Nimrod Maintenance Handbook

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INTRODUCTION TO THE INJECTION SYSTEM

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INTRODUCTION TO THE INJECTION SYSTEM

CONTENTS

F O R E W O R D

Part 1 of this handbook outlines the injection system in functional terms and includes a table of typical parameters during operation.

In Part 2 the scope of the information has been taken a little further than might be suggested by the title. This material has been included with the thought in mind that it may be of assistance in gaining an overall appreciation of the system before proceeding to the handbooks which deal in detail with each item of equipment. The diagrams and photographs of sections of the injection system are included to supplement the information given in the text.

PART 1

I LOCATION

The system is installed in the injector room - a building 170 ft long arranged tangentially to the synchrotron.

II FUNCTION

Low energy protons are extracted from a source and are accelerated, focused, and directed by the injection system to form a beam suitable for injection into the synchrotron.

III DESCRIPTION

The injection system is based upon a linear accelerator (linac) which accelerates the proton beam to 15 MeV. The linac is an alternating gradient focused Alvarez structure using a pulsed 115 Mc/s r.f. power supply (see operating data overleaf).

Initially, protons are extracted from an ion source of the Thonemann type, and their energy is increased by an accelerating column which, together with the source, forms a d.c. gun. The gun is designed to meet the requirements of the linac and the synchrotron. A revolving drum (S.A.M.E.S.) electrostatic generator maintains the high voltage terminal of the gun and its immediately associated equipment at a potential of 600 kV.

The beam characteristics are matched to the input requirements of the linac by quadrupole magnets and a buncher installed along a low energy drift space between the d.c. gun and the linac.

After acceleration by the linac to 15 MeV the beam is matched to the synchrotron by quadrupole magnets and other devices within a high energy drift space.

An achromatic inflector system between the high energy drift space and the synchrotron turns the beam through an angle of 25° on to a line parallel with the equilibrium orbit of the synchrotron.

IV BIBLIOGRAPHY

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V OPERATING DATA

See table overleaf.

O P E R A T I N G   D A T A

Section	Typical parameters	Remarks
Ion Source		
R.F. power	10 kW	30 kW max.
R.F. frequency	120 Mc/s	
Extraction potential	10 kV	20 kV max.
Pulse length	400 µs	2 ms max.
Pulse rep. frequency	28 pulses/min	2 pulses/s max.
Extracted beam current	40 mA	100 mA max. to date
Accelerating Column		
E.H.T. potential	600 kV	
Beam energy	600 keV	
Beam current	40 mA	No loss in column
Beam emittance (Area/π)	5×10^{-3} cm rad	
Low Energy Drift Space		
Buncher:		
R.F. voltage on gap	23 kV max.	
Bunching factor	2.2.	
Beam current into linac	40 mA	No loss in LEDS
Linac		
Frequency	115 Mc/s	
Output beam current for 40 mA input:		
With buncher	20 mA	
Without buncher	10 mA	
Synchronous phase	30°	
R.F. pulse length	1.5 ms	2.5 ms max.
Pulse rep. frequency	28 pulses/min	2 pulses/s max.
Output energy	14.9 MeV $\pm$ 100 keV	Nominal 15 MeV
R.F. power	1.5 MW	800 kW loss in cavity
R.F. voltage on:		
Input gap	140 kV	
Output gap	680 kV	
High Energy Drift Space		
R.F. voltage on de-buncher gap	240 kV max.	
Beam energy spread:		
Without de-buncher	$\pm$ 100 keV	
With de-buncher	$\pm$ 50 keV	
Inflector		
Electrostatic element field	50 kV/cm	

PART 2

I INTRODUCTION

The synchrotron is extremely sensitive to errors in the position, direction, and energy of the injected beam. Because of the critical nature of these parameters, it is necessary to install a wide range of equipment which will produce a beam with controlled variable characteristics.

Although such an injection system comprises a number of devices it can be looked upon as a comprehensive installation designed to match the beam to the synchrotron and synchronise with its operation.

The Nimrod injection system includes a linear accelerator which brings the beam to an acceptable energy level for injection. In the discussion which follows it will be seen that the type of linear accelerator incorporated within the injection system brings its own matching requirements which must also be met by the equipment.

The general control system enables the injection system to function independently as a linear accelerator with its own local controls in the injector control room. When the synchrotron is operating the essential controls are operated remotely from the main control room.

