Metrology - Overview

Ferdos Dastgiri

PhD

Australian National University

HIAF, ANU

Team

Steve Tims
A. Professor

Zuzana Slavkovská
PostDoc

^{40}K
Characterisation

Michaela Froehlich
Research Fellow

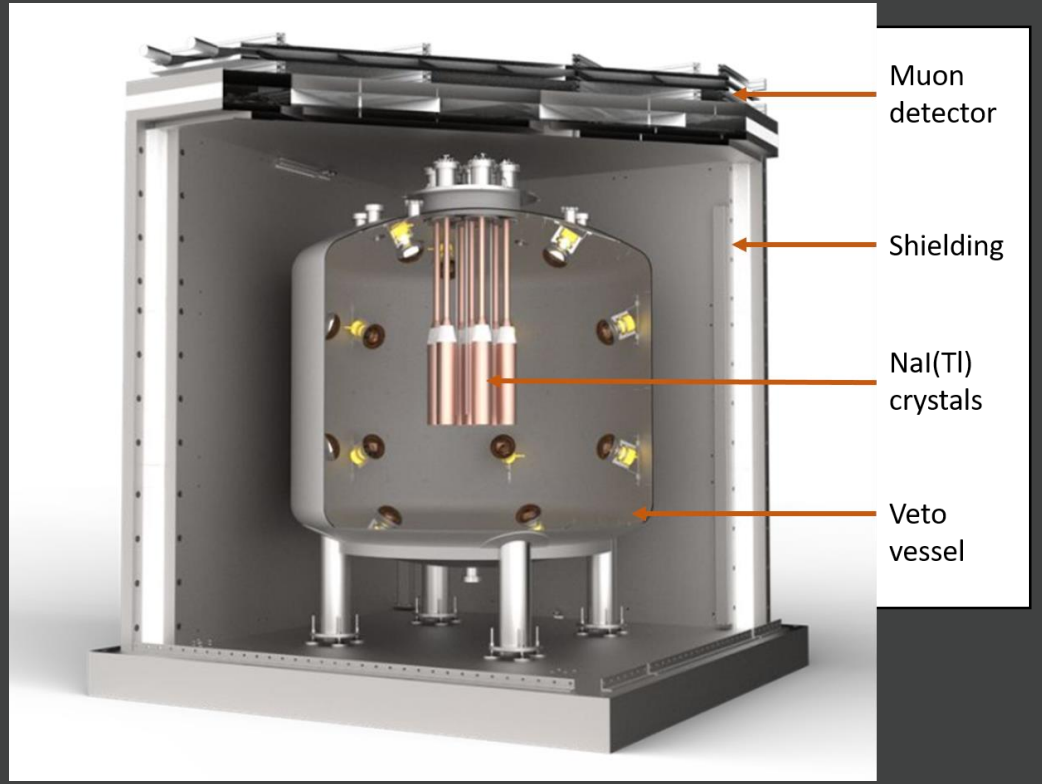
^{210}Pb
Characterisation

Ferdos Dastgiri
PhD

ARC CENTRE OF EXCELLENCE FOR DARK MATTER PARTICLE PHYSICS

Context

- SABRE South part of the SABRE international collaboration NaI dark matter detector
- Aim is to confirm or refute annual modulation claims by DAMA/LIBRA at LNGS
- Annual modulation is approximately 0.01 cpd/kg/keV - background is expected to be 1 cpd/kg/keV in the **2-6 keV region of interest [1]**
- Requires the lowest possible concentration of radio-contaminants



Cut-out view of a 3D rendering of SABRE.
Credit: Michael Mews (The University of Melbourne)

