Control of Radon Daughters in the DEAP-3600 Acrylic Vessel

Chris Jillings

Laurentian University Université Laurentienne

SNOLAB

for the DEAP Collaboration

DEAP Collaboration

University of Alberta

D. Grant, P. Gorel, **A. Hallin**, J. Soukup, C. Ng, B.Beltran, J. Tang, K. Olsen, R. Chouinard, T. McElroy, S. Crothers, S. Liu, P. Davis, and A. Vinagreiro

Carleton University

K. Graham, C. Ouellet, Carl Brown

Queen's University

M. Boulay, B. Cai, D. Bearse, B. Broerman, K. Dering, **M. Chen**, S. Florian, R. Gagnon, V.V. Golovko, P. Harvey, M. Kuzniak, J.J. Lidgard, **A. McDonald**, C. Nantais, **A.J. Noble**, E. O'Dwyer, P. Pasuthip, L. Veloce, **W. Rau**, T. Sonley, P. Skensved, M. Ward

SNOLAB/Laurentian

B. Cleveland, F. Duncan, **R. Ford**, **C.J. Jillings,** T. Pollmann

SNOLAB

I. Lawson, K. McFarlane, P. Liimatainen, O. Li, E. Vazquez Jauregui

TRIUMF

F. Retiere, Alex Muir, P-A. Amaudruz, D. Bishop, S. Chan, C. Lim, C. Ohlmann, K. Olchanski , V. Strickland

Rutherford Appleton Laboratory

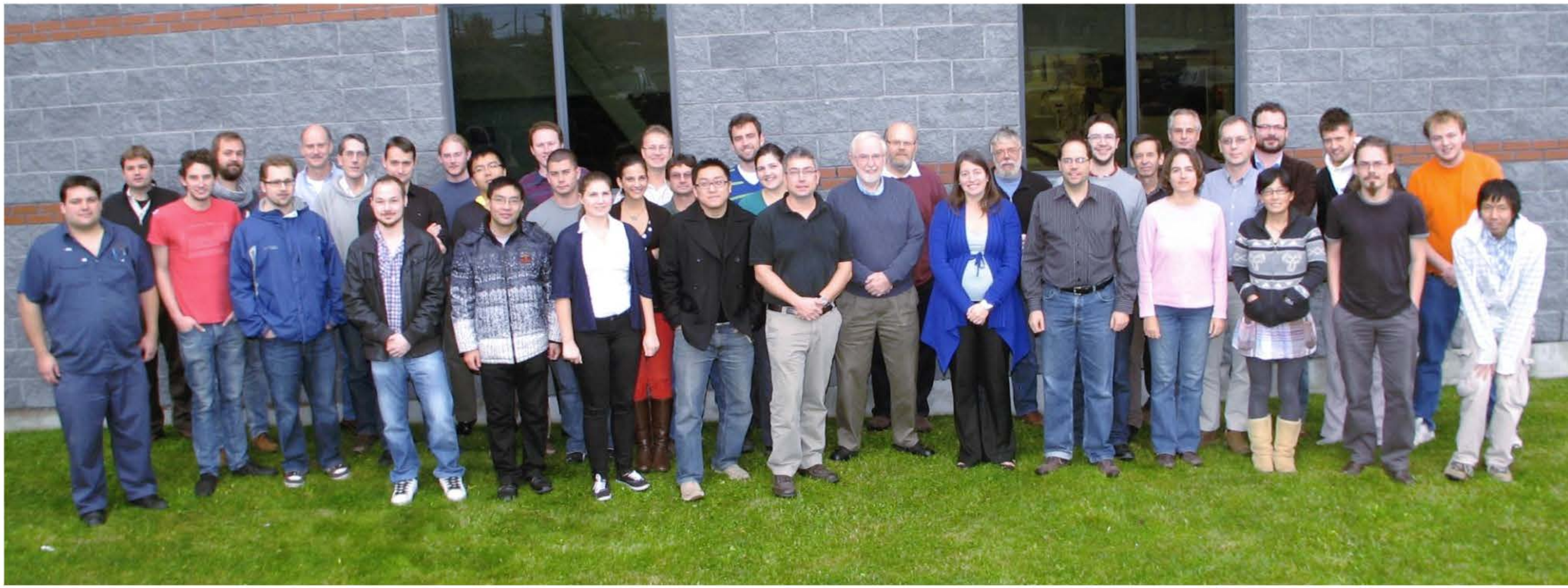
P. Majewski, R. Shah

