Hybrid system

Radon-222 trapping with liquid nitrogen

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Outline

- Motivation
- Commissioning
- System description
- Calibration step
- Characterization
- Conclusion

Motivation

Gas assay: (low pressure)	Increase sensitivity of radon measurement in large volume systems: PICO (PV 10 m^3)
Rn trap : activated carbon as sole material	Excellent adsorption capacity at ⇣ T° Prone to clogging at ⇣ T° → moisture, O_2 & N_2 condensation
Hybrid system	Water trap→ absorb the water before it reaches the charcoal Rn trap : Bronze wool + Activated carbon • Wool: Not prone to blockage + limited adsorption of O_2 and N_2 • Wool: To absorb residual moisture upstream • Wool: Allowing the system to breathe + limits the drop in P & Q.

Commissioning

Charcoal: Purification & Cleaning

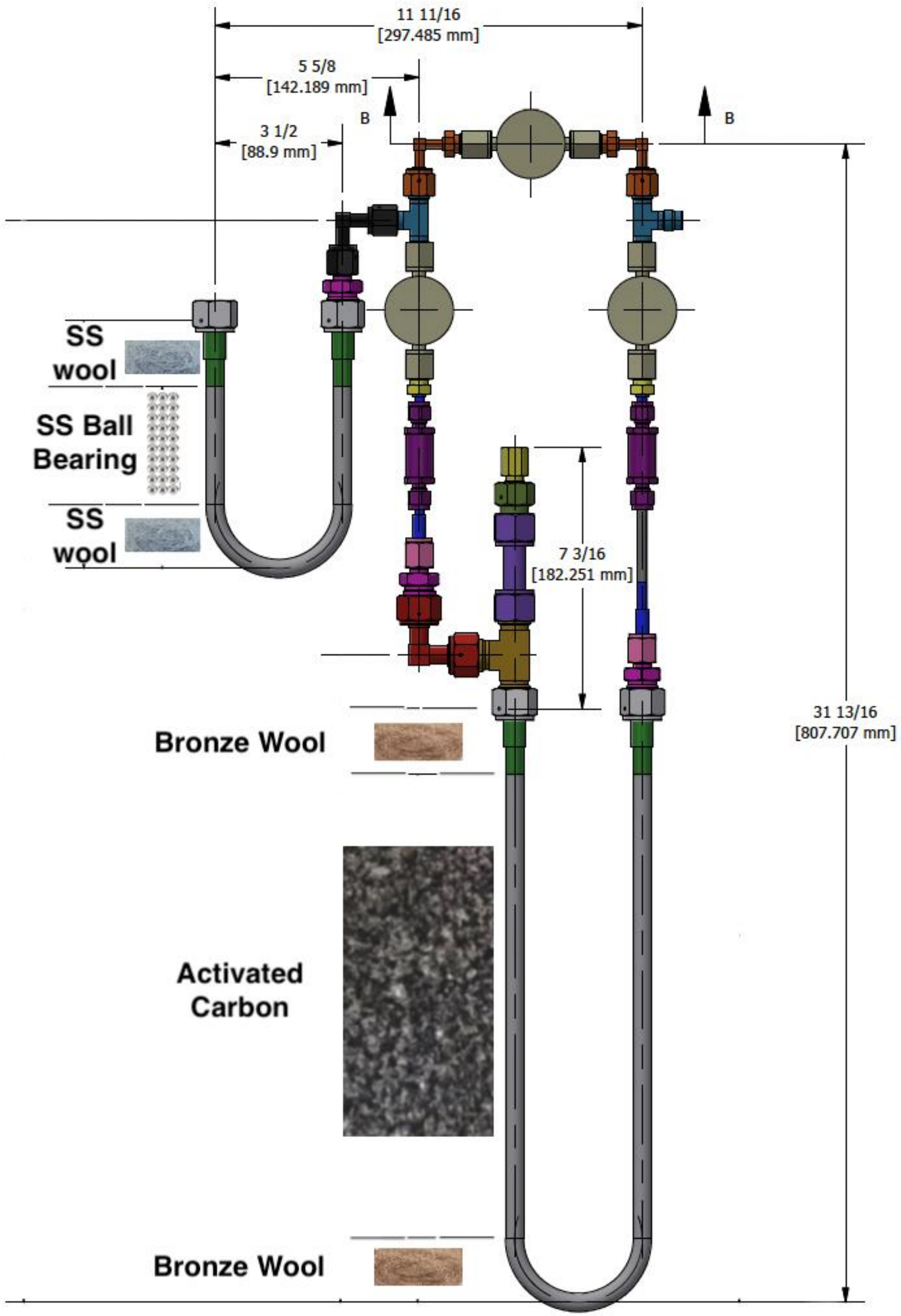
- Nitric acid (5 % HNO_3) → leach out and remove contaminants (238-U & 226-Ra)
- Increase surface roughness and the number of pores
- Rinsed with UPW
- Bake → 150°C for 24 to 48 hours, with a nitrogen flow

Materials: Pipe, Fittings, Flexible tube & Wool

- USC: nuclear radioactive decontamination solution
- Methanol cleaning : valve, ss & bronze wool
- Passivation and pickling

