

VERA, an AMS facility for “all” isotopes

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Abstract

VERA, the Vienna Environmental Research Accelerator, was equipped from the start in 1996 with magnets strong enough to bend any isotope of the nuclear chart. However considerable improvements were necessary to accommodate an AMS analysis of isotopes above mass 150, leading to an almost complete rebuild of the high energy analyzer. After the analyzer magnet, a new high-resolution electrostatic analyzer (ESA) was installed. First measurements of ^{182}Hf , ^{236}U , and ^{244}Pu were successfully performed. The higher background suppression has brought along a significant improvement for ^{26}Al measurements, where a background of $^{26}\text{Al}/^{27}\text{Al}$ of $\sim 6 \cdot 10^{-16}$ is reached.

Keywords: AMS; ^{236}U ; ^{244}Pu ; ^{182}Hf ;

Modifications and extensions to VERA

A detailed analysis of the requirements for AMS of very heavy ions at a small tandem accelerator is given in [1], which partly influenced our choice of the VERA upgrade. The current layout of VERA is shown in Figure 1.

By replacing the originally conical ionizer in our MC-SNICS source [2] with a modified, spherical type (supplied by the Australian National University, Canberra [3]) we were able to increase our typical source output by a factor of two. 40 sputter targets can be mounted in one sample wheel.

In VERA's injector, a magnetic quadrupole doublet exists immediately before the 90° magnet. The flexibility it provides is advantageous to span the mass range from 12 amu ($^{12}\text{C}^-$)

to 277 amu ($^{182}\text{HfF}_5^-$), since qualitatively different quadrupole settings are required for light and for heavy ions. Limited by the injector magnet, above mass ~ 200 amu the injection energy has to be lowered from the usual 70 keV to ~ 50 keV. The injection magnet achieves a mass resolution of $M/\text{FWHM}(M) \sim 500$ by closing the image slits to ± 1 mm.

Figure 1 shows the profound modifications of VERA's high-energy analyzer compared to the status reported at AMS-7 [4]. The new layout is based on simulations and measurements of the ion optics [5]. Most important is the addition of a high resolution spherical electrostatic analyzer (ESA) built by Danfisk, Denmark. It has a bending angle of 90° , a radius of 2000 mm, and a gap of 45 mm, between aluminum electrodes operated up to ± 100 kV.

A source of background escaping the ion optical filters are transient machine instabilities. We observe these once every few hours for the accelerator and for the new ESA, probably related to small high voltage discharges. Background which is usually suppressed can reach the detector during these fluctuations. The affected data is excluded from evaluation by computer programs which poll the voltage read-backs once per second.

Measurement techniques

Typical measurement conditions for the various AMS isotopes are given in Table 1.

The ^{10}Be detector [6] is now installed at the straight port of the switcher magnet. As expected, no improvement was observed for the ^{10}Be measurements with the new setup. For ^{14}C , a retractable silicon detector was mounted at the image waist of the ESA. No background peaks are visible in the energy spectra down to a level of 10^{-5} relative to modern ^{14}C . The now higher beam currents allow to measure two sample wheels per weekend.

Although the extension of VERA's analyzing system was motivated by the demands of very heavy ions, it has brought along significant advantages for ^{26}Al compared to [7]. ^{26}Al is measured in the same silicon detector as ^{14}C . With the new setup the count rate in the detector stays sufficiently low when the injector is switched to $^{27}\text{Al}^-$. This allows to use fast sequencing, which improves the duty factor for ^{26}Al counting. Additionally, we profit now from the reliable automatic measurement routines developed for ^{14}C . The ESA has also significantly reduced our ^{26}Al machine background (Figure 2). During extensive systematic measurements connected with the LOREX project [8] we have determined a background level of $^{26}\text{Al}/^{27}\text{Al}$ of $\sim 6 \times 10^{-16}$.

For very heavy ions all slits at the high energy side are closed horizontally to ± 2 mm. The detection system is installed at the 20° port of the switcher magnet. The ultra-thin DLC (Diamond Like Carbon) foils [9] used in the time-of-flight (ToF) detector provide minimal angular and energy straggling. AMS measurements were performed with flight paths between 1.0 and 1.5 m, yielding a velocity resolution of $v/\Delta v \sim 1000$. A Bragg-type ionization chamber is used for a final energy measurement. Recently, we have mounted a magnetic quadrupole doublet in the middle of the flight path, which now has a length of 3.0 m.