Royal Holloway University of London

A.Butcher, E. Grace, R. Guenette, **J. Monroe,** J. Walding**,** M. Widorski

University of Sussex

S. Churchwell, G. Booker, **Simon Peeters**



DEAP Collaboration
October 20, 2012

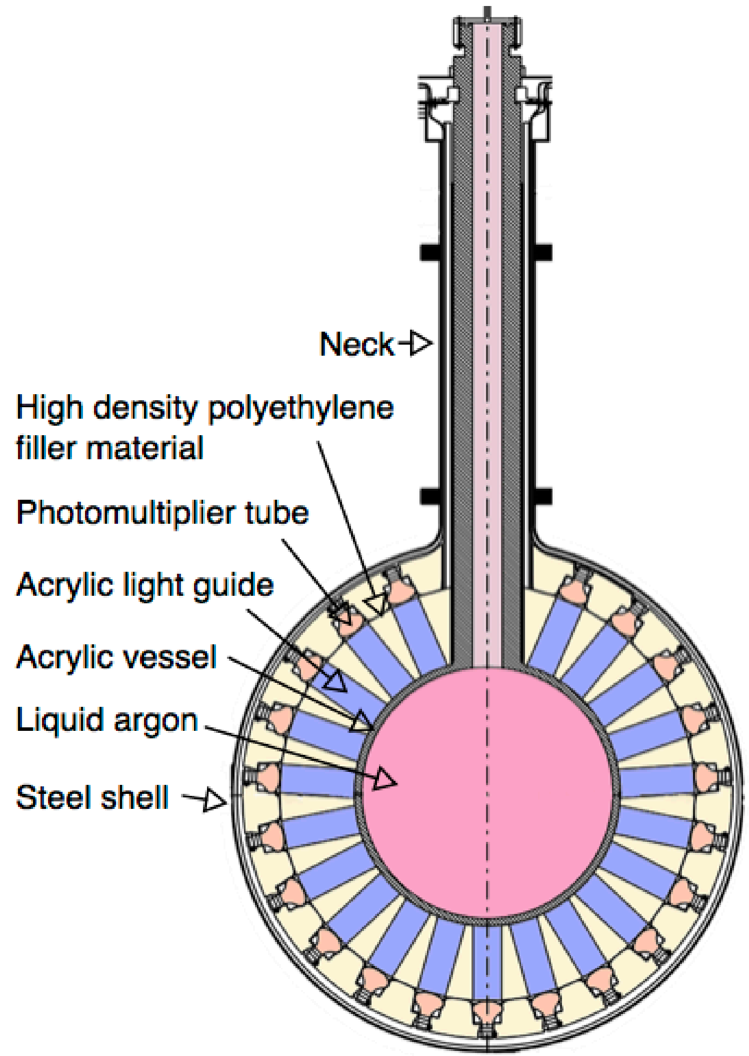
Single-Phase Liquid Argon

Dark matter
Experiment with
Argon and
Pulse-shape discrimination

3600kg LAr in a clean spherical acrylic vessel coated with wavelength shifter

Estimated light yield: 8 pe/keV

Backgrounds: < 0.2
Exposure: 1000kg FV for 3 years



Goal: 10^{-46}cm^2 sensitivity for 100 GeV WIMP

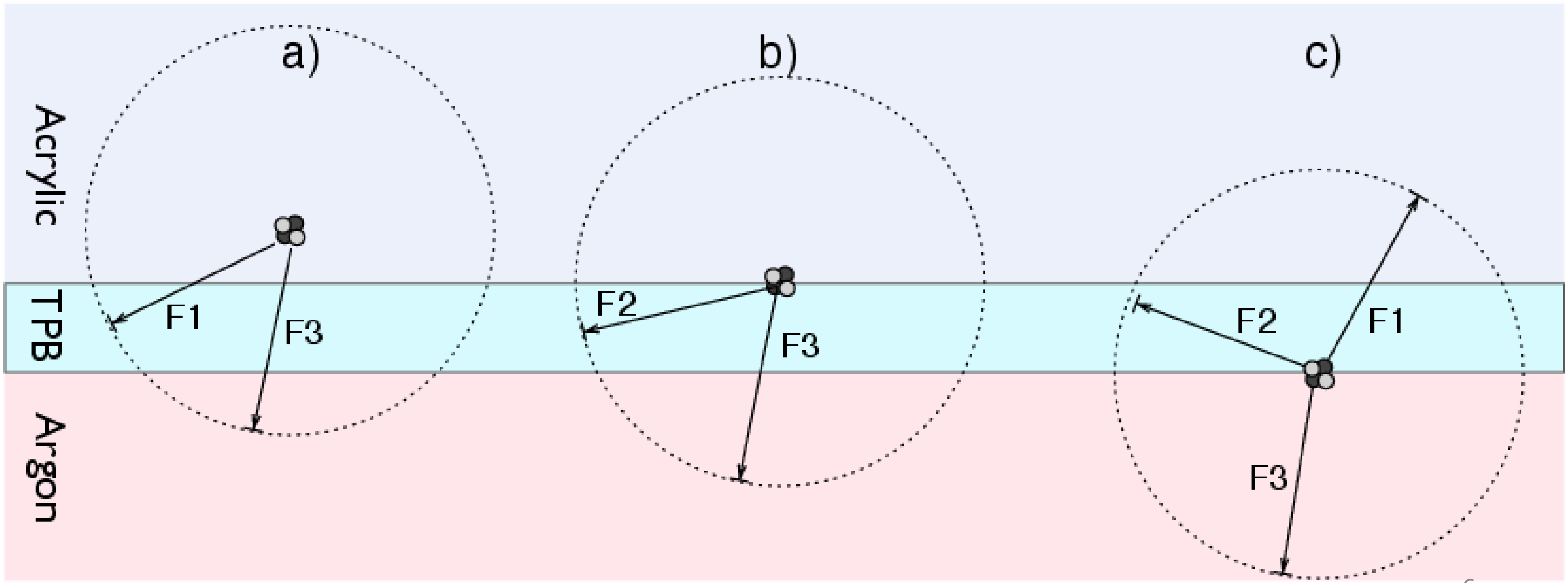
Background Control

Source	Methods
Radon in liquid argon	Charcoal traps; passivated SS lines
Betas and gammas	Pulse-shape discrimination
Neutrons	Screening of components; Plastic (hydrogen) around LAr; Control of alphas in acrylic $^{13}C(\alpha,n)$
Alphas at acrylic surface	This talk

Types of Surface Alphas

Path	Signal
F1	Fraction of E in TPB (Light yield of TPB less than LAr)
F2	Full energy in TPB only
F3	TPB + liquid argon (Much higher light production than WIMP scatter)