II GENERAL REQUIREMENTS

In order to ensure the efficient injection of protons into the synchrotron certain basic requirements must be satisfied. These can be summarised as follows:-

(a) A means for initiating a pulsed beam of protons.

(b) The acceleration of the protons to a certain energy level before injection. This energy is necessary if the injected beam is to circulate in the synchrotron in an orbit of the required radius.

The 15 MeV injection energy used in Nimrod is a compromise value determined by the synchrotron magnetic field conditions, reduction of gas scattering problems, and the cost of the accelerating system.

(c) The provision of beam control equipment to provide a variety of operating conditions and experimental facilities.

It is necessary to provide equipment for particle acceleration, control of beam intensity, focusing, and alignment (it can be observed in passing, that there is a broad resemblance to the functional requirements of a cathode-ray tube).

In common with the other major installations which serve the synchrotron, the injection system is the subject of continuous investigation and development. The equipment described in this handbook must, therefore, possess inherent flexibility to facilitate the incorporation of improvements as they arise.

III THE EQUIPMENT

It is convenient to examine the injection system from source to output and reference to figure 1 will show that the particle flight path can be divided into six main sections. These are identified under the following headings:-

1. The ion source
2. Pre-injector (d.c. gun or pre-accelerator)
3. Low energy drift space
4. The linear accelerator
5. High energy drift space
6. The inflector system

1. The Ion Source

The source is designed to provide an adequate output which allows for the beam losses that occur within the injection system.

Hydrogen gas is diffused through a heated nickel tube into a small Pyrex vessel. A high intensity r.f. field is applied by means of an external coil and causes an ionising discharge in the gas in the vessel.

By applying a pulsed voltage of suitable polarity, protons are extracted from the ionised hydrogen via a canal within an electrode at one end of the vessel.

A focussing lens box and the source are mounted inside a corona shield or 'bun'. Figure 4 illustrates this section of the system.

2. Pre-Injector

The linear accelerator installed further along the flight path requires a proton input energy of 600 keV. This energy is supplied by an accelerating column mounted integrally with the 'bun' and supported by a remotely controlled trolley.

The column is fabricated from twenty shaped metal discs used as electrodes and separated by ceramic insulator rings. These elements are bonded together by an adhesive and supported by insulating tie rods to form a hollow column.

The energising potential is derived from a 650 kV S.A.M.E.S. revolving drum electrostatic generator with its positive terminal connected to the 'bun' end of the column.

A potential divider is mounted along the column and terminates at earth potential. Equally spaced tappings are connected to the electrodes, and the electrostatic field gradient within the column accelerates the protons to 600 keV.

As the source and the 'bun' end of the column are kept at 600 kV, their immediately associated power supplies and other equipment are mounted on an insulated high voltage (H.T.) platform at the same potential.

3. Low Energy Drift Space (L E D S)

In addition to the input proton energy required by the linear accelerator the beam geometry must conform with its acceptance characteristics. The solution of these problems calls for a considerable amount of equipment and a brief review of the major problems may not be out of place here.

(i) The proton current from the d.c. gun is strong enough to produce appreciable space charge forces. This effect causes the beam to diverge (de-focus), and it is necessary to correct this change in beam geometry by means of electromagnetic and electrostatic focusing equipment.

(ii) Referred to an average particle some protons will have rather higher energy and others lower. This energy spread must be kept within certain limits. Drift spaces and the de-buncher (see HEDS) operate to this end.

(iii) The beam can be displaced from optimum alignment by the injection equipment and the applied electrical forces. The system should enable corrective measures to be taken.

(iv) Beam matching requirements exist at the input to the linac and later when considering the acceptance characteristics of the synchrotron.

The flight tube from the d.c. gun to the linac forms the low energy drift space (LEDS) and it is a useful simplication at this stage to regard this drift space as a system with terminating characteristics that match the acceptance of the linac.

Figure 1 shows some of the equipment in the LEDS and a view of this equipment will be found in figure 2.

(a) Triplets

De-focusing due to space charge effects is counteracted by alternating gradient electromagnetic focusing lenses which take the form of quadrupole magnets fitted around the flight tube. A series of three quadrupoles with suitable gradients and apertures form a triplet which has superior focusing properties to those of three independent quadrupoles.

(b) Toroids

These are beam current transformers installed at points along the flight path where knowledge of the beam amplitude is desirable without any interruption of the beam.

