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THE OTHER HIGH RESOLUTION POST ACCELERATOR APPROACH

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Abstract: There has been significant discussion in consideration of a high resolution mass separator followed by a RFQ and a linear accelerator as the basic format for IsoSpin Laboratory. There exists another strong possibility-namely a low-resolution mass separator coupled to a cyclotron. The major objection to this approach has been that the conversion from the + 1 mass separator beam to a q/m beam of 1/4 to 1/3 is thought to be highly inefficient. Since we are in the fortunate position of having the two expensive components of this system available for tests (an on-line mass separator and an ECR source), we intend to couple these devices to actually measure these efficiencies and to test ideas for improving the efficiency. We present some specifics of this approach.

The concept for the IsoSpin Laboratory (ISL) has been well characterized, namely a high intensity primary accelerator producing copious quantities of radioactivity in a target which is fed into an on-line isotope separator followed by a post accelerator. There have been numerous discussions regarding all of the various options. These discussions and the many symposia[1-4)] on the physics of radioactive beams have led to an initial set of ideal criteria for ISL. Normally, the "shopping list" of physics ideas is so extensive that one can quickly conceive of a very expensive universal machine. There exist, however, a few underlying tenets which suggest a range of operating parameters.

The primary accelerator should produce an ~1 GeV proton beam at >100 μA. Targets would necessarily be cooled to handle the large power dissipation. Radioactivity could either diffuse from a thick target or could recoil out of thin targets into a transport gas (most likely He) before injection into a suitable ion source capable of ionizing the species of interest with large efficiency in the +1 charge state. The extracted radioactive beam would be mass analyzed before injection into a post accelerator. The post accelerator would yield beams of almost all elements up to 30 MeV/nucleon. It has been generally agreed that a beam purity of at least $1:10^4$ is desired. To achieve this goal, primary discussions have centered upon utilizing a high resolution ($m/\Delta m > 20000$) mass separator as an injector for a RFQ followed by a superconducting linac. To raise the top beam energy of this system, one need only add more linac sectors. This is clearly a strong advantage for the linac based scenario.

This system, however, has a number of potential drawbacks. First, the mass separator necessarily must be operated in the high resolution mode at all times. We have been involved with an ISOLDE experiment[5)] on ISOLDE-3 which required a modest resolution of 4000 (7000 was achieved); our experience is that tuning the mass separator took substantial time. One anticipates that high voltage stability problems will be increased by the utilization of primary beam currents 100 times larger, making tuning times even longer.

Second, heavier beams require stripping of the +1 beam to +2 or +3 even before injection into the RFQ. Additional stripping is then required before acceleration by the linac. Although the idea of using an accumulating stripper ring to significantly increase the stripping efficiency has been proposed6), exact final transmission numbers are unknown. Additionally, these accelerating structures are relatively expensive.

There is general agreement in the ISL User Community that some nuclear physics decay studies require not only mass separation, but also element separation. For example in the aforementioned ISOLDE experiment, ^{37}Ca necessarily had to be separated from the copiously produced ^{37}K. But for many experiments involving nuclear beta decay, simple mass separation suffices. For accelerated beams at 30 MeV/nucleon, beam purity is essential for almost all proposed experiments. There does exist another option which more closely resembles this realistic approach to a post accelerator for radioactive nuclear beams.

This other high resolution post accelerator approach involves injecting a low resolution mass separated beam into a cyclotron with modest K (~200). To achieve reasonable radioactive beam intensities requires that the +1 beam from the mass separator be stripped to a high charge state (q/m = 1/3 or 1/4; these q/m values cannot achieve 30 MeV/A for K=200. It is assumed, however, that most experiments would not require 30 MeV/A and therefore the lower values would be adequate.). The efficiency for this last step is totally unknown, but it has always been assumed to be small. If this stripping efficiency could be demonstrated to be high, this low-resolution mass separator/cyclotron would probably be the preferred approach. Several stripping approaches can be devised such as collinear laser ionization, collinear electron beam stripping, and injection into an ECR source. Although the first two methods may be equally meritorious, the presence of a primary accelerator (the 88-Inch Cyclotron), an on-line mass separator (RAMA), and an ECR source (LBL ECR) make this last option a prime candidate for investigation.

