Constraining Radon Backgrounds in LZ

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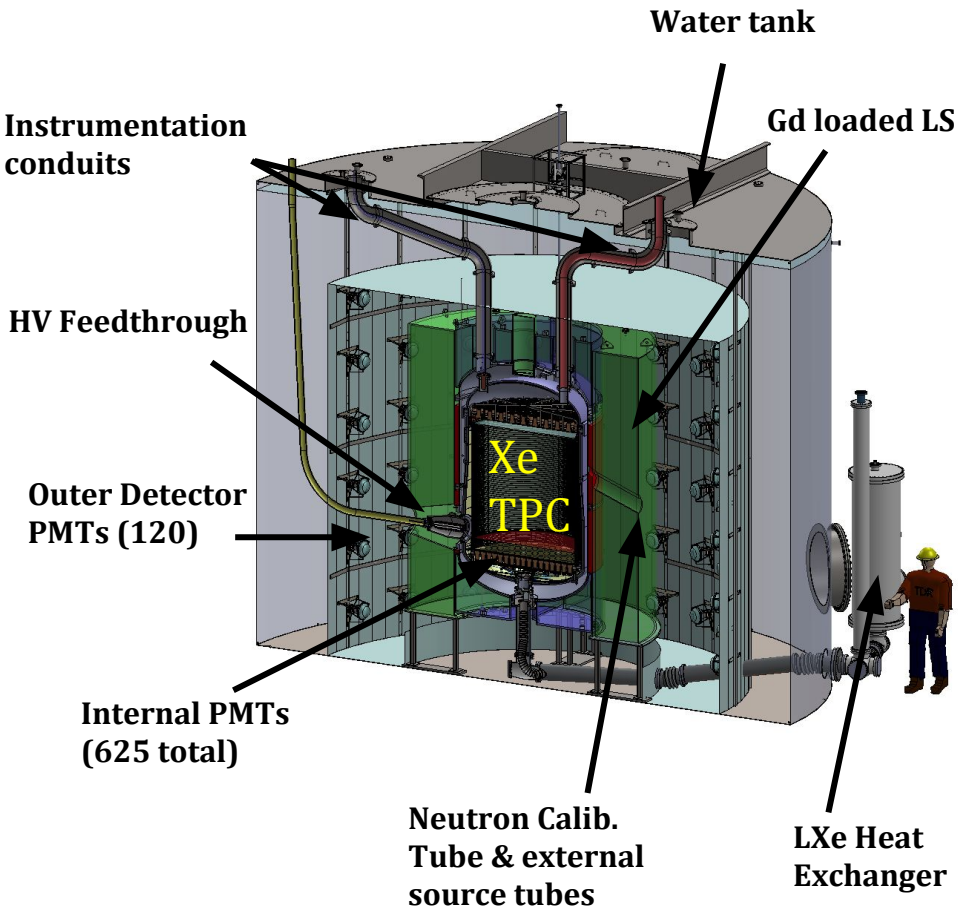
On Behalf of the LZ Collaboration
5/25/17
LRT 2017

The LZ Experiment



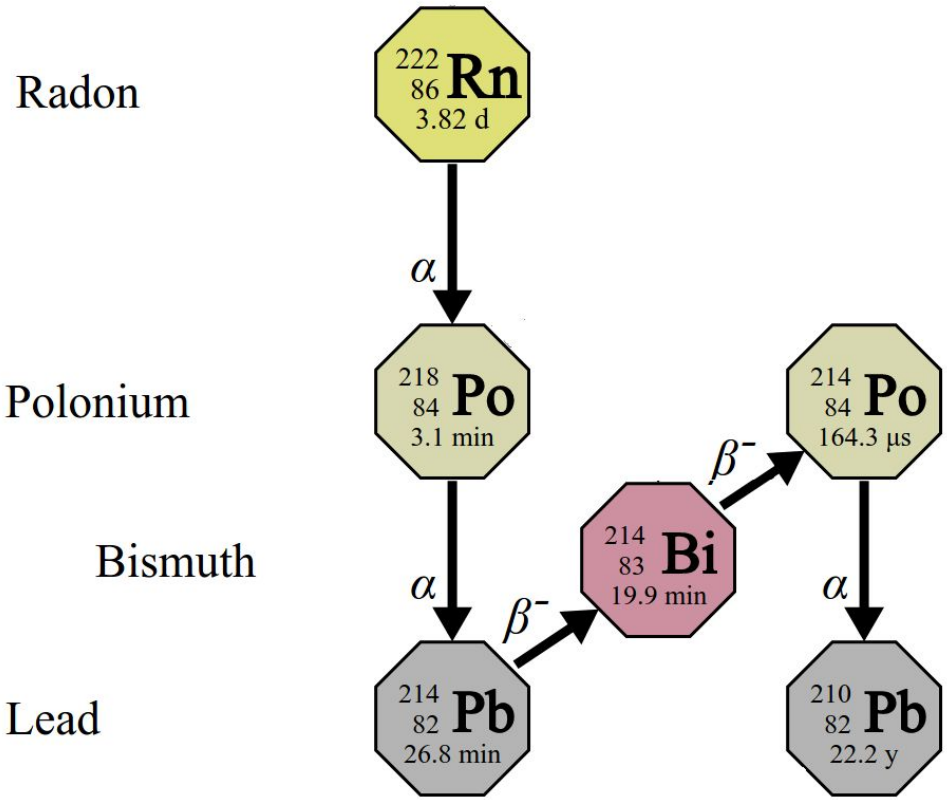
Successor of LUX and ZEPLIN Dark Matter experiments

