THE HOLIFIELD HEAVY-ION RESEARCH FACILITY AT OAK RIDGE

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ABSTRACT

A new heavy-ion accelerator facility is now under construction at the Oak Ridge National Laboratory. This paper presents a brief description of the scope and schedule of this project, a more complete discussion of the new large tandem accelerator which will be a major element of the facility, and a brief description of several studies which have been made or are in progress in Oak Ridge in preparation for operation of the tandem accelerator.

Un nouveau laboratoire de recherche sur les ions lourds est actuellement en construction au Laboratoire National d'Oak Ridge. Cet exposé présente une brève description de l'étendue de ce projet et de sa planification, une discussion du grand accélérateur en tandem qui constituera un élément majeur de l'installation, et une revue rapide de plusieurs études qui ont été effectuées ou qui sont en cours à Oak Ridge en prevision de l'opération de l'accélérateur en tandem.

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THE HOLIFIELD HEAVY-ION RESEARCH FACILITY AT OAK RIDGE

Introduction

A new heavy ion accelerator facility[1] is now under construction at the Oak Ridge National Laboratory. In this paper, I will present a brief description of the scope and schedule of this project, a more complete discussion of the new large tandem accelerator which will be a major element of the facility, and a brief description of several studies which have been made or are in progress at Oak Ridge in preparation for operation of the tandem accelerator.

Project Scope and Schedule

Construction of this facility will proceed in 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 Isochronous Cyclotron (ORIC),[2] and a building addition to house the tandem accelerator. In 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, another, more powerful booster will be added for coupled operation with either ORIC or the tandem accelerator.

An elevation view of the Phase I building addition is shown in Figure 1. 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] 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}.

A plan view showing experimental facilities of the existing ORIC building and the first floor of the Phase I addition is shown in Figure 2. Two additional target rooms have been provided for use with the tandem accelerator. Most experimental rooms of the existing ORIC facility will be served by beam lines from both the tandem accelerator and the ORIC (in either independent or coupled operation). Shielding in the Phase I addition is sufficient for operation with all beams of mass > 4 at intensities up to approximately 1 pμA.

Present plans call for the Phase II booster to be a room-temperature separated-sector cyclotron with an energy constant $K = M(\text{amu})\cdot E(\text{MeV})/q^2(\text{charge units}) = 400.$[3)] Figure 3 shows how this cyclotron and the Phase II building addition would be situated adjacent to the existing ORIC and Phase I facilities.

General features of the performance of the Phase I and II Oak Ridge accelerators are shown in Figure 4 where ion energy per nucleon is plotted as a function of ion mass. Also shown in this figure are similar functions for several other major heavy ion accelerator facilities as well as tandem accelerators with terminal potentials of 13 and 30 MV. All functions for tandem accelerators in this figure were calculated with the assumption of a gas stripper in the terminal, a foil stripper 1/3 of the way down the high energy acceleration tube, and a final beam intensity of approximately 1/10 the intensity which would be available if the most probable charge state were selected at each stripper. Functions for the Oak Ridge Phase I and II accelerators were calculated with the assumption of a final intensity of about 10^{11} particles/sec, again about 1/10 of the estimated maximum possible intensity.

A simplified schedule for Phase I of the project is shown in Figure 5.

Completion of the building addition is scheduled for mid-1978. This will be followed by a one-year interval for installation and testing of the tandem accelerator. Final completion of Phase I of the project is scheduled for late 1979.

A photograph of the building addition, taken in April 1977, is shown in Figure 6. At that time concrete had been poured to a level approximately 20 m above ground level.

At the present time, Phase II of the project has not yet been funded. Based on the assumption that funding begins in October 1978, Phase II of the project is scheduled for completion in 1983.

25 MV Tandem Accelerator - Specification

The 25 MV tandem accelerator system is being provided by the National Electrostatics Corporation (NEC) under a fixed-price contract awarded in May 1975. The technical basis for that award was a detailed technical specification[4)] prepared by the ORNL project staff in consultation with prospective manufacturers. In this section, I will discuss key features of that technical specification. In the following section, I will discuss certain aspects of the design which NEC has developed to satisfy requirements of the specification.

Several criteria strongly influenced specification and design of the accelerator. The most important were a terminal potential variable in the range 7.5 to 25.0 MV and the capability to accelerate ions in the mass range 12 to 250 amu at intensities up to 1 particle microampere. In addition, the intended utilization of the accelerator as an injector required high reliability, the ability to coordinate operation of the tandem accelerator with operation of other accelerators, and production of pulsed beams. Listed below are some of the features included in the technical specification in response to these criteria.

Folded Configuration. - In the folded configuration chosen for the accelerator, both the "low-energy" and "high-energy" acceleration tubes are contained within a single column structure and a 180° magnet located within the high-voltage terminal is used to direct the beam, after stripping, into the high-energy acceleration tube. This configuration, which is attractive only in large tandem accelerators,[5)] has the following principal advantages in comparison to a conventional, linear configuration:

1) Reduction in pressure vessel length of 20% to 30% with corresponding reductions in pressure vessel cost, building cost, and insulating gas inventory. (Stated another way, the folded configuration allows design of an accelerator with lower, more conservative fields for a given cost.)

2) Reduction in electrostatic stored energy.

3) Availability of the 180° terminal magnet as an excellent charge state selector after stripping.

4) More convenient injector location.

5) Preferential direction of bremsstrahlung produced near the high-voltage terminal away from both acceleration tubes.

The folded configuration also has several disadvantages:

1) Dependency on operation of the 180° terminal magnet.

2) Introduction of time dispersion into bunched beams by the 180° terminal magnet.

3) Displacement of acceleration tubes from the column axis with an associated possible increase in damage under sparking conditions.

4) Reduced column rigidity.

We believe that for our case these disadvantages are outweighed by the advantages cited above.

Conservative Physical Size. - Consistent with its role as an injector, the accelerator was sized to give conservative electric field gradients, both radially and longitudinally. Specific requirements included minimum pressure vessel diameter, 10.06 m; minimum column diameter, 3.35 m; and minimum column length (excluding terminal), 18.90 m.

SF_6 Insulating Gas. - SF_6 at a maximum gauge pressure of 110 psi was specified as the insulating gas. Storage will be in the liquid phase. Maximum specified SF_6 transfer cycle times, for either entry into the accelerator pressure vessel or for evacuation and pressurization of the accelerator pressure vessel, are 10 hours.

Chain-Belt Charging. - Dual, independent chain-belt charging systems with a total capacity of 600 μA were specified. Provision for later installation of a third unit, to give a total capacity of 900 μA, was also specified.

Efficient Beam Transport. - Ion optic components were specified to provide maximum possible acceptance, efficient beam transmission, operation with well-defined beams of known mass and charge state, and acceptably isochronous transport for bunched beams. A key feature of the ion optic design is use of quadrupole lenses in the low-energy acceleration tube and the high-voltage terminal.[6)] A more detailed discussion of ion optic considerations applicable to this and similar accelerators will be presented in another contribution to this Conference.[7)]

Digital Control System. - One of the more novel features of this accelerator is the use of a digital control system. As specified, this system will have the following features: Virtually all control and monitoring information will be digitized and stored in a common computer memory. A computer will act as an interface between this memory and the operator and between the memory and the accelerator. This computer will not be used in closed servo loops. Another computer will have access to the memory for more sophisticated functions such as monitoring, logging, diagnostics, and control. Two co-equal control consoles will be provided -- one for independent operation of the tandem accelerator, one for use with ORIC. Information will be transmitted from point to point over CAMAC serial highways. Optical isolation will be provided at appropriate points in these highways to avoid ground loops and to minimize the effect of transients associated with discharges in the accelerator.

