Lead-210: A Radioimpurity In Particle Detectors For Dark Matter Studies

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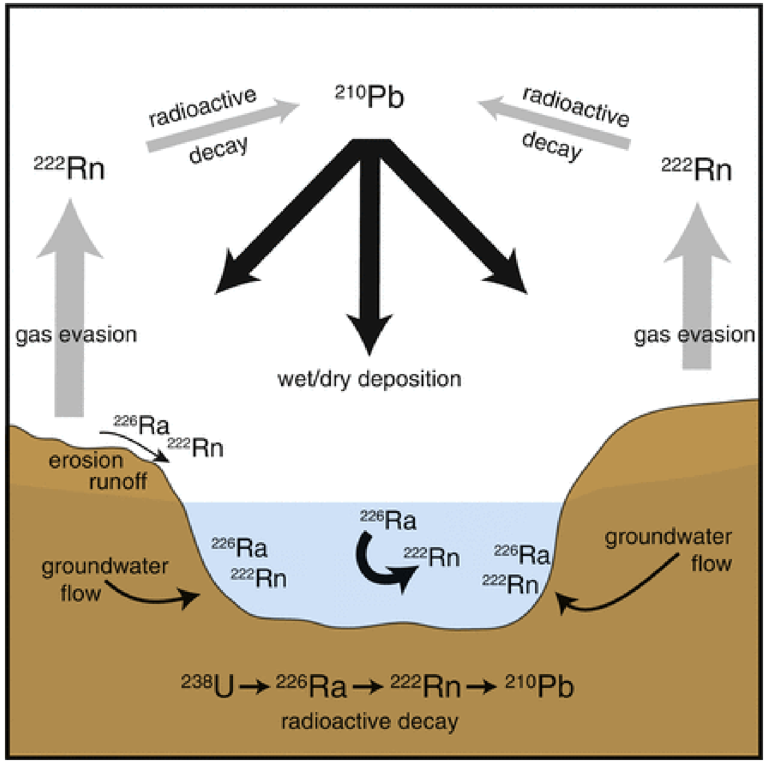
Challenges – ^{210}Pb ($T_{1/2}$ = 22.2 yrs)

Decay product of ^{238}U



Lead-210: intrinsic to the detector material or surface contamination → fundamental limit to the sensitivity of SABRE.

Therefore, it is crucial to characterise this background for improved identification.

Usual practice: direct detection is difficult → wait for in-growth of ^{210}Po.

Solution: Accelerator Mass Spectrometry.

