Construction and measurements of a vacuum-swing-adsorption radon mitigation system

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Low Radioactivity
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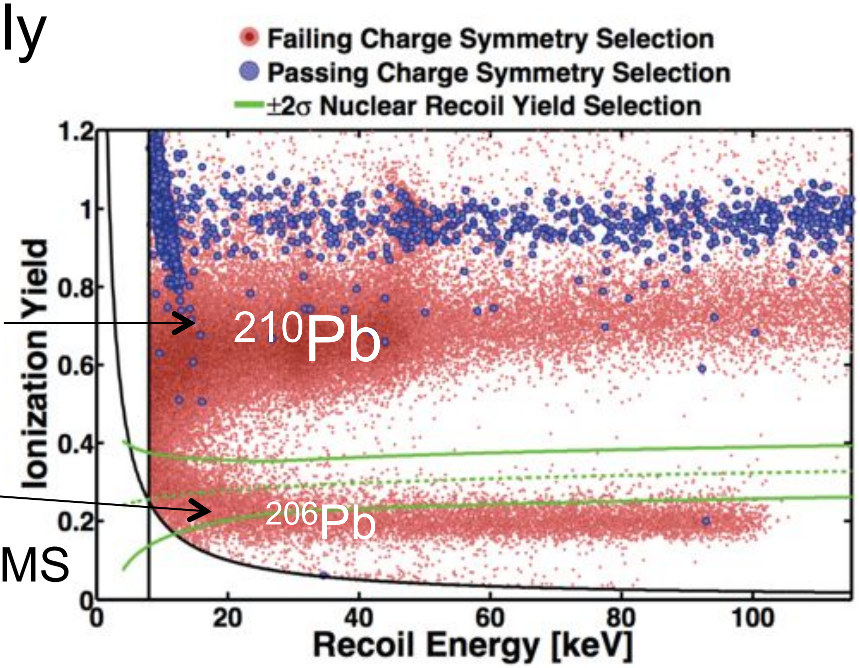
Motivation for Radon-Mitigated Cleanroom

- Radon daughters are a potentially dominant background for many low-background experiments
  - ^{214}Pb β SuperNEMO
  - ^{210}Pb β EDELWEISS, SuperCDMS
  - ^{210}Po α CUORE
  - ^{206}Pb recoil nucleus from ^{210}Po α
    - CRESST, DEAP/CLEAN, SuperCDMS
  - Neutrons from (α,n) on teflon
    - LUX, XENON1ton, DArKSIDE
  - ^{210}Pb on wires of BetaCage [*see R.H. Nelson talk, R. Bunker poster*]



- For some types of assembly, other methods not practical
  - Vacuum glovebox impractical for large objects or delicate assembly
  - Cleaning after assembly difficult & risky for complicated structures
    - But see e.g. DRIFT nitric etching or wires after assembly: http://www.youtube.com/watch?v=G4270rjtDnY

Radon Mitigation Systems

Continuous

- Most radon decays before it exits
- $C_{final} = C_{initial} \exp(-t/t_{Rn})$
  - [for ideal column]

Breakthrough time

lifetime

- Relatively simple & robust
- Need to cool carbon to be effective [*A. Nachab, LRT2006*]

Swing

- Stop gas flow well before *t*
  - Regenerate column #1
  - Flow through column #2
- $C_{final} = 0$
  - [for ideal column]
- More complicated
- Vacuum-swing
  - Potentially better performance than continuous system at lower cost [*A. Pocar, LRT2004*]
- Temperature-swing
  - Expect best performance, highest cost [*A. Hallin, LRT2010*]

