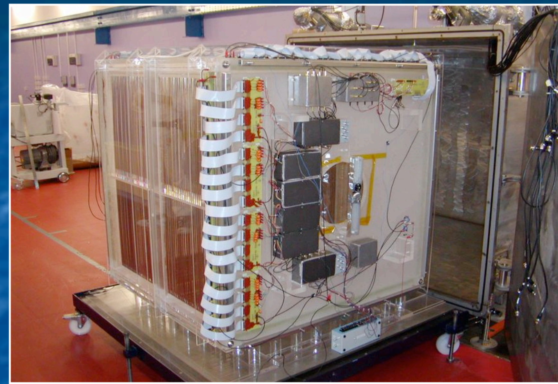
Radon Emanation Testing for DRIFT



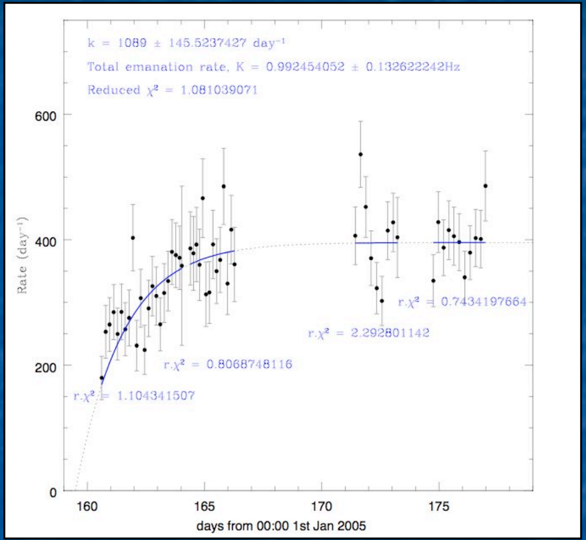
DRIFT-IIa @ Boulby

Direct & independent measurement of Rn emanation from detector components.

Sean Paling - Sheffield.

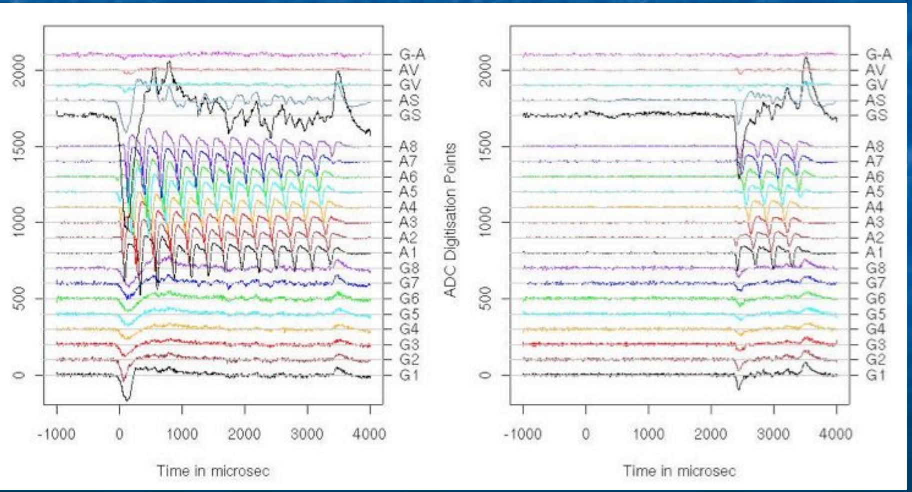
Rn in DRIFT-II

Cathode crossers vs time

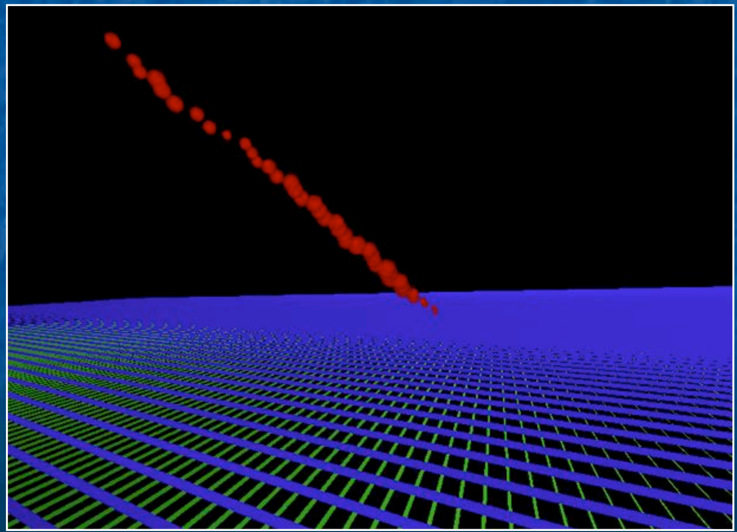


Clear evidence for **ALPHAs** from Radon decay...

