ПРИМЕНЕНИЕ УСКОРЕННЫХ ПУЧКОВ: ДЕТЕКТОРЫ И ДЕТЕКТИРОВАНИЕ ЯДЕРНЫХ ИЗЛУЧЕНИЙ

DEVELOPMENT OF THE BINP AMS COMPLEX AT CCU SB RAS

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The accelerator mass spectrometer created at BINP is installed at CCU "Geochronology of the cenazoic era" for sample dating by the ^{14}C isotope. Present status of AMS complex and the results of experiments for radiocarbon concentration measurements in test samples are presented.

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1. INTRODUCTION

The accelerator mass spectrometry is an ultra-sensitive method of isotopic analysis for archaeology, geology, biomedical science and other fields. The AMS is mainly dedicated for radiocarbon dating of samples by measurements of the ratio between carbon isotopes. The ratio between isotopes ^{14}C and ^{12}C in modern samples is about 10^{-12}. The radiocarbon concentration in "dead" samples is reduced by half every 5730 years, and can be less than 10^{-15}. The radiocarbon concentration is measured by direct counting of ^{14}C ions, and only 1 mg or less of carbon sample is required for this method.

The BINP AMS system consists of the ion source, low energy channel, tandem accelerator and high-energy channel [1]. The ion source is used for production of the negative ions by bombarding the carbon target with positive cesium ions. The low energy beam line is used for initial isotopes selection. The folded type vertical tandem accelerator is applied for rejection of the molecular ions and of course for obtaining necessary beam energy for rare isotopes detector. The high-energy beam line is used for the subsequent ions selection and for radioisotopes detection.

The negative ion beam, horizontally extracted from the source, passes through the 90° injection magnet. Then the ions are vertically accelerated to the positively charged high voltage terminal and stripped to plus charge state in magnesium vapors stripper. Then they pass through the 180° electrostatic bend and then again are accelerated vertically into the high energy accelerating tube to the ground potential. The extracted radioisotope ions are horizontally put to the final detector [2] through high-energy channel with 90° magnet.

The most distinguishing feature of our AMS machine is the use of additional electrostatic separator of ion beam, located inside the terminal. Interfering isobaric molecules are destroyed by collisions in the stripper into the terminal and are selected immediately after the stripping process. It is important to decrease the background from molecular fragments before the second stage of acceleration [3], because the energy of fragments is always less then the ion energy (at this moment). The next important distinguishing feature is magnesium vapours stripper [4] 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.

2. PRESENT STATUS

The BINP AMS facility is in operation for radiocarbon concentration measurements at CCU in Novosibirsk. The accelerator is placed into underground room with radiation shielding. The inner size of the room is $6 \times 6 \times 7.5$ meters.

The 1 MV terminal voltage was achieved by using low cost air-gas mixture. The tank was pumped to the 0.8 atm air pressure, and then the tank pressure was increased to 1.6 atm by four nitrogen gas-cylinder. The 4 kg of SF_6 gas was added (+0.02 atm) to increase the electrical strength of the mixture. The 1 MV has been achieved without breakdowns.

The new modification of the magnesium vapors stripper was used last year without replacement of magnesium. All hot parts of striper are located in vacuum for prevention of corrosion of striper surface by the tank gas mixture. The power consumption by stripper is about 50 W.

The electrical power, required in the terminal equipment, is generated by the 500 W gaseous turbine. The turbine is fed by compressed air follows from compressor, which is placed at ground potential. For prevention of water condensation on the cool surface of the gas turbine feeding dielectric tube (inside of the accelerator tank), the lower part of the tube (outside of the tank) was heated.

The multi-cathode (for 23 samples) sputter ion source is used for synchronous analysis of the samples and for comparison of the tested samples with the reference one. The negative ions are produced by bombarding the graphite target with positive cesium ions. The cesium oven was improved for a more rapid replacement of cesium.

The time-of-flight detector (ToF) is used for ion identification. At present, the ToF channel width is 70 ps. The moment of time for ion detection can be registered with 16 μs channel width. This data is used for calculation of number of detected ions per unit time, allowing to filter the background ions from electrical breakdowns at ion source.

The process of isotope measuring and sample changing (wheel rotation) is fully automated. The measurements and running conditions are on-line displayed and stored in the database files.

Now, the BINP AMS complex was routine used for radiocarbon measurements in archaeological samples, produced by CCU "Geochronology of the cenazoic era". The sample preparation group produced about 1 sample per day. The measured radiocarbon concentration in "dead" samples prepared from graphite was about several percent relative to the modern sample. It is due to contamination by background carbon during sample preparation procedure. Now, the reproducibility of sample preparation is not good enough for AMS testing by commonly used standard such as OxII. For testing of the reproducibility of AMS measurements and ion background, we used samples that do not require sample preparation procedures. It is graphite MPG (as "dead" sample) and carbon fabric (as modern sample).The experimental results from such test are presented below.