Fiducial mass: 5.6 tonne liquid Xe

WIMP sensitivity better than 2.3×10^{-48} cm^2 at 40 GeV

Located at the Sanford Underground Research Facility

Backgrounds in LZ



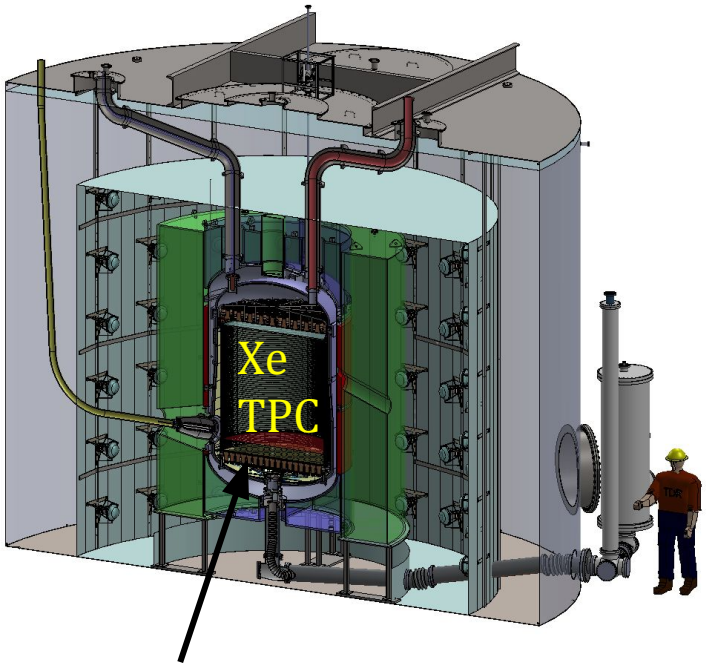
Most Probable (> 99.9%) decays from Radon

Background estimate for 1,000 livetime-days including discrimination and efficiencies:

Environmental	0.05
Argon + Krypton	0.13
^{210}Bi Migration	0.20
Material Contamination	0.28
^{136}Xe	0.34
Neutrinos	1.64
Radon & Daughters	3.49
Total	**6.12**

Radon migrates to fiducial volume; ^{214}Pb decays by untagged beta

Backgrounds in LZ



Radon can decay here

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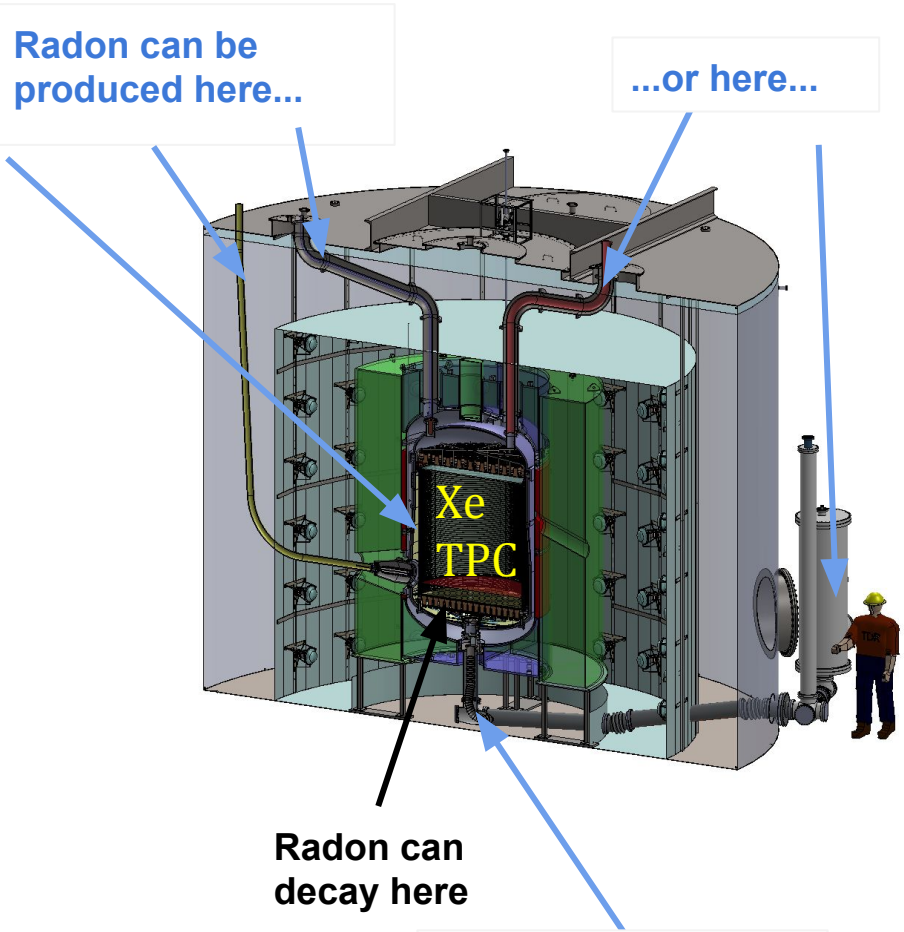

