

OPERATION AND DEVELOPMENT OF THE BINP AMS FACILITY

S.A. Rastigeev, V. V. Parkhomchuk, BINP SB RAS, Novosibirsk, and NSU, Novosibirsk, Russia
 A.R. Frolov, A.D. Goncharov, V. F. Klyuev, E.S. Konstantinov, A.V. Petrozhitskii, BINP SB RAS,
 Novosibirsk, Russia
 L. A. Kutnykova, IAE SB RAS, Novosibirsk, Russia

Abstract

The BINP AMS facility is the accelerator complex for accelerator mass spectrometry. The most distinguishing features of BINP AMS is the use of the middle energy separator of ion beams, the magnesium vapors target as a stripper and time-of-flight telescope for accurate ion selection. Present status and development of AMS complex for extension of applications are reviewed.

INTRODUCTION

The accelerator mass spectrometry is an ultra-sensitive method of isotopic analysis for archaeology, biomedical, environment science and for another field. It's based on measurements of the ratio between isotopes. The ratio between isotopes in sample can be less than 10^{-14} . So, the counting methods are used for detection of such low radiocarbon concentration [1-3]. The AMS system consists of the ion source, low energy channel, tandem accelerator and high-energy channel [4-6]. The tandem accelerator is a folded type vertical machine. The low energy beam line is used for initial isotopes selection. The tandem accelerator is applied for rejection of the molecular ions and of course for obtaining necessary beam energy for radioisotopes detector. The high-energy beam line is used for the subsequent ions selection and for radioisotopes detection.

The most distinguishing features of our AMS machine are the use of the middle energy ions separator. The middle energy electrostatic separator is located inside the tandem terminal. It can essentially decrease the ion background [7,8]. The next important distinguishing feature is the magnesium vapors stripper [9] instead of the gaseous one. The molecular destruction and ion recharging by magnesium are localized into the hot tube of the stripper. Moreover, the moment of time for ion detection can be registered with 16 μ s channel width by TOF detector [10,11]. This data is used for calculation of number of detected ions per unit time, allowing filtering the background ions from electrical breakdowns.

The accelerator mass spectrometer created at BINP SB RAS is installed at CCU "Geochronology of the Cenozoic era" for sample dating by the ^{14}C isotope and recently upgraded for biomedical applications. Over the past year have been analyzed more than 500 samples. Given the interest in using AMS in the biomedical field, the first biomedical researches are started jointly with biologists [12].

ION SOURCE

The multi-cathode (for 23 samples) sputter ion source is used for AMS analysis. The typical current of negative carbon ions is about 10 μA for analyzed samples. The negative ions are produced by bombarding the graphite target with positive cesium ions. The vapor is formed by heating of the reservoir with cesium. Then the vapor via the pipe rises from the reservoir to the ionizer. The positive charged Cs ions are produced on a hot tantalum ionizer. The cesium ion beam is focused on the carbon sample placed on the cathode, because the working surface of ionizer is a spherical-shape cup. The copper sample holder has the inner diameter of 2 mm. The sample after AMS analysis is present at the Fig.1. As seen, the sputtering region of the sample is about 0.5 mm in diameter.

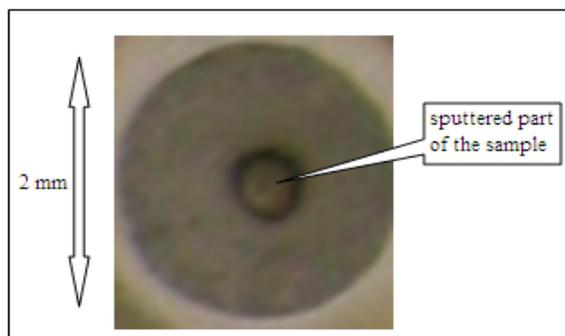


Figure 1: The sample in the ion source sputtered by cesium beam.

ION SELECTION

The sensitivity and reliability of radiocarbon measurement is limited by ion background. The nitrogen ions have the same mass as radiocarbon ones, but they are filtered by BINP AMS complex. The negative nitrogen ions are unstable, but the negative molecular NH^- ions can rich high voltage terminal. The positive nitrogen ions are produced from the breakup of NH^- ions after passing through the stripper. The energies for nitrogen from NH^- molecules are always less than the radiocarbon ions energy into tandem terminal, because nitrogen ion gets only a part of the molecule's energy. The BINP AMS complex has the electrostatic filter into tandem terminal for effective filtration of the different energy ions.

To test such selection, the NH^- molecular ions was accelerated and passed through 180° electrostatic bend which was set for ions energy 14/15 and charge state 3+

for a good passing through of nitrogen ions. The terminal voltage was increased so that the energy of nitrogen ion was same as usual radiocarbon energy at the exit of AMS. Thus, the time-of-flight of nitrogen and radiocarbon ions become the same, as shown at Fig.2.a. But the energy loss by passing the film is different for nitrogen and radiocarbon ions. The time-of-flights of such ions after passing through 2.5 μm Mylar film are present at Fig.2.b. As seen, radiocarbon beam at the exit of AMS is clean without nitrogen additive. The 180° electrostatic bend is very effective for the isobaric background filtration.