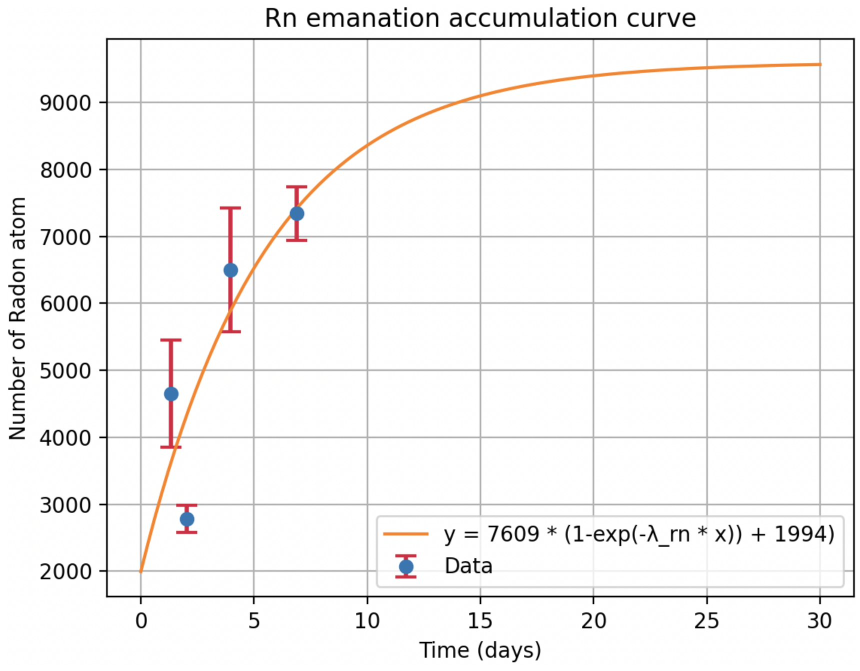
System description

- Water trap (short U-shaped ½” pipe)
  - SS wool
  - 3/16" AISI 316 stainless steel bearing balls
- 3X FVCR Bellows sealed valves
- 2X VCR Particle filter, 0.5 μ, 316 SS
- 11.22-inch, Type T Thermocouple, Probe
- Carbon trap (long U-shapped ½” pipe)
  - Carbo-Act International (0.2mBq/kg)
  - Bronze wool



Calibration step

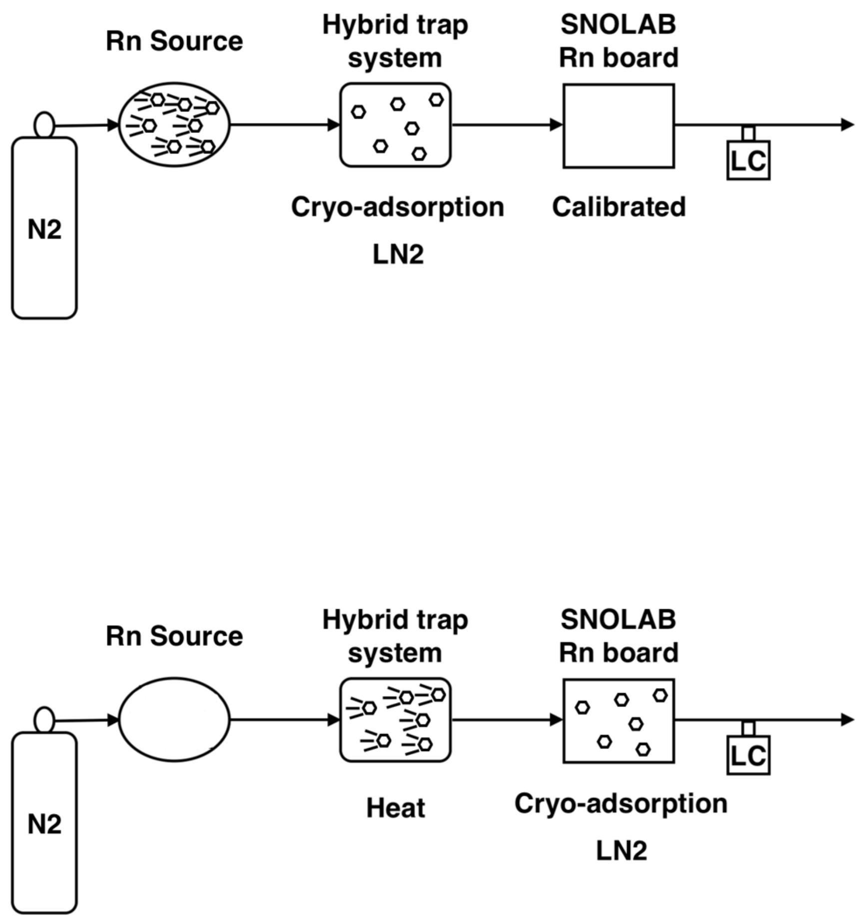
- Rn emanation (exhalation)
  - Radon atoms generated by the decay of radium in a material and escape through its interstices, mainly due to recoil effects
- Radon source : # of Rn when reaching secular equilibrium
- Rn capture by the trap system from the calibration source