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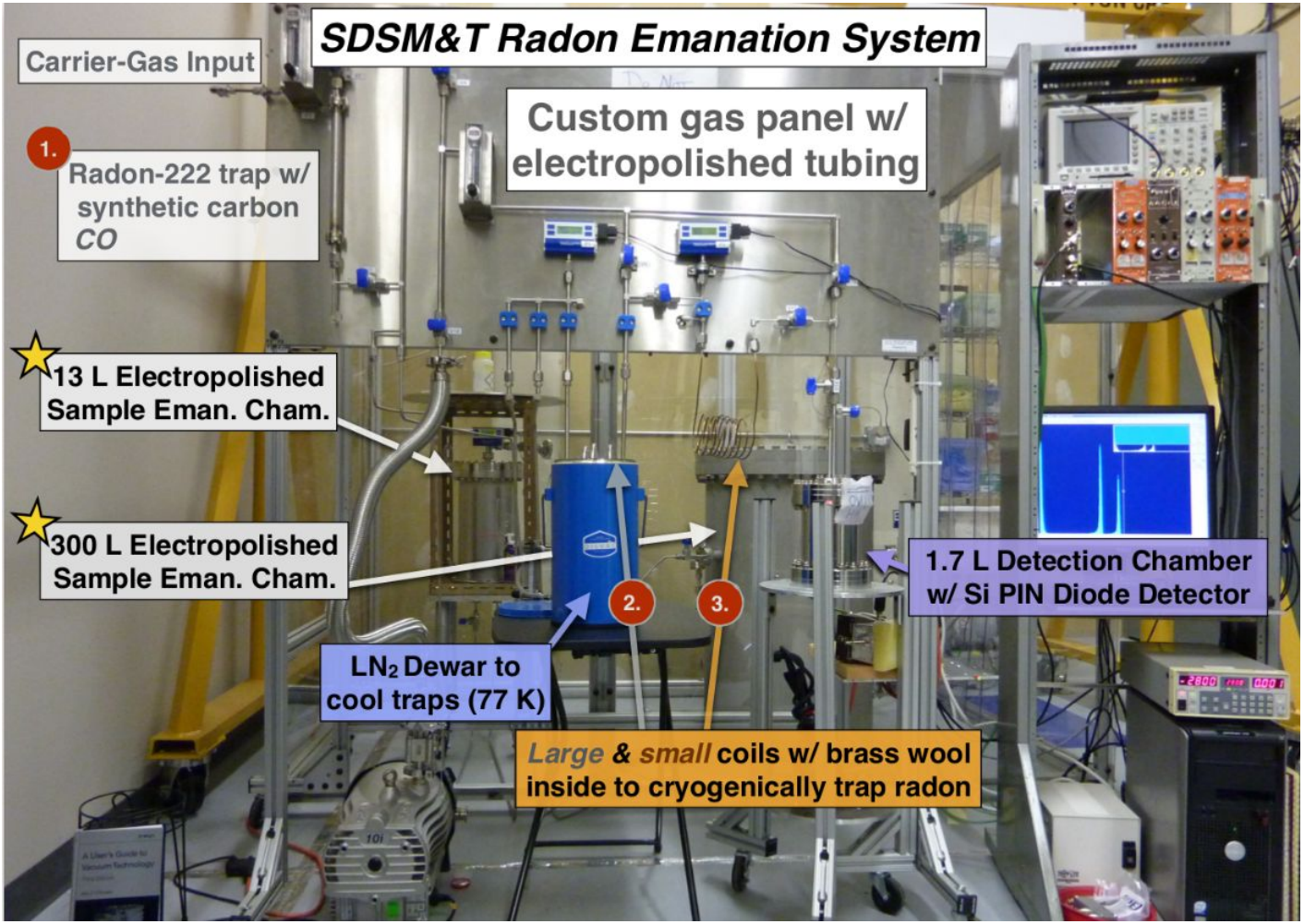
Measuring Radon from Materials



The Radon emanation system at SDSM&T. Image by M. Bowles.

Radon Screening Program for LZ

SOUTH DAKOTA SCHOOL OF MINES & TECHNOLOGY

Planned screening for all materials in contact with Xe

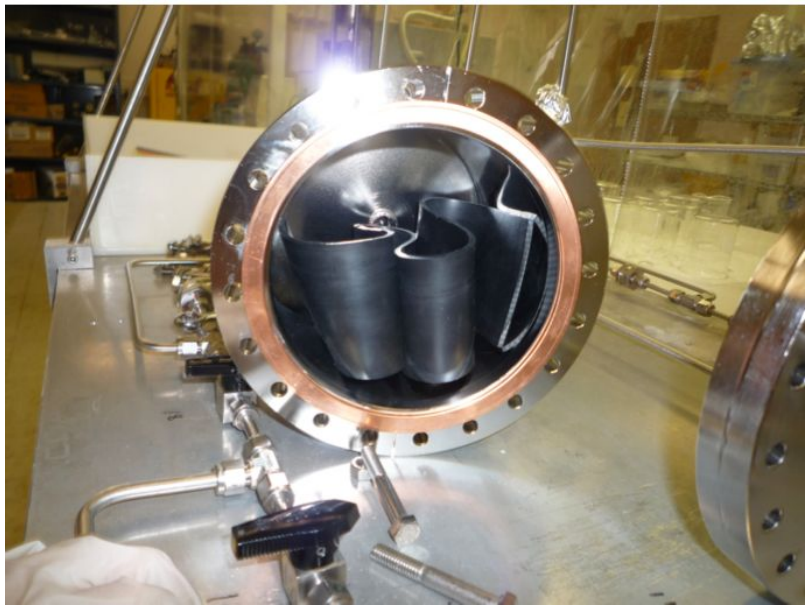
Screening devices at 4 LZ institutions

63 measurements completed so far

System	Technology	Emanation Chamber Volume	Blank Rate	LZ Sample Throughput
UCL	Electrostatic PIN-diode	2.6 liters 2.6 liters	0.2 mBq 0.4 mBq	6 / year
UMD	Electrostatic PIN-diode	4.7 liters	0.2 mBq	12 / year
SDSM&T	Electrostatic PIN-diode	13 liters & 300 liters	<0.3 mBq ~0.3 mBq	18 / year
Alabama	Liquid Scintillator Coincidence	2x 2.6 liters	0.2 mBq	24 / year