- Totally fiducial alphas detected - produced INSIDE detector
- Alpha Energies consistently ~6MeV
- Rate of alphas vs time consistent with expectation for Rn emanation
- BUT - alphas alone are NOT a problem!



Cathode crossing alpha

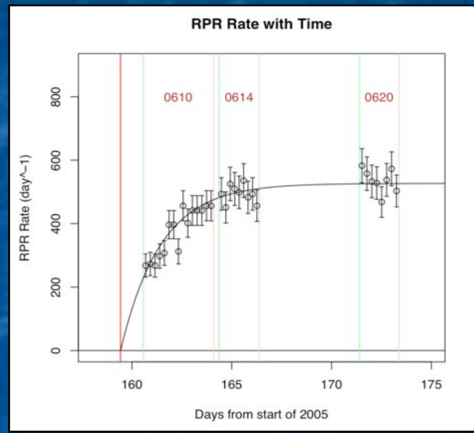


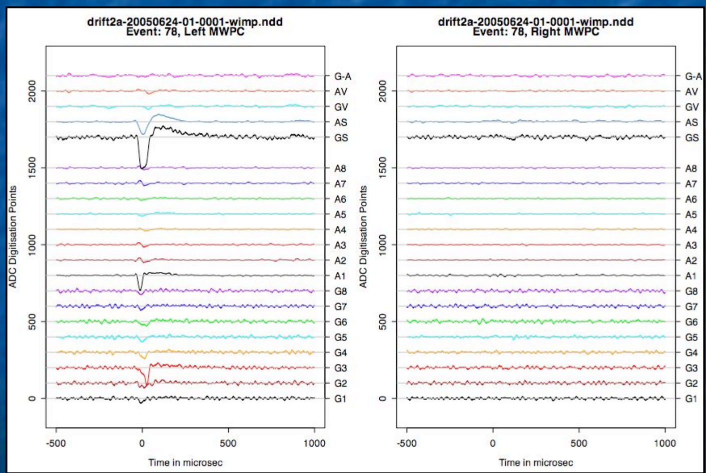
3d reconstruction

Radon Progeny Recoils (RPRs)

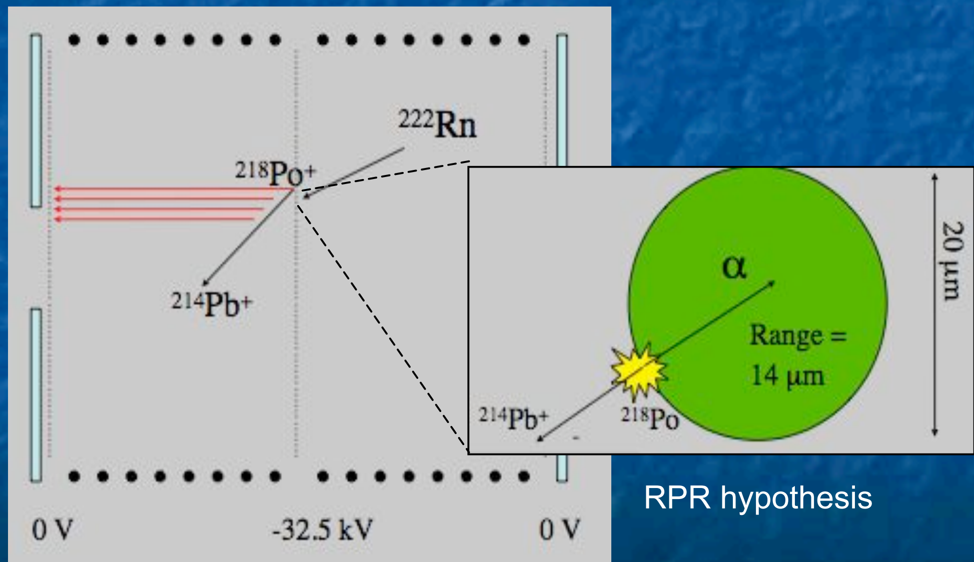
PROBLEM - we also saw mystery recoil-like events in background data.

- ~200-600 / day (50-250 keV)
- Increase with time consistent with Rn emanation.
- A limiting background
- Hypothesis: Recoil of radon progeny on central cathode - with alpha absorbed in wire.





RPR



RPR hypothesis

What is producing the Rn?