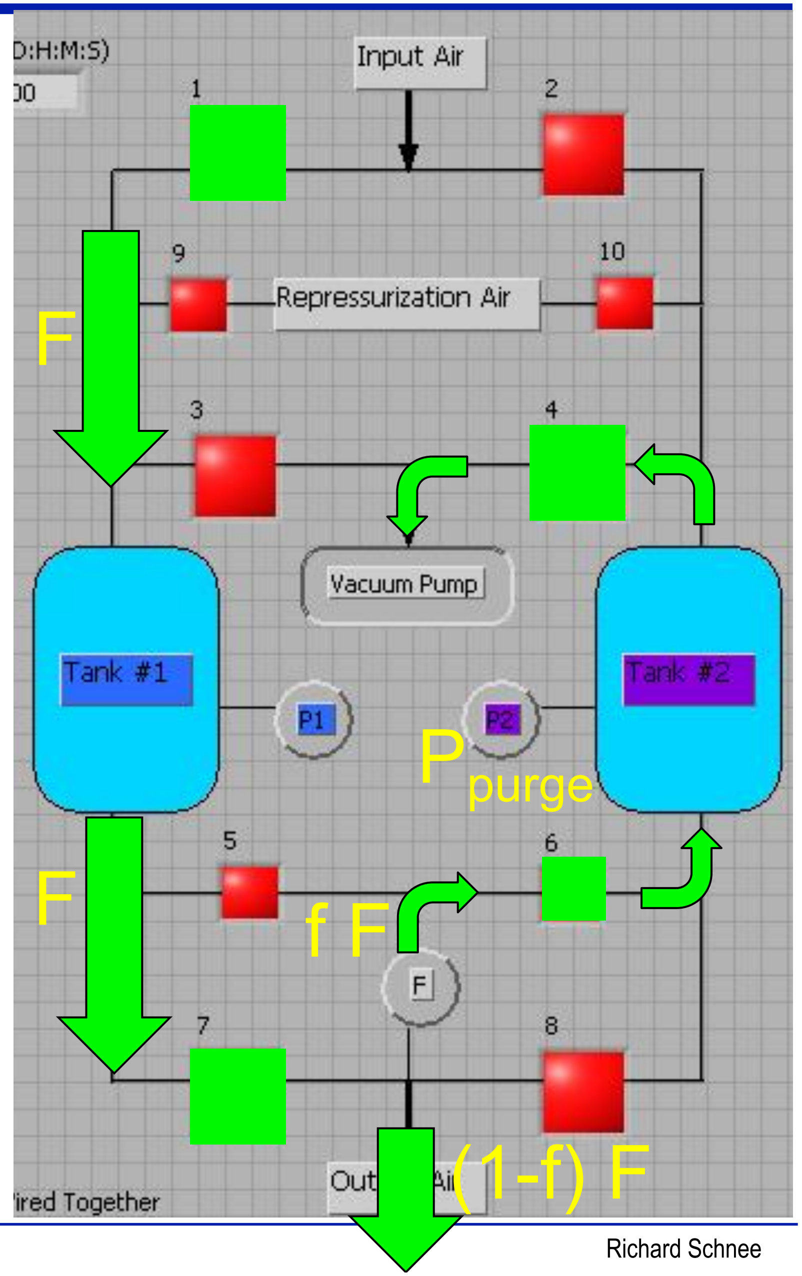
Vacuum-Swing Adsorption

- Takes advantage of greater adsorption capacity at high pressures
  - Regenerate carbon by flowing small fraction *f* of gas mass flow *F* back through tank at low purge pressure
  - Volume purge flow ϕ_{purge}

$$\phi_{purge} = \frac{P_{atm}}{P_{purge}} fF = \frac{fP_{atm}}{P_{purge}} \phi_{feed}$$

- Push back radon front (ignoring tails) if

$$G \equiv \frac{\phi_{purge}}{\phi_{feed}} = \frac{fP_{atm}}{P_{purge}} > 1$$



The Syracuse Radon Mitigation System

- Based closely on Princeton design (*described well in Pocar thesis, and thanks to T. Shutt, A. Hallin, A. Pocar for discussions*)
  - Tried to make some improvements, cut several corners

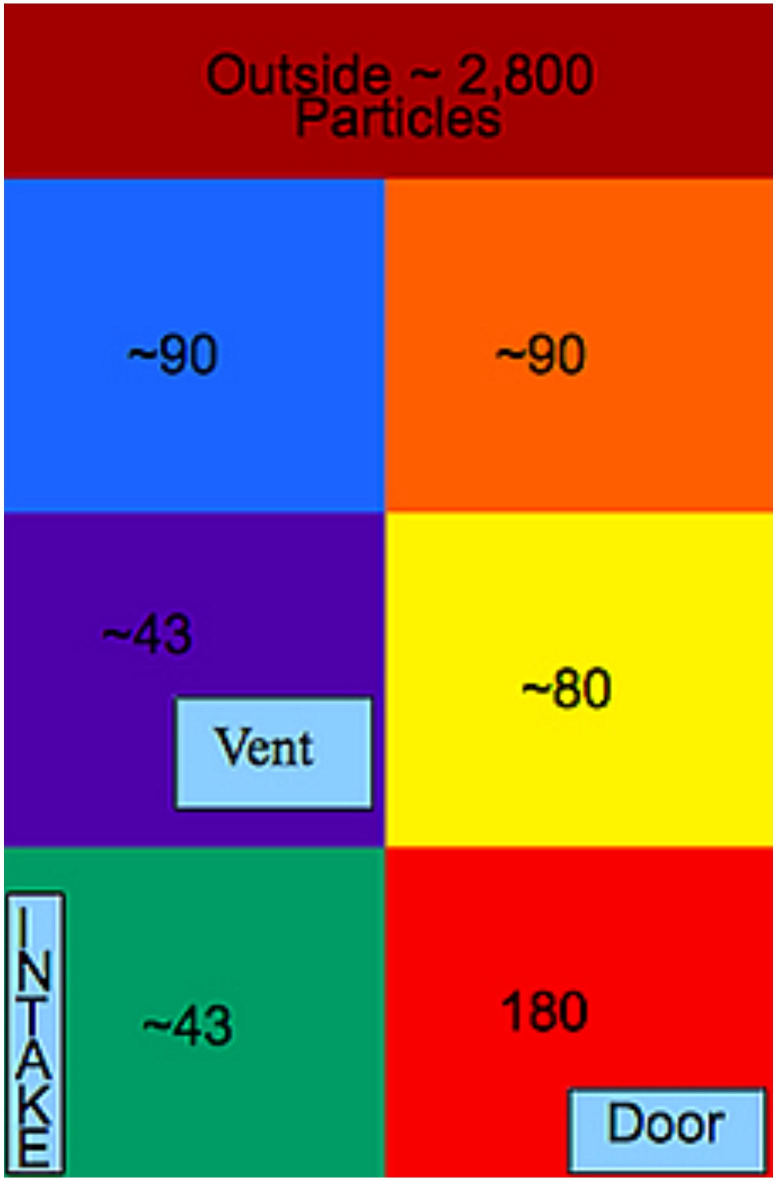
item	Princeton cost (US$)	Syracuse cost (10 years later)
tanks	8k	9k
charcoal (0.5 t)	6k	1.5k (140 kg / tank, different carbon)
vacuum pumps	22k	10k (roughing pump has lower capacity
valves	4k	7k at high pressures)
dryer	3.5k	7.5k
blower	1.5k	(none)
HEPA filter + housing	1.5k	1k
computer and valve control boards	1.5k	6k including gauges
other (fittings, tubing, ...)	5k	5k + 8k chiller
total	53k	

No prototype,
no radon source

- Commissioning in progress
  - Long-term results may be better (or worse) than what I show here
  - Hope to learn more about practical potential of this method

