UNIVERSITY OF ALBERTA

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Collaboration meeting, Grenoble

Gas Purification:
Goal & Status

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Goals in terms of background

- Crucial to be able to identify the contaminants
- Traces Uranium, Thorium, Oxygen, H_2O, Radon, Krypton etc.

- Oxygen, H_2O, electronegative impurities
- Well removed by hot getter included in the loop system
- But radon rate increased: emanates from the getter!

- Radon …
  - ~ 50mBq in the sphere at Queen’s S30
  - Level required for Ne mixture from simulations < 48 μBq

- Krypton …
  - For R2D2: removing the Kr85 from the Xenon
  - Level required from simulations < ?

Acceptable level of radon

- Estimated by simulations: (credits Alexis)
  - 10^4 decays of ^{222}Rn homogeneously distributed in volume
  - 10^4 decay of ^{218}Po /^{214}Pb on the inner surface

- Results in dru/Bq…

	He mixture	**Ne mixture**
^{218}Po	2411	612
^{214}Pb	663	227
^{214}Bi + ^{214}Po	987	210
Total	4061	1050
To obtain 0.05 dru < 1keV	$< 12\mu$Bq	$< 48\mu$Bq

Radon mitigation: Strategies

- Radon trap
  - Feasible but CH4 is also absorbed
  - Tests need to be done to find the optimal conditions of the column (Temperature, Flow) to remove the radon only.
    --> In progress led by José in Marseille.

- Queen's tests and plan with S30
  - Run plan already in place in order to control the CH4 amount.
  - Procedure in place for running with the trap.

- Material for trapping
  - Carboxen 564: Material also with the lowest radioactivity
  - Alternative Carboxen 1000

Radon adsorption measurements at CPPM

Radon : noble gas => physisorption on microporous materials

- **Optimum capture** => porous radious ≈ 2 x Rn atomic diametre

Experimentaly : *Porous radious ∈ [0.5 nm – 0.7 nm]*

(Capture ability is also enhanced by chemical composition, porous shape, …)

Many microporous adsorbents : Active charcoals, Carbon Molecular Sieves, Zeolite,
Metal Organic Framework, Organic Aerogels, Cryptophanes, etc, …

- **Adsorption competition**

(Atomic diametre)

He -> 0.218 nm   Ne -> 0.275 nm
Ar -> 0.340   Kr -> 0.369
Xe -> 0.410   **Rn -> 0.417**
CH_4 -> 0.380 N_2 -> 0.364

High difficulty to remove Rn from Xe

Swing adsorption (P,T,V) in optimized adsorbent could be a solution ?

❖ **Radon capture in mixed gases** with continuous circulation

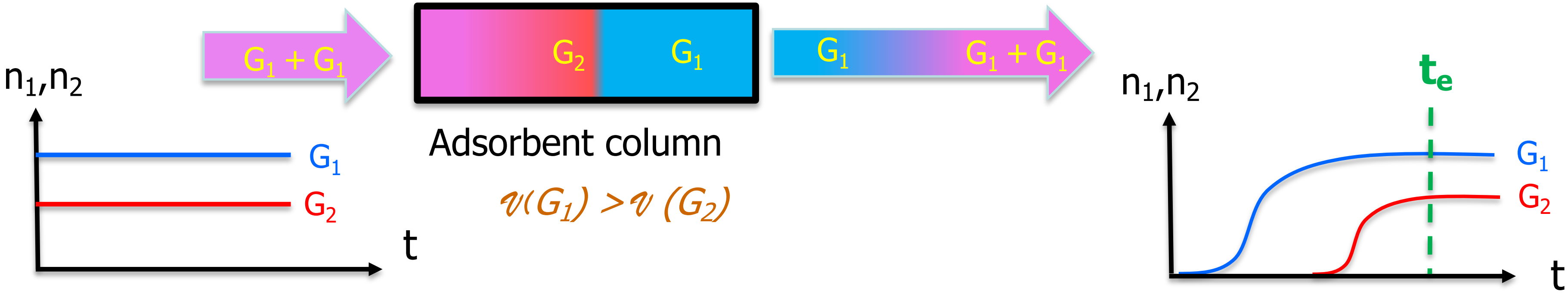
In a chromatographic column each gas component has different velocities

