*

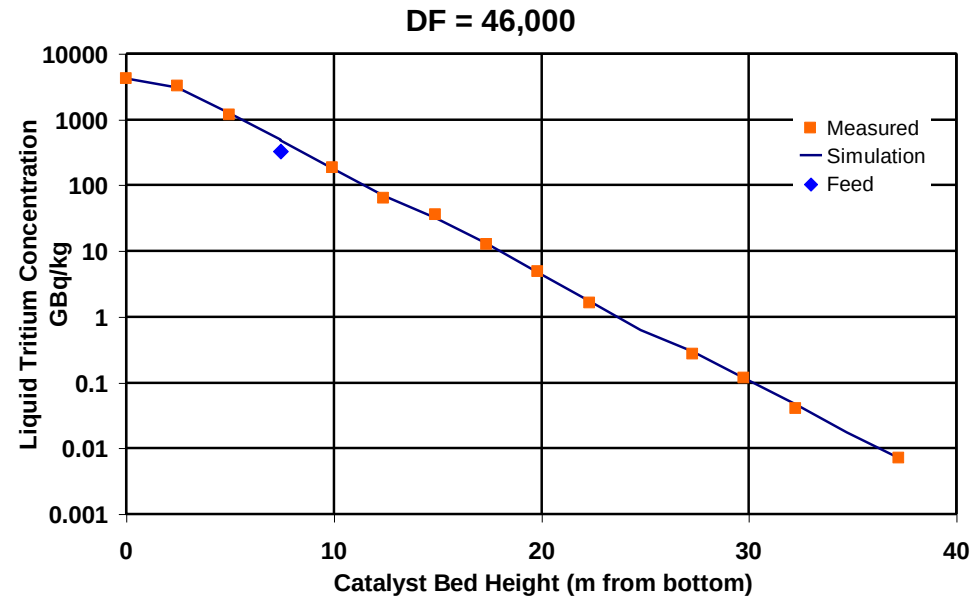
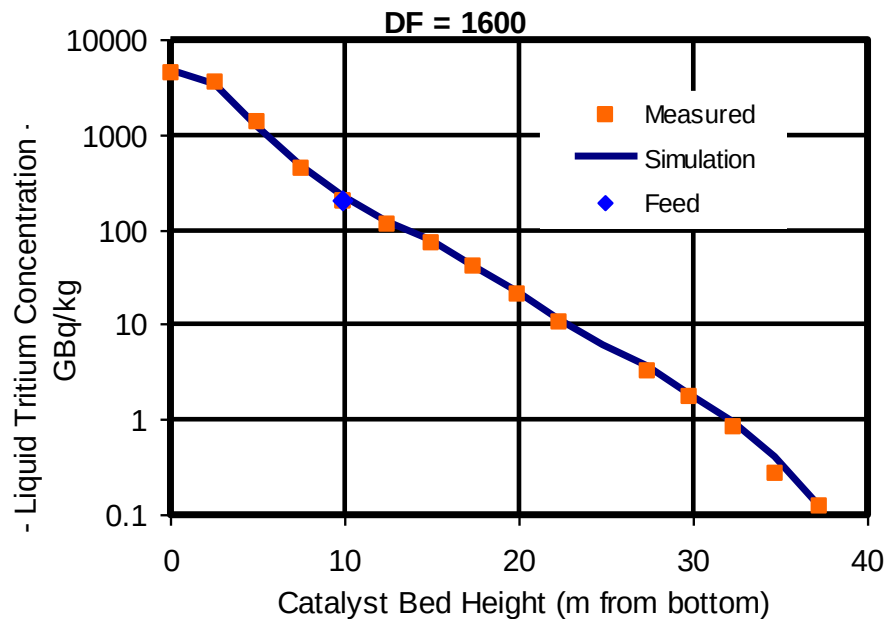
- **Designed, built and operated the facility for two years (1998-2001) – in compliance with Canadian Nuclear Standards N286**
- **Demonstrated**
  - upgrading and Detritiation of heavy water
  - detritiation factors up to 50 000
  - robustness of AECL's wetproofed catalyst
  - operation of E-cell at high tritium concentrations ( $\sim 220$  Ci/kg)
  - Tritium Laboratory provided analysis and technical support services



