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# THE HOLIFIELD HEAVY ION RESEARCH FACILITY[1]

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Development of the Holifield facility has continued with resulting improvements in the number of ion species provided, ion energy for tandem-only operations, and utilization efficiency. In this report, we describe our recent operational experience, development activities, and future development plans.



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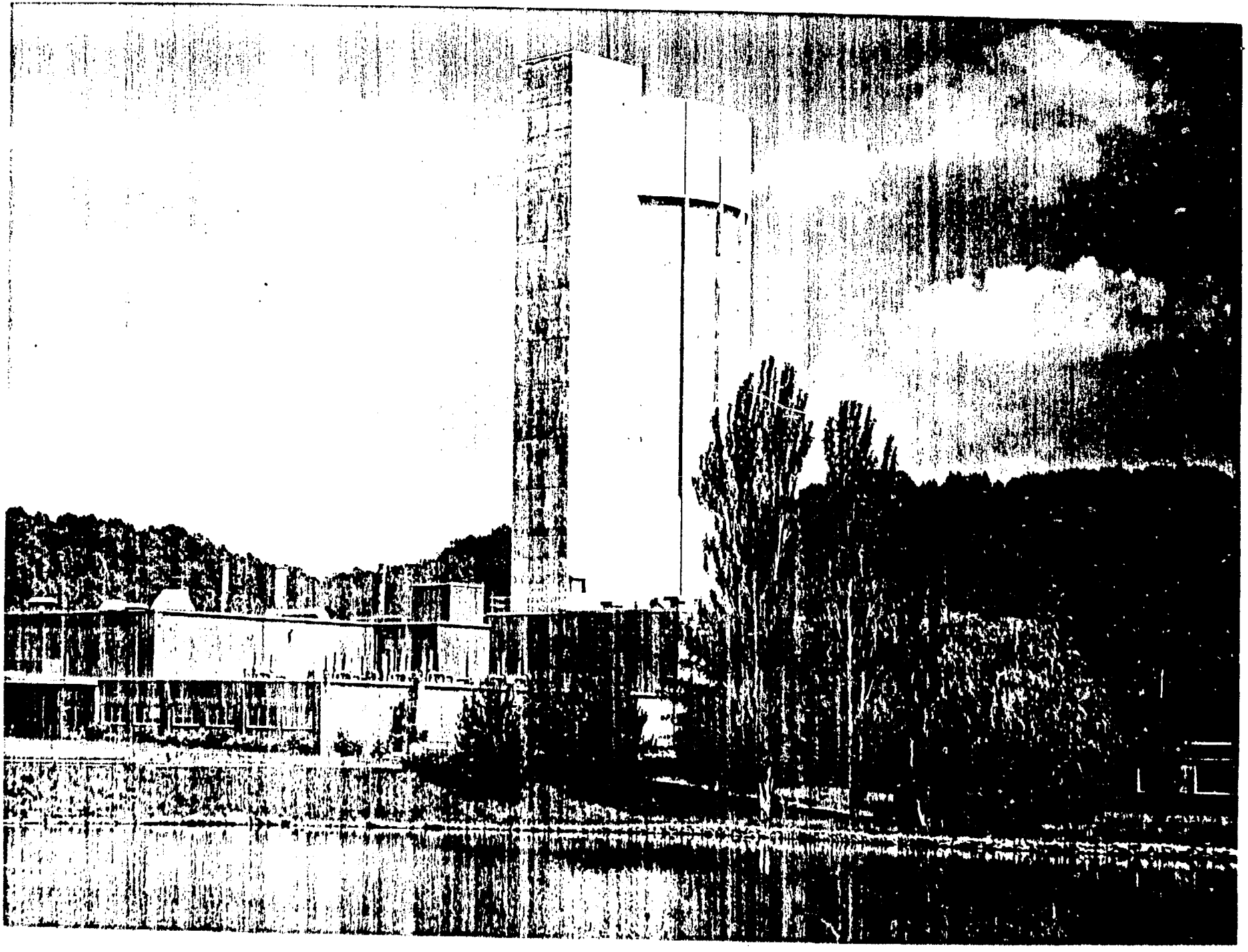
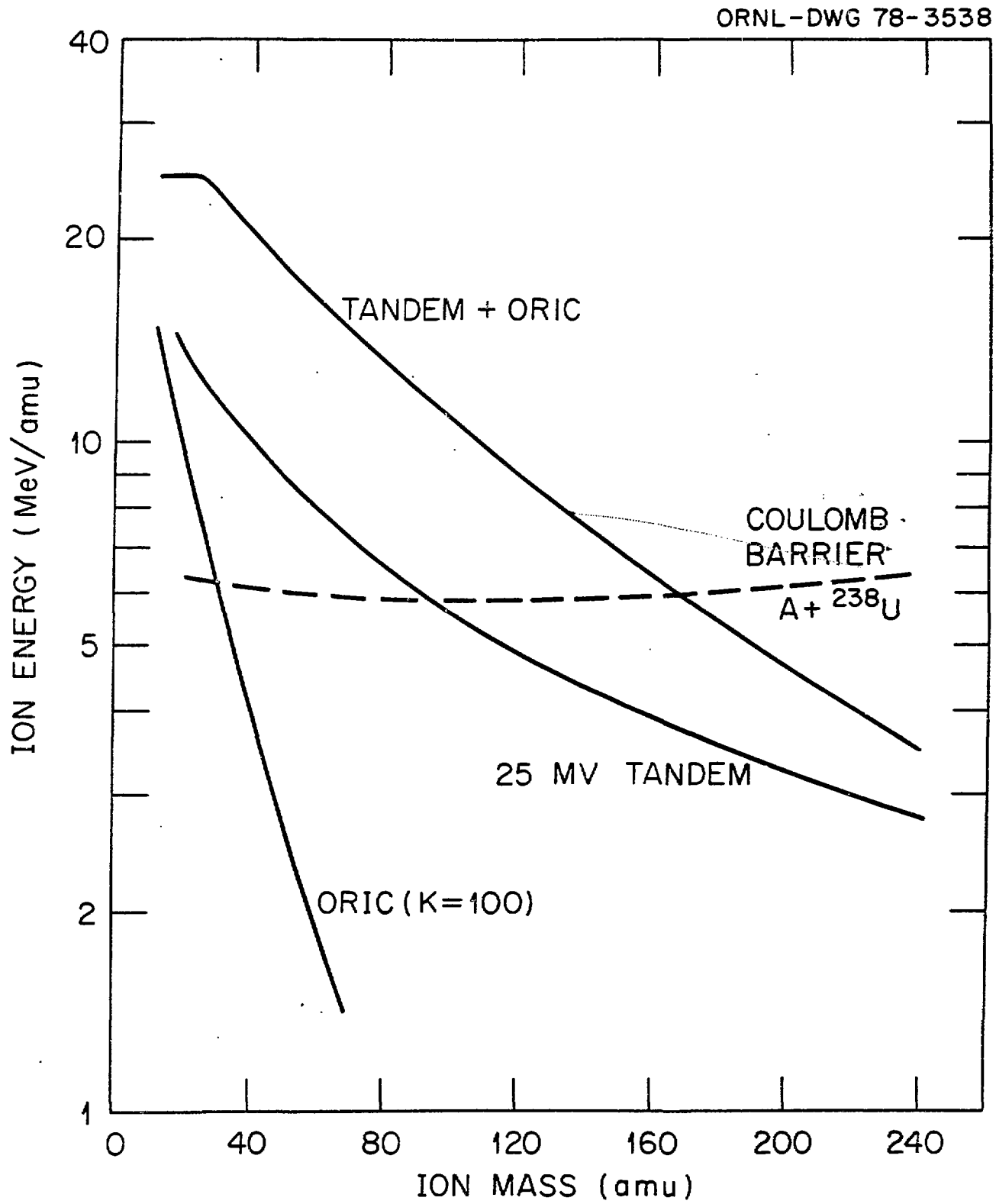
# INTRODUCTION

