MS Vacuum Swing Adsorption Gas System

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R.R. Marcelo Gregorio et al., Molecular sieve vacuum swing adsorption purification and radon reduction system for gaseous dark matter and rare-event detectors, arXiv:2312.07720 (2023)

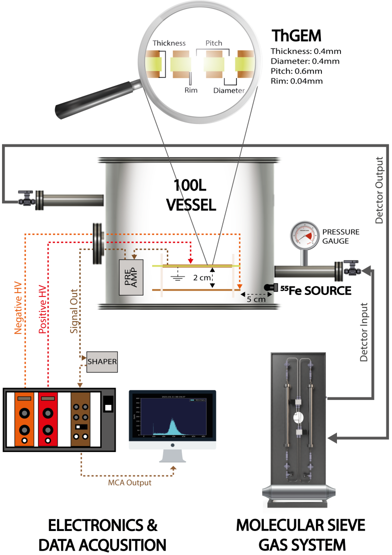
Dec 2023

Introduction

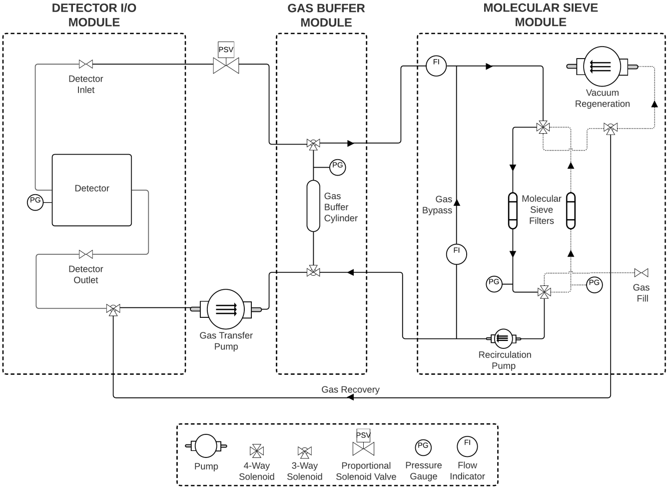
Molecular sieve (MS) vacuum swing adsorption (VSA) purification and radon reduction system for gaseous dark matter experiments

- **Radon gas contamination**
  - Radon progeny decay known to produce unwanted background events.
- **Common pollutants (H_2O, O_2, and N_2)**
  - Known to capture ionisation electrons, resulting in loss of detector gas gain.
- **Molecular Sieve VSA System**
  - Two independent problems solved by MS filtration.
  - VSA technique ideal for continuous long-term operation while recycling the target gas.

Experimental setup
Overview



Experimental setup
VSA Gas System



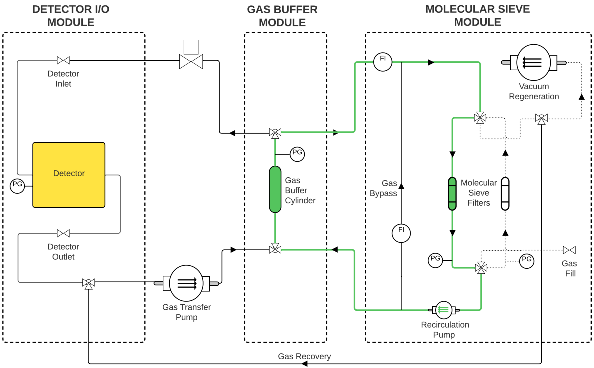


Figure: Schematic of the two separate volumes within the system: the gas inside the detector (shown in yellow) and inside the buffer (shown in green).

Experimental setup
VSA Gas System

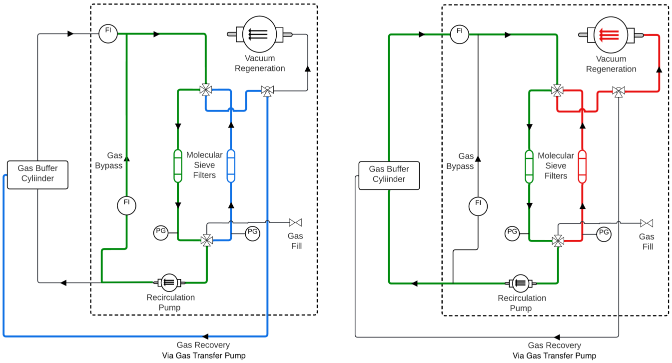


Figure: Schematic of the molecular sieve module during gas recovery (left) and vacuum regeneration (right).