Operation of the 88-Inch Cyclotron has been well documented7) and will not be covered here. While the original RAMA system has been described elsewhere8-11), a new version of RAMA is almost complete which will feature a target-ion source distance of ~15 cm. Figure 1 depicts the 88-Inch Cyclotron and beam delivery system layout. The old RAMA system began with a helium-jet system in Cave 2 coupled to an ion source via a ~6 m capillary (see ref 8). The new RAMA system depicted schematically in Fig. 2 has its ion source region directly above the helium-jet chamber. The beam is extracted vertically and then, by use of a 90° electrostatic mirror, the beam is injected into the old mass

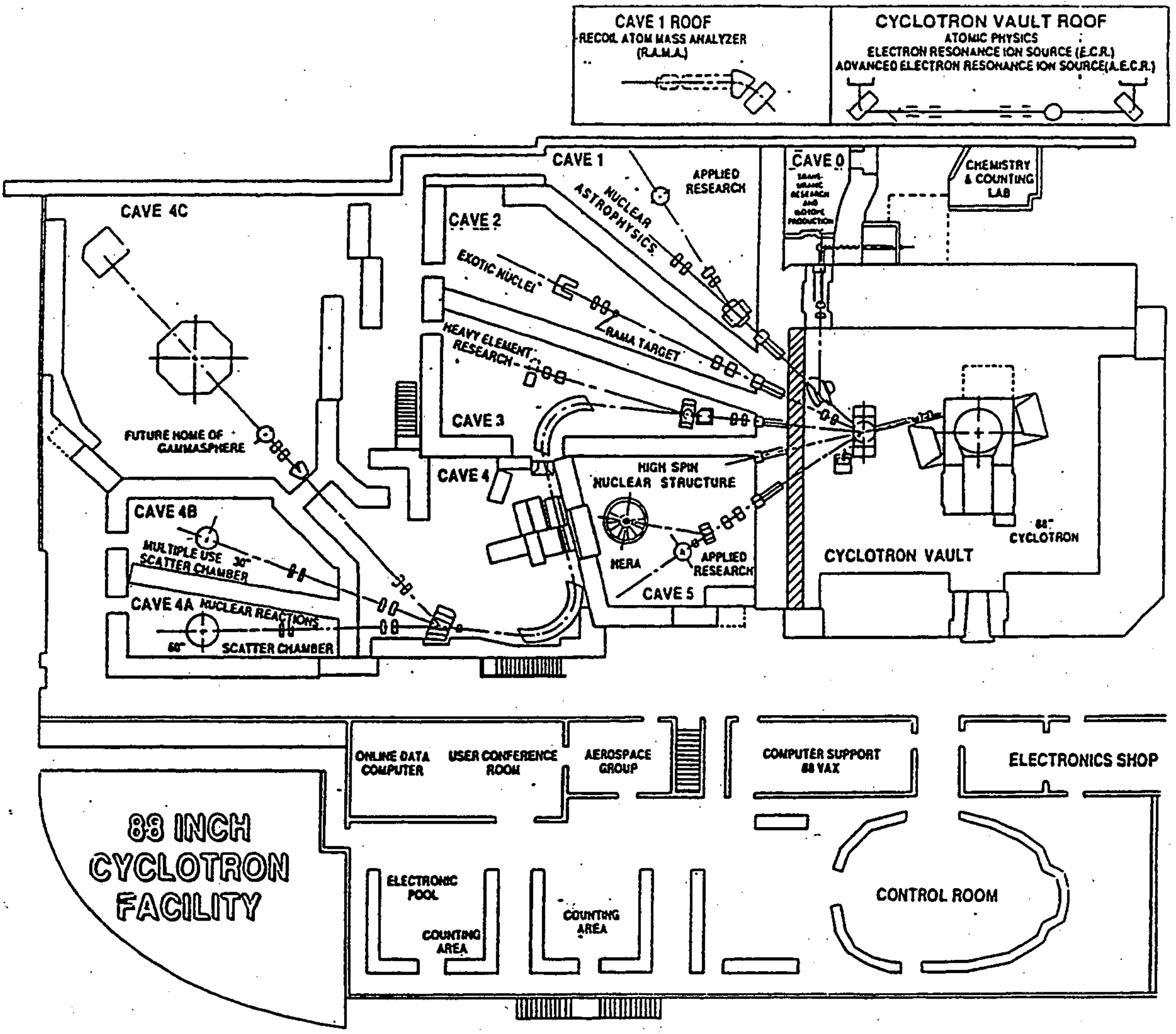

Figure 1. Schematic diagram of the 88-Inch Cyclotron Facility.

analysis system. Although experiments are still possible at the focal plane, all planned experiments will be mounted at the shielded detector station (see ref.11).