Nuclear Instruments and Methods in Physics Research A329 (1993) 291–298
North-Holland

NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH
Section A

^{222}Rn emanation into vacuum

Manqing Liu, H.W. Lee and A.B. McDonald
Department of Physics, Queen's University, Kingston, Ontario, Canada K7L 3N6

Received 3 November 1992

Table 1
Experimental Rn emanation rates into vacuum

Materials	^{222}Rn emanation rate	^{238}U content [7] $[10^{-9}$ g/g (ppb)]
molecular sieve 13X	1200 ± 120 l^{-1} hr^{-1}	225 ± 19
activated charcoal	250 ± 50 l^{-1} hr^{-1}	
silica gel	440 ± 50 l^{-1} hr^{-1}	197
coax cable RG-59	60 ± 30 m^{-1} hr^{-1}	
twinaxial PE cable	< 2 m^{-1} hr^{-1}	
coax cable 8240	6 ± 2 m^{-1} hr^{-1}	
coax cable 9067	< 0.6 m^{-1} hr^{-1}	< 10
Kevlar 3/8 in. rope	< 0.3 m^{-1} hr^{-1}	0.07
8 in. diameter PMT	< 20 PMT^{-1} hr^{-1}	
low-rad. glass	< 1.6 m^{-2} hr^{-1}	50
aluminum reflector	< 1.5 m^{-2} hr^{-1}	
black ABS plastic	< 1.1 m^{-2} hr^{-1}	20 ± 5
white polyethylene	< 0.9 m^{-2} hr^{-1}	
acrylic	< 0.1 m^{-2} hr^{-1}	
Al plates	< 0.5 m^{-2} hr^{-1}	5
SS 304L [supplier 1]	< 15 m^{-2} hr^{-1}	< 1
SS 304L [supplier 2]	< 0.3 m^{-2} hr^{-1}	

SNO Rn emanation survey...

Using low-background acrylic Lucas Cell (ZnS lined chamber) and cold traps to condense Rn output.

Total background = 20 counts / day
(3 / day from the Lucas cell)

Cables?
60 Rn atoms / m / hr
(72m in DIIa = 1.2Hz)

Durridge Rad7 Rn Detector

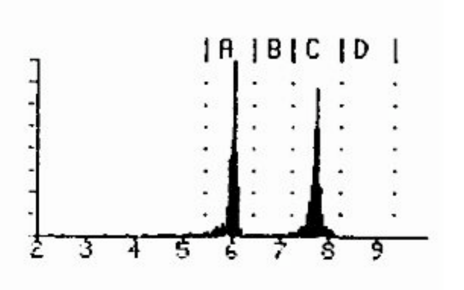
A low-background, real-time, solid state Radon detector.
(www://durridge.com/Manuals.htm)

- Uses alpha spectrometry to distinguish between daughters of ^{222}Rn and ^{220}Rn decaying in a 0.7l internal test chamber.

- Sample gas filtering followed by alpha identification means no assumptions about initial equilibrium required - & no problems of increasing background from long-lived PB210.

- Intrinsic Background <1 count / hr (<2×10^{-4} Bq)

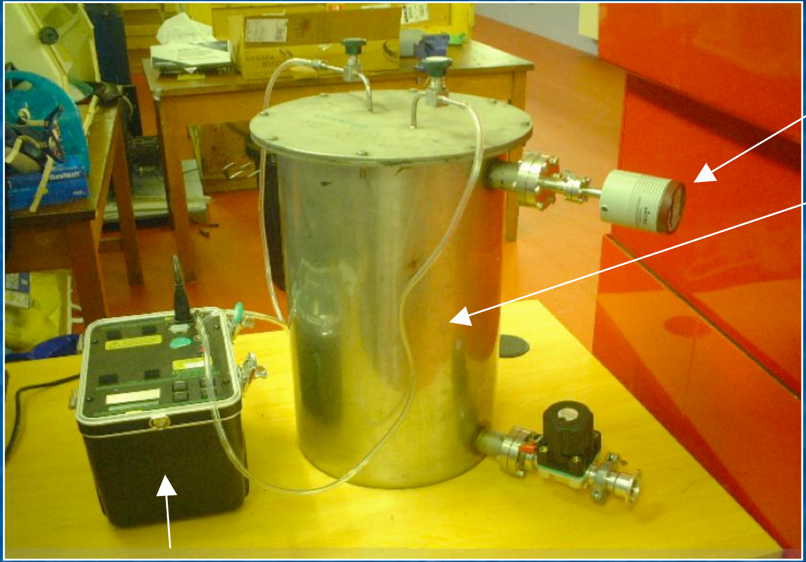
Alpha energy spectrum (Rn daughters)



A = ^{218}Po (6.0 MeV)
B = ^{216}Po (6.8 MeV)
C = ^{214}Po (7.7 MeV)
D = ^{212}Po (8.7 MeV)