THE HOLIFIELD HEAVY ION RESEARCH FACILITY (HHIRF) IS LOCATED AT THE OAK RIDGE NATIONAL LABORATORY AND OPERATED AS A NATIONAL USER FACILITY FOR RESEARCH IN HEAVY ION SCIENCE. THE FACILITY OPERATES TWO ACCELERATORS: AN NEC PELLETRON TANDEM ACCELERATOR DESIGNED TO OPERATE AT TERMINAL POTENTIALS UP TO 25 MV AND THE OAK RIDGE ISOCHRONOUS CYCLOTRON (ORIC) WHICH, IN ADDITION TO ITS STAND-ALONE CAPABILITIES, HAS BEEN MODIFIED TO SERVE AS AN ENERGY BOOSTER FOR BEAMS FROM THE TANDEM ACCELERATOR.

THE PRINCIPAL EXPERIMENTAL DEVICES OF THE FACILITY INCLUDE A BROAD RANGE SPECTROGRAPH ($ME/q^2 = 225$) EQUIPPED WITH A VERTICAL DRIFT CHAMBER DETECTOR SYSTEM, A $4\pi$ SPIN SPECTROMETER WITH 72 NaI DETECTOR (Ge DETECTORS AND BGO COMPTON-SUPPRESSION UNITS ARE BEING ADDED), A TIME-OF-FLIGHT SPECTROMETER, A 1.6-m SCATTERING CHAMBER, AND A HEAVY-ION/LIGHT-ION DETECTOR (HILI) WHICH WILL BE ABLE TO MEASURE A LARGE FRACTION OF THE LIGHT AND HEAVY PARTICLES EMITTED IN HEAVY-ION REACTIONS FROM HEAVY PROJECTILES WITH ENERGIES GREATHER THAN ~ 10 MeV/NUCLEON.

