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Low Charge-state AMS for Biological Research

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DISCLAIMER

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Purpose

University collaborations and internal research programs that trace isotopically labeled compounds in natural biological systems have grown significantly in the past few years. New research in molecular nutrition, protein sequencing, immunoassays, and toxicology now require hundreds to thousands of sample analyses per project. The goal of this effort was to strengthen this Laboratory and University health related research by the expansion of AMS access. This was achieved by our design and implementation of an AMS spectrometer that analyzes isotopic ions at lower energies in a more compact spectrometer without sacrificing precision or throughput. The decrease in ion energies is accompanied by a significant reduction in size and cost of the spectrometer. Our successful reduction in spectrometer cost, operation, and space will make this technology more appealing to research institutions, including industrial research centers. While others have also developed smaller spectrometers, these are limited in precision and throughput by the much lower intensities of ion beams that can be transmitted through them without differential loss of isotope species. The primary challenge in this project was mating the LLNL-designed high intensity negative ion

source (Roberts, et al. 1994; Southon & Roberts, 2000) to available accelerator components and then showing that the precision and throughput would remain high enough to serve the research that needs large numbers of AMS analyses. The project also required reduction in operating complexity so that scientists and students would not require technical specialists to make their measurements. This report describes the experiments done to assure the needed spectrometer performance.

Activities

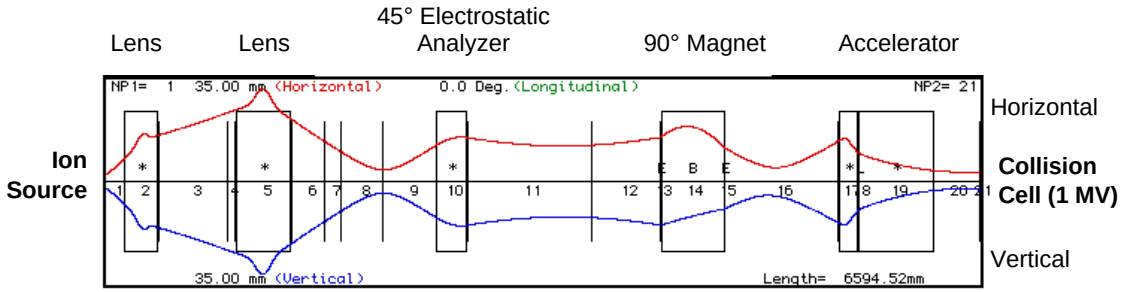

Figure 1. The final ion optics design of a set of lenses and transport that appeared capable of bringing the full ion output of the LLNL ion source to a beam size capable of entering the accelerator's collision cell. The lowest trace shows the vertical displacement and the upper trace shows the horizontal displacement from the center line as functions of longitudinal distance from the ion source to the high voltage collision cell.

Discovery of method to analyze intense ion beams

Accelerator and ion analysis components were obtained from National Electrostatics Corporation (NEC) of Middleton WI. These components were designed to accept ion beams from their proprietary ion source that is a factor of 5 to 10 lower in output than the LLNL-designed source (von Reden, et al. 2000). The greatest restriction appeared to be the injection of the full ion source output into the 1 megaVolt acceleration stage, since space-charge effects tend to broaden an ion beam as the intensity of the ion beam increases. We modeled the ion paths from our ion source to the center of the accelerator using computer programs to discover a way to control this broadening well enough for the desired performance. We found that the instrument could operate well at the lower charge state and higher ion beam intensity, but that some of the ion focussing would be counter to conventional concepts. Figure 1 shows the ion beam envelope as it passes from the ion source (left edge of Figure) to the central part of the accelerator where it enters a collision cell containing diffuse gas that will

break up molecular isobars of the desired isotope (right edge). The lower envelope line represents the vertical displacement from the spectrometer axis, while the upper trace represents the horizontal displacement, even as the axis itself bends through a 45° electrostatic analyzer and a 90° magnet. The ions are seen to cleanly enter the collision cell, but this was found possible only if a "zoom lens" assembly is used to maintain a relatively "fat" ion beam as it transits the electric and magnetic analysis elements. It is the width of the "waist" between the elements that is counter to many spectrometer designs, which often have a well focussed (thin waist) at the magnet's focal image.