Syracuse Cleanroom Design

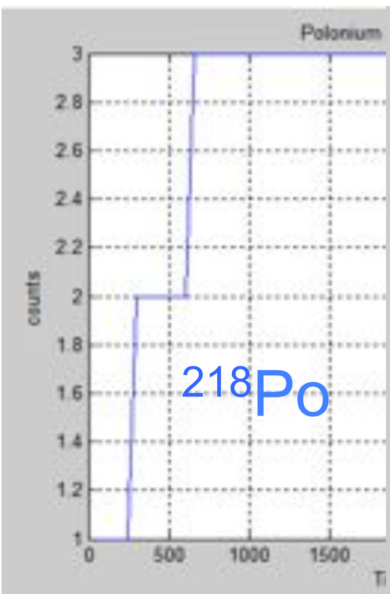
- 8 feet x 12 feet x 8 feet high
  - With 4’ x 8’ anteroom
  - As small as would be practical
- All aluminum panels/extrusions
  - Thick acrylic windows
  - Minimize emanation/permeation
  - Very leaktight
- HVAC outside
  - Efforts to make leaktight
- Aged water for humidification
- Designed for 30 cfm low-radon makeup air
- Fast HEPA filtration: 1 air exchange per 43 seconds

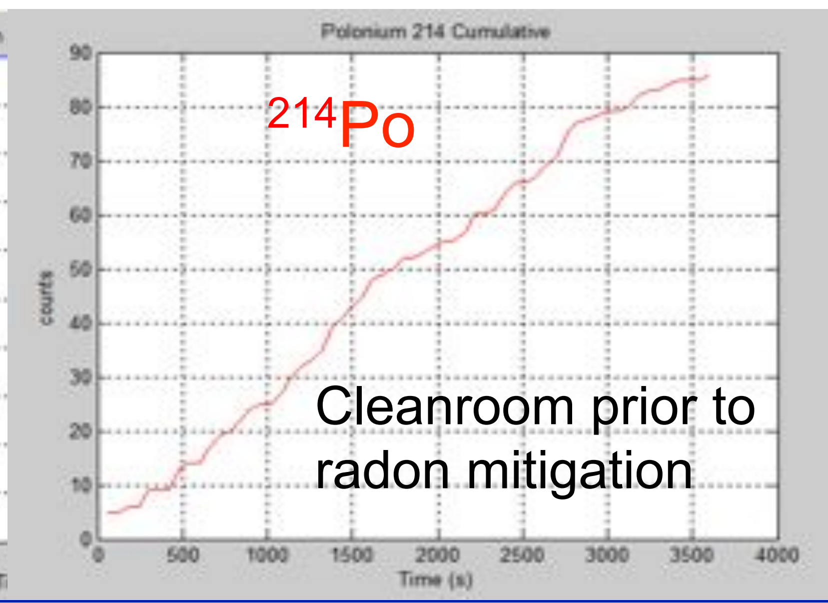


Syracuse Cleanroom

Air Sampling of Cleanroom

- Use high-volume air sampling system with Whatman GF/F glass-fiber filters, transfer to Ortec AlphaDuo to count ^{218}Po, ^{214}Po decays and infer airborn concentrations of ^{218}Po, ^{214}Bi, ^{214}Pb
  - Preliminary results indicate cleanroom ~10x lower radon daughter concentrations than outside lab, prior to radon mitigation



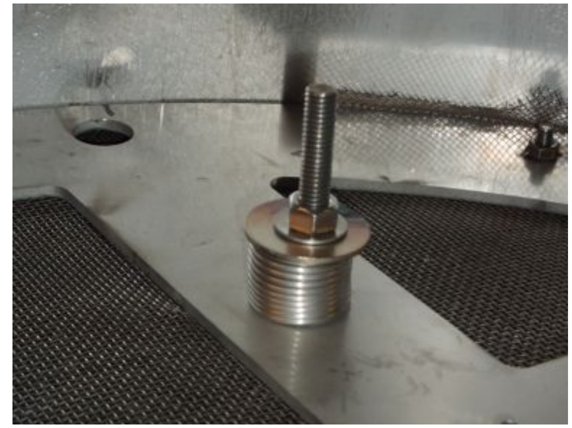


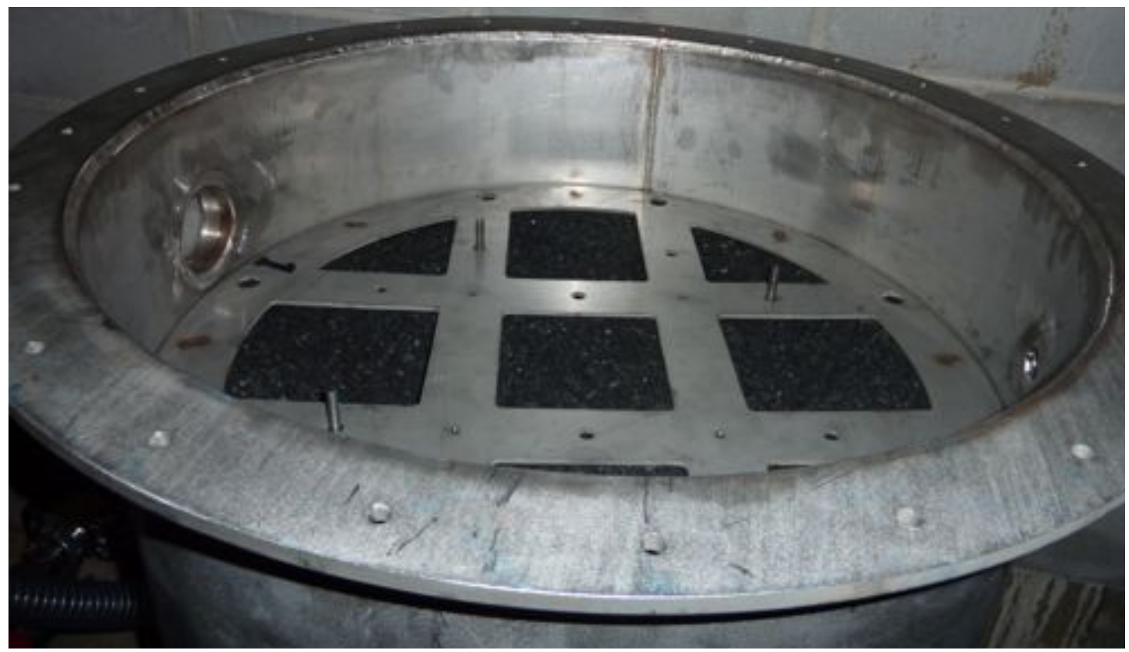
HI-Q Environmental Products CF-901 ($1200) 0-70 lpm