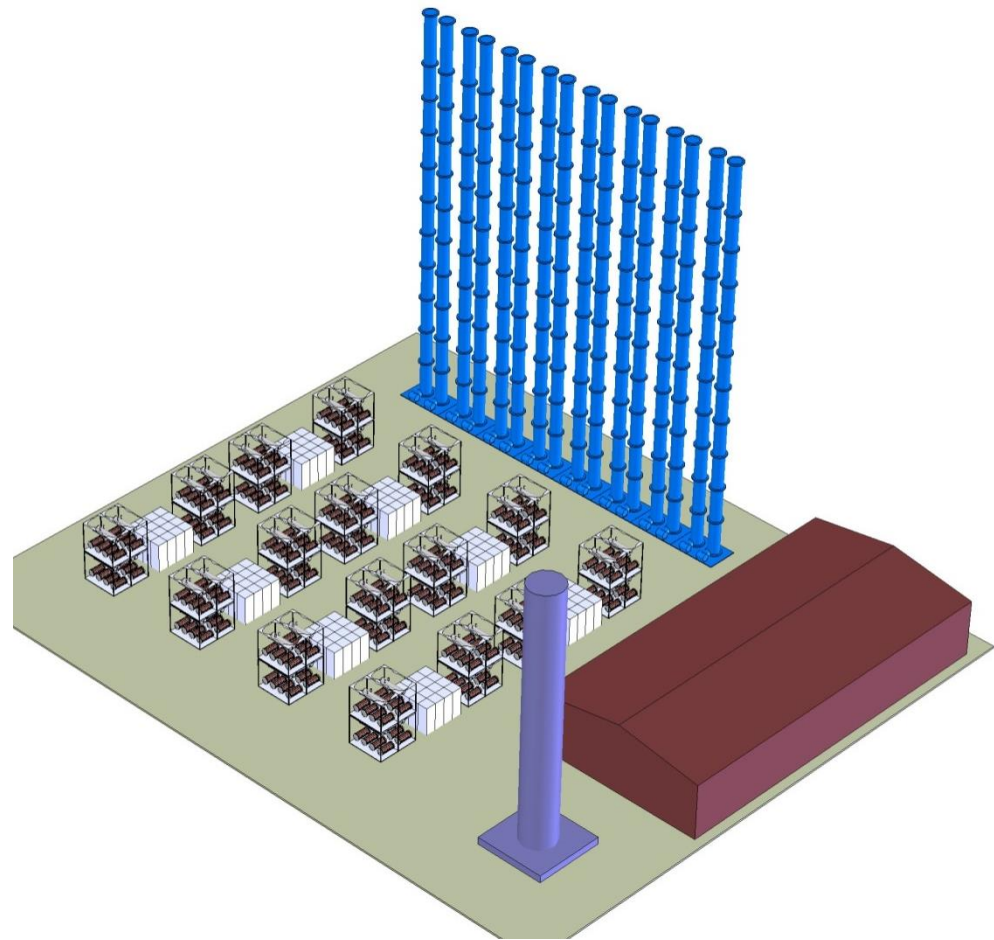
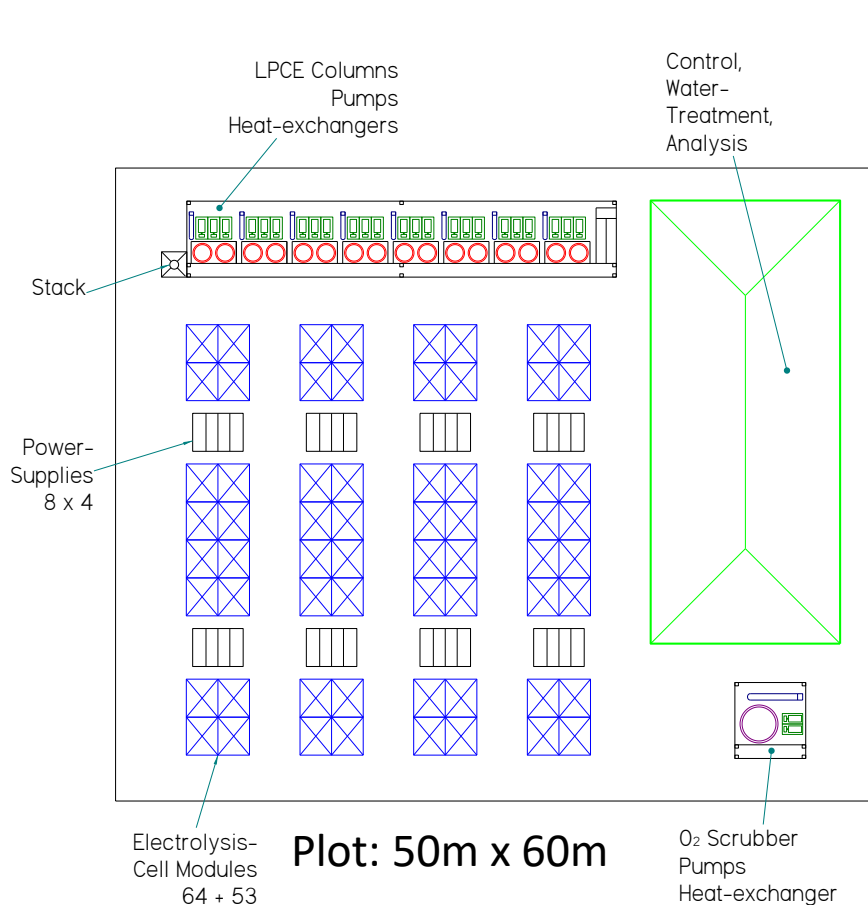
**CECE Demonstration Plant  
at Chalk River Laboratories**



