Trends in Accelerator Mass Spectrometry (AMS)

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15 MV 14UD accelerator at ANU

Mini Radiocarbon dating system (MICADAS)
2.5m x 3.0m

MICADAS – ETH Zürich

Negative Ion Source
Mass analysing magnet - bounced

Ion detector

+ve ion analysis Magnet + ESA
He gas stripper
Tandem accelerator 200 kV

22 m
Essential features of an AMS system

1. **Negative ion source** – can provide discrimination against isobars. E.g. $^{14}\text{C}^-$ and $^{26}\text{Al}^-$ are stable, whereas $^{14}\text{N}^-$ and $^{26}\text{Mg}^-$ are not.

2. **Dissociation of molecules**, e.g. $^{13}\text{CH}^-$, $^{12}\text{CH}_2^-$, and conversion to positive ions so that subsequent analysis selects only $^{14}\text{C}$. Requires acceleration to sufficient energy for high yield of positive ions.

3. Where the ion source does not provide isobar discrimination, e.g. $^{36}\text{Cl}$ and $^{36}\text{S}$, further acceleration to an energy at which ion identification techniques from nuclear physics can be used.
AMS’s debt to Nuclear (and Atomic) Physics

• Negative ion sources
• Tandem electrostatic accelerators, including foil and gas strippers
• Detectors – ionization chambers, silicon detectors, TOF
• Isobar separation techniques – absorbers, degraders, gas-filled magnet.
• Measurements of charge state distributions and charge-changing cross sections

Not all one way, however: AMS → Nuclear Physics

• Ion source development
• Gas stripper development
• Automation
• 107 facilities in total
• 64 used for $^{14}$C only.
Notes:


- $V = 4 - 6$ MV – versatile. Can do most isotopes.

- $V = 2 - 4$ MV – versatile, but many used only for $^{14}$C.
Notes
1. SSAMS and MICADAS – $^{14}$C only.
2. Others more versatile – $^{10}$Be, $^{26}$Al, $^{41}$Ca, $^{129}$I, actinides (Pu, $^{236}$U).
In Australia:

V>7 MV:
• 14UD (15MV) at ANU
• ANTARES (9 MV) at ANSTO

V = 4-6 MV
• SIRIUS (6 MV) at ANSTO

V = 2-4 MV
• STAR (2 MV) at ANSTO

V ≤ 1 MV
• VEGA (1 MV) at ANSTO
• SSAMS (0.25 MV) at ANU
Tranformative developments

1. **Silicon nitride foils** for detector windows and degraders. Thickness down to 30 nm, area 8x8 mm$^2$. Extremely uniform.

Manufactured by Silson in UK
2. Helium stripping.
   • Less scattering than argon.
     E.g. for the SSAMS at ANU, $^{14}$C transmission from 34% to 48% when switched from argon to helium.
   • Higher stripping yield in high charge states.
     E.g. $U^{3+} > 40\%$ at 0.3 - 1 MeV. Exploited by new ANSTO 1 MV system (VEGA).
3. **Ionisation detector developments** – silicon nitride foils and low-noise via design and preamps.

![Diagram of ionisation detector](image)

**Contributions to resolution for Be ions**

- **FWHM**
  - $^{9}\text{Be}$

![Graph showing contributions to resolution](image)
Separation of 750 keV $^{10}\text{Be}$ and $^{10}\text{B}$
4. **CO₂ gas sources** for ¹⁴C

- Allows very small samples (<5 µg) – compound specific ¹⁴C.
- May be coupled to automated CO₂ production systems. E.g. elemental analyser for charcoal, ‘gas bench’ for carbonates, laser ablation.
MICADAS system at CEREGE, Aix-en-Provence, France
Yield of $1^+$ ‘carbon’ ions after stripping in various gases as function of energy
myCADAS – AMS without the ‘A’
Isobar separation prior to the accelerator

A. Photo-detachment. Vienna.
Electron affinities:
\[ ^{36}\text{Cl}^- - 3.62 \text{ eV} \]
\[ ^{36}\text{S}^- - 2.08 \text{ eV} \]

Nd:YAG laser 532 nm = 2.33 eV

Long interaction time by decelerating and then cooling negative ions to eV energies in He gas in RFQ.

At eV energies

\[
{^{36}\text{S}^-} + \text{NO}_2 \rightarrow {^{36}\text{S} + \text{NO}_2^-}
\]
Rate constant \(1.3 \times 10^{-9} \text{ cm}^3/\text{s}\)

\[
{^{36}\text{Cl}^-} + \text{NO}_2 \rightarrow {^{36}\text{Cl} + \text{NO}_2^-}
\]
Rate constant \(<6 \times 10^{-12} \text{ cm}^3/\text{s}\)

Again, use gas-filled RFQ to cool beam to eV energies.
A multi-isotope AMS system at only 300 kV? ETH

MICADAS accelerator successfully scaled up to 300 kV

Problems with helium as stripper gas have been solved

Ultra-thin and ultra-uniform silicon nitride foils available

Second magnet in HE analysis system reduces background

Detectors are good enough to separate 450 keV $^{10}$Be from $^{10}$B

$^{10}$Be, $^{26}$Al, $^{41}$Ca, $^{129}$I, actinides ($^{239,240,242,244}$Pu, $^{236}$U, $^{237}$Np)
That's all Folks!

And Thanks
Single Stage Accelerator Mass Spectrometer - SSAMS
Applications:

$^{14}\text{C}$

- Archaeology
- Chronologies – marine and lake cores for palaeoclimate reconstruction
- Environmental tracing – much uses ‘bomb pulse’
  - Oceanography
  - Carbon cycle – soils
- Biomedicine – drug testing
$^{10}$Be ($T_{1/2}$ 1.4 Ma) and $^{26}$Al (0.7 Ma) – ‘Cosmogenic’ isotopes
- ‘Exposure dating’ – glacial advance and retreat, river and wave-cut terraces, landslides. Palaeoclimate and landscape evolution
- Erosion – landscape evolution
- Chronologies of marine crusts and cores beyond $^{14}$C

$^{36}$Cl (0.3 Ma)
- Exposure dating and erosion
- Hydrology – dating and tracing groundwater
- Artificial tracer – oil field tracing
Actinides – Plutonium and $^{236}$U

- Human-induced erosion.
- Tracing of releases from accidents and reprocessing
- Oceanography

Isotopes for nuclear astrophysics:

- $^{60}$Fe – produced in supernova and deposited on earth. Sensitivity $^{60}$Fe/$^{56}$Fe < $10^{-16}$ required. Needs gas-filled magnet and high energy (170 MeV) to discriminate against $^{60}$Ni.
- Cross-sections for reactions of astrophysical importance, e.g. $^{92}$Zr(n,γ)$^{93}$Zr. Irradiate $^{92}$Zr at a neutron facility, e.g. SARAF in Israel, and measure the $^{93}$Zr produced by AMS. High-energy and GFM to discriminate against $^{93}$Nb.
Charge state distribution for carbon ions in argon gas.