In our view, this system should have a number of advantages in comparison to a conventional, hard-wired system. These include:

1) Simplified installation and maintenance, resulting in large part from the use of multiplexed signal paths which reduce the complexity of the system outside the computer.

2) Inherent expansion and integration capability.

3) Simple implementation of multiple control consoles.

4) Simple ground-loop isolation.

5) Natural compatibility with digital light links required for data transmission across high voltages.

6) Natural future inclusion of computer-based logging, setup, and control functions.

Performance. - As indicated above, the accelerator is expected to provide analyzed beams with intensities up to 1 pμA at terminal potentials up to 25 MV for all ions for which sufficiently large negative ion beams may be obtained for injection into the accelerator. Acceptance tests for the accelerator will include long-term runs with analyzed heavy-ion beams of 1 pμA at 25 MV and operation with smaller beams at potentials up to 27.5 MV.

25 MV Tandem Accelerator - Design and Fabrication

In many ways the new Oak Ridge accelerator utilizes designs and philosophies which have recently been described by Herb.[8)] For this reason, I will not provide a detailed description of every aspect of the design of the new accelerator but rather will focus on those aspects which are unique either to this machine or which represent design departures for NEC.

The basic layout of the accelerator is shown schematically in Figure 7. Following previous NEC practice, the column will be built in 61-cm-high modules consisting of 10-cm-thick horizontal cast aluminum bulkheads supported by 16 circumferentially located insulating posts. Two major and three minor dead sections are used in the design. The lower major dead section, 122 cm in length, contains an electrostatic quadrupole lens on the low-energy side and space for a quadrupole lens on the high-energy side. The upper major dead section contains a foil stripper assembly on the high-energy side. Both major dead sections are provided with ion pumps on each side for intermediate pumping on the acceleration tubes. The minor dead sections, 20 cm in length, are provided with titanium sublimation pumps (for additional intermediate pumping on the acceleration tubes) and remotely controllable magnetic electron traps. Similar traps are provided for the major dead sections so that the maximum energy which an electron may achieve before encountering a trap is 5 MeV.

Acceleration tubes will be the standard NEC design. These are fabricated of titanium and alumina ceramic bonded together with an all-metal seal. They utilize flat field electrodes and are designed to operate at ultra-high vacuum. Voltage grading for each acceleration tube and for the column structure will be provided by three enclosed corona discharge tubes.

Two independent groups of three pelletron chains will be used for charge transport to the high-voltage terminal. Power for various components within the column structure will be provided by two rotating shafts, each capable of transmitting 50 horsepower.

The accelerator pressure vessel, which is being constructed by the Chicago Bridge and Iron Company under contract to NEC, will weigh approximately 400 metric tons. After installation of the column structure (about 50 metric tons) and addition of the SF_6 insulating gas, the total weight will increase to about 565 metric tons.

Beam transport apparatus external to the accelerator pressure vessel will follow conventional design practice for modern high-vacuum systems. Bakeable all-metal components and Conflat flanges will be used wherever possible. Normal operating pressures are expected to be less than 1×10^{-7} Torr. Bending magnets and the magnetic quadrupole lens on the post-accelerator beam line will be furnished by Alpha Scientific, Inc., under contract with NEC.

The injector will be a cylindrical structure with a graded support beneath and a graded housing above. The housing will contain a rotating shaft power transmission system, coolant lines, and the injector high-voltage power supply. The injector is designed to provide beams up to 100 pμA with energy regulation of the order of ± 30 eV over the energy range 150 to 500 keV. For economy and simplicity, the injector design uses aluminum bulkhead castings identical to those used in the column structure of the accelerator.

The control system design developed by NEC will employ two model 7/32 Interdata computers. They will drive four CAMAC serial highways linking seventeen crates. Six of these crates will be inside the accelerator pressure vessel -- complete crates in the terminal and each of the major dead sections and "minicrates" in the minor dead sections. Each crate in the pressure vessel will have its own optical links to the outside and provision will be made for bypassing malfunctioning crates.

NEC has been actively engaged in design and fabrication of the accelerator system over the past two years and major components of the system are now being assembled in NEC's plant in Madison, Wisconsin. Figures 8, 9, and 10 are photographs taken in Madison in February 1977 showing the status of components at that time.

Figure 8 is a view of the lower one-fourth of the column structure which at the present time has been assembled to full height. In ascending order, one can see the forged steel support ring, four 61-cm modules, the first minor dead section, and three 61-cm modules. The equipotential hoops have been placed in their final position only on the first module.

Figure 9 is a close-up view of the column structure at a higher elevation where bulkhead covers and hoops had not yet been installed. Here, one can see the power transmission shafts and the center hole in the bulkhead through which a small interior service lift will travel.

Figure 10 is a view of the partially completed injector structure.

A photograph of the partially completed pressure vessel, taken in March 1977, is shown in Figure 11. At this time, field preparation for erection of the vessel was almost complete.

Work in Progress at Oak Ridge

A number of activities are now in progress at Oak Ridge in preparation for installation and operation of the tandem accelerator. These activities include negative ion source development, studies related to ion-optics and heavy-ion stripping, and development of accelerator diagnostic techniques and computer-based models for SF_6 transfer processes. Some aspects of the work on ion-optics and heavy-ion stripping will be discussed in other papers presented at this Conference.[7,9] In addition, I wish to briefly describe two other of these activities.

Heavy-Ion Beam Bunching. - Injection into ORIC requires bunching of the beam into an interval which varies between 0.8 and 2.4 nsec at frequencies which vary between 4 and 14 MHz depending on the mass and energy of the accelerated ion. As indicated in reference 6, we have chosen to perform this function with a double-drift harmonic buncher system in which the second buncher operates at twice the frequency of the first. A primary motivation for this choice was the fact that our studies indicated that this type of buncher should have a buncher efficiency of 50 to 60%, a value approximately twice as high as that expected for a single-buncher system.

To further explore this concept we have built a double-drift harmonic buncher system very similar to that which will be used on the 25 MV tandem accelerator and installed it on our EN tandem accelerator for testing and development. This installation was completed in March 1977, and the first experimental run was performed in April 1977 with ^{16}O beams under conditions very similar to those which will be found on the 25 MV tandem accelerator. In this run we observed bunch widths in the order of 1 nsec (fwhm) and buncher efficiencies in the order of 50 to 60% confirming the theoretically predicted performance.

Further studies with this apparatus will focus on development of buncher controls, development of bunch diagnostic techniques, and study of the effect of various buncher grid designs. Primary participants in this work have been W. T. Milner and N. F. Ziegler.

[illegible]

the [illegible] accelerator [illegible]

R. C. [illegible], J. [illegible]

N. F. Ziegler. I also wish [illegible]

of the tandem accelerator community who have generously given their advice and assistance over the past several years.

References

1. J. B. Ball *et al.*, Journal de Physique 37, C5-227 (1976).
2. R. S. Livingston and F. T. Howard, Nucl. Instr. and Meth. 6, 1 (1960). The energy constant for ORIC $K = M \cdot E/q^2 = 90$.
3. Further details are given by J. B. Ball in another contribution to this Conference.
4. C. M. Jones *et al.*, Oak Ridge National Laboratory Report TM-4942 (1975), unpublished.
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7. J. D. Larson, Proceedings of this Conference.
8. R. G. Herb, Nucl. Instr. and Meth. 122, 267 (1974).
9. R. O. Sayer, Proceedings of this Conference.

