

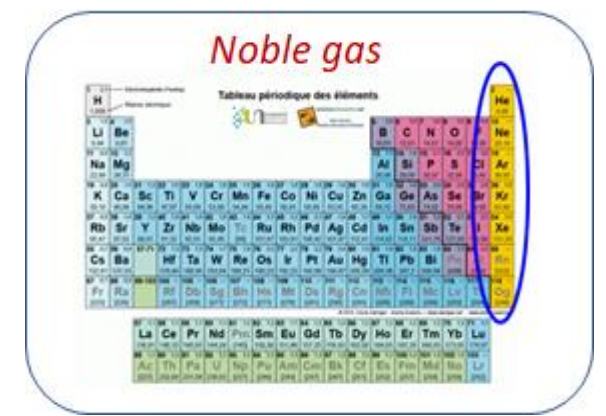
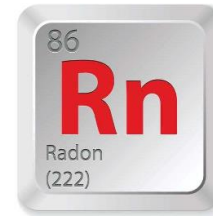
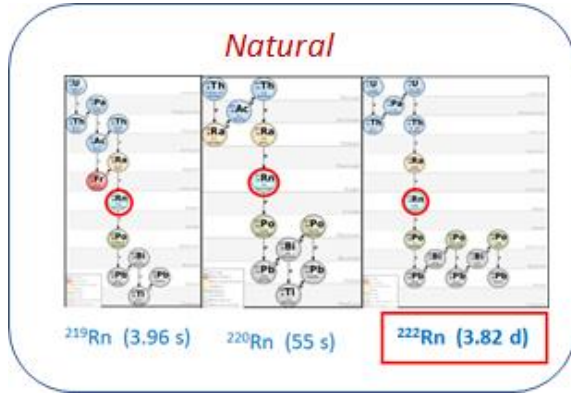
Study and development of new radon adsorbents

Update of the IRENE Project

(Innovative materials for Extreme radon capture)

LRT 2026, York
Hichem Tedjditi

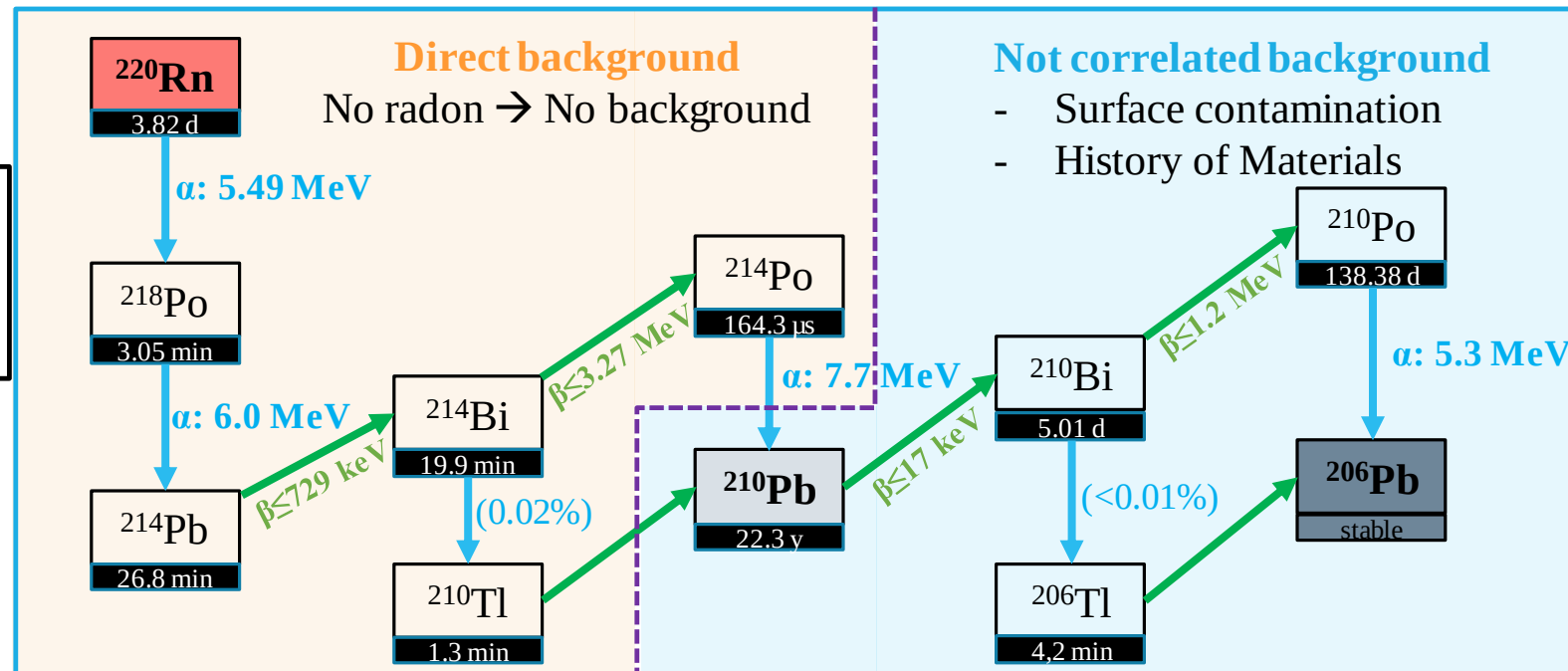
23/09/2026

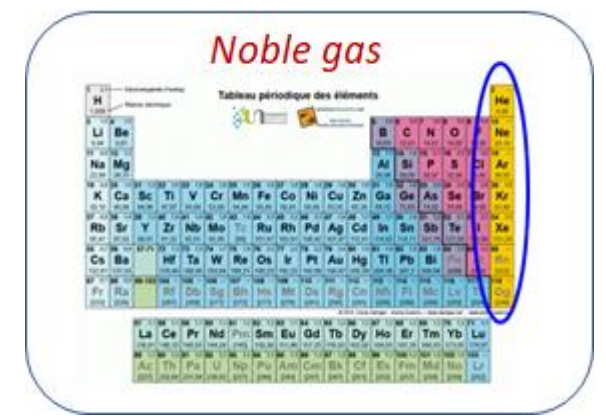
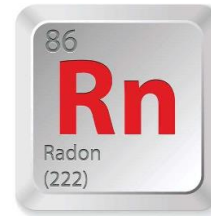
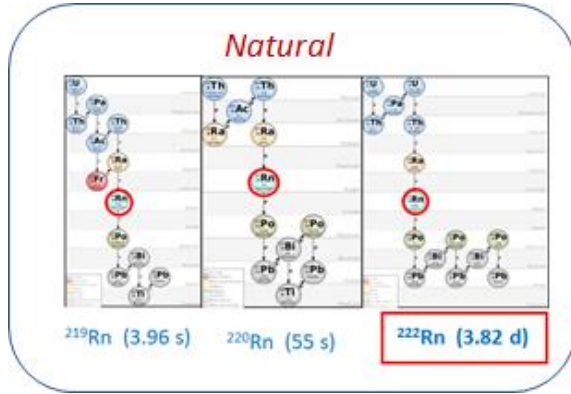


Natural, Radioactive, Noble gas from the U and Th chains

- Easy to transport, complicated to capture
- Short half-life, high intrinsic activity

→ α from 5 to 8 MeV
→ $\beta \leq 3.27$ MeV
→ $\gamma \leq 3.18$ MeV



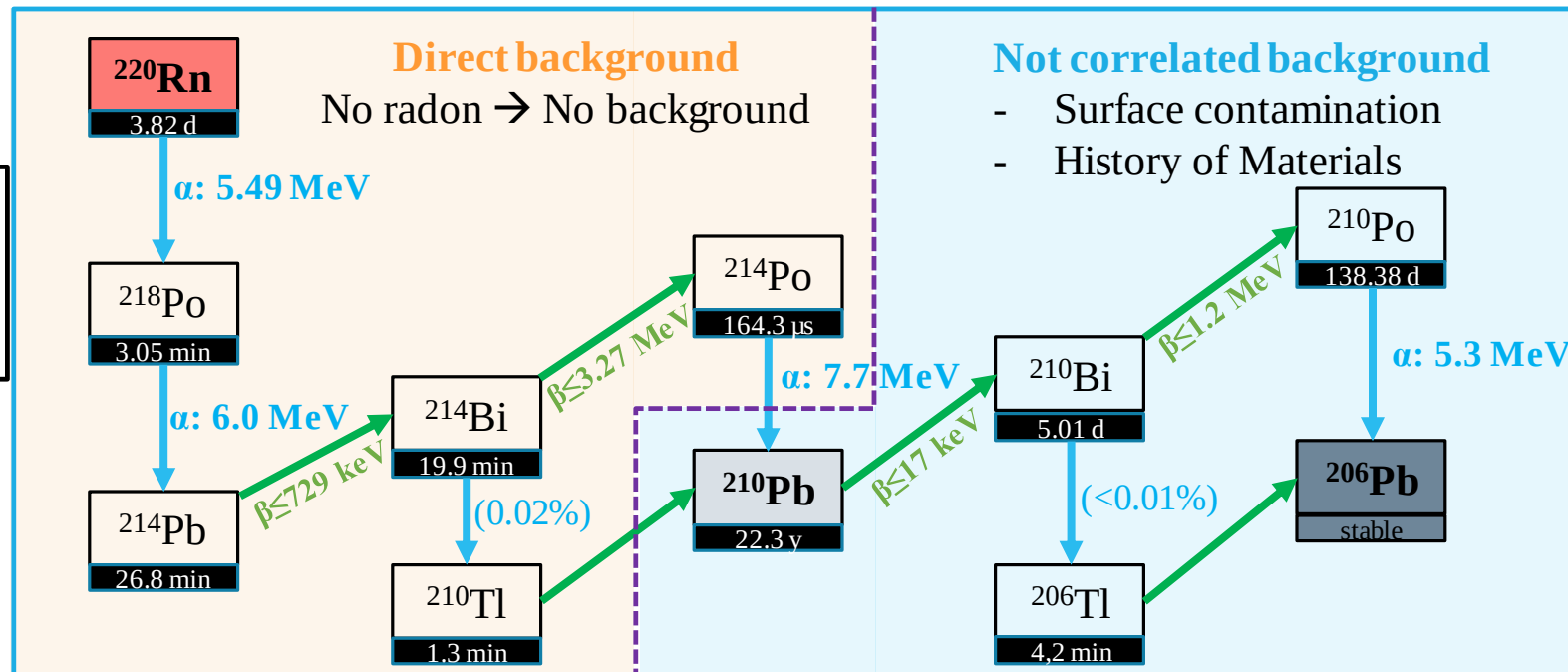


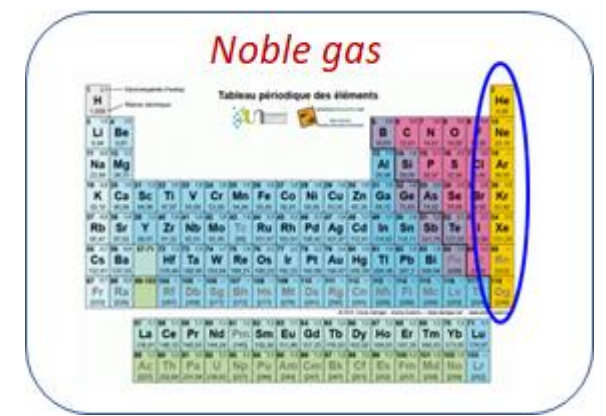
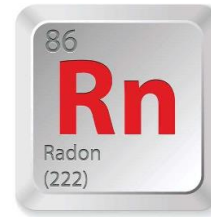
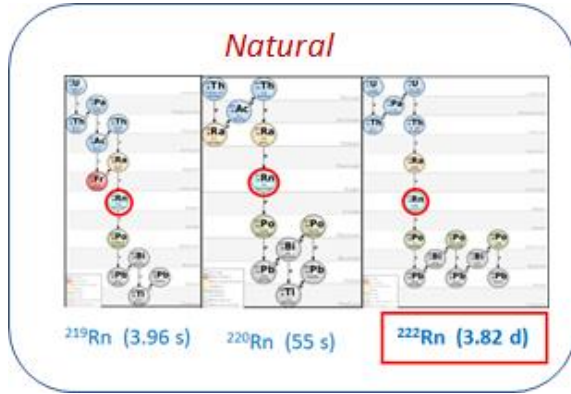
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from the U and Th chains**