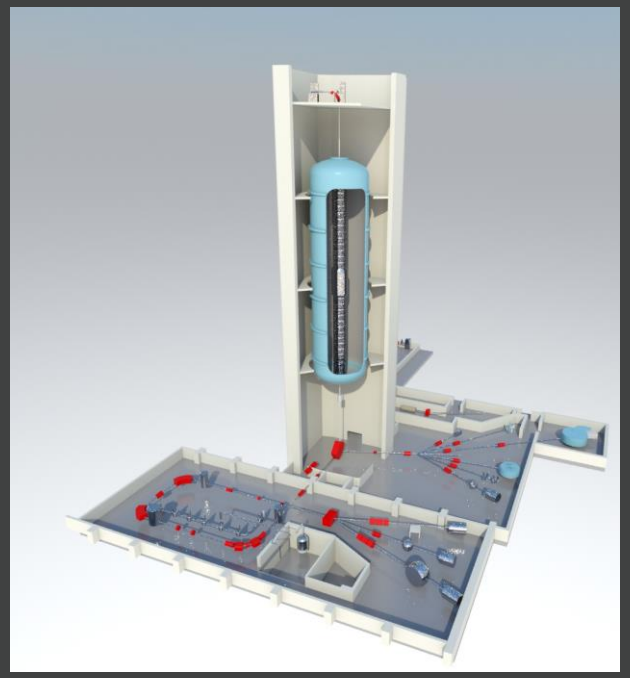
ARC CENTRE OF EXCELLENCE FOR DARK MATTER PARTICLE PHYSICS

[1] Suerfu, Burkhant et al. “Growth of ultra-high purity NaI(Tl) crystals for dark matter searches.”

AMS

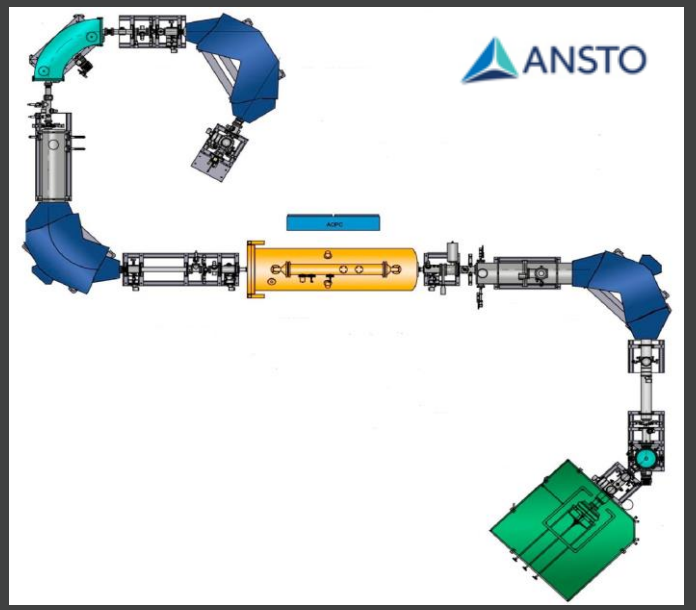
- Accelerator Mass Spectrometry (AMS)
- Precise atom counting technique utilising accelerator technology

14UD at ANU



Rendered image of the 14UD Credit: Thomas Tunningley (ANU)

VEGA, 1MV at ANSTO



Schematic image VEGA, 1MV ANSTO, Sydney

Mike Hotchkis
Principal Research Scientist, ANSTO

ARC CENTRE OF EXCELLENCE FOR DARK MATTER PARTICLE PHYSICS

ICP-MS

- Inductively Coupled Plasma Mass Spectrometry
- Used for detection of sensitive measurements of isotopes
  - Samples is atomised and ionised
  - Beam goes into mass analyser – separates m/q
  - Measure in detector
- Requires small amounts of sample
- Will be mentioned in ^{40}K talk