Activated Carbon

Calgon Coconut Activated Carbon Product OVC Plus 4x8 (mesh) Multiply rinsed, then dried under high-flow fume hoods

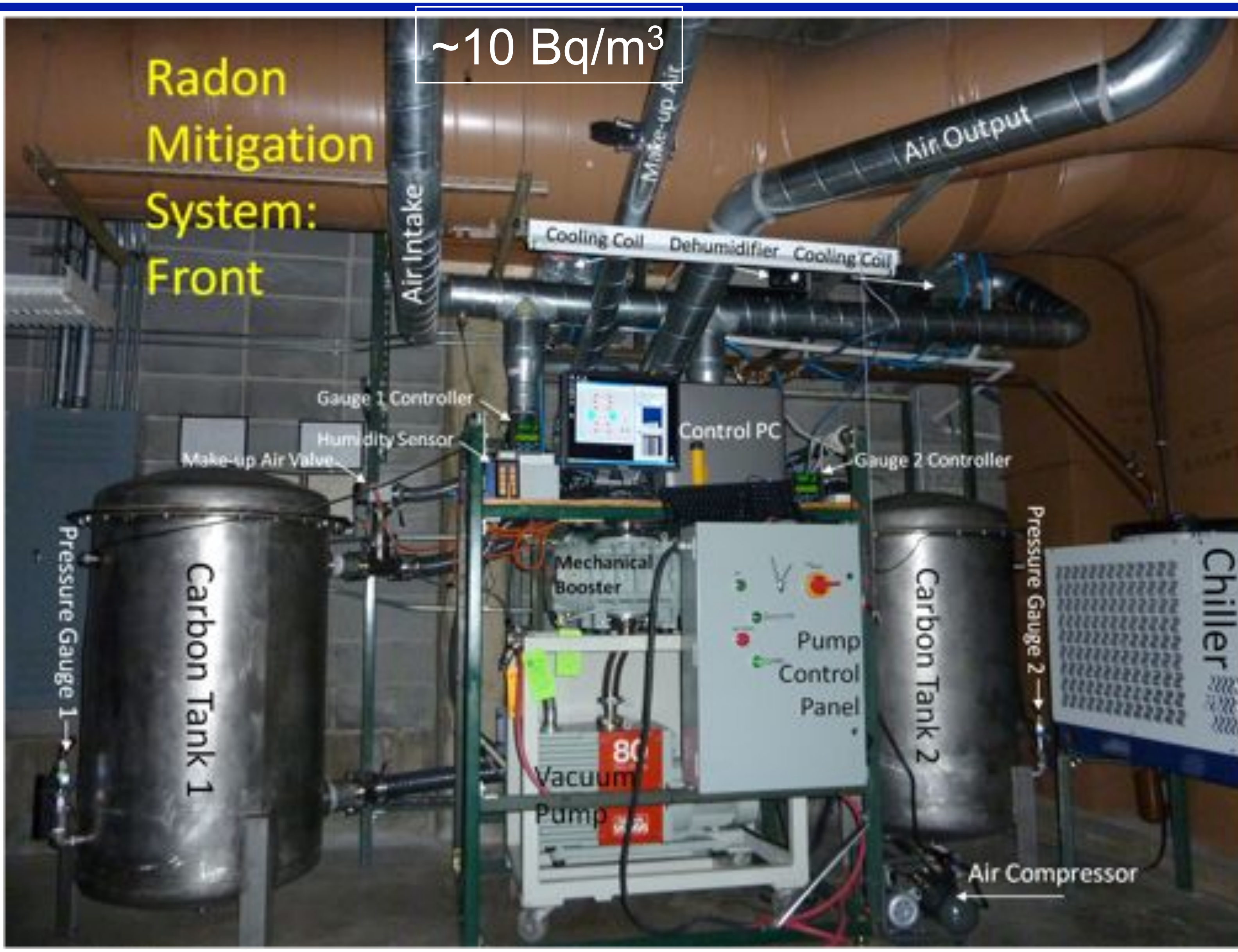
Two Identical Stainless-steel Vacuum Vessels Loaded with ~150 kg each & Spring Loaded