# CECE Process Model Validation



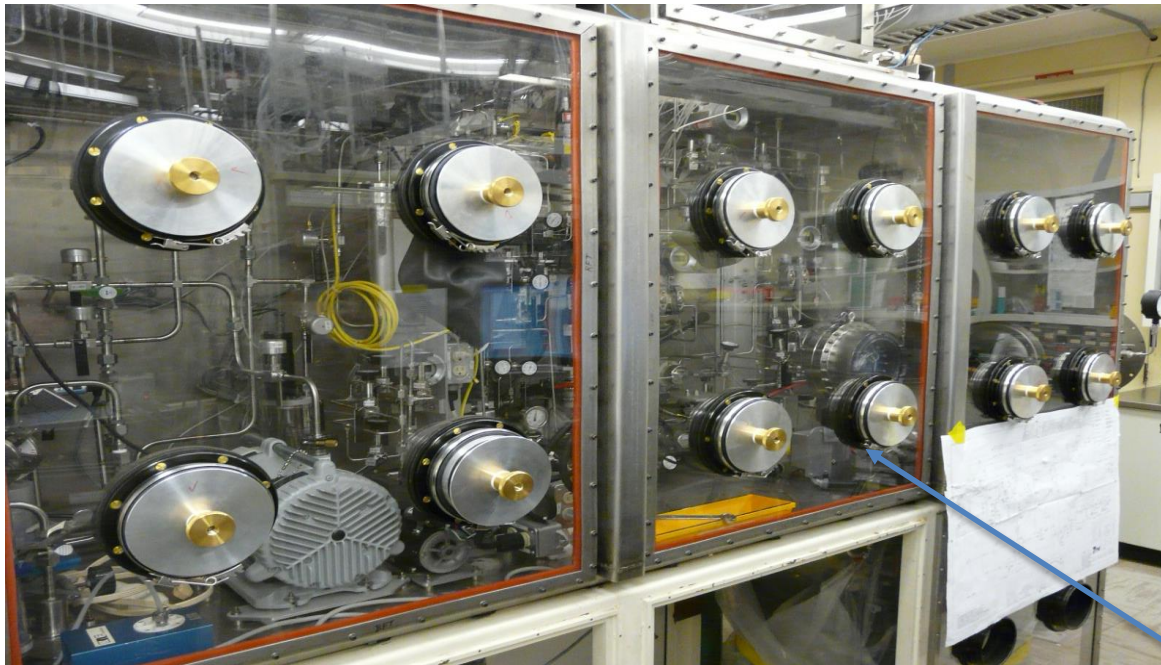
# Fukushima Light Water Detritiation Layout



