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ADVANCES IN THE HELIUM-JET COUPLED ON-LINE MASS SEPARATOR RAMA *

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ABSTRACT:

General improvements to the on-line mass separator RAMA have yielded a greater reliability and efficiency for some elements. A new utilitarian helium-jet chamber has been installed to facilitate quick target and degrader foil changes in addition to a new ion source holder. A higher efficiency hollow-cathode, cathode-extraction ion source for lower melting point elements (< 1200 °C) has also been designed. Tests with the beta-delayed proton emitter ^{37}Ca showed a factor of five increase in yield over the old hollow-cathode, anode-extraction source. A differentially-pumped tape drive system compatible with both γ-γ and β-γ experiments has been incorporated into the general detection system. All major operating parameters will soon be monitored by a complete stand-alone microprocessor system which will eventually be upgraded to a closed-loop control system.

I. INTRODUCTION

The versatility of the helium-jet coupled mass separator RAMA (Recoil Atom Mass Analyzer), placed on-line to the 88-inch cyclotron of the Lawrence Berkeley Laboratory, has been demonstrated in studies of nuclei far from stability.[1-3] A greater reliability and efficiency for some elements was desired to extend the scope of experiments beyond the existing capabilities. Improvements to achieve these results included the installation of a versatile target chamber, a new ion source holder, a hollow-cathode, cathode-extraction ion source, a fast tape drive, and a microprocessor monitoring and control system.

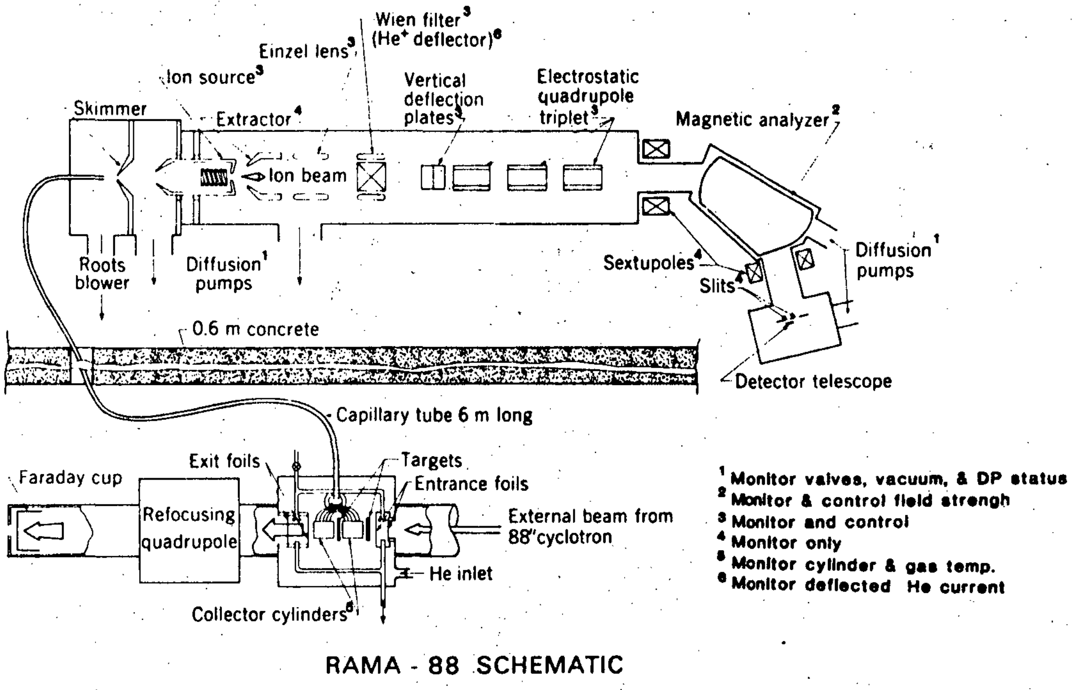

Fig. 1 Schematic diagram of the on-line separator RAMA with computer monitored functions indicated.