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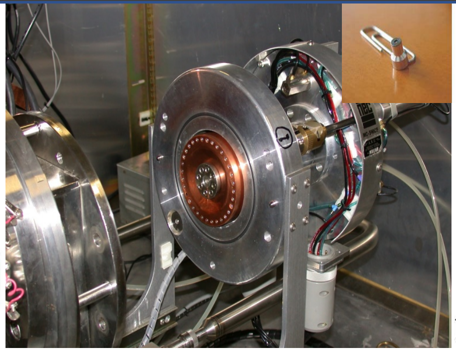
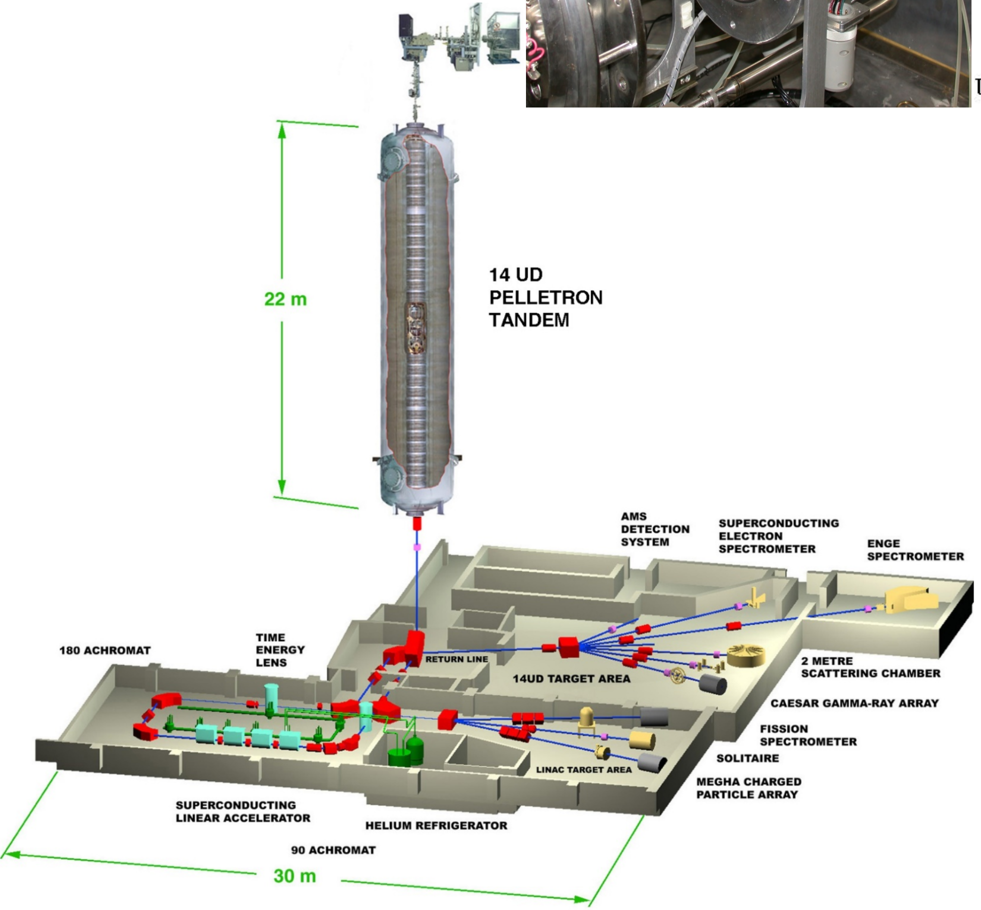
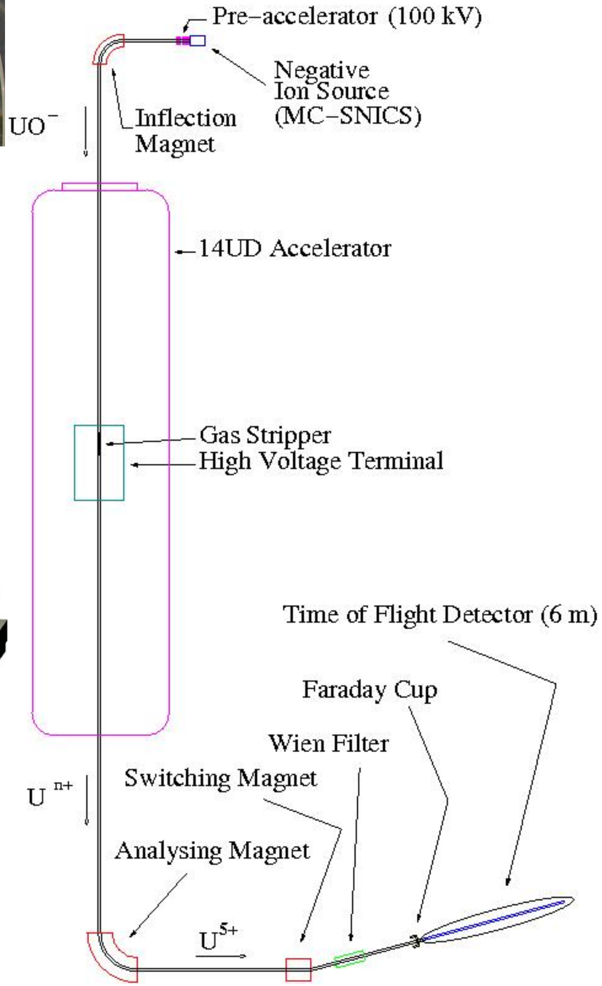
AMS 101







- An atom counting technique.
- Exquisite sensitivity.
- Measures unstable/stable atom ratio with a sensitivity of 10^{-12} - 10^{-17} → requires chemistry!
- Across the whole periodic table.
- Removes molecular interference.

