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MASTER

THE 25 MV TANDEM ACCELERATOR AT OAK RIDGE*

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Abstract

A new heavy-ion accelerator facility is under construction at the Oak Ridge National Laboratory. A brief description of the scope and status of this project is presented with emphasis on the first operational experience with the 25 MV tandem accelerator.

1. Introduction

A new heavy-ion accelerator facility [1] is nearing completion at the Oak Ridge National Laboratory. This paper presents a brief description of the scope and status of this project and a discussion of some aspects of the first operational experience with the 25 MV tandem accelerator.

2. Project Scope and Schedule

Construction of this facility will proceed in at least two phases. Phase I, which is now under way, will consist of a new 25 MV tandem accelerator, improvements to and modifications of the existing Oak Ridge

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DISCLAIMER

Isochronous Cyclotron (ORIC) [2], and a building addition to house the tandem accelerator. After completion of Phase I, it will be possible to operate the two accelerators independently and also in a coupled mode in which beams from the tandem accelerator are injected into the ORIC for further acceleration. In Phase II, it is proposed to modify the ORIC by addition of superconducting main field coils to increase its K value ($K = ME/q^2$) from the present value of 100 to a value of about 300.

The tandem accelerator, which has a vertical, folded configuration, is housed within a tower which is approximately 14 m in diameter and which rises approximately 47 m above ground level. When operated in the coupled mode, beam from the tandem accelerator will be transported about 36 m for injection into ORIC. Capture in ORIC is accomplished by stripping in a foil positioned at an appropriate point within the cyclotron [3, 4]. The tandem accelerator beam will also be bunched to maximize the fraction of beam injected within the 6° phase acceptance window of ORIC required for a final energy resolution, $\Delta E/E$, less than 10^{-3}.

General features of the performance of the Phase I and II accelerators are shown in Figure 1 where ion energy per nucleon is plotted as a function of ion mass. All functions in this figure were calculated for a nominal final intensity of 10^{11} particles/sec. Functions for the tandem accelerator and Phase I and II coupled operation were calculated with an assumed injected beam of 3.6×10^{13} particles/sec. The tandem accelerator function was calculated with the assumption of a gas stripper in the terminal and a foil stripper 1/3 of the way down the high energy acceleration tube. The coupled operation functions were calculated with the assumption of a gas stripper in the tandem accelerator terminal. The change in slope which occurs in the Phase II curve at about mass 120 is due to a focusing limitation which results from a limit on the azimuthal variation of the magnetic field due to saturation of the existing iron poles.

The 25 MV tandem accelerator system is being provided by the National Electrostatics Corporation (NEC) under a contract awarded in 1975. Since the accelerator has been described previously [1, 5, 6], only highlights will be noted here. The accelerator, which is insulated with pure SF_6 at pressures up to about 0.7 MPa (gauge), has been designed to operate at terminal potentials of up to 25 MV with analyzed beam intensities up to 1 pμA (0.62×10^{13} particles/sec). The accelerator pressure vessel, which is approximately 30 m high and 10 m in diameter, houses a column structure 18.9 m long (excluding the high voltage terminal) of which 16.5 m is insulated. As shown in Figure 2, the column structure has five dead sections with vacuum pumps and electron traps in each dead section. In addition to the terminal magnet, which provides excellent charge state separation, the column structure is equipped with three quadrupole lenses, three sets of steerers, and a "second" stripper located in the upper major dead section. The accelerator uses a CAMAC-based digital control system in which virtually all control and monitoring information is transmitted on five bit-serial highways.

A brief chronology of schedule milestones relevant to the tandem accelerator is shown in Table I. As can be seen, work started on the accelerator system in May 1975 and beam was successfully transmitted through the entire system in May 1980. The remainder of the paper will be devoted to three items noted in this schedule: the SF_6 handling system, the column voltage tests performed in May 1979, and initial beam tests performed in May 1980.

3. SF_6 Handling System

Essentially conventional SF_6 transfer, storage, and recirculation systems have been provided for the accelerator. The SF_6 inventory is stored in the liquid phase in three vessels. Oil-free reciprocating compressors, Kinney vacuum pumps, and a steam-heated vaporizer are used to transfer SF_6 to and from the storage and accelerator vessels. The system is controlled from a central point by a hard-wired control system which utilizes components typically used in chemical process systems.