Figure 1 presents the experimental lay-out of the RAMA system showing the 6 m long stainless steel capillary tube of the helium-jet which transports activity from the target chamber to the mass analyzer. A specially designed multiple-target, multiple-capillary system is used to provide optimal yield. Reaction recoils are thermalized inside a cylinder and collected by a set of capillaries spaced evenly over the distance of a maximum recoil range. The transported activity is introduced into an early Sidenius type hollow-cathode ion source[4] after the helium has been skimmed off by a large roots blower vacuum pump system. Singly charged ions are extracted at 18 kV, and mass analyzed as shown in figure 1. Ion source efficiencies for RAMA currently range from 0.1-0.5% for such elements as Na, Mg, Si, Ca, In, Te, Cs, Ho, Dy and At. The shortest half-life observed to date has been ~100 ms.

2. RAMA IMPROVEMENTS

Improvements to the RAMA system may be conveniently divided into four areas: the helium-jet, the ion source region, the detection system and the microprocessor system. Each of these improvements will be dealt with in terms of what has been determined to work well for the RAMA system. These changes necessarily preserve the capability for mass analysis of radioactive species with short half-lives (< 100 ms) and with application to a majority of the chemical elements.

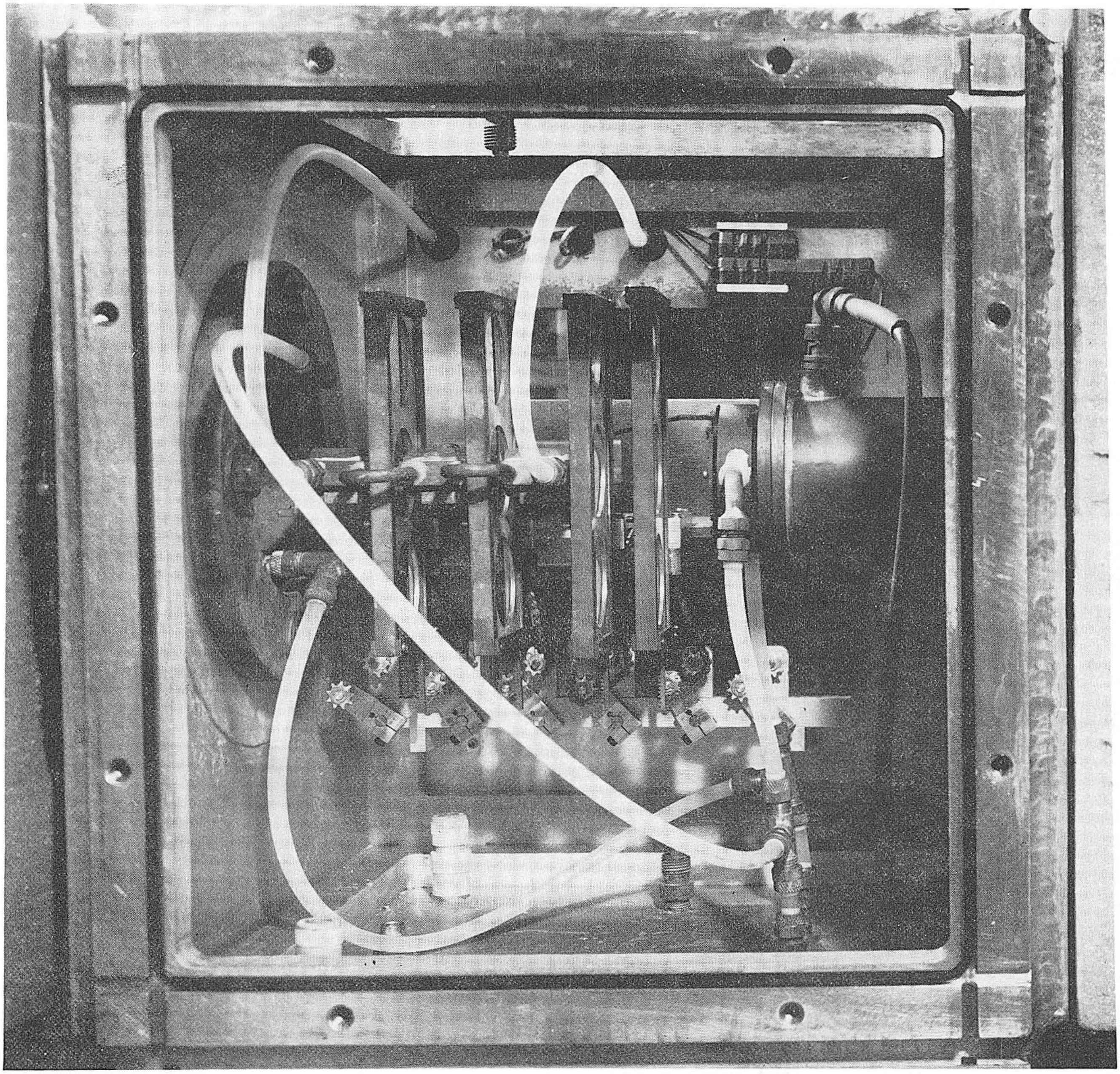

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Fig. 2 Photograph of the new RAMA helium-jet chamber.

2.1 HELIUM-JET

Figure 2 shows a photograph of the new helium-jet chamber with the multiple-target, multiple-capillary system in place. The chamber now permits the insertion of targets and degraders via externally moveable, three-position target and degrader foil ladders eliminating former costly time delays needed for recooling and purging the system. The volume of this chamber has been doubled to permit simplified access to the isolation foils. Because of the increased volume and surface area of the chamber, a separate refrigeration unit is employed to cool the chamber and gas within. Cold nitrogen gas is still used to chill the isolation windows.[2] All support brackets and pressure feed-throughs for the multiple-target, multiple-capillary system are now attached to a single removeable plate of the target chamber permitting easy access to the system and quick addition of new target-capillary configurations.

