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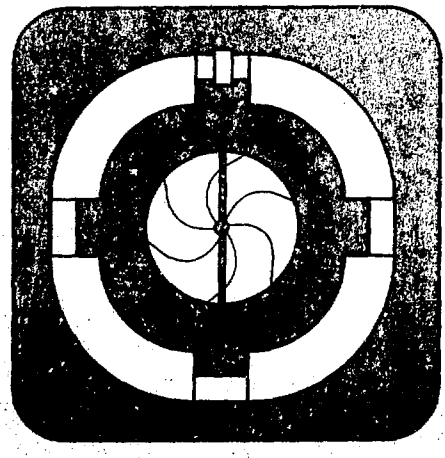

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Abstract: We propose that direct detection of natural radioisotopes can be accomplished by using a very low energy (20-100 keV) cyclotron accelerating negative ions.

The multi-MeV energy of cyclotrons and tandem Van de Graaff accelerators has played a central role in the development of direct dating techniques. The high energy has been necessary in order to allow the use of particle identification detectors which measure dE/dx and total energy, and for range filtering.[1] It also facilitates the disintegration of molecular backgrounds in the tandem machines.[2]

Also important has been the discovery that certain potential background ions (^{14}N for ^{14}C detection; ^{36}Ar for ^{36}Cl detection) do not form negative stable ions, and are therefore not accelerated in the tandem machines. This suppression has not been exploited with existing cyclotrons, which were all designed to accelerate positive ions.

Cyclotrons have a different feature which has proven useful in direct radioisotope detection: The great selectivity of the resonant acceleration process. This suppression arises from the requirement that the ion stay in phase with the applied electric field for the 100 to 200 or more cycles of acceleration. Ions which differ in charge-to-mass ratio by only a part in a thousand can be totally suppressed. Detuned by 1% from a 10 microampere beam, we once observed no counts in a half hour, a suppression factor better than 10^{-17}. Although ordinary mass spectrometers can achieve resolutions equal to or superior to that of the cyclotron, they cannot match the total suppression of background ions with different charge-to-mass ratios.

We believe that by combining the high selectivity of the cyclotron with the suppression of certain backgrounds by using negative ions, that one can achieve the sensitivity necessary for direct detection of natural radioisotopes without the need for

high energy. When all backgrounds are suppressed, particle identification is unnecessary.

We propose a negative ion cyclotron with a magnetic field of a few kilogauss. The maximum energy would be less than 100 kilovolts, and perhaps as low as 20 kilovolts. By using many turns to accelerate the ions, we should be able to obtain selectivity comparable to or better than that obtained with high energy machines. Good vacuum (less than 10^{-7} torr) may be necessary to achieve good efficiency, and we probably wish to use sector focussing. External ionization with axial injection would minimize space charge effects from non-resonant background ions. For the lighter ions (^{3}H, ^{10}Be, ^{14}C) the entire instrument should be smaller than a desk. Accelerated ions never reach sufficient energy to induce radioactivity, and in many ways the machine would be like a mass spectrometer rather than like an accelerator. (Perhaps it should be called a "cyclometer" rather than "cyclotron".) Detection with a dynode detector supresses scattered beam which had not been accelerated to its threshold energy of 15 to 20 keV. Solid state high bandwidth power supplies can easily provide the less than one thousand volts required on the Dees. Pulse shapes other than the usual sine-wave can be used. Normalization can be accomplished by rapidly switching the cyclotron frequency to accelerate a stable isotope, or by switching from the sample to a standard of known concentration.

On the Berkeley 88" cyclotron our resolution has been better than 20,000 : 1, and have resolved (although not completely separated) the isotopes ^{10}Be and ^{10}B. Our goal for the small cyclotron is a resolution of about 50,000 to 1. Small mass spectrometers based on the cyclotron principle have already achieved excellent resolution. The "Omegatron" of Sommer, Thomas, and Hipple[3] achieved a mass resolution of 1 part in 10,000 and had a radius of less than one centimeter. The "mass synchrometer" of Lincoln Smith and C. Damm[4] achieved a resolution of 1 part in 25,000 and was 15 inches in diameter. It combined slits with three turns of cyclotron acceleration. Negative ions and resolution of 50,000:1 should be sufficient to allow measurement of the following naturally occurring radioisotopes: ^{3}H, ^{10}Be, ^{14}C, ^{26}Al, ^{32}Si, ^{36}Cl, and ^{129}I. With other separation techniques or better resolution, other radioisotopes could be measured. In the table we list several of the interesting radioisotopes, and the properties of potential backgrounds. It is clear from the table that for certain radioisotopes, positive ions could be used as well. Not included in the table is the "higher harmonic" background. If ^{3}H is accelerated, ^{9}Be, ^{15}N, and molecules of the same mass are also accelerated, the dee frequency being the third, fifth, etc. harmonic of the approximate particle frequency. Most of these backgrounds are suppressed by the cyclotron resolution; further suppression

occurs at the deflector at the exit of the acceleration region because they have lower energy than the radioisotope.

Compact magnets of the size and field required for dating have been designed and built for microtrons (cyclotron-like devices for electrons). A typical microtron electromagnet, including return yoke, fits in a space 1.5 meter in diameter and 0.5 meter high, and gives a magnetic field of 2 kilogauss over a circular region with diameter 1 meter.[5] It may be possible to use permanent magnets by using rare-earth alloys such as Samarium-Colbalt.

The proposed low energy negative ion cyclotron is based on the extensive experience gained in the last five years with high energy systems. If successful, it may bring down the cost of detection, and make the direct detection technique more accessible to many scientists.

Acknowledgments

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TABLE

Selected Radioisotopes for Small Cyclotron Dating

Radioisotope	Background	Required Resolution	Comments
^{3}H	^{3}He	150,000	Eliminate with (-) ions
	HD	230	Easily resolved
	H_3	400	Easily resolved
^{10}Be	^{10}B	17,000	Resolvable
	^{9}BH	1,500	Easily resolved
^{14}C	^{14}N	83,000	Eliminate with (-) ions
	^{13}CH	1,800	Easily resolved
	$^{12}CH_2$	1,100	Easily resolved
^{26}Al	^{26}Mg	6,000	Easily resolved
^{32}Si	^{32}S	15,000	Resolvable
^{36}Cl	^{36}Ar	47,000	Eliminate with (-) ions
	^{36}S	29,000	Possible (?)
^{39}Ar	^{39}K	64,000	Very difficult; (+) ions required
^{41}Ca	^{41}K	89,000	Use CaH_3^- ions
^{53}Mn	^{53}Cr	82,000	Difficult
^{129}I	^{129}Xe	62,000	Eliminate with (-) ions