Could overlap DM signal

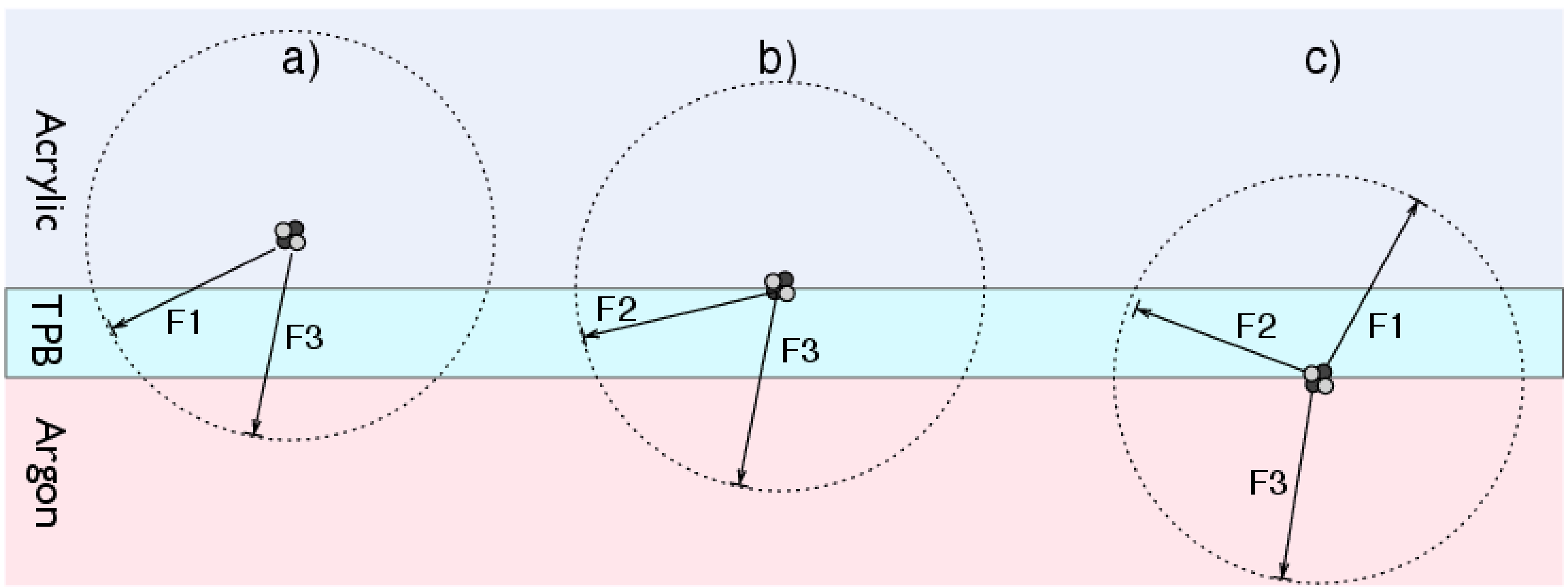


Control Strategy

Limit exposure to ^{222}Rn during manufacture to control long-lived ^{210}Pb

Resurface AV under vacuum after construction

Coat AV with pure TPB under vacuum



Radiopurity Requirements

	Acrylic Vessel Shell
Dominant background	Surface events from bulk contamination
^{238}U	0.3 ppt
^{232}Th	1.3 ppt
^{210}Pb	**1.1 x10^{-8} ppt (= 31mBq/tonne)**

Limits correspond to 0.01 events in 3 tonne-years.
We take credit for position reconstruction but not pulse-shape discrimination for alphas in TPB

^{210}Pb is a daughter of ^{222}Rn and can exist out of equilibrium with the higher isotopes of the ^{238}U chain.
We must quantify the exposure of acrylic material to ^{222}Rn, especially as Radon is soluble in acrylic.

Meeting the Requirements

- Interplay between design of AV and material cleanliness.
  - Must make vessel out of a pure-monomer panel.
  - Can not cast it as a sphere.
  - Start with panels and thermally form them into shape.
- Years of effort assessing optical properties
  - Multiple samples from five suppliers
- Gamma assay
- Verification of contamination levels
  - ***Advertisement: See poster by Corina Nantais***

Process (1/2)

Large petrochemical plant (eastern industrial seaboard of Thailand)

Fractional distillation last stage of process.

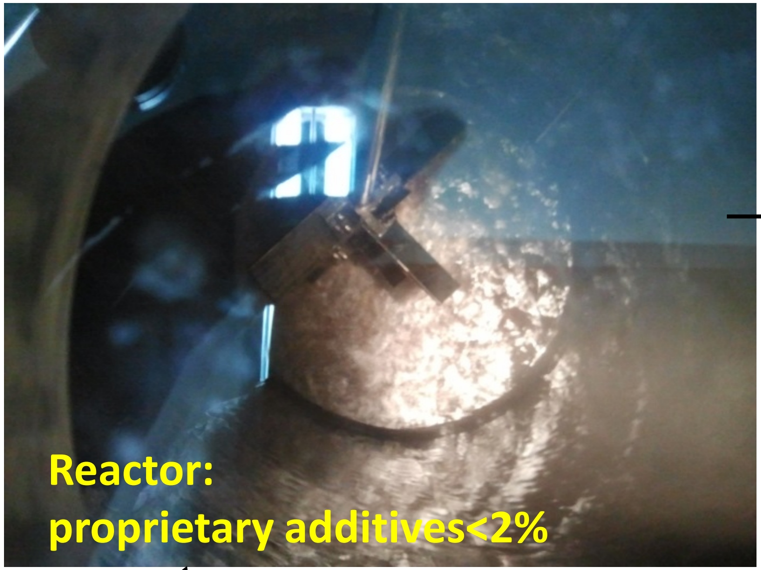
Air introduced with distillation to inhibit spontaneous polymerization.

Our MMA not stored at ThaiMMA.
Truck filled off continuous flow.