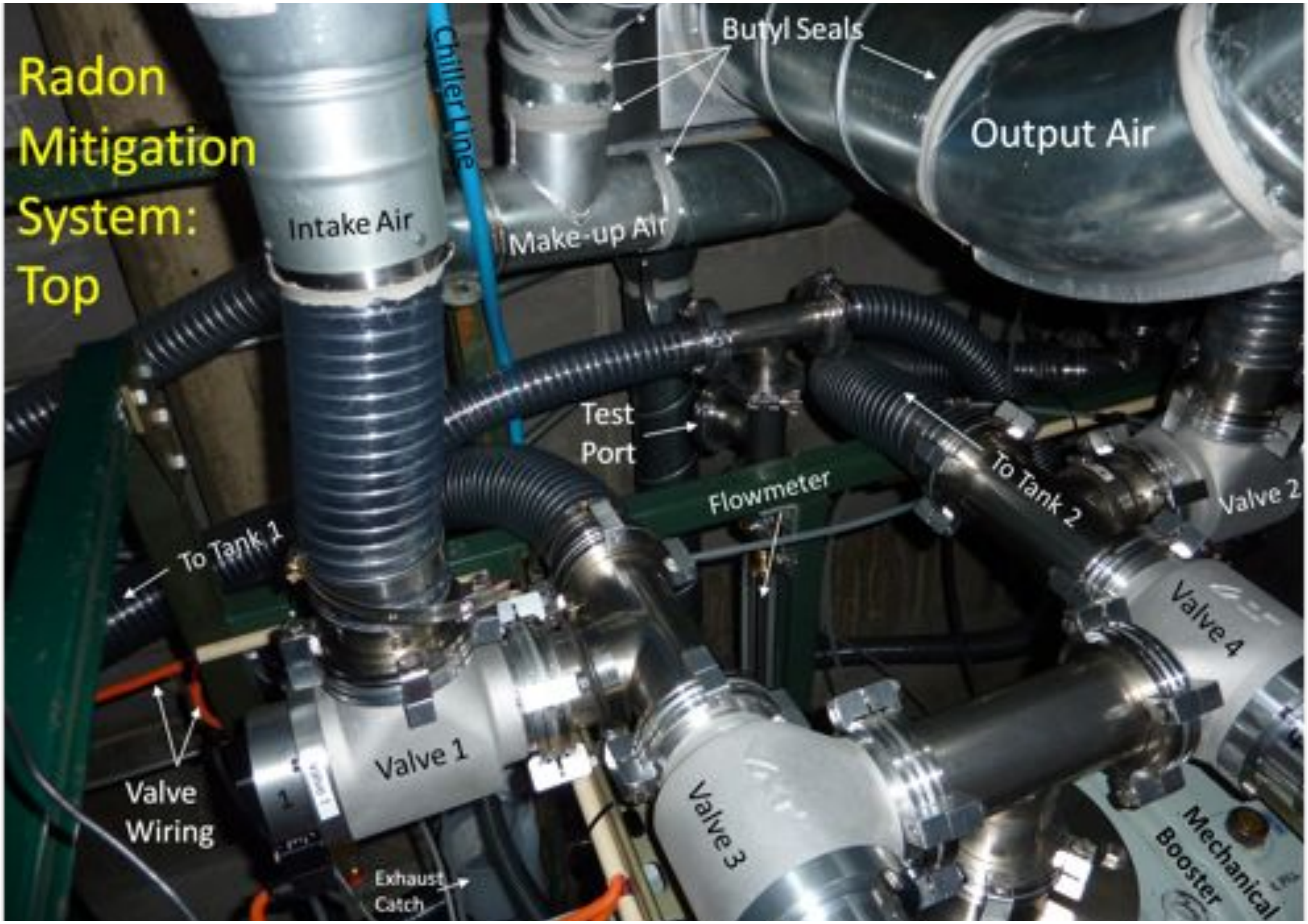


Opened up tank after first month commissioning, found carbon still in good shape & well packed.