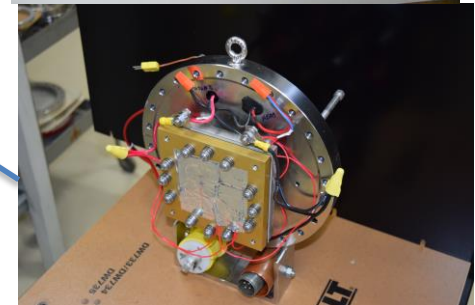
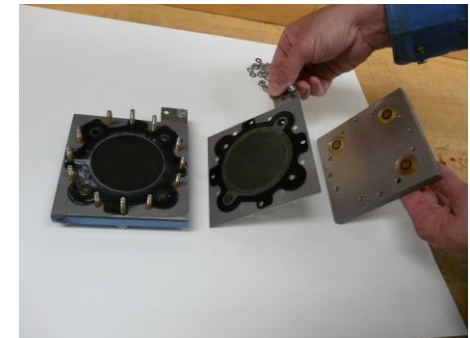
| Feed flow               | Capacity Factor | Feed tritium concentration | Discharge tritium concentration | Product tritium concentration |
|-------------------------|-----------------|----------------------------|---------------------------------|-------------------------------|
| 440 Mg/d<br>1018 kmol/h | 0.91            | 5 MBq/L<br>(135 µCi/L)     | 50 kBq/L<br>(1.35 µCi/L)        | 0.5 GBq/L<br>(13.5 mCi/L)     |



# Tritium Compatible Electrolysers



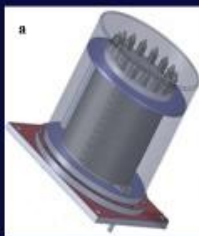
- Preparation of water containing 37 TBq/kg (1000 Ci/kg) – critical safety issues!
- Accelerated static material testing of PEM, IMET and CNL proprietary membranes over long term (up to 3 years) at 37 TBq/kg
- Step up concentration to 37 TBq/kg in the mini-CECE flow system



## Features of Tyne Tritium Resistant Electrolyzer

Some features that distinguish Tyne's tritium PEM electrolyzer from other commercially available PEM electrolyzers for tritium application include:

- Specially developed tritium resistant membrane for long term usage
- Designed to resist tritium leakage
- Outer container to monitor leaked tritiated water or gas.
- Each unit can operate independently and be able to produce 10 Nm<sup>3</sup>/hr of H<sub>2</sub>



a) CAD Model  
b) Tyne's Unit

April 16, 2019

Tyne Engineering Inc., Burlington, Canada

## Tyne's Tritium Resistant Electrolyzer



### Assembling of the Electrolyzer

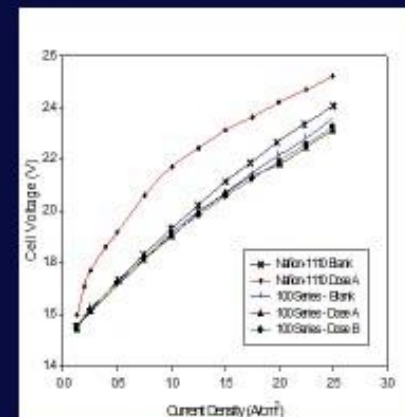
April 16, 2019

Tyne Engineering Inc., Burlington, Canada

## Collaboration with Tyne for Electrolyzer Design

## Electrochemical Performance Comparison

- Tested MEAs were made with both the Nafion® N-1110 and CNL's 100 Series membranes.
- Tritium exposure up to 159 kGy did not result in any performance deterioration for the exposed and unexposed 100 Series membrane.
- For the commercial Nafion® N-1110, the exposed membrane showed cell voltage of about 200 mV higher than the unexposed membrane at the current density of 1.0 A/cm<sup>2</sup>.
- The 100 Series membrane clearly shows superiority in tritium compatibility compared to commercial Nafion® N-1110.



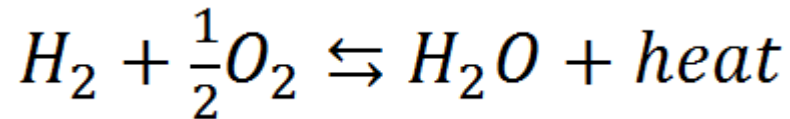
Comparison of 100 Series membrane and Nafion® N-1110 membrane at different current densities.