Calibration & Counting

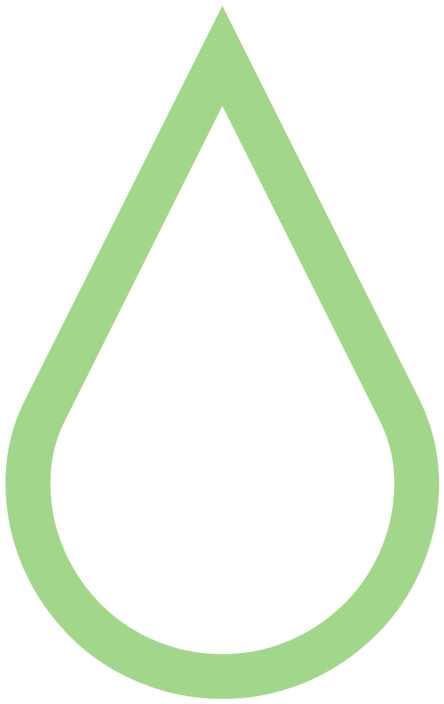
- Radon source
  - Use to calibrate the hybrid system → determine trapping efficiency
  - Detector (component) : Counting the Rn rate release (radon assay)

- SNOLAB radon board
  - Contains two traps
  - Calibrated : known efficiency
  - Not designed to handle large volumes of N2 → efficiency decreases



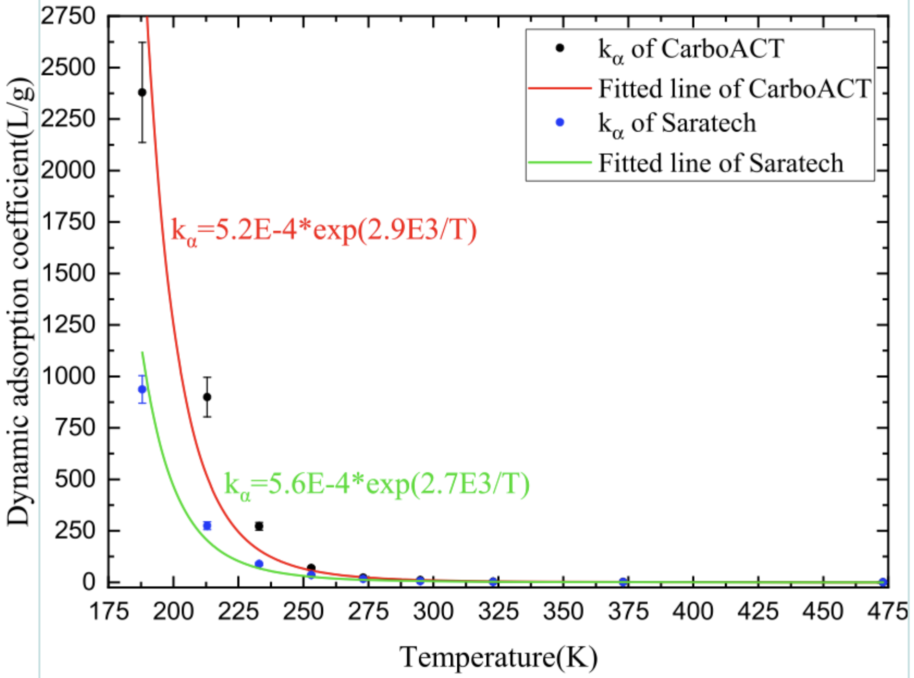
Characterization

- Moisture :
  - Reduces the dynamic adsorption coefficient
  - Can take the places of Rn on the microscope pores of the adsorbent.
  - Increase the probability that Rn escapes the trap
  - LC → reduces & distorts the counting efficiency.
    - Can condensate on scintillating material



Characterization

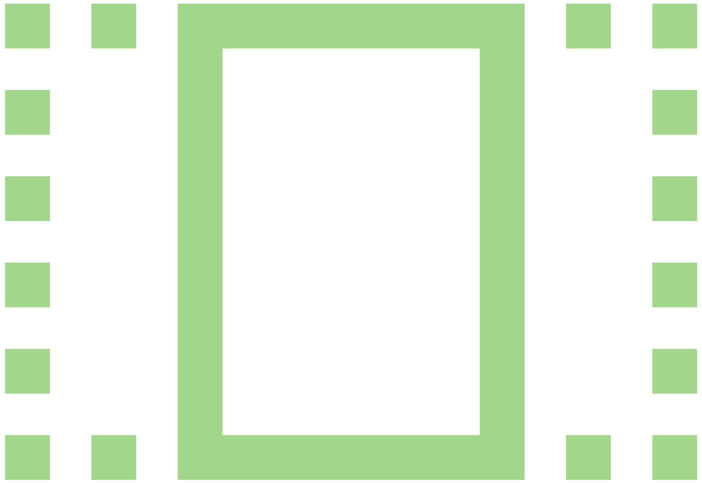
- Dynamic Adsorption (K_a)
  - $K_a[L/g] = \frac{\tau[min]Q[SLPM]}{m[g]}$
  - τ Is the retention (breakthrough) time
  - m is the mass of the absorbent
  - Increases exponentially as the temperature decreases