The transfer system was commissioned in April 1979 and used for the first time to pressurize the accelerator vessel to full pressure in May 1979. Since that time, eleven complete transfers have been completed without major incident or SF_6 loss. The present estimated transfer times under optimum conditions are storage to accelerator (0.55 MPa (gauge)): 13 1/4 hours and accelerator (0.55 MPa (gauge)) to storage: 11 1/4 hours.

Two significant problems remain to be solved before the SF_6 handling system can be judged to be complete. The first is through-leakage in valves associated with the recirculation system dryers which occurs after the dryers are reactivated with heated air. The second is transport of SF_6 liquid droplets through the SF_6 vaporizer. Specifically, the SF_6 vaporizer is a one-pass tube and shell heat exchanger located just downstream from an expansion valve where the phase and pressure transitions are made in the transfer from storage. At final pressures (after expansion) above the triple line (about 0.12 MPa (gauge)), transport of SF_6 liquid droplets through the vaporizer significantly cools carbon steel piping components located downstream from the vaporizer. This cooling requires a decrease in flow rate to minimize the danger of low temperature brittle fracture. NEC plans to solve this problem by installation of an entrainment separator just downstream from the vaporizer.

4. Column Voltage Tests

A. Breakdown Voltage vs Pressure

Tests of the voltage holding capability of the column structure before installation of acceleration tubes were performed by NEC in May 1979. In these tests, the accelerator was filled with SF_6 to a set of test pressures ranging between 0.034 MPa (gauge) (5 psig) and 0.62 MPa (gauge) (90 psig). At each test pressure, a set of measurements was made in which the terminal potential was slowly increased until a spark occurred, thus giving a distribution in breakdown voltage for each test pressure. These data are shown in Figure 3 where each circle represents a breakdown or spark (total of 33). The absolute calibration for the voltage scale of these measurements was established from previous calibrations (in other NEC accelerators) of current vs gradient in the corona voltage grading system and is estimated to be accurate to ± 5%. At the highest pressure, 0.62 MPa (gauge), the breakdown voltage ranged from 26.4 to 32.0 MV with an average value of 28.8 MV.

At the two higher pressures, 0.41 and 0.62 MPa (60 and 90 psig), there is good evidence for a conditioning phenomena in the sense that breakdown voltage tends to increase with breakdown number. For the highest pressure, for which we have thirteen data points, this increase averages about 1.3% per breakdown and does not appear to change over the thirteen breakdowns. That is, the breakdown voltage does not appear to level off with breakdown number for the number of breakdowns observed.

The tests described above were performed with SF_6 as taken from the storage vessels without operation of the recirculation system. (The estimated water concentration was 100 ppm). After completion of these tests, the recirculation system was operated to further dry the gas. Unfortunately, a residue of powder and scale from the recirculation system piping was transferred to the column structure significantly reducing its voltage holding capability. At this point, the voltage tests were terminated due to schedule constraints.

Examination of the column structure after these tests revealed 42 spark hits. The largest of these were characterized by a discoloration of 1 to 2 cm in diameter with some melting in the center and roughness of the order of 0.25 mm. There was no evidence of any other physical damage to the column structure and no evidence that sparks tended to occur at a previous spark site. Specifically, we see no reason to suppose that the surface roughness associated with a spark hit will pose a functional problem. The distribution of spark hits was approximately uniform over the surface of the high voltage terminal and upper column although there was some preference for upper terminal surfaces with compound curvature.

Data similar to that of Figure 3 for High Voltage Engineering Corporation type MP [7] and XTU [8,9] tandem accelerators and the NEC type 20 UR tandem accelerator [10] show little change in slope up to pressures of 0.62 MPa (gauge) (90 psig). A comparison of these data with that shown in Figure 3 and the high pressure conditioning effect described above suggest that the change in slope exhibited by the data in Figure 3 at pressures above 0.28 MPa (gauge) (40 psig) is due to dirt. As indicated, it was not possible to test this hypothesis due to schedule constraints. However, we believe these tests indicate that, even without this hypothesis, the column structure has been shown to be electrostatically adequate for the design voltage of 25 MV.