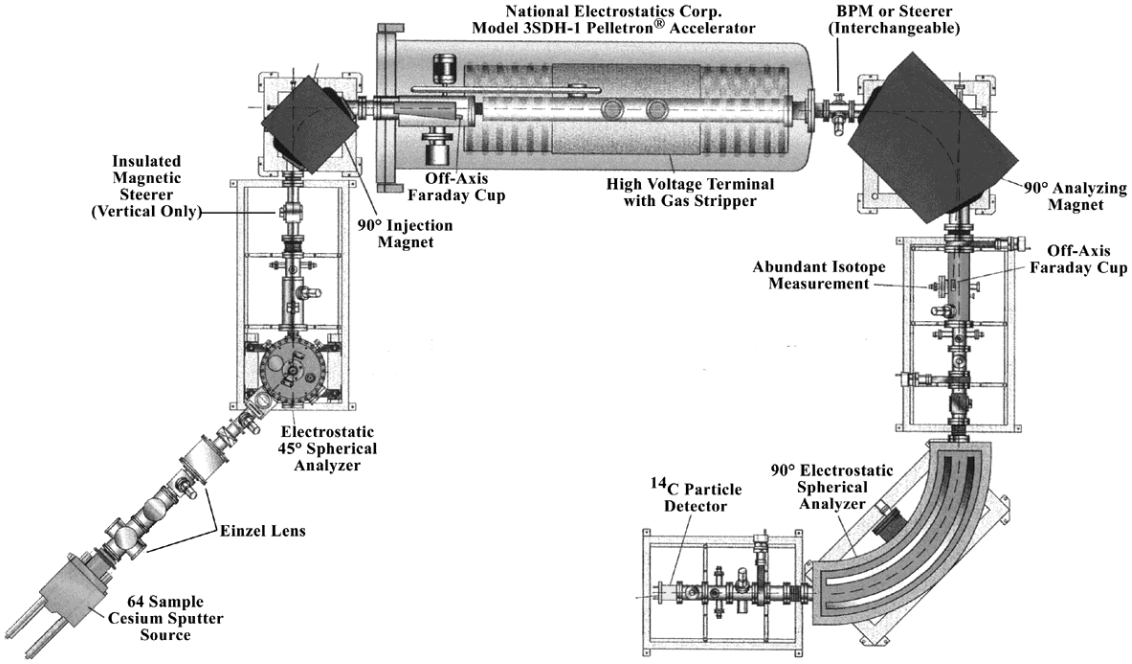

Figure 2. The overall layout of the low charge state spectrometer that combines an LLNL built ion source and control system to spectrometer components obtained from National Electrostatics Corporation. The ion source is on the left and the final ion detector lies near the lower middle. The zoom lens that is capable of transporting high intensity beams through the system with minimal loss is comprised of the einzel lenses at lower left.

Layout of spectrometer components

With this discovery in hand, the spectrometer was assembled as shown in Figure 2, which shows the ion source on the left, followed by the two lenses that comprise a zoom structure, the electrostatic analyzer, and the magnetic element prior to the accelerating system that contains the collision cell. After the accelerator, a magnet and electrostatic element are again used to sort out the chosen isotopic ions that have

changed from a charge of minus one to a charge of plus one from all of the debris from molecular breakup and scattering caused by the collision cell. We explored the ions emerging from the accelerator to determine if a high enough gas pressure could be reached within the collision cell to destroy interfering molecules without having so much ion scattering that our intense starting ion beams would be wasted.

Technical Outcome

We determined the minimal pressure required to break up all molecules by counting the ions that reached the detector after the large electrostatic element. As the cell pressure rose, the number of transmitted molecular ions decreases, until only atomic ions are left at a constant count rate. This effect is seen in Figure 3 (solid circles) which shows that a constant rate begins at a pressure of about 40 milliTorr in the collision cell. The rate of detector pulses settles at about 1 per second, which is a factor of several hundred lower than the count rate due to samples with natural ^{14}C. The overall loss of ions due to scattering out of the correct path due to their collisions with the gas in the accelerator was tested by measuring the ion current of a stable isotope transmitted through the accelerator as a function of cell pressure. The small open circles of Figure 3 show this relationship for a number of different ion source intensities. At the pressure required for molecular destruction, we obtain 35% of the incident ion beam emerging from the accelerator with a single positive charge, even for the intense ion beams from the LLNL source as installed. This confirms that a small spectrometer operating at a low (+1) charge state transition can have high efficiency and low background levels. Perhaps another 30-40% of the incident ions emerge at higher charge states (+2, ...) and a fraction even emerge with no electrical charge. These other charge states are lost to the analysis, but the 35% that are retained is comparable to the nearly 50% that are analyzed by our larger spectrometer at 6.5 million Volts.