Real time environmental radon monitor

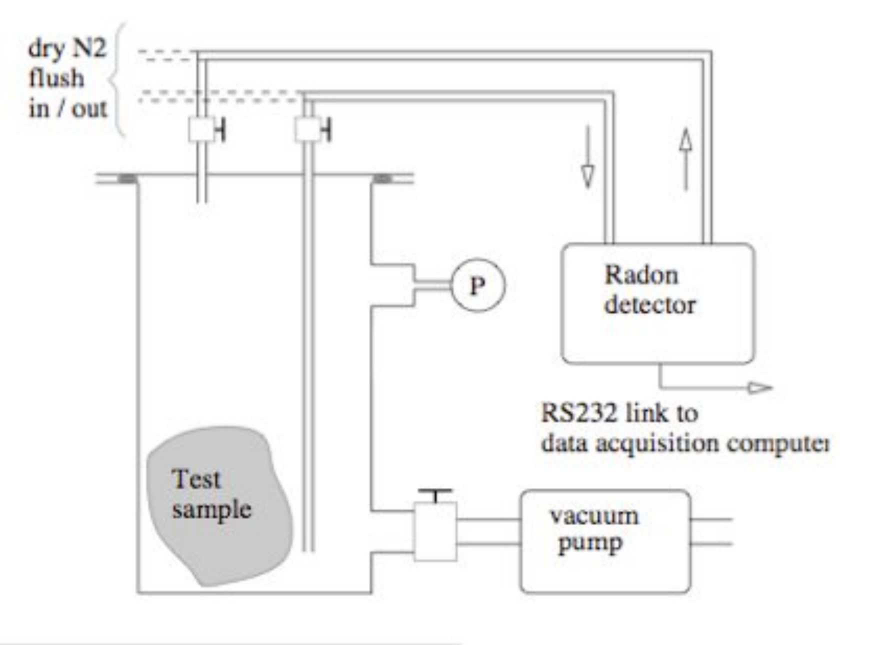
Rn Emanation Facility



Pressure guage

33l emanation chamber

Rad 7 detector



Test Procedure:
- Place sample in emanation chamber
- Evacuate emanation chamber
- Allow Rn emanation for many days (≥7)
- Back-fill with dry Nitrogen to P = 1 atm.
- Sample gas by circulating through Rad7 detector for ≥1 day

Rn Emanation

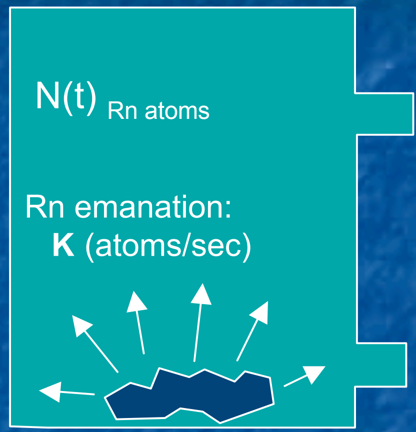
Radon emanation into chamber

Rate of change of number of Rn atoms (N)

$$\frac{dN}{dt} = K - \frac{N}{T}$$

Rn emanation rate

Rn decay
T = 1/e Rn decay time
= 3.85/ln2 = 5.52 days



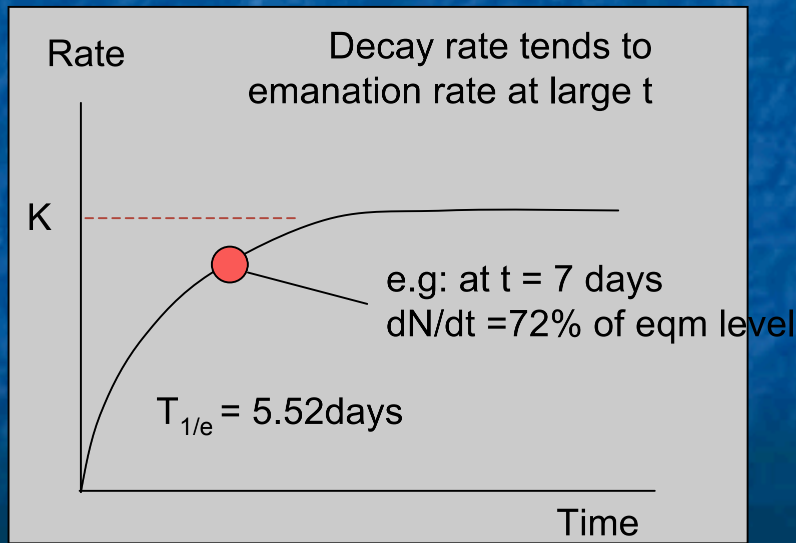
Emanation chamber: $0.033m^3$

Solving:

