CONF-820440--1

A STATUS REPORT ON THE HOLIFIELD HEAVY ION RESEARCH FACILITY

CONF-820440--2
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I. Introduction

At Oak Ridge we are now in the final stages of completion of our heavy ion project. The facility, shown in Fig. 1, has as its center-piece the 25MV Pelletron built by National Electrostatics Corporation. At the time of this writing (March 1982), the only tasks remaining for completion are the acceptance tests with beam to be performed at the design rating of 25MV on terminal. Along with the 20MV machine at Tokai and the 20MV machine at Buenos Aires, this trio of accelerators represents the new generation of Super-tandems presently in various stages of completion by NEC. In this paper, I shall review briefly some of the history of the work on the 25MV accelerator at Oak Ridge. In doing so, I will try to bring out those points that I feel are most illustrative of what may be expected as installation proceeds on the machine here in Argentina. Finally, as time permits, I'll discuss some of the other features of the Holifield Facility.

*Research sponsored by the Basic Energy Sciences Division, U.S. Department of Energy under contract W-7405-eng-26 with the Union Carbide Corporation.

II. The 25MV Pelletron

A. The High Voltage Generator

We chose to have the tandem for Oak Ridge built in a "folded" configuration, unlike the conventional linear column structure of most tandem accelerators. The resultant structure is indicated schematically in Fig. 2. The column structure is 3.3m (11 ft) in diameter and 18.9m high, topped with a 4.8m-high terminal shell. The column contains 27 of the standard 0.6m, 1MV, NEC modules. These are separated by two major dead sections into 3 sets of 9 units each. In turn, each of these thirds is divided once by a minor dead section. Pumps and electron traps are provided in all dead sections.

The pressure vessel housing the column structure is approximately 10m in diameter and 30m high. It is designed for operating pressures up to about 0.7 MPa (100 psig).

A view of the 180-deg magnet in place atop the column is shown in Fig. 3. A view looking down on the completed column structure, after installation of the top portion of the terminal shell, is shown in Fig. 4. The installation of the column structure, including charging chains and power transmission shafts but not the acceleration tubes, was completed in April, 1979.

The following month, May 1979, voltage tests on the column structure were run. These went quite smoothly and very quickly—requiring only about four days. A summary of the results of these tests is presented graphically in Fig. 5. Note that, at the higher pressures, the maximum breakdown voltage does not appear to level off with breakdown number. Instead, the voltage appears to be still rising toward the end of the test and exhibiting a conditioning behavior. The tests were terminated at this point because of uncertainties about the probability of spark-induced damage to the column components and since the voltage holding capabilities of the column had been sufficiently demonstrated.

Examination of the column following these tests revealed evidence of 42 spark "hits" that were rather uniformly distributed over the terminal shell and upper portion of the column. Areas of discoloration associated with these hits ranged up to about 2cm in diameter with some roughness of metal noticeable at the center of these spots. No evidence was observed that would suggest any "restriking" to the same spot due to this roughened surface. Our conclusion is that the column structure is able to withstand very well the effects of sparks at full design potential and beyond (Fig. 6).

B. Operation with Beam

The remaining components of the accelerator were installed in the column during the period from June to December, 1979. At this time, NEC began preparing the accelerator for tests with beam. However, a number of small, but time-consuming problems such as water leaks and vacuum leaks, delayed the first acceleration of beam through the machine until May, 1980. On May 12, a beam of oxygen ions was accelerated through the machine at a terminal potential of 15.5MV. The next few weeks were spent in utilizing the beam to perform a careful calibration of the high-energy beam analyzing magnet. In July and August 1980, system acceptance tests were performed at 7.5MV and at 17.5MV on terminal. These tests are summarized in Table I.

Following these tests, major maintenance was performed on the accelerator to prepare it for tests at higher terminal potentials. During this period, NEC chose to replace the closed corona grading system with an open corona system. All subsequent operation of the machine has been with this open corona system. Conditioning of the accelerator was resumed in October, 1980, and proceeded until early December. It was discovered at that time that eight of the modular sections of acceleration tube had been damaged. This damage, in the form of electrode material deposited on the inner surface of the tube insulator, was attributed by NEC to improper spacing of the annular spark gaps at the end of the tube sections. The damaged tube sections were replaced and all of the end spark gaps were readjusted. No further damage of acceleration tubes has been experienced.

In January, 1981, we had a brief use of the accelerator to test our existing cyclotron as a booster accelerator. This will be described in more detail below. In the period February through April of 1981, NEC continued to work on conditioning the machine to higher gradients. Maximum potentials achieved during this period were in the range of 22MV.

Table I. Operation Chronology

May 1979	- Column voltage tests
May 1980	- First beam through accelerator system, $^{16}O^{6+}$ at 15.5 MV on terminal.
July-August 1980	- System acceptance tests performed
	$^{127}I^{10+}$, 7.5 MV, foil stripper, 10 pnA for 10 min.
	$^{127}I^{4+}$, 7.5 MV, gas stripper, 1 pμA for 60 min.
	$^{127}I^{6+}$, 17.5 MV, gas stripper, 1 pμA for 60 min.
	$^{127}I^{13+}$, 17.5 MV, foil stripper, 10 pnA for 10 min.
January, 1981	- Successful use of ORIC as a booster accelerator, 401 MeV $^{16}O^{8+}$.
June-November 1981	- Operation of facility for experimental programs
March, 1982	- Operation for experiments
May, 1982	- Planned start of full-time operation for experiments.

In May, 1981, we reached an agreement with NEC for Oak Ridge to operate the accelerator for six months for the experimental program. During this period, beams were provided to some twelve experimental programs with the accelerator operating at terminal potentials up to 19MV. A summary is given in Table II.

In November, 1981, NEC returned to complete various mechanical tasks that remained inside the accelerator and on the gas handling system. Included in this work was installation of a complete set of new corona points. During this time, the acceleration tubes were not under vacuum for about six weeks. Various conditioning strategies were explored during January, 1982. The lowest third of the machine was subjected to glow discharge conditioning. The middle third was reconfigured by removing equipotential "stringers" to provide more decoupling of the acceleration tubes and the column. At this time, it is unclear whether any of these techniques will be beneficial.

This February, the accelerator was subjected to a very extensive bakeout. The present plans call for operation of the machine for experiments in March and for NEC to return in April to perform the final performance acceptance tests.

It is interesting to note that, even with the extensive February bake and the excellent acceleration tube base pressures achieved, the running period in March has been troubled by classical spark-induced deconditioning. This result only emphasizes the desirability of keeping the acceleration tubes under vacuum at all times. It seems clear that achieving the high potential capability

Table II. Experiments Run at HHIRF in the Period from June 17 to November 15, 1981

Experiment	Spokesman	Run Number	Target Station	Beam	
				Type	E(MeV)
TANDEM					
Coulomb Barrier Interactions of Ni+Ni: Elastic Transfer	K.A. Erb	H023	1.6-m chamber	^{60}Ni	175,225
m-Substate Study of Discrepancies in Single Nucleon Transfer Reactions on ^{208}Pb	J.L.C. Ford	H002	Split-pole magnet	^{11}B, ^{16}O	71
Lifetimes in the Backbending Region of ^{160}Yb using ORPSS	N.R. Johnson	H017	γ-ray spectrometer	^{48}Ti	204
In-Beam γ-Ray Spectroscopy Following $^{40}Ca(^{32}S)$ Reactions	A.V. Ramayya	H001	γ-ray spectrometer	^{32}S	120-160
Multi-particle Processes in $^{28}Si + ^{12}C$ and $^{28}Si + ^{24}Mg$ Systems	R.W. Novotny	0B03	1.6-m chamber	^{28}Si	120-150
Potential Energy Surfaces for Rotating Nuclei from Fission Studies	H.C. Britt	H024	1.6-m chamber	^{12}C	84-126
Nuclear High-Spin Properties from Continuum γ-Ray Studies	I.Y. Lee	9A02	γ-ray spectrometer	$^{25,26}Mg$	115-132
Incomplete Fusion and Deep-Inelastic Reactions of ^{19}F with ^{150}Nd	M. Jaaskelainen	H030	Spin spectrometer	^{19}F	162-190
Survey of the Entry Region and Gamma Decay Properties Near Limiting Angular Momentum	M.L. Halbert	H031	Spin spectrometer	^{50}Ti	230
COUPLED					
Excitation of Giant Multipole Resonances through Inelastic Scattering of Heavy Ions	F.E. Bertrand	H019	0.8-m chamber	^{16}O	400

of these new tandems will require very thorough and very patient conditioning of the acceleration tubes.

C. Ion Sources

A photograph of the injector platform for the Oak Ridge machine is shown in Fig. 7. The platform has been demonstrated successfully to its design rating of 500kV. In accelerator operation to date, typical operating voltage has tended to be of the order of 300kV.

Only one ion source is in place on the platform at a time. Each source is mounted on a self-aligning pump module to allow rapid replacement or change of source (1 to 2 hour change time). One such source module can be seen in the foreground of Fig. 7.

The ion source most utilized during the period of running for experiments has been the ORNL modified version of the Aarhus negative ion source. One of the exciting results from this early running experience is the ability to produce large currents of many ion species with this source. The source, as modified by Gerald Alton, is shown schematically in Fig. 8. The source is a radial extraction geometry plasma discharge source with a negatively charged ($\sim$1000V) sputter probe mounted near the plasma boundary. The source is equipped with a cesium oven which provides the electron donor and the sputtering agent to act on the probe material. Arc support gases may be introduced when needed to provide appropriate molecular ion species.

The range of ions produced with this source during our period of operation for experiments can be seen from Table II. Of particular significance was the production of large (>10 uA) beams of MgH^- and MgH_3^- from this source when using a MgCu alloy probe and hydrogen support gas. Microampere beams of ^{25}Mg and ^{26}Mg were obtained from a natural magnesium sample. Application of this same technique to produce calcium beams has not yielded such large currents but the results look promising and this work is continuing.

III. COUPLED ACCELERATOR OPERATION

As part of the present construction project, we have modified our existing cyclotron (ORIC) to provide a second stage of acceleration for ion beams from the Pelletron. The spatial relationship of the two accelerators is indicated in Fig. 9.

When the accelerators are operating in the coupled mode, the ion beam from the tandem is directed along a transfer line which terminates at the rear boundary of the ORIC rf resonator. The handling of the beam beyond this point is indicated in Fig. 10. An inflection magnet, located within the resonator, places the tandem-produced beam on a trajectory which is captured by the fringing field of the cyclotron magnet and brought tangent to an acceleration orbit. At this point, a special mechanism places a thin carbon foil to provide a sudden increase in the ion charge. The system is adjusted so that the ions stripped to the desired charge state are bent onto an acceleration orbit. From this point, the cyclotron accelerates the ion beam as in a conventional cyclotron.