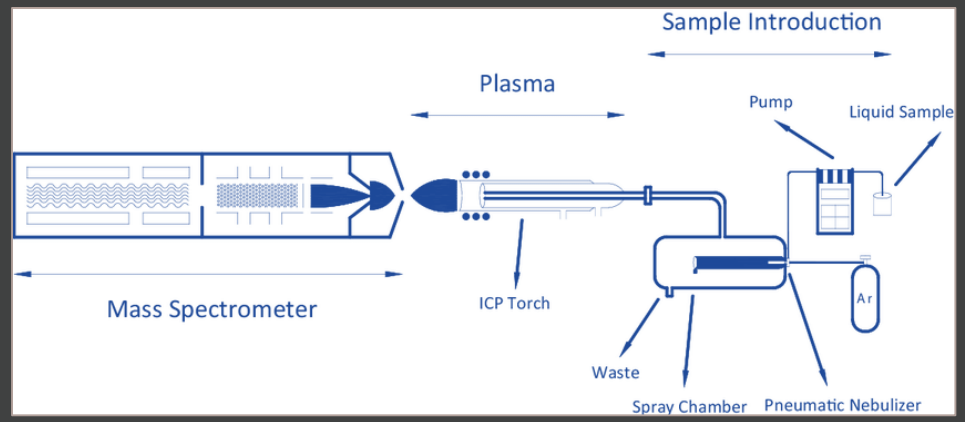
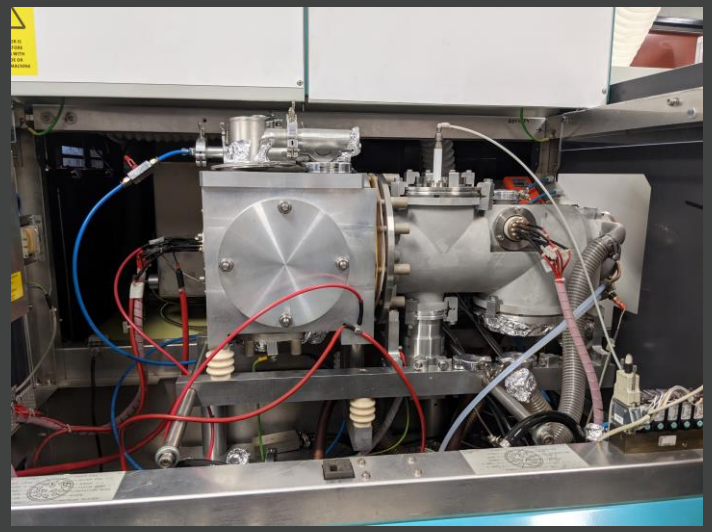


Image from: Kashani, Arash & Mostaghimi, Javad. (2010). 10.1615/AtomizSpr.v20.i5.40.



Inside the Neptune Thermo Scientific ICP-MS machine at the Research School of Earth Sciences, ANU