Heavy Ion Accelerator Facility at ANU

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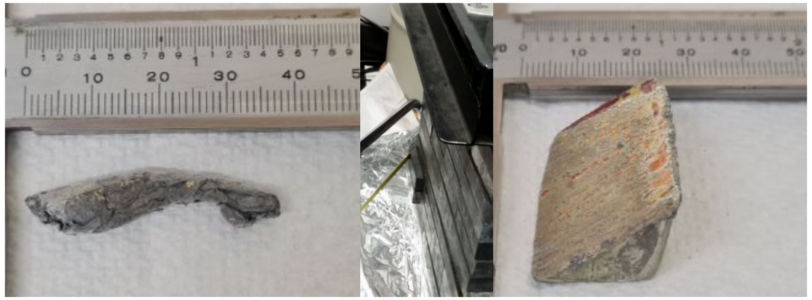
Challenges – Pb vs. NaI



In 1 kg NaI: expected ^{210}Pb = 10 atto gram [1]

→ we need a Pb carrier.

Goal: use only 1 mg Pb → competing with 1 kg NaI

→ Fe/Pb hydroxide precipitation.

Fe/Pb oxide – ideal AMS target?

[1] Antonello *et al.*, Astroparticle Physics, 2019; 106:1-9.

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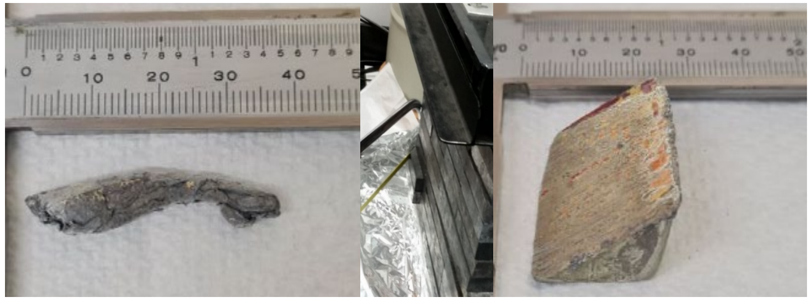