The conversion of ORIC to booster accelerator status required considerable reworking of the accelerator electrode, trimming capacitors, etc., to accommodate the required inflection orbits. During some of this period, a major program of detailed measurement of the ORIC magnetic field was accomplished. Setup of the ORIC for booster operation is done utilizing computer orbit calculations based on these measurements. To date, these have proved very reliable.

Initial experience with coupled accelerator operation was obtained during a series of brief tests in January, 1981. The first beam produced was a 324 MeV beam of oxygen ions. As the test proceeded, this energy was raised to 400 MeV (25 MeV/nucleon). This is the maximum energy/nucleon achievable with the ORIC booster.

A scattering spectrum taken during the initial coupled operation tests is shown in Fig. 11. We are particularly excited about the excellent energy resolution achieved. It appears that it is possible to couple the machines in such a way that the high beam quality of the tandem (particularly the brightness and energy resolution) is preserved.

When serving as an injector for the cyclotron, the tandem operates in a pulsed beam mode. A double-drift, harmonic buncher, designed by Bill Milner and Norval Ziegler, is installed on the low-energy beam line following the mass analyzing magnet. The system bunches about 50-60% of the DC beam of the tandem within the rf "window" required for injection into the cyclotron. Typical operation would be a 1½-nsec-wide beam pulse every 100 nsec. Tuning of the buncher system to the cyclotron rf has proven to be straightforward with long-term stabilities demonstrated. Note that one of the experiments run during the June-November 1981 cycle used coupled operation.

IV. THE EXPERIMENTAL FACILITY

It requires more than operating accelerators to provide a vigorous research facility. The experimental devices present at the facility will, to a large extent, determine the research possibilities even more than the accelerators. This section reviews briefly some of the major experimental devices available at the Holifield Facility and the types of programs to which they apply.

A layout of the Holifield Facility is shown in Fig 12. This floor plan shows rather graphically the effects of adding piecewise to what was originally a two-room cyclotron facility.

Shown on the figure are two in-beam gamma-ray spectroscopy facilities--each on a line from one accelerator. There are also two magnetic spectrographs. The smaller of these is served only by beams from the tandem. Note, however, that the larger spectrograph can be reached by beams from either accelerator. This is also true of the time-of-flight facility located in the same room. Neither of the magnetic spectrographs at Oak Ridge is a modern state-of-the-art device. However, we decided that the availability of these older devices allowed us the opportunity to delay on such an expensive new device until the research programs using spectrographs are better defined. The extremely high resolution beams obtained from our first coupled operation run suggest that this is an area we will need to readdress shortly.

The time-of-flight system, Fig. 13, is a device on which much of the fission-fusion work is performed. The trend on this device is toward larger and larger area detectors to examine as much of the reaction sphere as possible in coincidence with evaporation residues.

Our 1.6m scattering chamber is shown in Fig. 14 during setup of an experiment involving some 44 detectors in and out of the reaction plane.

A powerful research tool for nuclear spectroscopy is the on-line isotope separator UNISOR. This device (Fig. 15) is operated by a consortium of 11 universities. The device has four active mass lines and often supports 3 to 4 simultaneous research efforts. At the present time a laser system is being installed on one of the mass lines. This will make possible fast-atomic-beam measurements to determine magnetic moments, electric moments, isomer shifts, etc., of very short-lived nuclear species far from the region of beta stability. UNISOR itself has been operating since 1973. The laser system is expected to be operational in the next few months.

Finally, one of our most spectactular pieces of new equipment, the spin spectrometer designed and built at Washington University under the direction of Demitrios Sarantites, is shown in Fig. 16. This closely packed array of 7" deep, equal-area NaI detectors is used to make total energy and gamma-ray multiplicity measurements on an event-by-event basis. For most experiments, two of the 72 elements are missing to allow an entrance and exit path for the ion beam.

Perhaps the spin spectrometer is an extreme example of the degree to which the data acquisition system of a facility must accommodate the tremendous extent of parameter space presented by the coming generation of highly complex experimental devices. In a typical experiment, in addition to the NaI detectors of the ball, there will often be a number of charge particle detector telescopes within the central scattering chamber and sometimes neutron detectors outside the ball. Such experimental arrangements can present over 180 digitized outputs to the data acquisition system to be sorted for each event. In order to handle this sort of dimensionality, the system developed at the Holifield Facility has been executed fully in terms of CAMAC. This not only provides large expansion capabilities but allows us to benefit from design and development work done for high-energy physics.

Our data acquisition system is based on three independent Perkin-Elmer 3320 CPU's each with 1MB of fast memory. This year, two of these will be upgraded to 2MB. A schematic representation of one-third of our system is shown in Fig. 17. Each of these systems, including those on-line taking data, operate under a multi-tasking system which supports a number of concurrent tasks. This system, which has now been operational for about a year, has proven very effective during the first round of experiments.

V. FUTURE PLANS

With the Holifield Facility set to become fully operational later this year, it may seem a bit premature to be looking toward major facility expansion. However, the realities of the funding process are such that we have to plan now for what we may hope to have operating by the beginning of the next decade.

When we are able to operate routinely with 25 MV on the terminal of the Pelletron, we will have the ion energy capabilities shown in Fig. 18. Our recent studies for facility expansion have centered on replacement of one existing booster cyclotron with a superconducting cyclotron patterned after the second stage being built for the double cyclotron facility at Michigan State University. Typically, such a booster would provide us more than an order of magnitude increase in available ion energy. The performance capabilities are shown in Fig. 19. Of particular interest to us with this system is the total amount of energy that may be introduced at the reaction site. There are now indications that there are some processes where the important parameter is this total energy and not the energy per nucleon. Recasting the previous figure in terms of total ion energy yields the performance curve shown in Fig. 20. Thus, it is seen that the proposed facility would be capable of introducing a very large energy impulse at the reaction site for a wide variety of ion-target combinations.

That, however, is something to consider for the long-term future. In the nearer term, our efforts will be directed toward working to achieve full performance from the 25MV Pelletron and to utilize these new ion beams for physics research. An important aspect of this will be the continued development of new experimental devices and adding new accelerator capabilities.

This year, one such new experimental device, a velocity filter/beam trap will be added on a new beam line from the tandem. This device, designed under the direction of Harold Enge and built at MIT, will enable fusion-type reaction studies to be performed with detection at zero degrees.

Currently under design is a new subnanosecond beam pulser and chopper system for the tandem. The implementation of this system will include installation of a rebuncher cavity in the high voltage terminal of the tandem. This system, which we hope to have completed in about two years, will then add time-of-flight experimental capability to the tandem. This is particularly important for studies involving the emission of neutrons.

As we work on our accelerator and experimental programs over the next few years, we should expect that there will be many areas of common interest and concern between our facility at Oak Ridge and yours at Buenos Aires. We have enjoyed the participation of your staff members at Oak Ridge over the past several years and we look forward to an increasing collaboration between our facilities that will be to our mutual benefit.

Figure Captions

Fig. 1. The Holifield Heavy Ion Research Facility at Oak Ridge National Laboratory.

Fig. 2. Schematic view of the 25MV folded tandem accelerator.

Fig. 3. The 180-degree magnet installed in the terminal of the 25MV Pelletron.

Fig. 4. A view looking down on the high voltage terminal and column of the 25MV Pelletron.

Fig. 5. Terminal voltage at breakdown as a function of spark sequence for the Oak Ridge column voltage tests. A Recent recalibration indicates the voltage scale shown on this figure is too high by about 8%.

Fig. 6. A terminal spark during column voltage tests.

Fig. 7. The injector platform at the Holifield Facility.

Fig. 8. The Oak Ridge version of the Aarhus negative ion source.

Fig. 9. Cross-sectional view of the Holifield Facility.

Fig. 10. The Oak Ridge cyclotron (ORIC) as modified for booster accelerator operation.

Fig. 11. A spectrum of oxygen ions scattered from a lead target taken during initial tests of coupled accelerator operation.

Fig. 12. Floor plan of the Holifield Facility.

Fig. 13. The time-of-flight facility.

Fig. 14. The 1.6m general purpose scattering chamber.

Fig. 15. The on-line isotope separator, UNISOR.

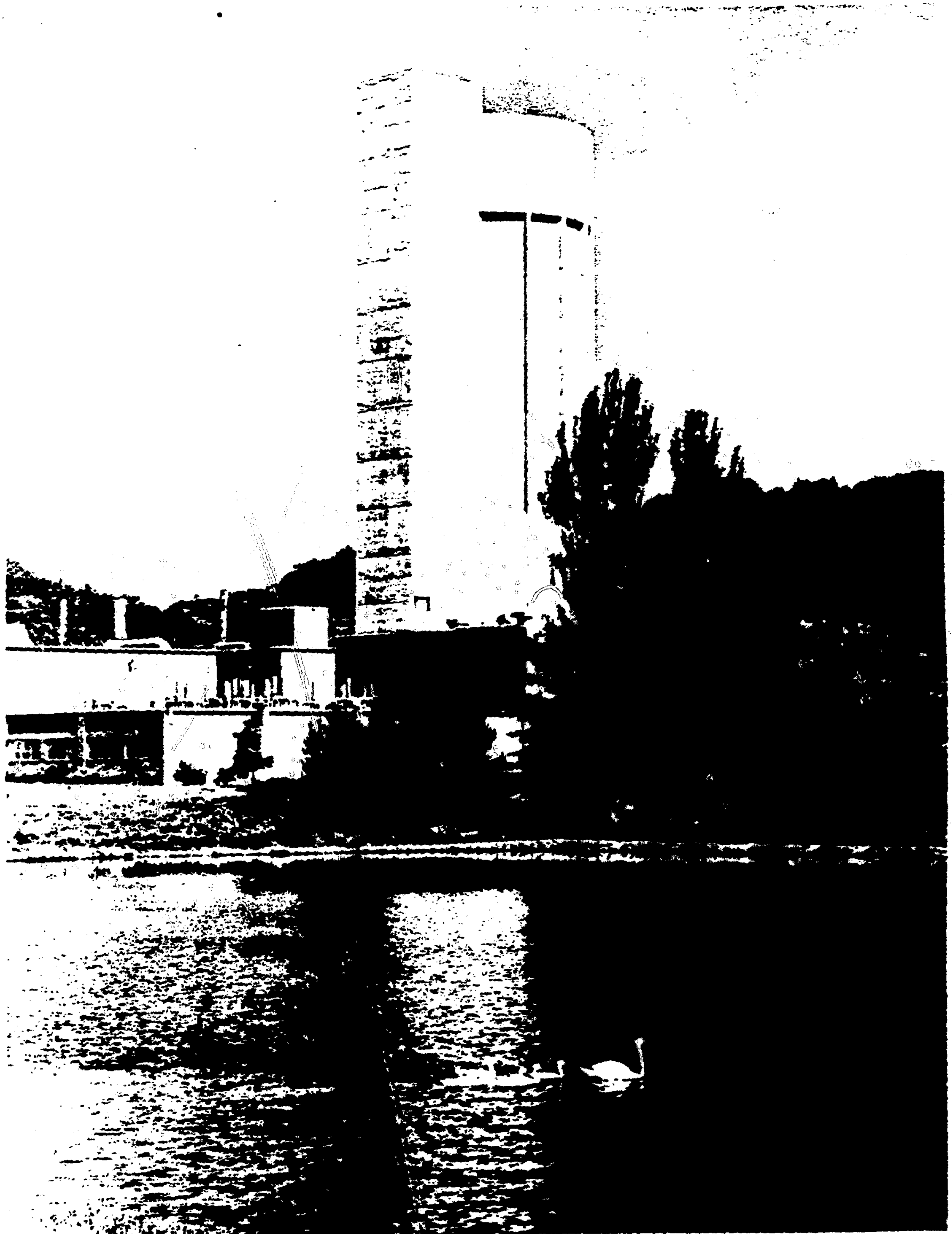
Fig. 16. The spin spectrometer.