The Radon Filter

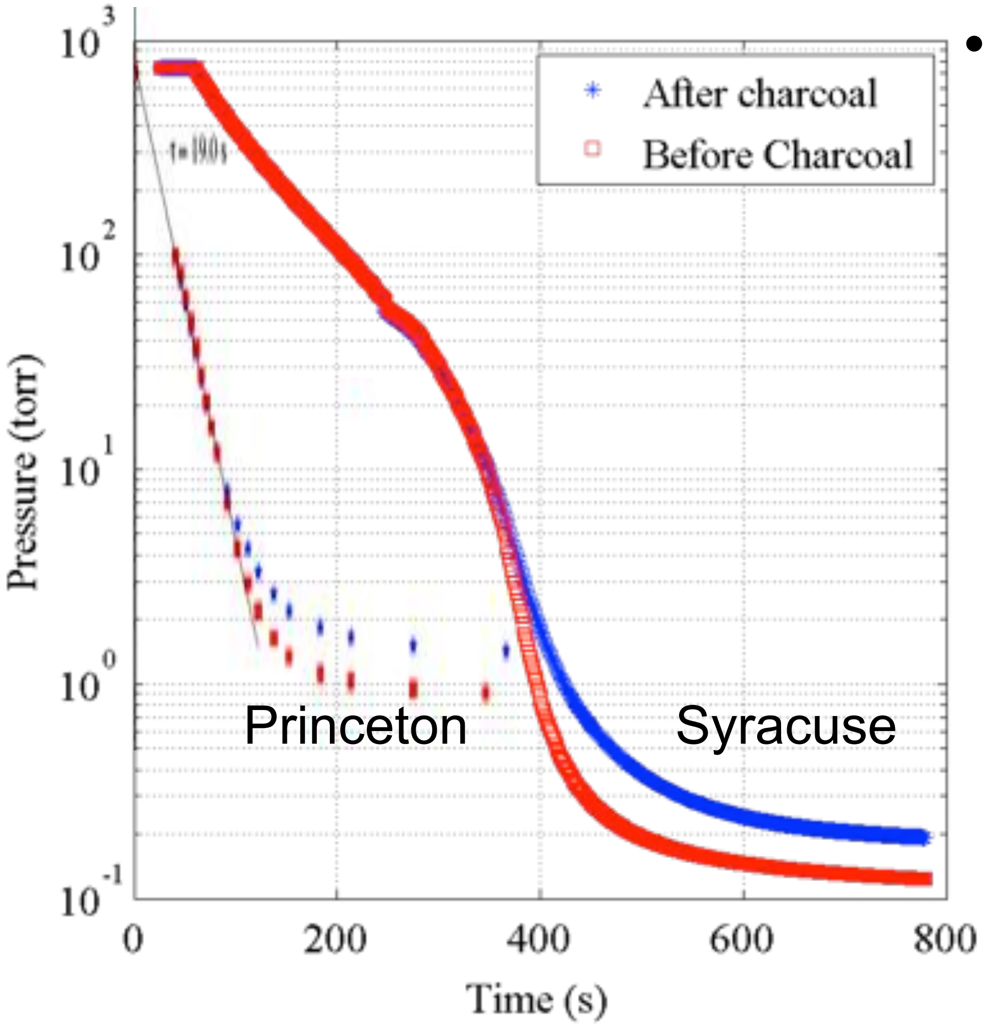


The Radon Filter – Close Up

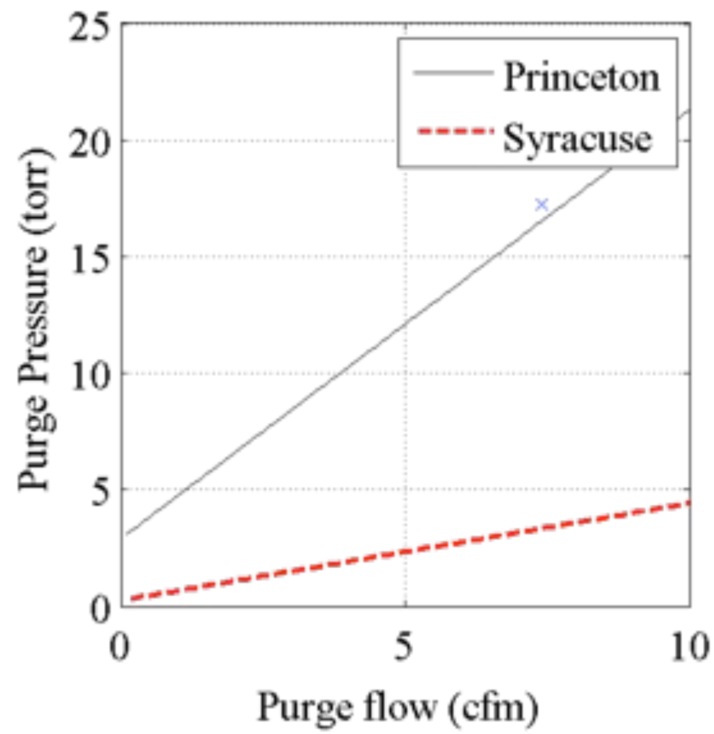


Comparisons to Princeton System

- Takes 5 minutes to pump down to ~10 torr (vs. Princeton ~1 minute), so part of cycle is inefficient

