

# The accelerator mass spectrometer facility at the Institute of Physics, Bhubaneswar (MUDRA, MultiDisciplinary Research Accelerator)

D. P. Mahapatra, K. Gopalan and B. L. K. Somayajulu\*

*This article reports on the augmentation of the 3 MV tandem accelerator in the Institute of Physics, Bhubaneswar into a state-of-the-art accelerator mass spectrometer supported jointly by the Department of Atomic Energy, Department of Space, Department of Science and Technology and Council of Scientific and Industrial Research. This national facility, first of its kind and expected to be operational by the end of 1998, will be available part time for ultrasensitive detection of the radioisotopes  $^{14}\text{C}$  and  $^{10}\text{Be}$  for a variety of applications in earth and ocean sciences, environmental chemistry, archaeology and biomedicine.*

THE interaction of energetic primary and secondary cosmic ray particles with the atmosphere<sup>1</sup> and rocks exposed on the earth's surface<sup>2,3</sup> produces a number of radioactive isotopes, many of which have already found imaginative applications<sup>4-7</sup> as tracers and chronometers of various processes in nature. Stable isotopes directly or ultimately produced from such interaction have been widely used in meteorite and lunar sample studies<sup>8</sup> but only marginally in geosciences. The best known such cosmogenic radioactive isotope is  $^{14}\text{C}$  which has been developed into an absolute dating technique in archaeology and human evolution by W. F. Libby<sup>9</sup> and others since the 1950s. Due to their extremely small production rates and concurrent radioactive decay their equilibrium concentrations in natural samples are restricted to ultratrace levels at less than  $10^{-12}$  of the abundant stable isotope of the element. For example, one gram of carbon extracted from a living organism (in equilibrium with the biosphere and atmosphere) will have  $5 \times 10^{22}$  atoms of  $^{12}\text{C}$ ,  $5.6 \times 10^{20}$  atoms of  $^{13}\text{C}$  and only  $5.8 \times 10^{10}$  atoms of  $^{14}\text{C}$  giving its  $^{14}\text{C}/^{12}\text{C}$  ratio as small as  $1.2 \times 10^{-12}$ . Due to the practical difficulties of conventional low energy mass spectrometers for measuring such low isotope ratios, the concentration of  $^{14}\text{C}$  and other cosmic-ray produced (cosmogenic) isotopes in natural samples could until recently be measured in favourable cases only by counting their radioactive decays. The decay rate of  $N$  radioactive atoms is given by  $N\lambda$ , where  $\lambda$  is their

characteristic decay constant ( $\lambda = 0.693/\text{half-life}$ ). With a decay constant of  $1.209 \times 10^{-4} \text{ y}^{-1}$ ,  $5.8 \times 10^{10}$   $^{14}\text{C}$  atoms will decay at the average rate of about 14 counts per minute, as was first measured by Libby<sup>9</sup> and others in radiation counters highly shielded from stray radiations. For a counting accuracy of 1%, about 10,000 decays are to be counted, which will take about 12 h. The  $^{14}\text{C}$  dating method depends on the uncompensated decay of  $^{14}\text{C}$  in a fossil biogenic carbon sample since it was isolated from the biosphere due to either death or other processes such as ocean circulation. For example, one gram of a 28,000 year [ $\sim 5$  half lives of  $^{14}\text{C}$ ] old fossil biogenic carbon will give a decay count of only about one every two minutes, requiring a total time of  $\sim 16$  days to accumulate 10,000 counts. This requirement of large samples (grams of solid or hundreds of litres of sea water) and impractically long counting times for old samples has seriously limited the scope of  $^{14}\text{C}$  applications using decay counting<sup>10</sup>. These two requirements are even more severe for the measurement by decay counting of the less well known cosmogenic isotopes<sup>2</sup> like  $^{10}\text{Be}$  (half-life  $1.5 \times 10^6$  years),  $^{26}\text{Al}$  ( $0.75 \times 10^6$  years),  $^{36}\text{Cl}$  ( $0.3 \times 10^6$  years),  $^{41}\text{Ca}$  ( $0.1 \times 10^6$  years) and  $^{129}\text{I}$  ( $16 \times 10^6$  years) because of their lower production rates and longer half-lives.

The obvious approach to reduce sample size (increased sensitivity) and measuring times is to be able to count directly the large number of radioactive atoms that are present in a sample rather than waiting for a few of them to decay<sup>10</sup>. For, even just one milligram of the 28,000 year old carbon sample will have as many as  $2 \times 10^6$   $^{14}\text{C}$  atoms of which just one will decay in about 1.5 days. By way of a morbid analogy, it is the difference

D. P. Mahapatra is in the Institute of Physics, Bhubaneswar 751 005, India; K. Gopalan is in the National Geophysical Research Institute, Hyderabad 500 007, India; B. L. K. Somayajulu is in the Physical Research Laboratory, Ahmedabad 380 009, India.