Instrument Cross-Calibration

- Each system already calibrated with radon source
- Plans to cross-calibrate all systems with at least two samples (blind)
  - One higher rate to calibrate efficiency w/o interference from backgrounds (rubber)
  - One lower rate to check understanding of backgrounds (thoriated rods)
- EXO Canadian collaborator J. Farine shared a rubber sample with UA to cross-calibrate systems.
- Measurements with 6/7 vessels agree on source strength within uncertainties
- Will begin sending around thoriated rods soon



The rubber sample in a chamber at UA

Preliminary Screening: PMT Cable

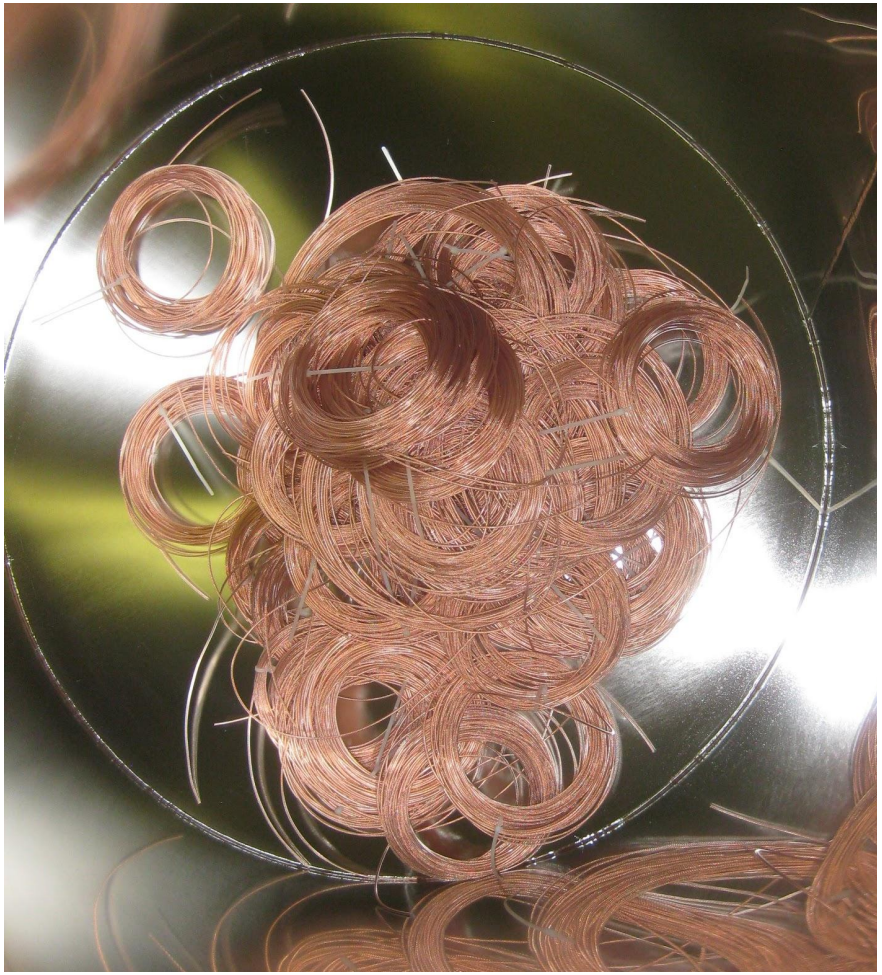
LZ to use over 17 km of PMT cabling

Screened 750 m sample of Axon cable

Preliminary measurement Results:

1.4 ± 0.1 mBq / km

1.4 ± 0.2 mBq / km



750 m of Axon cable in 300 L emanation chamber at SDSM&T

Preliminary Screening: HV Feedthrus

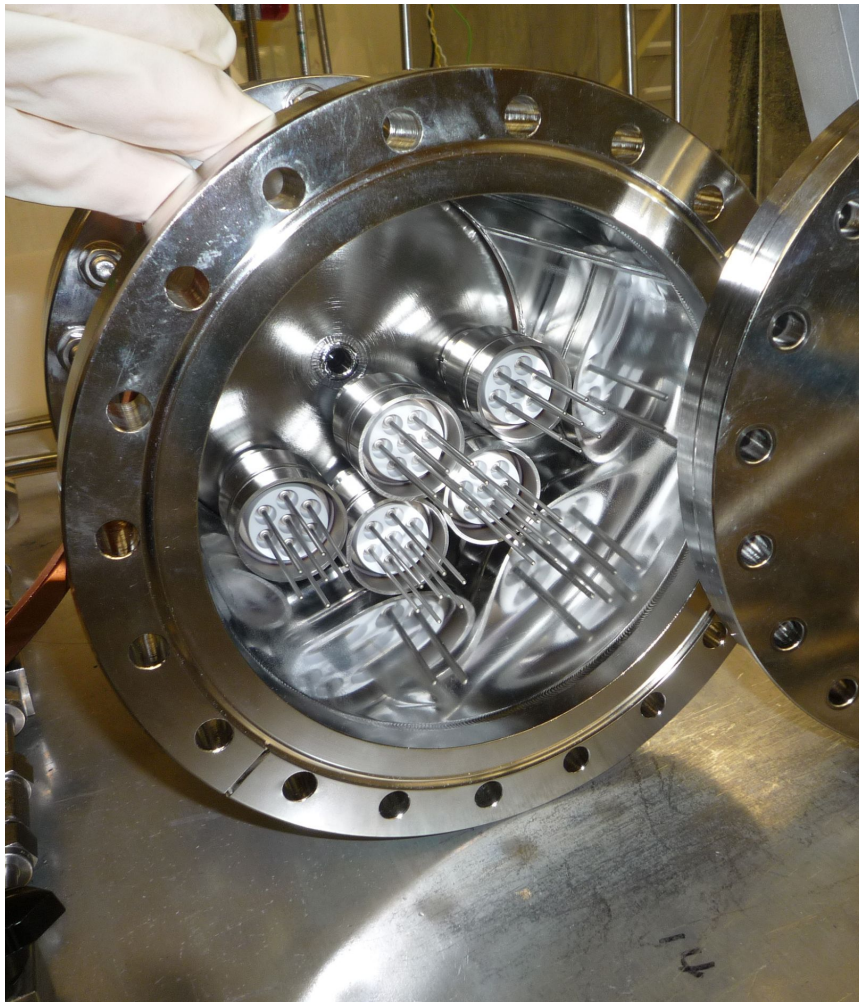
LZ Will have 116 HV feedthroughs, each with 7 pins

Screened 5 samples from manufacturer

Preliminary measurement Results:

0.1 ± 0.05 mBq / feedthrough

0.08 ± 0.06 mBq / feedthrough



5 PMT HV feedthrus in 2.6 L emanation chamber at UA

Preliminary Screening: PMT Bases

LZ Will have 625 PMTs in Xe space; therefore 625 PMT bases

Screened 100 bases post-production

Preliminary measurement Results:

0.28 ± 0.17 mBq / 100 bases

Component-wise assay suggests:

0.19 mBq / 100 bases

100x PMT Bases in 2.6 L emanation chamber at UCL

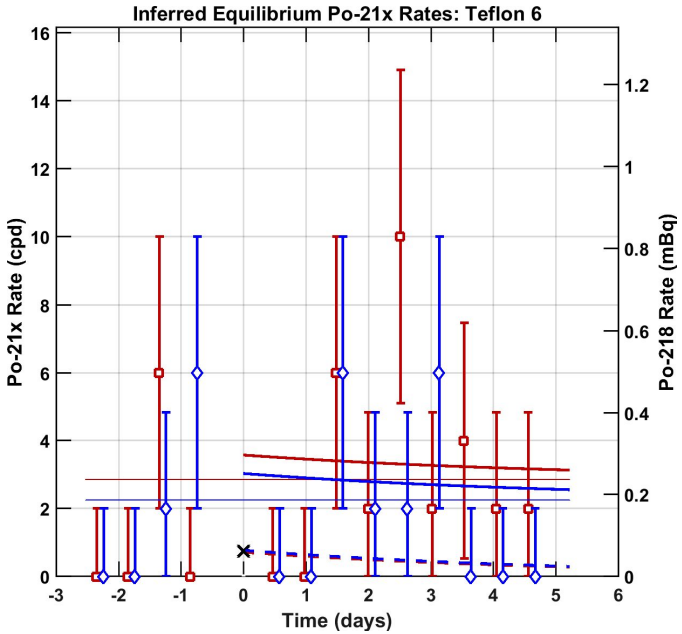
Preliminary Screening: PTFE

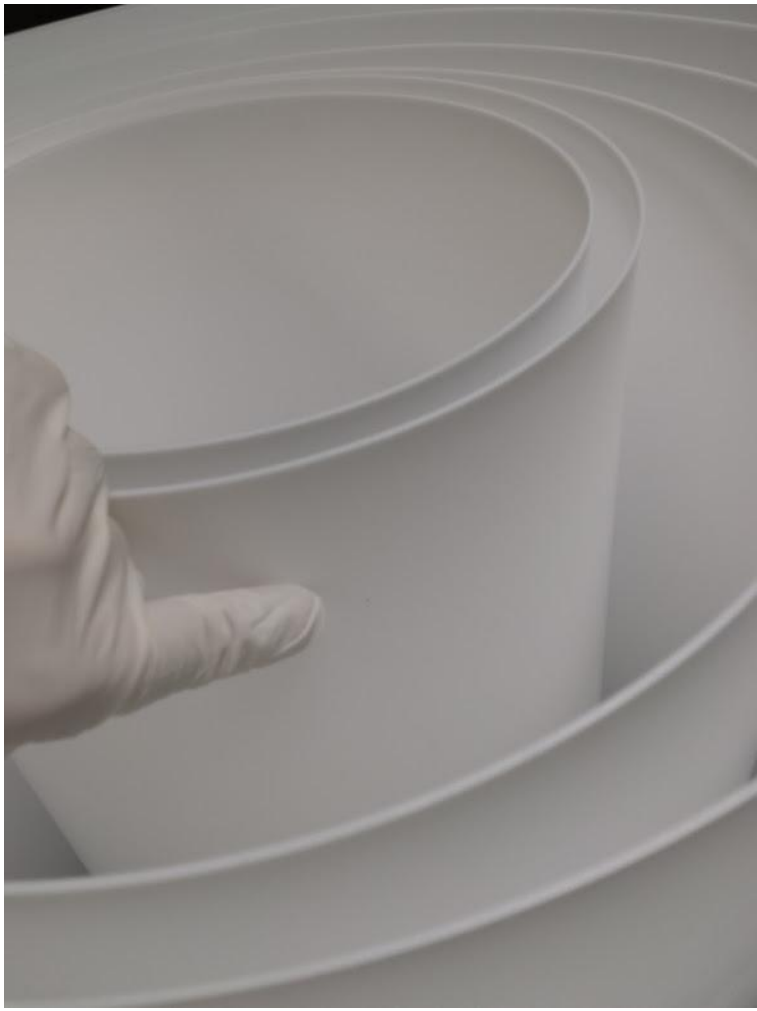
Approx 84 m^2 of PTFE in LZ

Screened 18 m^2 sample of skived material

Preliminary measurement Results:

< 0.015 mBq / m^2





18 m^2 of PTFE, prepared for emanation at SDSM&T

Preliminary Screening: Cathode HV Cable

LZ will have about 8 m of (very) high-voltage cable to provide power to cathode.

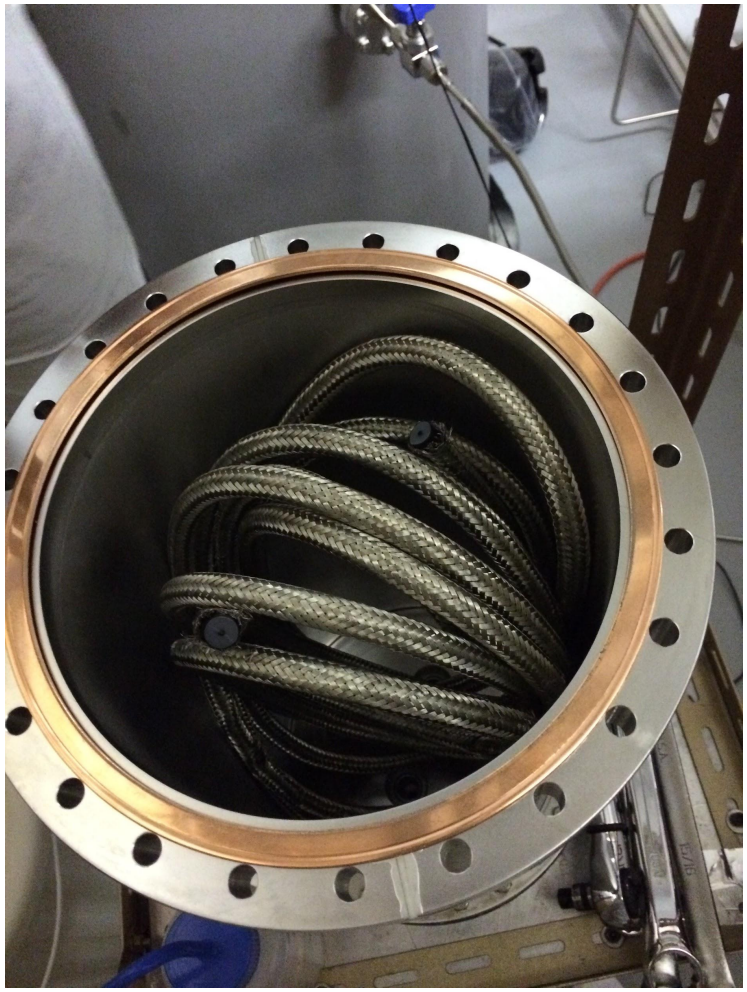
Screened 8 m sample of cable material

Preliminary measurement Results:

0.73 ± 0.33 mBq / m

0.26 ± 0.06 mBq / m (w/o ground braid)

This cable has been rejected, for a variety of reasons.



8 m of umbilical cable in 13 L emanation chamber at SDSM&T

Significant Preliminary Screening Results

Material	Result	Units	Contribution without mitigation
PMT Cable - Axon	1.4 ± 0.1 1.4 ± 0.2	mBq / km	24 mBq 24 mBq
PMT HV Feedthroughs	0.1 ± 0.05 0.08 ± 0.06	mBq / unit	12.2 mBq 9.8 mBq
PMT Bases	0.28 ± 0.17	mBq / 100	1.8 mBq
PTFE	< 0.015	mBq / m^2	< 1.29 mBq
Umbilical Cable (rejected)	0.73 ± 0.33 0.26 ± 0.06	mBq / m	5.6 mBq 2.1 mBq

Sum of Rn production from all materials should be less than 10 mBq.

10 mBq expected from dust as well.