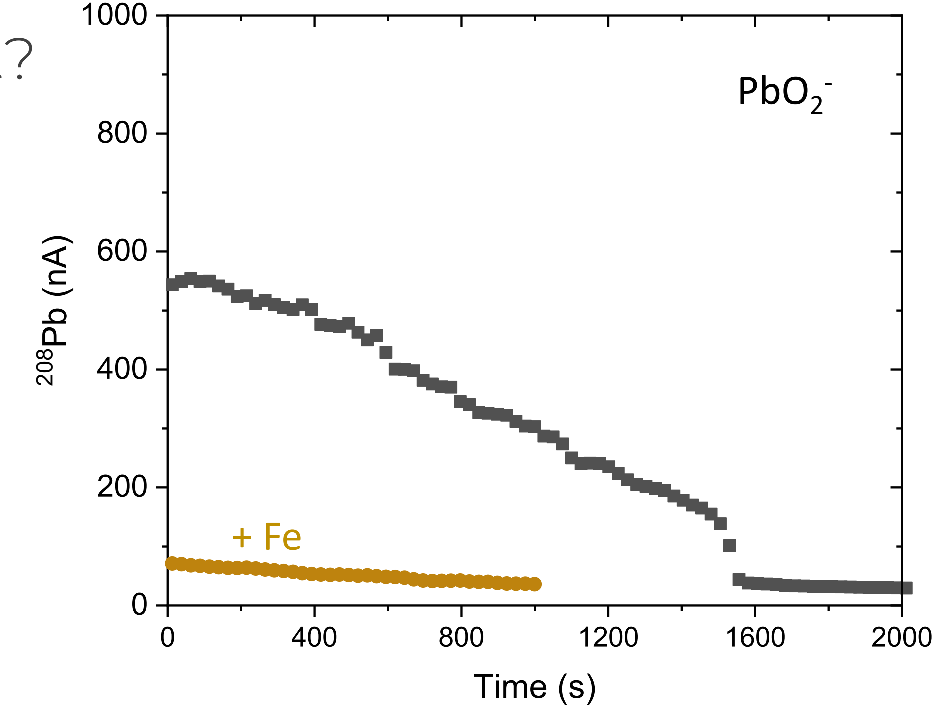

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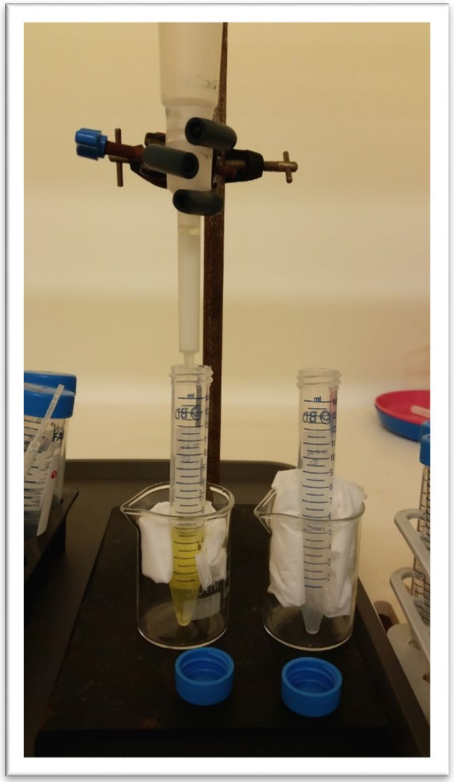