\*For correspondence. (e-mail: soma@prl.ernet.in)

between a direct quick, if laborious, census of a small town and an indirect estimation of its population from the number of deaths per year on the average in the population from the municipal records and the regional statistics on the average number of deaths per thousand people per year.

While conventional low energy mass spectrometers (LEMS), in which carbon ions from a sample are accelerated to a few thousand volts, can separate  $^{14}\text{C}$  from  $^{12}\text{C}$  and  $^{13}\text{C}$  atoms (ions), they cannot measure  $^{14}\text{C}$  unequivocally due to two severe limitations. The most serious is that they cannot distinguish  $^{14}\text{C}$  atoms from the comparable presence even in highly purified carbon samples of atomic and molecular species of nominally the same mass 14 such as  $^{14}\text{N}$ ,  $^{12}\text{CH}_2$  and  $^{13}\text{CH}$ . Secondly, LEMS can handle ion currents of not more than  $10^{-9}$  ampere, which means that the arrival of separated  $^{14}\text{C}$  atoms at the detector is too infrequent to be noticed over its intrinsic noise and background counts. A dramatic breakthrough was the ingenious use<sup>10-12</sup> of a particle accelerator used in nuclear physics applications to overcome both the above limitations of LEMS. This modified accelerator is appropriately called the accelerator mass spectrometer (AMS), which at the current state of its development can measure  $^{14}\text{C}$  and many other cosmogenic isotopes with an unprecedented atomic sensitivity of one atom in a sea of  $10^{15}$  of its stable isotopic counterparts. This has led to new dating or tracing capabilities in geological and planetary sciences, environmental monitoring, especially radiotoxicity of elements released from nuclear waste treatment, and biomedicine<sup>7</sup>.

An accelerator was first used as a very highly sensitive mass spectrometer in nuclear research as far back as 1939 (ref. 13). The impetus for sensitive detection of  $^{14}\text{C}$  stimulated the development of AMS as a practical tool in a few nuclear physics laboratories only in the mid-1970s. While a cyclotron type of accelerator was used in the early phase of development<sup>10</sup>, tandem Van

de Graff electrostatic accelerators were later found to be far more suitable for AMS<sup>11,12</sup>. Almost all the nearly 40 AMS laboratories currently active or being established throughout the world use various tandem electrostatic accelerators<sup>7</sup>, and except a few, only part time for AMS applications in non-nuclear/solid state physics research.

### Principle of AMS

A complete technical description of modern AMS can be found in many review articles<sup>14-16</sup>. Only an elementary introduction is given here for the benefit of nonspecialists. As  $^{14}\text{C}$  was the first radionuclide to be studied by AMS, it will be used to illustrate the method. Figure 1 gives a schematic of the basic components of an AMS system.

A conventional LEMS has three basic components—an ion source to convert the sample into positively or negatively charged ions and accelerate them into a fine beam, a magnetic and/or electrostatic analyser to separate ions according to their mass, and finally an ion detector to count the mass separated ions as they arrive at the detector either as individual ions or as continuous stream (ion current). AMS uses all these three and also includes an accelerator to increase the kinetic energies of ions to a few million electron volts to facilitate quantitative discrimination of the desired ions from interfering ones.

In the ion source, a finely focused  $\text{Cs}^+$  ion beam (tens of microamperes) is arranged to bombard a small button (typically 1 to 10 mg) of highly purified graphite prepared from the sample of interest. This beam sputters or ejects carbon atoms from the sample layer by layer with a small fraction ( $\sim 2\%$ ) of them being negatively charged. It is very fortunate that the ubiquitous  $^{14}\text{N}$  impurity invariably present in samples does not form negative ions and hence is almost completely excluded from the carbon ion beam. As this beam current can be at least 4 orders of magnitude higher than ion currents handled