FIGURE CAPTIONS

FIGURE
No.

1. An elevation view of the Phase I building addition.
2. A plan view of the Phase I building addition and selected portions of the existing ORIC building. The Phase I addition is the rectangular component at the lower left hand corner of the drawing (cylindrical tower, adjoining target rooms, and counting room).
3. A plan view of the planned Phase II building addition and portions of the existing facility.
4. Ion energy performance functions for several operating and planned heavy-ion accelerator facilities. Assumptions used in calculating some of the curves are discussed in the text.
5. A simplified schedule for construction of Phase I of the Oak Ridge facility.
6. A photograph of the Phase I building addition taken in April 1977.
7. A simplified schematic drawing of the Oak Ridge 25 MV tandem accelerator.
8. A photograph of the lower one-fourth of the accelerator column structure taken at NEC's plant in February 1977.
9. A photograph of details of the accelerator column structure taken at NEC's plant in February 1977.
10. A photograph of the partially completed injector structure taken at NEC's plant in February 1977.
11. A photograph of components of the partially completed accelerator pressure vessel taken at Oak Ridge in March 1977.

ORNL-DWG 75-13264

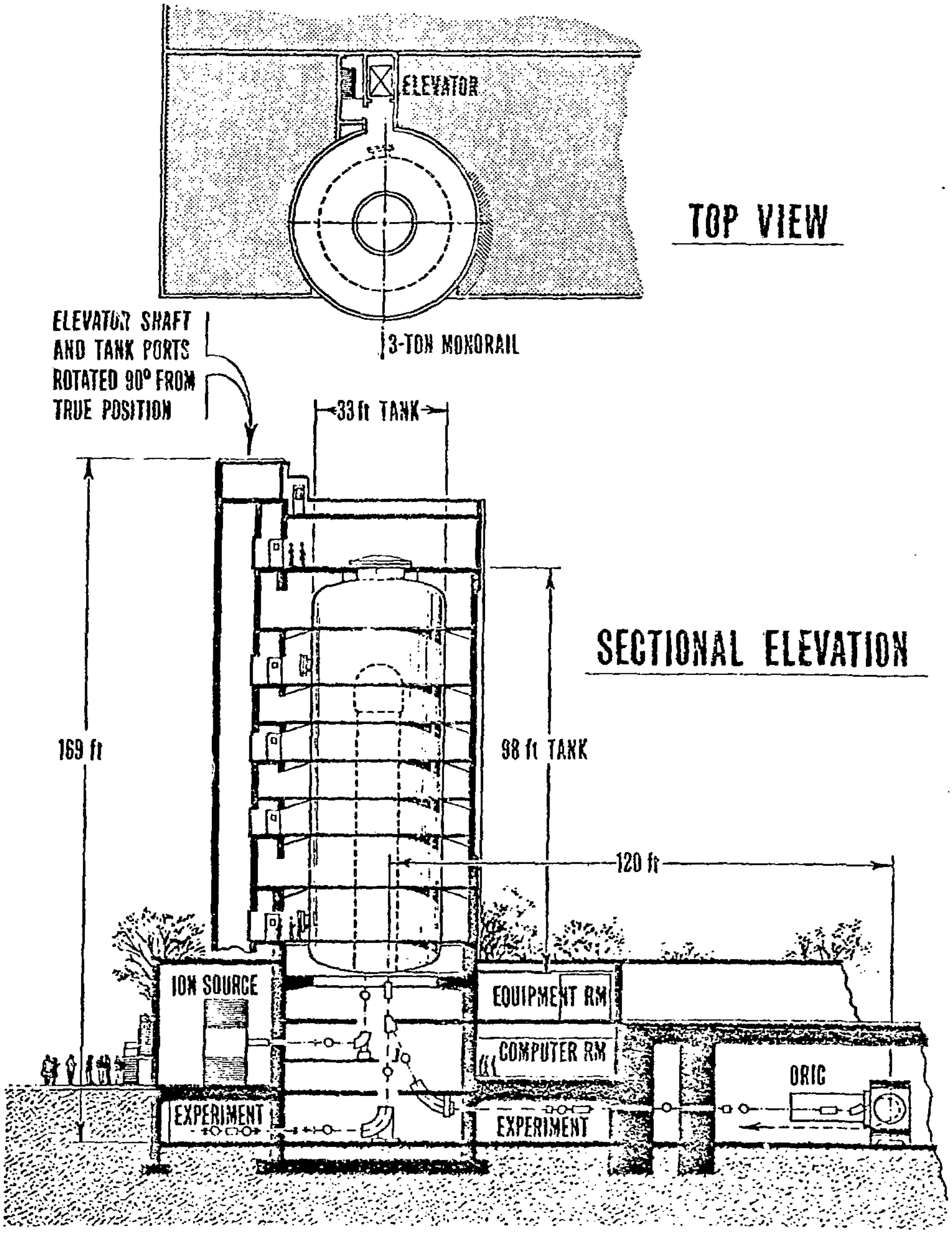

FIGURE 1

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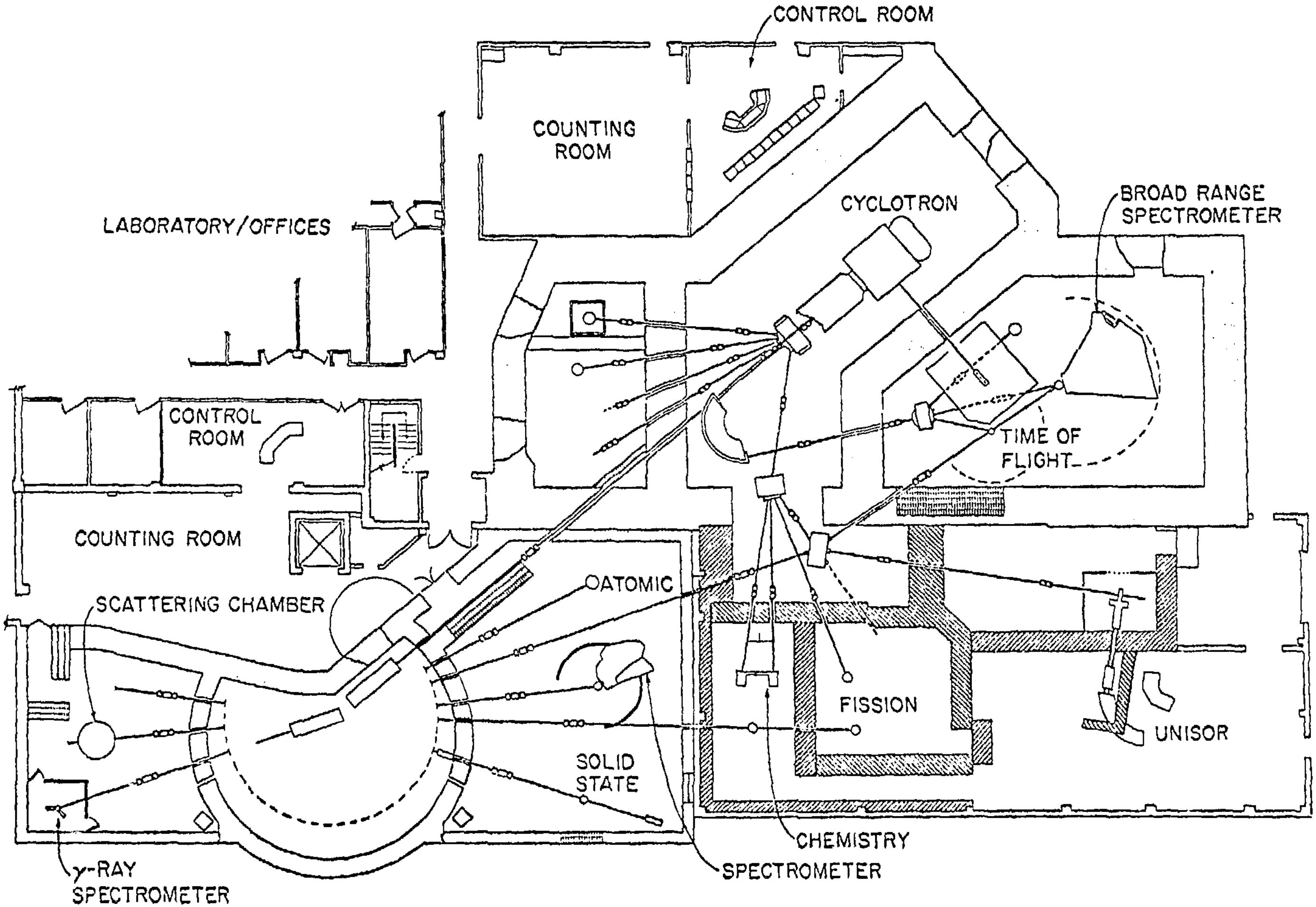