Emanation

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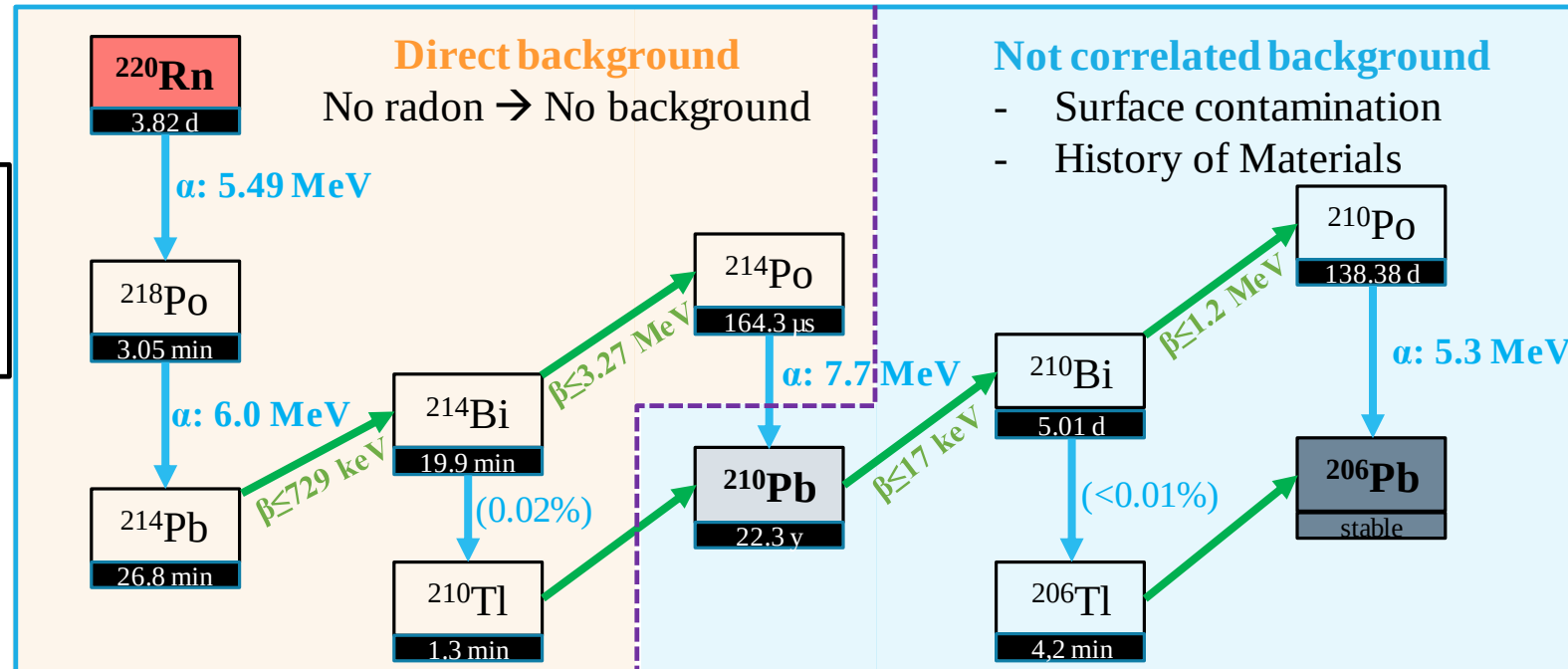
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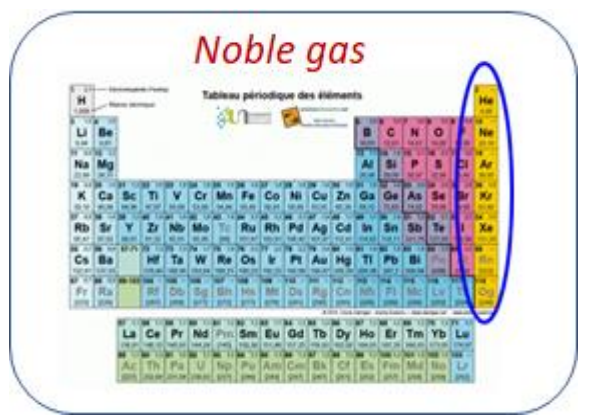
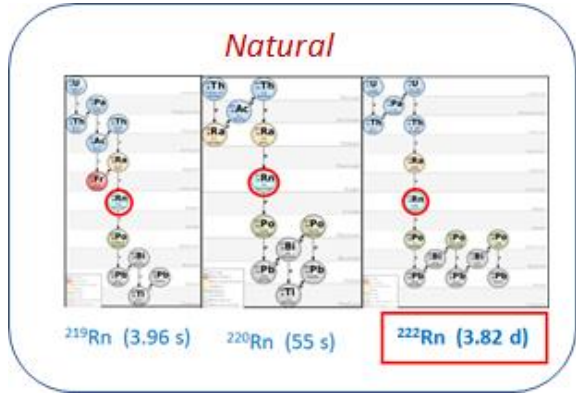
Emanation

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Adsorption

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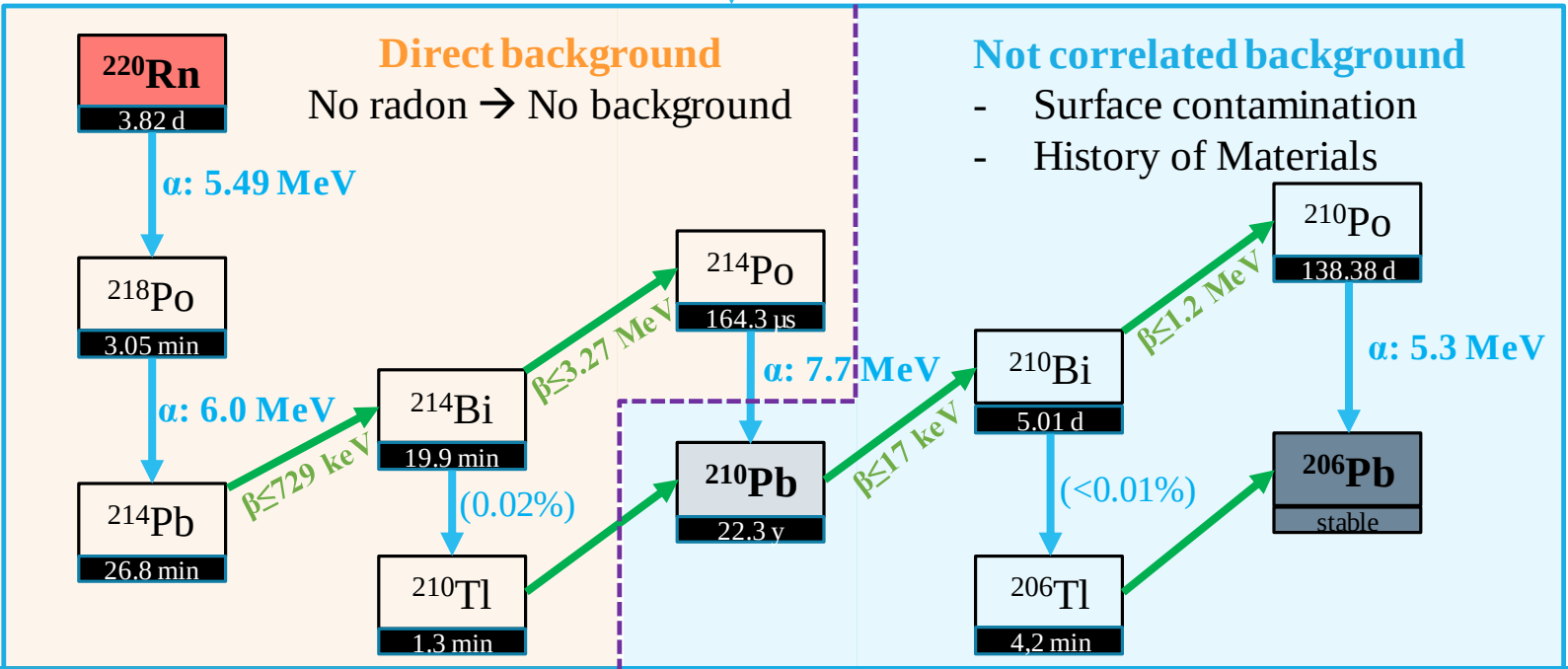
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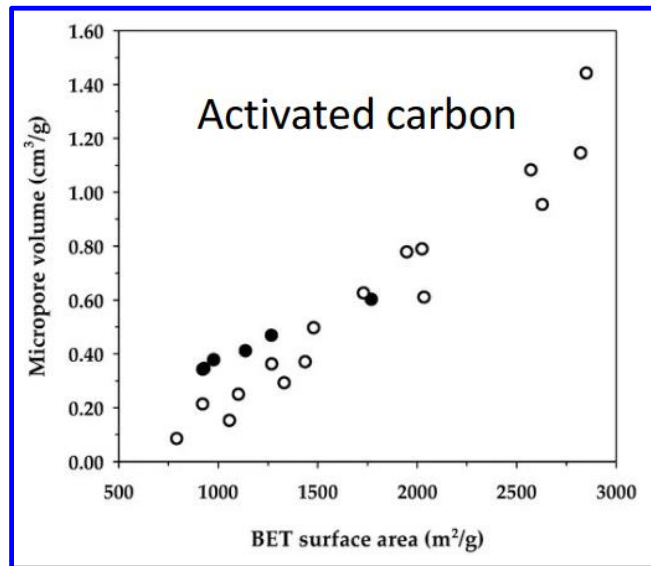
Rn is a Noble gas:

- No chemistry → Physical process

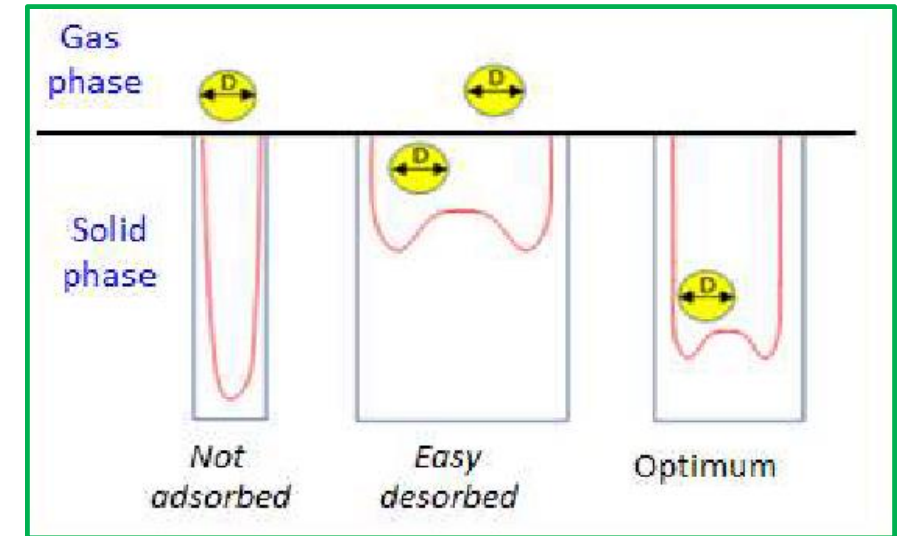
Physical adsorption:

→ **Surface** capture by Van der Waals forces

→ Use of porous materials: very high surface materials, up to 4000m²/g

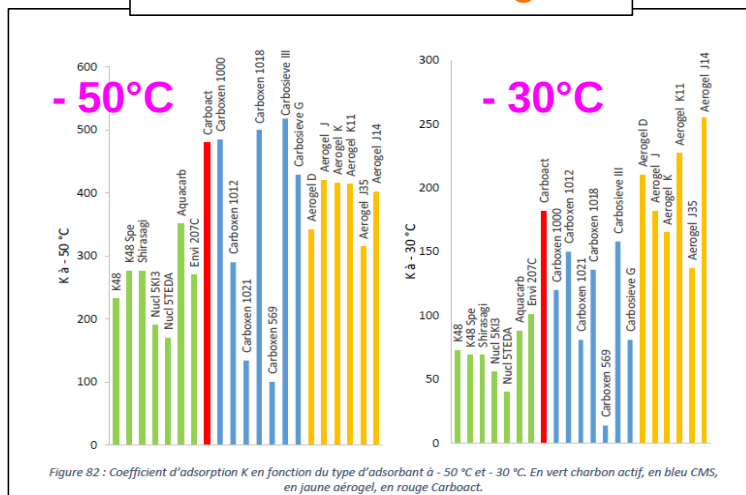


Need to optimized Porosity



→ 2015 : Study of Rn capture in 50 commercial or research microporous materials (SuperNEMO)

AC CMS Aerogel



Adsorption @ -50°C and -30°C in AC, CMS, Aerogels

Optimal porosity:

- 0.5 – 0.7 nm (Rn 0.4 nm)