B. Other Diagnostic Measurements

During the course of the breakdown voltage vs pressure measurements, two simple diagnostic measurements were made for each breakdown: First, three cameras were used to photograph sparks associated with the breakdown. Second, a storage oscilloscope was used to record the voltage induced on a 9.5-cm-diameter plate located at the tank wall opposite the high voltage terminal. (A simple RC network was used to give a decay time of 8 μsec and a terminal to oscilloscope voltage ratio of 13×10^6). Review of these data indicates the existence of an unexpected phenomena which, although not completely understood, may be of interest.

We find that the terminal voltage excursions associated with breakdowns exhibit two distinct modes. The first is an approximately sinusoidal oscillation with a frequency of about 2.8 MHz and an amplitude of almost twice the terminal voltage. For the purposes of discussion, we call this a "ringer". In the second mode, the terminal potential appears to decay as if critically damped and then oscillate with a complex wave form at a frequency of about 4.5 MHz. The total amplitude of this excursion is typically less than the initial terminal potential. This mode is called a "non-ringer".

Typical examples of these modes are shown in Figure 4 where we show oscillographs measured for the two modes along with corresponding photographs of the column. Both of the events shown occurred with a pressure of 0.14 MPa (gauge) (20 psig) and both were associated with a spark to the top of the high voltage terminal (observed with another camera). In both photographs of the column, light associated with current flowing in the column support post spark gaps can be seen and with careful examination it can also be seen (especially from the original photographs) that the light intensity associated with the ringer mode is more intense than that associated with the non-ringer mode. This correlation is characteristic of all the breakdowns for which we have appropriate photographs of the column. The most puzzling feature of this effect is that we find it to be a function of pressure. Specifically, the ringer mode is only observed at pressures of 0.28 MPa (gauge) (40 psig) and below, while the non-ringer mode is only observed at pressures of 0.14 MPa (gauge) (20 psig) and above. Both modes are observed at pressures of 0.28 MPa and 0.14 MPa. We have no explanation for this observed correlation with pressure.

It is tempting to associate the ringer mode with a column spark, i.e., an initial breakdown down the column structure (in contrast to an initial breakdown between the column structure (including the terminal) and the tank). This is consistent with the observed increased light intensity in the column spark gaps and the observed frequency of about 2.8 MHz which is close to the value of 3.1 MHz which we calculate for the resonant frequency of the column as a quarter wave transmission line shorted at the bottom and loaded at the top with the terminal-to-tank capacitance. However, this interpretation is not consistent with the observation of terminal-to-tank and column-to-tank sparks which do not appear to differ significantly from those observed with the non-ringer oscillation mode.

As noted above, the non-ringer mode appears to be a critically damped decay followed by a complex non-sinusoidal waveform of relatively small amplitude. The appearance of a critically damped decay is consistent with a simple model in which the column structure is approximated by a lumped constant circuit consisting of the terminal capacity and the arc inductance and resistance. Specifically, we note that using values of arc inductance (1.4 μH/m) and arc resistance (65 Ω/m) consistent with the recent measurements of Charlesworth and Staniforth [11], we estimate that the Oak Ridge accelerator (because of its large size) should be critically damped.

Although the simple models discussed above appear to have some bearing on what is in reality a complex situation, we believe that these measurements may have raised more questions than answers. We hope to pursue this problem in the future with instrumentation which will allow us to measure the sequence of events which occur in a breakdown as well as the time integrated effects.

5. Beam Tests

In the interval June-December 1979, NEC installed the acceleration tubes, terminal magnet, and other column components such as pumps, lenses, etc., and in January 1980, NEC began the process of commissioning the column in preparation for beam and voltage tests. The interval between January 1980 and May 1980 was characterized by several non-fundamental but time-consuming problems which delayed the first test, in which beam was completely transmitted through the accelerator, until May 12, 1980.

In this first test, an analyzed beam of 60 pnA of $^{16}O^{6+}$ was accelerated at a terminal potential of 15.5 MV. We were pleased to note that the accelerator was quite stable and that adjustment of the terminal and analyzing magnets in conjunction with the terminal potential was straightforward.

6. Future Schedule

At the present time, the entire accelerator system has been installed and NEC is now preparing for the commencement of system acceptance tests. The actual schedule for these tests will, of course, depend on the problems encountered. However, it is hoped that these tests will be completed by the end of 1980.