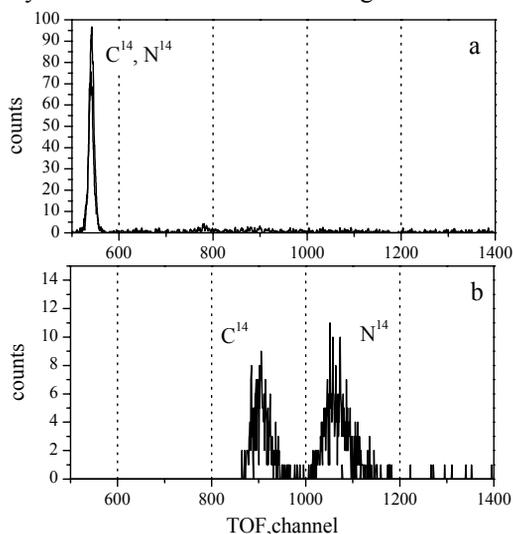


Figure 2: The time-of-flight of ions at the exit of AMS (a) and same, but after passing through 2.5um Mylar film (b).

AMS ANALYSIS

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

The 20 graphitized samples are setted in the ion source sample wheel to measure the concentration of radiocarbon. Furthermore, the 3 control sample with a known concentration of radiocarbon is setted in ion source sample wheel for control and normalization of the measurement samples. Typically, this sample are two carbon fiber with a carbon concentration on the natural content of modern plants and one sample of graphite MPG with radiocarbon concentration at $2 \cdot 10^{-3}$ compared to modern plants. It should be noted that the control samples did not require the procedure of graphitization and setted in the sample wheel in natural form.

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 is changed. The energy of the cesium ions remains constant. The electrostatic lens and correctors at the exit of the ion source are changed for

each isotope. Thus, the passage of isotopes is carried out through a first dipole magnet, without changing the magnetic field. The magnetic field in high energy magnet is not changed to, because the radial aperture is wide enough for passing radiocarbon ions to TOF detector and ^{13}C ions to shifted FC.

Now, the cycle of AMS-analysis of samples is represented as follows. For each sample, the ^{14}C ions are twice counted (20 seconds each) and twice the ^{13}C currents are measured. After that, the samples wheel is turned to the next sample for process repetition. Measuring of whole sample wheel (23 samples) takes about 20 minutes. For a set of statistics the wheel are moving to the second turn, third, etc. Typically, the measurement will take approximately 10 hours, with a statistical error of measurement for modern samples of approximately 2%. Typically, the next day the cycle repeats. The data from different days are compared. If they are within the statistical spread, the final result is given as a set of data for all measurements of these samples. The process of isotope measuring and sample changing (wheel rotation) is fully automated. The measured radiocarbon concentrations in samples are normalized to the radiocarbon concentration in carbon fiber (1.045 PMC).

The contamination level in the samples during the sample preparation procedure estimated by the radiocarbon content in graphite after combustion and graphitization (the radiocarbon concentration in graphite is insignificant before this procedure). Typically, the quantity of pollution (radiocarbon concentration) composes approximately 1% of the concentration level in the modern plants. The typical radiocarbon concentration of graphite MPG with and without sample preparation are shown at Fig. 3.

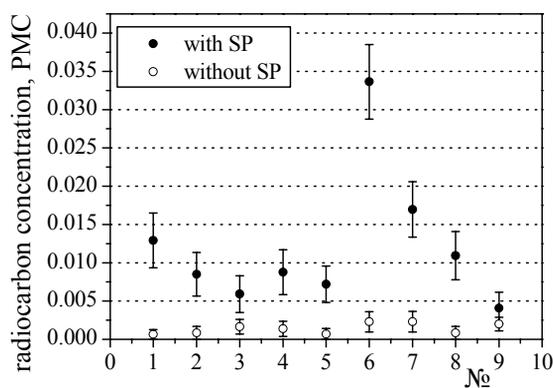


Figure 3: The radiocarbon concentration in graphite MPG samples with and without sample preparation procedure.

As an example of AMS-analysis, the data from archeological samples - peat deposits near Lake Baikal, depending on the depth from surface level (samples of Bezrukova EV, IAET SB RAS), presented in Fig. 4. Such analyzes are necessary to obtain a timescale for peat deposits. Such results are quite revealing, since in the

absence of mixings deposits should be observed dependence - the deeper the ancient.

