

# ORIC CENTRAL REGION CALCULATIONS\*

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## Abstract

The central region for the K=100 Oak Ridge Isochronous Cyclotron, ORIC, will be modified to provide better orbit centering, focusing of orbits in the axial direction, and phase selection, in order to improve extraction efficiency, and reduce radioactive activation of cyclotron components. The central region is specifically designed for the acceleration of intense light ion beams such as 60 MeV protons and 15 - 100 MeV alphas. These beams will be used in the production of radioactive atoms in the Radioactive Ion Beam Project at Oak Ridge National Laboratory.

## I. RIB PRODUCTION REQUIREMENTS ON ORIC

The Holifield Radioactive Ion Beam Facility, HRIBF, will use the K= 100, Oak Ridge Isochronous Cyclotron, ORIC, as a driver to provide beams of light ions (protons, deuterons, helium, and lithium) ranging from 10 - 65 MeV on target[1]. These will produce proton-rich radioactive atoms for acceleration in the HRIBF 25 MV Tandem. The Target Ion Source on the RIB Platform, presently has a carbon window 170 mg/cm<sup>2</sup> thick. Using the energy loss in this window as a guide, ORIC will need to operate at  $K \geq 15$  for protons,  $K \geq 35$  for deuterons and 2-plus helium, and  $K \geq 60$  with 3-plus lithium. These beams need intensity so as to provide experimenters with sufficient radioactive ions to study nuclear structure and astrophysics. Direct and induced radioactivity produced by these beams, require further constraints on ORIC. The administrative limits for operation as a low hazard facility will be 50  $\mu$ A of 65 MeV protons, and 200  $\mu$ A of 100 MeV alphas. Good extraction efficiency (90+%) is needed to minimize the induced radioactivity produced in ORIC.

## II. AN OVERVIEW OF ORIC HISTORY

ORIC was constructed and began operation over three decades ago[2]. It was initially used to accelerate both light ions. The acceleration of heavy ions in ORIC first

\*Work supported by the U.S. Department of Energy

<sup>†</sup>Managed by Martin Marietta Energy Systems, Inc., under contract No. DE-AC05-84OR21400 with the U.S. Department of Energy.

<sup>‡</sup>member institutions the University of Tennessee, Vanderbilt University, and the Oak Ridge National Laboratory; it is supported by the members and by the U.S. Department of Energy through Contract Number DE=FG05-87ER40361 with the University of Tennessee.

took place in 1968[3]. Extraction was achieved by inducing radial oscillations near the center of the cyclotron, and using the precession at 29 in., while  $\nu_r$  was still  $\approx 1.05$ , to increase the radial separation between turns near the deflector septum[4]. In the early 80's, ORIC was converted to be used as a booster for the 25 MV tandem accelerator. A new magnetic field mapping was performed for this conversion in the range of 12-20 kG. This enabled the writing of a set of cyclotron injection/orbit/extraction codes which accurately predicted machine settings for operating the cyclotron in coupled mode for  $K \geq 60$ [6]. A new extraction method soon followed. The injected tandem beam had a small emittance, a 6° RF Phase width, and was injected with very good centering. A first harmonic bump was then used at outer radii to produce radial separation closer to the  $\nu_r = 1$  resonance, ( $\nu_r \approx 1.017$ ). These qualities improved the extraction efficiency from a typical 30% to a typical 70%[5]. Calculated turn separation at extraction is .1 in.

## III. THE PRESENT ORIC CENTRAL REGION

The ORIC central region has been restored to a configuration similar to central regions used before the coupled operations. A PIG ion source is inserted on a radial arm from the North side of the machine. The source, which was modified to use a smaller chimney, can be positioned in both directions in the median plane. The puller, which is a little hook extending out from the dee, can be positioned in one dimension only, along the edge of the 180° dee. It's position in the other direction can be changed by removing the dee and replacing the puller. A radial clipper has been added. It is a small plate with a slot cut axially, that has been mounted on the dee, and runs parallel to the puller. In addition, the source head has been modified so that two plates can be mounted on them to form an axial slit which will restrict the beam axially within the first few turns[7].

Axial focusing in the central region is provided by two separate mechanisms. The first is geometric. The source chimney is set back from the leading edge of the source head. The electric field, which was calculated with RELAX3D[8], penetrates in to the source. Calculations, made with Z3CYCLONE[9], show that this provides axial focusing over most of the gap between the source and the puller when the electric field is accelerating the ions. This axial focusing in the first gap is extremely strong. It over focuses, causing the beam to expand axially. This