Extensive testing of this chamber has shown that the former optimum operating conditions are still valid, but with a greater reproducibility. Using a 1.27 mm i.d. capillary and three target system the chamber operates optimally when kept at a temperature of $\sim 10°$ C, and at a pressure of 1.5 atm, resulting in a helium flow rate of ~ 2 liters/min. For light ion beams addition of ethylene glycol is necessary to form the large molecular weight clusters which transport the activity. Heavy ion beams have need of far less additive due to their greater ionizing characteristics. The total transit time as measured by techniques given in ref. 2 remains the same at 280 ms.

A new two-stage roots blower vacuum pump system with a pumping speed of 6000 liters/sec of He at 0.1 torr, the operating pressure of the skimmer chamber, has just been installed which will more than triple our present pumping capacity, providing a faster transit time which should be between 100 and 150 ms.

2.2 ION SOURCE REGION

The new general purpose ion source holder, pictured in figure 3, was designed using the same single plate mounting technique employed for the multiple-target, multiple-capillary system. In addition to being easily removed and accurately repositioned, this system provides external (while in operation) x, y, and z positional adjustments. Motion in the z (beam) direction has eliminated the need for an overly complicated moveable extractor. Mounting of the holder from above has permitted a better vacuum in the ion source region, eliminating almost all spark discharges caused by local outgassing.

The present hollow-cathode, anode-extraction ion source, diagrammed in figure 4a, is quite versatile and reliable. Unfortunately, a large fraction of nuclides are never ionized due to the excessive distance from the capillary tube to the plasma, which results in condensation of the nuclides on the ion source walls. Any new ion source which attempts to alleviate this problem and is also suitable for the study of short-lived (< 100 ms) nuclides must