The primary motivation for this entire RAMA upgrade was to improve the overall efficiency by improving the capillary-ion source coupling and reducing the transit time from >200 ms to <10 ms. The former part of this project has been completed and tested. The total efficiency for many different elements has increased by ten to one hundred fold and is

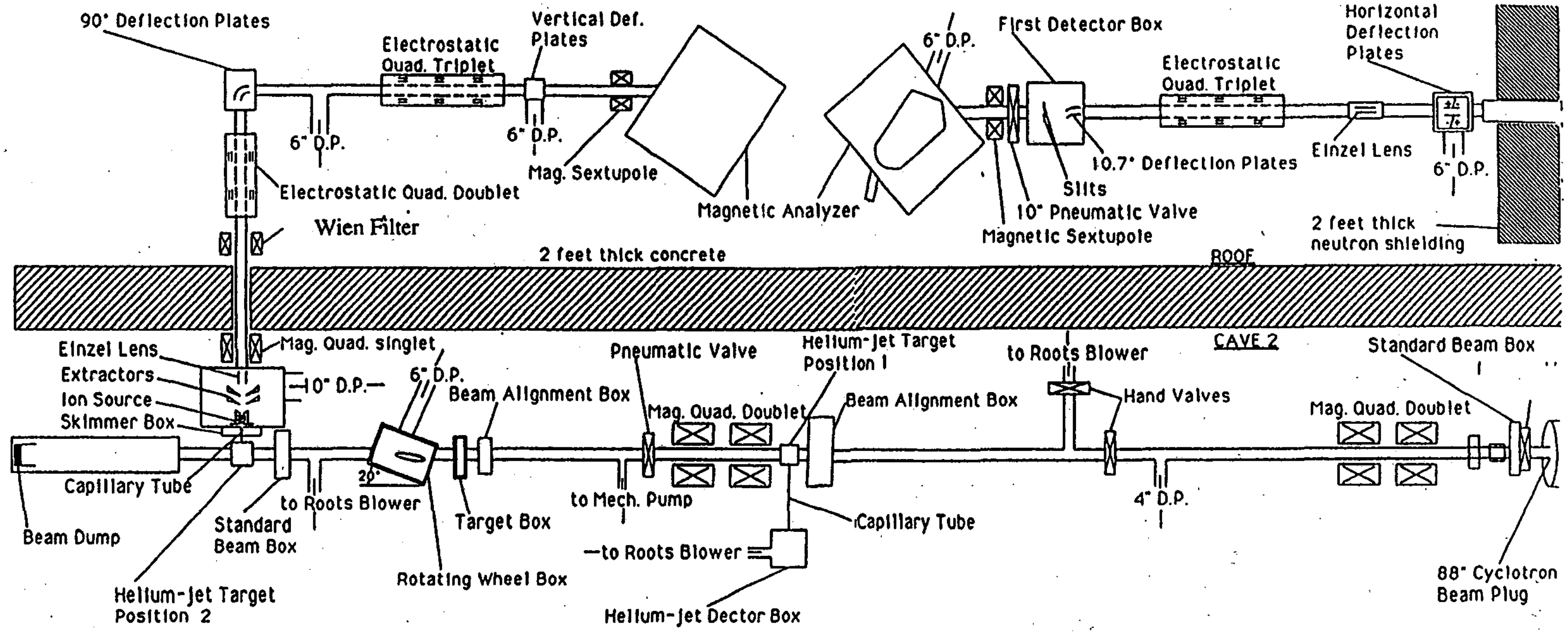

Figure 2. Schematic diagram of the RAMA on-line mass separator. The view represents a vertical cross section through the electrostatic mirror. At this point the view presented becomes a horizontal cross section with a linearized bend through the mass analyzing magnet. The actual bend angle is 75.5°. The point of closest approach to the LBL ECR occurs just beyond the last quadrupole triplet.

