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Determination of 14C by Acceleration Mass Spectrometry: Status Update

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Abstract: *In the present study it has been reviewed how Accelerator Mass Spectrometry is better than mass spectrometry for the determination of radiocarbon ^{14}C. Ion source design criteria for AMS has also been discussed as an edge over Mass spectrometry. Data acquisition technique has also been precisely discussed.*

Keywords: *Acceleration Mass Spectrometry, Ion source, Data Acquisition Technique etc.*

I. Introduction

The development of AMS in different nuclear science experimental facilities has been preferred rather than developing mass spectrometers because the design of critical components such as ion sources has been easily obtained after modification of the equipments designed for nuclear physics experiments. For the AMS of ^{14}C solid samples and other radioisotopes the principal requirements for ion source design are –

To eliminate the most molecular & atomic isobaric interferences which results in low abundances of the isotopes, the highest currents of ions that can be obtained from the sample are needed. Further stability of this current on the time scale of the switching or sampling cycles is important to reduce the systematic errors.

The ability to provide meaningful results even from very small samples by AMS has stimulated the need for the ion sources such that maximum part of target materials be converted into ions with trajectories which can be accepted by the spectrometer.

AMS system is comparatively a more complex one than conventional mass spectrometers with more filter stages and less well pumped paths for the ion becomes especially in the accelerator section. So, the drifts in elector and magnetic fields associate with the transport of ions and for vacuum pressure variations are possible. To reduce this for systematic reproducibility frequent comparison between the unknown and a standard target is required. So, in the ion source, reproducibility in target position must be maintained and the time lost in moving between targets must be minimized.

The initial success of AMS was founded on the removal of ^{14}N isobar of ^{14}C due to very short lifetime of N^-. Doing isobar separation at or near the ion source reduces the complexities of the analysis.

^{14}C concentration in a sample can be expressed as $\Delta^{14}C$ which is per mil (%o) deviation of $^{14}C/^{12}C$ ratio of the sample with respect to a modern ^{14}C standard whose ^{14}C activity equals to that of pre-industrial wood of AD 1890. Also, for isotopic fractionation of the ^{13}C isotope, the ratios are normalized and corrected for decay of ^{14}C. Old samples of carbon have less ^{14}C than a modern sample and therefore have positive ^{14}C ages in BP (Before present, present corresponds to AD 1950) and negative $\Delta^{14}C$ %o values, whereas the current terrestrial wood samples with higher ^{14}C show negative ^{14}C ages in BP and +ve $\Delta^{14}C$ %o values. Geologically, old carbon samples such as marble or old limestone, coal and other fossil fuels, are "^{14}C dead", that means ^{14}C is almost decayed from that sample. Such samples have ^{14}C appear as infinite and $\Delta^{14}C$ ~ 1000%o. ^{14}C dating of terrestrial samples, depends on part ^{14}C level of rapidly mixing global atmosphere with a small difference between the two hemisphere. ^{14}C is introduced in the atmosphere through its production in the upper atmosphere by the reaction of atmospheric nitrogen with thermal neutrons which are produced from cosmic ray spallation reaction on other components of the atmosphere $^{14}N_7{}^{+1}n_0={}^{14}C_6{}^{+1}H_1+\Delta$ (Energy).

These ^{14}C produced are soon oxidized in the presence of atmospheric oxygen to form Carbon Monoxide which eventually oxidizes to form Carbon dioxide.

$^{14}C+O={}^{14}CO$

$^{14}CO+O={}^{14}CO_2$

These $^{14}CO_2$ (radioactive) enters the biosphere through photosynthesis by terrestrial plants and then to entire food chain through herbivores living beings. However, when a living being dies, the ^{14}C exchange halts and the ^{14}C in the deal tissues start to decrease exponentially through radioactive decay.

$N=N_oe^{-\lambda t}$

^{14}C forms stable nitrogen through β-decay and has the half life approximately 5770 years.

$^{14}C_6={}^{14}N_7+\beta^-$

The radioactive decay of ^{14}C can be used for age determination of organic or biogenic samples. W.F. Libby in 1960 was awarded Noble prize for his pioneering work of $^{14}C^-$ dating. For the samples up to 50,000 years old, ^{14}C is suitable with its half life 5730±40 years. So, for Pleistocene period, $^{10}Be^{-}$ dating is being developed now a days ($t_{1/2}$ of $^{\gamma 0}Be$=1,25,000 years). A very simple way to enhance the separation between ^{14}C and ^{14}N in the ΔE–E plot is to insert a degrader foil just in front of SSD. As the ^{14}C ions of 4.5MeV energy lost about 22 KeV in a $31^{\mu g}/cm^2$ carbon foil, the Bohr straggling FWHM is this FWHM in this foil is about 6.8 KeV and the half width scattering angle is about 0.036^{o}, the number of electrons emitted per ^{14}C ion is 40–50. R. Gosler et.al.)

As the process studied at National Ocean Science Acceleration Mass Spectrometry Facility (Seguin, Schneider et.al., 1994), it is useful here to describe how the data acquisition technique works in C^{14}–AMS. For this a typical target carries 45 unknown samples, 10 reference standards, two process blanks, and a machine blank. As a programmed sequence, each individual targets are exposed to a sputtering beam for 5-min. periods with nine exposures for each sample over a run cycle of 10–12 hours. Each exposure results in a measurement of ^{14}C counts, ^{12}C and ^{13}C currents and various other parameters recorded with a time stamp. Every sixth target exposed in a reference standard with a known value of $^{14}C/^{12}C$ used to calibrate the relative efficiency of ^{14}C and ^{12}C, the knowledge of which will be useful for converting raw measurements of ^{14}C counts and ^{12}C current to an accurate value of $^{14}C/^{12}C$ for each unknown sample.

II. Conclusion

^{14}C dating has become the most precise & convenient technique by AMS. Terrestorial production of ^{14}C is however less than the oceanic radiocarbon production. In our next study it is planned.

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