3. EXPERIMENTAL RESULTS

During the experiments, the injection energy of radiocarbon beam was 25 keV. The ^{12}C beam current was about 10 uA. The terminal voltage was 1 MV. The 180° electrostatic bend was set to transmit the ions with charge state 3+. The ions in charge state 3+ will be used for isotope analysis because the molecules in charge state 3+ are unstable. The magnesium vapors stripper was heated for obtaining the equilibrium charge state distribution, but not more. The ion energies at the exit of AMS facility are 4025 keV. The ions transmission of AMS system at this energy is about 10 % (includes the stripping yield for 3+ charge state). The vacuum in the beam line was about 10^{-6} Torr. The ^{12}C ions are measured in shielded Faraday cups with secondary electron suppression. The ^{14}C ions are counted by ToF telescope. Each channel ToF telescope is 70 ps.

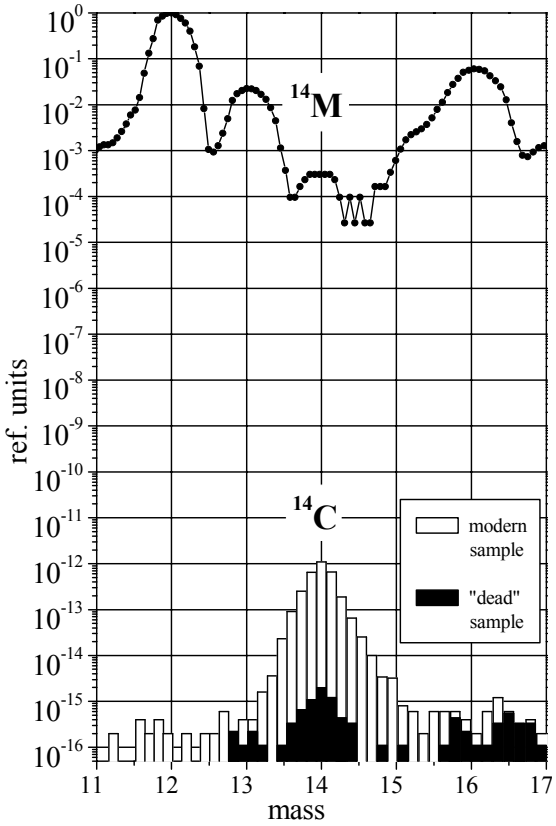

Fig.1. Mass spectrums of the injected (upper curve) and accelerated (lower curves) beams

The typical mass spectrum of the carbon target before acceleration is shown in Fig.1 (upper curve). The plot is obtained by varying the injection magnet field. The intensity of the mass-14 peak is more than 10^{-4} per ^{12}C isotope. It is mainly the $^{12}CH_2$ and ^{13}CH molecular currents. The intensities of the molecular beams are changed in time. It depends on vacuum conditions in ion source and sample quality. The ToF spectrums at the exit of AMS for graphite MPG and carbon fabric are also shown in Fig.1 (lower curves). The mass is calculated from ToF channels with assumption that energy is constant. The AMS system is tuned for radiocarbon transmission. The molecular background of the mass-14 is suppressed by the destruction process in the magnesium target and then filtered by tandem 180° bend. The small mass-13 peak is also visible in the spectrum, but the mass separation is good enough for radiocarbon measurements. The carbon fabric is made of organic materials. The radiocarbon isotope ratio of the modern organic matter is about 10^{-12} ($^{14}C/^{12}C$). The intensity of the radiocarbon in graphite MPG is about 500 times lower than in carbon fabric. It is seen that the ^{14}C peak value in graphite MPG significantly exceeds the sensitivity limit of BINP AMS facility. We plan to test other brands of graphite for direct determination of present-day sensitivity limit.

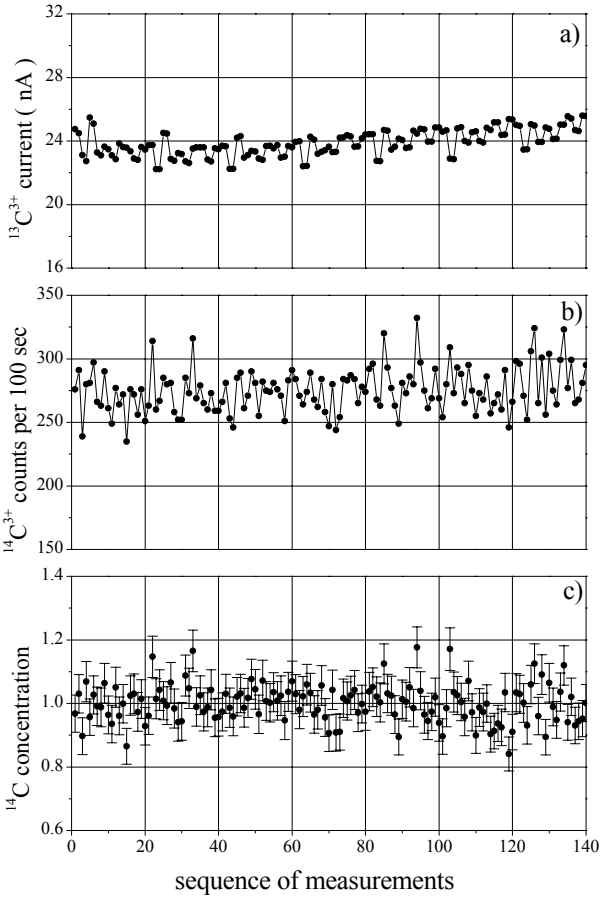

Fig.2. The $^{13}C^{3+}$ current (Fig.3,a), $^{14}C^{3+}$ counts (Fig.3,b), and radiocarbon concentration (Fig.3,c) for 10 carbon fabric samples