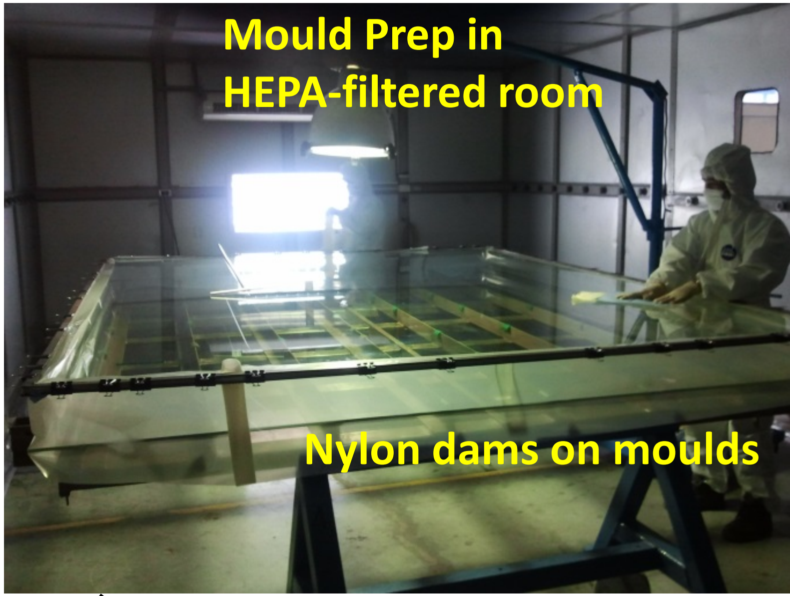
Connection for MMA and air return

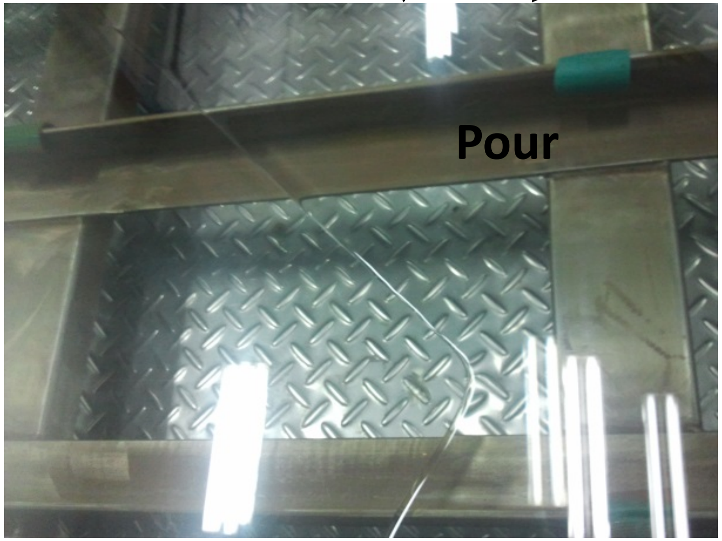
Clean hose to sealed SS storage tank.

Process (2/2)



(short term storage)





Stack moulds for Hydroclave.
Panels "cooked" under water for ~ 1 week.

Construction of Sphere from 5 panels

Most panels for DEAP were 96" x 128" x 4.5" thick
Five panels thermoformed into sphere

Once Panels Are Formed….

Radon penetrates into solid PMMA a distance of 0.17mm
 - Wojcik NIM B61 (1991) pp8-11

The resurfacer will deal with lead left behind by normal (~5Bqm^{-3}) air.

Once the panels are formed we are most concerned with the vessel underground at SNOLAB (~120Bqm^{-3}) and when the vessel is at elevated temperatures (annealing)

One Unit of Radon Contamination

- If MMA is moved into a closed volume, the radon in the volume will enter the MMA.
- Using ρ(MMA) $\cong$ 1 tonne/m^3 and the decay constants of ^{222}Rn and ^{210}Pb we obtain

$$A(^{210}Pb)\left[\frac{mBq}{tonne}\right] = 0.46\, A(^{222}Rn)\left[\frac{Bq}{m^3}\right]$$

This is one unit of radon contamination.

Radon Loads (1/2)

