High-precision and high-accuracy 14C dating with an AMS system at Nagoya University

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1. Principle of 14C dating

Radiocarbon (14C) is produced continuously by galactic cosmic rays impinging on atmosphere. Primary cosmic rays, composed mainly of proton, interact with atmospheric elements to produce neutron and other secondary particles. Neutron, one of the secondary cosmic rays, interacts with 14N atom to produce 14C by the nuclear reaction of 14N(n, p) 14C. The production rate of 14C is about 2 atoms/sec/cm2 (OBrien 1979).The produced 14C is soon oxidized to CO2 and the 14CO2 mixes well with 12CO2 and 13CO2 in the atmosphere, and exists in a constant isotopic ratio of around 12C: 13C: 14C = 0.989: 0.011: 1.2x10-12. The number of 14C is in a radioactive equilibrium state, because of a balance between production rate and decay rate of 14C. The half life of 14C is 5,730+-40 years. When CO2 is incorporated into plants by photosynthesis, 14C follows 12C and 13C in a constant rate. Carbon isotopes in plants move to animals by food chain. After plants withered and animals died, no more 14C atoms are incorporated, and 14C atoms in the dead plants and animals decrease very regularly according to radioactive decay. The present 14C concentration of dead plants and animals gives the time passed after their death. This is the principle of the 14C dating method used widely for chronological researches in archeology and geology.

2. AMS system for 14C measurement

The method of 14C measurement with accelerator mass spectrometry (AMS) was developed in 1977 (Nelson et al. 1977). The development in techniques of accelerator mass spectrometry (AMS) has actuated a huge change in the application of 14C dating. The AMS system requires only 1mg of carbon in precise determination of 14C/12C and 13C/12C isotope ratios. This character of AMS has broadened the applicability of 14C measurements to those samples that were previously considered unable to be measured by any radiometric dating method, because of small sample amount available for dating. Nowadays, the AMS technique contributes to almost all researches that utilize 14C dating in geology, environmental science, archeology, cultural property science, etc.

3. Performances of the 2nd AMS system at Nagoya University

A Tandetron AMS system dedicated to 14C measurements, developed by General Ionex Corporation, USA, was installed at Nagoya University, and its routine operation of 14C measurement was started in 1983 firstly in Japan. In 1996, another AMS system as a modified version of the old Tandetron AMS system, manufactured by High Voltage Engineering Europe, the Netherlands, was purchased and has been used for high precision 14C measurements.

With the 2nd AMS system at Nagoya University, by 30 minutes measurement of carbon isotopes repeated for consecutive three days for a sample may archive one-sigma uncertainty of +-17 to +-30 years for samples younger than 5000 BP. A reproducibility test for ten individual walnut samples collected from an archeological site in Hokkaido, Japan, yielded the averaged 14C age of 2700 BP with a fluctuation error as small as +-11years (one-sigma value).

We have evaluated accuracy in our 14C measurements by participating in the international 14C inter-comparison tests. We joined the 4th and 5th inter-comparisons and confirmed that our 14C results were quite consistent with the median values estimated by the results from all participants: the maximum disagreement of our result from the median value was 70years. After the critical tests described above, we are sure that the AMS system at Nagoya University can be applicable to date historical samples that require high precision as well as high accuracy measurements.