At various stages of the VERA upgrade, systematic measurements on lead, uranium, and plutonium isotopes were performed with the ToF/E telescope [5]. After the magnet/ESA combination we observe not only background peaks from neighboring masses with the same magnetic rigidity, but also a background with the same energy (Figure 3a). Ions which by chance match the tuning of either the magnet or the ESA elude the respective suppression factor and are therefore strongly enriched in the residual background. However, since the most relevant background process is charge changing on residual gas [11], the unsuppressed ions will often be in a different charge state than the ions of interest. To our delight, the remaining background is completely suppressed by the relatively low resolution switcher magnet (see Figure 3b). We aim at an analogous effect with the newly added Wien filter directly after the accelerator. For dilution series of ^{182}Hf [12], ^{210}Pb , ^{236}U [10], and ^{244}Pu [13] we achieved a relative measurement precision of $\sim 5\%$.

Our analyzer magnet imposes a lower limit on the charge states we can use for very heavy ions. Recent investigations motivated by [14,15] showed that stripping with O_2 gives about twice as much yield for these relatively high charge states compared to Ar.

Conclusions

As predicted by Kilius et al. in 1990 [11] a tandem accelerator with 3 MV terminal voltage is sufficient for detection of all nuclides where no stable isobar exists. We have performed first measurements at the upgraded VERA facility of the heaviest long-lived isotopes in nature [10,12,13]. Switching between heavy “non-routine” isotopes (^{182}Hf , ^{236}U , ^{244}Pu) and “routine” light isotopes (^{10}Be , ^{14}C , ^{26}Al) is possible within one day, without compromising the high precision required for ^{14}C dating.

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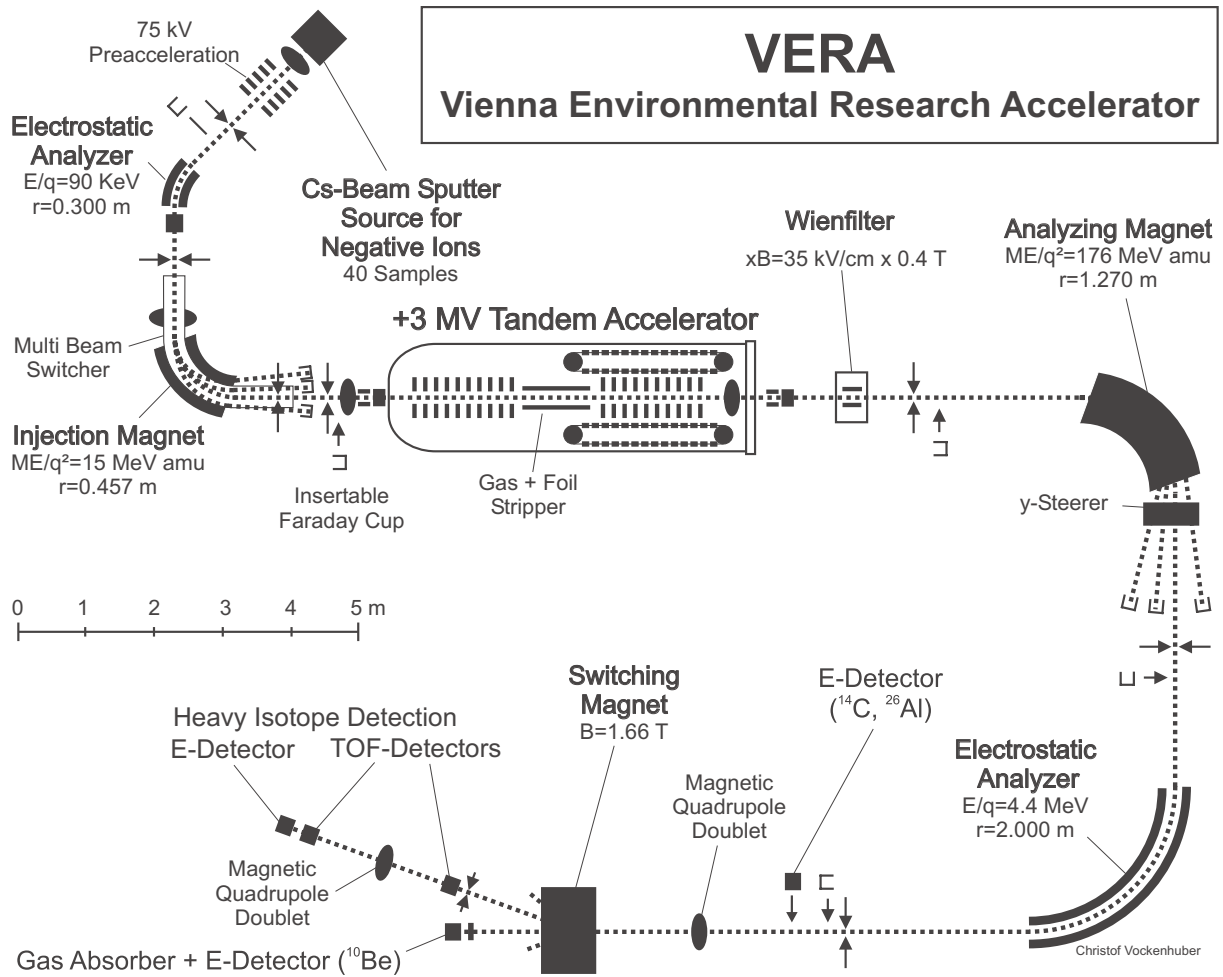


Figure 1: The upgraded layout of VERA.