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# MASTER

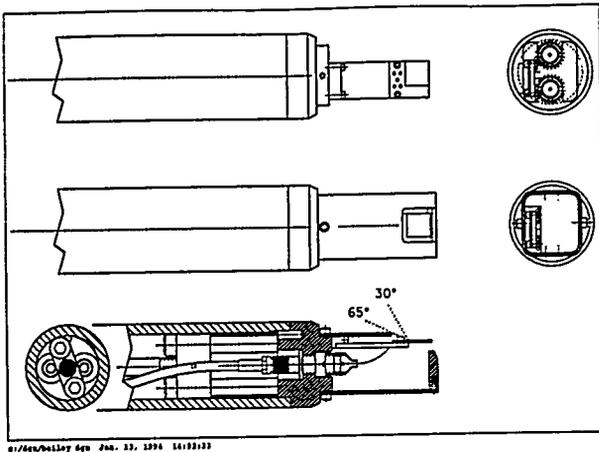


Figure 1. K1200 Timing Probe Head. The detector mount, and RF shield are depicted above. The cut away shows vacuum feed throughs, and beam clearance of the RF shield.

pushed into the beam, allowing the ions to traverse only a small part of the detectors active area. To simulate the response of the detector, the energy loss profile for ions incident on the detector was calculated with the program ELOSS[4]. A simple model of the detector, developed by Spieler[5], was then used to simulate the charge collection of the detector. The output signal from the program simulated the output of the detector reasonably well. This was then passed through a simulation of a constant fraction discriminator. The final result, was that there would be a variation of 40 to 50 ps in the measured time of arrival of ions hitting the edge and center of the detector.

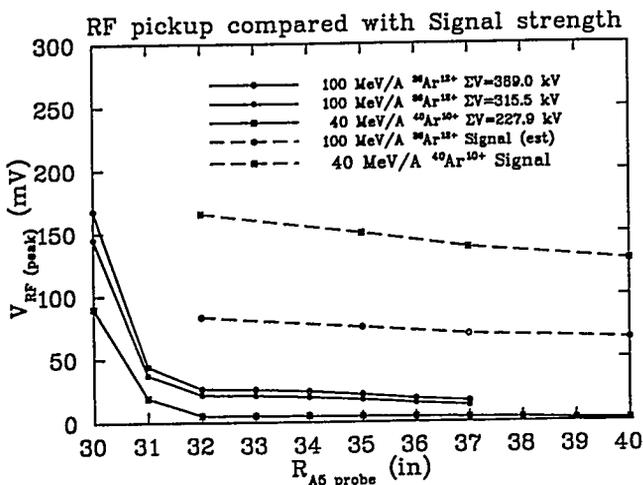


Figure 2. Relative Strengths of Beam Signal and RF Pickup. The measured RF pickup of the detector from the dees is relatively constant until the probe begins to approach the accelerating gap. The strength of the beam signal is also displayed as a reference.

Second, the slot in the RF shield allows the detector, which is a capacitor, to pick up a signal from the accelerating electric field. Since the hills spiral, as the detector travels deeper into the cyclotron, it begins to approach an accelerating gap. Figure 2 shows the measured strength of this pickup, compared to the signal strength of Ar ions as a function of detector radius. It is clear that inside of 32 in the detector won't be able to see any signal. To calculate the effect of the RF pickup on the measurements, the pickup sine wave was added to the detector simulation. Care was taken so that beam followed the calculated phase curve of the cyclotron, and that the phase of the sine wave was correct for the time of arrival of the ion on the probe. The measured time of arrival has a radially dependant shift. The RF stop signal used in the time measurement is relative, and not absolute, so the net shift is unimportant, but radial differences are important. The radial difference varies by 40 ps when the pickup is 6% of the beam signal, but when the difference is 30%, the measured beam time can vary by 800 ps. Also, since the beam has a time spread, a 30% RF pickup will widen the measured beam time by up to 200 ps for  $\Delta\phi = 10^\circ$  RF, and 600 ps for  $\Delta\phi = 40^\circ$  RF.

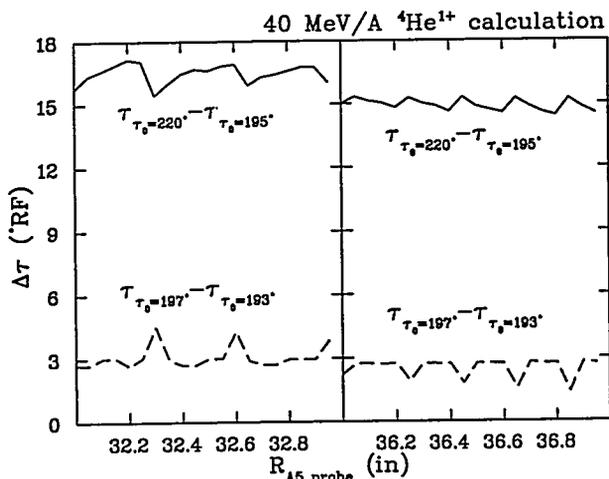


Figure 3. Calculated Variation in Measured Time Widths Due to Precession. Precession will cause the measured time width of the beam to vary periodically as a function of the radius at which it is measured. The starting time of 220° RF is centered.