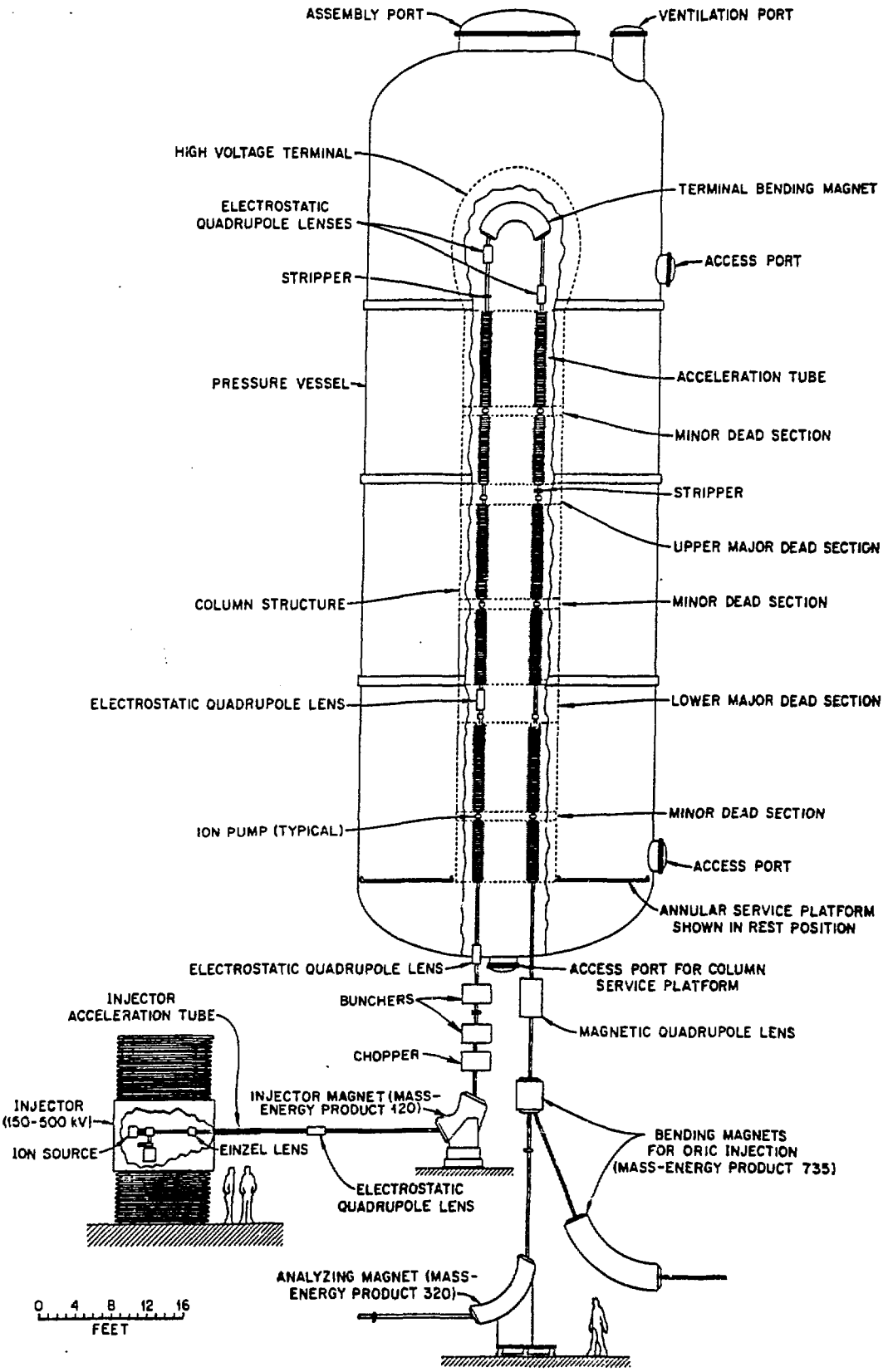
THE FACILITY HAS BEEN IN ROUTINE OPERATION SINCE 1982.






Ion energy performance functions for the ORIC, the HHIRF tandem accelerator (gas-foil stripper mode), and coupled operation of the tandem accelerator and the ORIC. The functions shown were calculated with the assumption of a final intensity of about $10^{11}$ particles/s.

# HHIRF TANDEM ACCELERATOR



# TANDEM ACCELERATOR VOLTAGE PERFORMANCE

SINCE THE INSTALLATION OF RECONDITIONED ACCELERATION TUBES IN 1983, VOLTAGE PERFORMANCE OF THE TANDEM ACCELERATOR HAS GRADUALLY IMPROVED. THE TABLE BELOW SUMMARIZES OUR PRESENT SITUATION:

| | AS RECEIVED FROM NEC (1982) | NOW (1987) |
|---|---|---|
| MAXIMUM VOLTAGE FOR ROUTINE OPERATION | 18.0 MV | 21.0 MV (Since July 1985) |
| MAXIMUM VOLTAGE FOR SCHEDULED EXPERIMENTS | 19.0 MV | 22.0 MV (January 1986) |
| MAXIMUM STABLE VOLTAGE WITH BEAM | 20.0 MV | 23.5 MV (February 1986) |

OPERATING VOLTAGES DURING A RECENT ONE-YEAR PERIOD ARE SUMMARIZED IN THE FIGURE TO THE RIGHT.

IN AN EFFORT TO FURTHER IMPROVE VOLTAGE PERFORMANCE, WE ARE NOW INSTALLING AND TESTING "COMPRESSED GEOMETRY" ACCELERATION TUBES. THIS WORK IS DESCRIBED IN ANOTHER PAPER AT THIS CONFERENCE.

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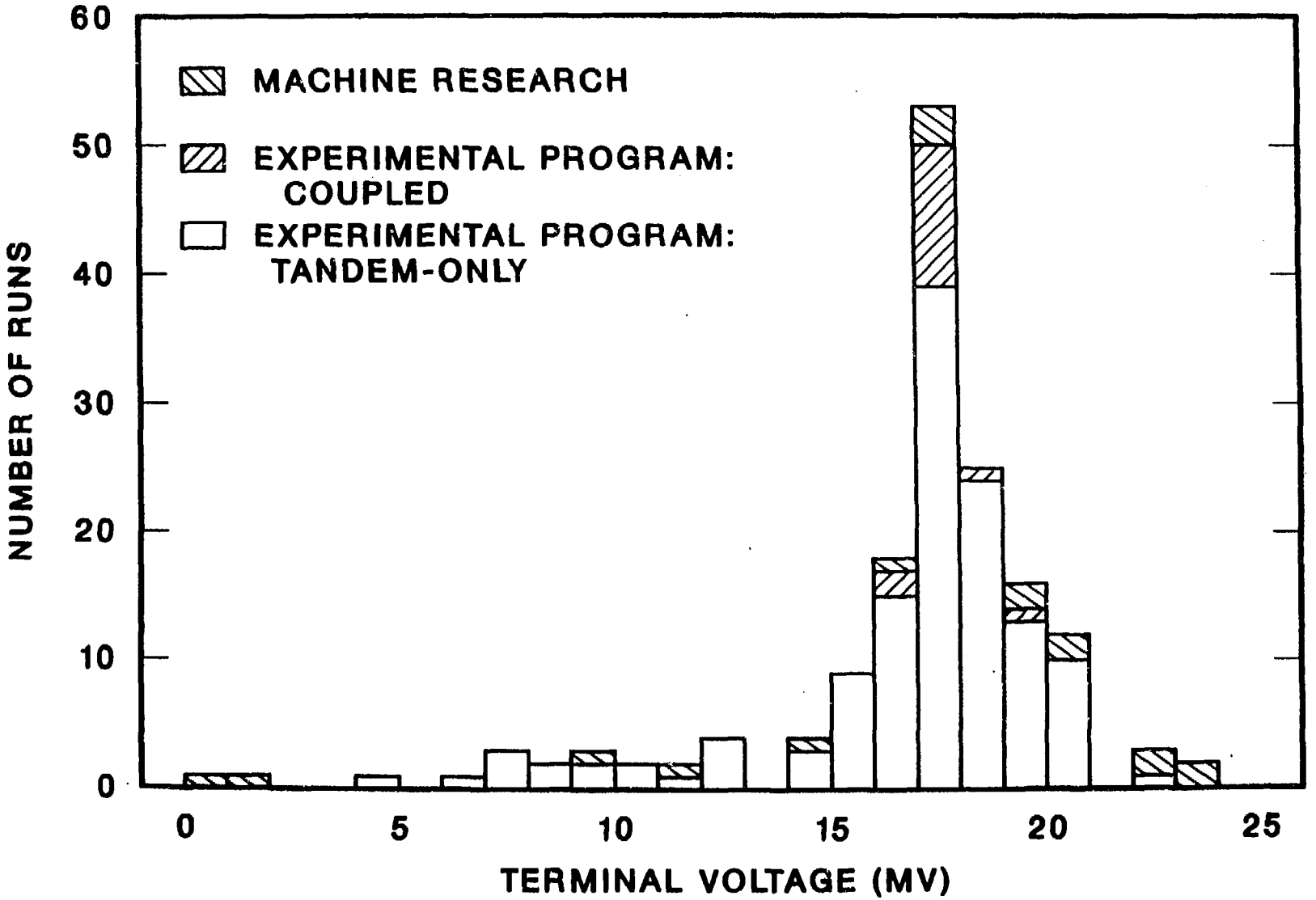