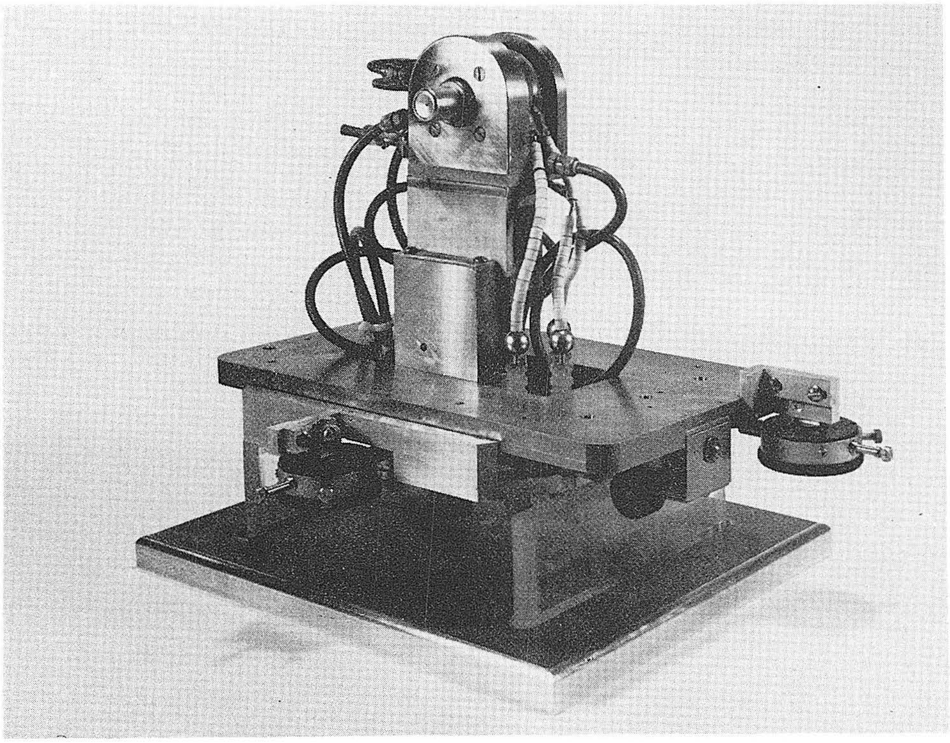

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Fig. 3. Photograph of RAMA ion source holder with ion source in position.

retain the very short holdup times (< 10 ms) of the hollow-cathode, anode-extraction source because of the relatively long helium-jet transport time. The time distribution of the helum-jet is narrow (10-25 ms FWHM) making the exponential loss of radioactivity while being transported a reasonable assumption.

These factors led to the design of the hollow-cathode, cathode-extraction ion source diagrammed in figure 4b. The arc is struck in the middle of the source, thus reducing the capillary-plasma distance by ∿20%. Since much of the incoming radioactivity is lost on the source walls (see ref. 1) this source also reduces the wall area presented to an incoming cluster. This suggests that the increase in yield would be greater than that from just the geometrical shortening of the source. Indeed, tests with the 175 ms beta-delayed proton emitter ^{37}Ca[5] (MP = 846° C) produced in the ^{40}Ca (^{3}He,α2n) reaction at 70 MeV, indicate a factor of five increase in yield for this source relative to its predecessor. Various tests with ^{37}Ca and K activities indicate also that this source is limited to elements with melting points below 1200° C. Other ion sources[6] with much greater efficiencies have been considered for on-line use with the RAMA helium-jet, and an ISOLDE type thermal ion source is currently being developed for future use .