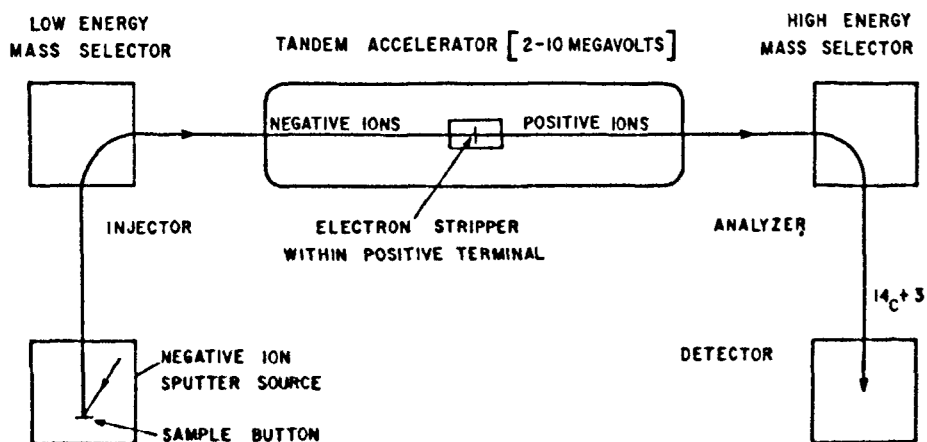


Figure 1. Basic components of tandem accelerator mass spectrometer.

by LEMS, the frequency of arrival of  $^{14}\text{C}$  ions at the detector will be substantially higher than that of its background and other thermal noise counts. The carbon ion beam after acceleration to a few tens of thousand volts enters a low resolution magnetic mass analyser to preferentially select ions of mass 14 ( $^{14}\text{C}$  and other interfering ions of the same mass) for injection into a tandem accelerator with its central high voltage terminal kept at about +3 million volts. With a total gain in energy of 3 MeV on arrival at the terminal, the ions are passed through a thin gas cell or foil within the terminal, which strips several of their outer chemical electrons, thus rendering them positively charged. At about 3 MeV, a large fraction of ions in the beam lose 4 electrons bringing their net positive ionic charge to 3+. This charge change in the gas cell is the key to the elimination of molecular ions, as monoatomic ( $^{14}\text{C}$ ) ions will still be stable with a 3+ charge but triply charged molecules will dissociate into smaller fragments within  $10^{-9}$  s due to excessive Coulomb repulsive forces. The  $^{14}\text{C}^{3+}$  ions and fragments will now be repelled by the positive voltage on the terminal down the second half of the accelerator tube to emerge with total energies between 9 and 12 MeV. They are focused into a second magnetic mass analyser similar to the first one but powerful enough to deflect or sort the higher energy positive ions according to their mass. With this analyser tuned also to mass 14,  $^{14}\text{C}$  ions will be preferentially selected and lower mass molecular fragments filtered out. If the vacuum in the flight tube is very high, the ions selected by the high energy analyser will be entirely  $^{14}\text{C}^{3+}$  and counted by the detector as such.

Elimination of nagging isobaric interfering atomic species at the ion source itself works well only for  $^{14}\text{C}$  against  $^{14}\text{N}$ , and  $^{129}\text{I}$  against  $^{129}\text{Xe}$ , but not, for example,  $^{36}\text{Cl}$  against  $^{36}\text{S}$ , as both these form negative ions readily. The latter will therefore be carried through the AMS system to the detector. However, the detector can be chosen to discriminate between  $^{14}\text{C}$  and  $^{14}\text{N}$ , and also  $^{36}\text{Cl}$  and  $^{36}\text{S}$  based on their different ranges of penetration within the detector medium. Such a range discrimination, however, requires final ion energies >30 MeV that can be attained only in accelerators with terminal voltages

>7 MV.  $^{10}\text{Be}$  presents a different problem in that beryllium does not form negative ions in the ion source. The proven solution is to optimize production of  $\text{BeO}^-$  in the ion source and then select  $\text{Be}^{3+}$  from the breakup of these molecules due to electron stripping. Each radionuclide, therefore, presents a separate set of analytical challenges that must be met with patience enlivened by ingenuity.

## AMS at Bhubaneswar

### Background and existing accelerator

The tandem pelletron accelerator in the Institute of Physics (IOP), Bhubaneswar is the model 9SDH-2 of the National Electrostatics Corporation, Wisconsin, USA installed in 1992 with a maximum terminal voltage of 3 MV. Like the other three similar electrostatic accelerators but with higher terminal voltage in the Nuclear Science Centre, New Delhi, Tata Institute of Fundamental Research, and BARC, Mumbai, the IOP machine is being used for a variety of studies in materials science, atomic, molecular and nuclear physics. It has, in fact, been serving as a national facility under the Inter University Centre (IUC) programme of the Department of Atomic Energy to facilitate research in the above areas by university scientists. It was strongly felt that if this accelerator could also be used as an AMS part of its time, it would considerably widen the scope of its applications to other sciences for which facilities in the country are either nonexistent or woefully inadequate. Even the comparatively inexpensive facility for conventional decay counting of  $^{14}\text{C}$  is available only in two/three laboratories. Since even the essential AMS specific modifications to the existing system were found to be expensive, a multiagency support was sought and enthusiastically given to establish the first AMS in the country and thereby provide Indian scientists excellent opportunities for modern research in geology<sup>17-19</sup>, geophysics<sup>20,21</sup>, climatology<sup>15,22</sup>, oceanography<sup>23-25</sup>, archaeology<sup>26</sup>, limnology and biomedicine<sup>27-29</sup>.