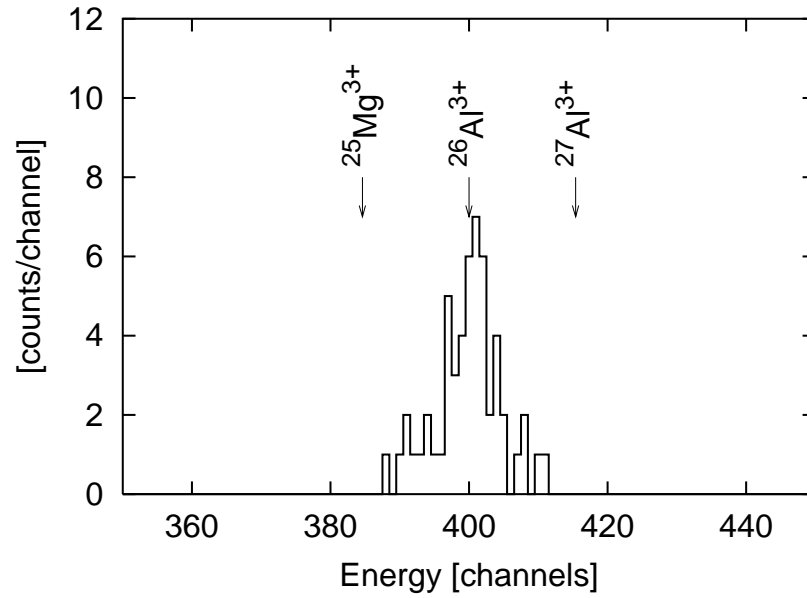


Figure 2: The summed detector spectrum for all ^{26}Al blank materials. The 54 counts obtained in 37.3 hours constitute a clear peak at the position where $^{26}\text{Al}^{3+}$ is expected. The most likely background ions are $^{25}\text{Mg}^{3+}$ and $^{27}\text{Al}^{3+}$ with the same magnetic rigidity as $^{26}\text{Al}^{3+}$. No events are visible at the respective positions.