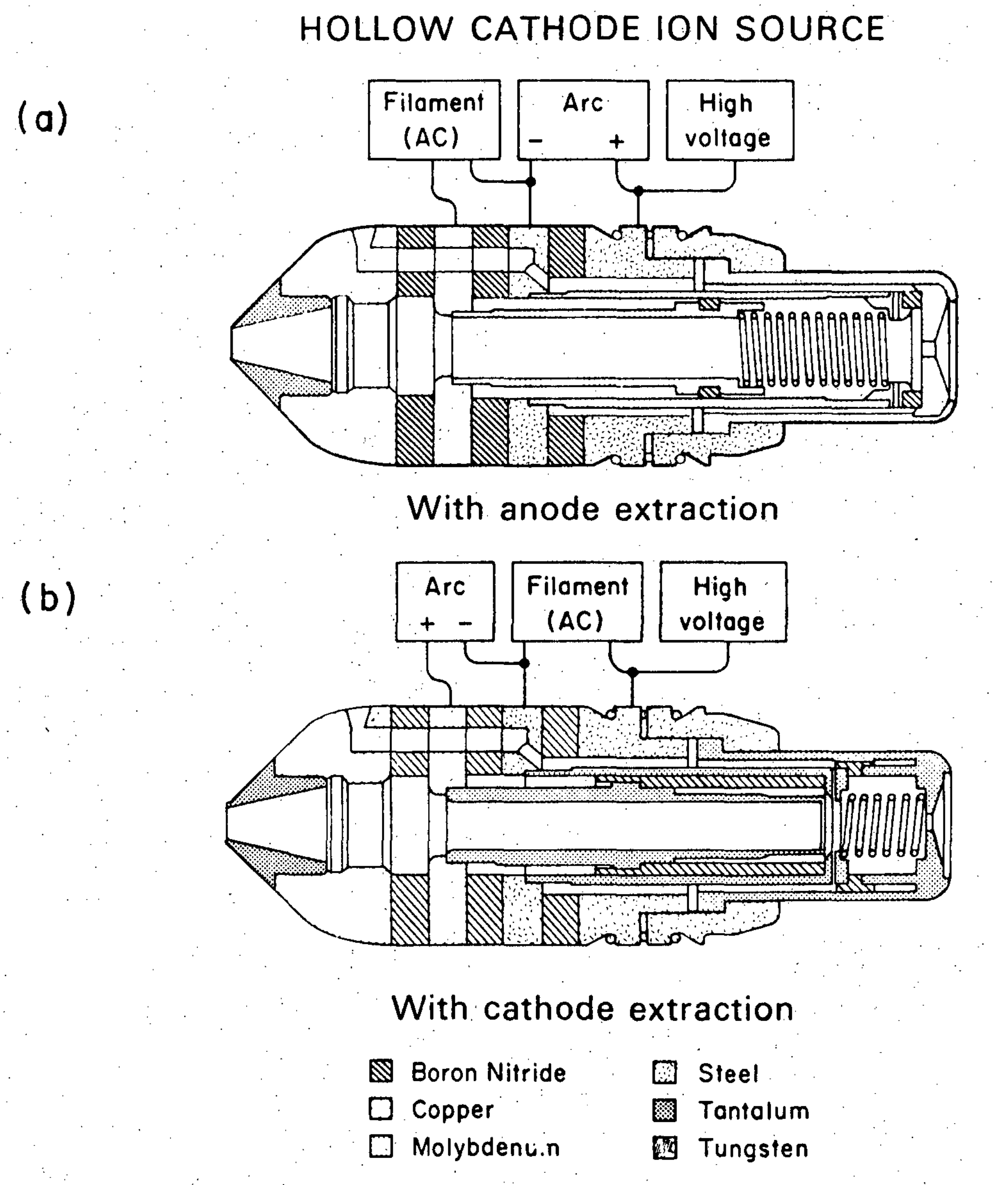

Fig. 4 Schematic diagram of the RAMA hollow-cathode ion source:
a) Anode-extraction ion source
b) Cathode-extraction ion source