As the maximum terminal voltage of the IOP accelerator is not more than 3 MV, and for the technical

Table 1. Cosmogenic nuclides of different half-lives that are commonly measured by AMS with typical sensitivities of their detection

	$^{10}\text{Be}$	$^{14}\text{C}$	$^{26}\text{Al}^*$	$^{36}\text{Cl}^*$	$^{41}\text{Ca}^*$	$^{129}\text{I}$
Half life (years)	$1.6 \times 10^6$	5730	$7.05 \times 10^5$	$3.0 \times 10^5$	$1.05 \times 10^5$	$1.6 \times 10^6$
Stable isotopes	$^9\text{Be}$	$^{12}\text{C}, ^{13}\text{C}$	$^{27}\text{Al}$	$^{35}\text{Cl}, ^{37}\text{Cl}$	$^{40}\text{Ca}, ^{42}\text{Ca}$	$^{127}\text{I}$
Stable isobars	$^{10}\text{B}$	$^{14}\text{N}$	$^{26}\text{Mg}$	$^{36}\text{Ar}, ^{36}\text{S}$	$^{41}\text{K}$	$^{129}\text{Xe}$
Chemical form for analysis	$\text{BeO}$	$\text{C}$	$\text{Al}_2\text{O}_3$	$\text{AgCl}$	$\text{CaF}_2$	$\text{AgI}$
Sensitivity (parts per $10^{15}$ )	3	2	1	1	1	10
Sample size (mg)	1	0.5	1	4	2	1

\*These isotopes require accelerators with terminal voltage >7 MV.

reasons given earlier, it will be set up first for  $^{14}\text{C}$  and later  $^{10}\text{Be}$  measurements. This expertise is expected to be useful for modification of any of the other higher energy accelerators in the country for quantitative detection of other nuclides (Table 1).

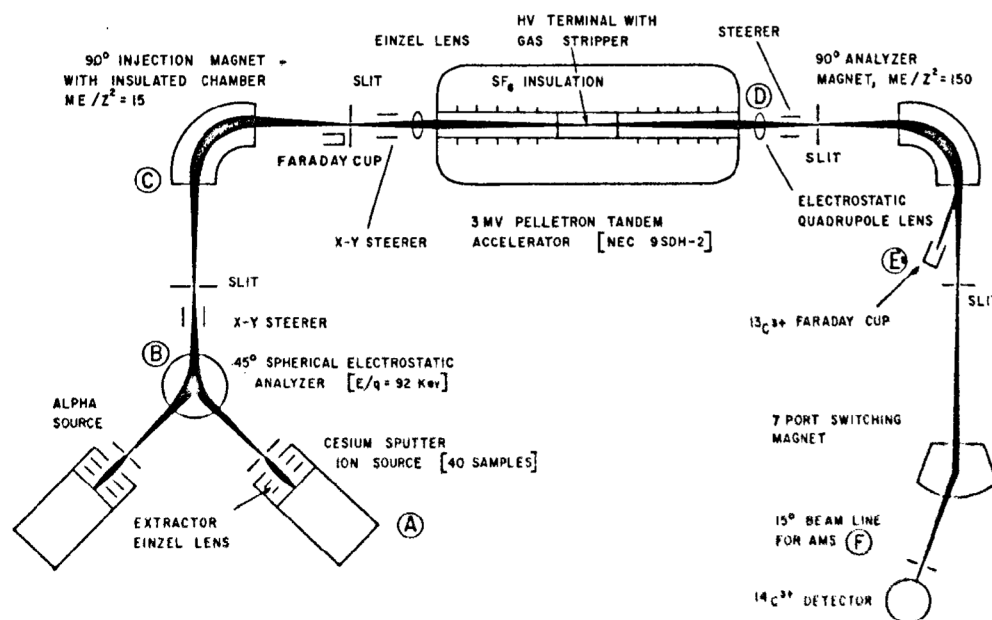
The IOP accelerator has two ion sources – a  $\text{Cs}^+$  sputter source for production of heavy ions from different targets and another exclusively for hydrogen and helium ions. The ions accelerated up to 50 keV from either of these sources can be switched into a  $45^\circ$  sector magnetic analyser to select ions of a specific mass for injection into the accelerator. As explained earlier, the selected ions will undergo charge polarity change in the gas or foil stripper within the high voltage terminal, and hence a second stage of acceleration to emerge as multiply charged positive ions. These ions will be refocused by a magnetic quadrupole doublet lens on the object slit of a  $90^\circ$  sector magnetic analyser to select any desired ionic species from the composite input beam. The selected species can be transported to any one of the 7 ports (beam lines) for different experiments by a switching magnet. Different types of ion detectors can be provided in each beam line according to experimental requirements.