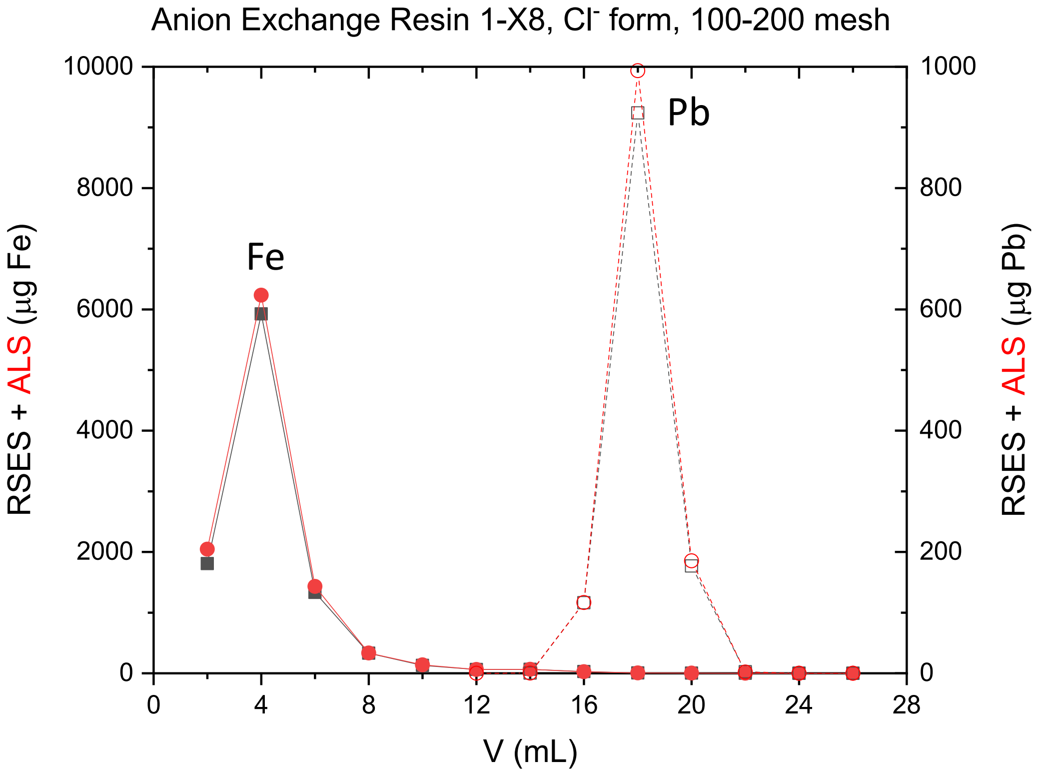
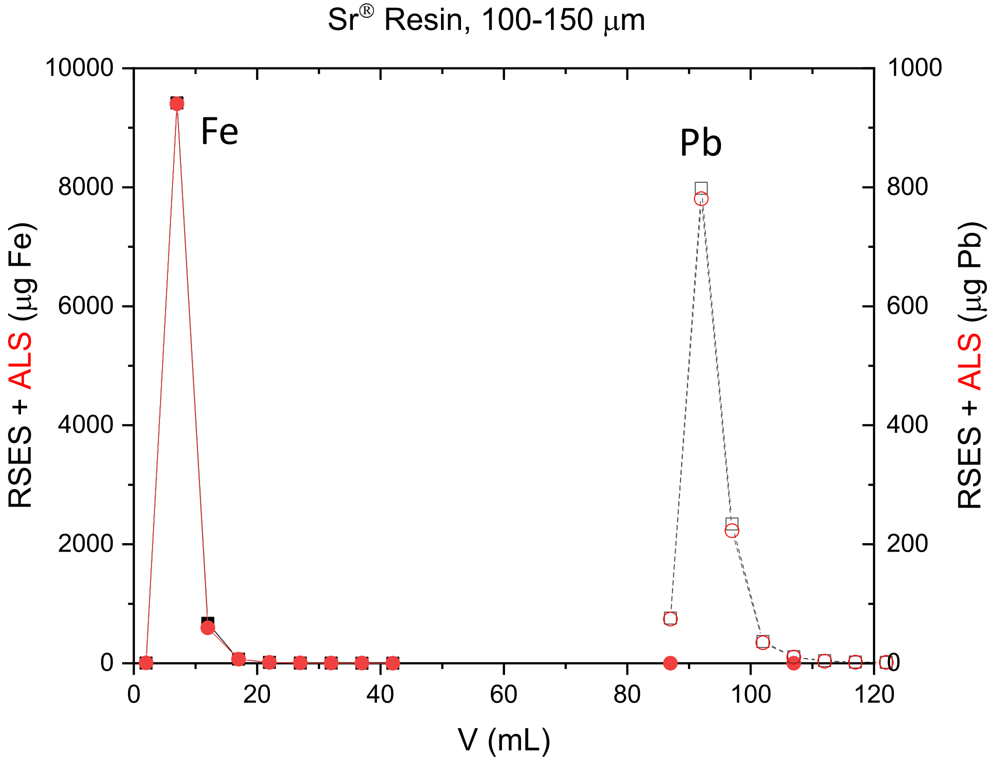
Fe/Pb → need to be separated