FIGURE 2

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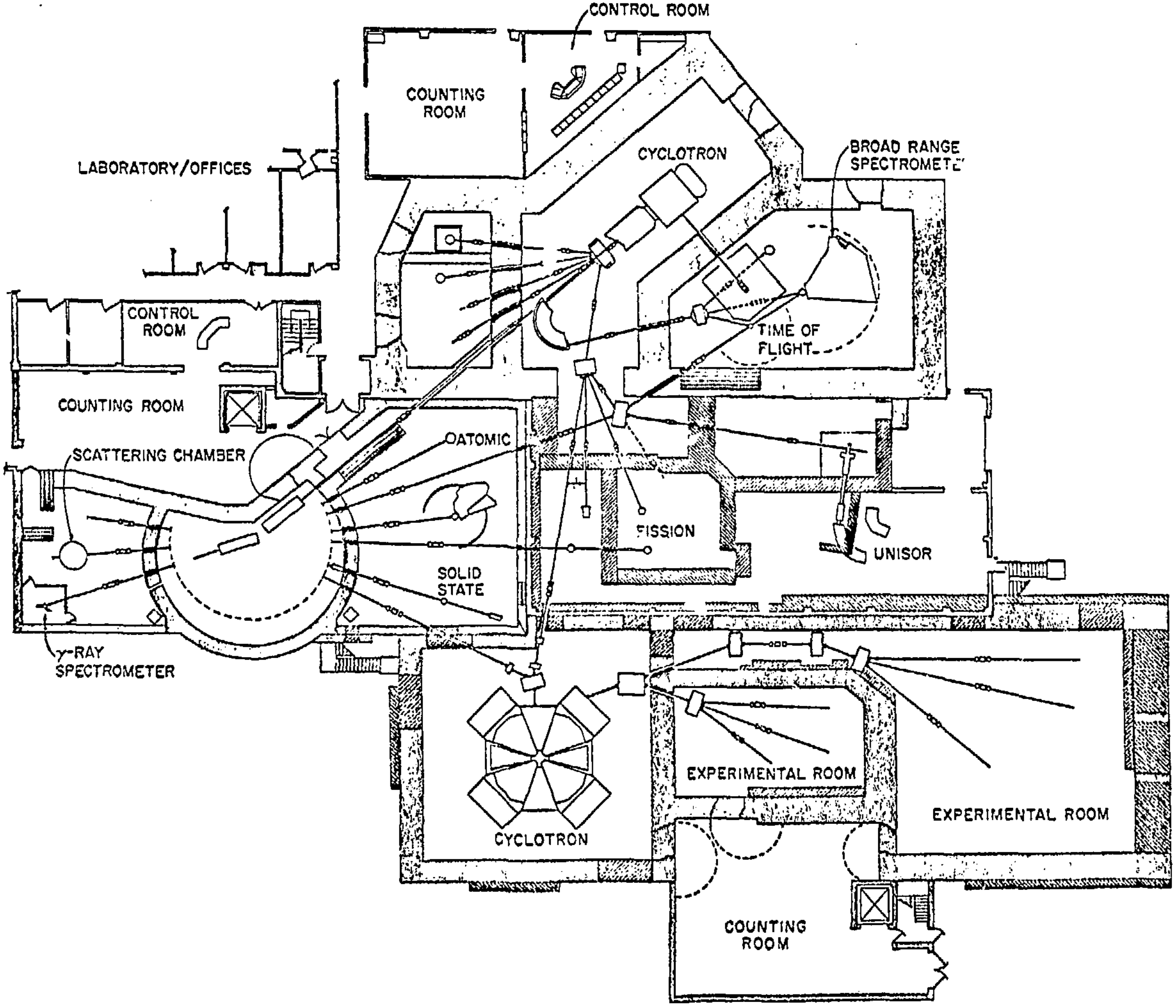

FIGURE 3

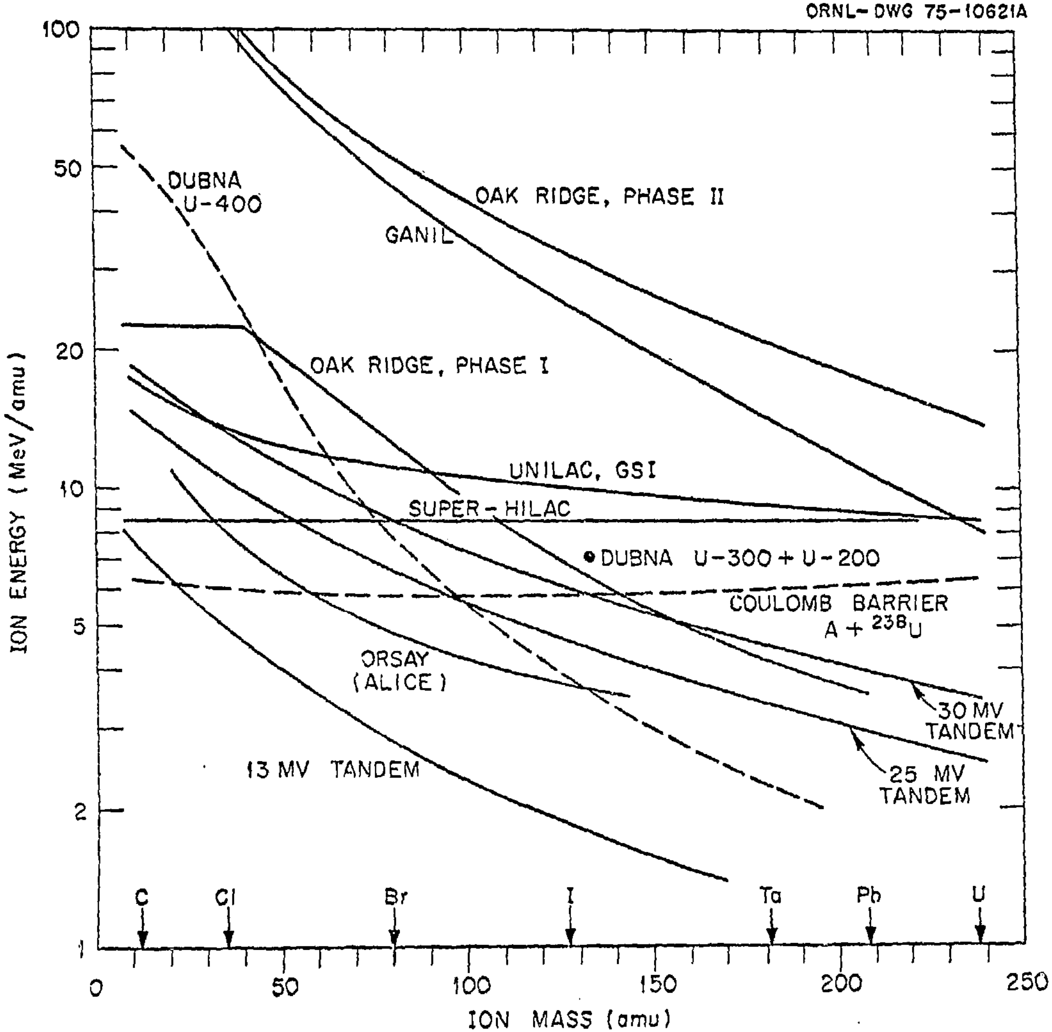
ORNL-DWG 75-10621A
100
50
20
10
5
2
1
ION ENERGY (MeV/amu)
DUBNA
U-400
OAK RIDGE, PHASE II
GANIL
OAK RIDGE, PHASE I
UNILAC, GSI
SUPER-HILAC
DUBNA U-300 + U-200
COULOMB BARRIER
A + 238U
ORSAY
(ALICE)
30 MV
TANDEM
25 MV
TANDEM
13 MV TANDEM
C
Cl
Br
I
Ta
Pb
U
0
50
100
150
200
250
ION MASS (amu)