The number of runs in 1-MV-wide intervals is shown as a function of tandem accelerator terminal potential for the period October 1, 1985, through September 30, 1986.

# TANDEM ACCELERATOR DEVELOPMENT

DEVELOPMENT OF THE TANDEM ACCELERATOR HAS CONTINUED OVER THE PAST SEVERAL YEARS. IMPROVEMENTS DURING THIS PERIOD INCLUDE:

- CONTROL SYSTEM COMPUTER HARDWARE UPGRADE (INCLUDING NEW CPUs AND INCREASED MEMORY CAPACITY)
- IMPROVED SOFTWARE FOR BOTH THE CONTROL SYSTEM OPERATING PROGRAM AND AIDS TO OPERATION
- A NEW CHOPPER/BUNCHER SYSTEM WHICH PROVIDES BOTH VARIABLE FREQUENCY BUNCHED BEAMS FOR ORIC INJECTION AND LOW BACKGROUND PULSED BEAMS FOR DIRECT USE IN THE EXPERIMENTAL PROGRAM
- CHARGING SYSTEM MODIFICATIONS TO IMPROVE RELIABILITY AND DIAGNOSTIC CAPABILITY

THESE AND OTHER IMPROVEMENTS ARE DESCRIBED IN MORE DETAIL IN OTHER PAPERS AT THIS CONFERENCE.

# NEGATIVE ION SOURCE DEVELOPMENT

A NEW ION SOURCE TEST FACILITY, WITH PROVISIONS FOR BOTH ION BEAM MASS ANALYSIS AND DC AND PULSED BEAM EMITTANCE MEASUREMENT, HAS BEEN COMMISSIONED. THIS FACILITY HAS BEEN IN ACTIVE USE FOR BOTH OPERATIONAL BEAM DEVELOPMENT AND ION SOURCE DEVELOPMENT.

A PROTOTYPE HIGH-CESIUM-PERVEANCE NEGATIVE ION SOURCE BASED ON THE USE OF AN ELLIPSOIDAL GEOMETRY CESIUM IONIZER HAS BEEN DESIGNED AND IS PRESENTLY UNDER EVALUATION. PRELIMINARY RESULTS INDICATE THAT THIS SOURCE IS SUPERIOR TO SOURCES EQUIPPED WITH SPHERICAL AND CYLINDRICAL CESIUM IONIZERS, ESPECIALLY FOR PRODUCING IONS FROM LOW SPUTTER RATE MATERIALS SUCH AS Nb AND FROM DIFFICULT IONS SUCH AS $Li^-$ AND $CaH^-$.

HIGHLIGHTS OF THIS WORK ARE DESCRIBED IN ANOTHER PAPER AT THIS CONFERENCE.