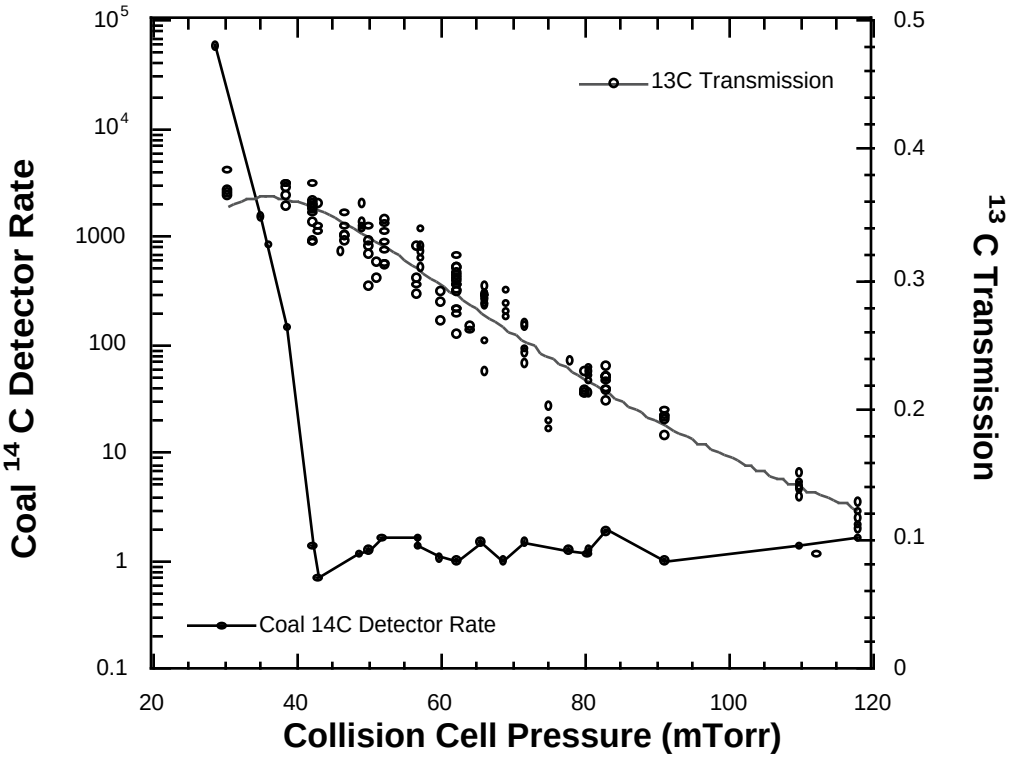

Figure 3. The ^{13}C ion transmission through the acceleration stage and the "^{14}C" count rate at the spectrometer detector are plotted as functions of the pressure of argon gas within the high voltage collision cell. The fall in "^{14}C" count rate is due to more complete breakup of molecular mass 14 ions ($^{12}CH_2$ and ^{13}CH). The best transmission with complete molecular destruction occurs at 45 mTorr pressure.

We explored the identity of the 1 count per second background rate from Figure 3 by scanning the energy selection of the large electrostatic sector when the analysis magnet remained set for the transmission of ^{14}C. Figure 4 shows the particle count rate arriving at the detector as a function of the energy band pass of the analyzer. Most particles passing the magnetic analysis are not random events, but are created by distinct processes that are revealed by the peaks at specific energies. The majority of these magnetically analyzed events are products of molecular dissociation in the collision cell. The probable causes of the peaks near the desired ^{14}C peak are noted in Figure 4.