Fig. 17. Schematic representation of one-third of the HHIRF data acquisition system.

Fig. 18. Ion energy performance capabilities of the present phase of the Holifield Facility.

Fig. 19. Increased performance capabilities provided by the proposed new booster accelerator.

Fig. 20. Total energy performance available from the proposed facility upgrade.



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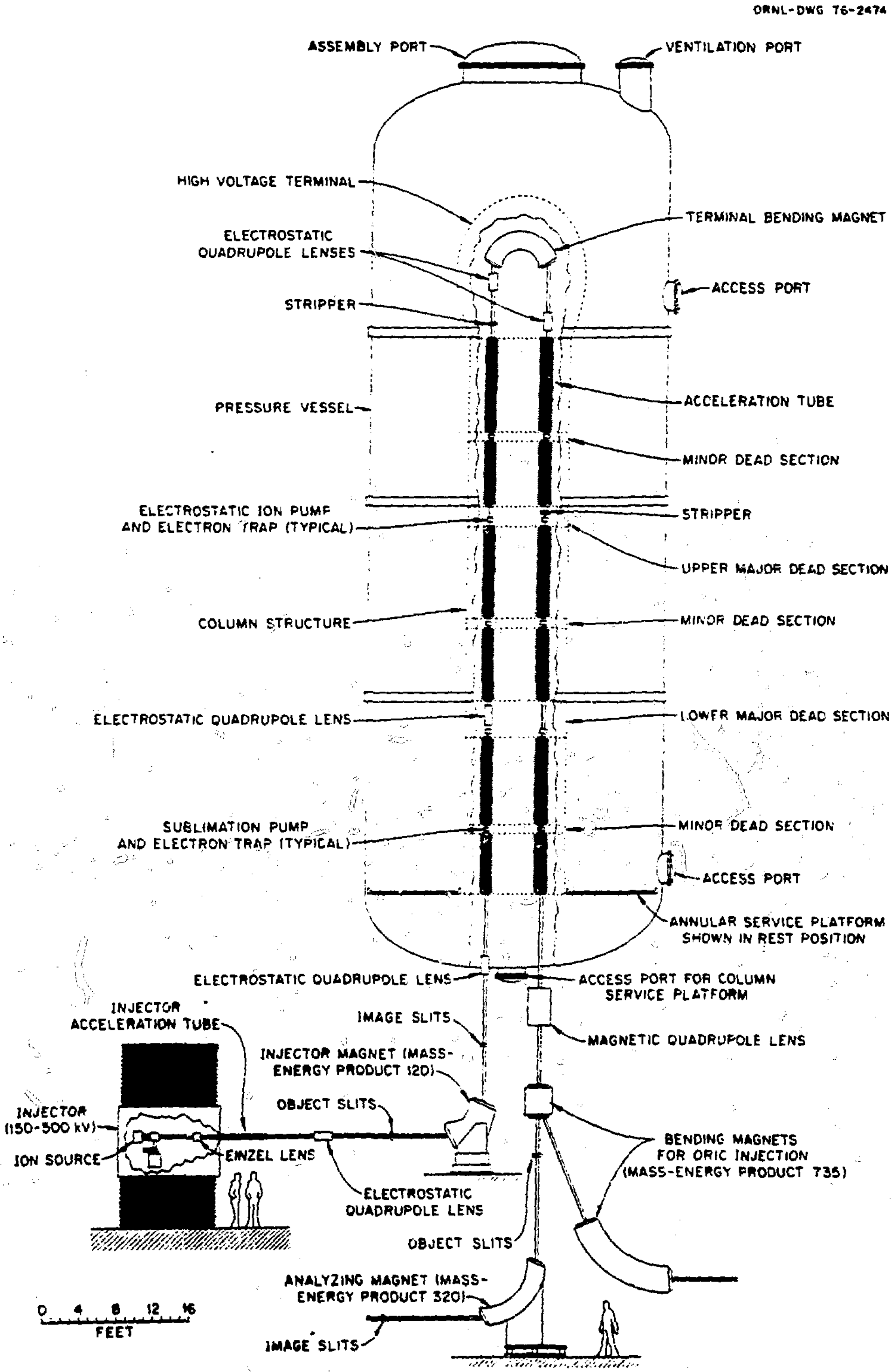

Fig. 2. Schematic view of the 25MV folded tandem accelerator.

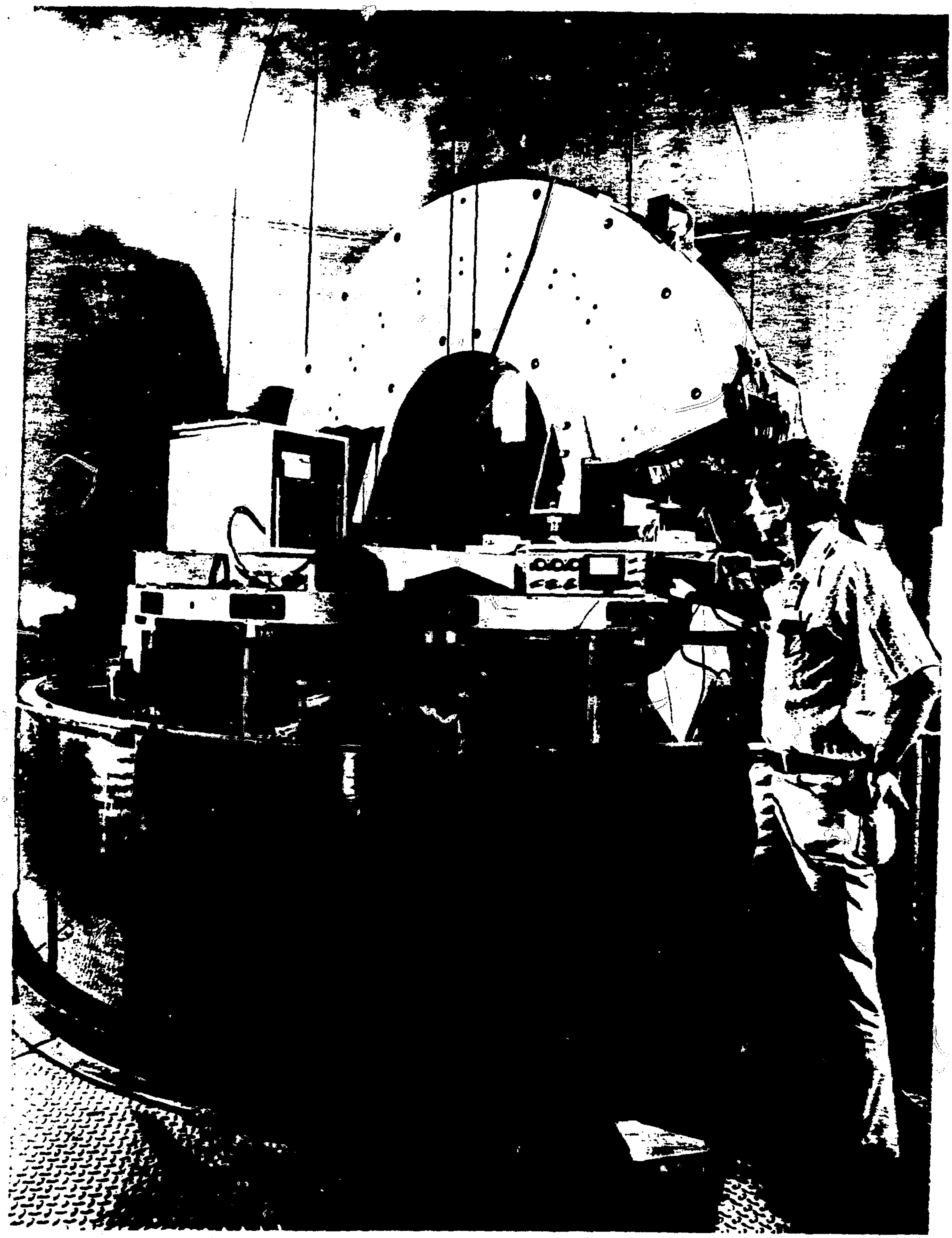

Fig. 3. The 180-degree magnet installed in the terminal of the 25MV Pelletron.