Experimental setup

VSA Gas System

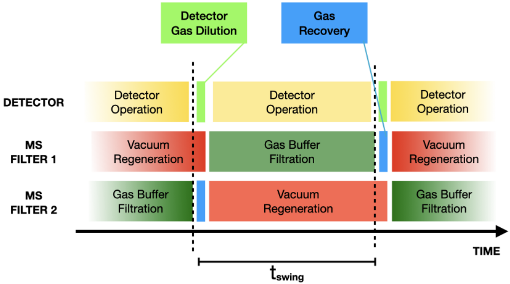
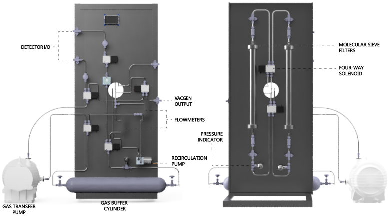
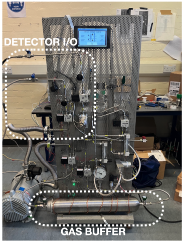
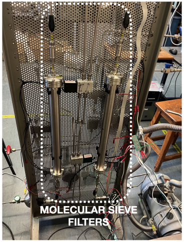


Figure: Example timeline of VSA operation showing the operation modes for the detector and dual MS filters.

Experimental setup
VSA Gas System







Experimental setup

New low radioactive MS

- New Nihon University developed MS (V2) material was found to emanate radon at 98% less per radon captured compared to commercial counterparts
- Lowest known MS emanation at the time of writing

NU-developed MS	^{222}Rn Captured per kg (Bq kg^{-1})	^{222}Rn Emanated per kg (mBq kg^{-1})	^{222}Rn Emanated per ^{222}Rn Captured ($\times 10^{-3}$)
V1 (Granules)	35$\pm$2	99$\pm$23	2.8$\pm$0.7
V1 (Powder)	330$\pm$3	680$\pm$30	2.1$\pm$0.1
V2 (Powder)	254$\pm$3	$<$14.4	$<5.7\times10^{-2}$

Table: Radon filtration, intrinsic MS emanation and comparison parameter results for the NU-developed MS.

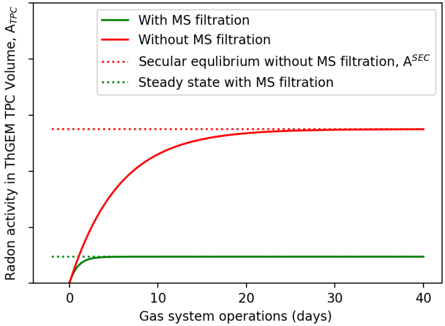
R.R. Marcelo Gregorio et al., Test of low radioactive molecular sieves for radon filtration in SF6 gas-based rare-event physics experiments, JINST 16 (2021)

Radon reduction test

Gas System Settings

- MS: 5A NU-MS (V2); 40g in each filter
- Target gas: SF_6 50 torr
- $t_{swing} = 24$ hours

$$A_{V_{\mathrm{TPC}}}(n) = \frac{1}{2}\sum_{n}\left(A^{\mathrm{ema}}_{\mathrm{TPC}}(t_{\mathrm{swg}}) + A^{\mathrm{ema}}_{\mathrm{GS}}(t_{\mathrm{swg}}) - A_{\mathrm{MS}}(N_{\mathrm{tot}}, t_{\mathrm{swg}})\right)$$



Radon reduction test

Results

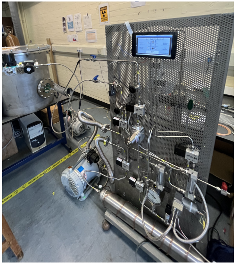
- Radon measurements was made using DURRIDGE RAD7 radon detector using a sampling method
- Intrinsic background of radon measurement apparatus was 14±5.7 mBq

Measurement Run	Extrapolated Steady State Activity (mBq)
Without MS filtration	43.3±14.4
With MS filtration	0.8±6.4

→ Intrinsic radon activity in the ThGEM-based TPC detector setup reduced to **less than 7.2 mBq** at a 95% C.L., corresponding to a **total reduction of at least 83%.**

Gas gain conservation test

Gas System Settings



- MS: 3A:4A 250g:250g in each filter
- Target gas: CF_4 50 torr
- $t_{swing} = 24$ hours
- $\sim$ One week detector runs with and without GS operating

Gas gain conservation test

Experimental method

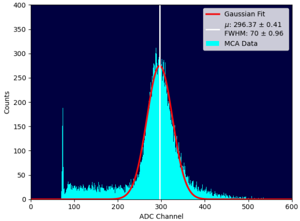


Figure: Gaussian fit to ^{55}Fe source pulse height spectrum peak to calculate gas gain

