PRESENT STATUS OF BINP AMS

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Abstract

The accelerator mass spectrometer (AMS) created at BINP is used for biomedical, archaeological and other applications. Current status and experimental results are described.

INTRODUCTION

The accelerator mass spectrometry is an ultra-sensitive method of isotopic analysis. The radiocarbon concentration in living organisms, plants and atmospheric air are about 10^{-12} in comparison with the main carbon isotope - ^{12}C. After death of the living organism, the radiocarbon concentration is reduced by 2 times for every 5730 years, according to the half-life of the radiocarbon. The radiocarbon concentration for 50 thousand years age objects is about $2*10^{-15}$. About 1 mg of carbon sample is required for radiocarbon analysis by AMS. So, the AMS is very demanded by users. So, it is possible to analysis of natural objects by using a small fraction. This allows obtain information about objects of cultural and historical value without destroying. And it is also possible to study the processes of natural deposits accumulation with a small spatial step. Similarly, the biomedical research can be conducted with a small number of radiocarbon labels introduced into living systems. In this case, the radiocarbon labels concentration can be detected in various organs of the living object under study without significant radiation exposure.

PRESENT STATUS

The BINP AMS is based on the folded type electrostatic tandem accelerator [1-3]. The AMS system consists of the ion source, low energy channel, tandem accelerator and high-energy channel. The low energy beam line is used for initial isotopes selection. The tandem accelerator is applied for rejection of the molecular ions. The high-energy beam line is used for the subsequent ions selection and for radioisotopes detection.

The most distinguishing feature of BINP AMS is the use of additional electrostatic separator of ion beam [4-6], located inside the terminal. In this configuration of the AMS, the ions background is significantly reduced by the energy filter in the high voltage terminal [7-8], because the energy of fragments is always less then the ion energy (at this moment). The next important distinguishing feature is magnesium vapours stripper [9] instead of the gas stripper. The gas flow into the accelerator tubes leads to big energy spread in the beam thus limiting the sensitivity and accuracy of spectrometer. The molecular destruction and ion recharging by magnesium are localized into the hot tube of the stripper. Moreover, time of flight and the time of the ion detection can be registered TOF detector [10,11] for filtering the background ions from electrical breakdowns.

Now the BINP AMS is a single Russian facility for radiocarbon analysis of samples by accelerator mass spectrometry. At the end of 2017, the facility was officially registered as a "unique scientific installation" called "BINP AMS SB RAS". Now every scientific organization can leave an online application on the site for the conduct of joint research with BINP using AMS. Over the past year, the about 1000 samples was analyzed at BINP AMS for 25 user organizations.

RADIOCARBON MEASUREMENTS

During the measurements of user samples, the injection energy of radiocarbon beam is about 25 keV. The terminal voltage of tandem accelerator is 1 MV. The 180° electrostatic bend is set to transmit the ions with charge state 3+.

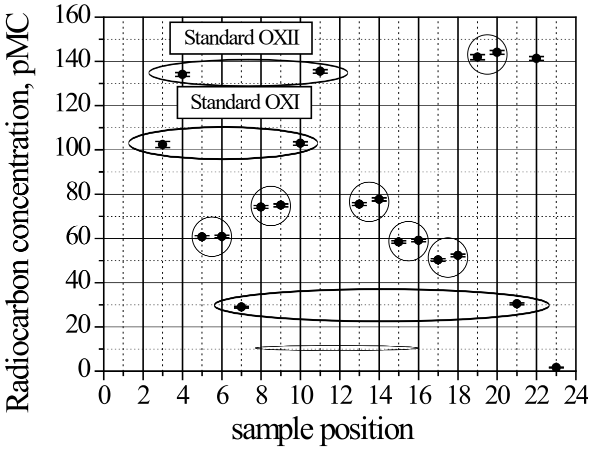

Figure 1: Example of AMS analysis of the sample wheel with user samples.

When measuring the concentration of radiocarbon in the samples, the switching algorithm is used. The isotope ^{14}C is detected by TOF telescope and ^{13}C currents are measured at the exit of AMS. For switching algorithm the high voltage of ion source and voltage on some electrostatic elements are changed. About 80% of the time is used on radiocarbon ions counting, the rest 20% of the time is used for isotope switching, the current ^{13}C measurements, and the sample wheel rotation.

The cycle of AMS-analysis of samples is represented as follows. For each sample, the ^{14}C ions are counted four times (10 seconds each) and twice the ^{13}C currents are measured for each 10 seconds counting. After that, the samples wheel is turned to the next sample for process repetition.