ARC CENTRE OF EXCELLENCE FOR DARK MATTER PARTICLE PHYSICS

Background

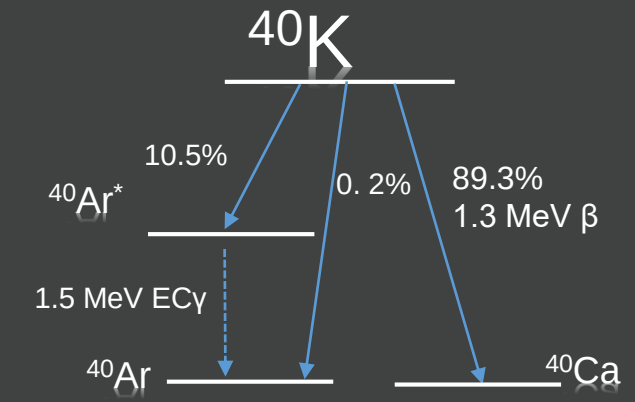
- Main contaminants of interest include

In NaI crystal and Tl doping

^{40}K ^{129}I ^{210}Pb ^{232}Th ^{238}U

Background

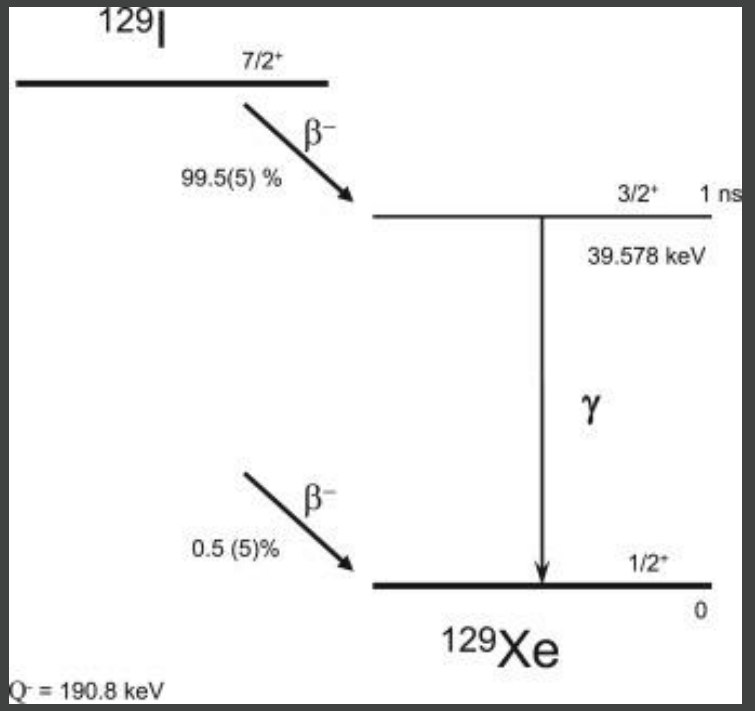
- ^{40}K
  - $T_{1/2}$ = 1.3 x10^9 years – very long
  - Primordial isotope exists on earth at a well-known concentration of ~110 ppm
  - Difficult to separate from NaI
  - 1.5 MeV followed by orbital rearrangement producing a 3 keV X-ray or Auger
- More details in ^{40}K presentation



^{40}K decay scheme

^{129}I

- $T_{1/2}$ = 15.7 x 10^6 years - very long
- Present in natural iodine, but mainly from anthropogenic nuclear activity
- β^- decay to $^{129}Xe^*$ at ~ 40 keV and de-excitation γ of ~ 40 keV
- Routine AMS isotope
- Measured in two sets of NaI powder. Found in ratio of $^{129}I/^{nat}I$ to be 2 x 10^{-13} = 1 mBq/kg
- DAMA estimated $^{129}I/^{nat}I$ = 1.7 x10^{-13} [2]

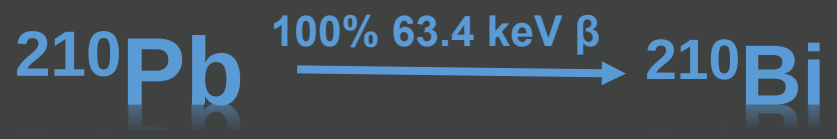


From: V.P. Chechev, V.O. SergeevTable of Radionuclides (Vol.1 – A=1 to 150), Monographie BIPM-5

[2] https://doi.org/10.1016/j.nima.2008.04.082

^{210}Pb

- $T_{1/2}$ = 22.3 years – long
- β decay at 63.4 keV
- Part of the U/Th → Rn decay chain
- More details in ^{210}Pb Presentation



ARC CENTRE OF EXCELLENCE FOR DARK MATTER PARTICLE PHYSICS

^{232}Th and ^{238}U

- ^{232}Th – $T_{1/2}$ = 14 billion years
- ^{238}U - $T_{1/2}$ = 4.5 billion years
- Both produce a variety of backgrounds
- Estimated in DAMA [3] and ANAIS [4] NaI crystal to be:

  ^{232}Th - ~ 1.5 mBq / kg

  ^{238}U - ~ 7 mBq / kg
- Improvements in crystal purity may be required to perform AMS
- Can potentially measure with ICP-MS

[3] https://doi.org/10.1016/j.nima.2008.04.082

[4] https://doi.org/10.1140/epjc/s10052-019-6911-4

Other contaminants

- Checked other contaminants that can be measured using AMS
- Simulations of cosmic activation, list of 800+ isotopes
- Narrowed this down to 26 key isotopes based on half-life and abundance
- Determined ^{3}H could be of interest

	A	B	C	D	E	F	G	H	I
1	#Z	Symbol	A	E_level[MeV]	halflife[s]	amount_p[nuclei/n]	error_p[nuclei/n]	amount_d[nuclei/n]	error_d[nuclei/n]
2	1	H	2	0	inf	0.003507141	4.74329E-06	0	0
3	1	H	3	0	388800000	0.001005917	2.54025E-06	3.67732E-07	4.77492E-08
4	1	H	4	0	0	4.98545E-07	5.60655E-08	2.69285E-07	4.1815E-08
5	1	H	5	0	7.995E-23	2.90701E-09	2.90701E-09	6.98372E-09	6.98372E-09
6	1	H	6	0	2.848E-22	7.79934E-09	7.01113E-09	0	0
7	2	He	3	0	inf	0.000259146	1.28903E-06	0.000980185	2.50753E-06
8	2	He	4	0	inf	0.004733958	5.51209E-06	9.59455E-05	7.83814E-07
9	2	He	6	0	0.807	1.43714E-05	3.03927E-07	0	0
10	2	He	7	0	3.038E-21	7.75308E-08	2.24506E-08	0	0
11	2	He	8	0	0.119	6.08993E-06	1.97482E-07	3.79325E-09	3.79325E-09
12	2	He	9	0	0	3.79325E-09	3.79325E-09	0	0
13	3	Li	4	0	7.557E-23	3.00273E-08	1.33662E-08	2.27594E-08	1.2667E-08
14	3	Li	6	0	inf	1.63375E-05	3.23399E-07	1.41054E-05	3.01359E-07
15	3	Li	7	0	inf	6.65062E-06	2.06368E-07	2.19661E-06	1.18776E-07
16	3	Li	8	0	0.84	1.07065E-05	2.61483E-07	5.94337E-06	1.95334E-07
17	3	Li	9	0	0.178	0	0	4.25058E-08	1.59514E-08
18	3	Li	10	0	0	4.25058E-08	1.59514E-08	1.89667E-08	1.04532E-08
19	4	Be	7	0	4598208	2.19877E-06	1.18759E-07	0	0
20	4	Be	8	0	8.181E-17	2.37466E-05	3.90187E-07	1.53538E-07	3.06845E-08
21	4	Be	9	0	inf	6.412E-07	6.29625E-08	5.46299E-08	1.82092E-08
22	4	Be	10	0	4.765E+13	2.34613E-07	3.97362E-08	0	0
23	4	Be	11	0	13.76	1.41092E-08	9.98933E-09	0	0
24	5	B	8	0	0.77	1.44455E-06	9.58958E-08	0	0
25	5	B	9	0	8.439E-19	1.53538E-07	3.06845E-08	0	0
26	5	B	10	0	inf	2.40806E-05	3.91641E-07	2.56131E-07	4.15678E-08
27	5	B	11	0	inf	1.69425E-05	3.29607E-07	2.00067E-06	1.13715E-07
28	5	B	12	0	0.0202	1.14822E-06	8.63144E-08	0	0
29	5	B	13	0	0.0173	8.68545E-09	7.9757E-09	0	0
30	5	B	14	0	0.0124	9.58598E-08	2.42301E-08	3.43887E-08	1.24141E-08
31	5	B	15	0	0.0102	1.23722E-08	8.74937E-09	0	0
32	5	B	16	0	1.9E-10	1.66627E-09	1.66627E-09	0	0
33	6	C	9	0	0.127	5.49484E-09	5.49484E-09	0	0
34	6	C	11	0	1221.84	1.95497E-06	1.12405E-07	0	0
35	6	C	12	0	inf	0.000200354	1.13364E-06	1.14822E-06	8.63144E-08
36	6	C	13	0	inf	9.53038E-05	7.82186E-07	8.41782E-07	7.31038E-08
37	6	C	14	0	1.799E+11	6.79149E-06	2.0931E-07	6.06927E-08	1.90509E-08
38	6	C	15	0	2.449	9.11433E-08	2.55221E-08	1.23722E-08	8.74937E-09
39	6	C	16	0	0.747	7.72817E-09	7.72817E-09	0	0
40	6	C	17	0	0.191	1.18761E-08	8.74893E-09	0	0
41	6	C	18	0	0.092	4.25534E-10	4.25534E-10	4.25534E-10	4.25534E-10
42	7	N	13	0	597.9	8.33096E-07	7.26674E-08	0	0
43	7	N	14	0	inf	0.000257048	1.28408E-06	6.8535E-06	2.10177E-07
44	7	N	15	0	inf	0.00022109	1.19197E-06	7.32889E-06	2.18349E-07
45	7	N	16	0	7.13	2.31428E-05	3.85619E-07	0	0
46	7	N	17	0	4.171	1.31016E-06	9.15305E-08	1.18761E-08	8.74893E-09
47	7	N	18	0	0.619	6.05112E-07	6.15129E-08	4.25534E-10	4.25534E-10
48	7	N	19	0	0.336	4.32857E-08	1.57517E-08	0	0
49	7	N	20	0	0.136	6.03367E-08	2.0139E-08	0	0