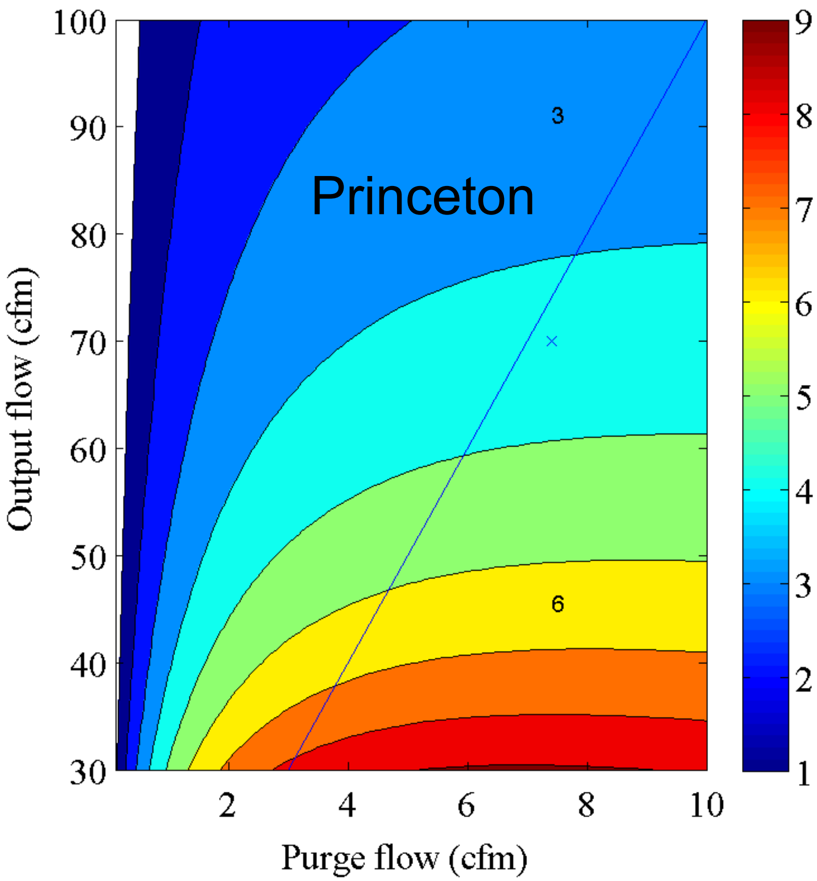


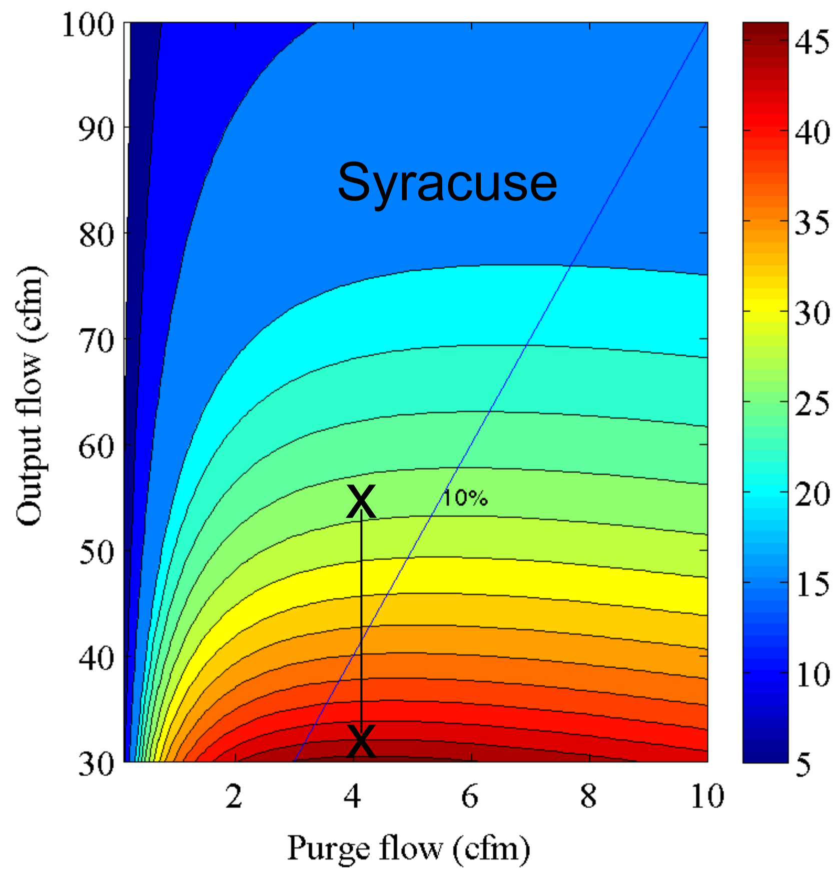
- Lower base pressure allows higher volume flow gain



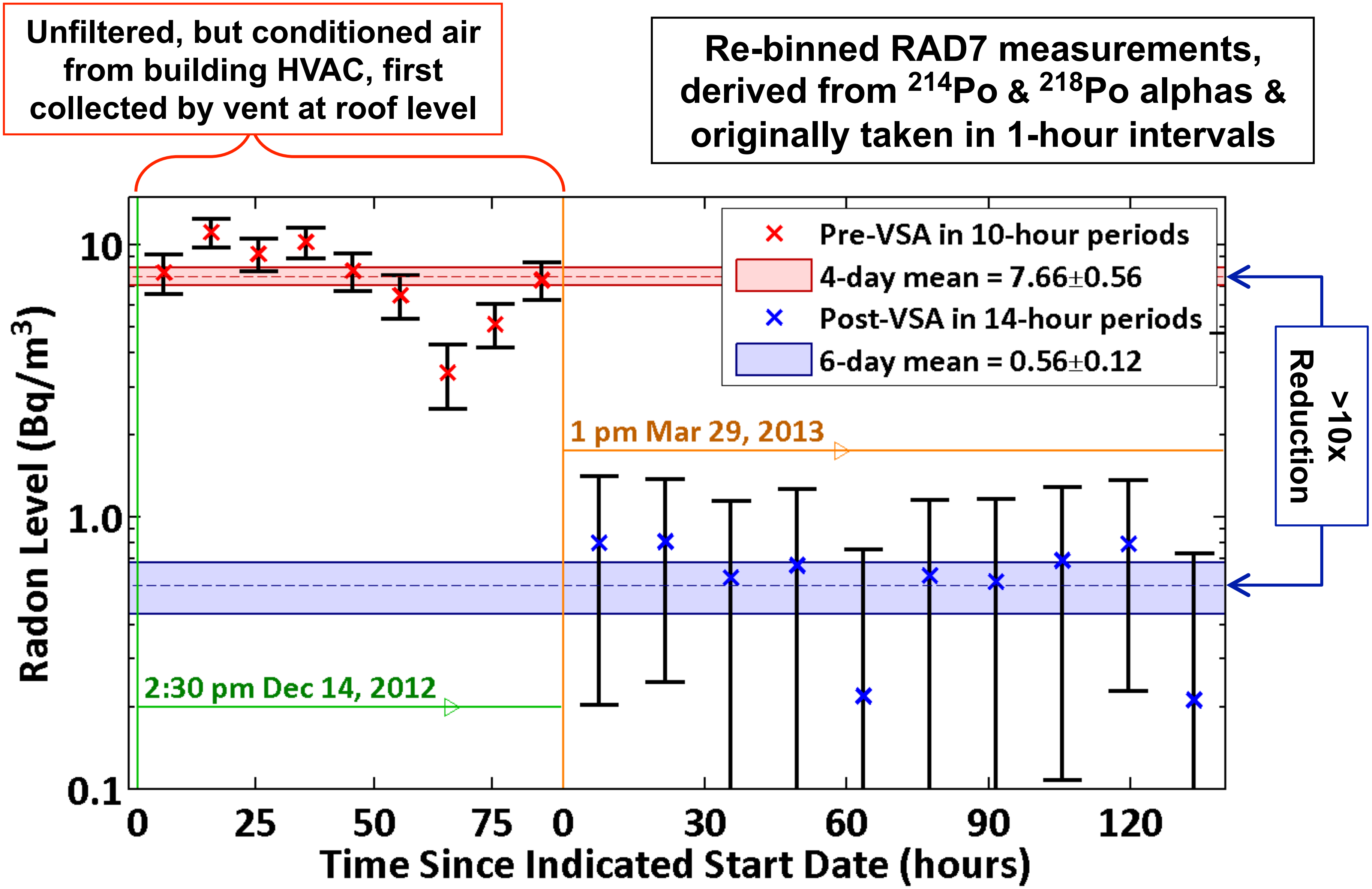
Expected Volume Flow Gains

- Want big G, big output flow, and short cycle times
  - Must have G>1 for system to mitigate at all
  - Note this is not a comparison (same G in different systems can be different performance)