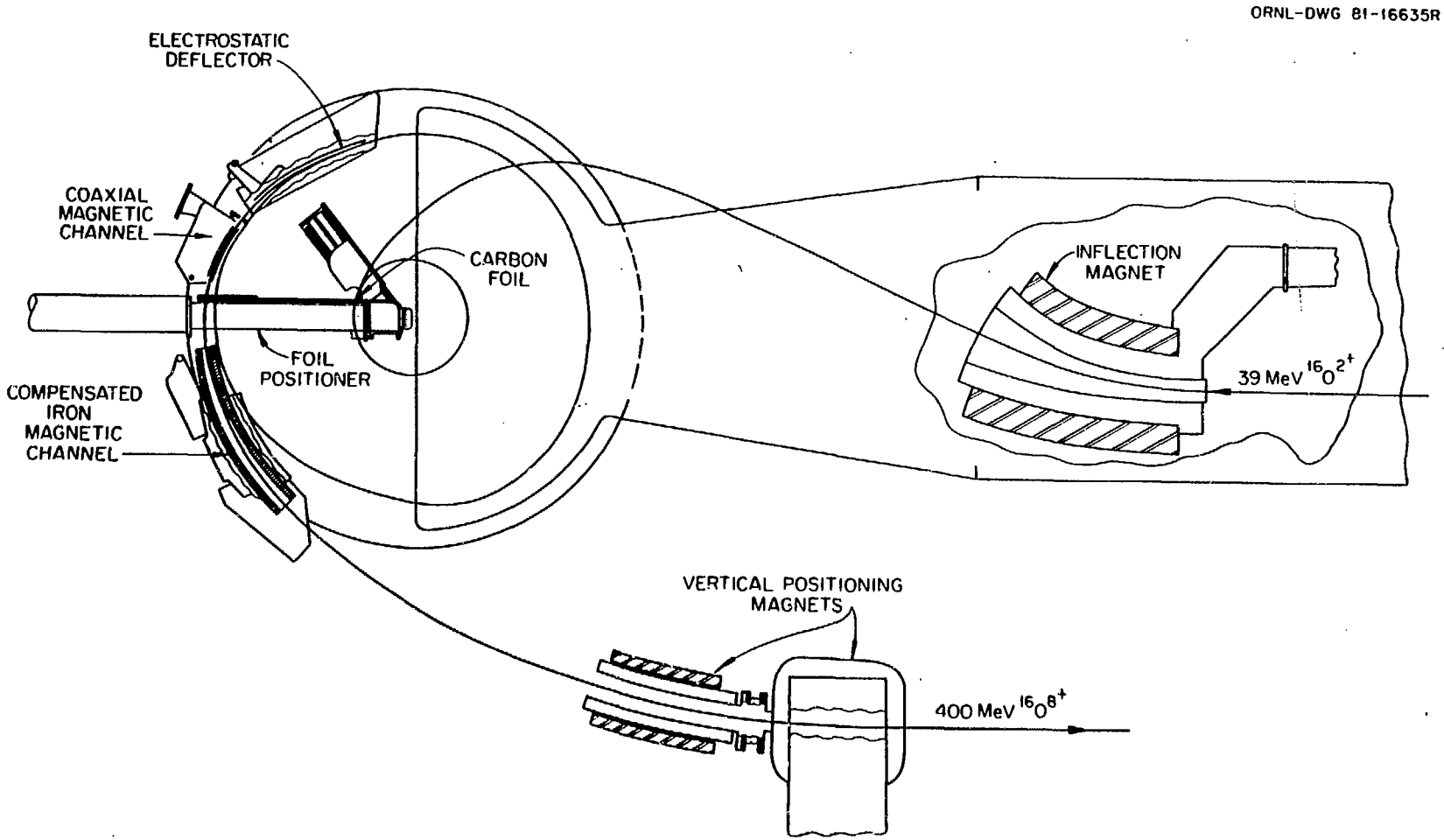
# ORIC DEVELOPMENT

USE OF THE ORIC AS AN ENERGY BOOSTER HAS PROVED TO BE AN EFFECTIVE MEANS OF PRODUCING A WIDE RANGE OF ENERGETIC ION BEAMS. TO DATE, 21 ION SPECIES HAVE NOW BEEN PROVIDED FOR THE FACILITY EXPERIMENTAL PROGRAM AT ENERGIES UP TO 1 GeV.

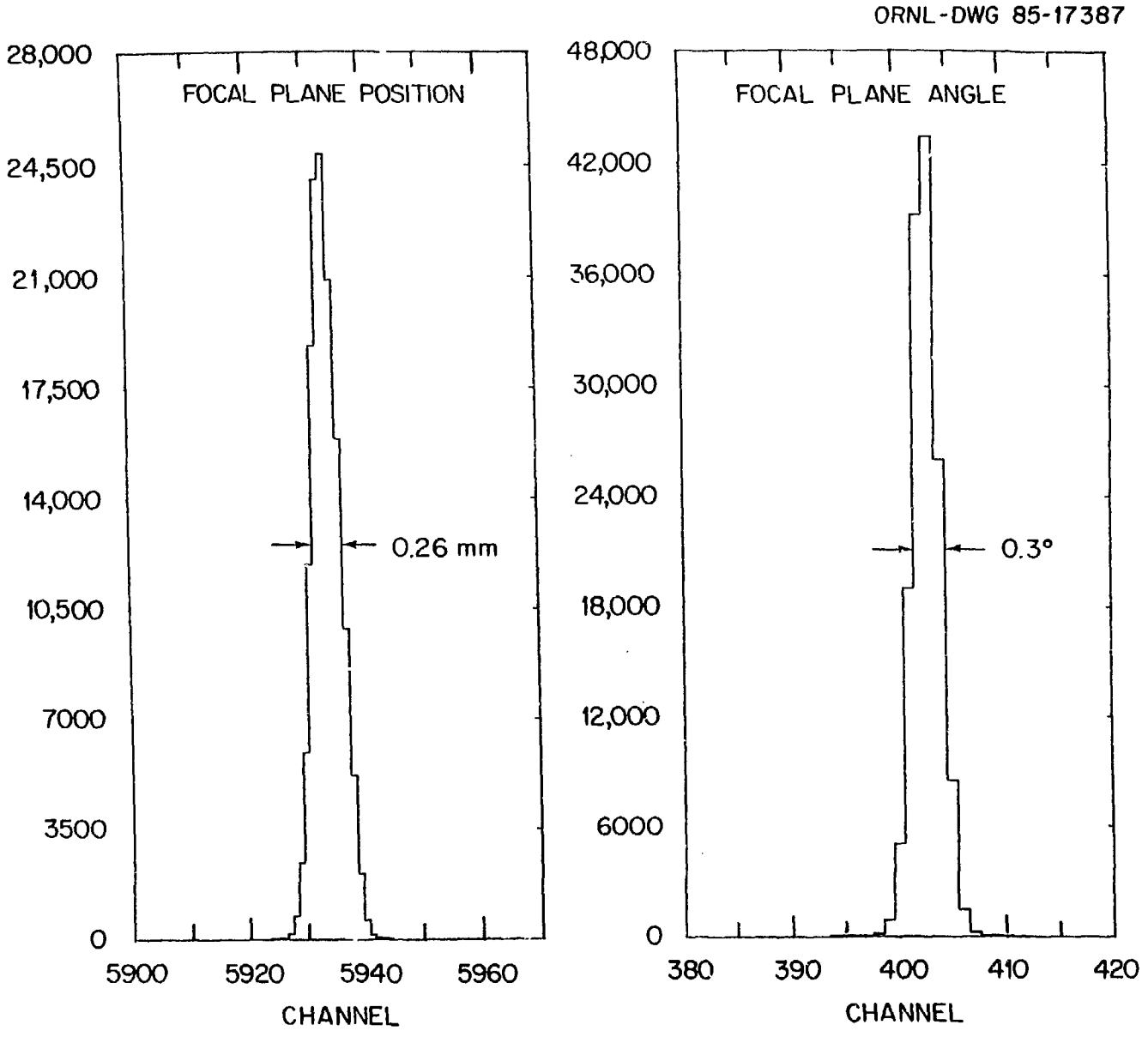
RECENT DEVELOPMENT ACTIVITIES FOR THE ORIC INCLUDE:

- INSTALLATION OF A NEW CONTROL SYSTEM COMPUTER
- MODERNIZATION OR REPLACEMENT OF ALL TRIM COIL AND HARMONIC COIL POWER SUPPLIES
- REDUCTION OF THE DEE APERTURE - TO ACHIEVE A FULL RF TUNING RANGE OF 6.7 - 20.1 MHz
- OVERHAUL AND REDESIGN OF THE RF SHORTING PLANE
- CONTINUED IMPROVEMENT OF BEAM SETUP PROGRAMS - SO THAT BEAM DEVELOPMENT TIME IS NO LONGER NEEDED

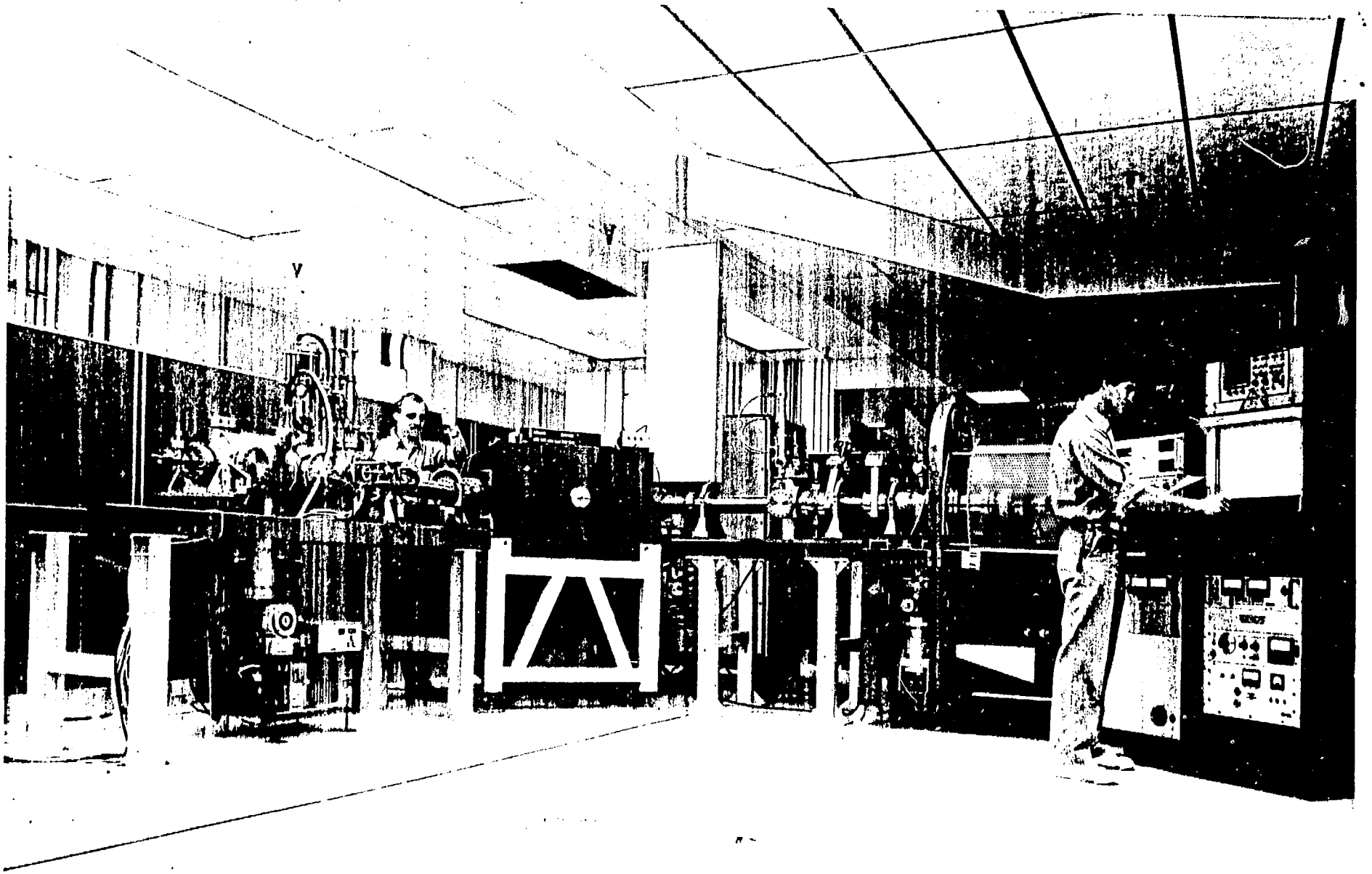
DETAILS OF COUPLED OPERATION OF THE TANDEM AND ORIC, ALONG WITH RECENT IMPROVEMENTS TO ORIC, ARE DISCUSSED IN A PAPER BY J. A. MARTIN, ET AL., PRESENTED AT THE ELEVENTH INTERNATIONAL CONFERENCE ON CYCLOTRONS AND THEIR APPLICATIONS, TOKYO, JAPAN, OCTOBER 13-17, 1986 (PREPRINTS AVAILABLE).