(c) Buncher

This device converts the steady beam into a bunched beam which is more acceptable to the linear accelerator. Basically, it is a single r.f. cavity with re-entrant drift tubes and takes advantage of the bunching effect produced by the r.f. field which appears across the central gap within the cavity.

Its action is somewhat similar to that occurring in klystrons, and compared with the quadrupoles which provide radial focusing, the buncher provides phase focusing.

The bunching action needs a certain beam drift distance to reach its maximum effect and the section of flight tube which follows the buncher allows for this delay.

(d) Four-Jaw Box

An assembly of two 2-jaw boxes enables a cross-section of the beam to be scanned in order to determine the current emittance or beam angle. It also provides a beam defining facility for experimental work.

By arranging two 2-jaw boxes at 90° to each other the beam can be defined in both planes.

A 2-jaw box consists essentially of two graphite coated thick water cooled metal plates located in a slide and actuated hydraulically. In use, the variable dimension collimating slits formed by the plates are controlled hydraulically and are traversed across the beam in a series of settings.

4. The Linear Accelerator (Linac)

Design criteria for linear accelerators are well established but complex and in this section it is only possible to state briefly the principles involved.

The accelerating structure consists of a cylindrical r.f. cavity resonator enclosed in a steel vacuum vessel some 50 ft in length.

A series of drift tubes containing focusing quadrupoles are fitted along the axis of the cavity. Proceeding along the machine each drift tube is made slightly longer than, and is spaced a little further away from, the previous one. This ensures that the accelerating electric fields in the gaps between the drift tubes synchronise with the increasing velocity of the protons.

The cavity is excited into resonance by a 1.5 MW pulsed r.f. power supply at a frequency of 115 Mc/s. The axial r.f. field electrical component between the drift tubes accelerates the protons along the axis to an energy of 15 MeV at the linac output.

The screening provided by the drift tubes removes the decelerating effects of the negative half cycles.

Pulse duration is of the order of 2 ms with a typical repetition frequency of 28 pulses/min.

5. High Energy Drift Space (H E D S)

The 15 MeV beam from the linac has to be focused, steered, and have its energy spread minimised in order to reduce the beam losses that arise during injection into the synchrotron. It will be seen in figure 1 that the high energy drift space includes the necessary equipment and runs from the linac output to the inflector. The overall function of the HEDS is to match the beam emittance characteristics of the linac to the acceptance requirements of the synchrotron.

Several of the items of equipment installed in the HEDS were described in the section dealing with the LEDS, and as these only differ in their operating parameters the information is not repeated here.

(a) De-buncher

Operating in a similar manner to the buncher but with reversed effect, the de-buncher reduces the energy spread of the 15 MeV pulsed beam.

It is also a single resonant cavity of re-entrant drift tube geometry with facilities for tuning.

(b) Steering Magnets

The small deflection fields produced by these electro-magnets are used to offset alignment errors which arise within the system and to reduce any small perturbations that may occur in the beam due to the earth's magnetic field.

Horizontal and vertical magnets are used to align the beam in the two planes.

(c) Probe Boxes

These are self-explanatory in their function and are used for a variety of experimental purposes.

A probe box takes the form of a square vacuum box which breaks the flight tube and enables the beam to be viewed by means of a suitable target. A number of boxes will be found along the flight path at selected points.

An aperture in the top of the box is normally sealed off, and when a probe is used it is inserted into the top and fitted with its sealing plate to preserve the vacuum in the flight tube.

A glass window in the side of the box enables the target to be viewed during operating conditions.

(d) Beam Stops

It is important to be able to stop the beam completely at certain points and under certain conditions. This is effected by inserting a graphite faced water cooled metal plate across the flight tube.

The beam stop is a pneumatically operated device which isolates the beam from the synchrotron.

Operation of the beam stops is by push-button control from the injector control room (ICR) or the main control room (MCR). In addition, certain beam stops are coupled into the master interlock system and close automatically to protect personnel or equipment.

Reference to figure 1 shows that the HEDS passes through a wall which separates the injector room from the magnet hall. A double beam stop is installed on the injector room side of the boundary wall as an additional safety precaution at this point.

(e) Beam Chopper

The beam chopper is included in the system for diagnostic and experimental purposes. It plays no part in the ordinary functioning of the system.

Two parallel plates are used as the electrodes in an electrostatic deflection system which can produce chopped beams down to 1 μs in pulse length.