Then prepare AMS target.

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PbO or PbF_2 as AMS target?

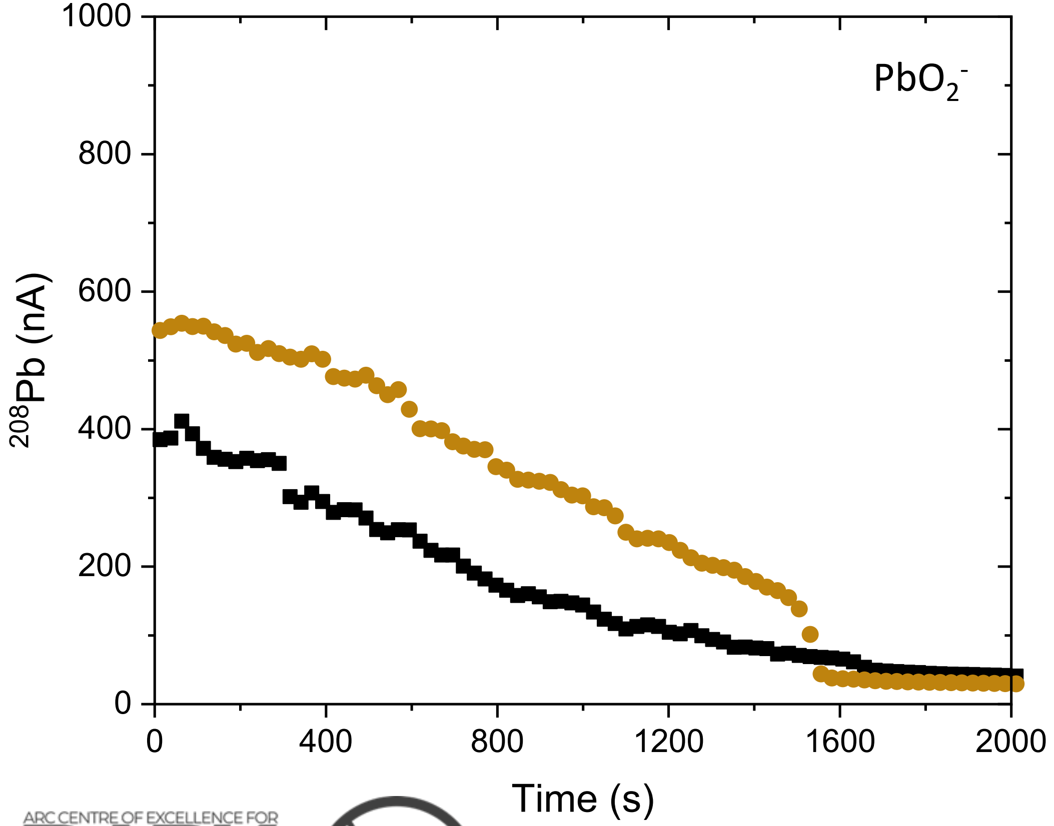
Setting	Pb isotope	Current [nA]
PbO_2^-	^{208}Pb	370
	^{207}Pb	160
	^{206}Pb	160
PbO^-	^{208}Pb	52
	^{207}Pb	23
	^{206}Pb	25

Setting	Pb isotope	Current [nA]
PbF_3^-	^{208}Pb	400
	^{207}Pb	160
	^{206}Pb	185
PbF_2^-	^{208}Pb	50
	^{207}Pb	20
	^{206}Pb	25
Pb^-	^{208}Pb	14
	^{207}Pb	5.6
	^{206}Pb	6.8