ORIC injection and extraction system used in coupled operation. Beam enters the cyclotron through the rf resonator, and is directed by the inflection magnet to the stripping foil which is placed at the radius and angle appropriate for acceleration of centered orbits. The inflection magnet can provide bend-angles of 17 to 37 degrees to accommodate a wide range of beam rigidities and stripping foil positions. In the example shown, 39 MeV $^{16}O^{2+}$ is injected and stripped to $^{16}O^{8+}$.




Dispersion matched beam transport between the ORIC analysing magnet and the Broad Range Spectrograph in conjunction with the use of vertical-drift-chamber focal plane detector allows excellent resolution to be achieved in the spectrograph. In this example, for which a 1 GeV $^{58}Ni$ beam was observed at $0^{o}$, the effective energy resolution was 1/6400 FWHM (dispersion: 600 keV/mm).



HHIRF Negative Ion Source Test Facility

## OPERATIONAL EXPERIENCE

SINCE THE BEGINNING OF ROUTINE OPERATION IN 1982, WE HAVE FOCUSED ON IMPROVED RELIABILITY AND OPERATIONAL EFFICIENCY. AS CAN BE SEEN IN THE TABLE BELOW, THIS EFFORT HAS RESULTED IN MORE RELIABLE AND EFFICIENT OPERATION.

HHIRF ACCELERATOR UTILIZATION 4/1/87

| | FY 83*[1] | FY 84 | FY 85 | FY 86 | 1st Half FY 87 |
|---|---|---|---|---|---|
| BEAM PROVIDED FOR RESEARCH (HOURS)*[2] | 3249*[3] | 3172 | 3904 | 4162 | 1864 |
| FRACTION OF TANDEM ACCELERATOR "UP TIME"*[4] HOURS PROVIDED FOR RESEARCH | 57% | 64% | 67% | 70% | 65% |
| UNSCHEDULED MAINTENANCE (TANDEM + ORIC) (HOURS) | 1470 | 1882 | 1013 | 529 | 243 |
| NUMBER OF INTERRUPTIONS OF EXPERIMENTAL PROGRAM BY UNSCHEDULED TANK OPENINGS | 6 | 5 | 7 | 3 | 1 |
| COUPLED OPERATION MACHINE RESEARCH (HOURS) | 161 | 130 | 73 | 0 | 1 |

*1 OCTOBER 1982, THROUGH SEPTEMBER 1983 (FOR EXAMPLE).
*2 BEAM PROVIDED FOR RESEARCH WAS REDUCED IN FY 83 AND FY 84 AND WILL BE REDUCED IN FY 87 BY WORK DESIGNED TO IMPROVE TANDEM ACCELERATOR VOLTAGE PERFORMANCE.
*3 INCLUDES 280 H OF ORIC STAND-ALONE OPERATION.
*4 UP TIME = RESEARCH + BEAM TUNING + MACHINE RESEARCH.

3/24/87

# HHIRF BEAMS PROVIDED FOR SCHEDULED EXPERIMENTS

| BEAM | MAXIMUM ENERGY (MeV) | MODE† |
|---|---|---|
| $^{1}H$ | 25 | T |
| $^{7}Li$ | 128 | T,C |
| $^{9}Be$ | 158 | C |
| $^{10}B$ | 168 | C |
| $^{11}B$ | 169 | T,C |
| $^{12}C$ | 300 | T,C |
| $^{13}C$* | 67 | T |
| $^{16}O$ | 405 | T,C |
| $^{17}O$* | 381 | C |
| $^{18}O$* | 352 | T,C |
| $^{19}F$ | 190 | T |
| $^{24}Mg$ | 178 | T,C |
| $^{25}Mg$ | 132 | T |
| $^{26}Mg$* | 160 | T |
| $^{27}Al$ | 196 | T |
| $^{28}Si$ | 333 | T,C |
| $^{29}Si$ | 150 | T |
| $^{30}Si$ | 264 | T |
| $^{32}S$ | 725 | T,C |
| $^{34}S$* | 155 | T |
| $^{36}S$* | 123 | T |
| $^{35}Cl$ | 692 | T,C |
| $^{37}Cl$ | 187 | T |
| $^{40}Ca$ | 227 | T |
| $^{44}Ca$* | 201 | T |
| $^{45}Sc$ | 200 | T |