2.3 DETECTION SYSTEMS

The flipper wheel system described in ref. 1 does not work well for activities with half-lives < 1 m. because of the need to move quickly the activity from collection to detection station, which results in severe mechanical stresses on the entire system. Furthermore, it was incompatible with either standard γ-γ or γ-Xray experiments. The fast vertical beam switching technique described in ref. 2 is only suitable for small solid state detectors (or tele-scopes) due to geometry constraints which do not permit large detec-tor coincidence measurements. A fast tape drive was thus construc-ted and is shown schematically in figure 5. In order to utilize an existing computer tape drive with its inherent reliability, speed, and positional accuracy, the system adopted incorporates a two-stage differentially pumped entrance and exit system. The first stage pressure is maintained at 1 torr by a roots blower vacuum pump and the second stage is maintained at 1×10^{-2} torr by a standard mech-anical pump. The primary vacuum in the detector box is normally 3×10^{-6} torr. Common 1.25 cm computer magne-tic tape is pulled over a series of rollers at 75 cm/s, moving a collected sample of activity from the focal plane to the appro-priate detector station. Figure 5 depicts both a γ-X ray (or γ-γ) detec-tor station (Tran-sit time = 1.0 s) and a β-γ station (Transit time = 0.42 s.). Tape positioning is ob-served to be as accurate as that with computer tape drives used in the more conventional way. Simple up-grading of the main capstan motor

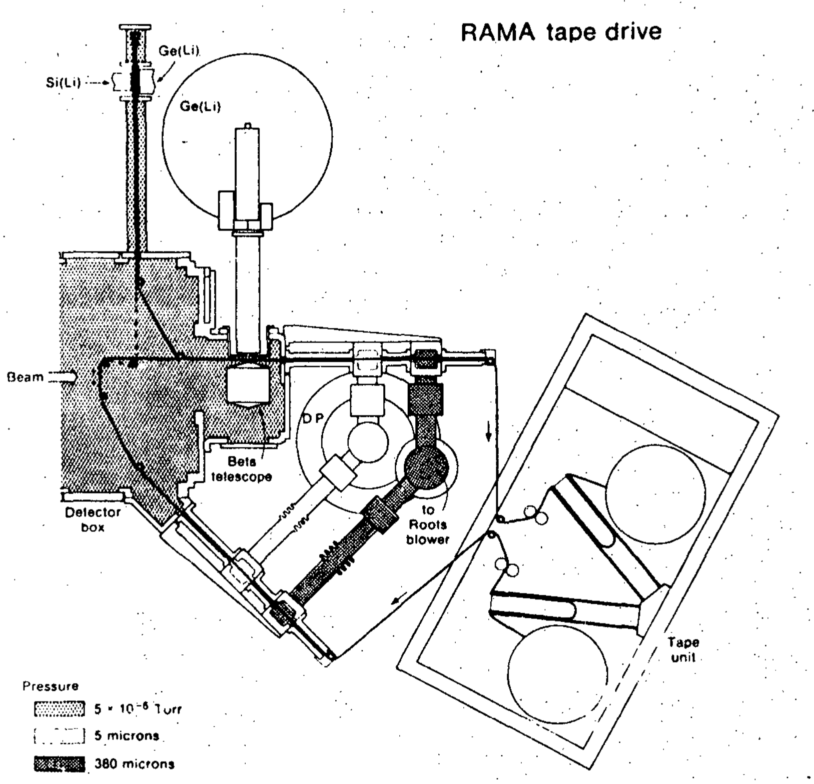

Fig. 5 Schematic diagram of the differentially pumped tape drive system showing both β-γ and γ-(X-ray or γ) capabilities.

should permit a factor of two increase in tape speed.

The beta-telescope depicted in figure 5 is designed to measure Q values to 20 MeV. It consists of a 1 mm thick disk ΔE detector and, as an E detector, a partially cut cylinder (to present a uniform thickness for large angle particles) 11.4 cm in both diameter and depth; both are constructed from NE102 scintillator. The thin ΔE detector is used for γ-ray rejection. Typical coincidence timing between the ΔE and E detectors is 5 ns FWHM. A standard large volume ($\sim$15%) high resolution (2.1 keV at 1332 keV) Ge(Li) counter is used in coincidence with the high geometry ($\sim$31% of 4π) beta-telescope; typical coincidence resolution is 20 ns FWHM.

