UC Berkeley
Berkeley Scientific Journal

Title
Radiocarbon Dating: Applications of Accelerator Mass Spectrometry

Permalink
https://escholarship.org/uc/item/52s156rh

Journal
Berkeley Scientific Journal, 17(2)

ISSN
1097-0967

Author
Purcell, Sean

Publication Date
2013

DOI
10.5070/BS3172020103

Copyright Information
Copyright 2013 by the author(s). All rights reserved unless otherwise indicated. Contact the author(s) for any necessary permissions. Learn more at https://escholarship.org/terms

Undergraduate

eScholarship.org Powered by the California Digital Library
University of California

RADIOCARBON DATING

Applications of Accelerator Mass Spectrometry

BSJ

By Sean Purcell

At this very moment, cosmic rays are penetrating the Earth's atmosphere and colliding with atoms in the stratosphere to form secondary cosmic trays of highly energetic neutrons . These energized subatomic particles then collide with the nitrogen-14 that in large part makes up our atmosphere; the subsequent neutron capture produces both hydrogen and radioactive carbon-14 atoms (subsequently referred to as C-14). These radioactive carbon atoms go on to form carbon dioxide molecules that are absorbed by plants, and eventually consumed by humans. This, however, should not be cause for alarm, but rather reason to celebrate. Because C-14 undergoes beta-decay, and C-14 absorption ceases at death, this process serves as a molecular timestamp, effectively putting a date on the death of biological organisms. The exploitation of this chemical phenomenon allows scientists to conduct what has come to be known as radiocarbon dating.

In late 2011, scientists in Europe used a modified radiocarbon dating process to arrive at the startling realization that Neanderthals must have coexisted with anatomically modern humans, a claim that was once widely contested among historians and anthropologists as it defies generally accepted human evolutionary and migratory patterns (Higham, 2011). Research conducted at University of Oxford's Radiocarbon Accelerator Unit (ORAU) under scientist Thomas Higham dated a human jawbone discovered at Kent's Cavern, UK between 44.2 - 41.5 kyr cal BP (between 41,500 and 44,200 years old), filling a "key gap between the earliest dated Aurignacian remains and the earliest human skeletal remains" (Higham, 2011). Similarly, research conducted by Stefano Benazzi at the University of Vienna dated two teeth discovered at Grotto de Cavallo, Italy much earlier than previously thought, to between 43,000 and 45,000 calendar years before present (Benazzi, 2011). These scientists utilized a specialized form of carbon dating known AMS radiocarbon dating, which relies upon atomic mass spectrometry and

Archaelogists recently identified the newly uncovered skull of English king Richard III, using modern carbon dating and genetic techniques.

specialized sample preparation techniques to date particularly old and small samples with remarkable precision.

Carbon dating as a process is relatively new, developed by Nobel Laureate and UC Berkeley professor Willard Libby in 1936 (Libby, 1967). Knowing that organic matter, after death, is unable to absorb significant levels of C-14 and that the atmospheric concentration of C-14 is relatively stable, Libby's model claimed that because the radioactive isotope C-14 undergoes beta decay with a half life of approximately 5730 calendar years, organic matter could be dated by determining the concentration of the isotopic carbon in fossils and remains (Libby, 1967). Scientists have since developed a wide array of techniques to measure the radioactive decay of C-14. Two early methods, gas proportional counting and liquid scintillation counting (both radiometric methods which rely on monitoring the decay of specific C-14 atoms over time) while effective, presented scientists with a unique problem. These radiometric-counting methods produced results with significant statistical uncertainty (due to the long half life of C-14) and required large sample sizes. In April of 1977, Richard Muller, while conducting research at the Lawrence Livermore Radiation Laboratory, found that by using a cyclotron as a high energy mass spectrometer, maximum

"Because C-14 undergoes beta-decay, and C-14 absorption ceases at death, this process serves as a molecular timestamp, effectively putting a date on the death of biological organisms."

A fossilized jaw, this section of jawbone was analyzed by the Higham group at the Oxford Radiocarbon Accelerator Unit, Oxford University.

One of the infant teeth from the Grotto de Cavallo, examined by Stefano Benazzi of the University of Vienna.

age determination could be increased while simultaneously decreasing required sample size — bringing much headway to the problem of radioisotope dating that had so long troubled scientists researching trace element detection (Muller, 1977). This discovery resulted in the subsequent use of accelerator mass spectrometry as a means to isolate radioactive isotopes by bringing energy levels to amounts capable of removing interferences by other isotopes and atoms present (namely atomic nitrogen). The use of accelerator mass spectrometry to isolate radioactive C-14 has since transformed the carbon dating process, primarily because AMS radiocarbon dating not only removes much of the statistical uncertainty of radiometric counting methods and requires small sample sizes.