7. Acknowledgements

In presenting this paper I am serving as a representative of many individuals, both at NEC and ORNL, who have worked together to develop the design of the tandem accelerator and who are now working to assure the successful implementation of that design. Within the Oak Ridge heavy-ion accelerator facility project the individuals most directly concerned with the tandem accelerator have been J. K. Bair, J. A. Benjamin, J. A. Biggerstaff, R. C. Juras, J. E. Mann, E. G. Richardson, and N. F. Ziegler. The analysis described in Section 4.B was performed by J. K. Bair.

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Figure Captions

Fig. 1. Ion energy performance functions for the present Oak Ridge Isochronous Cyclotron (ORIC), the Oak Ridge 25 MV tandem accelerator, coupled operation of the 25 MV tandem accelerator and the present ORIC (labeled, TANDEM, ORIC (100)), and coupled operation of the 25 MV tandem accelerator and ORIC as upgraded in the proposed Phase II of the Oak Ridge heavy-ion accelerator facility project (labeled TANDEM, ORIC (300)). Assumptions used in calculating these functions are discussed in the text.

Fig. 2. A simplified schematic drawing of the Oak Ridge 25 MV tandem accelerator.

Fig. 3. Values of terminal voltage at breakdown plotted as a function of accelerator vessel pressure (gauge) for the May-1979 column voltage tests of the Oak Ridge 25 MV tandem accelerator. The absolute voltage scale has an estimated uncertainty of ± 5%.

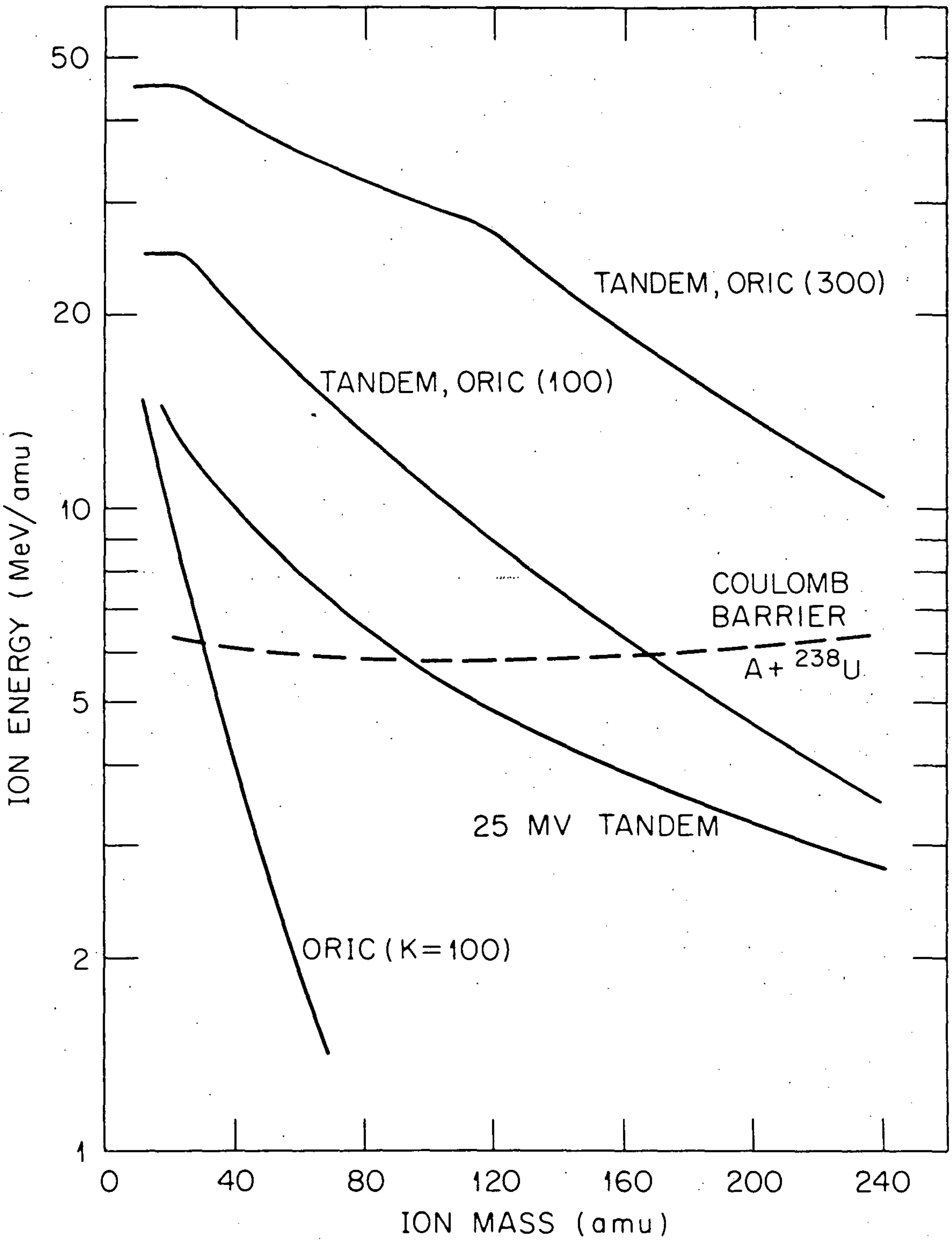
Fig. 4. Characteristic oscillation modes for voltage breakdowns in the Oak Ridge 25 MV tandem accelerator at a pressure of 0.14 MPa (gauge) (20 psig). The upper photograph is a side view of the column showing column support post spark gap currents integrated over the entire breakdown. The lower photograph is an oscillograph of the terminal voltage as a function of time. The left and right modes have been named "ringer" and "non-ringer", respectively.