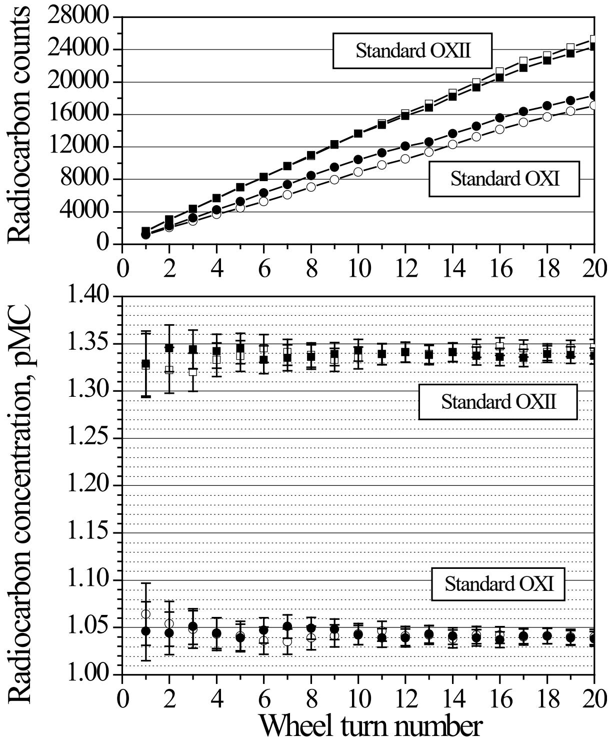

Figure 2: Example of accumulation of counted radiocarbon ions and a change in the measured value of the radiocarbon concentration in the standards, depending on the wheel turn number.

For AMS analysis, all natural samples must be converted to a universal form by sample preparation procedure. For these purposes, a sample is combusted in vacuum. Then the carbon from formed CO_2 gas catalytically deposited on iron powder. The Fe-C mixture is pressed in aluminum sample holder (cathode for ion source) for AMS analysis. Sample preparation for the BINP AMS is carried out by chemists from LRMA NSU [12].

Usually, the 23 samples are placed in the sample wheel. Three of 23 are without sample preparation and 20 samples with sample preparation. Samples without sample preparation are used to tune the beams passage through AMS and, if necessary, used to test the performance of the AMS. Samples without sample preparation are not included in the cycle of the statistics set during AMS analysis. Of the 20 samples with sample preparation, the four samples are usually standards with a known concentration of radiocarbon. Usually, it is two OXI (SRM 4990 B) standards and two OXII (SRM 4990 C) standards.

An example of a radiocarbon analysis of samples is shown in Fig. 1. The values are given in units of pMC (percent modern carbon). 100 pMC is about the radiocarbon concentration in living systems (or in atmospheric CO_2). Usually, in order to increase the reliability of AMS analysis, samples are prepared in pairs. The circled points correspond to one natural sample, but with independent sample preparation procedures. It seen that the radiocarbon concentration in duplicate samples is statistically same. The final result of AMS analysis is the average radiocarbon concentration in sample pairs. The statistical measurement error is determined by the total number of detected radiocarbon ions for pairs of samples. If duplicate samples are not statistically same, then an additional sample is prepared and measured. In this case, 2 out of 3 statistically same samples is averaged.

Measuring of whole graphitized sample wheel (20 samples) takes about 15 minutes for each wheel turn. For a set of statistics the wheel are moving to the second turn, third, etc. The example of statistics set is shown in Fig. 2.

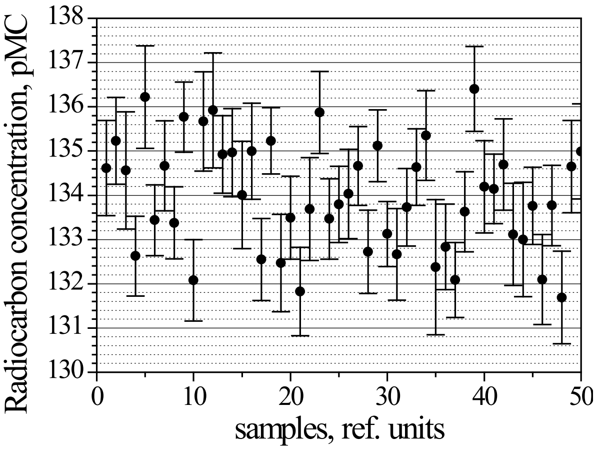

Figure 3: Individual values of the radiocarbon concentration in the OXII standards.