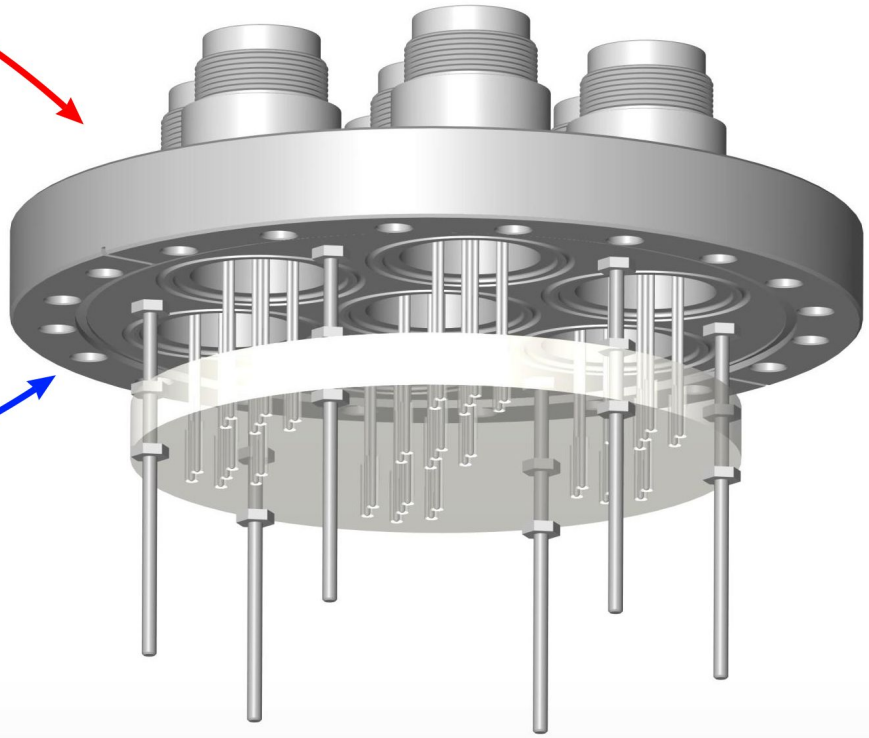
Radon Mitigation: Epoxy on Feedthrough

Coat wetted side of ceramic feedthrough with epoxy to prevent migration of radon.

Mine Air

Artist's representation of the wetted side of the HV feedthroughs with a Rn plug. Just add epoxy!

Gaseous Xe



Radon Mitigation: Carbon Trap

Radon can be removed from Xe with cooled carbon trap

Purification of full recirculation impractical, but can clean select regions:

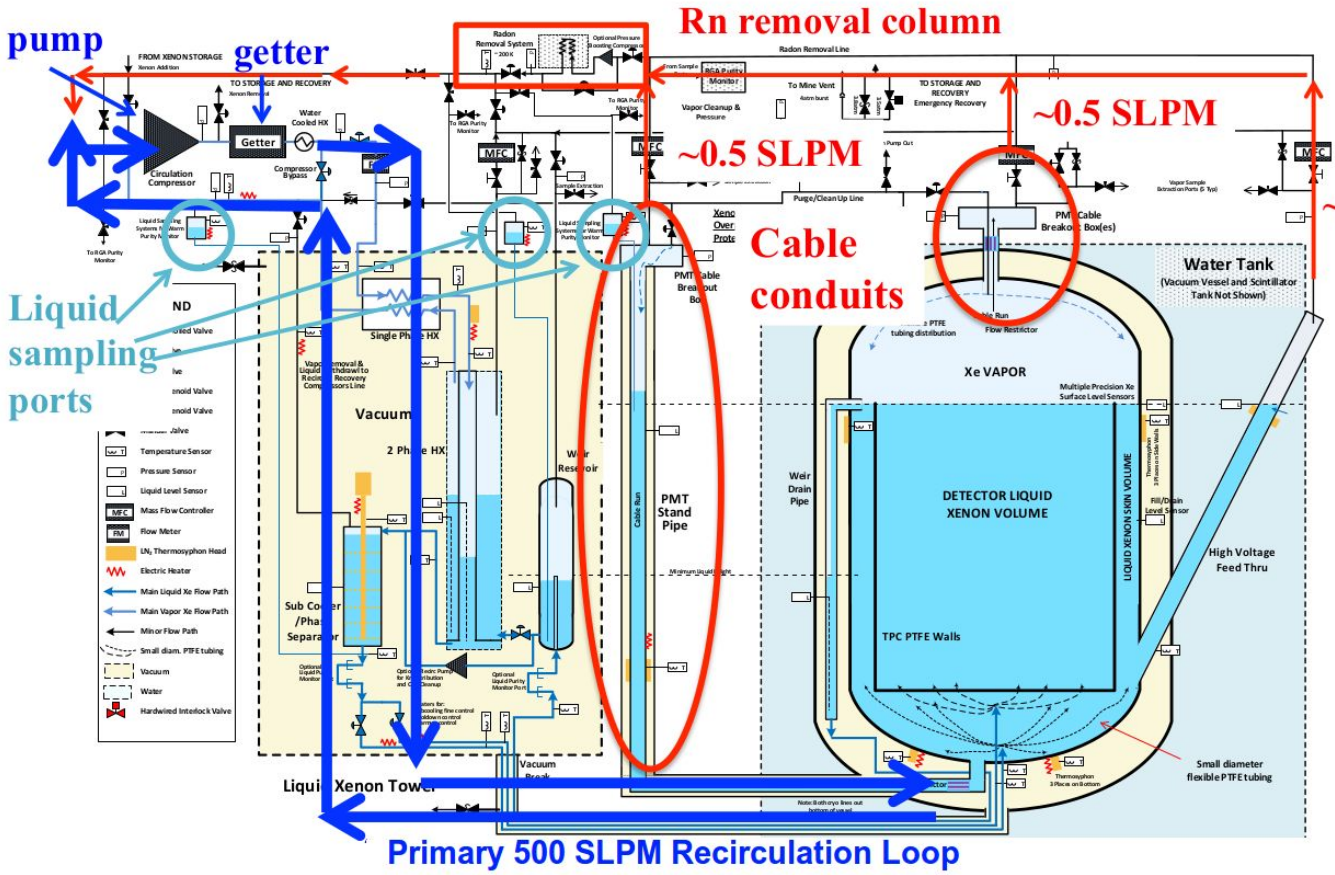


Image by
K. Pushkin, UM

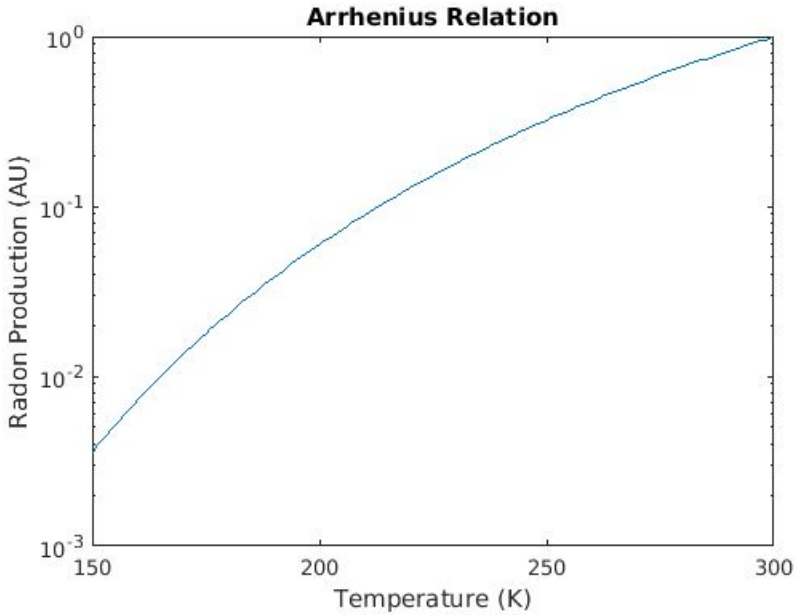
Radon Mitigation: Temperature

Diffusion of radon slows at low temperature, following Arrhenius relation:

$$D = A \exp(-T/T_0)$$

This implies ~100x reduction of radon **diffusing** out of typical materials and into LZ (170K) relative to screenings (300K)

Surface effects, like emanation from recoils or dust, are unaffected by temperature



Preliminary Screening Results After Mitigation

Material	Result	Units	Contribution	After Mitigation
PMT Cable - Axon	1.4 ± 0.1 1.4 ± 0.2	mBq / km	24 mBq	1.2 mBq
PMT HV Feedthroughs	0.05 ± 0.02 0.04 ± 0.03	mBq / unit	6.1 mBq 4.9 mBq	0.6 mBq 0.5 mBq
PMT Bases	0.28 ± 0.17	mBq / 100	1.8 mBq	< 1.8 mBq
PTFE	< 0.015	mBq / m^2	< 1.29 mBq	< 1.29 mBq
Umbilical Cable (rejected)	0.73 ± 0.33 0.26 ± 0.06	mBq / m	5.6 mBq 2.1 mBq	

Sum of Rn production from all materials should be less than 10 mBq.

10 mBq expected from dust as well.

Preliminary Radon Estimate for LZ

Material	Component(s)	Quantity	Unit	Estimate (mBq)
Al_2O_3 resistor	PMT Bases	9790	#	**0.58***
$BaTiO_3$ capacitor	PMT Bases	3010	#	**0.016***
Cirlex	PMT Bases	6000	cm^2	**0.37***
Titanium	Cryostat, PMT Mounts, Field Rings, Grid Supports	412,000	cm^2	0.41
PTFE	Reflectors, HV Umbilical	840,000	cm^2	**<1.3***
PMT Cabling†	PMT Cabling	17,000	m	0.09
PMT Feedthrough†	Signal Flange	88	#	**<0.24**
Steel Conduit†	Cabling Conduit	100,000	cm^2	0.055
R11410 PMT	R11410 PMT	488	#	1.26
R8520 PMT	R8520 PMT	90	#	0.15
R8778 PMT	R8778 PMT	36	#	0.09
Polyethylene	HV Umbilical	4200	cm^2	0.10
Tin-coated copper	HV Umbilical	11,000	cm^2	0.002
Tivar	HV Umbilical	3894	cm^2	0.004*
Acetal	HV Umbilical	195	cm^2	0.0002*
Copper	HV Umbilical	39	cm^2	0.000007
Epoxy	HV Umbilical	1000	cm^2	0.0001*
Steel	Cryostat Seals, Xe Recirculation	135,000	cm^2	0.104
Recirculation Pump	Xe Recirculation	1	#	0.1
Purification Getter	Xe Recirculation	2.5	kg	1.34
Transducers & Valves	Xe Recirculation	30	#	0.17
Welds	Recirculation System, Cryostat	32.3	m	**0.11**
Dust				10.0
Total				<16.5

Table slightly updated from LZ TDR

Bo items are measured by collaboration

* items expected to reduce at low temperature

† items whose Rn is mitigated by carbon trap: > 90% reduction.

Summary

Most significant backgrounds in LZ likely to be from Rn daughters

Radon screening program underway for LZ, employing sensitive screeners at 4 institutions

We have identified some mitigation strategies for problematic materials

Satisfactory expectation of 6.5 mBq from materials, and 16.5 mBq total

Questions?