The initial gas composition is destroyed (for some time)

($He + CH_4$, $He + Ar$, $Ar + CH_4$, $Ne + CH_4$, $CF_4 + CHF_3 + C_4H_{10}$)

Initial gas composition

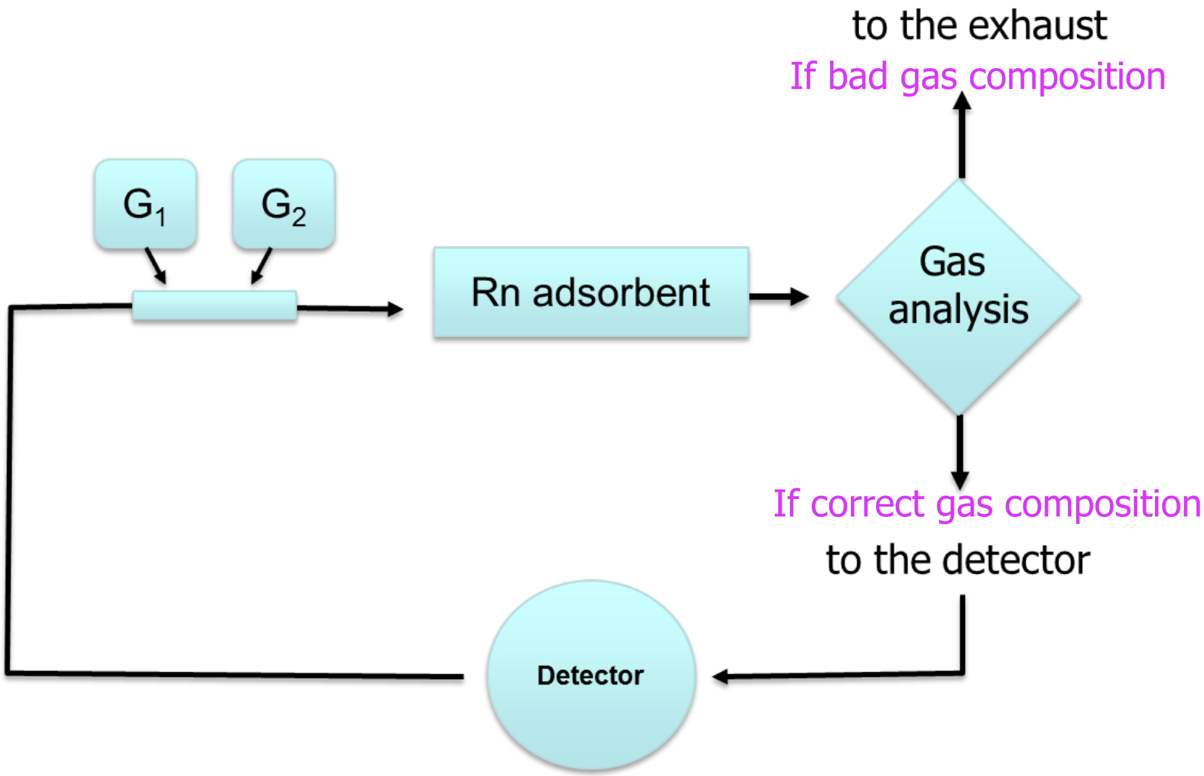
Final gas composition is fonction of time



If no chemical interaction with adsorbent, the initial gas composition is reached after some time (t_e).

We need optimization of adsorbent to enhance Rn capture, and reduce the delay time