Measured positron spectra are distorted by several energy-dependent effects such as energy resolution, Compton electron pile-up due to annihilation radiation and surface back-scattering. In narrow energy ranges above 1 MeV, only the first effect is of great importance[7] in determining positron endpoint energies. The overall resolution of the E detector was determined by measuring the energy resolution of $\sim$1 MeV ($\sim$200 keV FWHM) conversion electrons from ^{207}Bi and by assuming the response function is a Gaussian curve whose width varies[7] as $\sqrt{E}$. A Fermi-Kurie plot for a known beta spectrum is shown in figure 6 after correcting the original spectrum for the response of the detector. Overall energy calibrations are normally determined by a linear least squares fit to the endpoint energies of several known positron emitters.

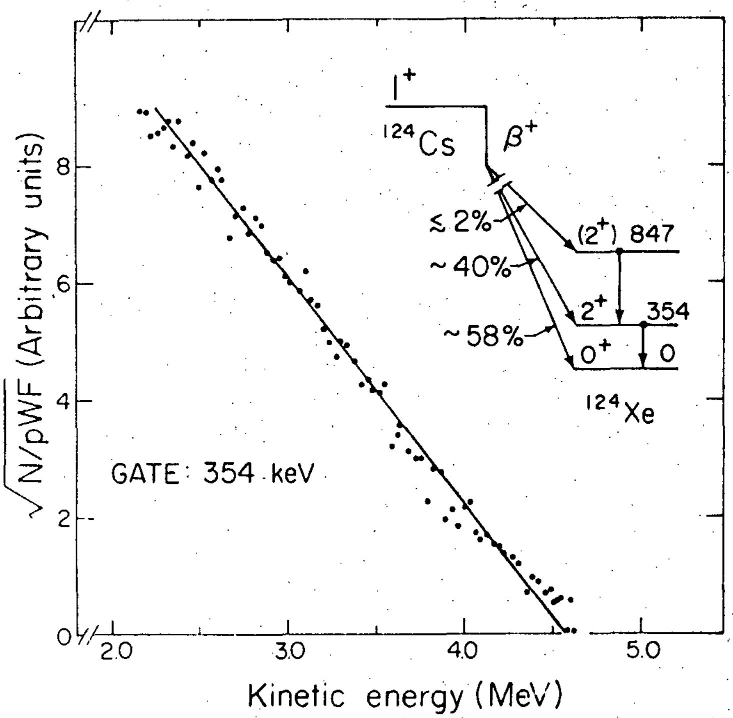

Fig. 6 Fermi-Kurie plot and partial decay scheme for ^{124}Cs. Beta-branching ratios were obtained from the γ-spectrum in coincidence with positrons. More details are given in ref. 8.

2.4 MICROPROCESSOR

Soon after RAMA began operating on a regular basis, it became apparent that many critical parameters (e.g. ion source operating conditions) needed continual atten-