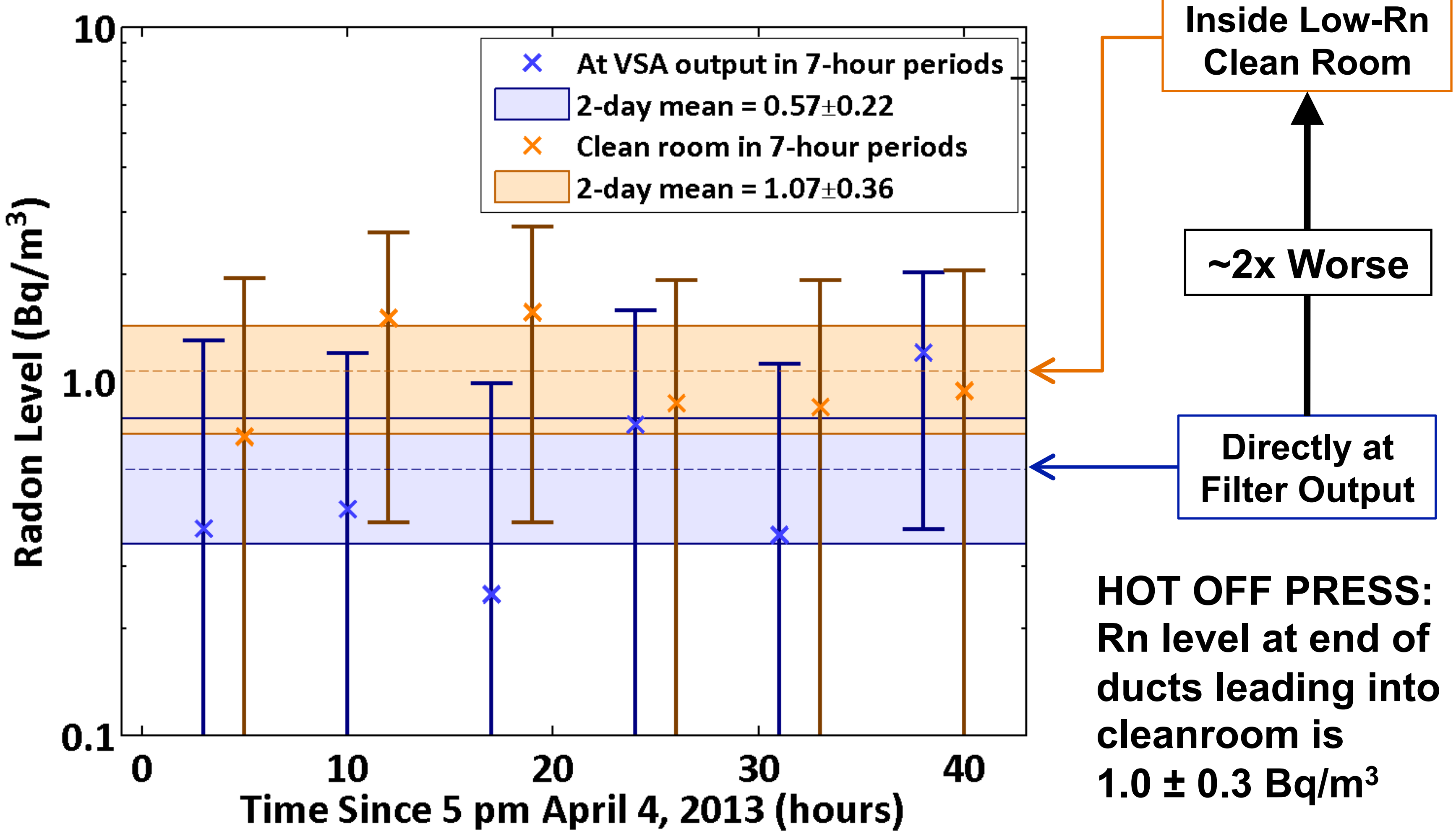


Radon Reduction at Filter Output



Radon Mitigation Results

Sampled simultaneously with dual RAD7's in 1-hour intervals

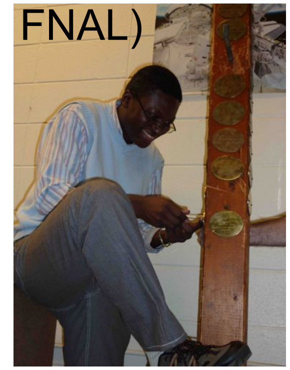


HOT OFF PRESS: Rn level at end of ducts leading into cleanroom is 1.0 ± 0.3 Bq/m^3

Conclusions

- Syracuse VSA radon-mitigation system working
  - >10x reduction, to 0.6 Bq/m^3, at filter output
  - >5x reduction, to 1.1 Bq/m^3, inside cleanroom
    - About same level as old Princeton Borexino system
  - Not (yet) at expected performance
  - Many knobs yet to turn, possible fixes to make

Grad Joseph Kiveni (now at FNAL)



The Syracuse Radon Mitigation Team

Phil Arnold and Lou Buda

Post-bac Dan Jardin

Mark Kos (now PNNL)

Post-doc Ray Bunker

ug Andrew Tenney

h.s. student John Roberts (now at U.Chicago)