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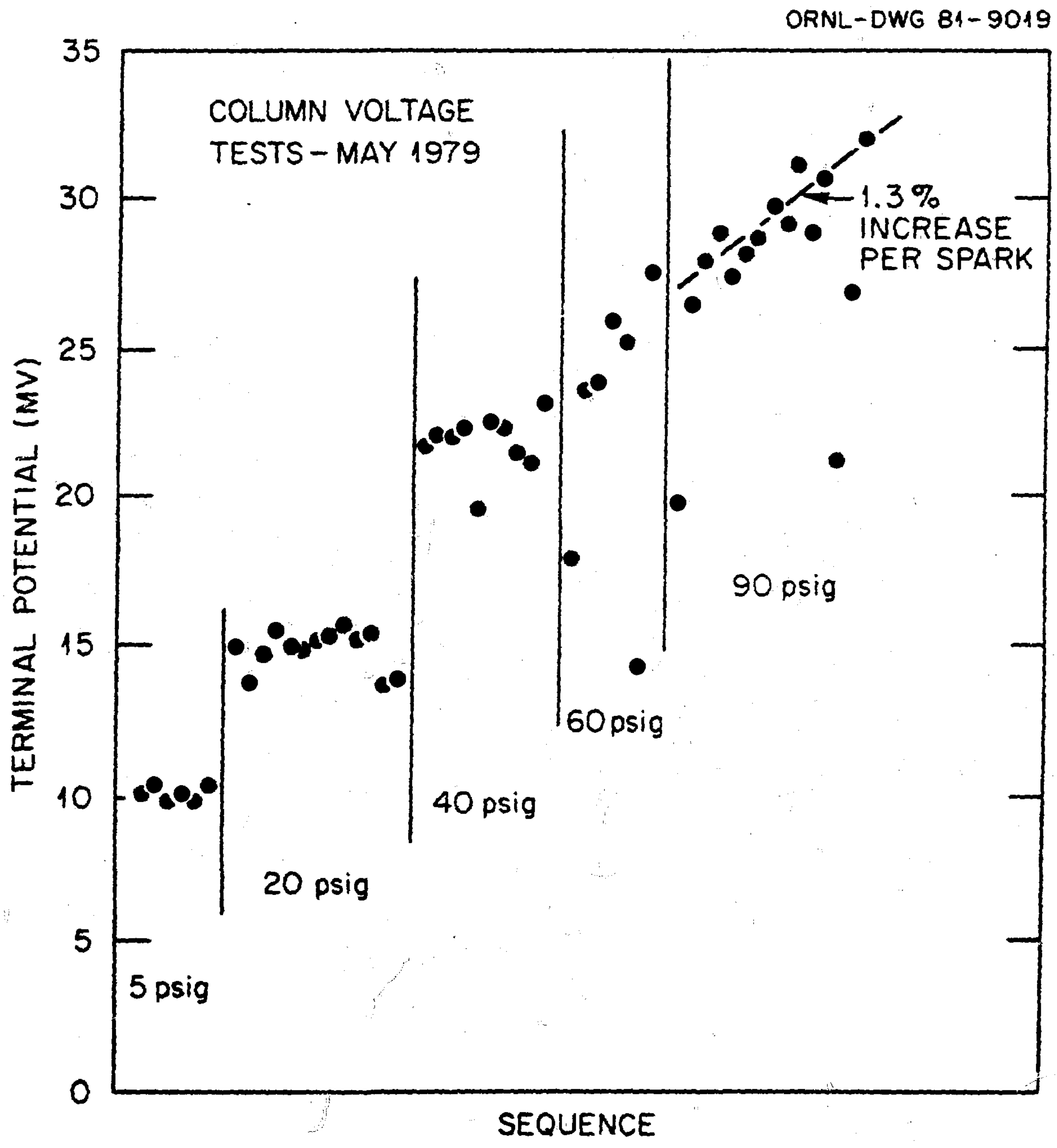

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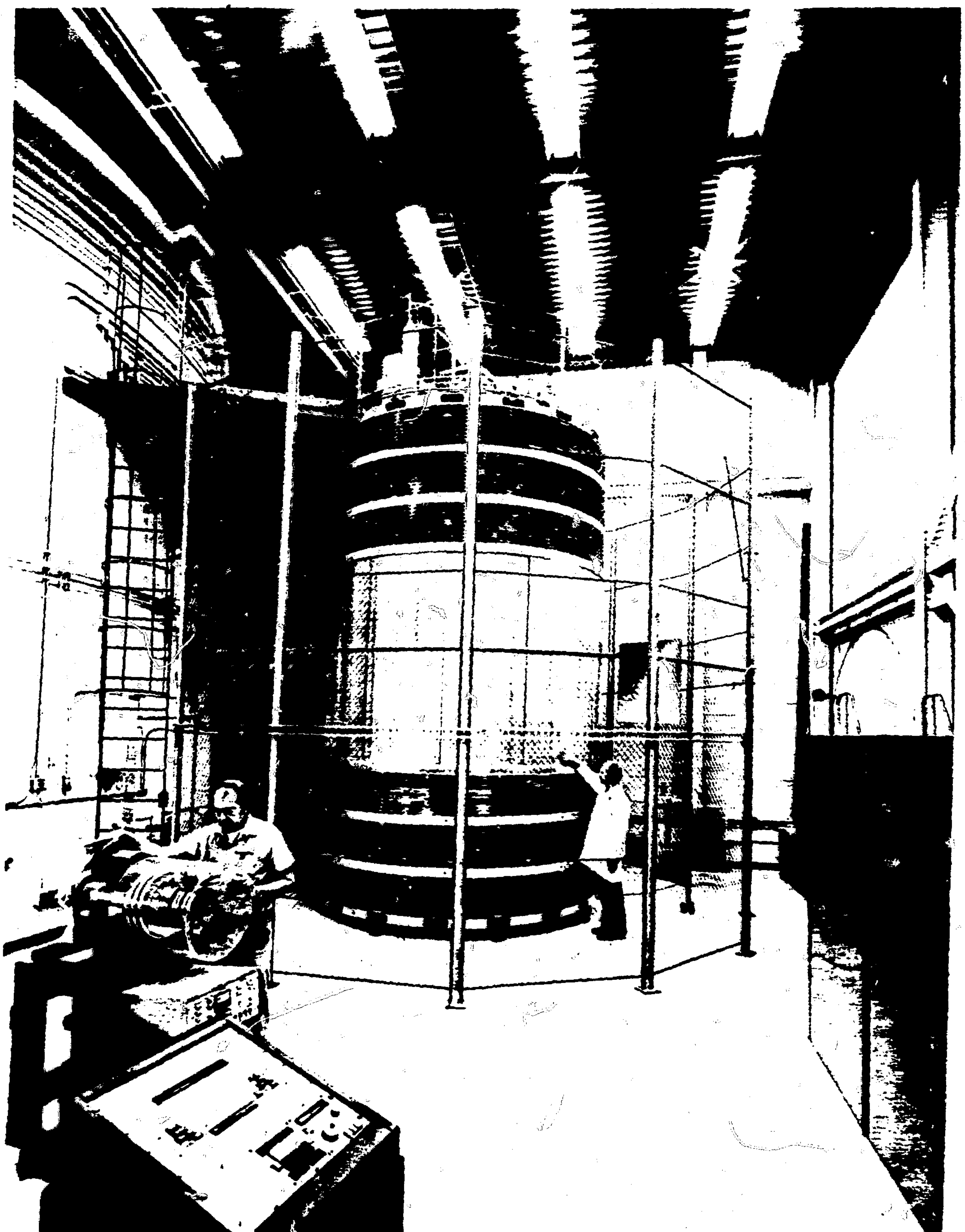

Fig. 7. The injector platform at the Holifield Facility.

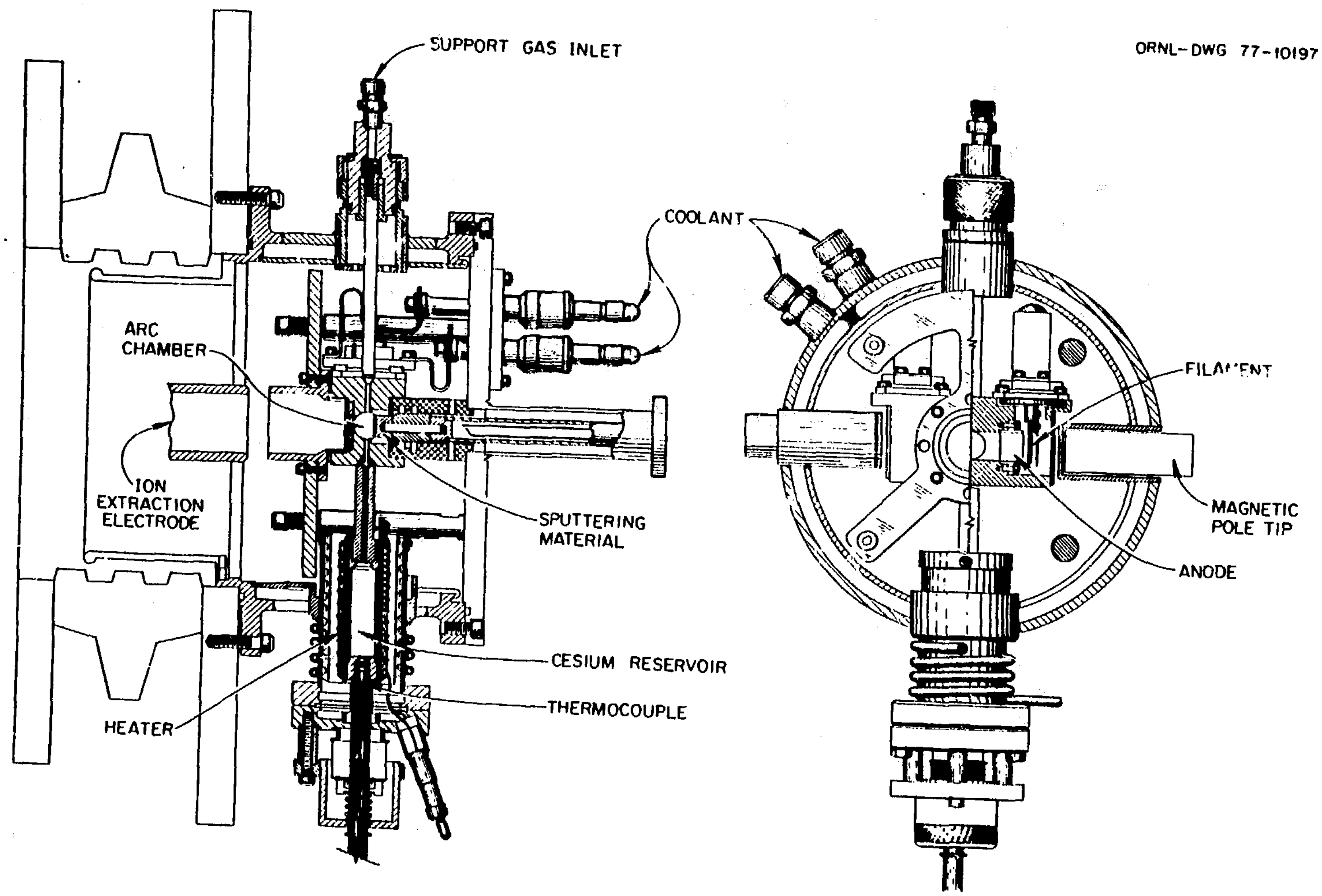

Fig. 8. The Oak Ridge version of the Aarhus negative ion source.