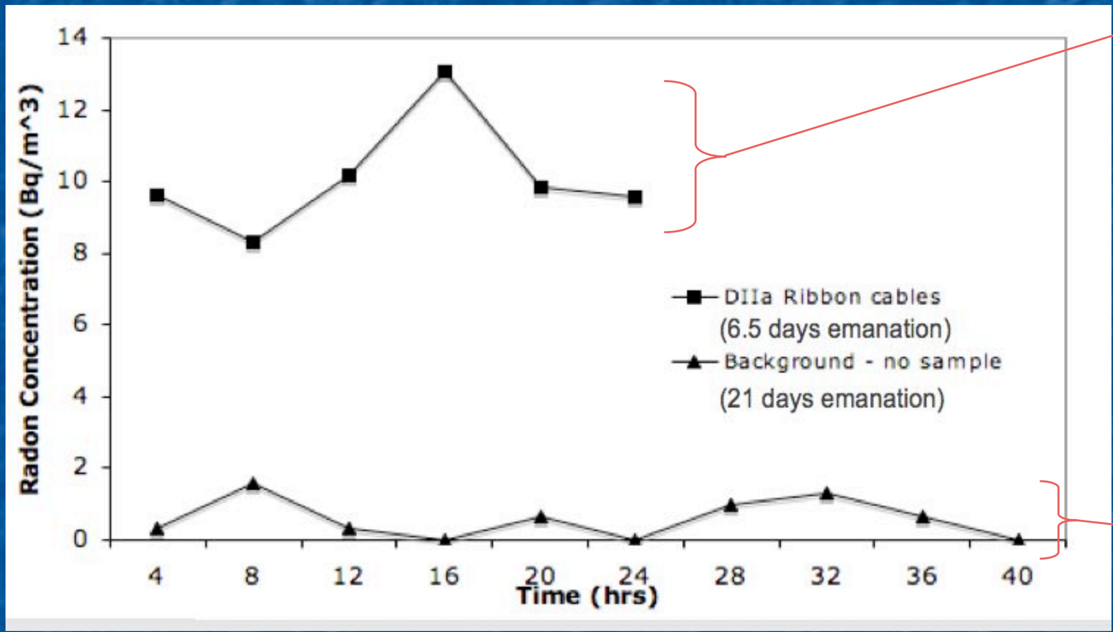
Number of Rn atoms (N) $$N = KT(1 - e^{-t/T})$$

Number of Rn decays $(dN/dt_{decay} = N/T)$

$$\frac{dN}{dt}_{(Rn\_decay)} = K(1 - e^{-t/T})$$



Example (raw) results



DRIFT-IIa Ribbon cables
Result = 10.1 +/- 0.7 Bq/m^3
(Error = 1 sigma from STDerr)

Background (Nitrogen Back-fill)
Result = 0.6 +/- 0.2 Bq/m^3
(Error = 1 sigma from STDerr)

Note: Result = Rn decays per second (NOT radon + daughter decays)

Raw data adjustments

1) Volume Adjustment: Accounting for the volumes of the test vessel + test chamber (33+0.7 litres):

2) Humidity Adjustment: Accounting for loss in sensitivity due to plate-out on water droplets in detector (Humidity <6% - giving an adjustment of <6%)

3) Background Subtraction: Remove background from measurement measured background: = 0.021 +/- 0.007 Bq total activity

4) Emanation time adjustment: To convert result to expected equilibrium level.

Adjust by: $1/(1-e^{t/5.52})$ with 't' in days)

Backgrounds & Sensitivity

Background tests:

Sample	Fill gas	Emanation time (days)	Mean humidity	Raw result (Bq/m^3)	Adjusted result (Rn atoms.s^{-1})
Empty Vessel	Dry nitrogen	0	20.0	0.5 +/- 0.1	0.017 +/- 0.003
Empty Vessel	Dry nitrogen	21	22.7	0.6 +/- 0.2	0.021 +/- 0.007

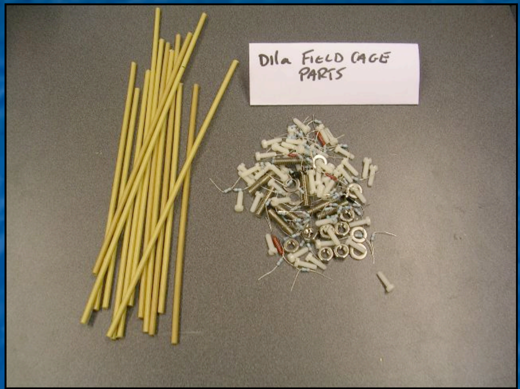
Background level measurements consistent and reproducible (with a given fill-gas) and apparently independent of emanation time (so likely not due to production of Rn in system)