Small effect on the chemical composition (Sulphur)

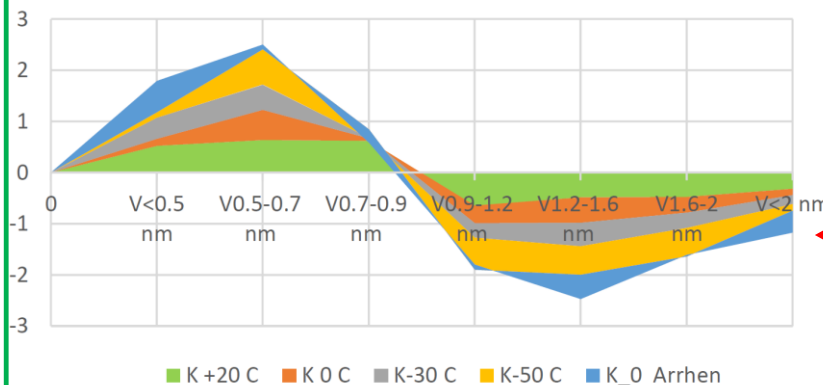
Micro porosity from 0.5 to 2 nm: IJL

Échantillons	Sect N ₂ (m ² /g)	V _t < 0.5 nm (cm ³ /g)	V _{0.5-0.7 nm} (cm ³ /g)	V _{0.7-0.9 nm} (cm ³ /g)	V _{0.9-1.2 nm} (cm ³ /g)	V _{1.2-1.6 nm} (cm ³ /g)	V _{1.6-2 nm} (cm ³ /g)	V _{2-2.2 nm} (cm ³ /g)	V _{>2 nm} (cm ³ /g)
Carbosieve SIII (1)	1062	0,076	0,233	0,062	0,018	0,020	0,000	0,308	0,102
Carboxen 1000 (2)	812	0,064	0,161	0,044	0,001	0,000	0,000	0,225	0,045
Carboxen 569 (3)	299	0,074	0,011	0,000	0,000	0,000	0,000	0,085	0,000
K48 (4)	799	0,074	0,138	0,034	0,033	0,032	0,006	0,212	0,105
Nuclearcarb 208C STEDA (5)	1298	0,053	0,136	0,084	0,087	0,106	0,044	0,189	0,321
SHIRASAGI G2x4 (6)	1383	0,051	0,161	0,096	0,090	0,103	0,033	0,212	0,322
Carboact (7)	1096	0,077	0,206	0,053	0,033	0,048	0,022	0,283	0,156
Envirocarb 207C (8)	1073	0,075	0,181	0,058	0,046	0,050	0,011	0,256	0,165
K48 (9)	793	0,078	0,137	0,026	0,034	0,034	0,005	0,215	0,099
Nuclearcarb 208 SKI3 (10)	1315	0,057	0,145	0,081	0,084	0,110	0,046	0,202	0,321
Carboxen 1012 (11)	1140	0,074	0,145	0,054	0,076	0,078	0,016	0,219	0,223
Carboxen 1021 (12)	585	0,083	0,049	0,020	0,037	0,026	0,017	0,132	0,100
Carboxen 1016 (13)	77	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000
Carboxen 1018 (14)	804	0,061	0,155	0,045	0,010	0,024	0,014	0,216	0,092
Aquacarb 207C (15)	1040	0,063	0,165	0,066	0,044	0,052	0,019	0,228	0,181
Carbosieve G (16)	1273	0,074	0,183	0,112	0,046	0,050	0,025	0,257	0,233

Chemical composition: CINAM

Échantillons	% N	% C	% H	% S
Carbosieve SIII (1)	0,5	97,3	0,1	0,0
Carboxen 1000 (2)	0,3	92,6	0,5	5,1
Carboxen 569 (3)	0,4	94,3	0,1	3,8
K48 S (4)	0,3	89,8	1,3	0,0
Nuclearcarb 208C STEDA (5)	1,7	91,6	1,3	0,0
SHIRASAGI G2x4 (6)	0,5	94,9	0,8	0,0
Carboact (7)	0,3	92,5	1,0	0,0
Envirocarb 207C (8)	0,3	91,6	0,9	0,0
K48 (9)	0,3	90,4	1,2	0,0
Nuclearcarb 208 SKI3 (10)	0,3	86,7	0,8	0,0
Carboxen 1012 (11)	0,1	97,3	0,6	0,0
Carboxen 1021 (12)	0,4	95,8	0,2	2,1
Carboxen 1016 (13)	0,1	99,7	0,1	0
Carboxen 1018 (14)	0,1	94,9	0,7	2,2
Aquacarb 207C (15)	0,2	90,8	1,7	0,0
Carbosieve G (16)	0,0	87,1	1,3	0,0

Correlation Factor Adsorption v.s. porosite



→ 2015 : Study of Rn capture in 50 commercial or research microporous materials (SuperNEMO)

Optimal porosity:

- 0.5 – 0.7 nm (Rn 0.4 nm)

Small effect on the chemical composition (Sulphur)

→ 2018 : Xenon / Radon adsorption with macromolecular cages: Cryptophane



- Used for the complexing of Xe
- Adjustable size



Atomic Radius		
Gas	Van der Waals (nm)	Covalent
Xe	0.216	0.130
Rn	0.220	0.145

Compétition Xe / Rn

Rn Adsorption (CPPM)

Adsorbant	K (m ³ /kg) @-30°C
Cryptophane A/MCM-41	103,2 ± 25
AC K48 special	66,6 ± 5

Xe Adsorption (MADIREL)

Echantillon	Adsorption Xe (mmol/g)
Cryptophane A (MCM-41)	0.176 ± 0.010
Cryptophane A (SBA-15)	0.123 ± 0.006
Charbon actif Silcarbon K48	2.31 ± 0.04

13.12

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→ 2020 : Radon adsorption on silver zeolite. <https://doi.org/10.1093/ptep/ptad160>



Three commercial Ag Zeolite

Zeolite	Supplier	Chemical formula	Silver content (wt%)	Pore size (Å)
Ag-ZSM-5	Riogen	$\text{Ag}_{4.8}[(\text{AlO}_2)_{4.8}(\text{SiO}_2)_{91.2}] \cdot 16\text{H}_2\text{O}$	7.9	5.2×5.7 and 5.3×5.6
Ag-13X	Sigma Aldrich	$\text{Ag}_{84}\text{Na}_2[(\text{AlO}_2)_{86}(\text{SiO}_2)_{106}] \cdot x\text{H}_2\text{O}$	35	10×10
Ag-ETS-10	Extraordinary Adsorbents Inc.	$\text{Ag}_{16}[\text{Si}_{40}\text{Ti}_8\text{O}_{104}]$	30	4.9×7.6

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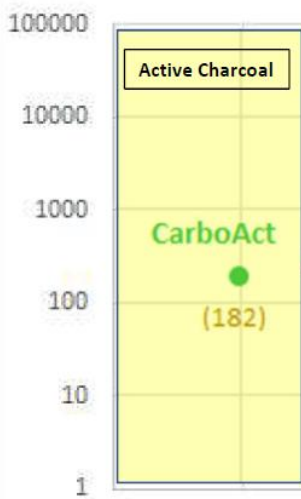
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→ 2020 : Radon adsorption on silver zeolite

$$K = \frac{\text{Rn in the Adsorbent}}{\text{Rn in the Gas}} \quad [\text{m}^3/\text{kg}]$$

m^3/kg Rn capture K factor in N2 @ -30°C



1

1 Reference charcoal (carboAct)

→ 2015 : Study of Rn capture in 50 commercial or research microporous materials (SuperNEMO)

Optimal porosity:

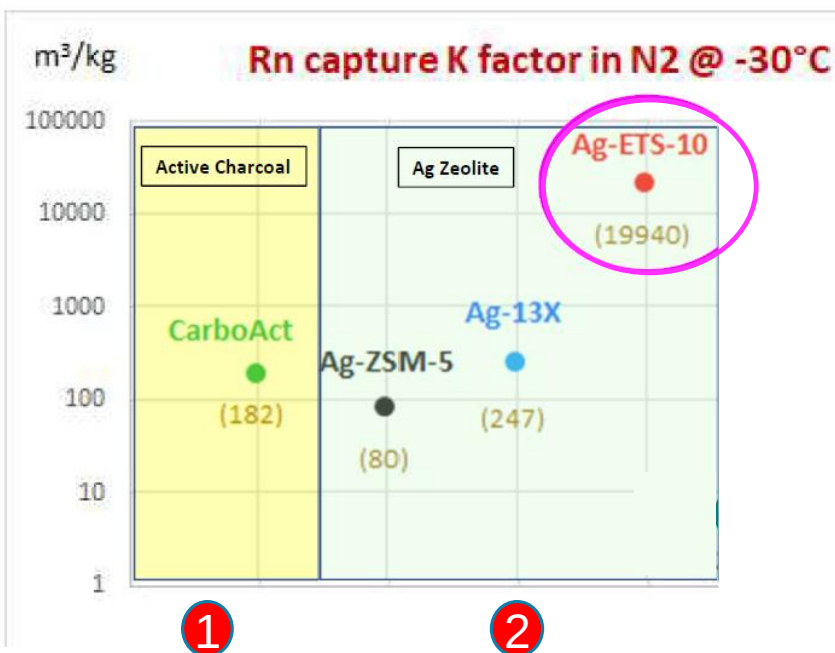
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- Ag-13X
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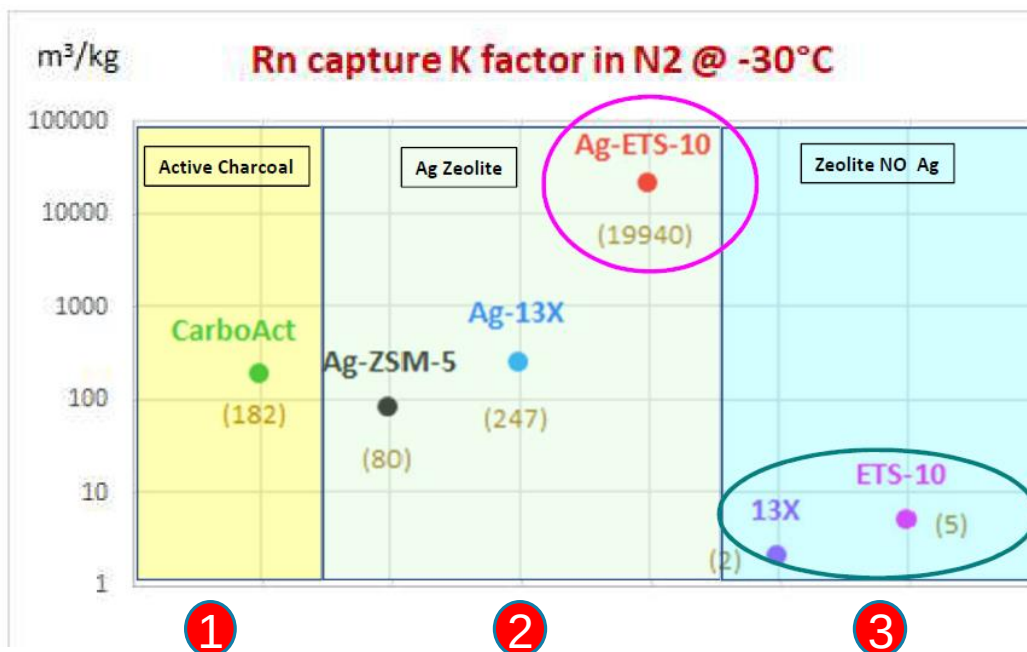
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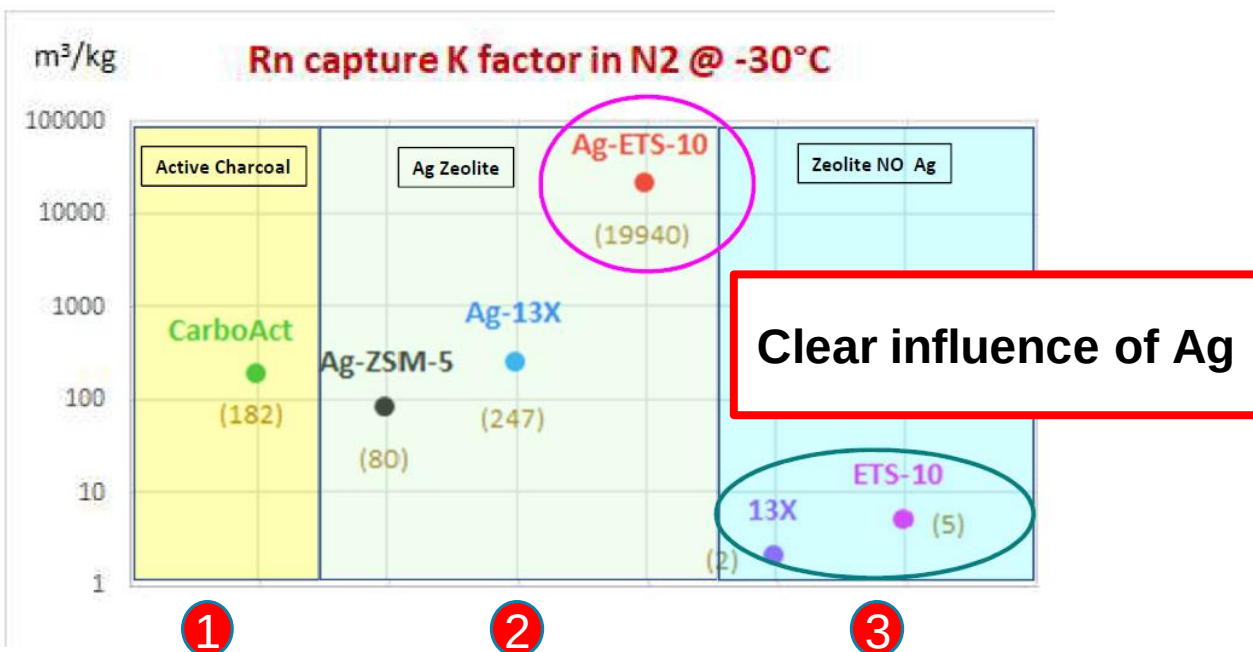
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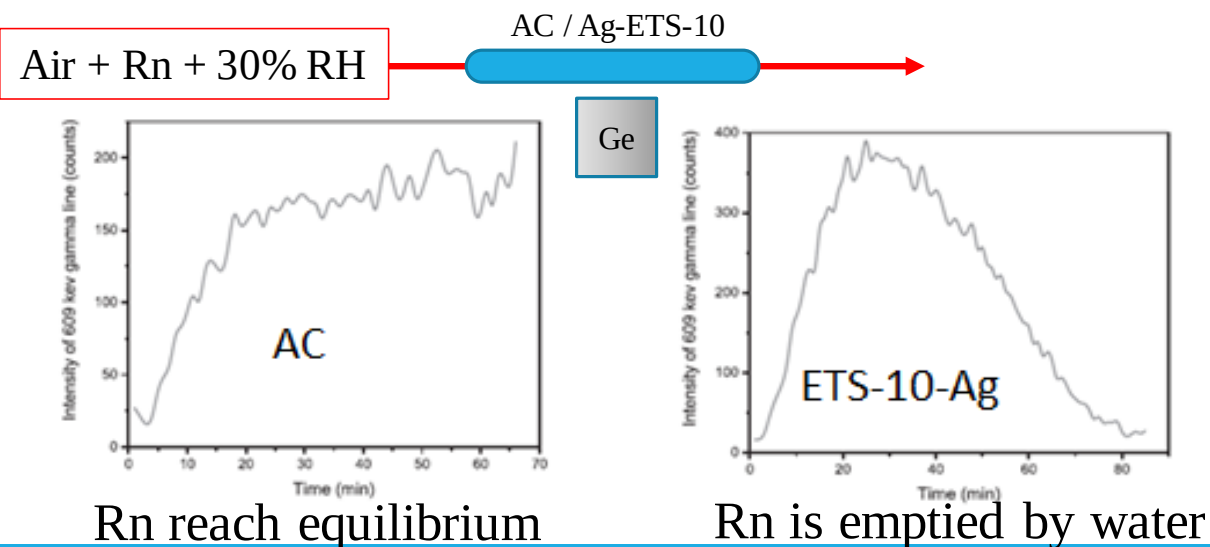
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High ^{226}Ra concentration