1 unit of contamination

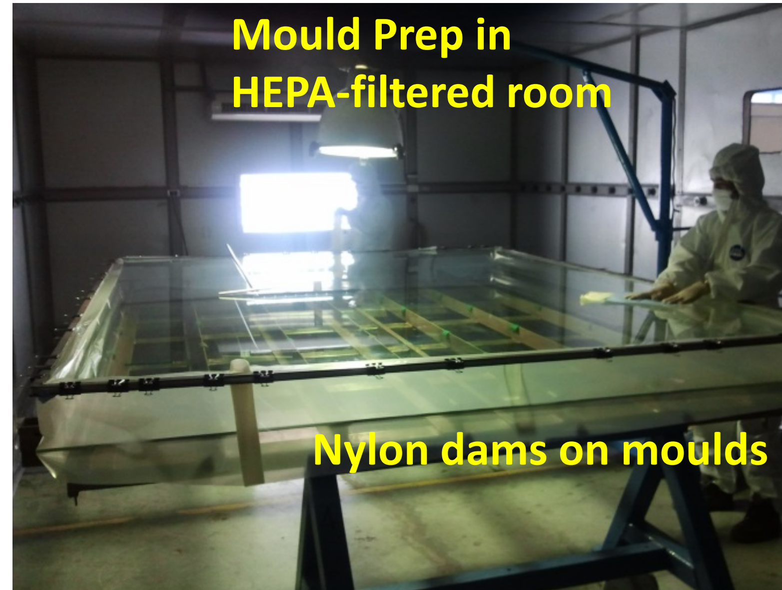
$A = 6.3 \pm 3.5$ Bq/m^3

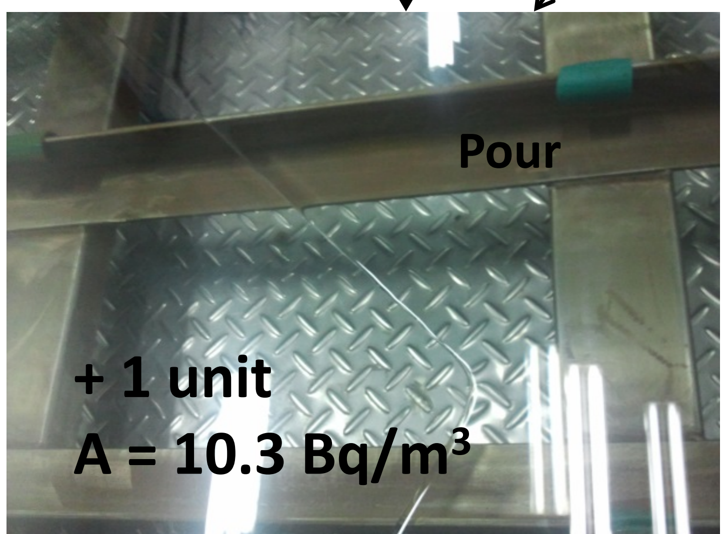
1 unit of contamination

$A \cong 5$Bq/m^3

Radon Loads (2/2)

short term
Storage
+ 1 unit
10.3 Bq/m^3





Stack moulds for
Hydroclave.
Panels “cooked” under
water for ~ 1 week.

Estimated ^{210}Pb Loads

	AV Shell
	Thai MMA
Distillation [cont. units]	1.25
Storage [cont. units]	0
Truck [cont. units]	1
A(^{222}Rn) [Bq/m^3]	3.5±2
Expected ^{210}Pb [mBq/tonne]	3.6
	RPT Asia
MMA Storage tank [cont. units]	1
Reactor Vessel [cont. units]	0.5
Post-reactor storage [cont. units]	1
Moulds [cont. units]	1
A(^{222}Rn) [mBq/m^3]	6.3 to 10.8
Expected ^{210}Pb [mBq/tonne]	10 to 17
Total ^{210}Pb [mBq/tonne]	**14 to 21**

Detailed Radon Diffusion Calculations

$$\frac{\partial C}{\partial t} = D\frac{d^2 C}{dx^2} - \lambda C$$

$$\frac{C_j^{n+1} - C_j^n}{\Delta t} = D\,\frac{C_{j+1} - 2C_j + C_{j-1}}{(\Delta x)^2} - \lambda C_j^n$$

See *Numerical Recipes* or your favourite numerical textbook.

$$\mathrm{Stability} \equiv \frac{2D\Delta t}{(\Delta x)^2} \leq 1$$

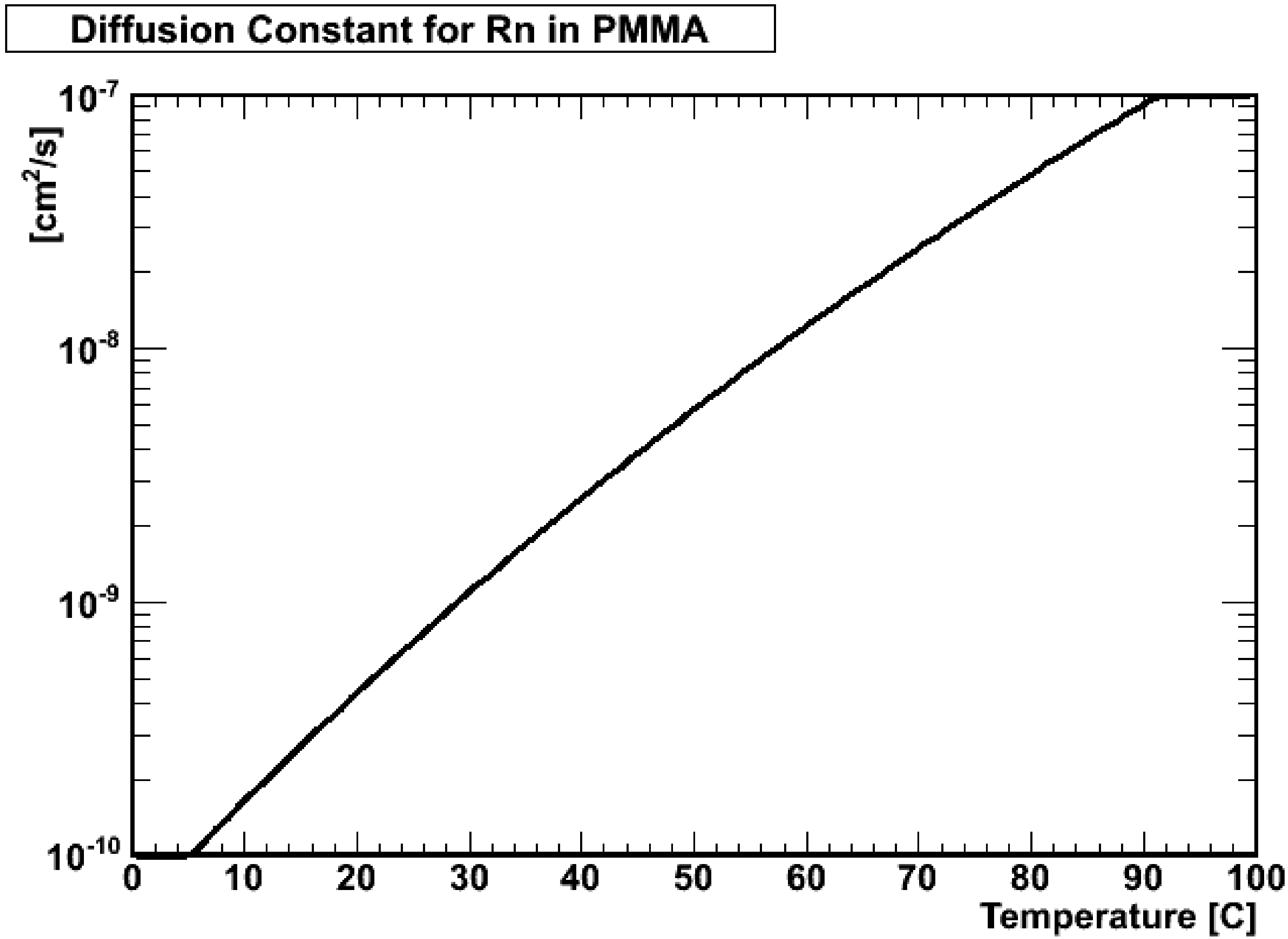
Need the solubility, S, to know the concentration in the first layer of acrylic.