ARC CENTRE OF EXCELLENCE FOR DARK MATTER PARTICLE PHYSICS

^{3}H

- $T_{1/2}$ = 12.3 years
- Cosmogenically activated
- Pure β emitter with transition energy ~19 keV
  - Half are in the range of 1 - 7 keV
- Electrons emitted are in the region of interest
- Quantification is not easy
  - ANAIS inferred through background models [4]
  - DAMA estimated its upper limit rate ~ 20 cpd/kg [3]
- Not a routine AMS isotope → requires specialist laboratories because of the sample preparation

[3] https://doi.org/10.1016/j.nima.2008.04.082

[4] https://doi.org/10.1140/epjc/s10052-019-6911-4

^{3}H

- Estimated that with cosmic activation (~ 3 months) result in order of **10^5 atoms in 1 kg of crystal** → low
- Asked several laboratories specialising in ^{3}H measurement
- Current measurement methods have detection limits orders of magnitude above what will be required (660,000 tritium atoms).
- Minimisation of exposure to cosmic rays will likely be sufficient to achieve manageable ^{3}H levels.

Measurements using ICP-MS

- ^{238}U and ^{232}Th
- ^{87}Rb – high natural abundance

Thank you for listening!

Next up: ^{40}K

ARC CENTRE OF EXCELLENCE FOR DARK MATTER PARTICLE PHYSICS

NATIONAL PARTNER ORGANISATIONS:

Australian Government
Australian Research Council

THE UNIVERSITY of ADELAIDE

Australian National University

THE UNIVERSITY OF MELBOURNE

SWINBURNE

THE UNIVERSITY OF SYDNEY

THE UNIVERSITY OF WESTERN AUSTRALIA

ANSTO

DST GROUP

INTERNATIONAL PARTNER ORGANISATIONS:

CALIFORNIA INSTITUTE OF TECHNOLOGY 1891

INFN LNGS

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

UNIVERSITET STOCKHOLMS

UNI FREIBURG

UNIVERSITEIT VAN AMSTERDAM

The University Of Sheffield.

UNIVERSITY OF WASHINGTON 1861