Echantillon	^{226}Ra (Bq/kg)
K48	< 0,25
NuclCarb 5TEDA	<0,3
ENvCarb 207C	0,28 +- 0,17
Shirasagi	0,164 +- 0,023
CarboAct	0,0023 +- 0,0019
ETS-10-AG	0,988 +- 0,05

Highly sensitive to H_2O



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Other results

@ room temperature

Sample	Reference	K factor [m ³ /kg]
Ag-ETS-10	Heinitz et al.	3400
Ag-ZSM-5	Heinitz et al.	3500
8 Ag-FER-B	Takeuchi et al.	6500
Ag-ETS-10	10.1093/ptep/	5323.2–5608.3

AC @ 20°C : ~ 10 m³/kg

Very good results but not well understood

Can we do better ?

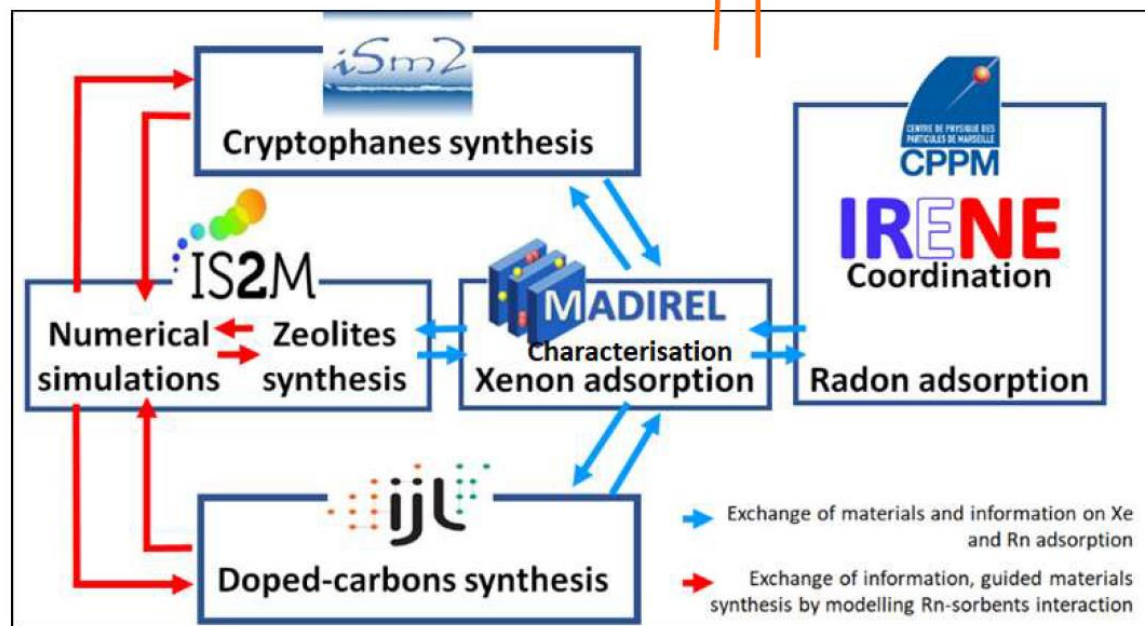
- Higher adsorption
- Improved radiopurity
- Lower sensitivity to water

Innovative materials for Extreme radon capture

Understanding and optimizing the capture of Rn in new materials

Physics Chemist

Part Physic



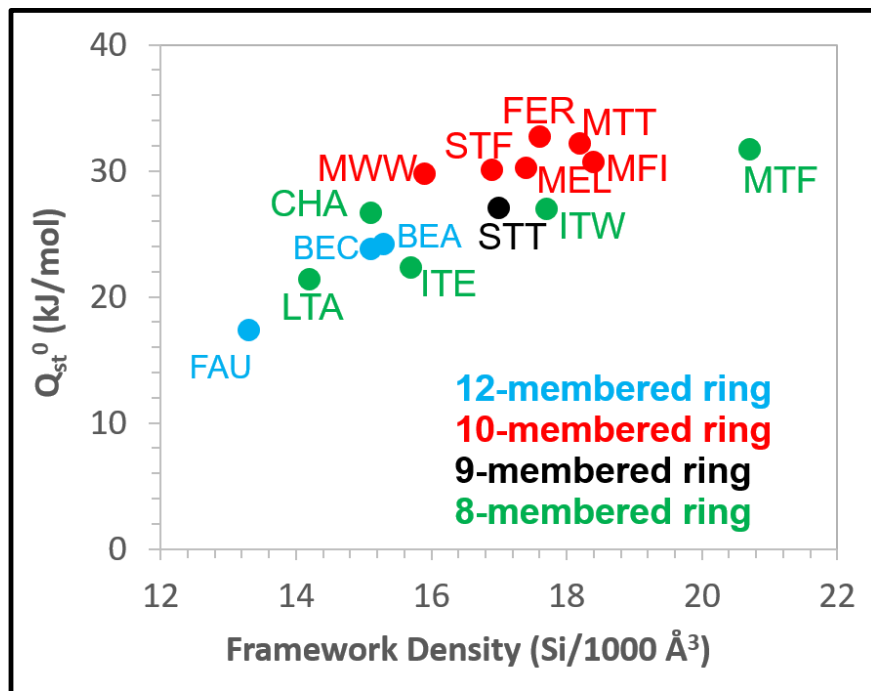
Project started in February 2024

Philosophy:

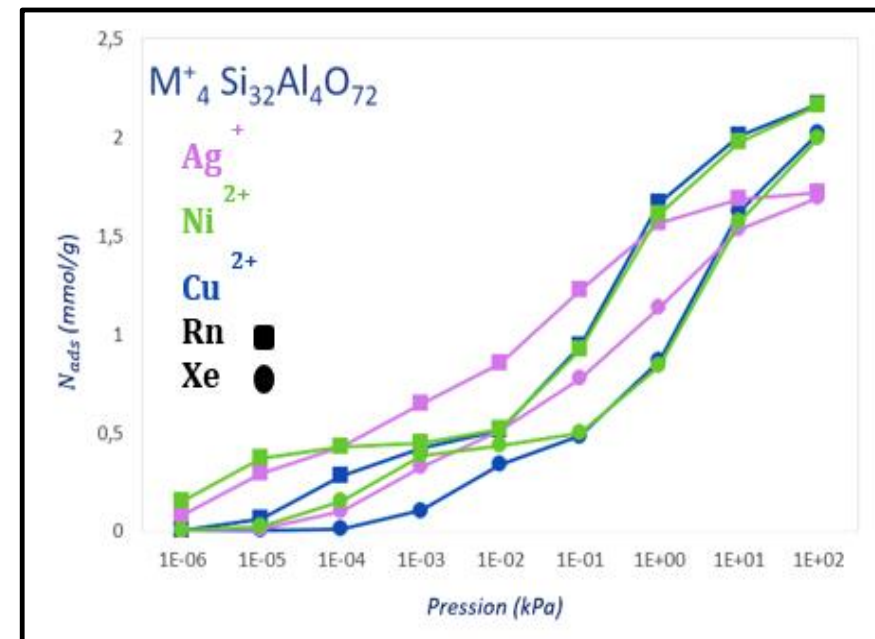
- Feedback between the 5 laboratories
- Modelling as a guide
- 3 families of adsorbents:
 - Zeolites
 - Mol. Cages
 - Carbon based
- Xenon as a reference gas
- Radon capture in N₂, He and Xe

Simulations

Influence of membered ring configuration



Influence of Metal on Rn/Xe adsorption



- Zeolite with 10MR are the best candidate for Rn adsorption
- Cu⁺ Ni²⁺ should perform better than Ag⁺

Synthesis & measurement

Active Charcoal :

- Base Charcoal is Carbio12 G90 with $K = 63,83 \pm 5,3 \text{ m}^3/\text{kg} @ -30^\circ\text{C}$
- Study the effects of the treatments that will be applied before metal doping of the AC:
 - NH_3
 - UREA
 - H_2O_2
 - HNO_3
- Radon adsorption is reduced after the treatment

Radium removed from the Charcoal treated with HNO_3 :