TABLE I

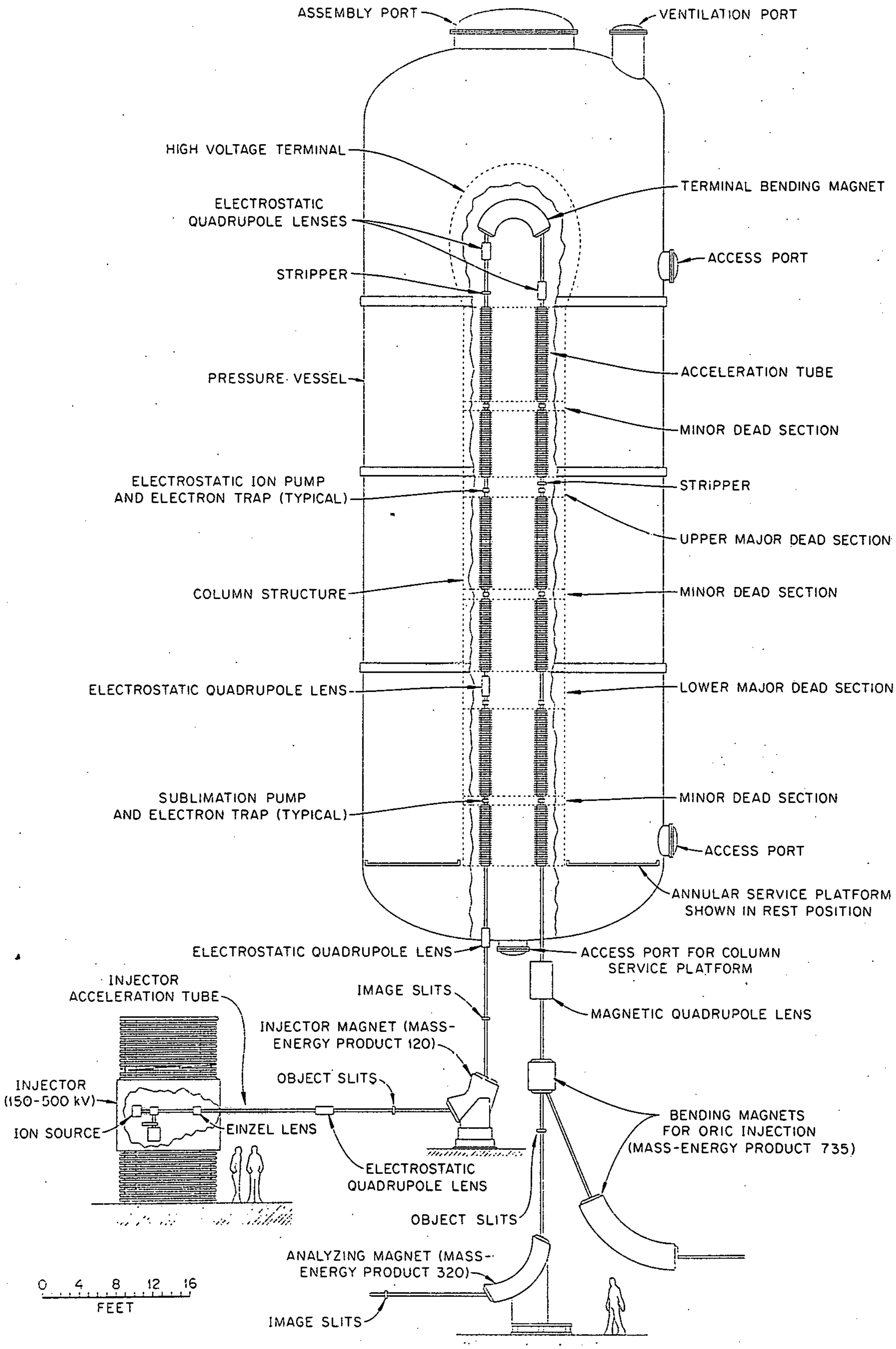
TANDEM ACCELERATOR MILESTONES

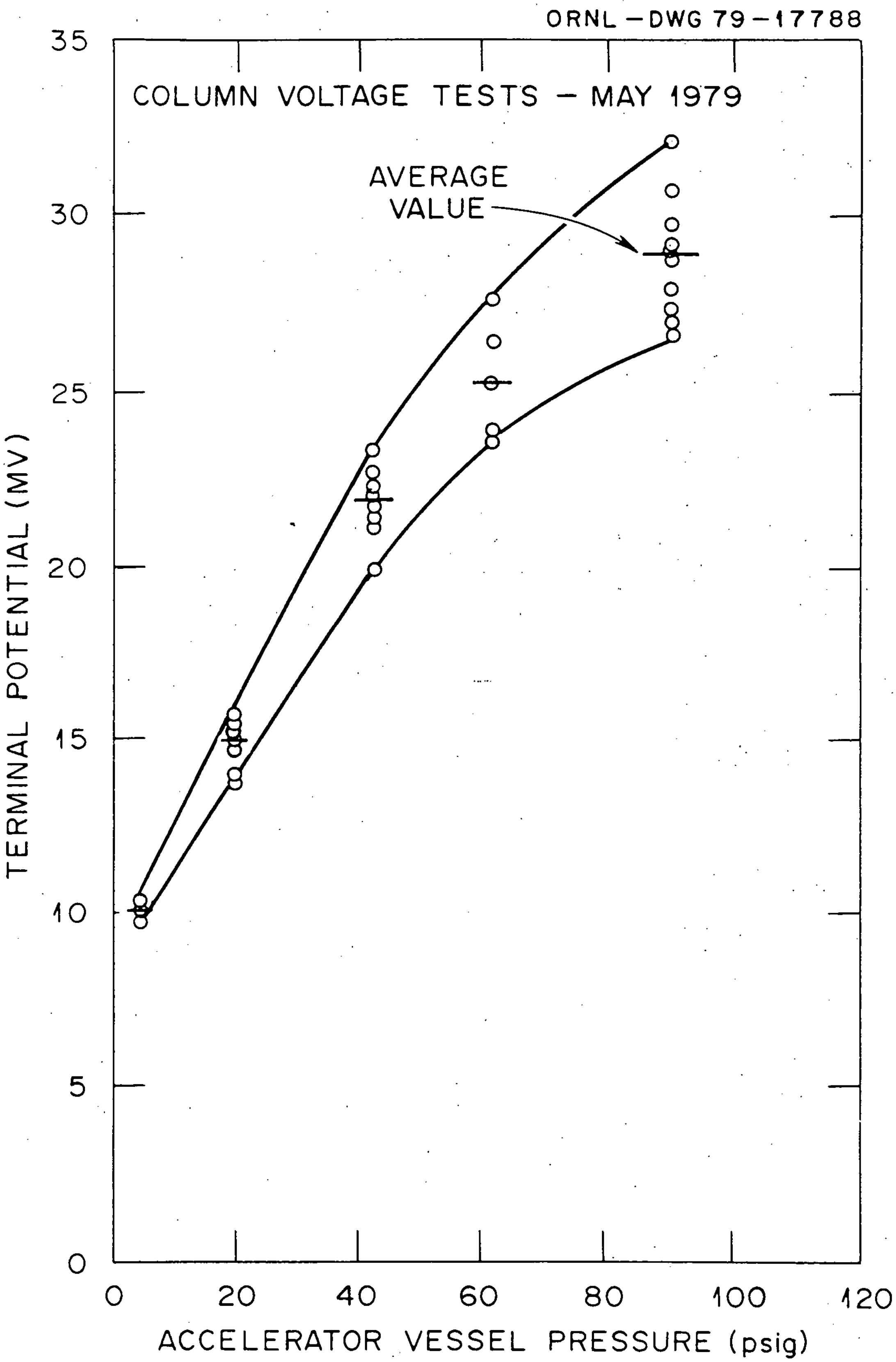
May 1975	Contract signed with NEC
August 1975	Site preparation for building begun
July 1977	Installation of pressure vessel begun
January 1978	Installation and testing of pressure vessel complete
March 1978	Receipt of SF_6 begun
June 1978	Tower completed to full height
August 1978	First shipment of components from NEC (Annular service platform)
September 1978	Injector and column structure tested in air under computer control (in Madison)
October 1978	SF_6 shipment complete - 128,000 kg on hand
November 1978	First shipment of column components from NEC
December 1978	Building completed
April 1979	Column installation completed (with chains and shafts)
April 1979	SF_6 transfer system commissioned
May 1979	Column voltage tests (without acceleration tubes)
February 1980	Column complete (with acceleration tubes) - ready for beam tests
May 1980	First successful transmission of beam through entire system (Oxygen 6+ at 15.5 MV)