Limit of sensitivity (The minimum activity detectable) is determined from error in the background ×2 (for 2 sigma) and ×1.4 (to account for combination of errors for sample and background)

Limit of Sensitivity ~ 0.02 Rn atoms.s^{-1} (for emanation time >7 days)

(About 3 times higher than the SNO emanation tests)

DIIa Samples



DIIa sample results

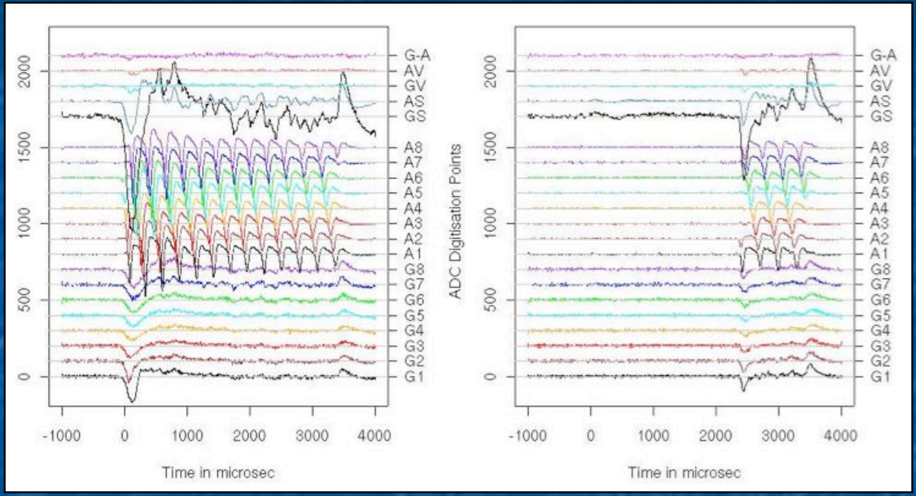
DIIa samples:

Sample (Emanating into vacuum)	Fill gas	Emanation time (days)	Humidity (%)	Raw result (Bq/m^3)	Adjusted result (Rn atoms.s^{-1})
RG58 coax cables (72m)	Dry N2	12.5	24	9.4 +/- 0.7	0.36 +/- 0.03
Electronics boxes	Dry N2	12	37	1.5 +/- 0.3	0.05 +/- 0.01
Ribbon cables	Dry N2	6.5	23	10.1 +/- 0.7	0.50 +/- 0.03
Grouping Boards	Dry N2	10	37	0.3 +/- 0.2	<0.02 *
Single core & thin coax cables	Dry N2	7	19	1.3 +/- 0.3	0.04 +/- 0.02
Field cage parts	Dry N2	7	33.3	0.6 +/- 0.2	<0.03 *
				Total	0.95 +/- 0.05

* The limit of sensitivity of the method (see above)

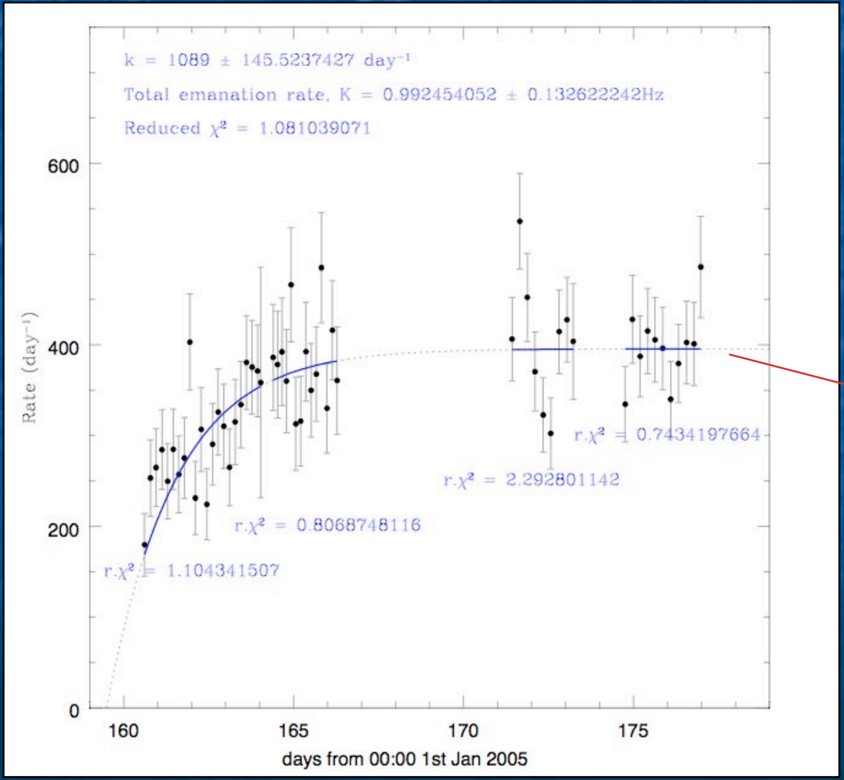
- Main offenders = Ribbon cables and Coax. cables
- Total from items measured = 0.95 +/- 0.05 Rn atoms.s^{-1}:

Comparison with DIIa data



Cathode crossing alpha

Cathode crossing alphas vs. time



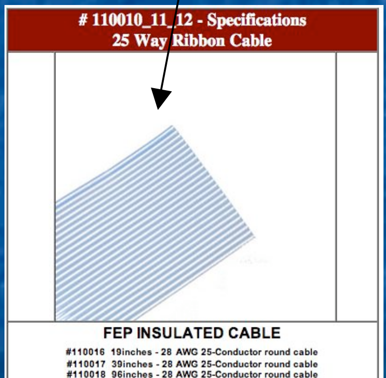
K = 0.99 +/- 0.13 Rn atoms.s^{-1}
(Fits well with material test results)

Replacement DIIa components?

Alternative material samples:
Note: the quantities used are approximately the same as would be required in future DRIFT modules.

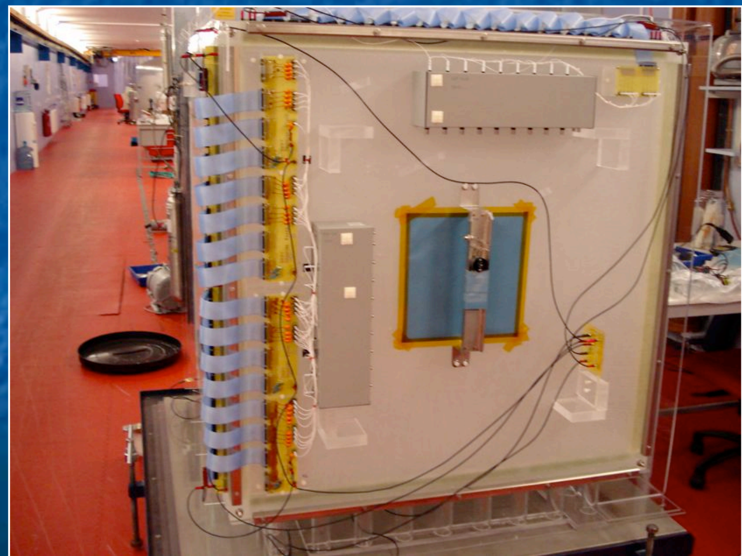
Sample (Emanating into vacuum)	Fill gas	Emanation time (days)	Humidity (%)	Raw result (Bq/m^3)	Adjusted result (Rn atoms.s^{-1})
PTFE signal cables	Dry N2	20	23	0.4 +/- 0.1	<0.02*
Low-Pb ribbon cables	Dry N2	12	17	4.3 +/- 0.3	0.14 +/- 0.01
FEP ribbon cables	Dry N2	12.5	24	0.6 +/- 0.2	<0.02*

* The limit of sensitivity of the method (see above)



Radon reduction refit @ Boulby (Jan/Feb 2007)

Expect SIGNIFICANT decrease in Rn



DIIa results

DRIFT Run	Cathode Crossing Alphas
DRIFT-IIa: July 2005	390 events / day
DRIFT-IIb: July 2006 RG58 cable sheaths removed CS2 directed into inner vessel	99.3 events / day
DRIFT-IIb: Feb 2006 New Coax and Ribbon cables	31.3 events / day

92%
reduction

Summary

- We have a simple but effective Rn emanation facility for measurement / selection of detector components.

- We have used the system to identify the most offending Rn emanators in DIIa - and to screen replacement parts for the DIIb low-Rn refit.

- Although simple - the limit of sensitivity is ~0.02 atoms.s^{-1}: (comparable with the purpose-built SNO apparatus & a factor >20 below level seen with (e.g) the DIIa ribbon cables).

Need anything measured? - Let me know...

What next?

Current DRIFT-IIb tests...

• We have replaced the central cathode to reduce RPRs from long-lived Pb210 (22yr half life).
• Now running at high CS_2 flow rate (8 vessel changes per day).

Longer term...
We need to find a way to discriminate against RPRs...