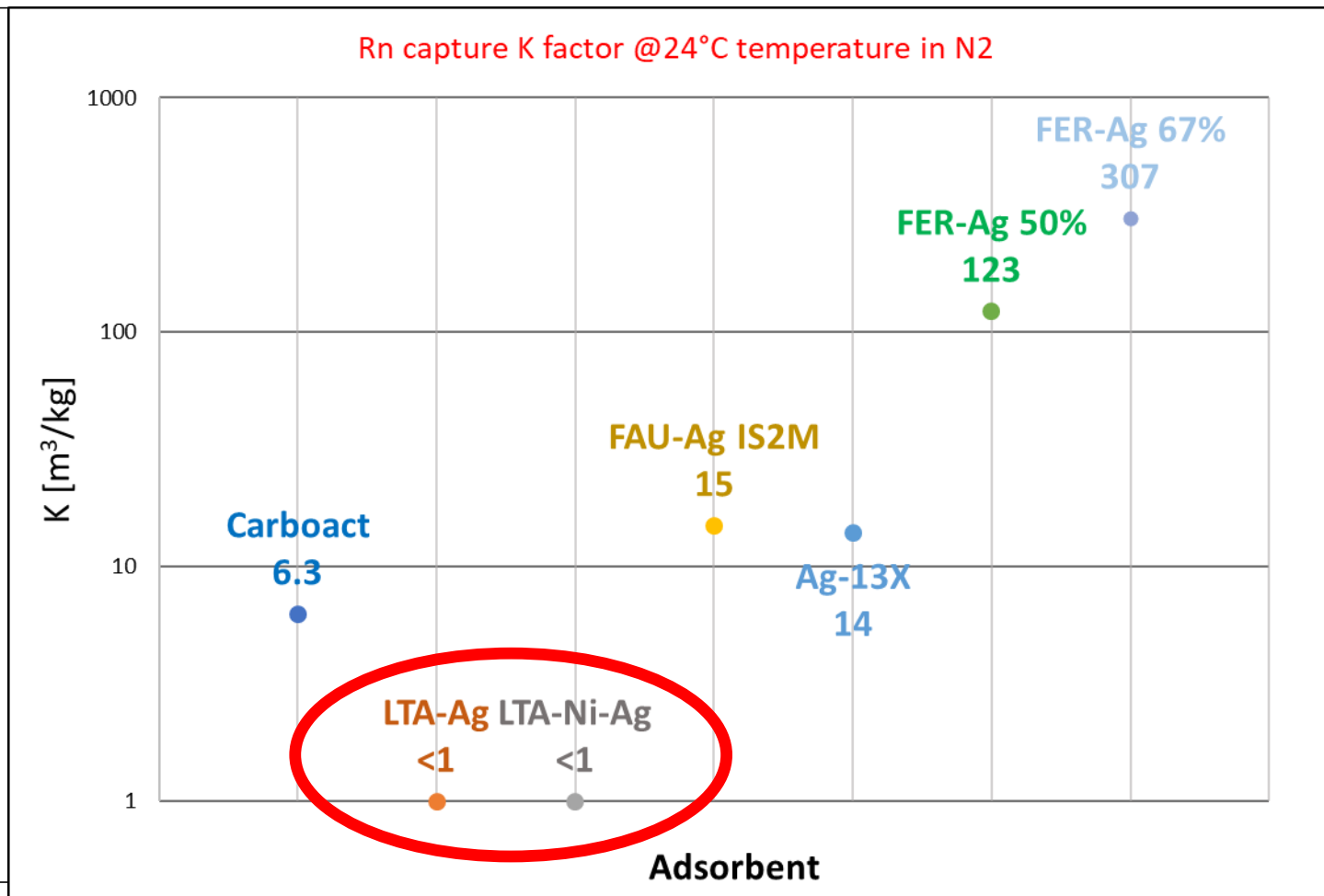
- Base charcoal is Carbio12 G90: $A(\text{Ra}) = 0,24 \pm 0,04 \text{ Bq/kg}$
- Carbio12 G90 treated with HNO_3 : $A(\text{Ra}) < 0,16 \text{ Bq/kg}$

2 silver AC produced, waiting for measurement

Synthesis & measurement

Zeolite synthesis:

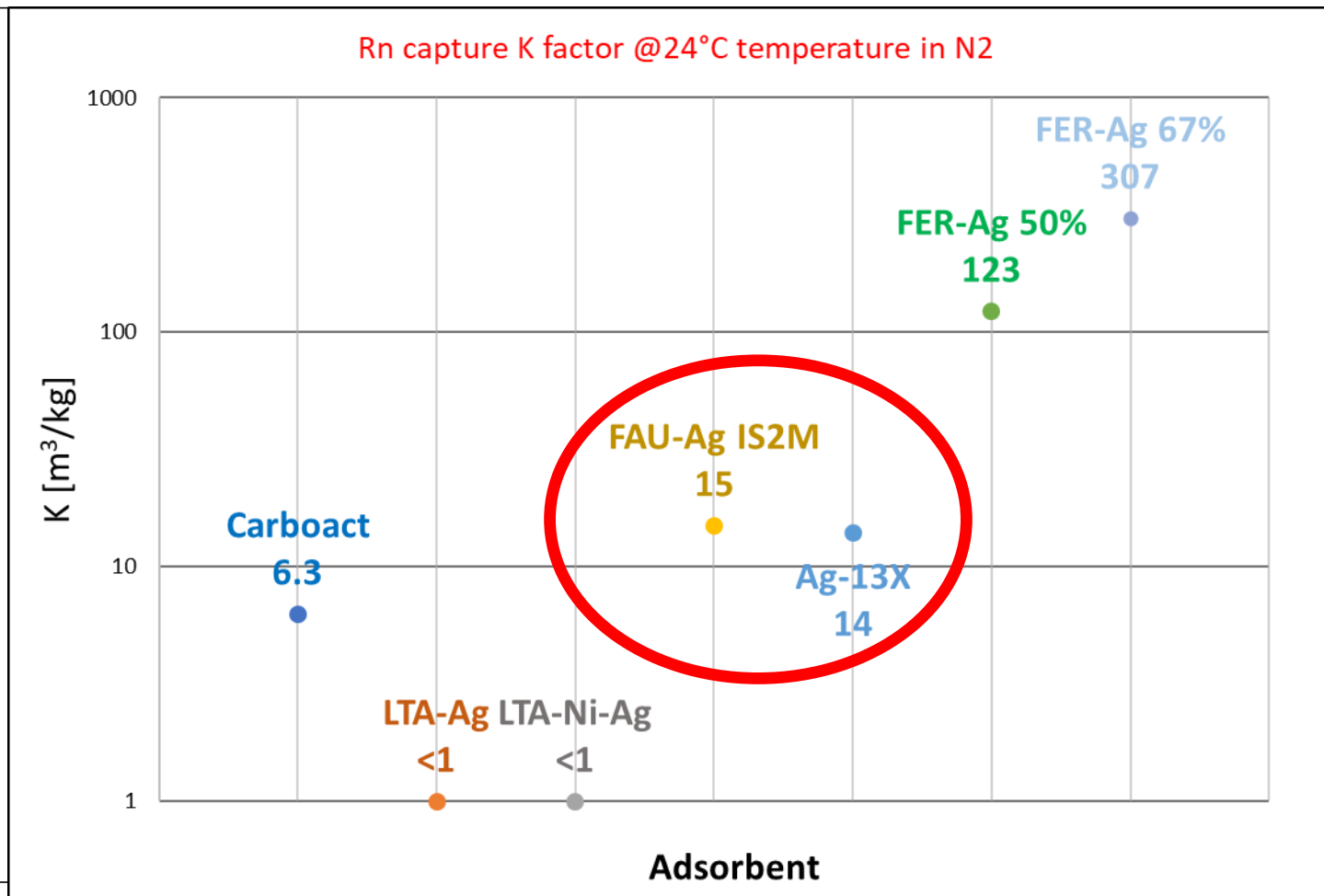
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2. FAU-Ag equivalent to Ag-13X
 - $K(@-30^{\circ}\text{C}) = 293 \pm 56 \text{ m}^3/\text{kg}$
3. FER-Ag exchanged at 50%:
 - $K(@24^{\circ}\text{C}) = 123 \pm 16 \text{ m}^3/\text{kg}$
 - <10x better than standard AC
4. FER-Ag exchanged at 67%:
 - $K(@24^{\circ}\text{C}) = 307 \pm 48 \text{ m}^3/\text{kg}$
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Synthesis & measurement