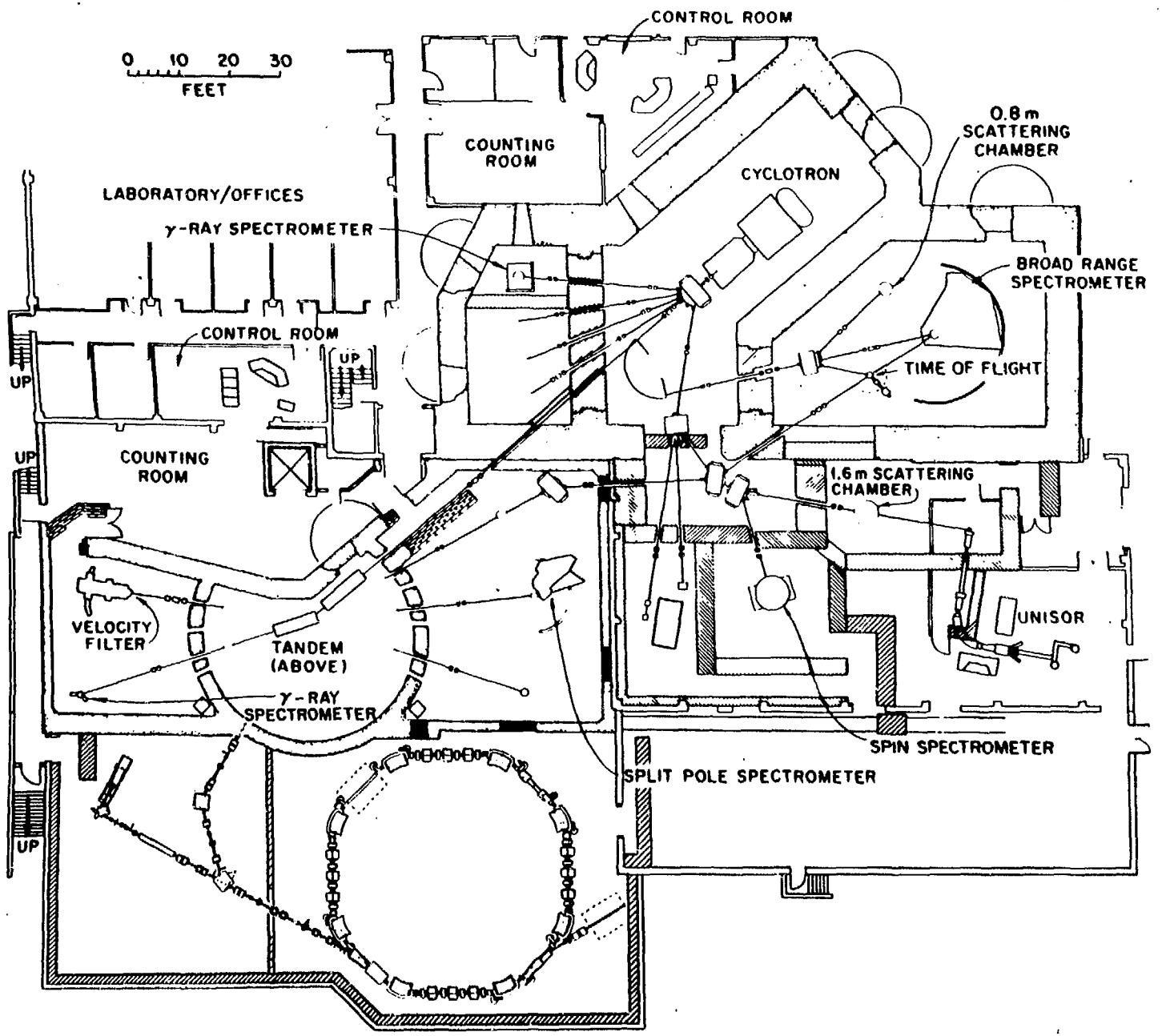
| BEAM | MAXIMUM ENERGY (MeV) | MODE† |
|---|---|---|
| $^{46}Ti$* | 280 | T |
| $^{48}Ti$ | 581 | T,C |
| $^{49}Ti$* | 235 | T |
| $^{50}Ti$* | 250 | T |
| $^{51}V$ | 220 | T |
| $^{52}Cr$ | 230 | T |
| $^{56}Fe$ | 842 | T,C |
| $^{58}Ni$ | 1010 | T,C |
| $^{60}Ni$ | 228 | T |
| $^{63}Cu$ | 189 | T |
| $^{65}Cu$ | 290 | T |
| $^{64}Ni$* | 290 | T |
| $^{74}Ge$ | 306 | T |
| $^{76}Ge$ | 305 | T |
| $^{79}Br$ | 1000 | C |
| $^{81}Br$ | 604 | C |
| $^{82}Se$ | 295 | T |
| $^{90}Zr$ | 395 | T |
| $^{93}Nb$ | 276 | T |
| $^{107}Ag$ | 374 | T |
| $^{109}Ag$ | 733 | C |
| $^{116}Cd$* | 499 | C |
| $^{116}Sn$* | 684 | T,C |
| $^{120}Sn$ | 240 | T |
| $^{150}Nd$* | 760 | C |
| $^{197}Au$ | 591 | T |
| $^{238}U$ | 119 | T |

† T = Tandem alone; C = Coupled mode.

* Beam provided with separated isotope probe sample.

## FUTURE DEVELOPMENT

OUR PRINCIPAL FOCUS FOR SHORT-TERM DEVELOPMENT OF THE FACILITY IS A PROPOSED SYNCHROTRON-COOLING-STORAGE RING WITH THE ACRONYM HISTRAP (HEAVY ION STORAGE RING FOR ATOMIC PHYSICS). HISTRAP IS OPTIMIZED TO ACCELERATE, DECELERATE, AND STORE BEAMS OF HIGHLY CHARGED VERY-HEAVY IONS AT ENERGIES APPROPRIATE FOR ADVANCED ATOMIC PHYSICS RESEARCH. THE RING IS DESIGNED TO ALLOW STUDIES OF ELECTRON-ION, PHOTON-ION, ION-ATOM, AND ION-ION INTERACTIONS. AN ELECTRON COOLING SYSTEM WILL PROVIDE ION BEAMS WITH SMALL ANGULAR DIVERGENCE AND ENERGY SPREAD FOR PRECISION SPECTROSCOPIC STUDIES AND ALSO IS NECESSARY TO ALLOW THE DECELERATION OF HEAVY IONS TO LOW ENERGIES. HISTRAP WILL BE INJECTED WITH IONS FROM EITHER THE EXISTING 25-MV TANDEM ACCELERATOR OR FROM A DEDICATED ECR SOURCE AND 250 keV/NUCLEON RFQ LINAC. THE RING WILL HAVE A MAXIMUM BENDING POWER OF 2.0 T·m AND HAVE A CIRCUMFERENCE OF 46.8 m.




Plan View of the proposed HISTRAP facility as an addition to the HHIRF. The storage ring in the lower left will be injected with ions from either the existing 25-MV tandem accelerator or from a dedicated ECR source and RFQ preaccelerator.