### Technical details

Configuration of the above basic accelerator system into a modern AMS requires a few major changes or modifications which will not in any way affect the types of experiments carried out presently with this accelerator.

A schematic of the layout of the modified system is shown in Figure 2 and described below.

The earlier single sample  $\text{Cs}^+$  sputter source is replaced by a multicathode MC-SNICS source (A in Figure 2) which can accept up to 40 samples on a rotatable cathode wheel for analysis in a single batch. Samples each pressed into a 1 mm diameter hole are arranged symmetrically along the rim of cathode wheel that can be rotated to bring the desired sample into position for analysis. A 10 mg graphite sample can typically give a negative sputtered carbon ion current of  $10\ \mu\text{A}$  up to 10 h.  $\text{BeO}$  currents will be much less, about  $1\ \mu\text{A}$ . A rotatable  $45^\circ$  spherical electrostatic analyser, B is added to the old system for a quick change-over from the new MC-SNICS source to the older alpha source and to energy-analyse the ion beam before it is projected into a new  $90^\circ$  double (stigmatic) focusing injection magnet, C in place of the earlier  $45^\circ$  single focusing magnet. The double focusing action of this magnet ensures almost 100% ion transmission, and its electrically insulated magnet chamber can be biased with appropriate voltage pulses (both amplitude and duration) from a programmable power supply to rapidly select the three isotopes  $^{12}\text{C}$ ,  $^{13}\text{C}$  and  $^{14}\text{C}$  from a carbon sample for their sequential injection into the accelerator, keeping the magnetic field constant. Such a rapid (within a few milliseconds) sequencing is not possible with magnetic field switching, but necessary for precise isotope ratio measurement. For example, a typical sequence can inject  $^{12}\text{C}$  for 0.5 ms,  $^{13}\text{C}$  for 1.5 ms and the weak  $^{14}\text{C}$  for 98 ms during each cycle of about 100 ms duration. It



**Figure 2.** Schematic layout of the AMS system under progress in the Institute of Physics, Bhubaneswar. Although ion beams from both ion sources are shown, only one will be on at a time with the electrostatic analyser, B aligned accordingly.

is to be noted that AMS measures only the ratio of a rare isotope to any of the abundant stable isotopes, whereas conventional decay counting gives its absolute abundance in a sample.

Near the image plane of this injection magnet a position-adjustable Faraday cup is provided to monitor the abundant stable isotopic currents on the low energy side. An X-Y steerer is also provided just before the accelerator inlet to correct small angular deviations of the beam from the axial trajectory due to bias changes on the insulated magnet chamber.

The accelerator is a horizontal version equipped with two charging chains carrying up to 250  $\mu$ A to the high voltage terminal. The pressure vessel is 5.18 m long and 1.22 m in diameter and filled with 80 psig of SF<sub>6</sub> gas for insulation. The terminal and pre- and post-acceleration tubes of titanium/ceramic construction are insulated by cast acrylic supports. The acceleration tube is designed to limit the maximum energy of electrons produced at the tube electrodes to about 350 keV. Permanent magnets are so placed in the acceleration tube as to sweep out electrons from beam axis to reduce hard X-ray radiations. The stripper gas (argon) tube is 60 cm long with a diameter of 4.5 mm. A turbomolecular pump is used to recirculate the stripper gas and to minimize its flow to the acceleration tubes.

Stabilization of the terminal voltage is particularly critical in AMS work and achieved by negative feedback or error signals from either a generating voltmeter or jaws of a slit at the image plane of the analysing magnet. Ripple in the terminal voltage is controlled by signals on two capacitive pickoff plates. The voltage stabilization is better than  $\pm 300$  V at 3 MV and ripple less than 600 V.