April 16, 2019

Tyne Engineering Inc., Burlington, Canada

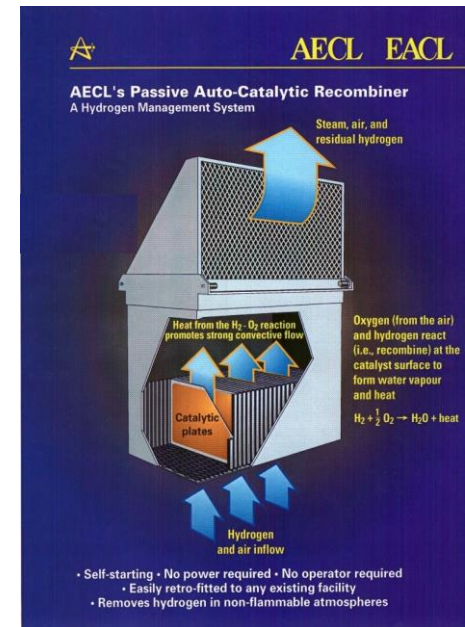
# Robust High Performance Recombiner Catalysts

## Catalysts for Safe Recombination of H<sub>2</sub>



## Numerous H<sub>2</sub> Recombination Applications

- Hydrogen purification
- Gas phase recombiner
- Trickle bed recombiner
- Passive autocatalytic recombiner
- Tritium-in-air monitoring
- High radiation tolerance



# Robust High Performance Recombiner Catalysts

## Gas Phase Recombiner

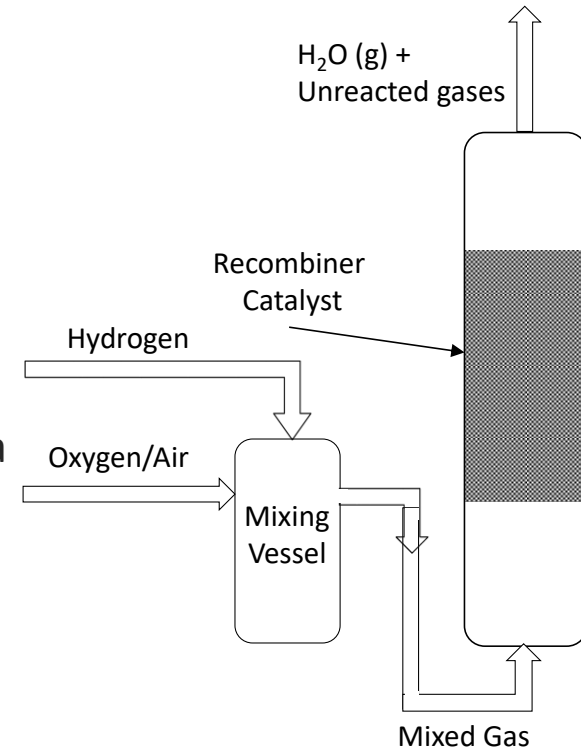
Recombine  $\text{H}_2\text{-O}_2$  gas mixtures at low  $\text{H}_2$  concentrations and low temperatures

### Specifications:

- $\text{H}_2$  concentration:  $< 4 \text{ vol.}\% \text{ H}_2$
- Operating Temperature:  $> 20^\circ\text{C}$
- Operating Pressure: less catalyst required for higher pressures
- Pressure drop: low (structured catalyst material)
- Conversion:  $> 99\%$
- Radiation: tolerant for tritium applications and high gamma radiation (2000 kGy)