S = S(T) and D = D(T)

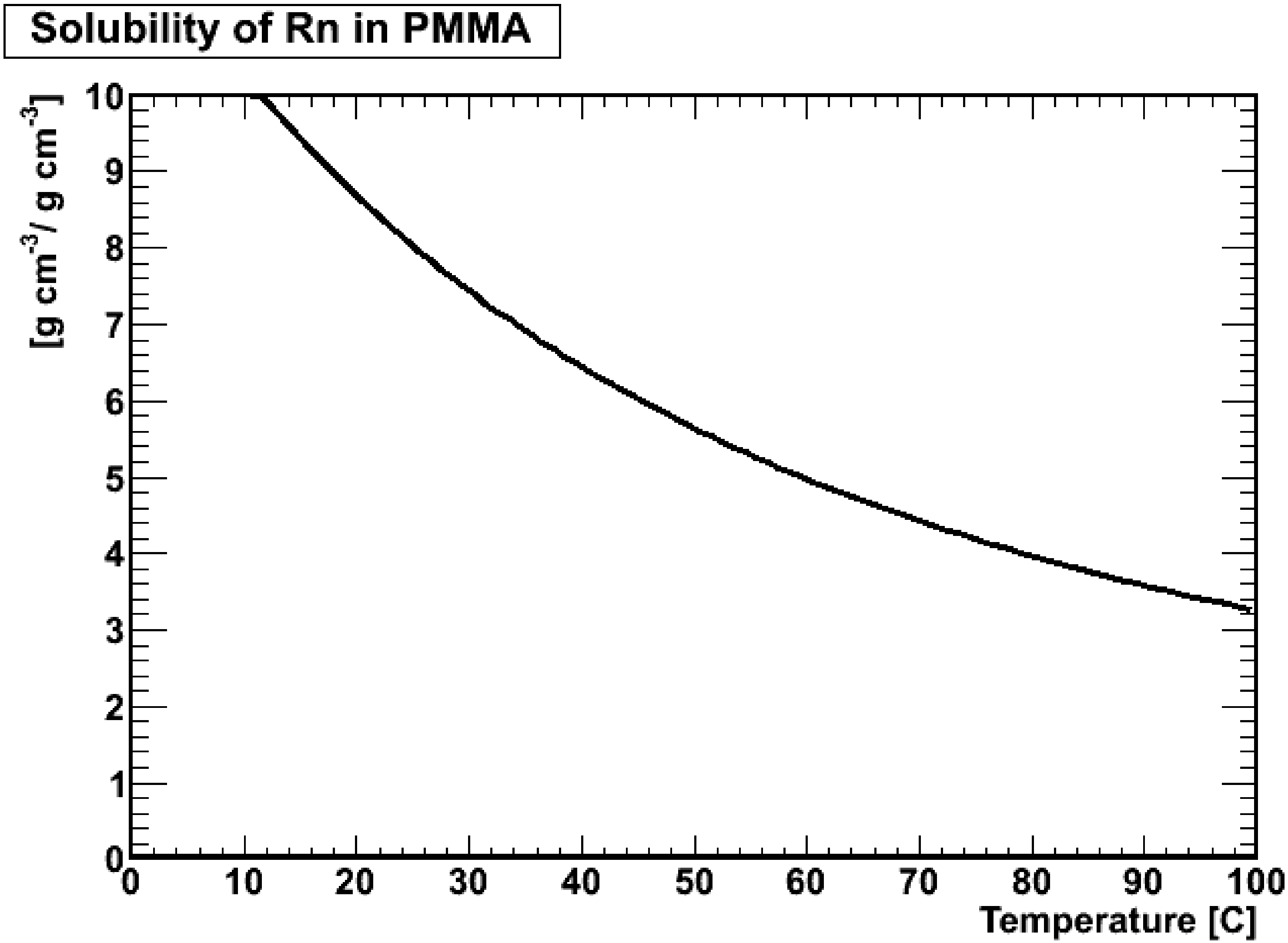
Parameters

- Use Wojcik NIM B61 (1991) pp8-11
- CheFEM, The Sanchez-Lacombe equation of state is used over the complete temperature range, diffusion based on the Free Volume theory for diffusion and the mass transfer is based on Maxwell-Stefan equation for diffusion (chemical potentials from Sanchez Lacombe in combination with the Free Volume expression are used for the mass transfer = permeation calculation)
- $D = D_0 \exp(-\Delta E_d/RT)$ [cm^2/s]
- $S = S_0 \exp(-\Delta H_S/RT)\ 76\ T/273$ [$g\ cm^{-3}$ / $g\ cm^{-3}$]
- $R = 1.986e{-3}$ kcal/mol
- $D_0 = 481.5$; $\Delta E_d = 16.14$
- $S_0 = 3.55e{-4}$; $\Delta H_s = -3.32$