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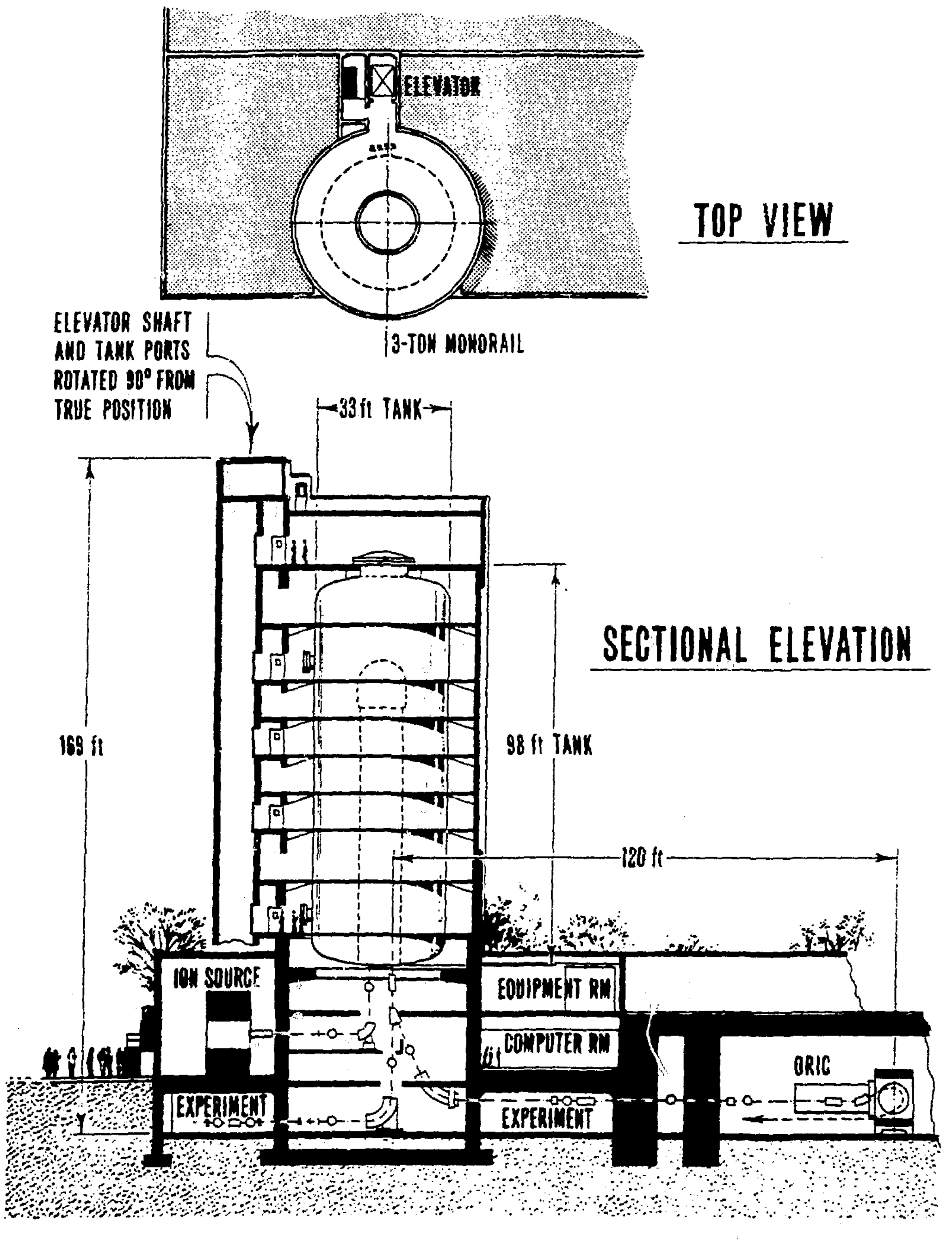

Fig. 9. Cross-sectional view of the Holifield Facility.

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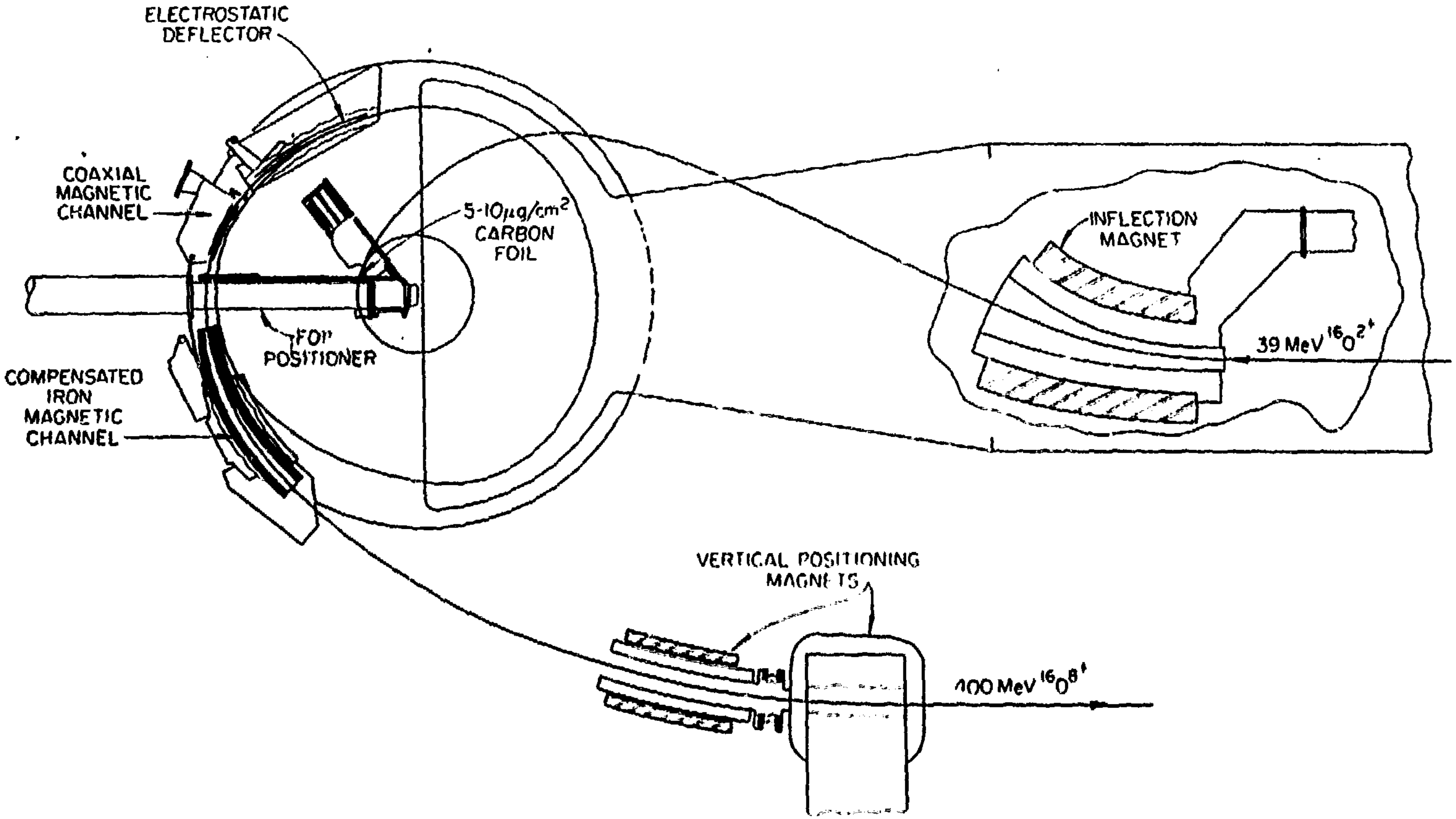

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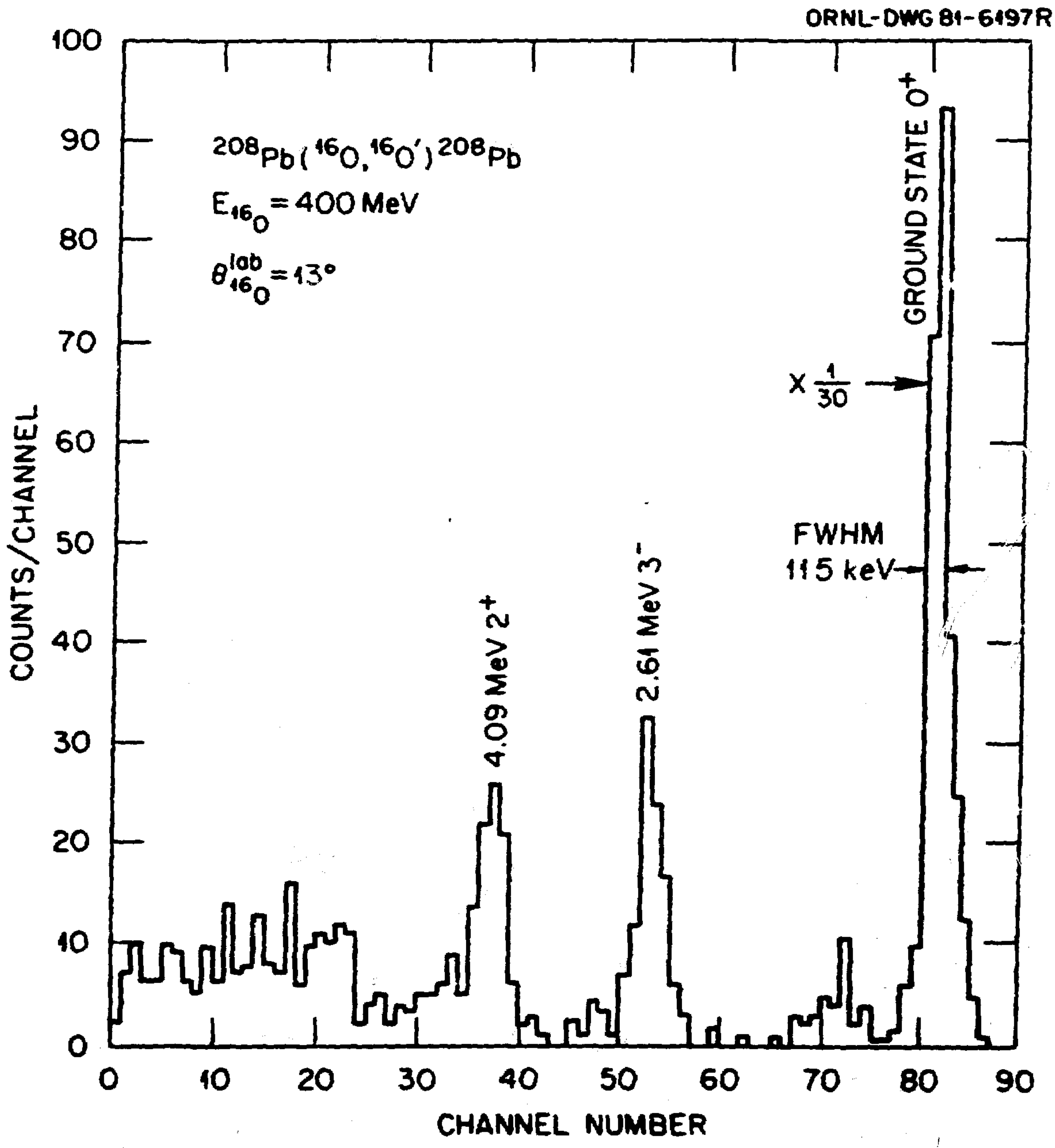

Fig. 11. A spectrum of oxygen ions scattered from a lead target taken during initial tests of coupled accelerator operation.