Wang et al., Applied Radiation and Isotopes 191 (2023) 110564

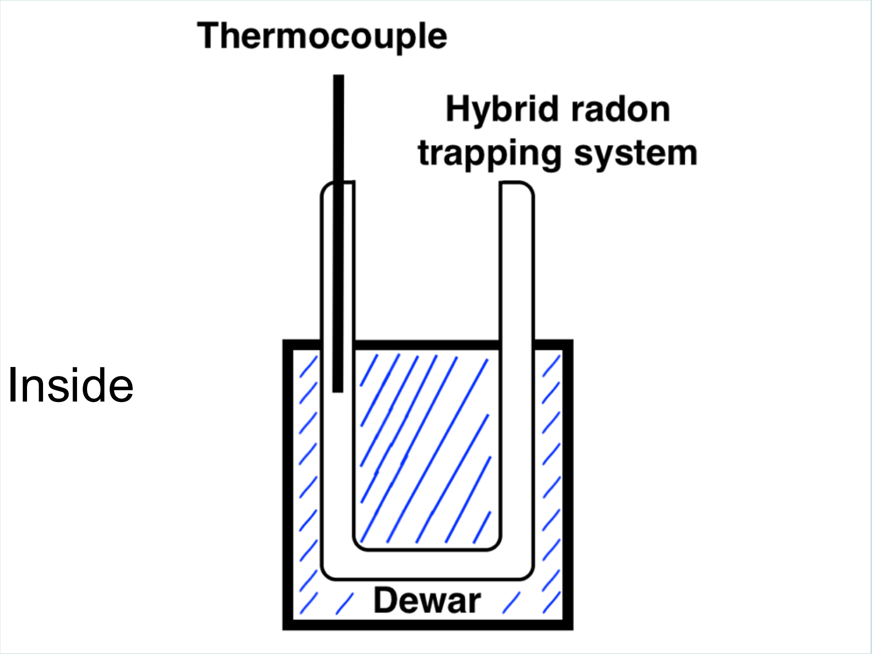
Characterization

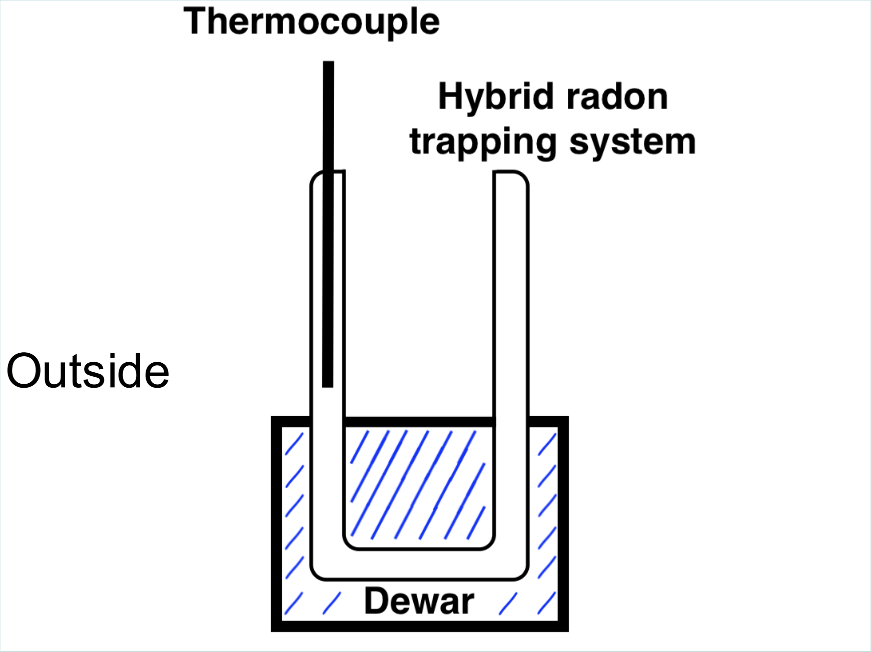
- Retention (Breakthrough) time →
  - Designates the period during which carbon reaches saturation and can no longer reliably retain radon.
  - The breakthrough time must always be greater than the assay (exposure) time.
  - $m[g] = 15.3 \pm 0.3g \;\; ; \; \mathrm{Q} = 0.5 \pm 0.1\mathrm{SLPM}$
  - $\tau[min] = \frac{K_a[L/g]m[g]}{Q[SLPM]} \sim 10^2 - 10^7\,min$