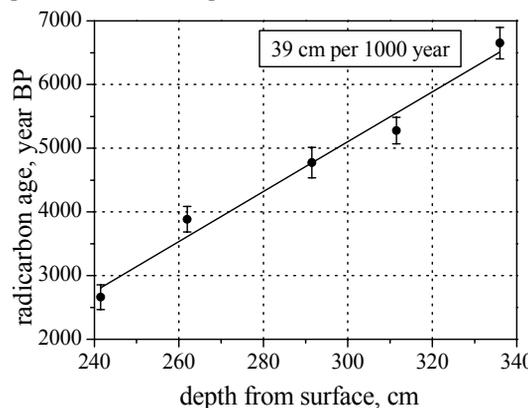


Figure 4: The radiocarbon age of peat deposits, depending on the depth from surface level.

Now, jointly with NSU (Gulyaeva LF et al.), the biomedical researches are started. As an example, the radiocarbon concentrations in the mice kidney versus time after injection of methanol with (20 Bq/mouse) and without ^{14}C labels for each individual are present at Fig. 5. As seen, the radiocarbon concentration in the labeled mice significantly larger, than the concentration in the control mice. The range of radiocarbon concentration values for individual animals is considerably greater than the statistical error of AMS analysis. Radiocarbon concentration in samples without ^{14}C label is independent of time and corresponds to the natural level.

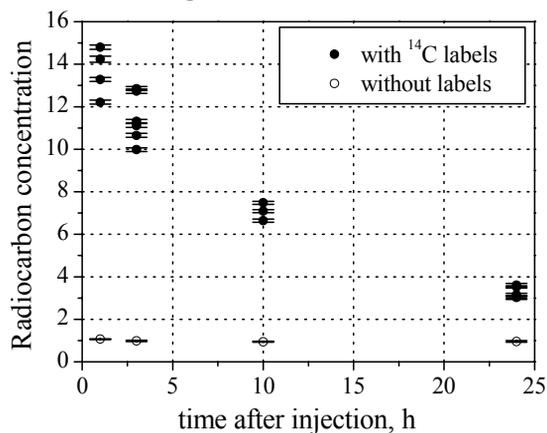


Figure 5: The radiocarbon concentrations in the mice kidney versus time after injection of methanol with and without ^{14}C labels.

SUMMARY

The BINP AMS with additional ion selection properties has demonstrated the good radiocarbon ions identification. The process of AMS analysis was described. The BINB AMS is used for radiocarbon dating, and more recently for biomedical applications.

ACKNOWLEDGMENT

This work is supported by the Ministry of Education and Science of the Russian Federation, NSh-4860.2014.2

REFERENCES

- [1] S.A. Rastigeev et al, "First radiocarbon measurements at BINP AMS", Proceedings of RuPAC-2010, Protvino, Russia, 2010, p. 309.
- [2] S.A. Rastigeev et al, Accelerator mass spectrometer SB RAS // Problems of Atomic Science and Technology/ Series "Nuclear Physics Investigation". 2013, №6(88), p. 16.
- [3] Parkhomchuk, V. V., Rastigeev S.A., Accelerator mass spectrometer of the center for collective use of the Siberian Branch of the Russian Academy of Sciences // Journal of Surface Investigation. X-ray, Synchrotron and Neutron Techniques, 2011, V. 5, Issue: 6, p.1068
- [4] N.I. Alinovskii et al, Accelerator mass spectrometer for the Siberian Branch of the Russian Academy of Sciences. // Technical Physics, 2009, Vol. 54, No 9, p 1350.
- [5] S.A. Rastigeev et al, Development of the BINP AMS complexes at CCU SB RAS. // Problems of Atomic Science and Technology/ Series "Nuclear Physics Investigation". 2012, №3(79), p. 188.
- [6] S.A. Rastigeev et al, Recent results in accelerator mass spectrometer construction at BINP. // Problems of Atomic Science and Technology/ Series "Nuclear Physics Investigation". 2008, №5, p. 8.
- [7] Parkhomchuk, V. V., Rastigeev S.A., Ion selection in accelerator mass spectrometer at the Budker institute of nuclear physics // Physics of Particles and Nuclei Letters, 2012, V. 9, Issue 4-5, p. 406
- [8] V.V. Parkhomchuk and S.A. Rastigeev, Analysis of the ion background in an acceleration mass spectrometer of the Siberian Division of the Russian Academy of Sciences. // Technical Physics, 2009, Vol. 54, No. 10, p 1529.
- [9] V.F. Klyuev, V. V. Parkhomchuk, S.A. Rastigeev, A magnesium vapor charge-exchange target for an accelerator mass spectrometer. // Instruments and Experimental Techniques, 2009, Vol. 52, No. 2, p. 245.
- [10] N.I. Alinovskii et al, A time-of-flight detector of low-energy ions for an accelerating mass-spectrometer. // Experimental Techniques, 2009, Vol. 52, No. 2, p. 234.
- [11] V. V. Parkhomchuk et al, Thin-film detector for ion registration in accelerator mass spectrometers // Physics of Particles and Nuclei Letters, 2012, V. 9, Issue 4-5, p. 448
- [12] S.A. Rastigeev et al., Acceleration Mass Spectrometer of the Budker Institute of Nuclear Physics for Biomedical Applications // Physics of Particles and Nuclei Letters, 2014, V. 11, № 5, p. 642