The magnetic quadrupole doublet lens originally used after the accelerator exit port is replaced by an electrostatic quadrupole triplet lens, D to get rid of effects associated with mass-dependent focusing. This lens focuses ions at the object slit of the 90° double focusing analyser magnet, ( $ME/Z^2 = 151$ , radius 1.27 m). Since the field of this magnet is kept constant, the lighter but abundant isotopes <sup>12</sup>C and <sup>13</sup>C will be more strongly deflected than <sup>14</sup>C into off-axial trajectories as shown. The flight tube is enlarged in this region to introduce an off-axis Faraday cup, E to collect <sup>13</sup>C<sup>3+</sup> ions as and when they are injected into the accelerator during a sequence. The ratio of the axial <sup>14</sup>C<sup>3+</sup> beam to the off-axial <sup>13</sup>C<sup>3+</sup> beam will differ from the true ratio due to unavoidable mass fractionation in transmission, and have to be corrected by analysis of isotopic standards. The <sup>13</sup>C<sup>3+</sup> currents intercepted by two split slit plates before the Faraday cup can be used (as referred to earlier) to stabilize the terminal voltage.

The rare isotope (<sup>14</sup>C in this case) is deflected by 15° by the switching magnet into one of the 7 beam

lines (only one shown) to be used exclusively for AMS work. A cylindrical electrostatic analyser (not shown) will be used, if necessary, before the ion detector, to eliminate stray ions produced by scattering or charge exchange with residual molecules in the flight tube so that only ions with the correct energy-to-charge ratio enters the detector. The detection of <sup>14</sup>C ions will be by a surface barrier detector covered with a mylar foil to suppress any residual <sup>14</sup>N ions from <sup>14</sup>C. Detection of <sup>10</sup>Be ions (to be taken up later) will use a combination of a surface barrier detector and gas absorption cell. The entire system will be controlled by a main computer (Pentium PC, 133 MHz) to operate it both manually and automatically.

### *Progress and performance tests*

The use of a tandem electrostatic accelerator as an AMS calls for very stringent criteria on its performance, namely high ion transmission, stability of ion trajectory, and low background. The overall ion transmission is the fraction of isotopic ions leaving ion source that ultimately reach the detector, which depends on both optical (geometrical) transmission of ions over a total flight path of a few tens of meters and the stripping efficiency for ions of the charge state (typically +3 in 3 MV accelerators) selected for final detection. Both these must be optimized for high sensitivity, ensuring at the same time that the mass fractionation between the different isotopic species during the transmission is both small and reproducible between standards and samples for high ultimate precision and accuracy of measurement of the rare isotopic species. The acceleration and focus voltages must be quite stable so that ion beams do not drift across defining slits during measurements. Low background requires ultrahigh vacuum all along the long flight tube. Tests and adjustments for the above performance had to be carried out without serious dislocation of ongoing nuclear and solid state physics studies with the accelerator in the Institute of Physics.

In order to estimate and optimize transmission of the accelerator for <sup>14</sup>C ions, overall transmission was measured for the much more abundant <sup>12</sup>C and <sup>13</sup>C ions generated from a graphitized sample of modern carbon in the existing single sample, low current Cs + ion sputter source. <sup>12</sup>C and <sup>13</sup>C ions were injected sequentially into the accelerator by simultaneously varying the magnetic fields of both the 45° injection and 90° analyser magnets. This slow sequential switching is in fact used in many AMS laboratories even for routine <sup>14</sup>C and other measurements instead of fast isotope switching using an injector with an electrically insulated magnet chamber described earlier. While slow, it does not suffer

from slight shifts in beam trajectory due to changes in injection energy of the fast switching system. With a  $^{12}\text{C}$  negative ion current of 5 microamperes, the best transmission for 3+ ions was obtained for an injection energy of 40 keV and a terminal voltage of 2.2 MV. At this setting, the rare isotope  $^{14}\text{C}^{3+}$  gave about 5 counts per sec in the silicon surface barrier detector. This represents about 50% overall transmission, as 5 microamperes of  $^{12}\text{C}$  current will correspond to about 10  $^{14}\text{C}$  ions per second. Figure 3 shows a typical mass spectrum of 3+ ions with a clean separation of  $^{14}\text{C}$  from  $^{13}\text{C}$  and  $^{12}\text{C}$  ions.

With the above performance figures very encouraging, the next step is to integrate the new AMS specific components (A to F in Figure 2) with the accelerator into an operational AMS. This is expected to be completed by August/September 1998 for exhaustive test runs to be taken up soon after. All relevant parameters of the AMS will be controllable through a PC-based interfacing system that is flexible enough for future expansion to include all the remaining components in the system that will be initially controlled manually or locally.