Characterization

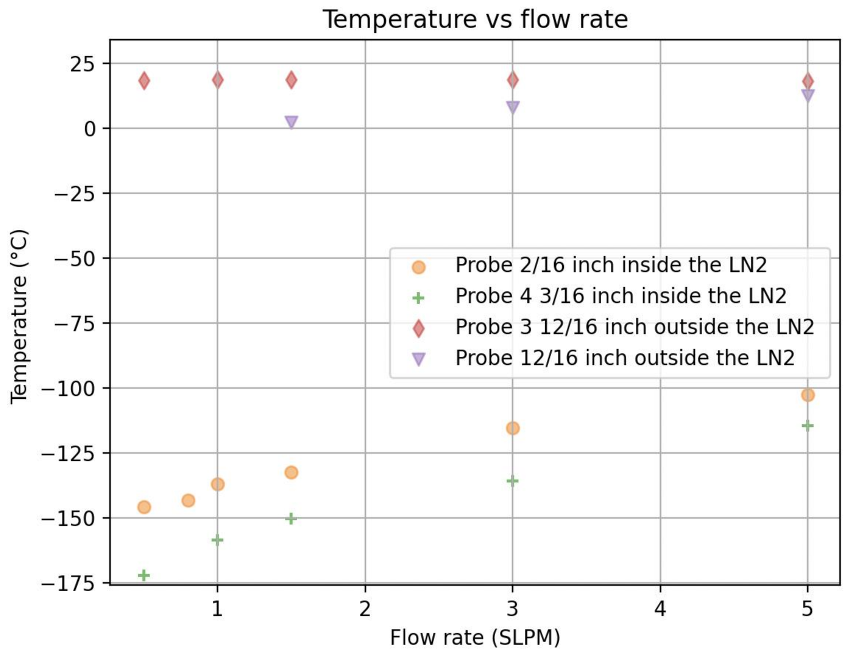
- Understanding the behavior of the system under vacuum
  - Flow rate on T, P
  - P and flow rate drop
  - Homogeneity of T in the charcoal column
    - Thermocouple directly in the carbon
    - Cryofluid level in the dewar
    - T around the probe region: internal material vs. external fluid





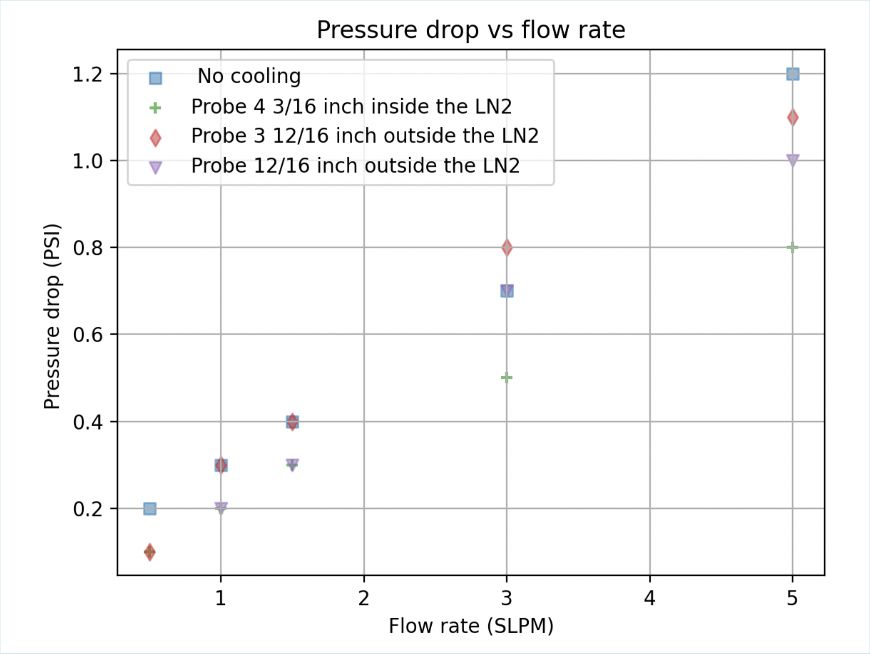
Internal Temperature

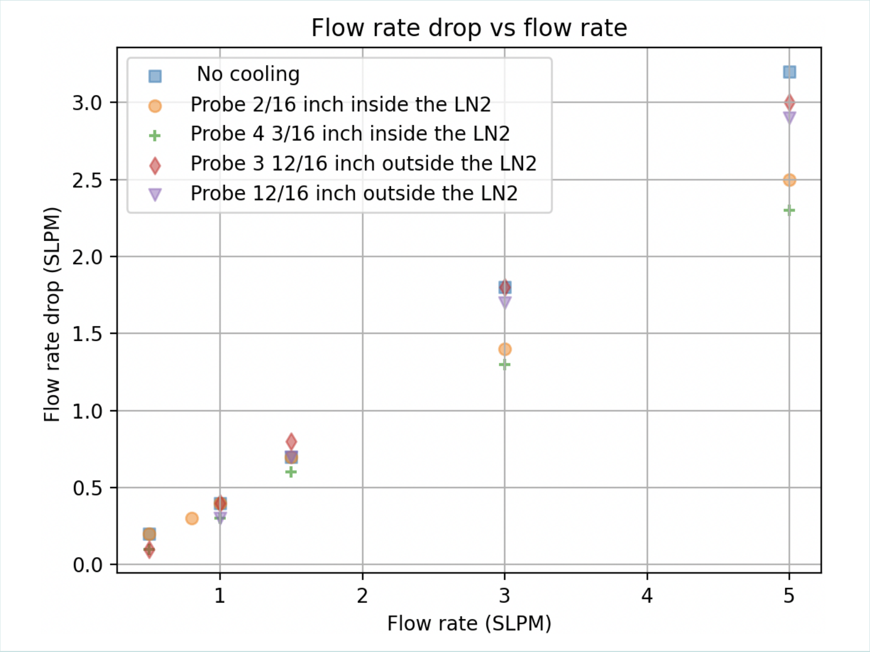
- Cryogenic fluid level in dewar dependent
- T of the external fluid is not the same as that of the internal system.
- Without heating, the temperature of liquid nitrogen (LN2) would have to be reached over a long period.
  - However, the analysis is carried out within a limited time frame