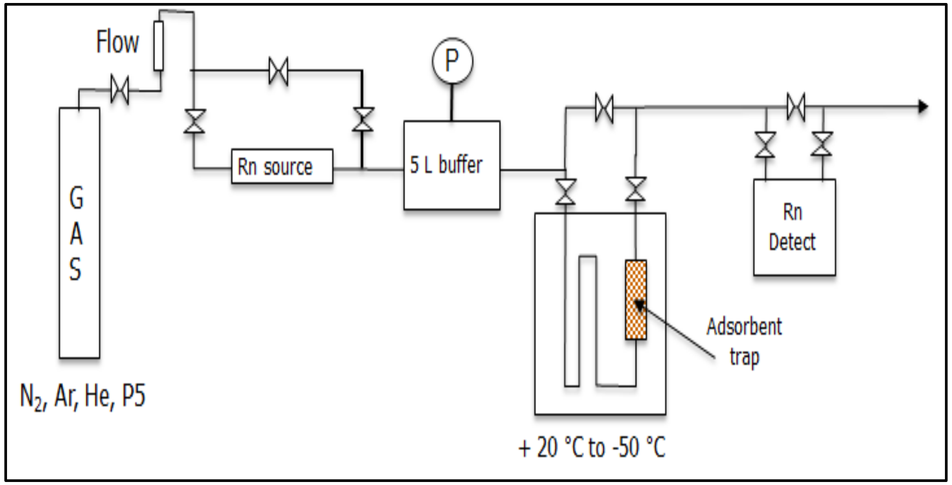
Basic setup


to the exhaust
If bad gas composition
G_1
G_2
Rn adsorbent
Gas analysis
If correct gas composition
to the detector
Detector

Gas analysis : many technologies (IR, UV, catality, semi-conductor, …)

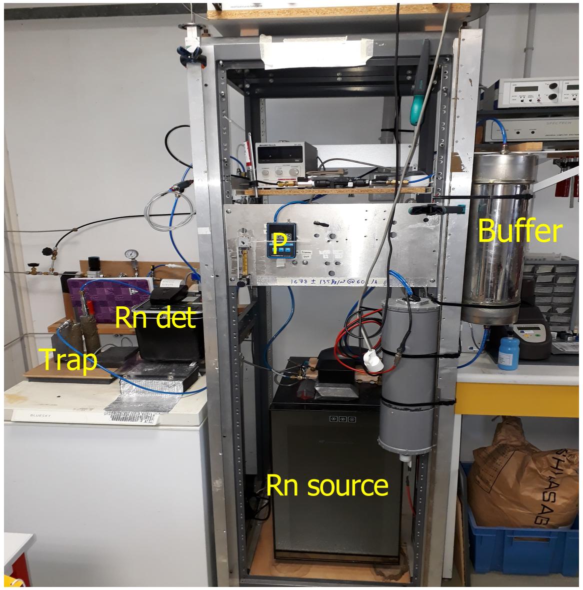
Ex : OLDHAM OLCT 100 – XP- IR
Range 0 – 5 % CH_4

❖ Radon adsorption test bench of CPPM



$$\text{Rn adsorption}\left[\frac{m^3}{kg}\right] = \frac{\text{Rn activity in adsorbent}}{\text{Rn activity in gas}}$$

Activity in adsorbent => Ge spectrometry
Activity in gas => Lucas Cell or RAD7



Performed mesurements

- 60 adsorbents samples measured @ 20, 0, -30, -50 , - 80 °C
- Carrier gases used N_2, He, Ar,
- Collaboration with physical-chemist
  => microscopic adsorbent properties

Current tests and projets

- Rn adsorption in Ar +CH_4, Ne + CH_4 -> Marie Cécile
- Rn adsorption in CF_4+CFH_3+Isobut -> MIMAC (Daniel)
- Rn adsorption in Xe -> R2D2 (big challenge)

For special gases (Ne, Xe, CF_4,…), a closed circuit is required

Summary

- Radon can be capture in microporous adsorbents with high efficiency
- Competition between Rn and carrier gas need new optimized materials
- Cleaning of gas mixture is possible but we need a more in-depth study.
- A radon adsorption facility exist at CPPM (Marseille) for optimization of radon capture in different gases and materials.

→ Several studies in progress or in project

Radon mitigation: Strategies

- Electrophoretic radon removal
  - Based on the first ionisation energy, exploiting favorable ion charge-exchange dynamics.