Accelerator mass spectrometry is remarkable in its ability to detect extremely low concentrations of an isotope. In the case of C-14, the AMS technique detects quantities as low as one C-14 atom per trillion C-12 atoms (Nelson, 1995). In order to carry out such a process, negatively charged carbon ions generated by a cesium sputter ion source and charged to between 3-10 keV physically knock atoms from the sample and contribute electrons to a fraction of the ejected particles forming negative elemental and molecular ions (Nelson, 1995). These ions are selected at a single mass unit by a magnetic dipole and then injected into a tandem electrostatic accelerator. The ions are immediately accelerated toward a highly charged positive potential, passing through a carbon film that removes electrons, making the carbon atoms positive ions. Positively polar carbon ions then accelerate through a second stage of the accelerator that brings their kinetic energies between 5-150 MeV, effectively eliminating interference from other isotopic atoms in the sample, including N-14 (Nelson, 1995). Using magnetic quadrupole lenses to focus the C-14 and charge state to the entrance of a second dipole mass spectrometer removes interference before being filtered by a Wien system (Nelson, 1995). In combination with a multianode gas ionization chamber or solid-state detector, both the ion's total energy and the rate of deceleration as it passes through the detector can be measured for low-medium mass isotopes, allowing C-14 to be identified (Nelson, 1995). Extracting and counting C-14 through the use of particle physics eliminates both the large sample requirements and timetable of radiometric counting methods while also determining the concentration of stable carbon isotopes (C-12, C-13) in a sample.

"AMS techniques can detect quantities as low as one C-14 per trillion C-12 atoms."

The process of AMS radiocarbon dating, while statistically more accurate, does have a major drawback. Due to the high costs of purchasing and operating a nuclear particle accelerator and its components, access to AMS radiocarbon dating methods is often limited. However, AMS radiocarbon dating offers scientists remarkable capabilities that surpass those of radiometric counting methods. Current research studies suggest the use C-14 as a biomedical tracer that can be used for labeling when fast analysis (less demanding accuracy than for carbon dating) of a large number of samples is desired, by using low voltage compact AMS facilities (Suter, 2000). AMS is sufficiently sensitive to detect C-14 at levels so low that much of the hazard and most significant interference has been eliminated. Recent studies show that AMS has a sensitivity over radiometric decay counting for long lived radioisotopes and common radiotracers that will allow for smaller samples and lower radioisotope concentrations. New methods are being developed to exploit this selectivity and sensitivity in biochemical laboratories interested in pharmacokinetics and biomolecular interactions. These remarkable characteristics show great promise to researchers studying metabolism, macromolecular binding of candidate drugs and toxins, and even the pathology of bacterial and viral infection.

The combination of accelerator mass spectrometry and radiocarbon dating demonstrates the remarkable capabilities of science at disciplinary boundaries. Research conducted at the junction of chemistry and physics has led to unprecedented discoveries relevant to both the biological and anthropological fields. For instance, the ORAU group's discoveries serve to correct historical and anthropological beliefs and introduce the possibility of two waves of modern human migration and Neanderthal extinction, all in a timescale significantly different than previously recorded and accepted by the academic community. It is instances like these that demonstrate the remarkable capabilities of AMS radiocarbon dating and more generally the remarkable capabilities of interdisciplinary science.

References

Benazzi, S., Douka, K., Cocquerelle, M., & Condemi, S. (2011). Early Dispersal of Modern Humans in Europe and implications for Neanderthal behaviour. Nature, 479, 525-529.

Higham, T., Jacobi, R., & Ramsey, C. (2006). AMS Radiocarbon Dating Of Ancient Bone Using Ultrafication. Radiocarbon, 48(2), 179-195.

Higham, Tom, Tim Compton, Chris Stringer, Roger Jacobi, and Chris Collins. "Earliest Evidence for Anatomically Modern Humans in Northwestern Europe."

Nature 479 (2011): 521-524. Print.

Gaisser, T. K. (1990). Preface, Cosmic Rays, Particle Physics. Cosmic rays and particle physics (pp. xv-21). Cambridge [England: Cambridge University Press.

Libby, W. (1967). History of Radiocarbon Dating. Los Angeles, USA: Department of Chemistry and Institute of Geophysics, University of California Los Angeles.

Muller, R. A. (1977). Radioisotope Dating with a Cyclotron. Science, 196(4289), 489-494.

Nelson, D. E., Vogel, J., Turteltaub, K., & Finkel, R. (1995). Accelerator Mass Spectrometry: Isotope Quantification at Attomole Sensitivity. Analytical Chemistry, ACS, 0003-2700/95/0367-353A, 353A-359A.

Suter, M. (2000). Tandem AMS at sub-MeV energies - Status and Prospects. Nuclear Instruments and Methods in Physics Research, 172(B), 144-151.

Table of Isotopic Masses and Natural Abundances. (n.d.). University of Alberta, Chemistry . Retrieved March 10, 2013, from www.chem.ualberta.ca/~massspec/atomic_mass_abund.pdf

Vogel, J.S. (1990). Application of AMS to the Biomedical Sciences. Nuclear Instruments and Methods in Physics Research, 52(3-4), 524-530.