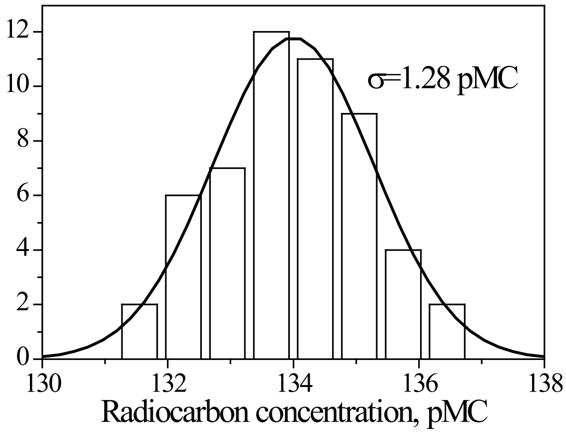

Figure 4: The distribution of radiocarbon concentrations for OXII standards and the approximation by the Gaussian function.

For demonstration of the reproducibility of the AMS analysis results, the radiocarbon concentrations in the 50 samples of OXII standards are given in Fig.3. These values were not measured purposefully, but were obtained by measuring sample wheels with user samples. The rate of radiocarbon concentration measurement is 20 samples in about 5 hours. The distribution of radiocarbon concentrations for OXII and the approximation by the

Gaussian function is given in Fig. 4. It is seen that the average error value is slightly less than 1%.

Atmospheric carbon is permeated into the samples during sample preparation [13]. Samples used for radiocarbon dating must be handled carefully to avoid contamination. The contamination level in the samples during the sample preparation procedure is estimated by the radiocarbon content in graphite with and without sample preparation, as shown in Fig. 5. The content of radiocarbon atoms in graphite MPG without sample preparation is 15 orders of magnitude smaller than the content of main carbon isotopes. But the content of radiocarbon is increased by an order of magnitude after sample preparation. The radiocarbon concentration in graphite after sample preparation corresponds to the radiocarbon age of about 40 thousand years.

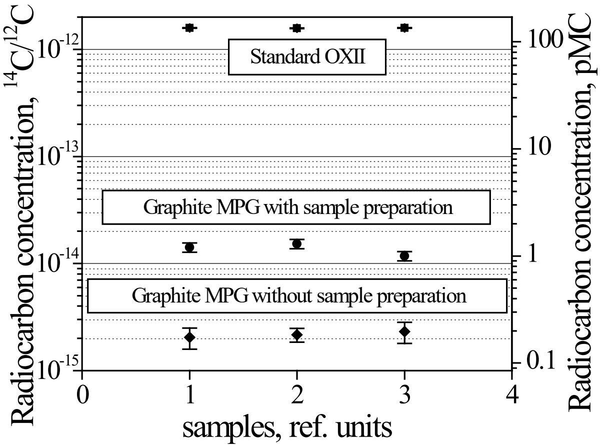

Figure 5: Radiocarbon concentrations in graphite MPG with and without sample preparation, as well as in OXII standards.

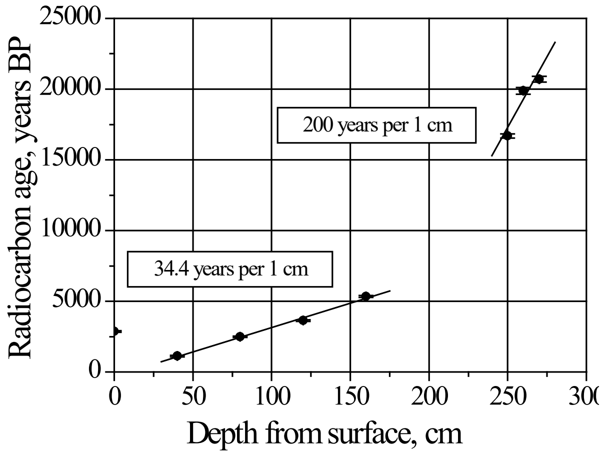

Figure 6: The radiocarbon age of lake sediments, depending on the depth from surface level.

As an example of AMS-analysis, the data from geological samples - lake Ebeity sediments, depending on the depth from surface level (samples of Krivonogov S.K., IGM SB RAS), presented in Fig. 6. The measured radiocarbon concentration in the user samples are normalized to the concentration in the standards for calculating the radiocarbon age of the samples. Such analyzes are necessary to obtain a timescale for lake sediments. As seen, the deposits accumulation rate at small depths is an about order of magnitude higher than at deep depths.

SUMMARY

The BINP AMS with additional ion selection properties is demonstrated the sustained performance on 1MV running and the good radiocarbon ions identification. The BINB AMS is used for radiocarbon analysis of graphitized natural samples for users. About 1000 samples were measured last year for 25 user organizations. The statistical error of radiocarbon analysis for modern samples less than 1% when measuring 20 samples per 5 hours. The concentration of radiocarbon in the very old samples is approximately 10^{-14} ($^{14}C/^{12}C$) due to contamination by atmospheric carbon during sample preparation of natural samples.

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