ORNL-DWG 78-3538R

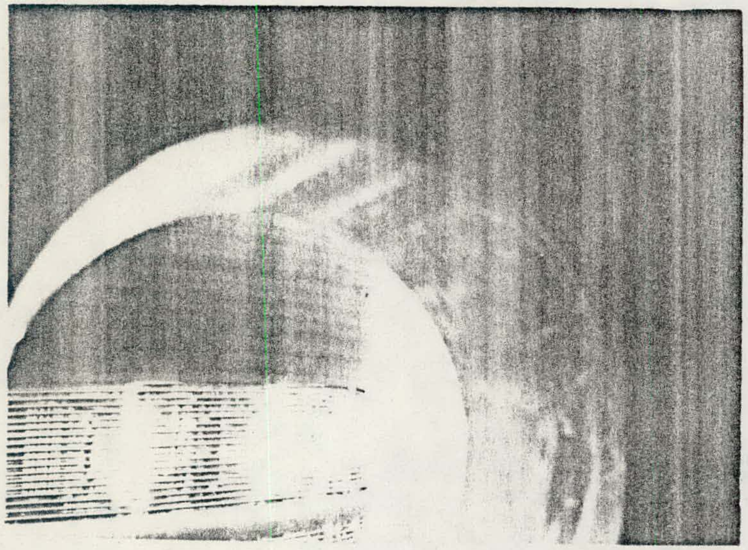


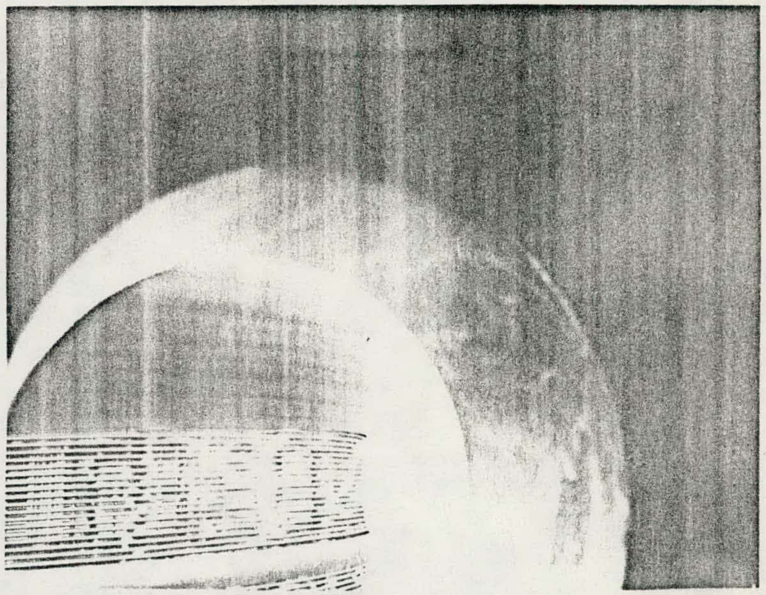
ORNL-DWG 76-2474

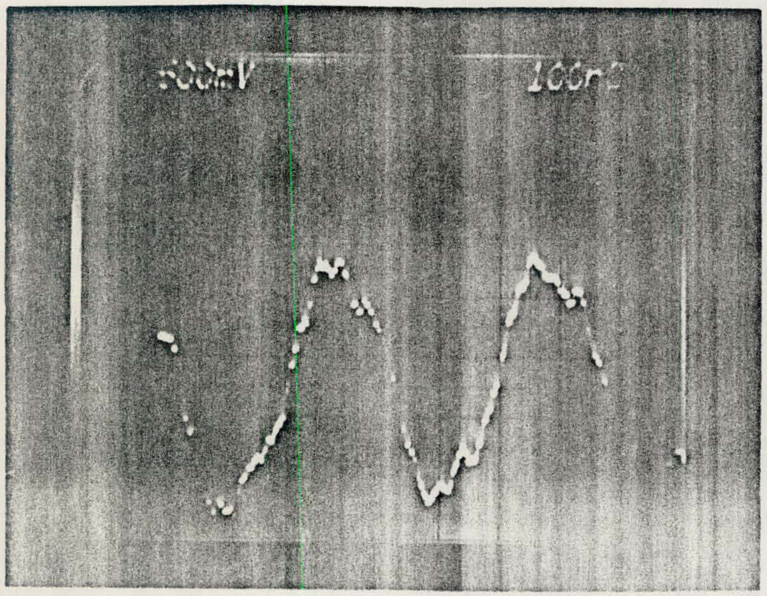


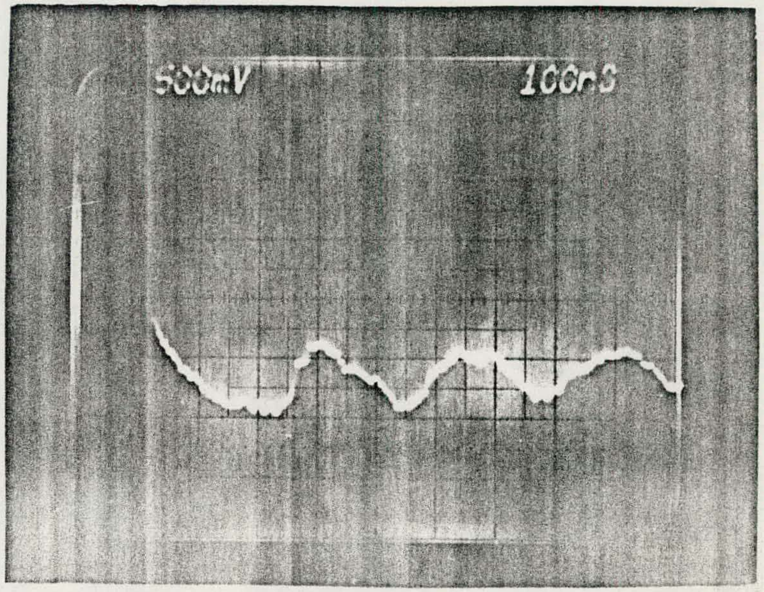

ORNL – DWG 79 – 17788
COLUMN VOLTAGE TESTS – MAY 1979
AVERAGE
VALUE
TERMINAL POTENTIAL (MV)
35
30
25
20
15
10
5
0
0
20
40
60
80
100
120
ACCELERATOR VESSEL PRESSURE (psig)

CHARACTERISTIC OSCILLATION MODES









Breakdown Potential: 15.4 MV
Voltage Excursion: ∿ 26 MV
Frequency: ∿ 2.8 MHz

Breakdown Potential: 15.0 MV
Voltage Excursion: ∿ 11.5 MV
Frequency: ∿ 4.5 MHz