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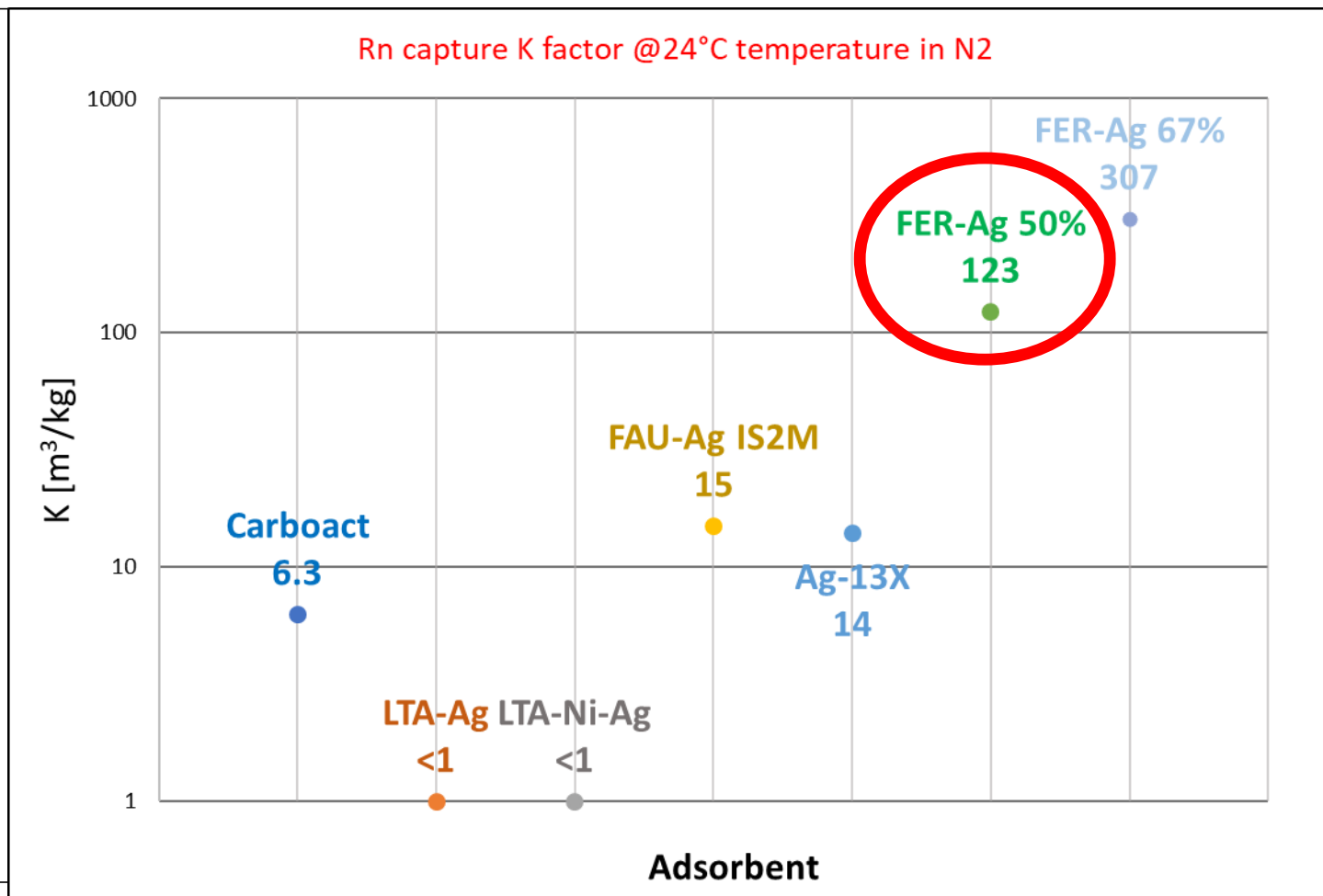
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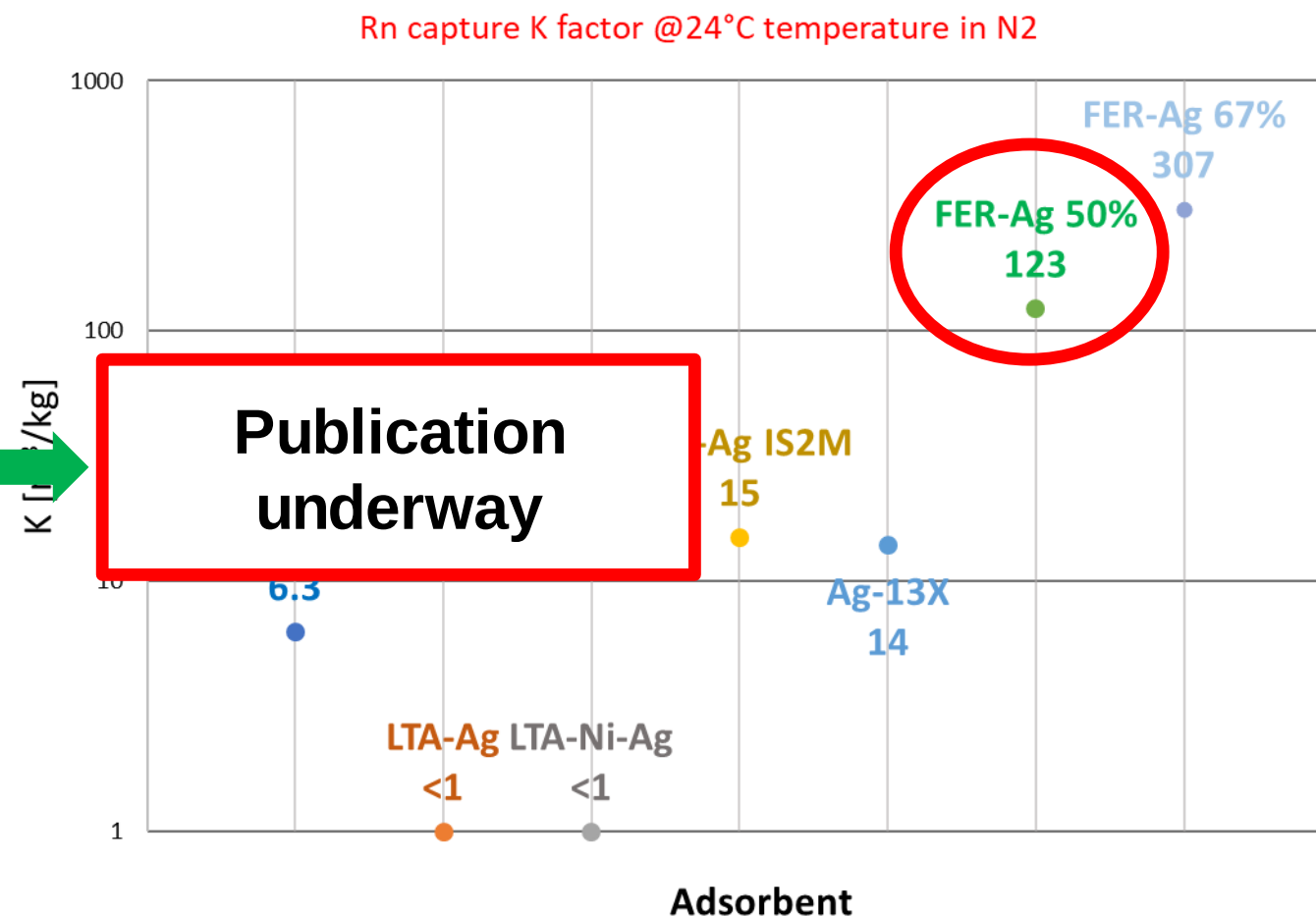
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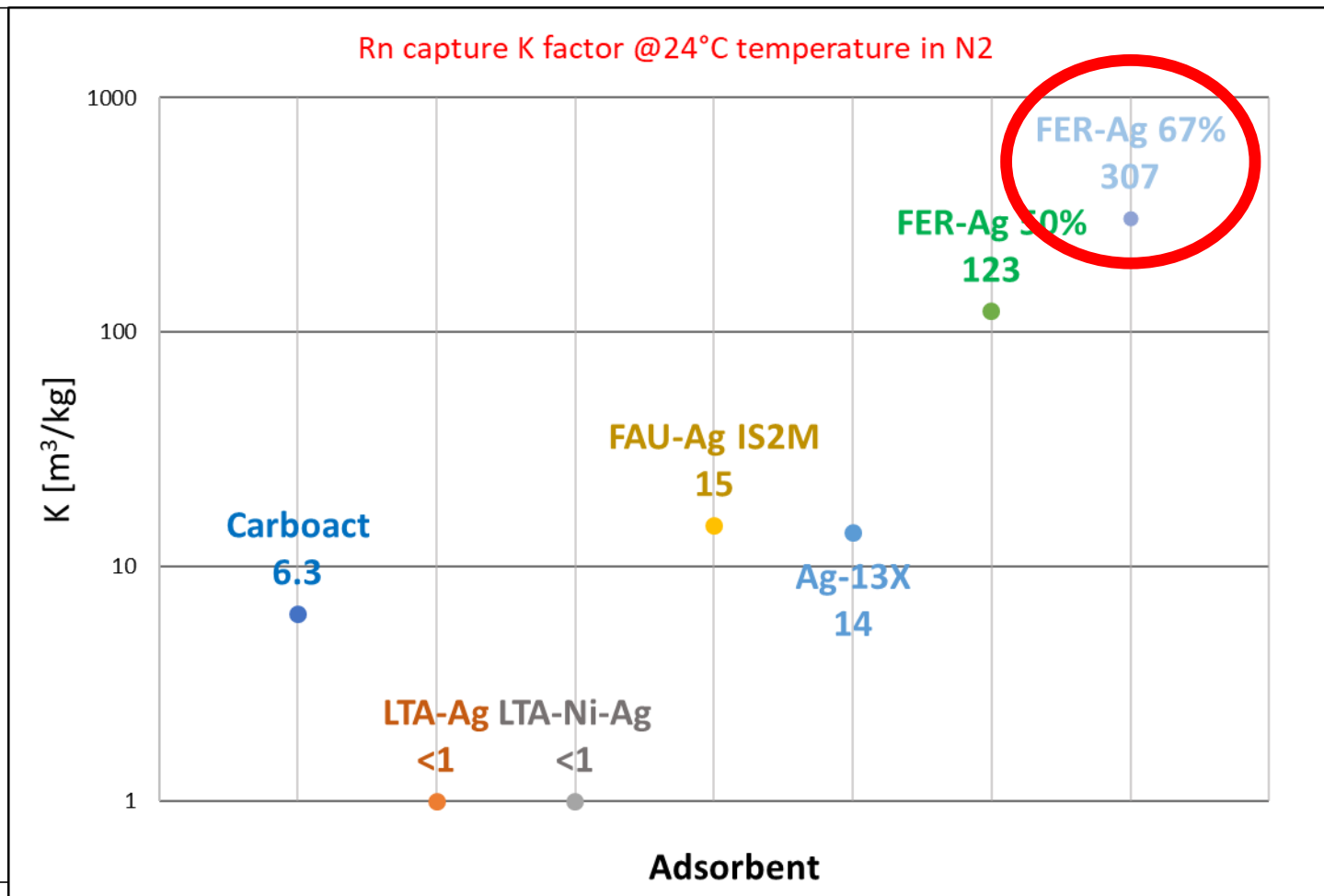
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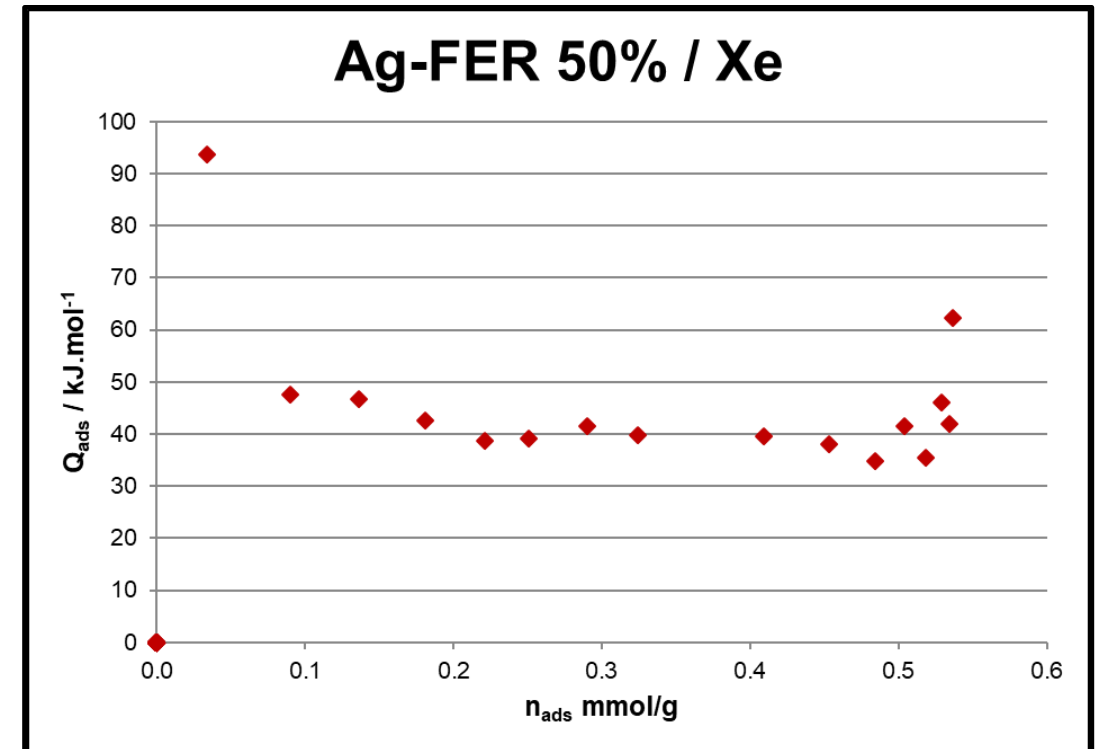
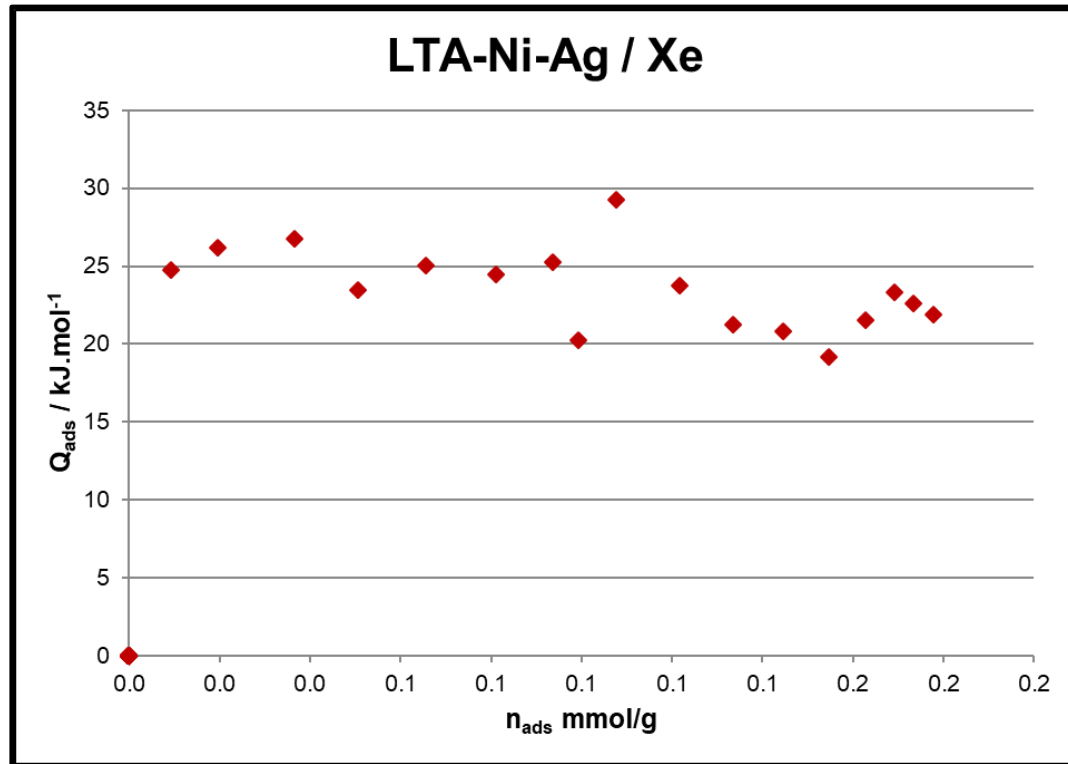
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Xe enthalpy of adsorption measurement

Xe enthalpy of adsorption @30°C measurement for:



→ Zeolite that adsorb well Rn adsorb also well Xe

Conclusion

- The objective of the **IRENE** project is to tackle the problem of radon capture in microporous materials in a scientific and coherent way, thanks to a unique consortium of physical chemists and particle physicists
- **IRENE** has produced new adsorbent doped with silver and other metals while controlling all the step !
- The produced FER-Ag exchanged at 50% showed an adsorption factor **10 times** better than standard AC at room temperature and the publication is underway.
- And the FER-Ag exchanged at 67% showed an adsorption factor **30 times** better than standard AC at room temperature.
- **IRENE** is continuing to produce new adsorbent, Metal doped AC, Cryptophane and Metal doped Zeolite.
- The next step is to measure the radio purity of the produced FER-Ag.
- And also the Radon adsorption factor in Xe of those zeolite.