### CNL Capabilities

- Design
- Catalyst Supply
- Testing/Verification



**Catox (Removal of  $\text{O}_2$ )  
(WTRF)**



# Robust High Performance Recombiner Catalysts

## Trickle Bed Recombiner

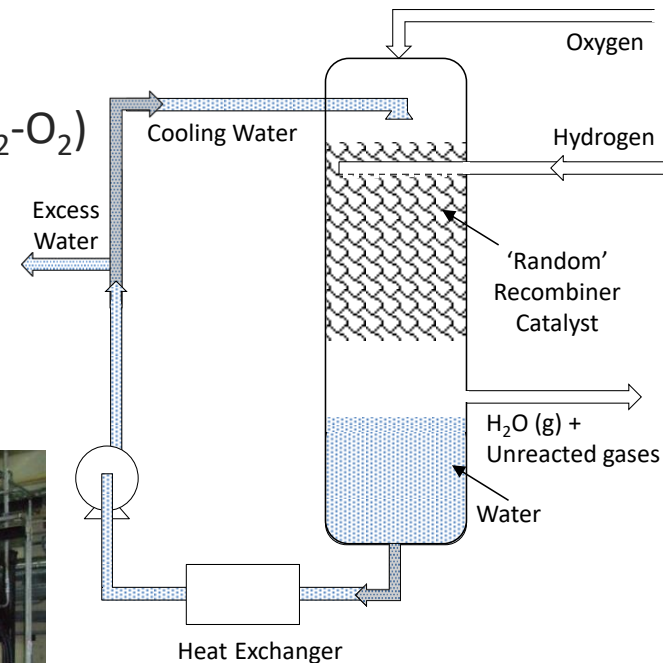
Recombine  $H_2$ - $O_2$  gas mixtures at high  $H_2$  concentration and low temperature  
Environmentally Safe and Efficient Alternative to Burners

### Specifications:

- $H_2$  concentration: any (typically stoichiometric mix of  $H_2$ - $O_2$ )
- Operating Temperature: 60-80°C
- Operating Pressure: <15 psi(g)
- Conversion: > 99%
- Radiation: tolerant for tritium applications

### CNL Capabilities

- Design
- Catalyst Supply
- Testing/Verification



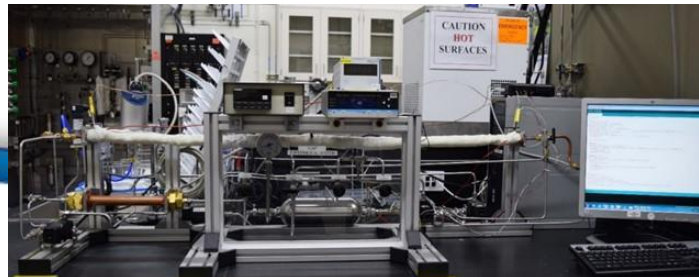
**Purge Gas Recombiner System  
(WTRF)**



# Tritium Concentrator Related Activities

## Absorbent Materials for TCAP applications

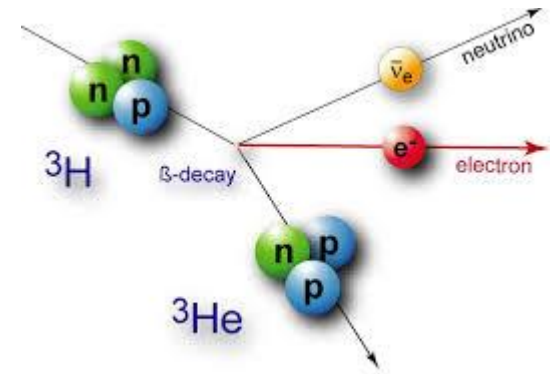
- In-house Production of novel absorbent materials
  - Develop efficient and effective processes for producing Pd-based absorbents on porous materials
  - Characterization: SEM, EDX, thermal conductivity, & surface area
  - CNL method showed:
    - higher capacity to absorb hydrogen, higher Pd dispersion, lower amounts of pulverization and shorter processing times.
- Constructed experimental system for testing absorbents
  - Separate hydrogen-deuterium mixtures



# Tritium Activities Towards Commercialization

## Helium-3 - Collection and Purification

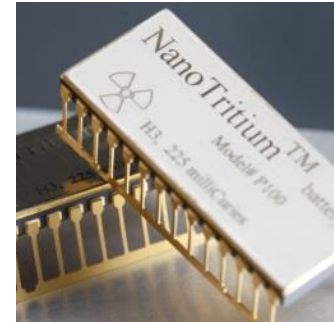
- Determine optimal processes for
  - Collection from ITCs, Purification, and Storage
- Collected gas may contain tritium, tritiated organics, inert gases, etc.
- Purification of Helium-3 (Goal)
  - Gas must contain  $> 99.9995\%$  He-3 + He-4
  - $< 1 \mu\text{Ci}/\text{m}^3$  tritium
  - $< 1 \text{ ppm}$  of other impurities ( $\text{N}_2$ ,  $\text{O}_2$ , Ar, CO,  $\text{CO}_2$ )