	First ionization Energy (eV)
Rn	10.4875
Xe	12.14
Ne	21.56
CH_4	12.61
F	17.42
Ar	15.75
C_3F_8	13.38

  - By comparing the energy, in collision with xenon ions, radon will be efficiently ionized via charge transfer: $Xe^+ + Rn \rightarrow Xe + Rn^+$

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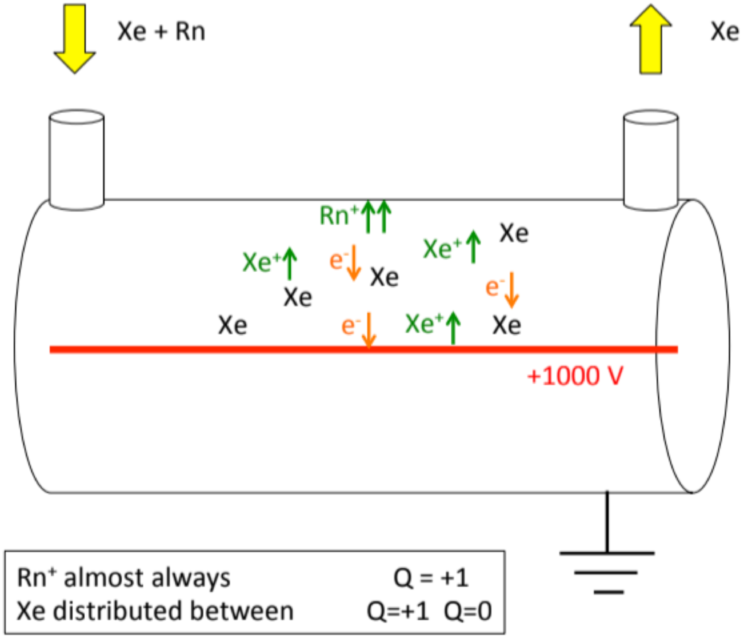

Rn⁺ almost always	Q = +1
Xe distributed between	Q=+1 Q=0

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Distillation

Thermodynamic properties:

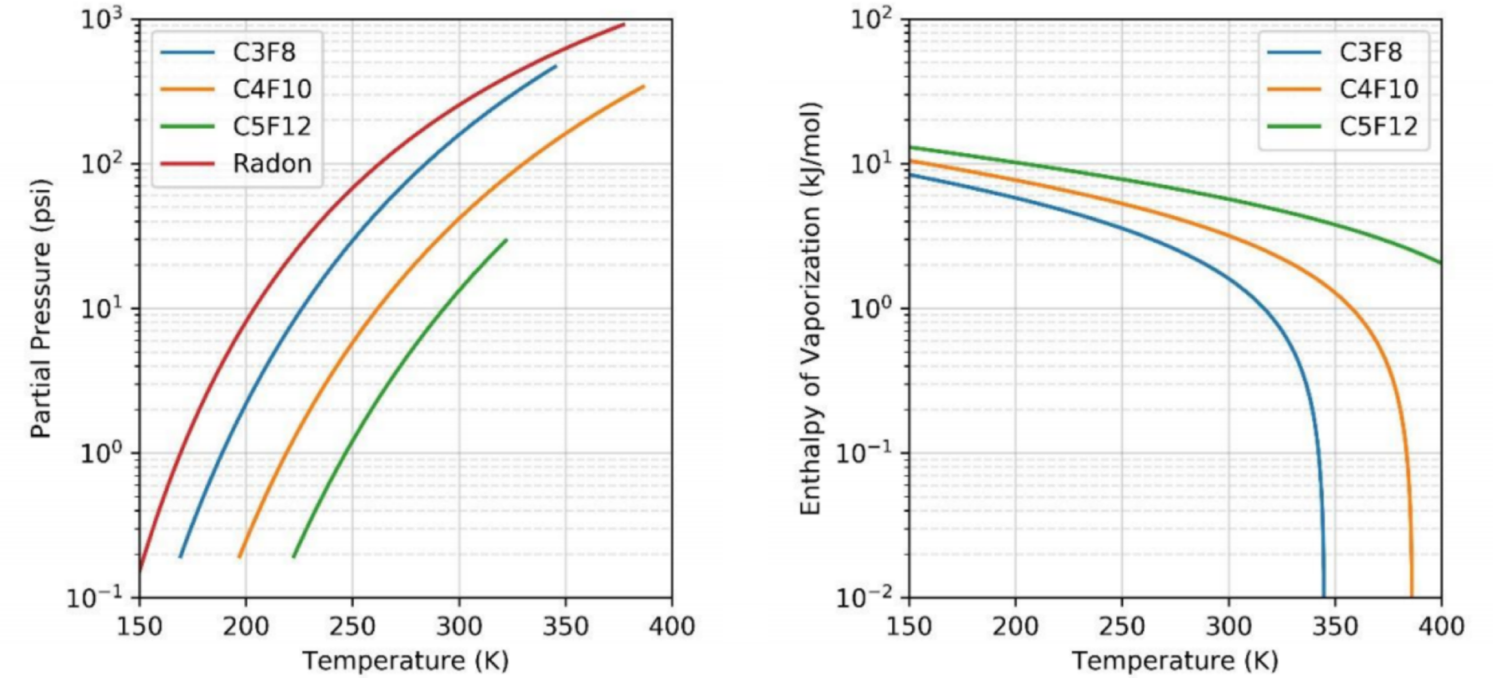
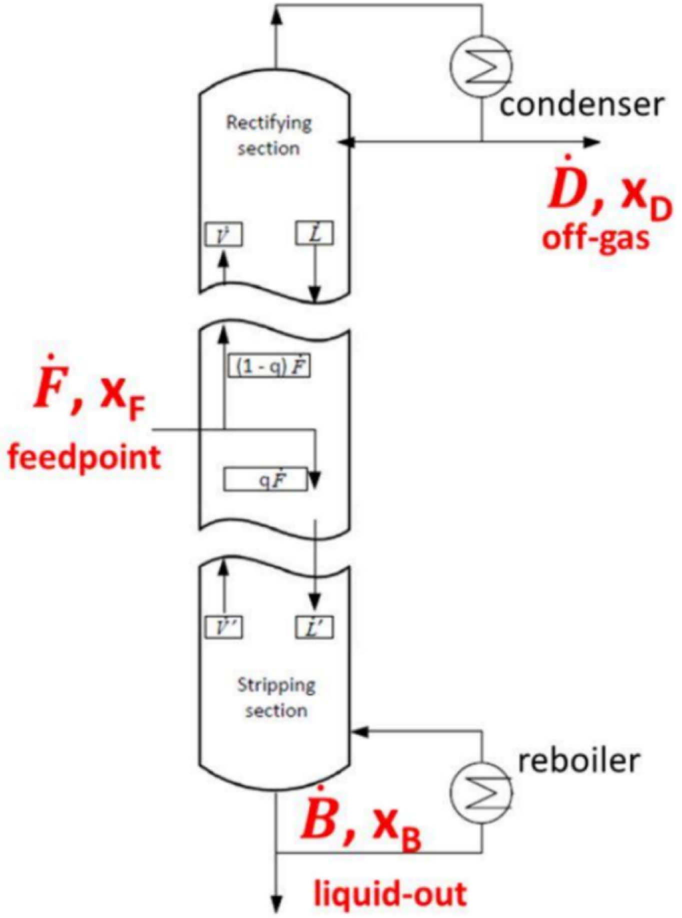


Figure 1: (left) Vapour pressures of Radon and fluorocarbons against temperature and (right) enthalpy of vaporization at saturation of fluorocarbons against temperature.

Distillation



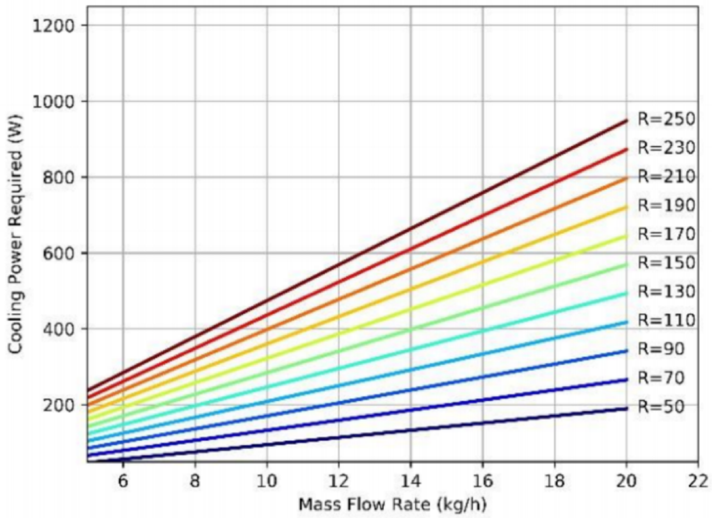
The required heating power and the required cooling power depend on:

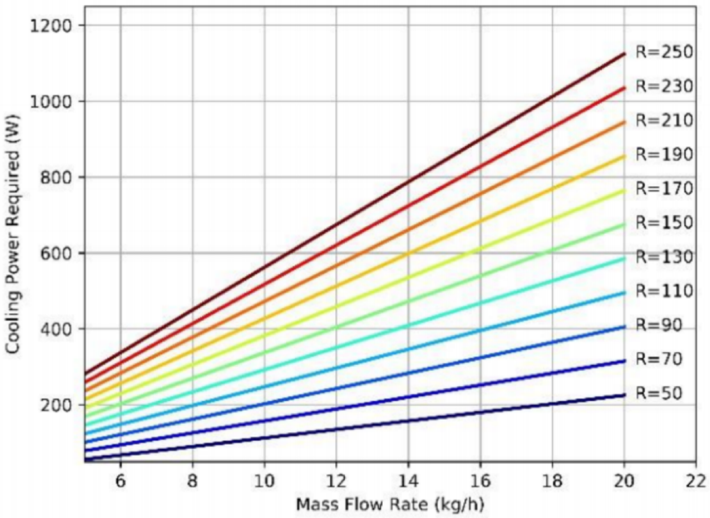
- the vapor flow from the stripping (bottom) section
- the liquid flow from the rectifying (top) section
- the enthalpy of vaporization, plotted for different temperatures

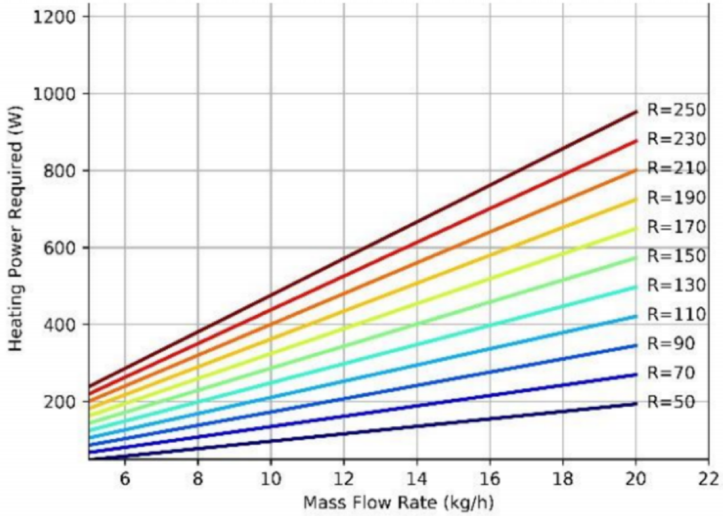
These calculations assume a gas feed into the column at:

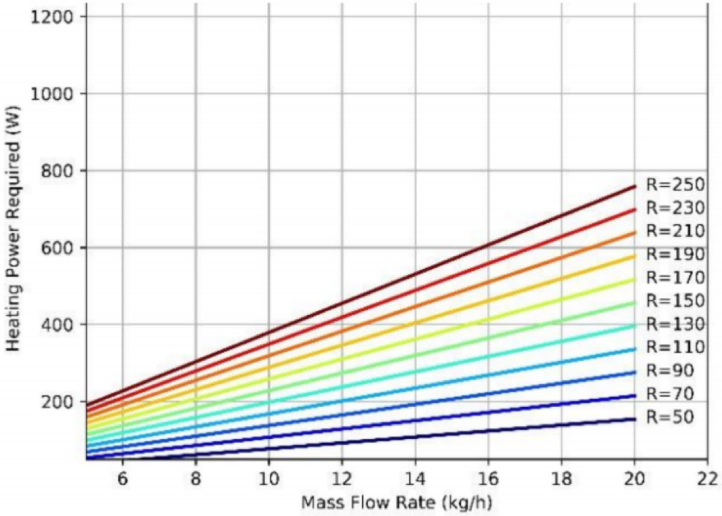
- saturation temperature and pressure
- no heat loss to the surroundings
- flow rate into the column
- the reflux ratio