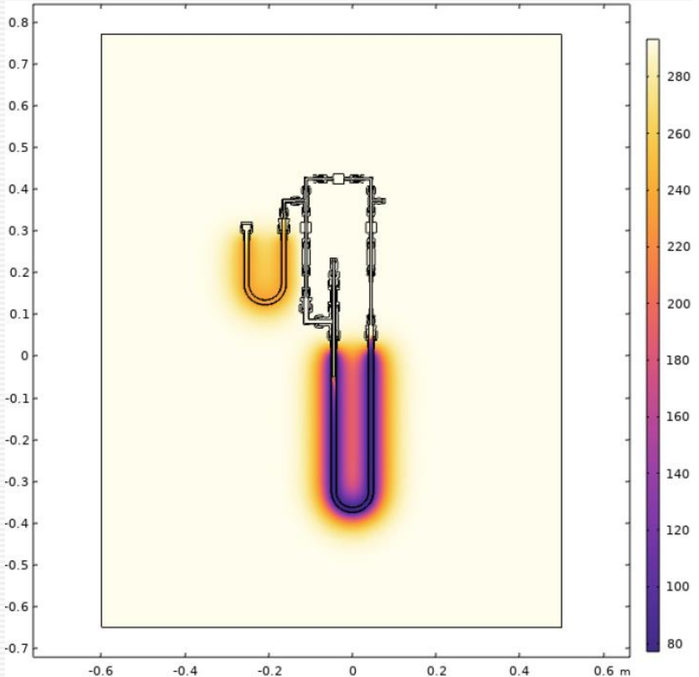
Flow rate & Pressure drop

- $i_{drop} = (i_{Bypass} - i_{Trap})$
- i_{drop} amplify with flow rate
- Should be monitored during an assay : assess clogging.
- Trapping efficiency
  - more time to interact and adhere with adsorbent material





Conclusion



- Has been done
  - Hybrid system to trap Rn
  - No blockage when LN2 is used as a cryo-fluid
  - Characterize : P & T change in the system with the input flow
  - Improve procedure, calibrate initial T as an example

- Need to be done
  - Add an CO_2 trap
    - ↑ trapping efficiency: competes for the same adsorption sites
    - Prevents and reduces cryogenic blockages
  - Run thermal model to have a better understanding
    - Compared with recorded data: T, P & Q

Annex

- Reynolds
  - $Re = \frac{\rho v L}{\mu} = \frac{\rho (Q/A) L}{\mu} = \frac{(1.165\ kg/m^3)([8.333X10^{-6} m^3/s]/[1.266769X10^{-4} m^2])(0.0127\ m)}{1.7X10^{-5} Pa \cdot s} = 55.3$
  - $<< 2100$ → laminar flow
- Laminar flow
  - Uniform
  - Predictable residence time