The detector collects one beam pulse over many turns. At 32 in, it takes about 20 turns, and at 40 in, it takes 35 turns. This allows multi-turn effects to influence the measurement. Except near extraction, the phase slip per turn is small, so this will have little effect. One measurement though did show that for extreme conditions this slip, will make a difference. An analog beam that was about to fall out of resonance grew fourfold in width before it was lost. Also, as the energy gain per turn became so small that only the radial precession could clear the

detector dead area, the beam spread into several small peaks. Radial precession of off centered beams, though, will have an effect. Figure 3 shows the calculated effect of precession at two different radii for a beam 4° wide and one 25° wide in RF starting times. The phase compression is from the central region, and is real, but the variation in calculated width shows that the precession can cause an error as large as 2° RF. The sign of the error has the same sign as the slope of the phase curve. This will be true for any method of measuring phase widths internally, not just for this detector. The solution will be to take a measurement in an area where one expects the phase curve to have zero slope, and to move the detector a small amount and repeat the measurement.

### III. INTERNAL BEAM TIME MEASUREMENTS

Both of the cut detectors have been successfully used as timing detectors in the K1200 cyclotron, performing equally well. Figures 4 & 5 show the versatility of these detectors. In Figure 4, the detector was used to measure

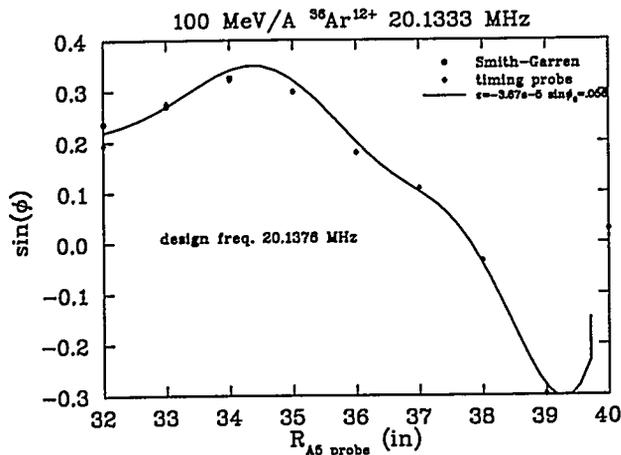


Figure 4. Phase Curve Measured with the Internal Timing Probe. The phase curve was measured using the internal detector. The timing probe can only measure relative changes, so one point was fixed using a Smith-Garren measurement. The calculated phase curve was then fit to the data, varying frequency and starting time, demonstrating the accuracy of the magnetic field calculations.

the outer portion of the phase curve. Spectra were taken every inch, from 32 to 40 inches. The centroids were calculated, and corrected for travel time of the beam from the dee center to the probe. These were then fixed in absolute phase by a Smith-Garren frequency swinging phase measurement at the three innermost data points. (This technique, which is extremely slow, does not work in the K1200 at radii greater than 34 inches, since the phase diagram has a maxima there.) For comparison, a phase curve from a calculated magnetic field was fit to the data, with extremely good agreement.

Figure 5 shows several beam time spectra which were taken with the internal probe. The left most, and center

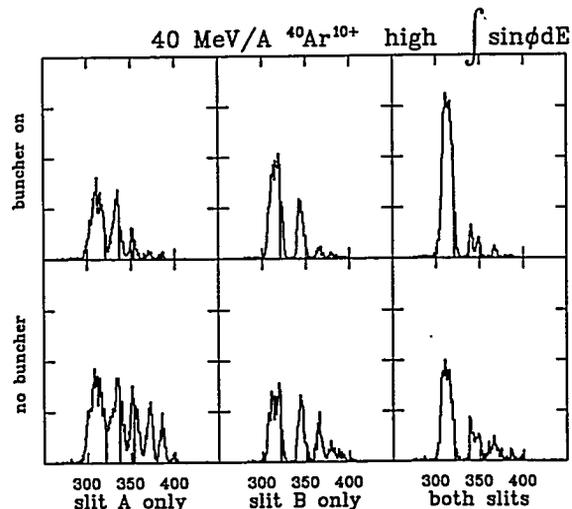


Figure 5. Time Spectra Measured with the Internal Timing Probe. Time spectra measuring the effects of the phase slits, which are really posts inserted into the beam, and the buncher. One phase slit makes multiple cuts in the beam, and the two together with the buncher are used to select and enhance one peak for transmission, while cutting the others. Each channel is 50 ps. Note the small peak widths, one of which is only five channels wide FWHM.

spectra show the results of inserting one of the phase slits, while the right most spectra show the results of both slits being inserted into the beam. The scale is in channels, at 50 ps per channel. The bottom row was done without the buncher, and the top row was used to emphasize the intensity of the main peak, relative to the other peaks. These spectra show the detectors ability to resolve fine sub-nanosecond structures, approx 250 ps wide, as well as its usefulness in tuning the phase slits.

In summary, a Si detector has been implemented as an internal beam timing detector in the K1200 cyclotron. It has proven to be useful in measuring phase curves, and tuning the phase slits, as well as demonstrating a 250 ps resolution. It stands ready for use in studying the time aspects of single particle beam dynamics.

### References

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