Distillation









Distillation

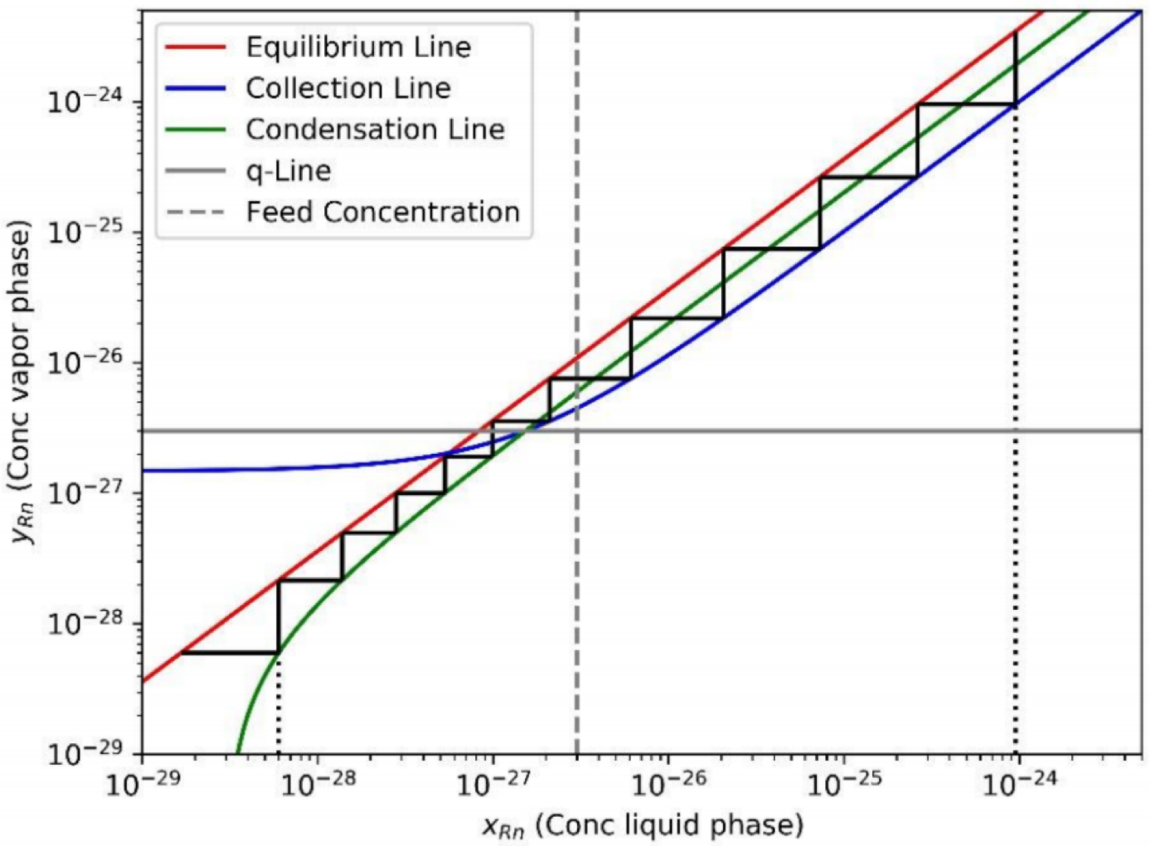


Figure 5: McCabe Thiele diagram for distillation of Radon from C_4F_{10}, with a gaseous feed, and a reflux ratio of 200. The number of theoretical stages is 11.