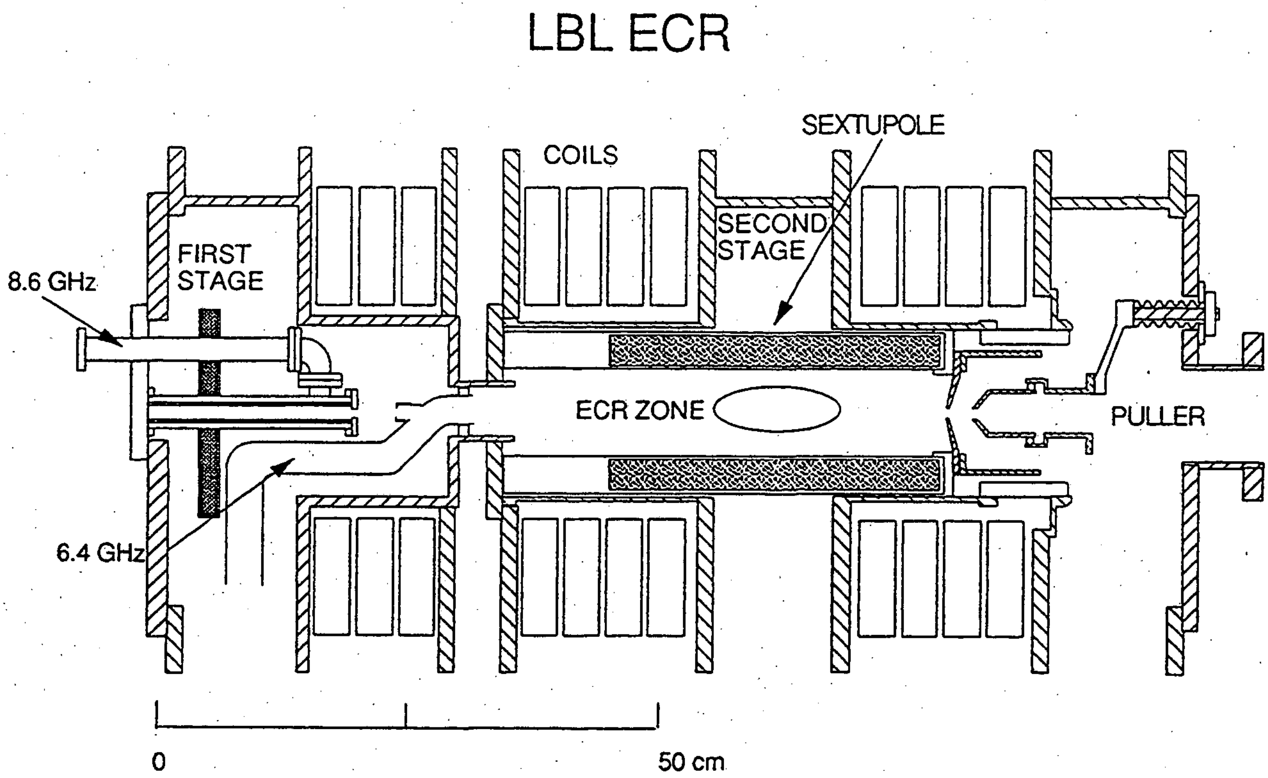

Figure 3. Vertical cross section of the LBL ECR source.

now 0.1-2%. The outlet beam line to the shielded detector station passes <5 m from the LBL ECR source. We intend to investigate methods and efficiencies of coupling a mass resolved +1 ion beam to an ECR for subsequent injection into the cyclotron. Under the proper conditions, one can envision the possibility of accelerating co-resonant primary and radioactive beams. There exist three coupling methods which we intend to investigate.

Figure 3 depicts a cross section of the two-stage LBL ECR source. Normal operation of this source entails a background plasma such as oxygen or helium in the first stage with direct injection of the desired species into the second stage (either by slow gas feed or by use of an oven). Our three proposed coupling schemes can best be understood by referring to Fig 3. The first idea is to catch the RAMA beam on a very hot foil in one of the ECR ovens. This method requires diffusion of the desired species and automatically loses 50% of the radioactivity due to reverse diffusion. The second idea is to create a slow landing for the RAMA beam onto a rod inserted into the ECR plasma region. Ablation from such a rod has been used to inject non-volatile elements into an ECR plasma[12]. The soft landing (<100 eV) is necessary to minimize the implantation depth. The third idea is to slow the RAMA beam to an energy of <1eV and let it drift though the ECR zone (axial injection). This method is similar to what might be used with an electron beam stripper.

The efficiencies for these methods are very difficult to predict; this is the motivation for these proposed measurements.

Although we cannot presuppose any efficiencies, we can set criteria which would permit the evaluation of this option for a post-accelerator. Utilizing general guidelines for ISL[4] , we have constructed Table I. As can be seen from these numbers, a stripping (or reionization) efficiency of 2% makes a cyclotron a viable option for the ISL post-accelerator. A cyclotron is also more reliable. It is sufficient to conclude that there are many questions to answer before the post-accelerator issue is finally decided.

Table I. Approximate effiencies for different post-accelerator options at ISL.

	LINAC	CYCLOTRON
ISOL	30%	90%
Stripping	5%	?
Transmission	80%	50%
Tuning	80%	95%
TOTAL EFFICIENCY	1%	?

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