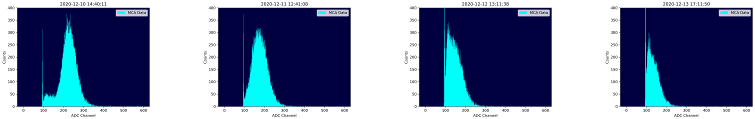
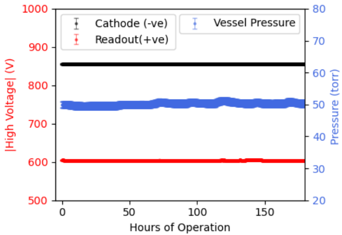
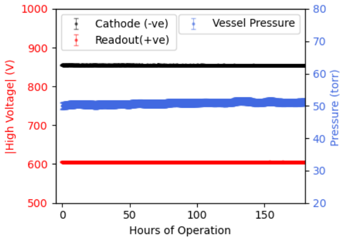


Figure: Example of ^{55}Fe Photo peak shifting due to gain deterioration

Gas gain conservation test
Gain measurements



(a) Detector run without gas system.

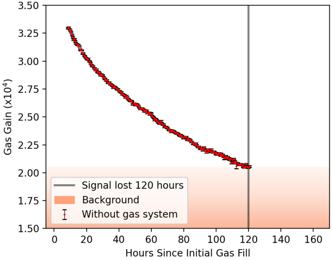


(b) Detector run with gas system operating.

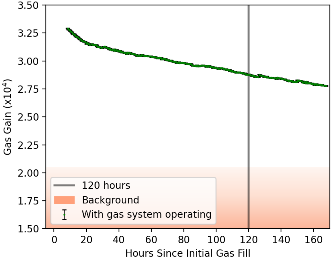
Measurement Run	Average Detector Pressure (Torr)	Average ThGEM HV (V)	Average Cathode HV (V)
Without Gas System	50.2 ± 0.8	604 ± 0.8	855 ± 0.3
With Gas System	50.9 ± 0.7	604 ± 0.1	855 ± 0.6

Table: Average values of detector pressure and applied high voltages over the measurements runs. Errors shown are 2σ deviation.

Gas gain conservation test
Gain measurements



(a) Gain deterioration due to intrinsic common pollutants.



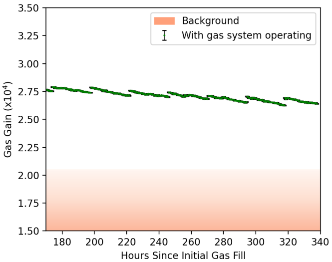
(b) Gas system operating.

Figure: Gas gain against time elapse since gas filled.

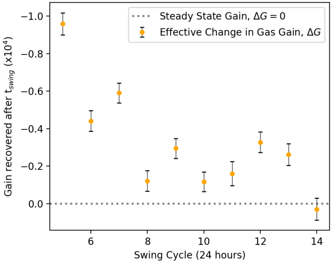
Gas gain conservation test

Gain measurements

$$\Delta G = G_R - G_L$$



(a) Extended detector run with gas system operating.



(b) Effective change in gas gain, ΔG, over swing cycle, t_{swing}.

Measurement Run	**Gas Used (TPC vol.)**	**Gas Gain (%)**			**Signal notes**
		50h	**120 h**	**340h**	
Without Gas System	1	80%	62%	-	lost after 120 hours
With Gas System	2	92%	87%	80%	remained until termination

→ Without gas replacement, the signal was lost after 120 hours, whereas with the gas system operating, it remained above background levels for the entire 340-hour run, achieving 80% of the highest gain.

→ Maintaining an 80% gas gain for 340 hours without gas replacement would require seven times more detector volume replacements

→ Suggestions for operation beyond 340 hours with effective gain change approaching zero

Conclusions

- **MS VSA Gas System Concept**
  - Evaluated with a 100L ThGEM-based TPC detector.
- **Radon Reduction**
  - Effective reduction to less than 7.2 mBq using NU MS (V2) 5Å, achieving an 83% decrease in intrinsic radon.
- **Gain Conservation**
  - Gain deterioration mitigated with MS types 3Å and 4Å, extending operation to 340 hours, compared to only 50 hours without it.

→ Demonstrated potential of a VSA system with suitable MSs for enhancing operation and reducing radon in gas-based detectors.

Further Work

- **Production scale of MS NU V2 (H. Ogawa)**
- **MS filters integration and R&D**
  - CYGNO, Italy
  - CYGNUS-OZ, Australia
- **Optimisation of MS VSA gas system**
  - Filtration parameters
  - Material and component screening
- **Low background measurements with DURRIDGE Next-gen radon detector RAD8**
  - 70% less intrinsically emanation
  - 70% more sensitive

Thank You!

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