PbO_2^- vs. PbF_3^-

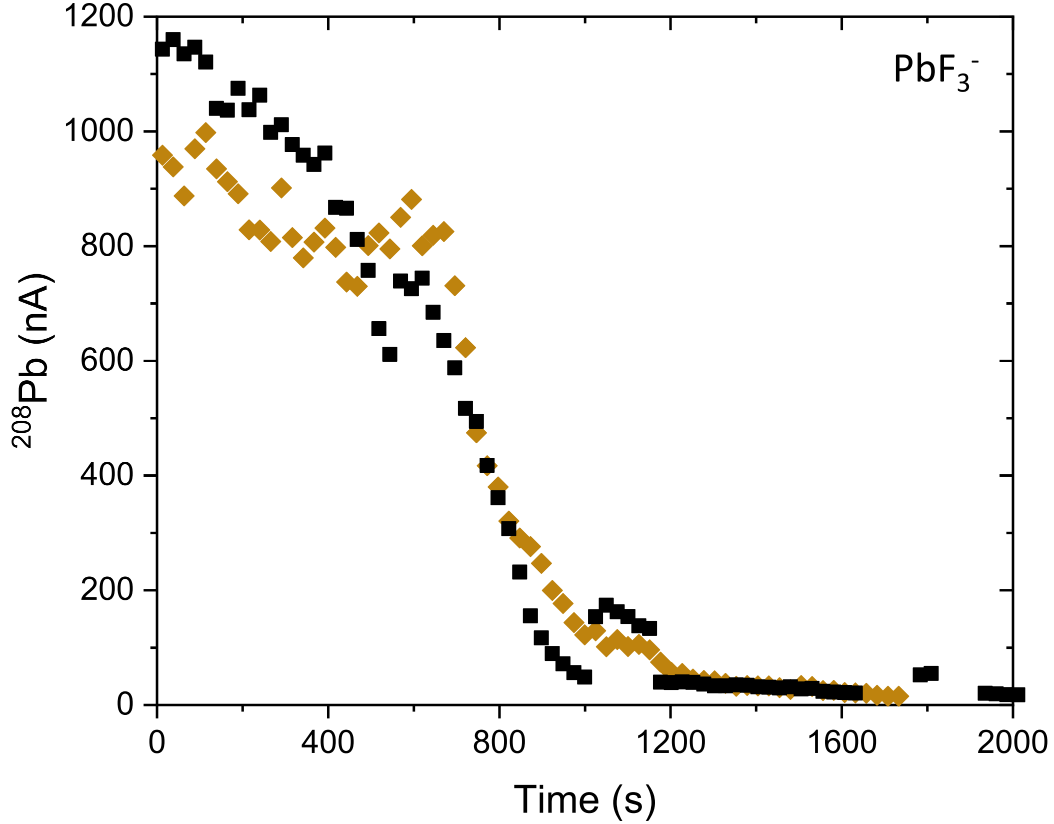
Commercial PbO: 3.5×10⁵ nAs

Procedural PbO: 5.8×10⁵ nAs



Commercial PbF_2: 7.5×10⁵ nAs

Procedural PbF_2: 7.2×10⁵ nAs



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AMS target

- Investigate ways to minimise Pb → Fe is obviously not an option.
- Fluorine source → CsF [2]? Or others within the alkali metal group?
- Try NaF.

Table 1
Ratios of $PbXY^-$ compounds mixed with fluorinating agents or Ag and the currents measured from the respective mixtures.

Target composition	Ratio by weight	Average ^{208}Pb molecular anion current (nA)	Molecular anions
$PbF_2 + AgF_2$	1:1	75	$^{208}PbF_3^-$
$PbF_2 + AgF_2 + CsF$	9:6:10	175	$^{208}PbF_3^-$
$PbO + AgF_2$	3:5	63	$^{208}PbOF^-$
$PbO + PbF_2$	3:5	23	$^{208}PbF_3^-$,
		53	$^{208}PbOF^-$
$PbO + PbF_2 + AgF_2$	4:5:3	27.5	$^{208}PbF_3^-$,
		120	$^{208}PbOF^-$
$PbO + PbF_2 + AgF_2 + CsF$	5:5:4:4	145	$^{208}PbF_3^-$,
		25	$^{208}PbOF^-$
$Pb(SCN)_2 + Ag$	2:3	0.6	$^{208}Pb(SCN)_2^-$
$Pb(SCN)_2 + AgF_2$	7:6	60	$^{208}PbF_3^-$
$Pb(NO_2)_2 + Ag$	5:2	0	–
$PbSO_4 + Ag$	4:5	4	$^{208}PbO_2^-$ &
			$^{208}PbS^-$
$PbCO_3 + Ag$	5:8	12.5	$^{208}PbO_2$

[2] A. Sookdeo et *al*. NIMB 361 (2015) 450.

PbF_2 [mg]	NaF [mg]
0.1	2.4
0.25	2.25
0.5	2.0
0.75	1.75
1.0	1.5
2.5	-
-	2.5

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0.25	2.25
0.5	2.0
0.75	1.75
1.0	1.5
2.5	-
-	2.5

Sample	nA
PbF_2/NaF (0.1)	-
PbF_2/NaF (0.25)	< 0.15
PbF_2/NaF (0.5)	< 0.15
PbF_2/NaF (0.75)	~ 1
PbF_2/NaF (1.0)	~ 1
PbF_2 (2.5)	300
NaF (2.5)	-

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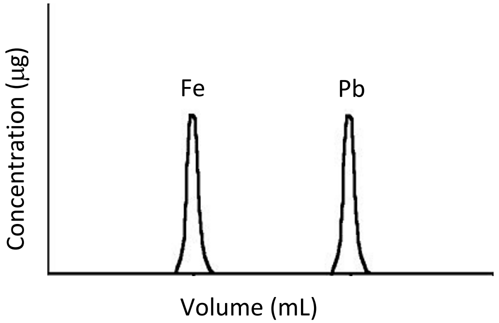
Outlook



- Refine chemical procedure.
- Optimise AMS target → fluorinating agents (AgF, AgF_2 & SbF_3).