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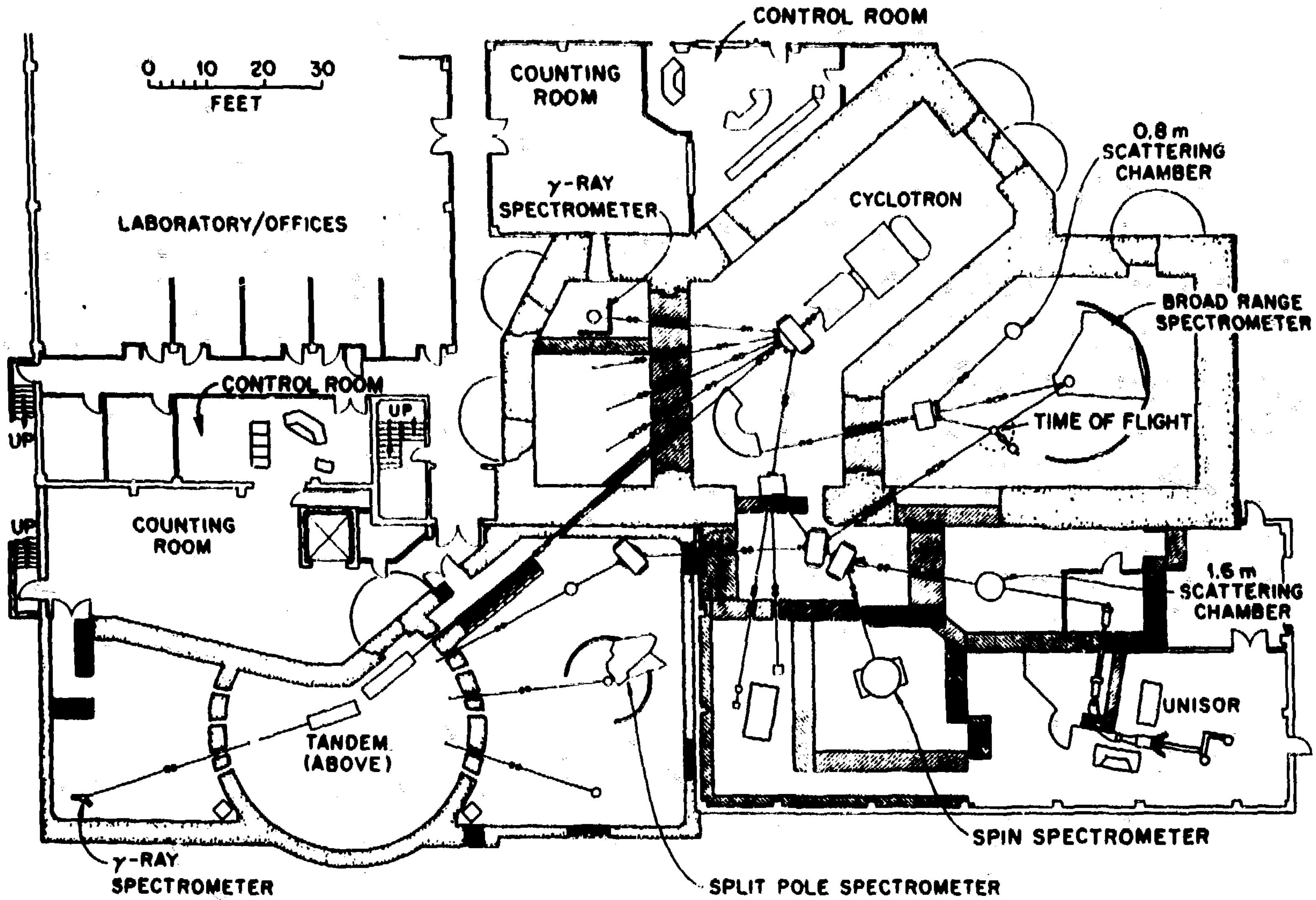
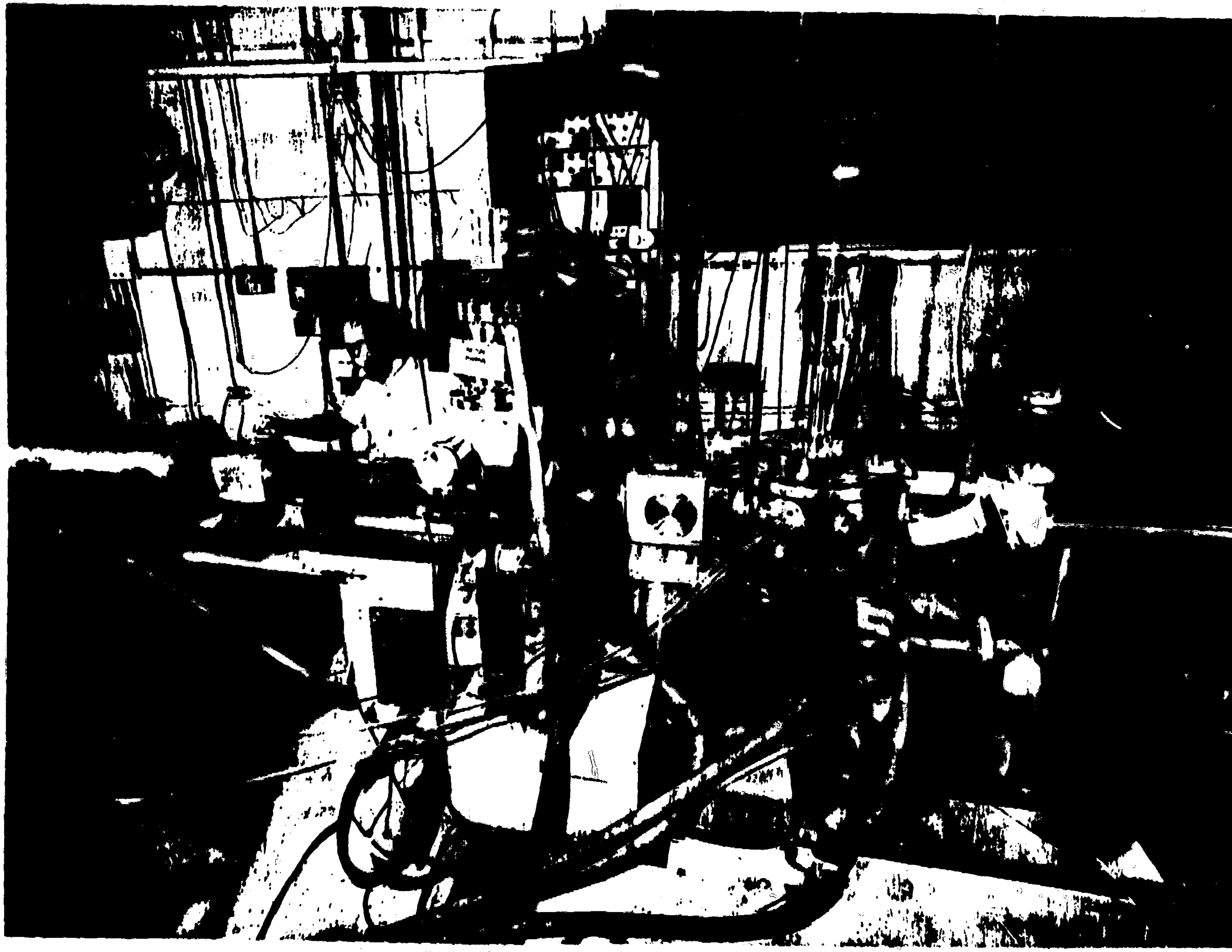


Fig. 12. Floor plan of the Holifield Facility.