Thanks for your attention

Back up

Adsorption: K coefficient

Radon adsorption coefficient “K”

K is the volume of radon a sample can capture:

$$\bullet \quad K \left[\frac{m^3}{kg} \right] = \frac{C(Rn)_{sample} [Bq/kg]}{C(Rn)_{gas} [Bq/m^3]}$$

The retention time τ is the time it take for Rn to exit the adsorbent

$$\bullet \quad \tau [s] = \frac{m[kg] * K [m^3/kg]}{\phi [m^3/s]}$$

And the reduction factor **R** is define as:

$$\bullet \quad R = \frac{Rn_{out}}{Rn_{in}} = e^{-\frac{\ln(2)}{T_{1/2}(Rn)} * \tau}$$

K can be expressed as an Arrhenius-type law:

$$\bullet \quad K = A e^{\frac{E}{RT}}$$

K increased exponentially with respect to 1/T

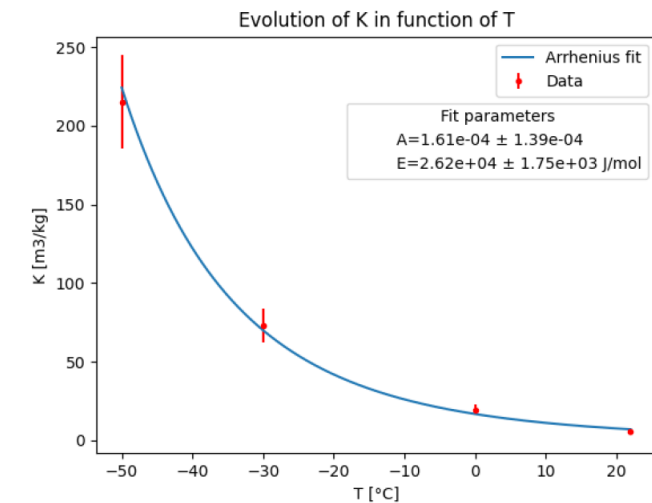


Figure 3.1: Graph of the variation of K with respect to the temperature for an adsorbent measured at CPPM. The fit is an Arrhenius-type law with factor $A = 1.61 \cdot 10^{-4} \pm 1.39 \cdot 10^{-4}$ and $E = 26247.17 \pm 1747.08 \text{ J/mol}$.

Adsorption: Analysis technic

How do we measure the K coefficient of Material

Dynamical adsorption method

Similarly to chromatography on a column, we force Rn carried by a neutral gas (N_2 , Ar, He, etc) through the adsorbent. When it is totally filled with Rn, we measure the Radon concentration inside with an HPGe. We can then calculate the K coefficient described previously.

- Measure the absolute K coefficient
- Take a long time (1 sample/day/bench)
- Done in 3 step:
 1. Activation of the sample
 2. Radonisation
 3. HPGe analysis

Adsorption

Activation

Objective:

- Ensure the reproducibility
- Maximum radon adsorption

Purpose:

- Removal of all traces of physically and chemically adsorbed molecules or atoms

How:

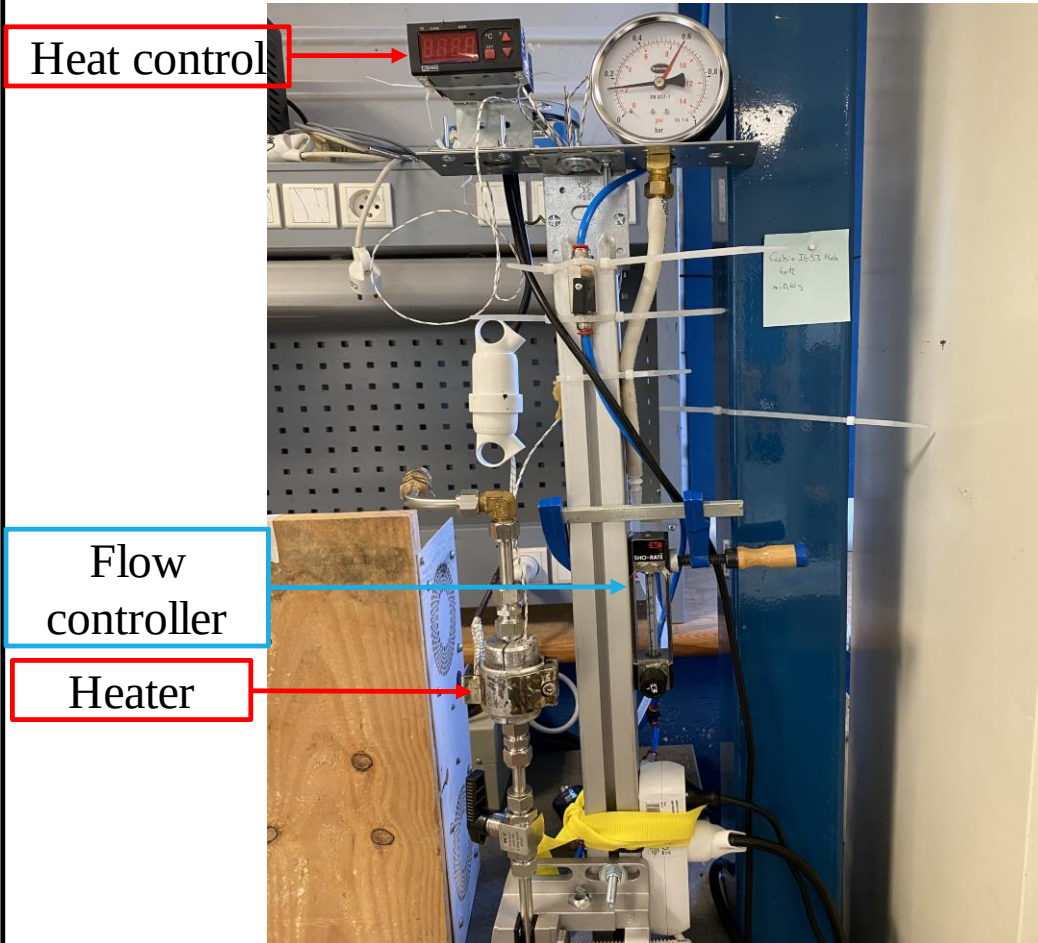
- Heating of the sample under vacuum or flow of neutral gas

Temperature and condition depends on adsorbent:

- AC/Zeolite $\rightarrow 200^{\circ}\text{C}+$
- MOF & Molecular cage $\rightarrow <100^{\circ}\text{C}$

CPPM activation bench:

- Temperature between 20 and 250°C
- Flow of $\text{N}_2/\text{Ar}/\text{He}$
- Vacuum



Adsorption

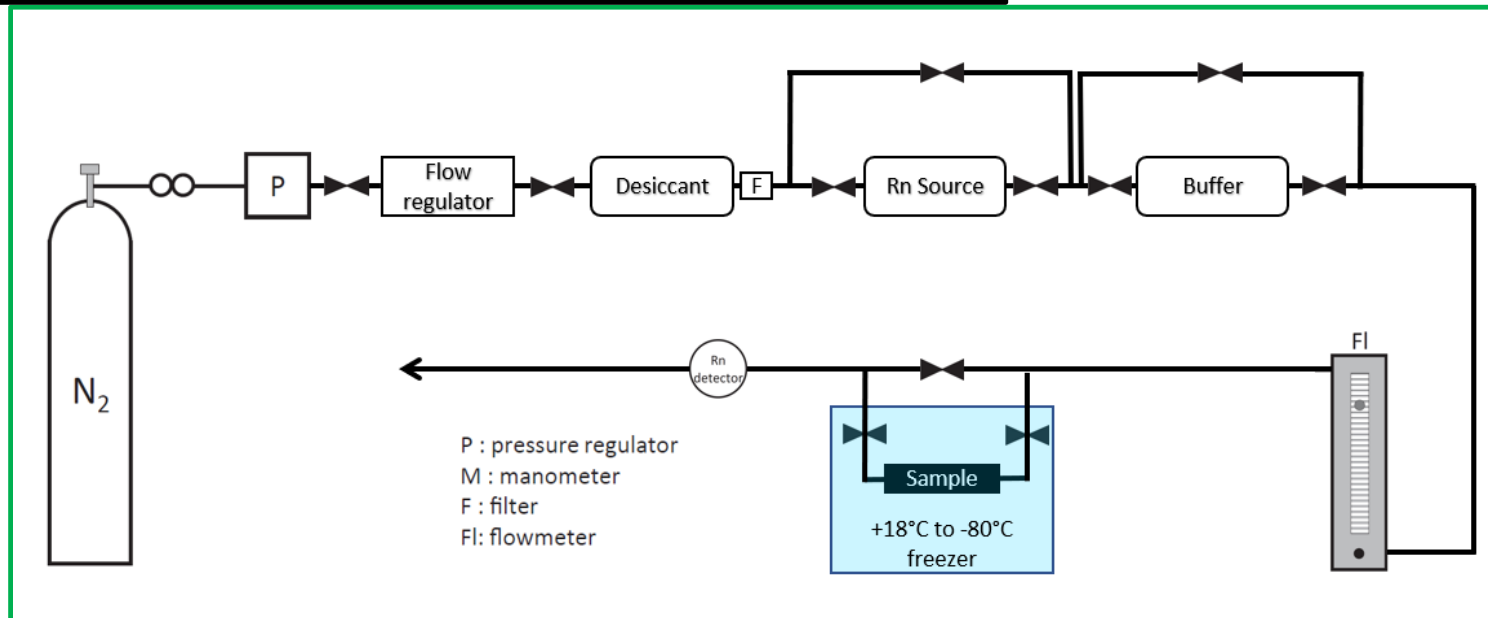
Radonisation

Set up:

- Send a constant concentration of radon through the sample
- Control of radon concentration with a Rn detector at the output
- Sample cooled at up to -80°C

CPPM platform bench:

- “Strasbourg”, open loop, $A = 932 \pm 18 \text{ Bq/m}^3$;
- “Marseille”, closed loop, $A = 1240 \pm 41 \text{ Bq/m}^3$;