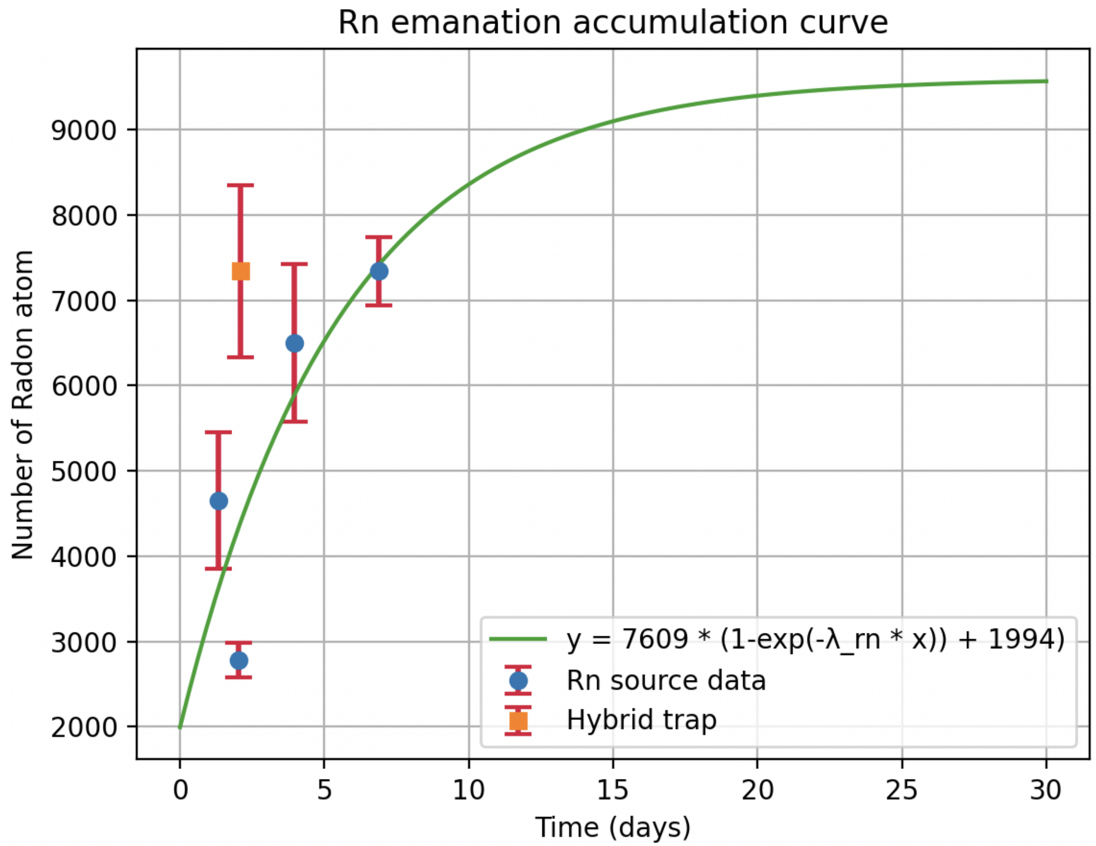
Annex

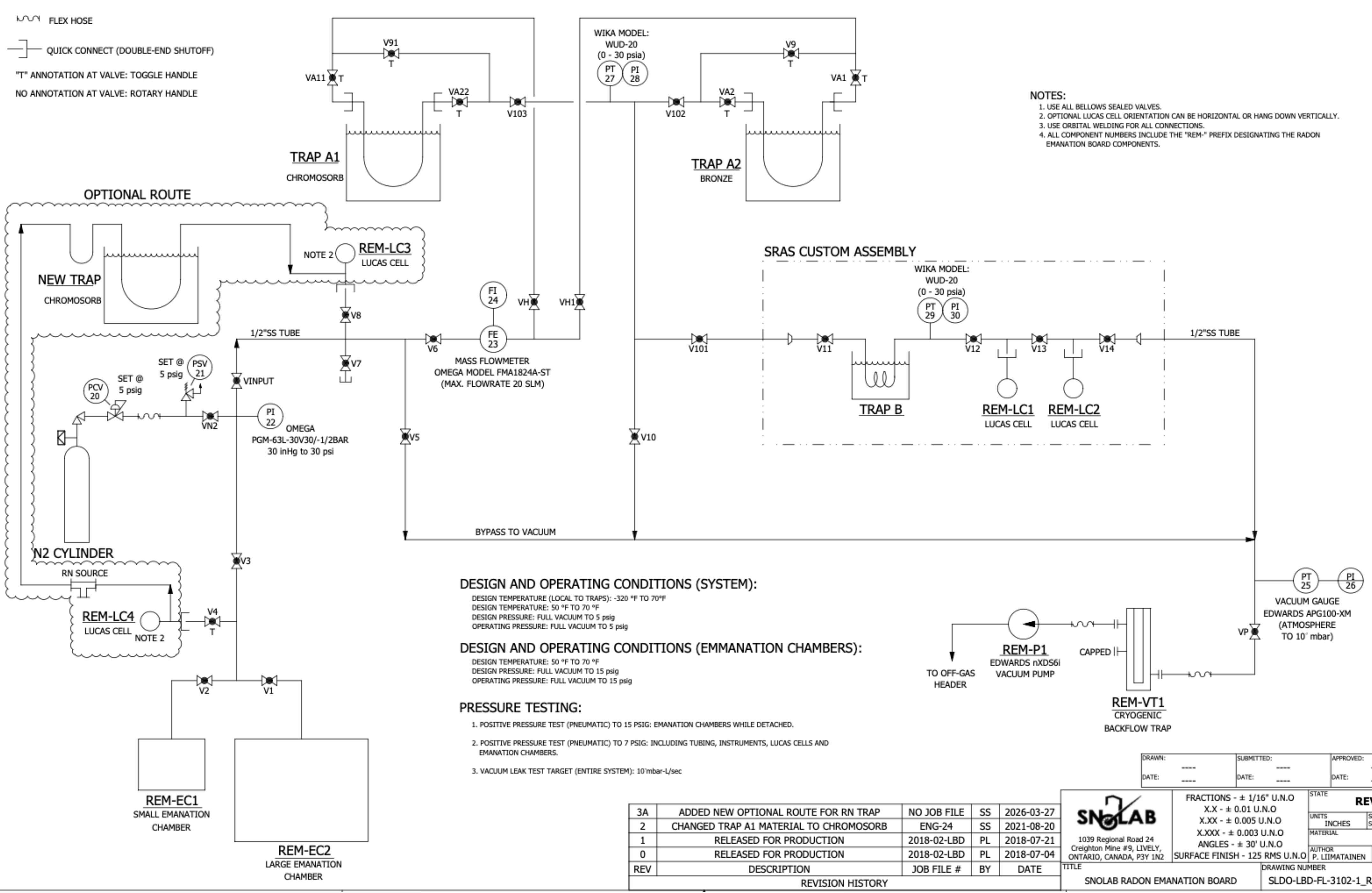
- Parameters :
  - N_{Rn}^{sample} $defines\ the\ number\ of\ Rn\ decay\ in\ a\ given\ sample \cdot \lambda$ (activity=Nλ→ Bq or disintegration / day)
  - N_α $is\ the\ number\ of\ alpha\ counts$
  - N_{Bkg}^{LC} and N_{bkg}^{board} $are\ the\ bkg\ count\ for\ the\ LC\ and\ board\ for\ the\ counting\ period\ and\ syst.conf.respectively$
  - ϵ_i $are\ the\ efficiency\ of\ transfer,\ trapping\ and\ counting\ of\ the\ system\ used$
  - $\epsilon_{trans} = 0.64 \pm 0.16,\ PV \rightarrow water\ trap\ \rightarrow charcoal\ \rightarrow Trap\ A\ \rightarrow Trap\ B\ \rightarrow LC$
  - $\epsilon_{trap} = 0.94 \pm 0.06,\ efficiency\ of\ trapping\ radon\ from\ the\ combination\ of\ Trap\ A\ \&\ B$
  - $\epsilon_{counting} = 0.74 \pm 0.07$ LC in count alpha
  - t_i $are\ the\ time\ parameters$
  - Please note : the expression in (parentheses) is the number of radon atoms