# Tritium R&D Activities

## Tritium Betavoltaics

- Use energy from tritium decay as a power source
  - Low power, high reliability applications
    - Medical – pacemakers, hearing aids
    - Remote sensors – Internet of Things
    - Micro-electrical mechanical systems (MEMS)
    - Trickle-charge lithium-ion batteries
  - Two types:
    - Direct:  $\beta \rightarrow$  conduction electrons
    - Indirect:  $\beta \rightarrow$  photons  $\rightarrow$  conduction electrons



# Tritium Safe Handling Course

June 6-8, 2017 - Chalk River, Ontario, CANADA

❖ Canadian Nuclear Laboratories (CNL), formerly AECL, is Canada's premier nuclear science and technology organization. CNL is a world leader in developing peaceful and innovative applications from nuclear technology through its expertise in physics, metallurgy, chemistry, biology and engineering.

❖ Highly skilled employees enthusiastically deliver a range of nuclear services – research and development, design, engineering, specialized technologies, waste management and decommissioning. These highly-qualified people will present this comprehensive tritium handling course.

## Course Modules:

### 1. Tritium Interaction with Materials:

- ❖ Properties of tritium
- ❖ Interactions with ceramics, metals and polymers
- ❖ Tritium containment and permeation effects
- ❖ Decontamination

### 2. Radioactive Materials Transportation:

- ❖ Regulations for transporting radioactive materials
- ❖ Methods for safe transport

### 3. Tritium Accounting:

- ❖ Principles of record keeping
- ❖ Inventory controls

### 4. Tritium Dosimetry:

- ❖ Monitoring tritium in the body
- ❖ Effects of tritium on the human body
- ❖ Medical research.

### 5. Tritium Monitoring in Laboratories:

- ❖ Monitoring tritium in air, water and on surfaces
- ❖ Monitoring work areas

### 6. Environmental Tritium Monitoring:

- ❖ Regulations for tritium emissions in air and water
- ❖ Methods for environmental tritium monitoring
- ❖ Record keeping.

### 7. Tritium Gas Chromatography:

- ❖ Quantitative analysis of tritium gas
- ❖ Preparation of GC columns for tritium service
- ❖ Operation of GCs containing tritium

### 8. Liquid and Gaseous Tritium Separation Processes:

- ❖ Tritium in liquids and gases
- ❖ Separation from other hydrogen isotopes

### 9. Tritium Waste Management:

- ❖ Forms of tritiated waste
- ❖ Segregation and handling of tritiated waste.

### 10. Atmospheric Detritiation:

- ❖ Tritium removal from air

### 11. New Facility Design Philosophy:

- ❖ Lessons learned

## Laboratory Training

### 1. Tritium Gas Handling:

- ❖ Desorbing gas from a uranium bed
- ❖ Gas volume measurement
- ❖ Gas chromatography for tritium gas analysis

### 2. Getter Beds for Atmospheric Detritiation:

- ❖ Effects of impurities on performance

### 3. Decontamination:

- ❖ Tritium removal from surfaces
- ❖ In-situ ion chamber decontamination

## Course Cost

- ❖ 2000 C\$ + Applicable Taxes
- ❖ Complimentary lunches and coffee breaks
- ❖ Group Dinner included



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### To Register or for Information, contact:

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# Catalyst Production Capabilities



**Catalyst Component Production**



**Large Scale Catalyst Production**



## Process Utilities & Services for Catalyst Production & Testing



# Summary

- Canadian Government through AECL and CNL has made a large investment for the future in the opening of the new Tritium Facility
- CNL, with its availability of the new Tritium Facility, is committed to continue to being the leading supplier of tritium for national and international customers of the Ontario Power Generation (OPG)
- CNL is well positioned to provide a wide range of capabilities in the area of tritium
  - R&D
  - Commercial Products, Services and Consulting
  - Collaborations





# *Thank you. Merci.*

Questions?



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