Adsorption

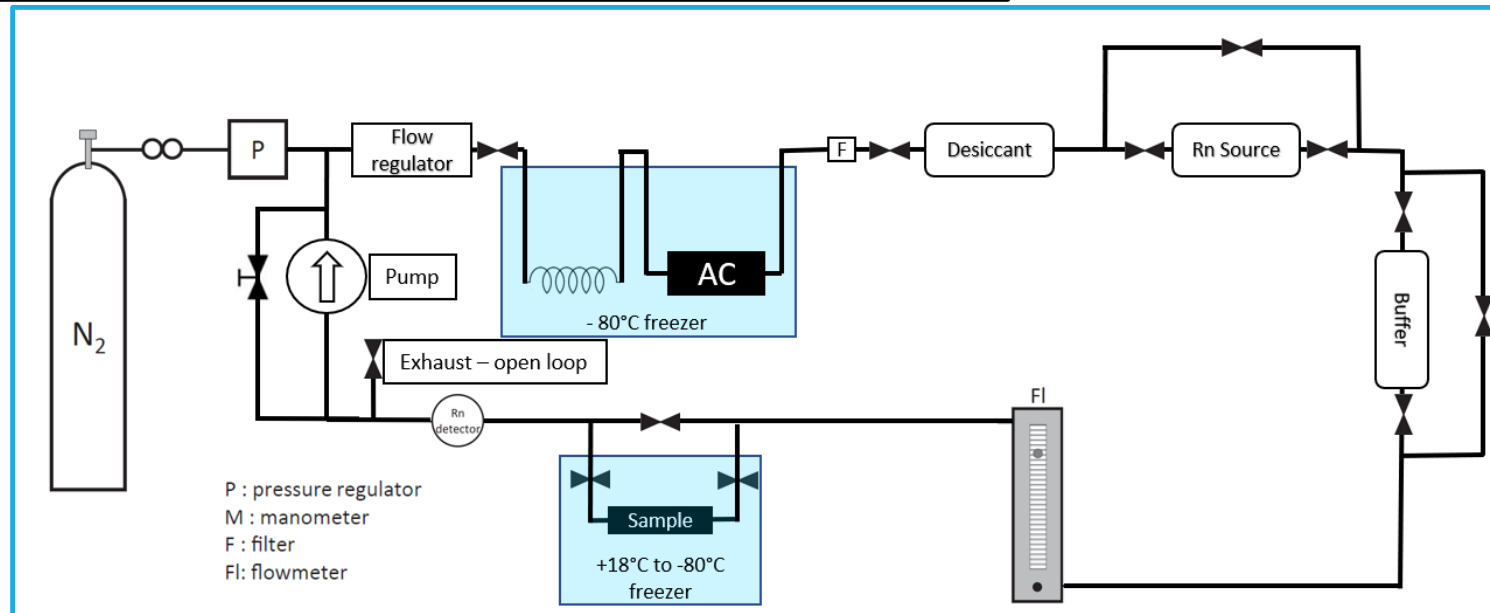
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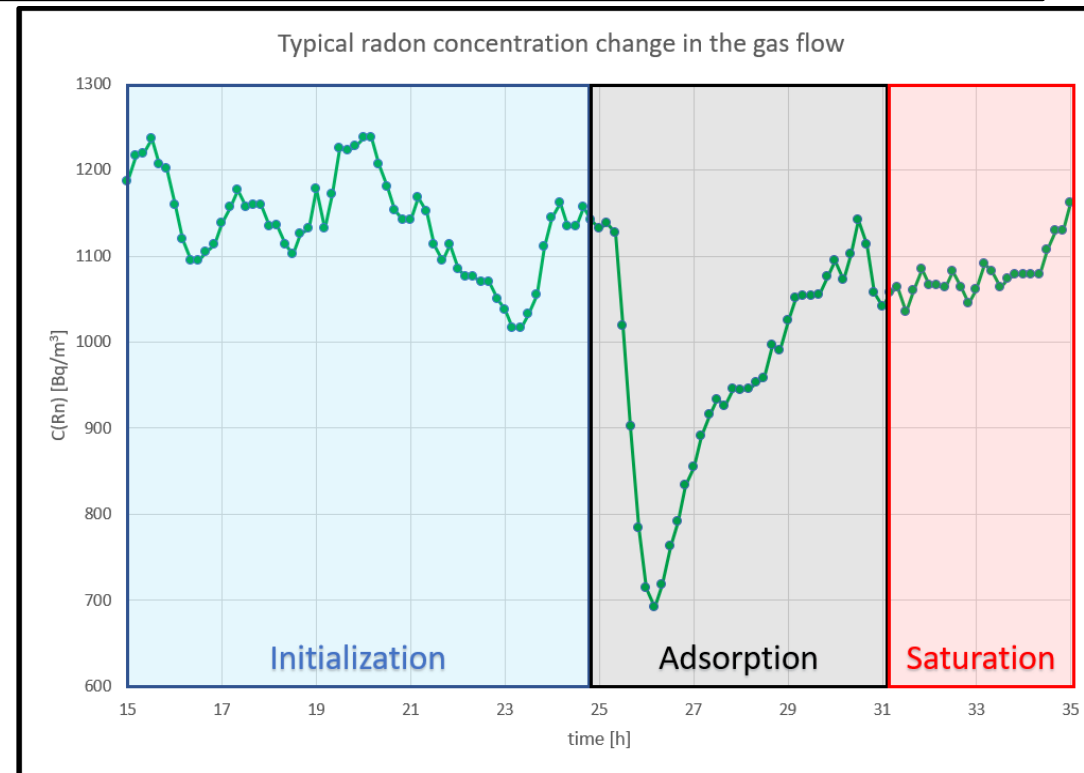


Adsorption

Radonisation

Typical Rn concentration change:

1. Carrier gas is radonised to a concentration C_1 , “initialization”
2. Flushed through the column, “adsorption”
3. $C(\text{Rn})$ stabilized at a value C_2 , “saturation”

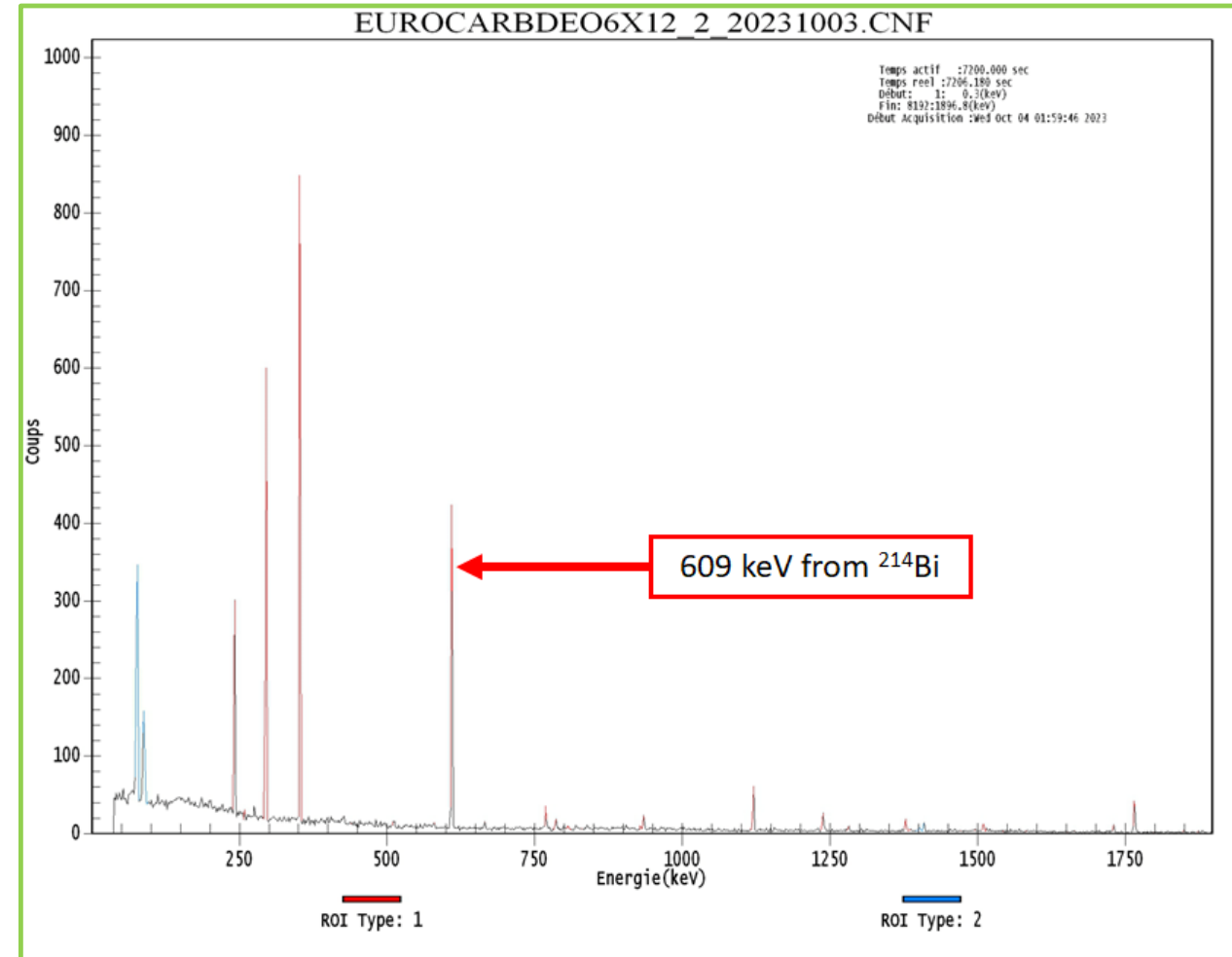


Adsorption

HPGe measurement

Measurement of the Radon inside the sample by gamma spectrometry

- 100 cm³ HPGe shielded by 15cm lead shielding
- Measurement of ²¹⁴Bi 609 keV gamma line
- A_{sample} in Bq/kg



Measurement of Extremely Adsorbent at high Temperature:

- For extremely adsorbent materials, low temperature measurement is complicated.
- Maximum K measurable for 0,2g is $39 \times 10^3 \text{ m}^3/\text{kg}$; $10^4 \text{ m}^3/\text{kg}$ for 0,8g.
- We can lower the mass, but it increase the uncertainty and enhanced the sensibility to humidity
- K can be expressed as an Arrhenius-type law:
 - $K = K_0 e^{\frac{Q}{RT}}$

Goal: Estimate the K factor of extremely adsorbent materials at low temperature by measuring K at high temperature and with an higher mass.

→ Adsorption at high temperature is a advantage for the Rn purification of gas mixture.

Measurement of Extremely Adsorbent at high Temperature:

Preliminary Results with ETS-10-Ag

- ETS-10-Ag measured at -5, 22, 40, 80, 100 and 150°C, mass between 0,8 and 0,9g

Temperature [°C]	K[m ³ /kg]
-30	19940 ± 5980,8
-12	9951,9 ± 2404,6
-5	6593,8 ± 684,6
22	2332,1 ± 165,5
40	989,1 ± 63,1
80	186,5 ± 11,7
100	136,8 ± 8,0
150	29,3 ± 2,3

From DOI: 10.1093/ptep/ptad160

→ ETS-10-Ag K factor is still significant at high temperature !

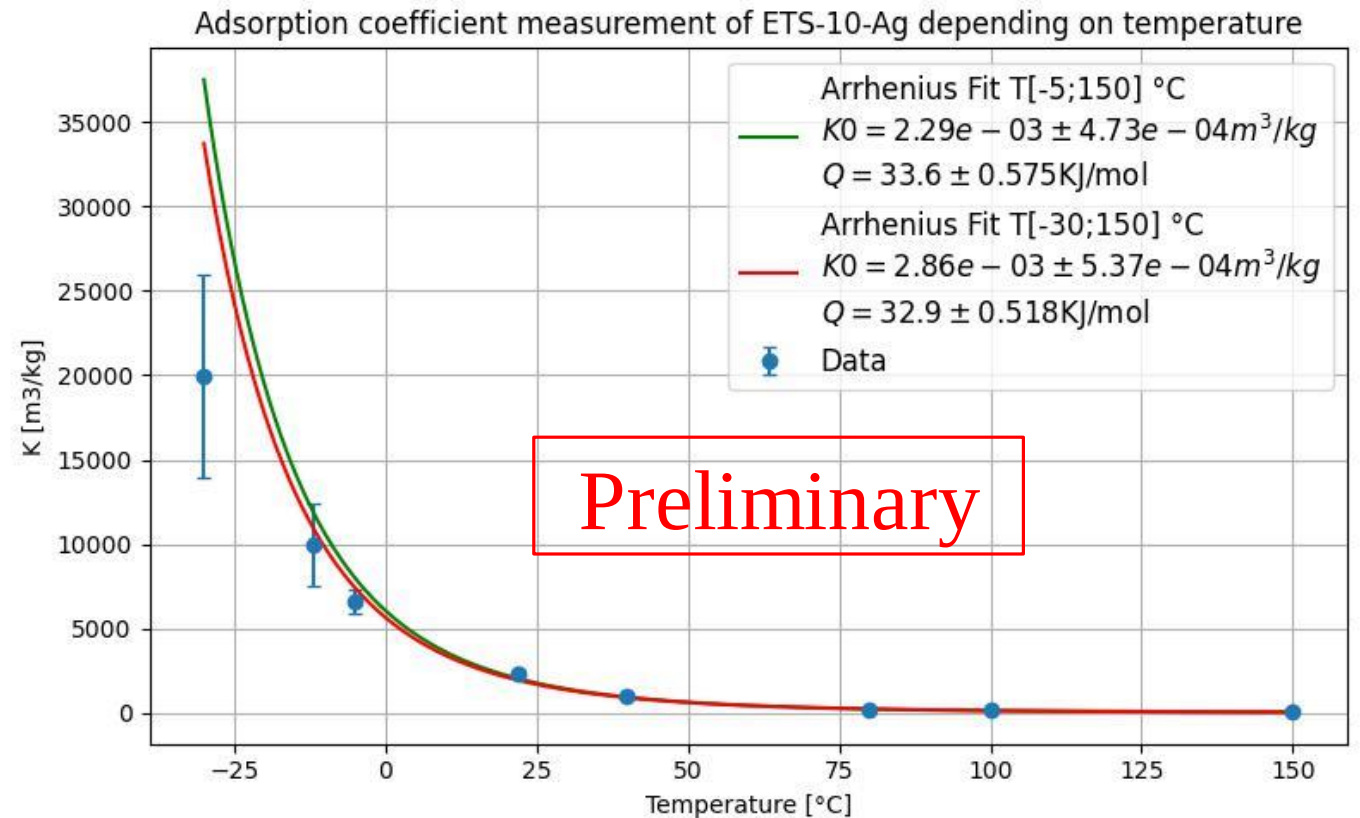
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- Fit is in accordance with data up to -12°C.
- Need more measurement at inflexion point to improve K_0 and Q estimation.