$$N_{Rn}^{sample} = \left(\frac{N_\alpha - N_{Bkg}^{LC}\, t}{3\epsilon_{trans}\epsilon_{trap}\epsilon_{counting}(e^{\lambda_{Rn}t_{delay}})(1 - e^{\lambda_{Rn}t_{count}})(1 - e^{\lambda_{Rn}t_{eman}})} - N_{bkg}^{board} \right) \frac{ln(2)}{T_{1/2}}$$

Annex

- Preliminary result: effectiveness of the activated carbon trapping system
  - *Not enough counting time.*





NOTES:

1. USE ALL BELLOWS SEALED VALVES.
2. OPTIONAL LUCAS CELL ORIENTATION CAN BE HORIZONTAL OR HANG DOWN VERTICALLY.
3. USE ORBITAL WELDING FOR ALL CONNECTIONS.
4. ALL COMPONENT NUMBERS INCLUDE THE "REM-" PREFIX DESIGNATING THE RADON EMANATION BOARD COMPONENTS.

DESIGN AND OPERATING CONDITIONS (SYSTEM):

DESIGN TEMPERATURE (LOCAL TO TRAPS): -320 °F TO 70°F
DESIGN TEMPERATURE: 50 °F TO 70 °F
DESIGN PRESSURE: FULL VACUUM TO 5 psig
OPERATING PRESSURE: FULL VACUUM TO 5 psig

DESIGN AND OPERATING CONDITIONS (EMMANATION CHAMBERS):

DESIGN TEMPERATURE: 50 °F TO 70 °F
DESIGN PRESSURE: FULL VACUUM TO 15 psig
OPERATING PRESSURE: FULL VACUUM TO 15 psig

PRESSURE TESTING:

1. POSITIVE PRESSURE TEST (PNEUMATIC) TO 15 PSIG: EMANATION CHAMBERS WHILE DETACHED.
2. POSITIVE PRESSURE TEST (PNEUMATIC) TO 7 PSIG: INCLUDING TUBING, INSTRUMENTS, LUCAS CELLS AND EMANATION CHAMBERS.
3. VACUUM LEAK TEST TARGET (ENTIRE SYSTEM): 10 mbar-L/sec

DRAWN: ----	DATE: ----	SUBMITTED: ----	DATE: ----	APPROVED: ---- DATE: ----

REV	DESCRIPTION	JOB FILE #	BY	DATE
3A	ADDED NEW OPTIONAL ROUTE FOR RN TRAP	NO JOB FILE	SS	2026-03-27
2	CHANGED TRAP A1 MATERIAL TO CHROMOSORB	ENG-24	SS	2021-08-20
1	RELEASED FOR PRODUCTION	2018-02-LBD	PL	2018-07-21
0	RELEASED FOR PRODUCTION	2018-02-LBD	PL	2018-07-04

REVISION HISTORY

SNOLAB
1039 Regional Road 24
Creighton Mine #9, LIVELY,
ONTARIO, CANADA, P3Y 1N2

FRACTIONS - ± 1/16" U.N.O
X.X - ± 0.01 U.N.O
X.XX - ± 0.005 U.N.O
X.XXX - ± 0.003 U.N.O
ANGLES - ± 30' U.N.O
SURFACE FINISH - 125 RMS U.N.O

STATE: REVIEW
UNITS: INCHES | SHEET SIZE: B | SCALE: D.N.S.
MATERIAL:
AUTHOR: P. LIIMATAINEN | CREATION DATE: 2018-01-26

TITLE: SNOLAB RADON EMANATION BOARD
DRAWING NUMBER: SLDO-LBD-FL-3102-1_Rev_3
SHEET: 1/1