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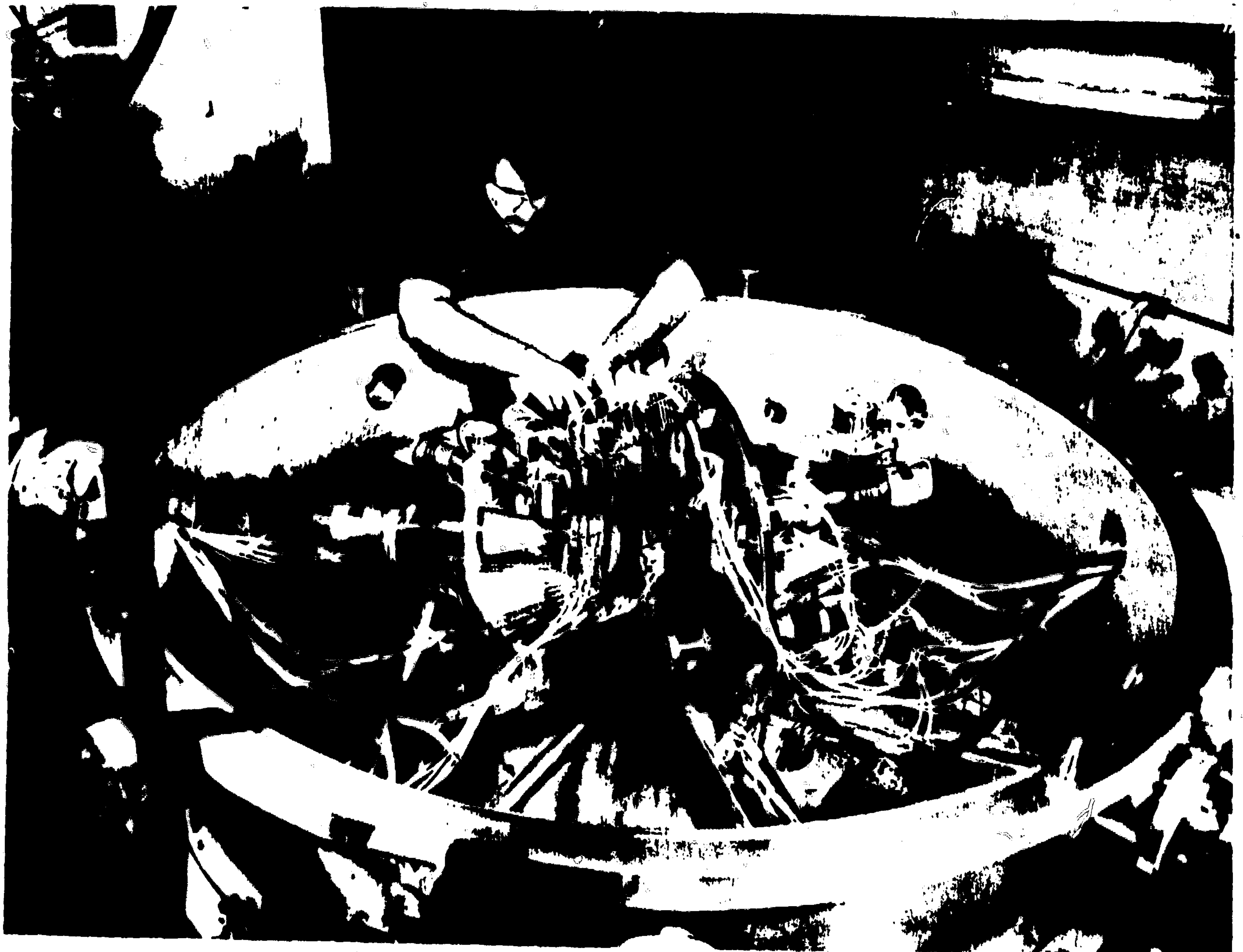

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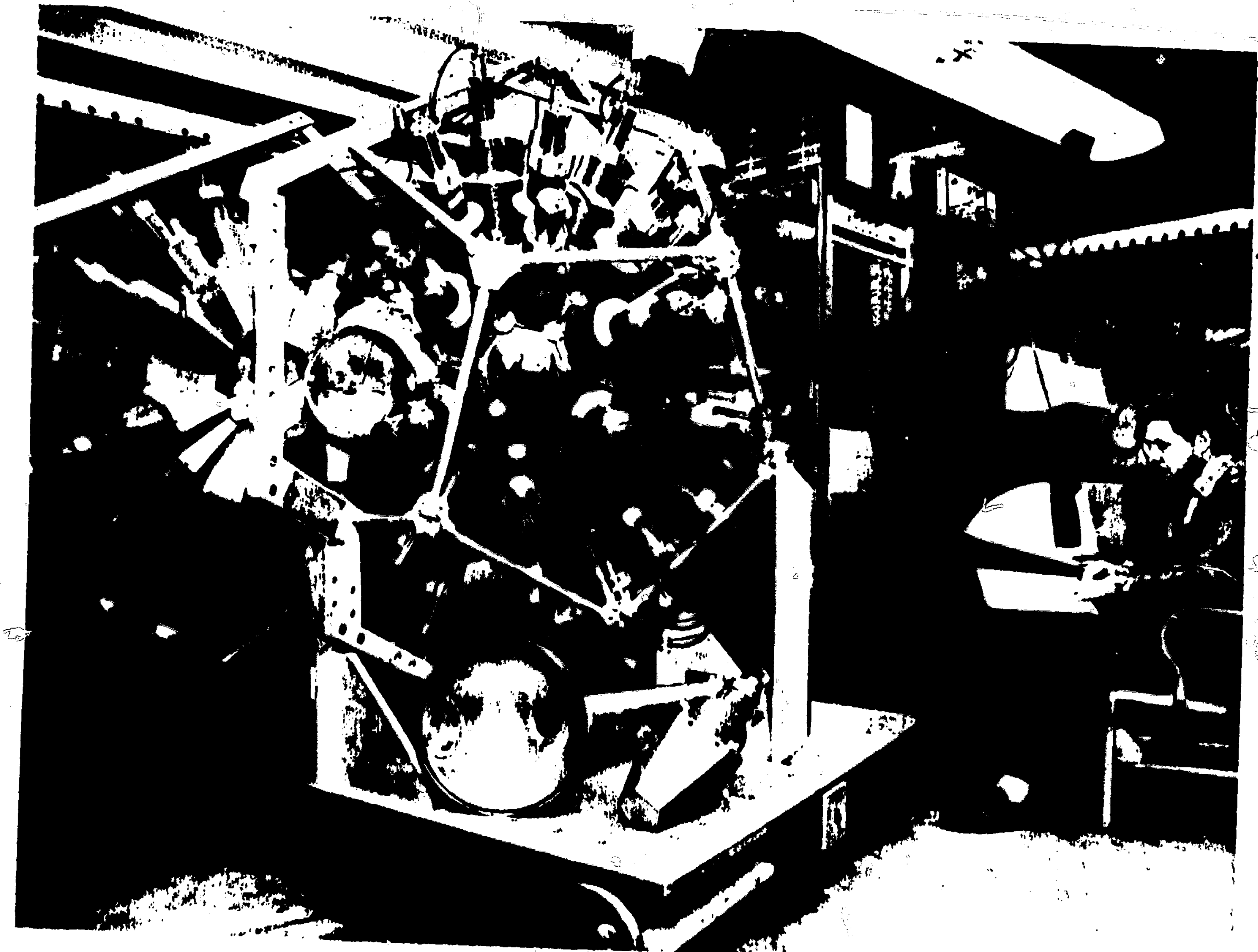
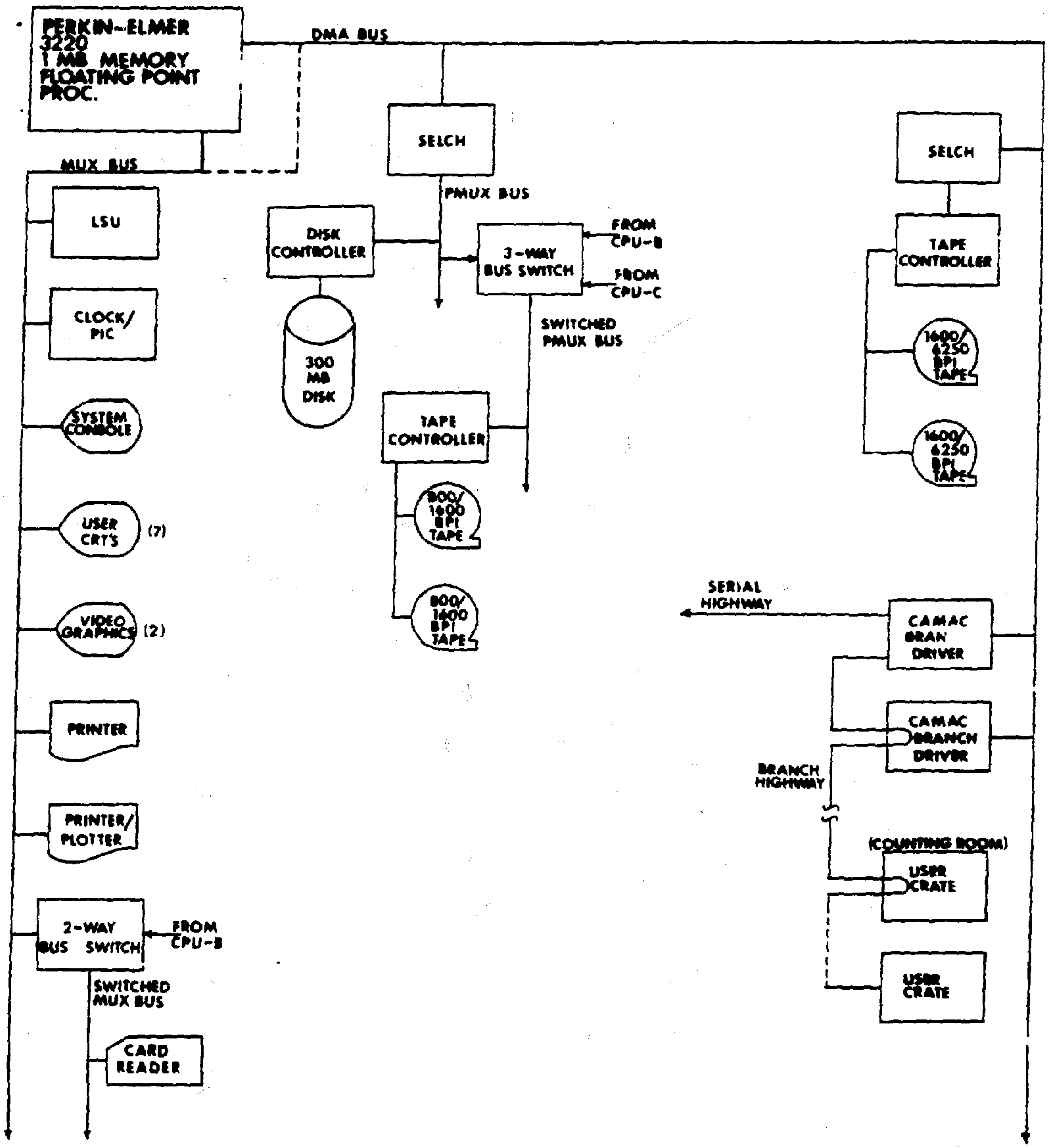


Fig. 16. The spin spectrometer.