FIGURE 4

ORNL-DWG 76-14169R

SCHEDULE - HOLIFIELD HEAVY ION LABORATORY

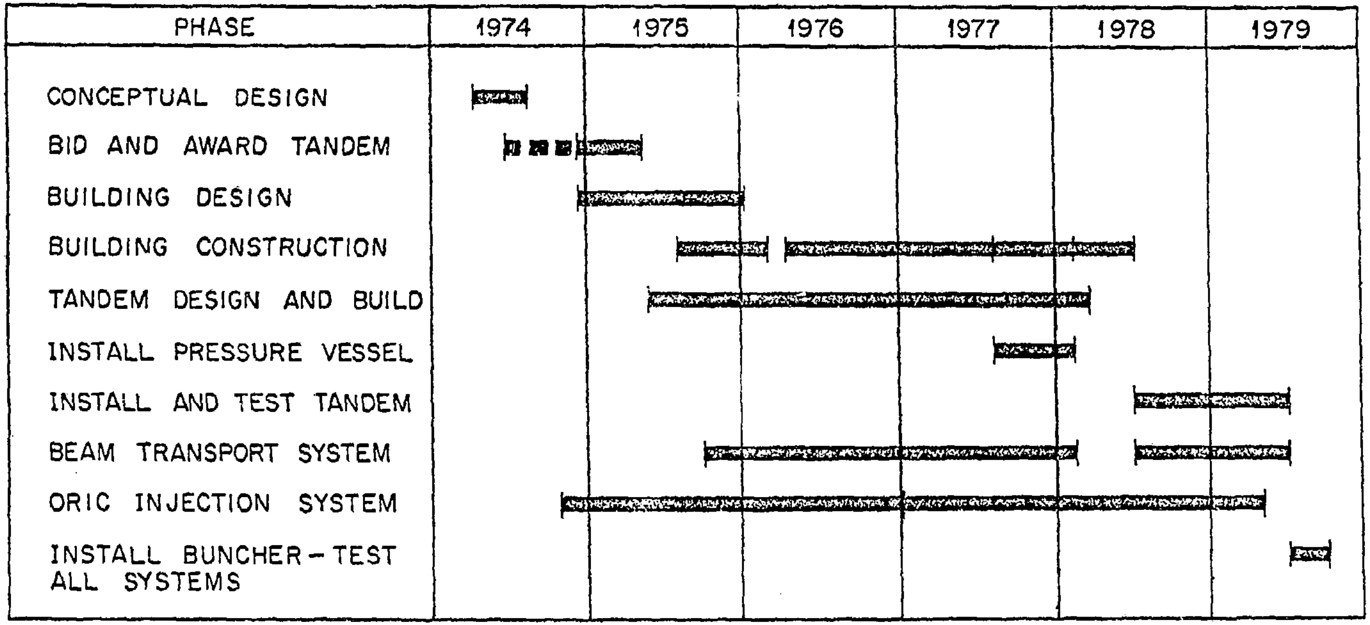

FIGURE 5

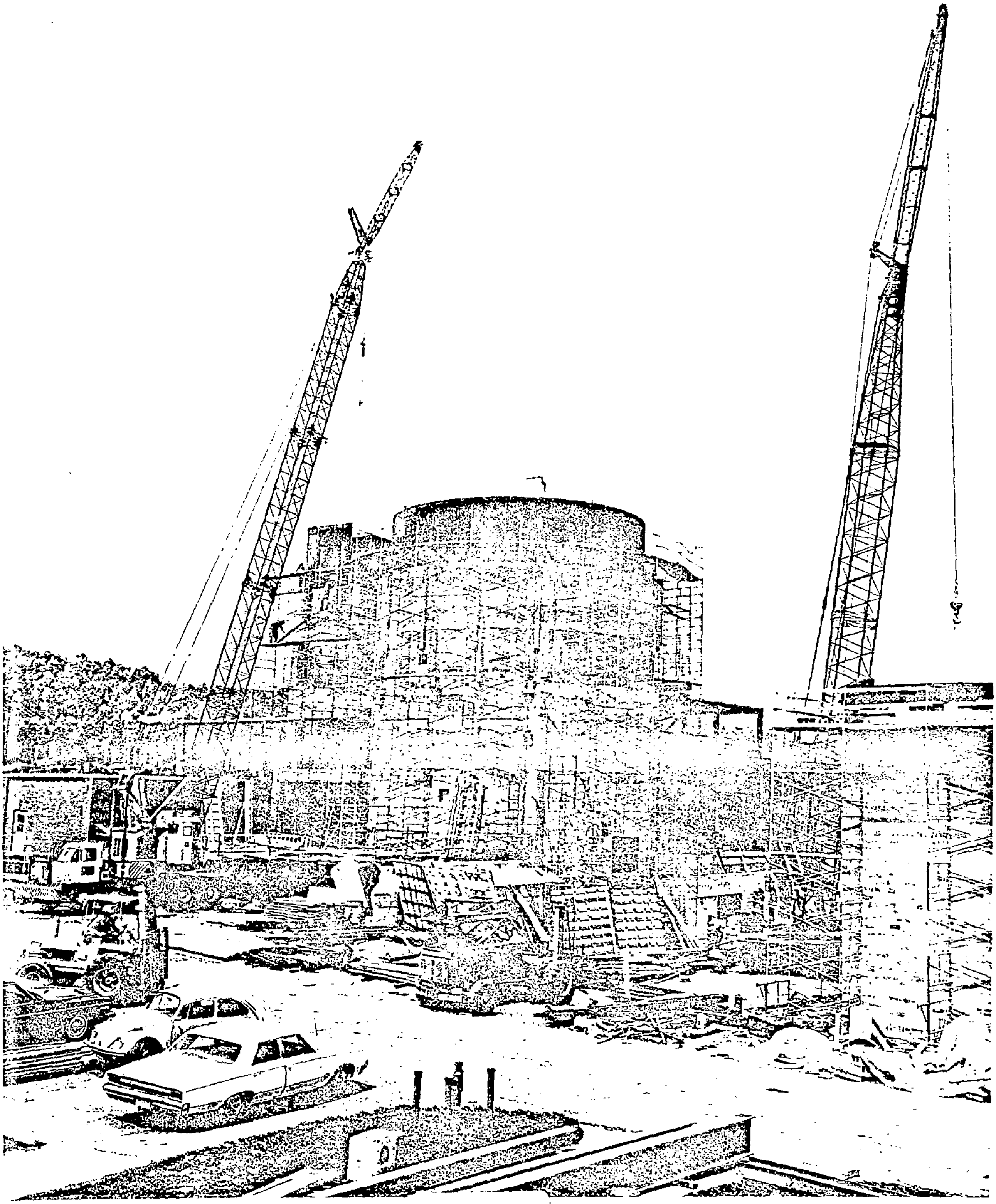

FIGURE 6

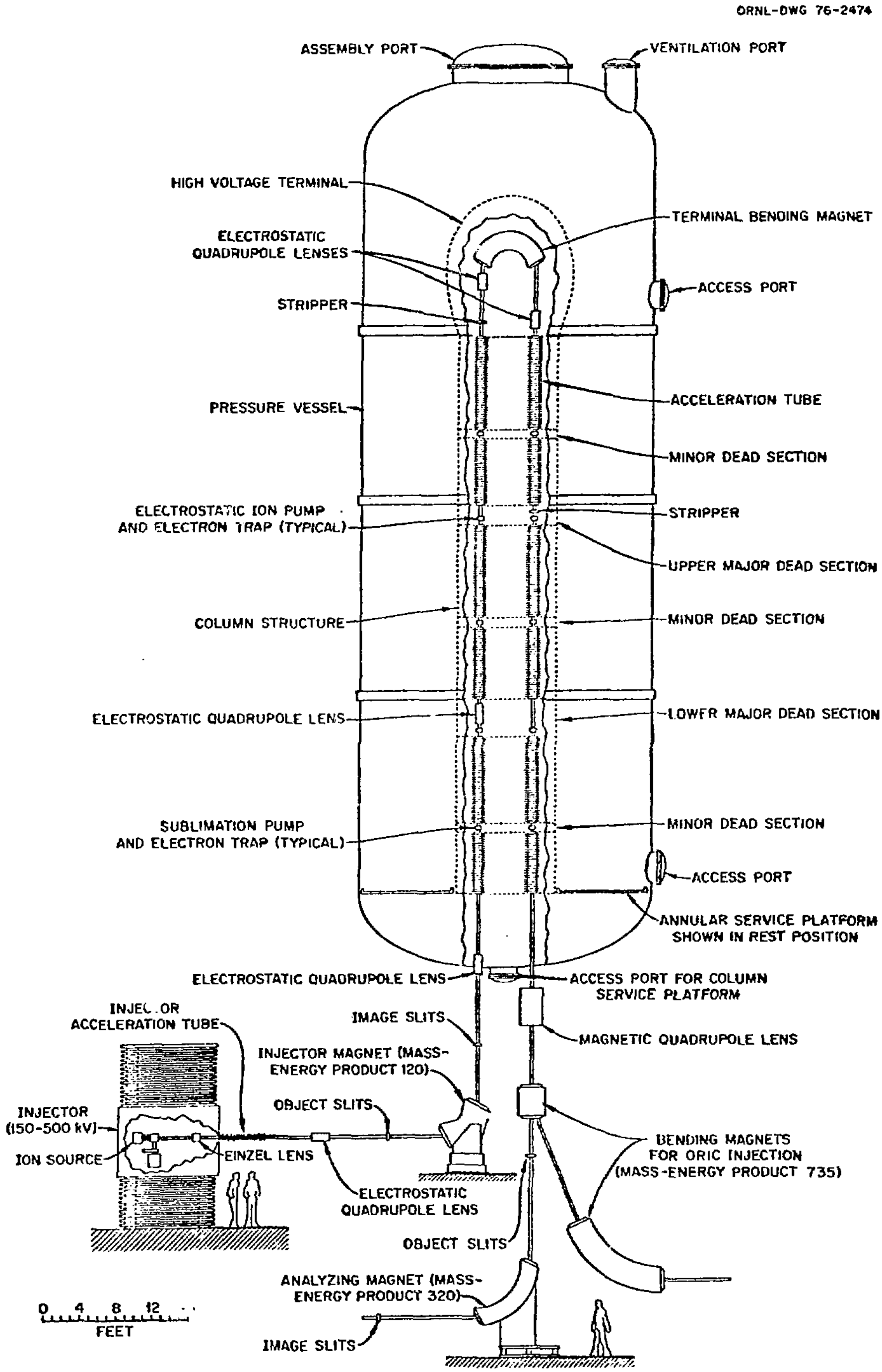
ORNL-DWG 76-2474
ASSEMBLY PORT
VENTILATION PORT
HIGH VOLTAGE TERMINAL
TERMINAL BENDING MAGNET
ELECTROSTATIC QUADRUPOLE LENSES
ACCESS PORT
STRIPPER
PRESSURE VESSEL
ACCELERATION TUBE
MINOR DEAD SECTION
ELECTROSTATIC ION PUMP AND ELECTRON TRAP (TYPICAL)
STRIPPER
UPPER MAJOR DEAD SECTION
COLUMN STRUCTURE
MINOR DEAD SECTION
ELECTROSTATIC QUADRUPOLE LENS
LOWER MAJOR DEAD SECTION
SUBLIMATION PUMP AND ELECTRON TRAP (TYPICAL)
MINOR DEAD SECTION
ACCESS PORT
ANNULAR SERVICE PLATFORM SHOWN IN REST POSITION
ELECTROSTATIC QUADRUPOLE LENS
ACCESS PORT FOR COLUMN SERVICE PLATFORM
INJECTOR ACCELERATION TUBE
IMAGE SLITS
MAGNETIC QUADRUPOLE LENS
INJECTOR MAGNET (MASS-ENERGY PRODUCT 120)
INJECTOR (150-500 kV)
OBJECT SLITS
ION SOURCE
EINZEL LENS
BENDING MAGNETS FOR ORIC INJECTION (MASS-ENERGY PRODUCT 735)
ELECTROSTATIC QUADRUPOLE LENS
OBJECT SLITS
ANALYZING MAGNET (MASS-ENERGY PRODUCT 320)
0 4 8 12
FEET
IMAGE SLITS