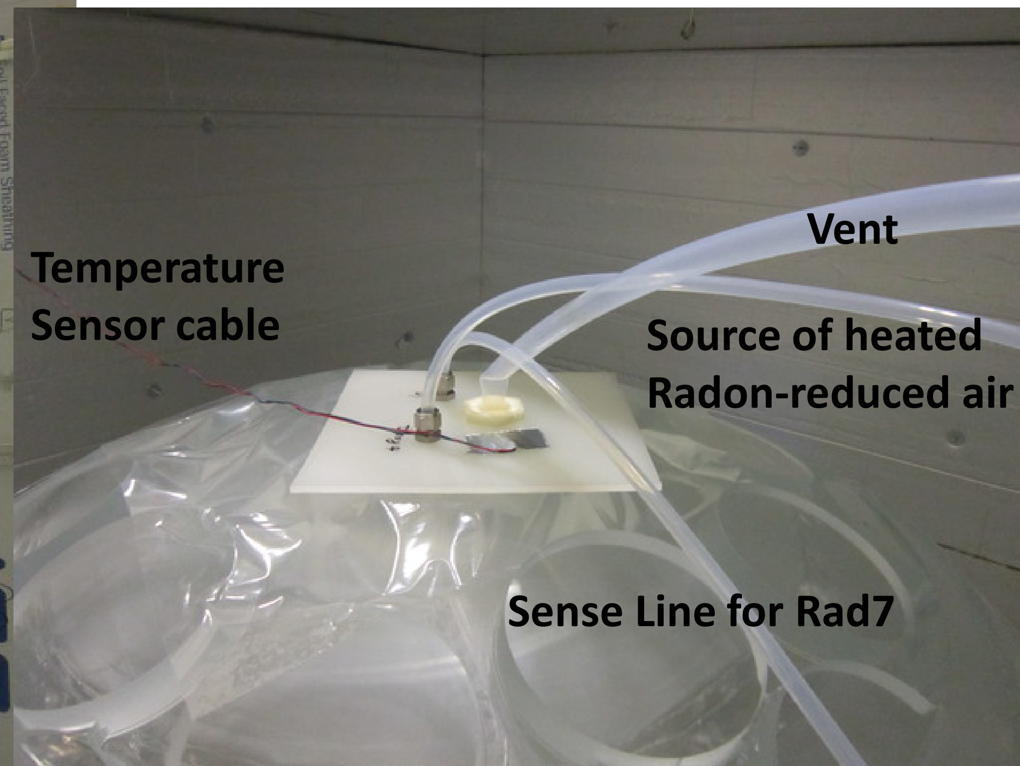
Rn more mobile at high temperature



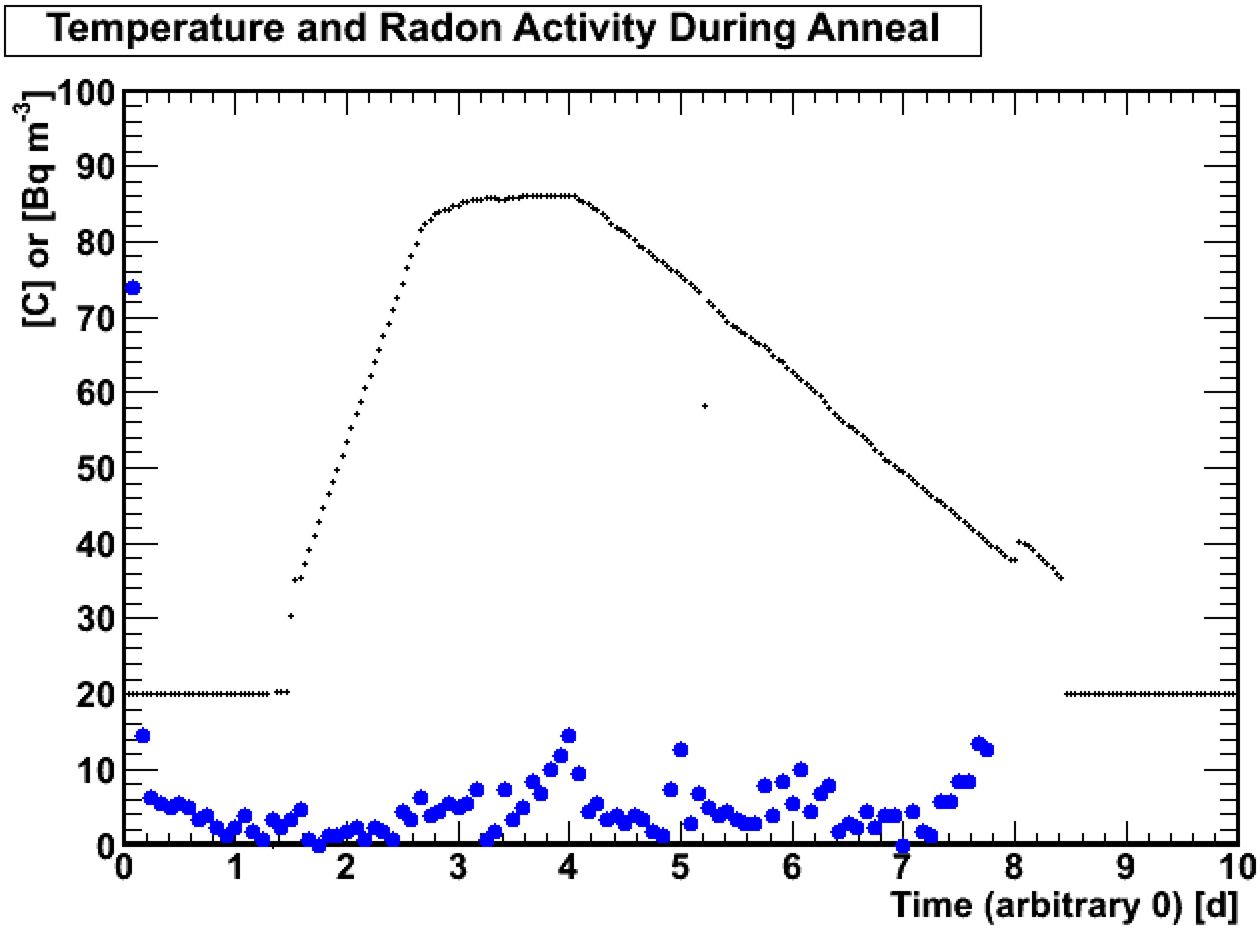
… but less soluble



AV in Oven with Lid for Radon-Reduced Air

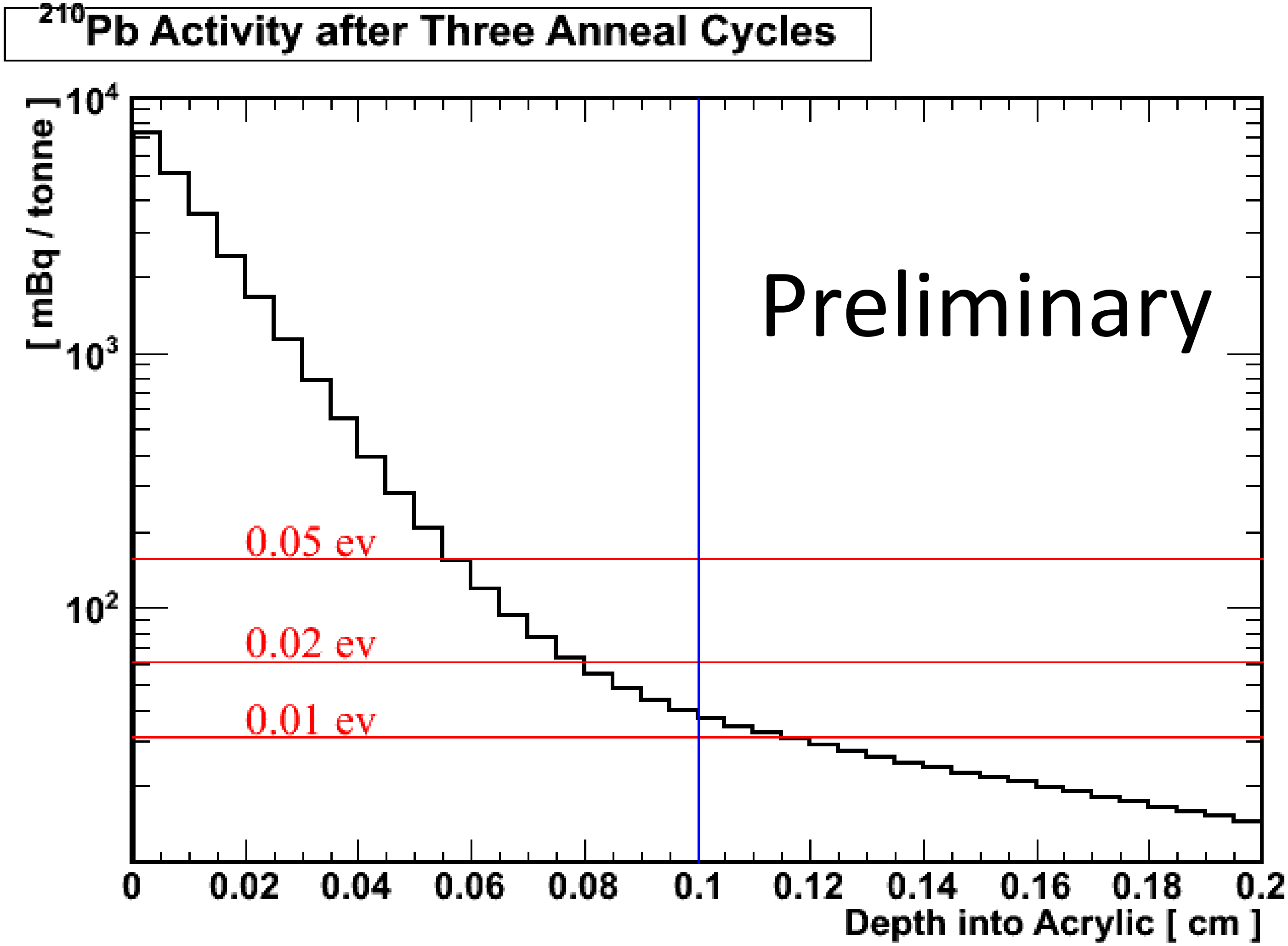


RRA verified with Durridge Rad7*



* Thanks to Ian Lawson for assistance with the Rad-7.

Calculated ^{210}Pb Activity



(Diffusion equation with measured temperatures and activities.)

Conclusions

- A physically strong, optically transparent, radiologically pure acrylic vessel is being built for the DEAP experiment.
- Extensive QA including multiple site visits and excellent co-operation with Reynolds Polymer Technology (Colorado, USA) and RPTAsia (Rayong, Thailand) has resulted in a vessel that will meet DEAP's background requirements.
- To achieve this the vessel was made of virgin monomer with a known radon-exposure history.
- Care was taken during annealing to keep Radon diffusion within acceptable limits.
- With suitable care, a future experiment could improve on our work.