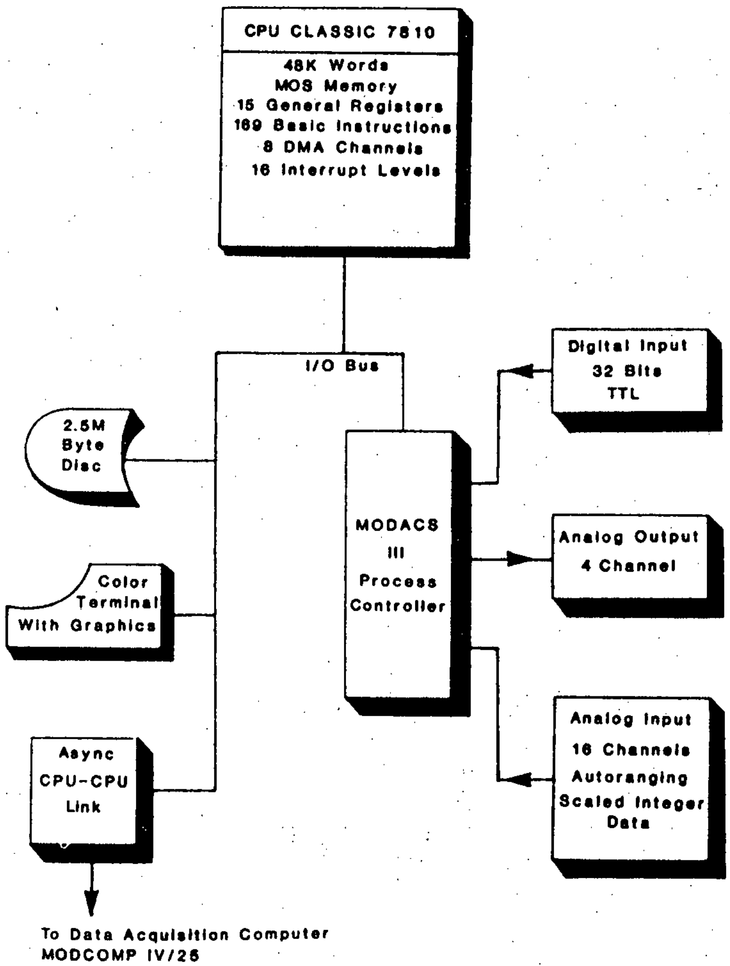

Fig. 7 Block component diagram of the RAMA microprocessor system for monitoring and controlling operating parameters.

tion. As such, a microprocessor system is being installed to monitor and record standard operating parameters and alert experimenters to any RAMA system deviations.

Several criteria were considered in choosing an appropriate microprocessor system. It had to have maximum compatibility with the existing computer facilities (in our case the ModComp IV/25[9] at the Lawrence Berkeley Laboratory 88-Inch Cyclotron) for use in data transfer for mass storage and review, for programming and simulation, and for down loading capabilities for programming in higher level languages. The system had to be a stand alone computer that could be operated via a standard RS232 link with terminal and storage scope. It also had to have sufficient potential for expandability for future monitor and closed loop applications, and finally had to have a minimum core space of 32K of 16 bit words and data handling rates on the order of 10 ms for 20-30 channels of both analog and digital information.

The system that was chosen that fulfilled these requirements was a process control system known as the ModComp MODACS III. The computer has a link for connection to the ModComp IV/25 main frame, independent control operations, and plug in cards for analog and digital input/output. The computer chosen offered the simplest solution since the two computers (the ModComp IV/25 and MODACS III) are hardware and software compatible resulting in a minimum need for hardware development. The present system (fig. 7) is supported by a standard moving head disc drive, an eight color terminal with moderate graphics capabilities, appropriate interfaces between itself and the devices being monitored, and 48K of 16 bit memory.

Figure 1, the schematic diagram of RAMA, details parameters that will be monitored and/or controlled. Currently only the sextupole currents (see ref. 1), the dipole NMR frequency and the extraction voltage are recorded, though this list will soon be expanded to include the filament voltage and current, the arc voltage and current, the Einzel lens voltage, the Wien filter electric field voltage, the vacuum system status and the quadrupole voltages. All of these parameters readily lend themselves to closed-loop control. Future candidates for monitoring include operating pressures, gas flow rates, gas and target chamber temperatures and various detector parameters (e.g. leakage currents).

3. SUMMARY

Redesign of the helium-jet chamber and the ion source holder has enabled easier maintenance and greater reliability of these two devices. A new hollow-cathode, cathode-extraction ion source has yielded approximately a factor of five increase in efficiency for some lower melting point elements. Development of the differentially-pumped tape drive system now permits experiments using both γ-γ and β-γ detection techniques. This tape system with a large volume beta-telescope has been utilized to determine preliminary positron endpoint energies for the neutron deficient nuclides ^{103}In and ^{105}In.[8] The microprocessor system currently monitors several important operating parameters. These changes and improvements have served to make RAMA a more reliable and effective tool for studying the decays of nuclei far from beta stability.

4. ACKNOWLEDGEMENTS

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FOOTNOTES AND REFERENCES

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