FIGURE 7

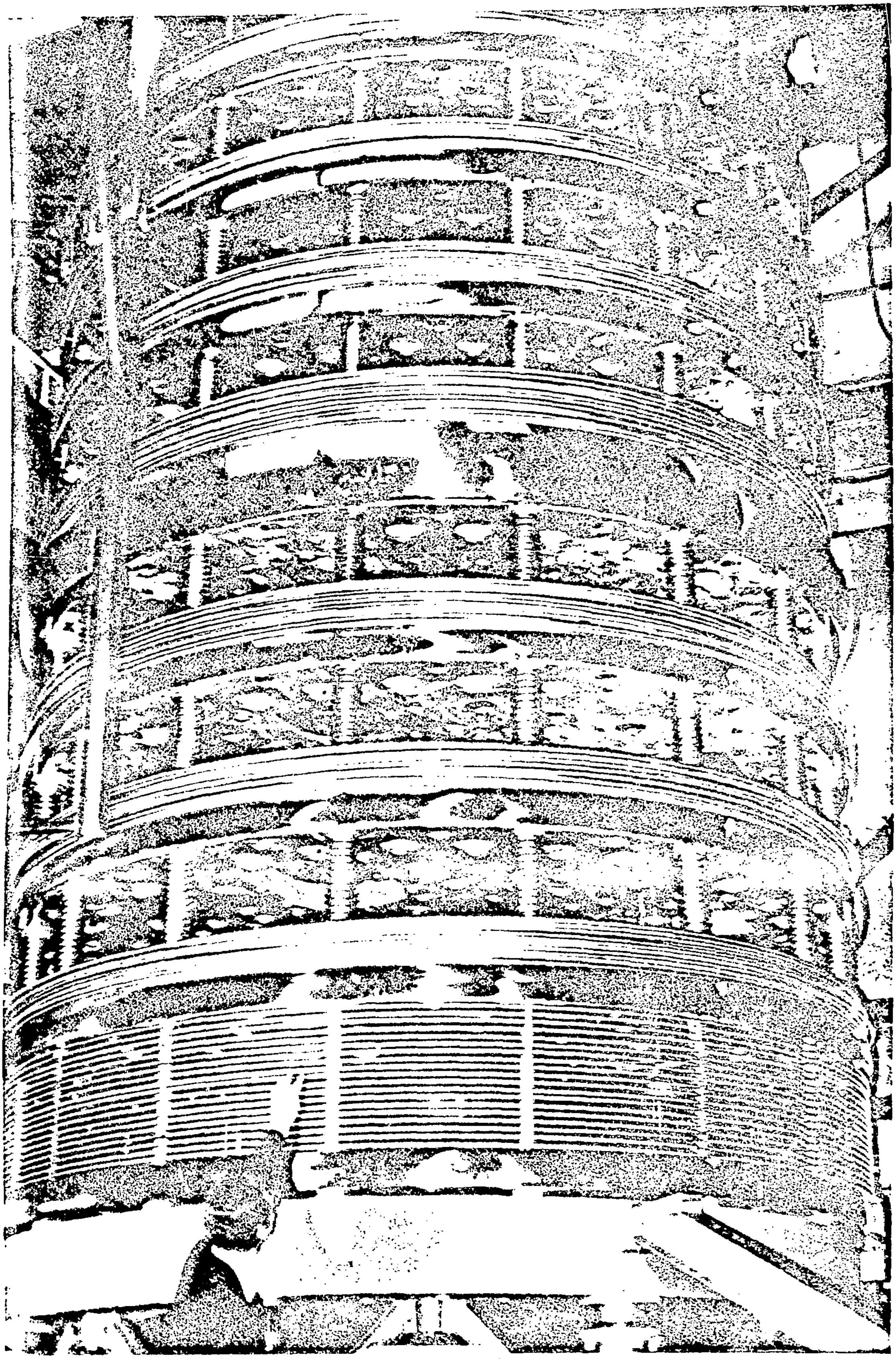

FIGURE 8

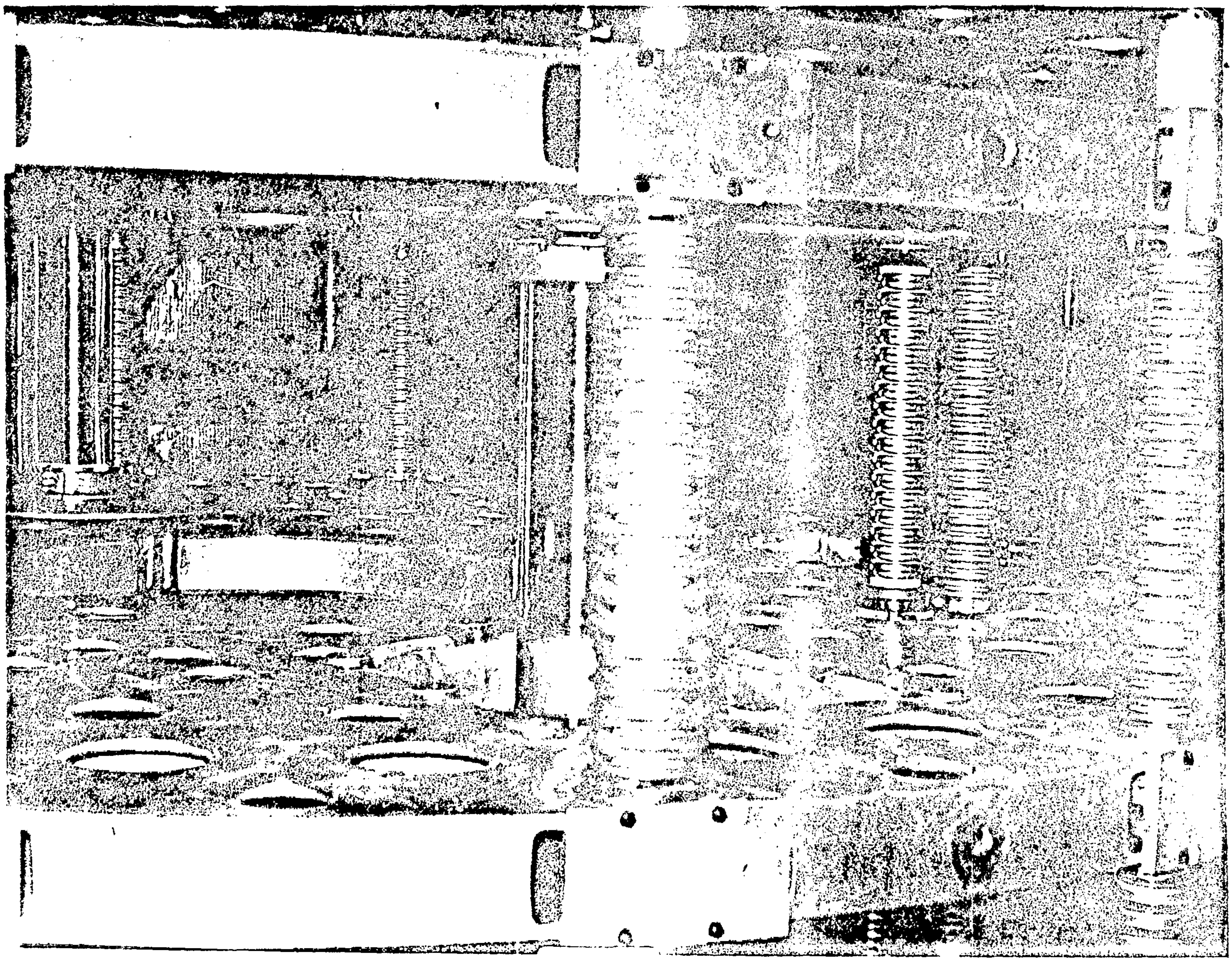