- Test reagents, binder & cathode material for ^{210}Pb.
- Extract and measure ^{210}Pb from 1 kg analytical grade NaI.
- If successful, then get the Astro-grade NaI.

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Thank You

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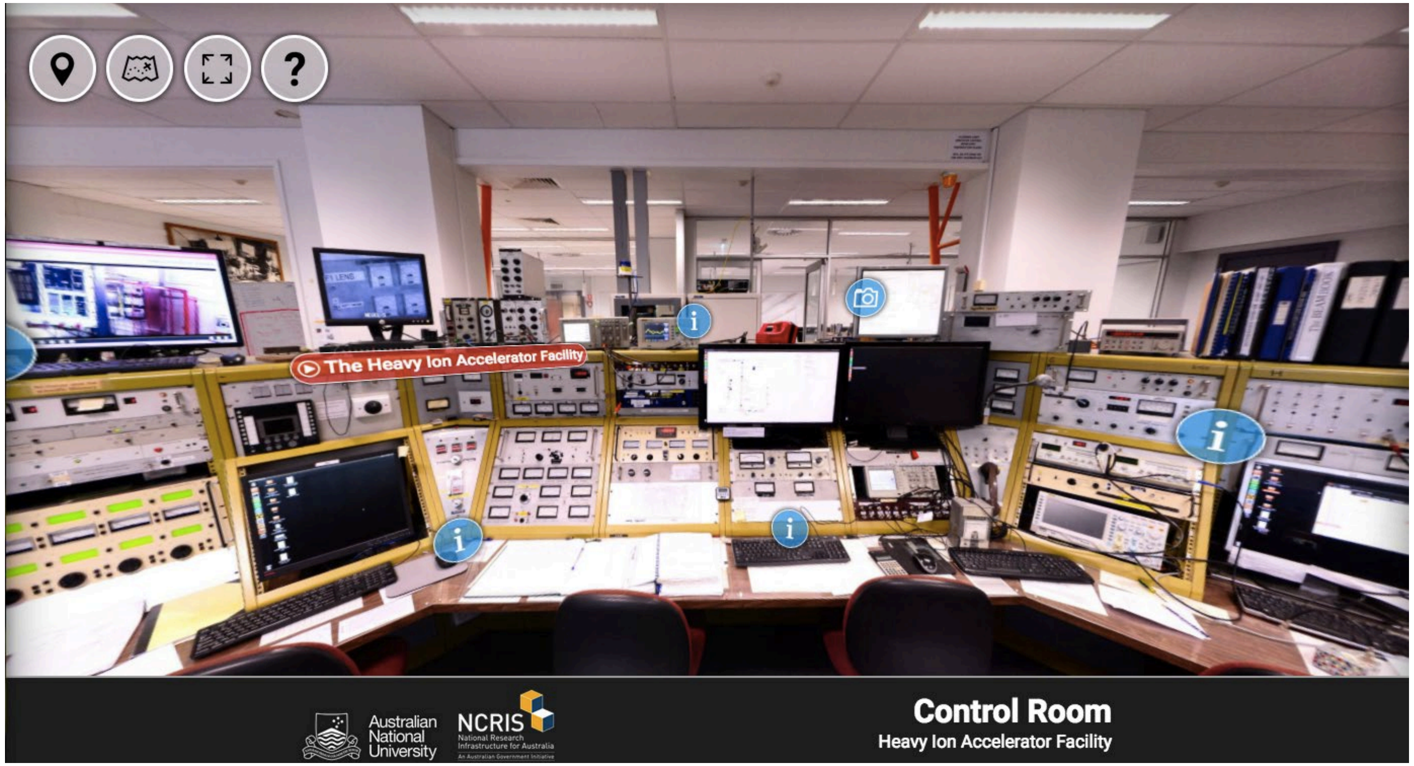

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