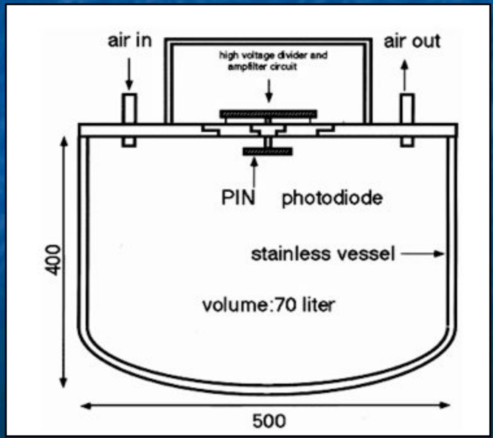
• Absolute Z position from diffusion?
• Take signal from cathode?
• Scintillator cathode?
• Cathode screening?
• Optical readout?

Future material screening.

We have plans to expand / improve our material screening capabilities @ Boulby

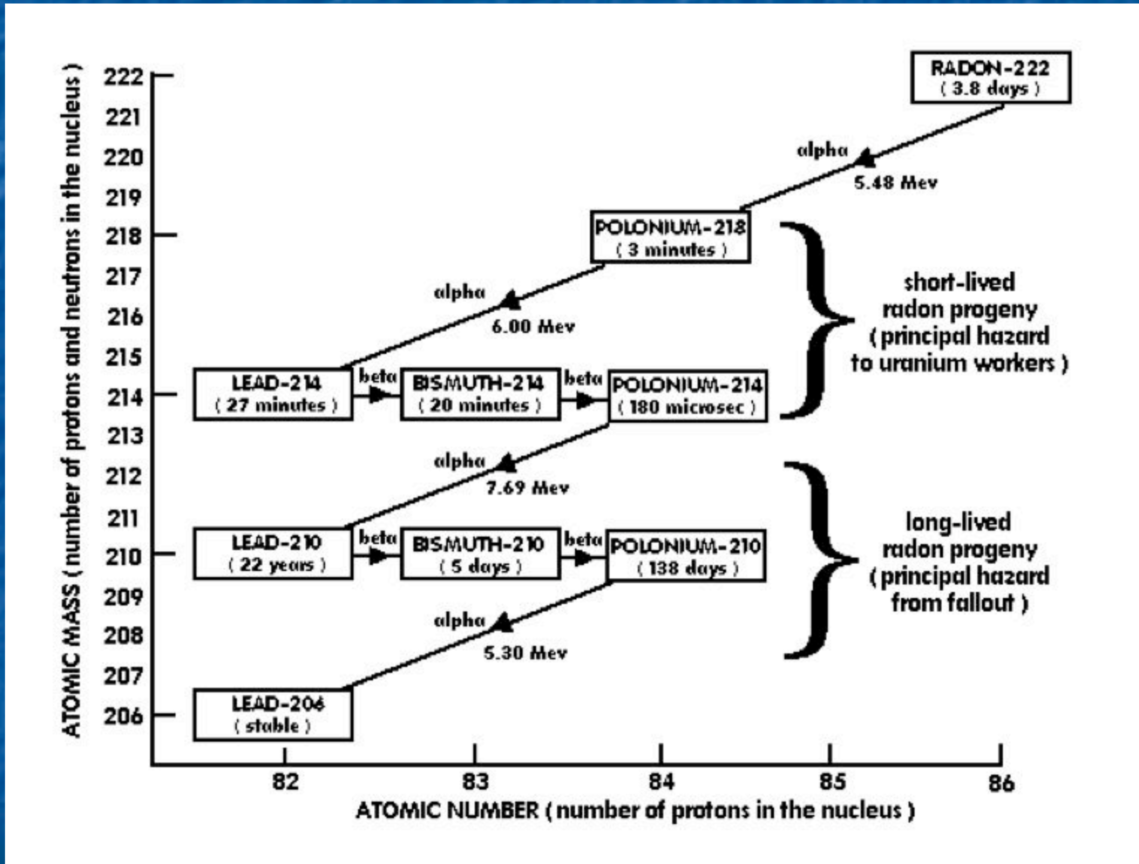
• An additional ultra-low background Germanium detector - sensitivity of 10^{-1}-10^{-2} ppb U/Th for typical samples.

• An improved Rn emanation detection system. An electrostatic trapping device with PIN photodiode detector (similar to module currently used at Modane)



Target sensitivity ~ 10^{-4} atoms.s^{-1} ($\times$100 improvement)

Rn decay chain



- Gaseous element in Uranium decay chain
- Rn222 half life = 3.8 days
- 4 alpha decays before reach stable Pb-206
- Radon levels at Boulby are actually very low! (~3 Bq/m^3)