FIGURE 9

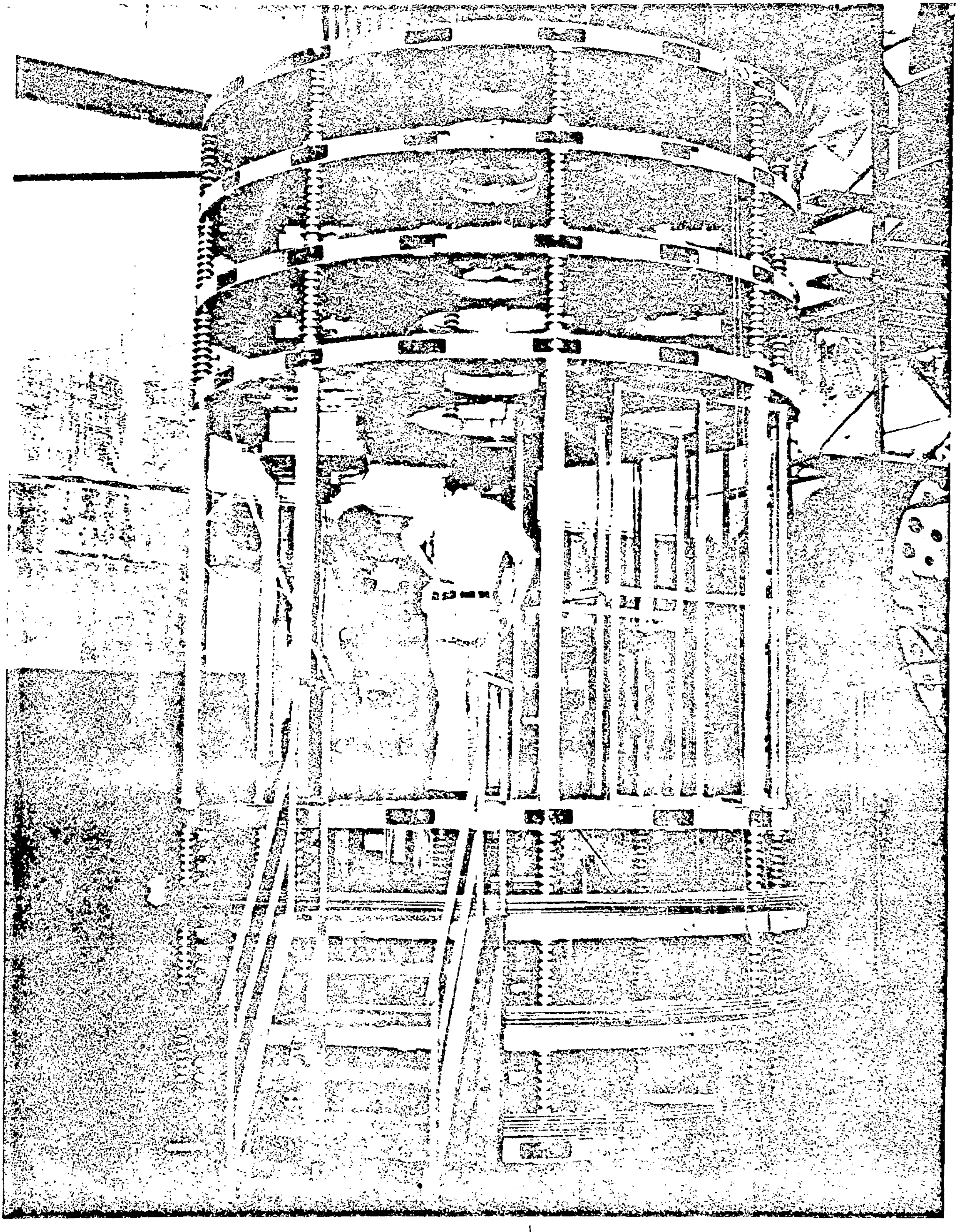

FIGURE 10

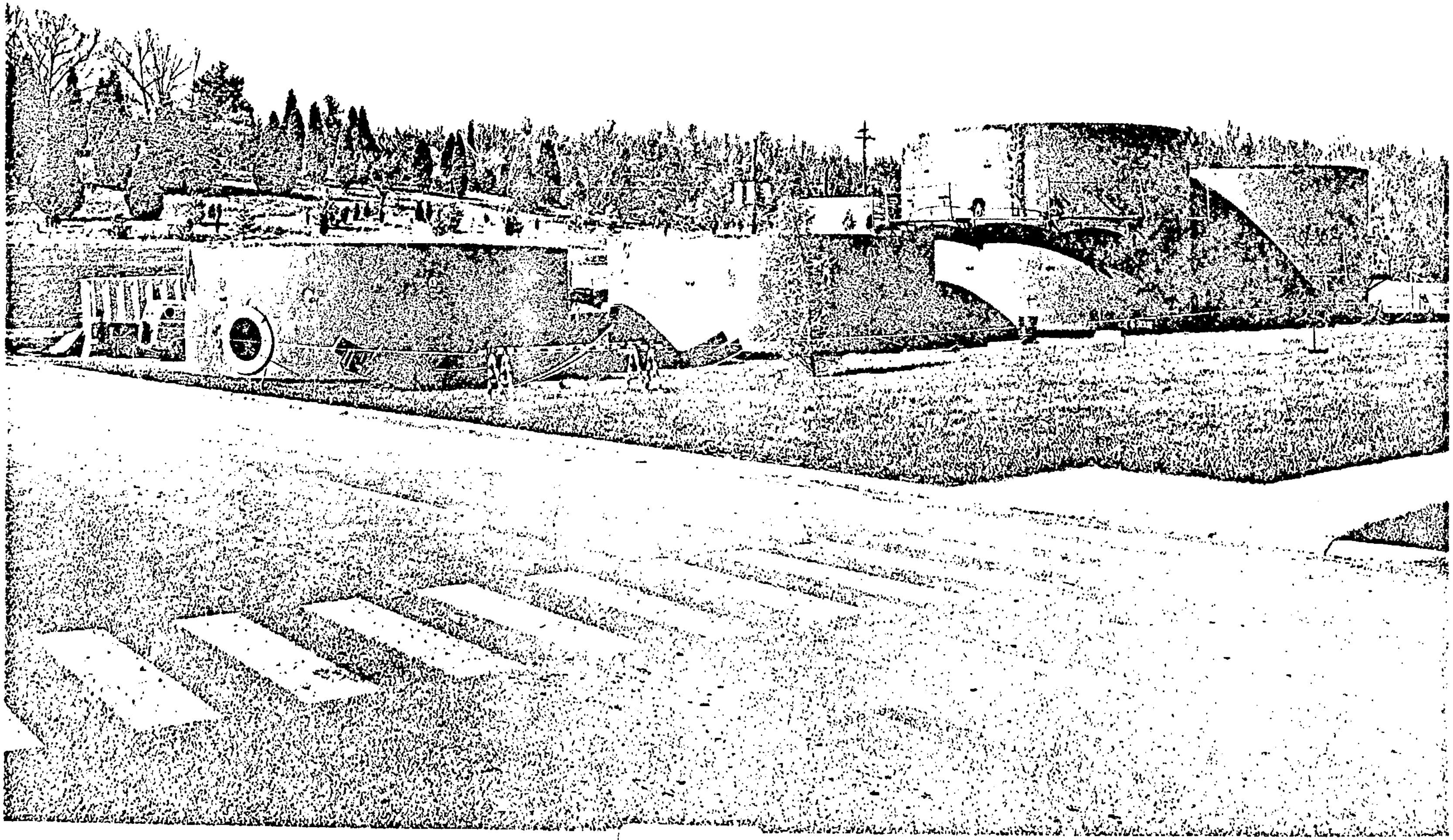

FIGURE 11