For radiocarbon concentration analysis, the number of $^{14}C^{3+}$ counts was normalized to the $^{13}C^{3+}$ current. During the experiments, the $^{13}C^{3+}$ ion current was measured one time of each 100 s interval of radiocarbon

counting. During switching between the isotopes, the ions injection energy, low energy electrostatic correctors and the high energy magnet settings are changed. The ^{13}C ions current and ^{14}C ions number are measured twice for each sample, and then the sample is changed by rotating the wheel with samples of the ion source.

Fig.2 shows the $^{13}C^{3+}$ current (see Fig.2,a), $^{14}C^{3+}$ counts (see Fig.2,b), and measured radiocarbon concentration (see Fig.2,c) for 10 carbon fabric samples are measured alternately. This corresponds to a double measurement of 10 samples within 7 sample wheel revolutions. The measurement time was 5.7 hours. The samples were degased at 350°C for 3 hours to reduce surface contamination. As seen from the Fig.2,a, current is not much change from sample to sample and with time. The number of counts is changed at Fig.2,b due to statistical fluctuations. The statistical uncertainty of radiocarbon concentration is shown at Fig.2,c by error bars. The mean statistical uncertainty of each measurement is about 6%.

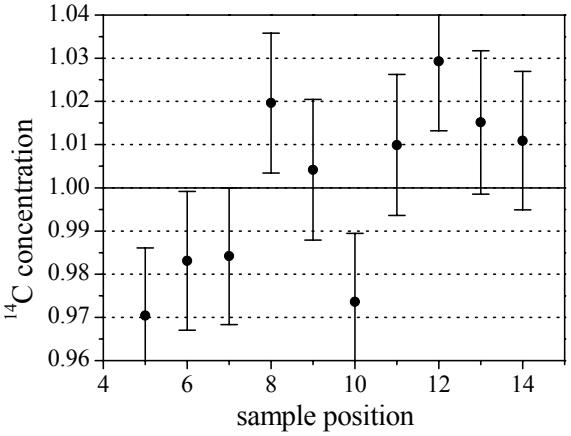

Fig.3. Radiocarbon concentration in ten modern samples (carbon fabric)

The radiocarbon concentrations in 10 samples computed from data in Fig.2 are presented at Fig.3. The value 1 on the vertical axis corresponds to the mean concentration value of all measurements. The statistical uncertainty of radiocarbon registration is about 1.5 % (shown by error bars).

The same data as at Fig.3, but after an additional set of statistics are presented at Fig.4. It is seen, that the scatter in the data decreases with the decrease of statistical error. The final results of all ten samples are in agreement with average value within the 1 % ranges.

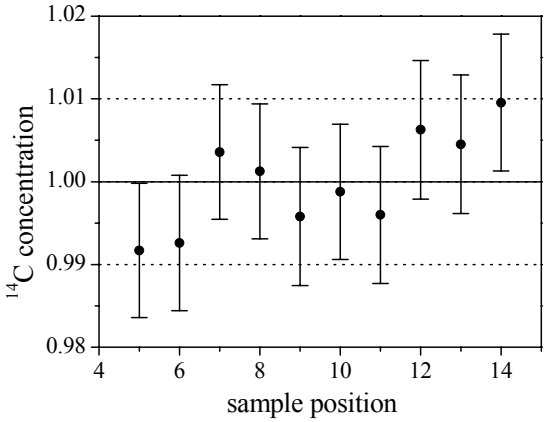

Fig.4. Radiocarbon concentration in ten modern samples (carbon fabric) after an additional set of statistics

SUMMARY

The accelerator complex has demonstrated the sustained performance on 1MV running. The reproducibility of radiocarbon concentration measurements is about 1 %. The measured radiocarbon concentration in "dead" sample is about 0.2 % of the modern sample concentration.

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РАЗВИТИЕ КОМПЛЕКСА УМС ИЯФ В ЦКП СО РАН

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Созданный в ИЯФ ускорительный масс-спектрометр установлен в ЦКП «Геохронология кайнозоя» для датирования образцов по изотопу ^{14}C. Представлены текущее состояние комплекса УМС и результаты экспериментов по измерению концентрации радиоуглерода в тестовых образцах.

РОЗВИТОК КОМПЛЕКСУ УМЗ ІЯФ В ЦКП СО РАН

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Створений у ІЯФ прискорювальний мас-спектрометр встановлено в ЦКП «Геохронологія кайнозою» для датування зразків по ізотопу ^{14}C. Представлено поточний стан комплексу УМЗ і результати експериментів з вимірювання концентрації радіовуглецю в тестових зразках.