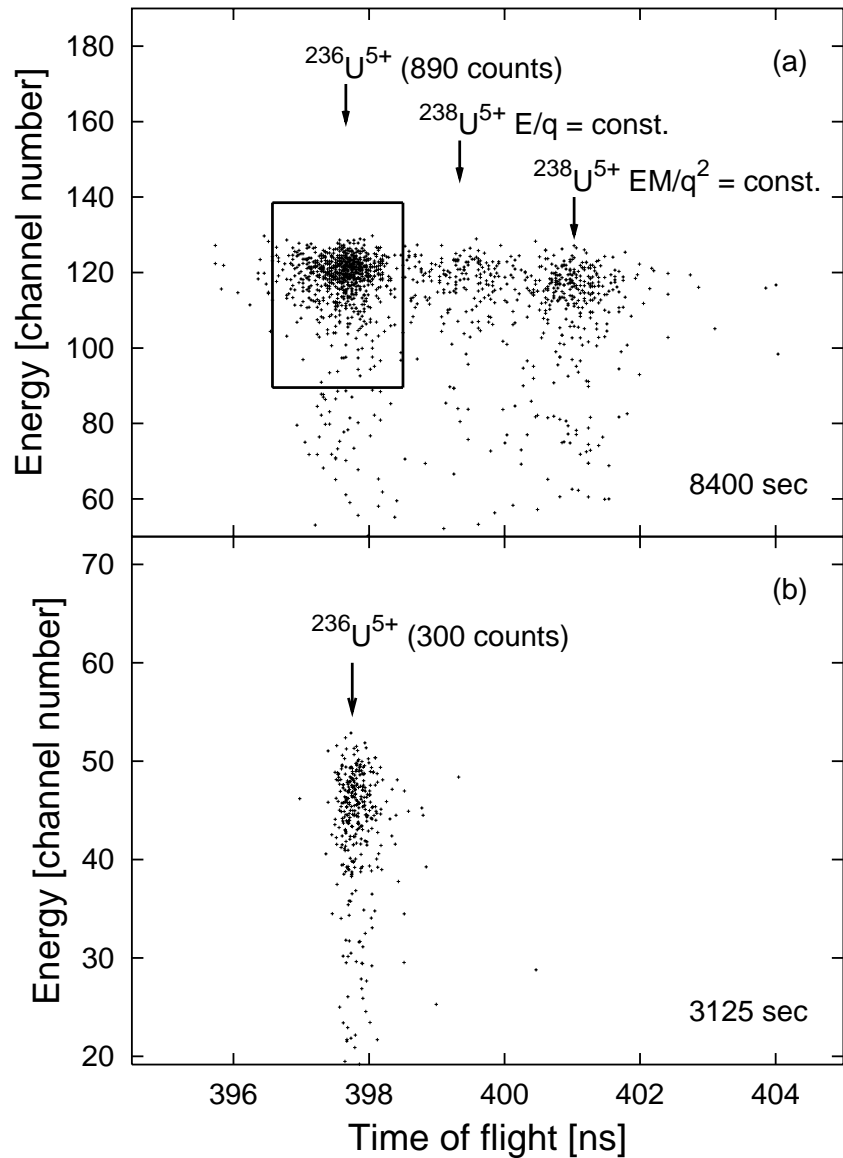


Figure 3: 2-dimensional spectrum for ^{236}U obtained with the ToF/Energy detector mounted after the new ESA (a) and after the switching magnet (b). The time scale in (b) was corrected for a slightly different flight path. Background of ^{238}U ions is visible in (a) from ions with the same energy and from ions with the same magnetic rigidity as $^{236}\text{U}^{5+}$ (see also [5]). Both peaks are suppressed in (b). The measured isotopic ratio for this Joachimsthal ore sample is $^{236}\text{U}/^{238}\text{U} = 6.1 \cdot 10^{-11}$ [10].

Table 1: Parameters for the various isotopes measured at VERA.

Trace isotope	¹⁰ Be	¹⁴ C	²⁶ Al	¹⁸² Hf	²³⁶ U	²⁴⁴ Pu
Target material	BeO+Cu	C+Fe	Al ₂ O ₃ +Cu	HfF ₄ +Ag	U _x O _y	FeO ₂ +Fe ⁸
Injection energy	70 keV	70 keV	70 keV	54 keV	57 keV	54 keV
Injected ion	¹⁰ Be ¹⁶ O ⁻	¹⁴ C ⁻	²⁶ Al ⁻	¹⁸² HfF ₅ ⁻	²³⁶ U ¹⁶ O ⁻	²⁴⁴ Pu ¹⁶ O ⁻
Terminal voltage	3.0 MV	2.7 MV	3.0 MV	3.0 MV	3.0 MV	3.0 MV
Analyzed ion	¹⁰ Be ³⁺	¹⁴ C ³⁺	²⁶ Al ³⁺	¹⁸² Hf ⁴⁺	²³⁶ U ⁵⁺	²⁴⁴ Pu ⁵⁺
Reference ions	⁹ Be ³⁺	¹² C ³⁺	²⁷ Al ³⁺	¹⁸⁰ Hf ⁴⁺	²³⁸ U ⁵⁺	²⁴² Pu ⁵⁺
Typ. neg. ion current (of reference species)	1 μA (⁹ Be ¹⁶ O ⁻)	50 μA (¹² C ⁻)	200 nA (²⁷ Al ⁻)	300 nA (¹⁸⁰ HfF ₅ ⁻)	50 nA (²³⁸ U ¹⁶ O ⁻)	not meas. ⁸ (²⁴² Pu ¹⁶ O ⁻)
Stripping yield ¹	4%	50%	43%	6%	5%	
Machine background ²	< 5×10 ⁻¹⁴	< 3×10 ⁻¹⁶	< 6×10 ⁻¹⁶	1×10 ⁻¹¹	<<6×10 ⁻¹¹	
Detector efficiency ³	70%	100%	100%	20%	20%	
Total efficiency ⁴	~5×10 ⁻⁵	2%-3%		1×10 ⁻⁴		>6×10 ⁻⁶
Typ. precision ⁵	< 5%	< 40 yrs ⁷	< 1%	7%	5%	~5%
Targets measured ⁶	280	> 2600	160	~20	<10	~20

¹ Ratio of analyzed reference ion to injected reference ion, including ion optical losses.

² Quoted for the ratio of trace to reference isotope. The chemistry blank will be higher.

³ Measured as the fraction of analyzed ions observed in the final detector.

⁴ Measured as counts in detector per total number of atoms in sputter target.

⁵ For the ratio of trace to reference isotope in a sample significantly above the background and the efficiency limit.

⁶ Within 9/2001 and 8/2002 incl. standards.

⁷ For routine archaeological measurements given in radiocarbon years.

⁸ Only trace amounts of PuO_x are present in the FeO₂+Fe matrix.