### Sample preparation

The small sample (milligram or less of carbon and many other elements) capability of AMS is an obvious requirement for analysing intrinsically small samples like microscopic carbonate shells of foraminifera in marine sediments, pollen, carbon dioxide trapped in ice cores and precious and irreplaceable archaeological or historical artifacts, and for reducing radiological dose in biomedical tests. The ultrasensitivity of AMS is often

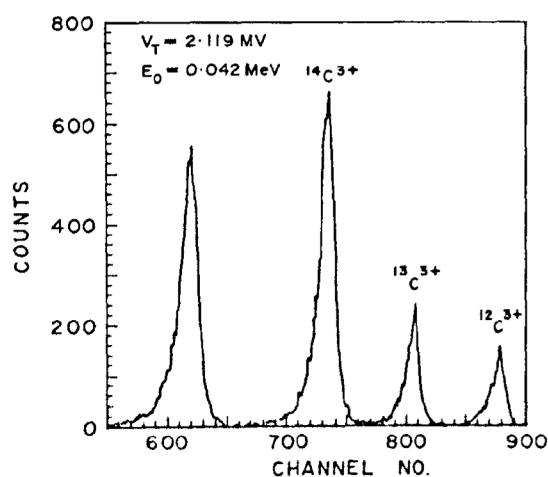


Figure 3. Mass spectrum of modern carbon measured by the final detector in the existing accelerator showing clear separation of  $^{14}\text{C}$  and reduction of the natural abundance  $^{13}\text{C}$  and  $^{12}\text{C}$  isotopes by several orders of magnitude.

required even for large and easily available natural samples like sea water, as one needs only a few hundred millilitres rather than  $\geq 100$  litres of sea water for its  $^{14}\text{C}$  determination. Also, more often than not, not all carbonaceous components of a large solid sample would have retained their isotopic integrity since their formation. For example, bones can pick up carbonates from ground water, be subject to fungal or bacterial attack or absorb organic compounds of recent origin from surrounding soil. All these contaminating processes introduce extraneous carbon into bone specimens that can give misleading  $^{14}\text{C}$  results, particularly if the specimen is old. In such cases it may be necessary to isolate an organic component of bone sample that has been immune to such contamination. The separated component from a large natural sample may be too small to preclude its dating by conventional decay counting. Many analytical separation techniques can be used for isolation of a suitable component from simple physical separation under an optical microscope to chemical separation by differences in solubilities to chromatographic and electrophoretic processes.

The Cs ion sputter source commonly used now in AMS requires samples that are thermally and electrically conducting pure solids of the element to be analysed. The physical or chemical extraction of a suitable component from sample matrix and its conversion into a solid form to suit ion source must be carried out with negligible or precisely known isotopic fractionation and extraneous contamination of the element of interest either from laboratory procedures or equipment. Uniformity and comparability between samples and standards are ensured by reducing all samples to a homogeneous state from which the final target material in ion source is prepared. Carbon samples ( $^{14}\text{C}$ ) are combusted or hydrolysed into homogeneous  $\text{CO}_2$  before reduction to graphite by hydrogen or zinc over an iron catalyst. Beryllium ( $^{10}\text{Be}$ ) samples are homogenized as solutes before precipitation and conversion to an oxide. If a sample to be analysed is too small for introduction into the ion source, it can be mixed with sample carrier compounds of known isotopic composition before or during the homogenizing phase of preparation.

The smallest carbon sample that can be reliably analysed is now limited not by AMS sensitivity but unavoidable contamination of extraneous carbon due to sample isolation, homogenization and target preparation. The current  $^{14}\text{C}$  preparative contamination on 1 mg carbon is about 0.2 to 0.3% of modern carbon. Much smaller samples (typically 50 micrograms) of carbon have indeed been analysed but subject to contamination of about 3% of modern carbon.

Considering the importance of clean sample preparation for AMS analysis and following the general practice in most AMS laboratories, chemistry laboratories initially

for carbon and later for beryllium preparation are being set up in the Institute of Physics as an integral part of its AMS facility. Organic carbon samples will be sealed in evacuated quartz tube with CuO (Ag metal to remove halogens), and oxidized at 450° C in an electric furnace. The resulting CO<sub>2</sub> will be purified cryogenically in a vacuum preparation line and converted to graphite on precleaned Fe catalyst with H<sub>2</sub> gas in a sealed quartz tube at 650° over a few hours. The resulting graphite will be pressed as such or mixed with Ag powder into a 2 mm diameter hole in the aluminium target holder of the SNICS ion source. The <sup>14</sup>C/<sup>13</sup>C ratio measured in the AMS will be converted into <sup>14</sup>C/<sup>12</sup>C ratio by analysing each sample separately for its <sup>13</sup>C/<sup>12</sup>C ratio on a stable isotope mass spectrometer, which is also being set up with the AMS facility. For <sup>10</sup>Be, an appropriate amount of sample is brought into solution and mixed with a Be carrier (equivalent to 1 mg or BeO). Be is then precipitated and ignited to BeO to serve as the target in ion source. Finkel and Suter<sup>4</sup> give brief accounts of sample preparation for different elements analysed currently with AMS.