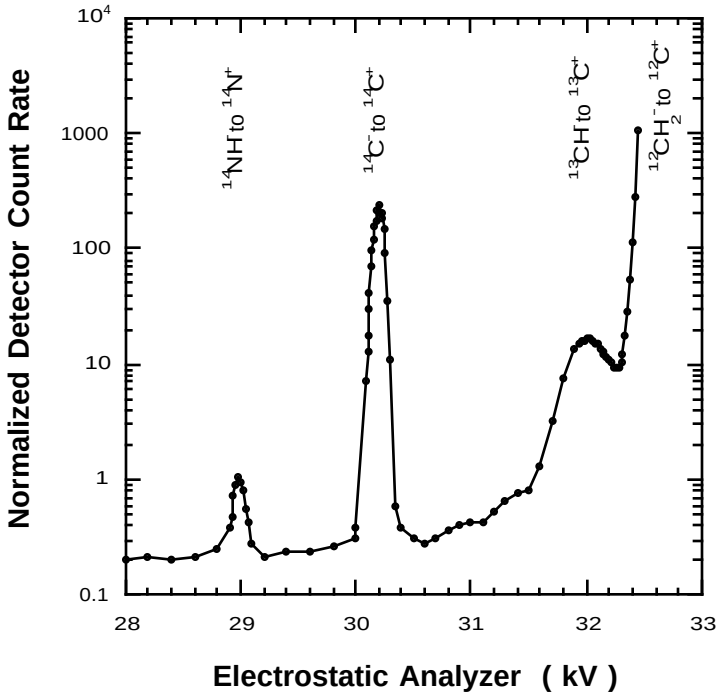

Figure 4. The count rate for particle detection after the final high energy electrostatic analyzer is shown as a function of voltage on the analyzer plates with the analyzing magnet set to transmit the $^{14}C^+$. Molecular breakup products form the peaks in count rate, but a scattered component provides about 0.3 counts of the 300 counts per second due to a natural radiocarbon level.

The non-peak related counts found with the ^{41}C peak are ions that scattered on residual gas while the ions were still accelerating after the collision cell. This level was seen to be dependent on the quality of the vacuum in this section of the accelerator. This was tested by doubling the pumping capacity at the high energy analyzing magnet. The observed count rates will not cause sensitivity loss for biochemical and natural level ^{14}C measurements.

As a result of this project, we now have a spectrometer that has the capacity to measure up to 400 samples per 24 hour day, or even 500 per 40 hour week. This is the type of capacity demanded by new research in nutrition, proteomics, clinical chemistry, and other emerging uses of AMS in biological science.

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References

Roberts, M. L., Norman, P. J., Garibaldi, J. L., Hornady, R. S. (1994) The New LLNL AMS Sample Changer. Nuclear Instruments & Methods In Physics Research Section B-Beam Interactions With Materials and Atoms. B92: 111-114.

Southon, J.R., Roberts, M.L. (2000) Ten years of sourcery at CAMS/LLNL - Evolution of a Cs ion source. Nuclear Instruments & Methods In Physics Research Section B-Beam Interactions With Materials and Atoms. B172: 257-261.

von Reden, K.F., Bellino, M., Long, P., Schneider, R.J., Loger, R. (2000) Installation of a 134 sample MC-SNICS ion source at NOSAMS and the first results. Nuclear Instruments & Methods In Physics Research Section B-Beam Interactions With Materials and Atoms. B172: 247-251.

Publications

Ognibene, T. J., T. A. Brown, J. P. Knezovich, M. L. Roberts, J. R. Southon and J. S. Vogel (2000). “Ion-optics calculations of the LLNL AMS system for biochemical C-14 measurements.” Nuclear Instruments & Methods in Physics Research Section B-Beam Interactions With Materials and Atoms **172**: 47-51.

Vogel, J. S. (2000). “Accelerator mass spectrometry for human biochemistry: The practice and the potential.” Nuclear Instruments & Methods in Physics Research Section B-Beam Interactions With Materials and Atoms **172**: 884-891.

Ognibene, T.J., Roberts, M.L., Southon, J.R., Vogel, J.S. (2001) Low charge state AMS for high throughput ^{14}C quantification. in Pliess, U. & Voges, R., eds. Synthesis and applications of isotopically labelled compounds (John Wiley & Sons, Chichester) v. 7: 515-518.