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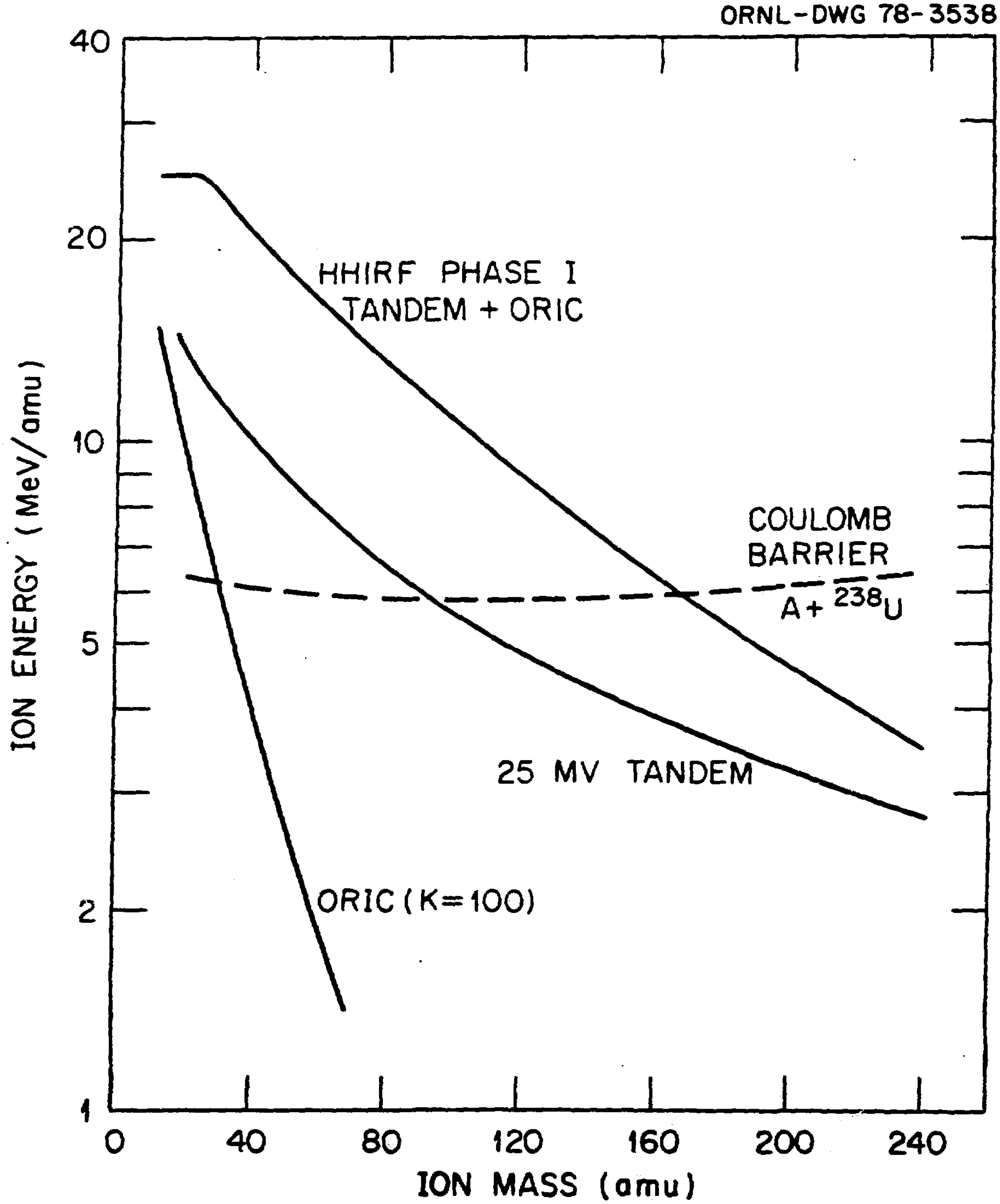

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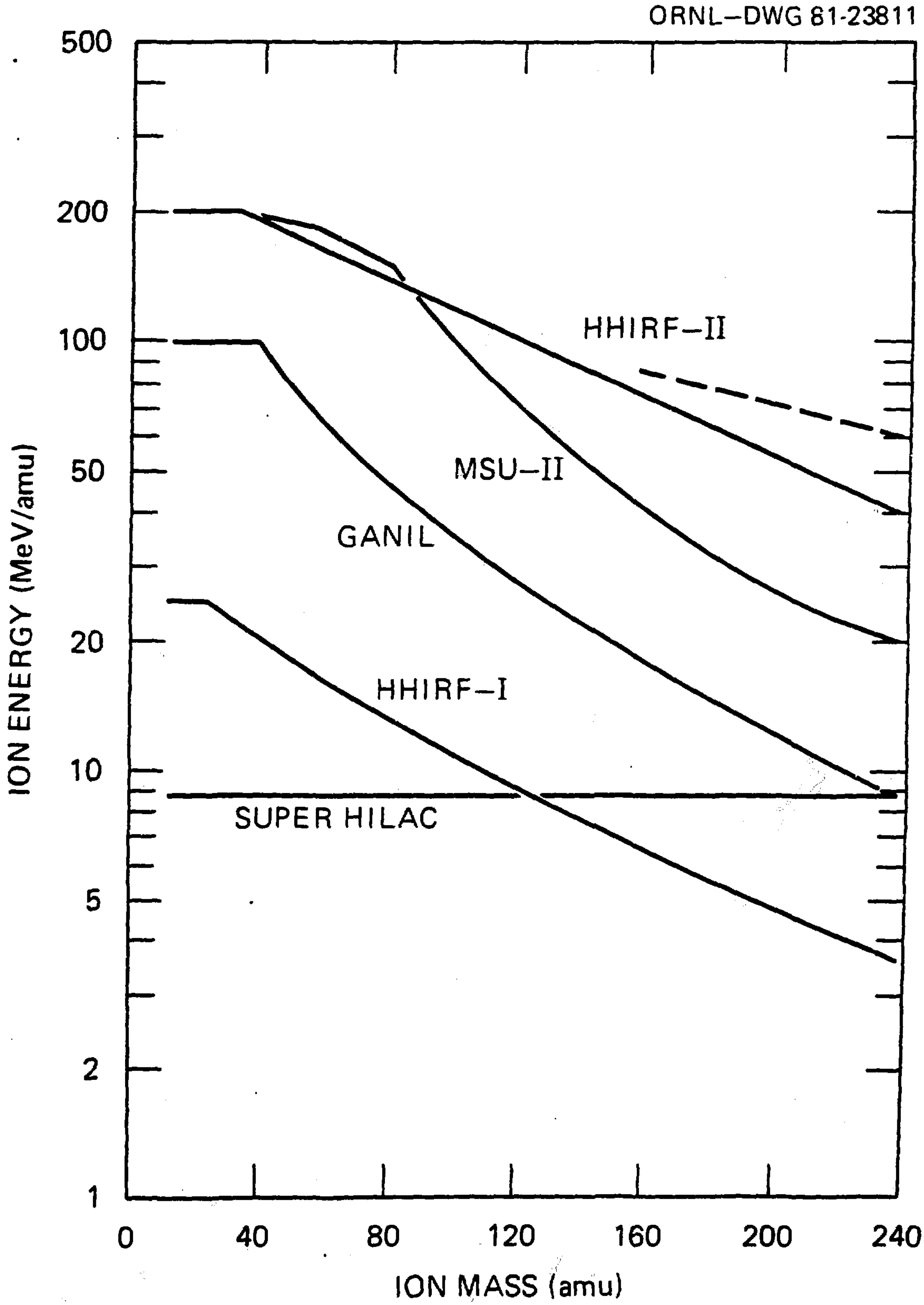

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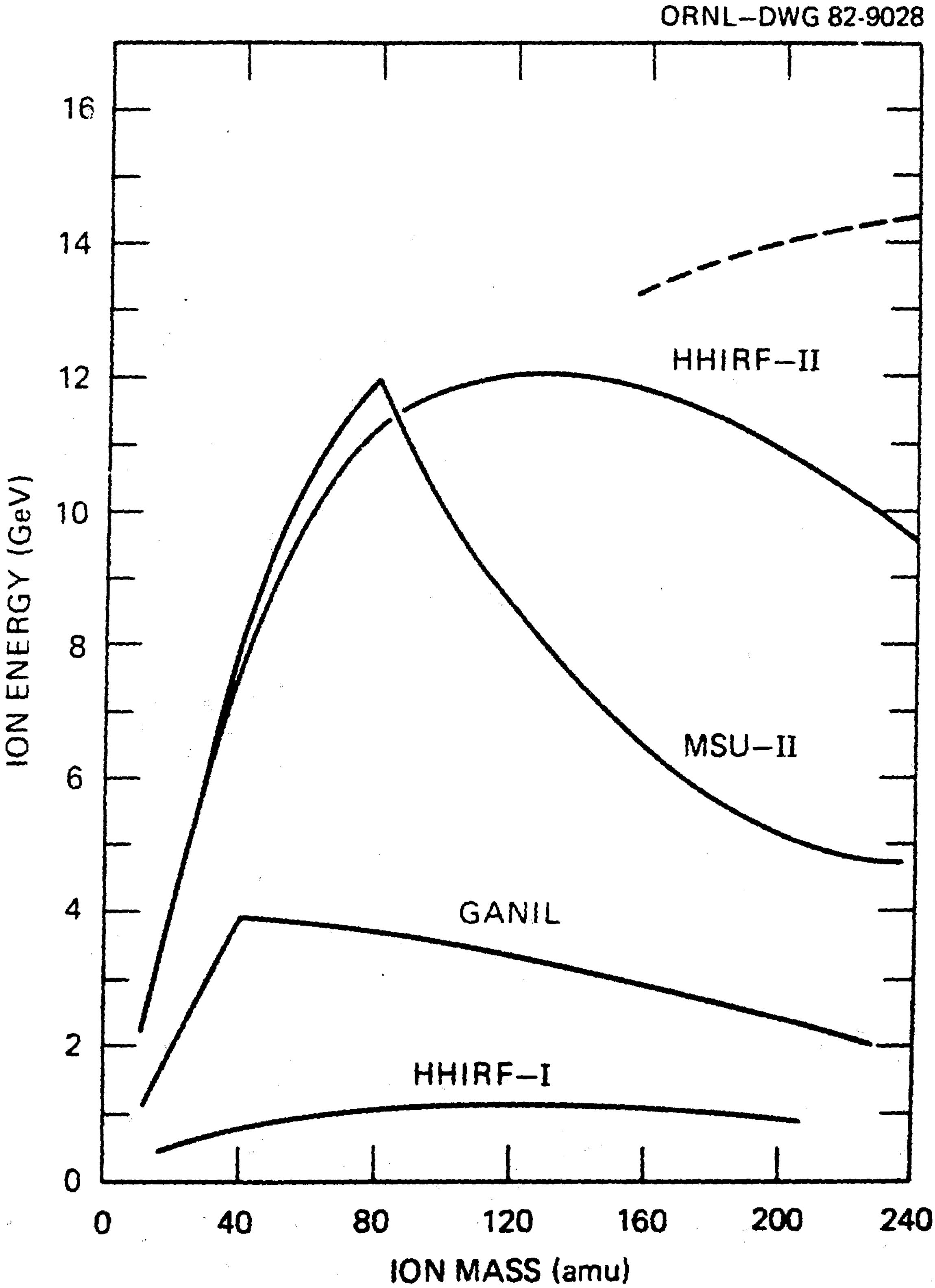

Fig. 20. Total energy performance available from the proposed facility upgrade.