Distillation

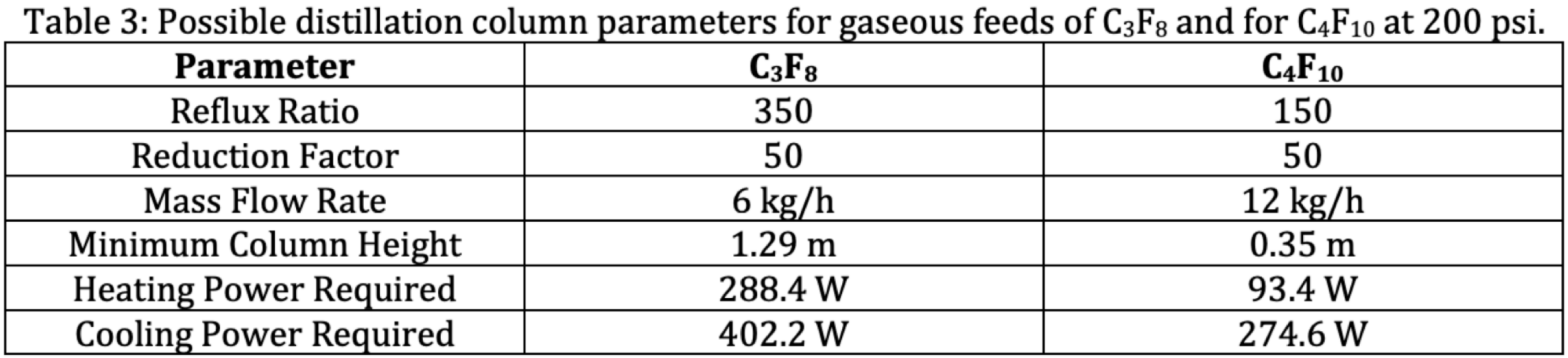


Table 3: Possible distillation column parameters for gaseous feeds of C_3F_8 and for C_4F_{10} at 200 psi.

Parameter	**C_3F_8**	**C_4F_{10}**
Reflux Ratio	350	150
Reduction Factor	50	50
Mass Flow Rate	6 kg/h	12 kg/h
Minimum Column Height	1.29 m	0.35 m
Heating Power Required	288.4 W	93.4 W
Cooling Power Required	402.2 W	274.6 W

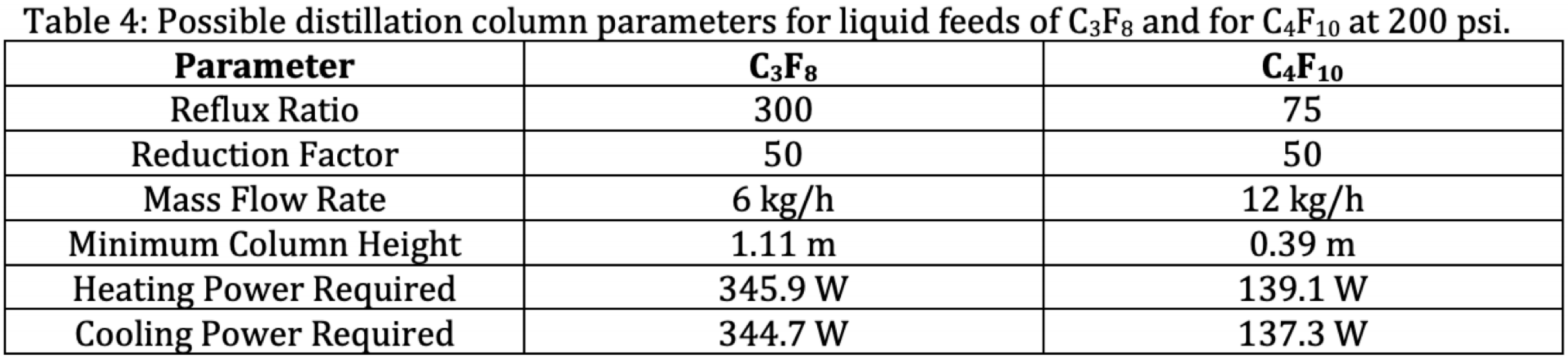


Table 4: Possible distillation column parameters for liquid feeds of C_3F_8 and for C_4F_{10} at 200 psi.

Parameter	**C_3F_8**	**C_4F_{10}**
Reflux Ratio	300	75
Reduction Factor	50	50
Mass Flow Rate	6 kg/h	12 kg/h
Minimum Column Height	1.11 m	0.39 m
Heating Power Required	345.9 W	139.1 W
Cooling Power Required	344.7 W	137.3 W

Distillation

- **Summary:**
  - Simulations with McCabe method done
  - Exploring stripping column to improve factor reduction
  - Compare the 2 models
  - CFI funded to build the column
  - Start this summer
- **Goal and time lines:**
  - Distillation ready by December 2019/ beginning of next year
  - Paper to be published with the code available