An AMS measurement usually requires only a few minutes of instrument time, but sample preparation prior to AMS analysis often takes a much longer time. So the AMS is not the factor limiting sample throughput, and hence needed only part time. Samples will therefore be prepared in large number for AMS analysis in batches at a time. While the sample preparation facility being set up in the IOP will be able to deal with specimens submitted by scientists initially, it may be necessary later for scientists requiring a large number of analyses to set up sample preparation systems in their laboratories including standards for optimal use of the IOP AMS time.

## Conclusions

With its unprecedented atomic selectivity and sensitivity, AMS is proving to be a very versatile tool in many fields of science, in particular, environmental sciences. Kutschera<sup>30</sup> cites AMS applications in seven major domains of our environment—atmosphere, biosphere, hydrosphere, cryosphere, lithosphere, cosmosphere and technosphere, the last being related to semiconductor materials, radioactive waste disposal, neutron flux of the Hiroshima bomb and characterization of fissile materials. There must be many more radionuclides than given in Table 1 in our environment, about which little is known because of their extreme rarity. AMS has the potential to uncover many of their secrets and hence open up new frontiers in environmental sciences<sup>31</sup>.

The first national AMS facility being set up around the tandem accelerator in the Institute of Physics, Bhubaneswar, will provide opportunities to Indian

scientific community to take up ultratrace measurements of <sup>14</sup>C and <sup>10</sup>Be isotopes for applications in a wide variety of studies like very recent geological events, palaeofloods, palaeoseismology, climatology, oceanography, limnology, archaeology and biomedicine. The extremely high cost of more than US \$ 700 for chemical preparation and analysis of just one nuclide per sample in foreign AMS laboratories has precluded above studies in India so far. This facility is expected to be operational by the end of 1998 and will be administered and operated by the Institute of Physics, Bhubaneswar. The Department of Science and Technology has planned a few contact sources to familiarize scientists from different disciplines with AMS principles, practice and applications. An AMS team in the IOP will be structured to offer interested researchers expert assistance in precise measurement of <sup>14</sup>C and <sup>10</sup>Be in different sample matrices.

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We finally hope that Indian scientists will use the effective remedy evolved from our infection, after it is field tested, to deal with similar and other cosmogenic viruses and a host of environmental pathogens.

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## MEETINGS/SYMPOSIA/SEMINARS

### XIII International Biophysics Congress

Date: 19–24 September 1999

Place: New Delhi, India

The scientific programme consists of symposia on proteins, nucleic acids, membranes, molecular assemblies, recognition and metabolic regulation, bioenergetics, sensory and neural biophysics, modeling theory and bioinformatics, biophysical technology and biophysics in 21 century.

Contact: Prof. Anil Saran,  
Secretary, National Organizing Committee  
XIII International Biophysics Congress  
Tata Institute of Fundamental Research  
Homi Bhabha Road, Colaba  
Mumbai 400 005, India  
E-mail: anil@tifrvax.tifr.res.in  
Website: <http://www.tifr.res.in:80/~iupbab99/>

### National Workshop on Electron Microscopy and Its Application in Biological Sciences

Date: 12–15 October 1998

Place: Calcutta

Topics include: Scanning electron microscope; Transmission electron microscope; Specimen preparation techniques; Appli-

cation of SEM in the studies of (i) erythrocytes, (ii) squid gills, (iii) ctenophor, (iv) moong bean; Electron microscopy of DNA; Immuno electron microscopy; Application of EM in biology and medicine; Electron auto radiography; Image analysis; Analytical electron microscopy; Other topics of current interest.

Contact: Dr A. N. Ghosh  
Convener, National Workshop on EM  
National Institute of Cholera and Enteric Diseases  
P 33, CIT Road, Scheme XM,  
Calcutta 700 010  
Phone: 350 4478 (O), 471 8224 (R)  
Fax: 350 5056

OR

Dr A. K. Ghoshal  
Convener, National Workshop on EM  
University Science Instrumentation Centre  
Jadavpur University  
Calcutta 700 032  
Phone: 472 0321 (O), 472 4445(R)  
Fax: 473 1484