6. The Inflector System

As will be seen in figure 1 the inflector system is in the magnet hall and runs from the termination of the HEDS to the point where the beam is injected into the synchrotron. Figure 7 provides a general view of the system.

Four vertical bending magnets separated by straight sections of flight tube form an achromatic system which orients the flight path towards the injection point. An electrostatic deflecting element at the end of the inflector completes the bending function which turns the 15 MeV beam through a total angle of 25°.

The inflector system has inherent focusing properties, and the available space permits the inclusion of emittance control and beam defining facilities.

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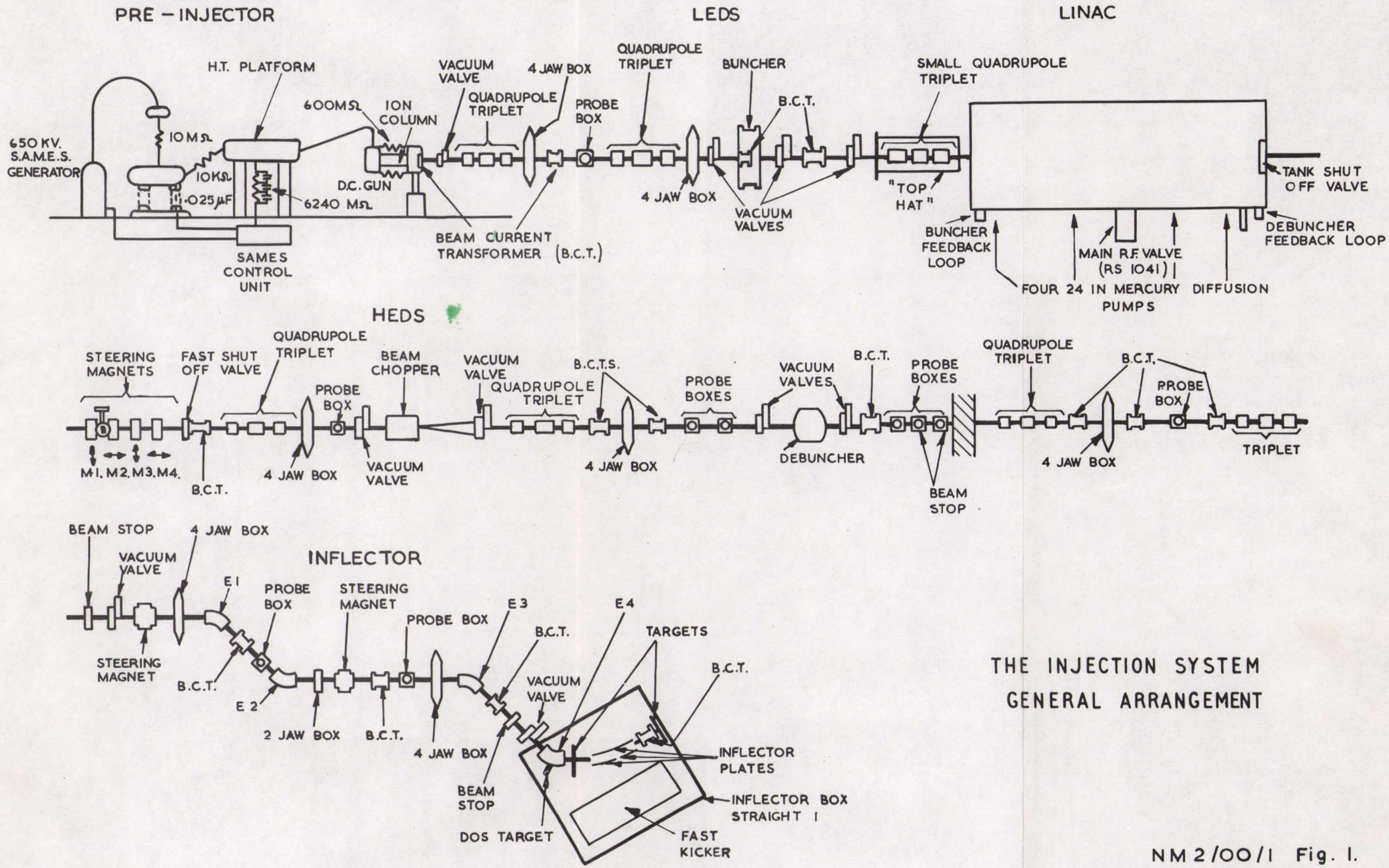
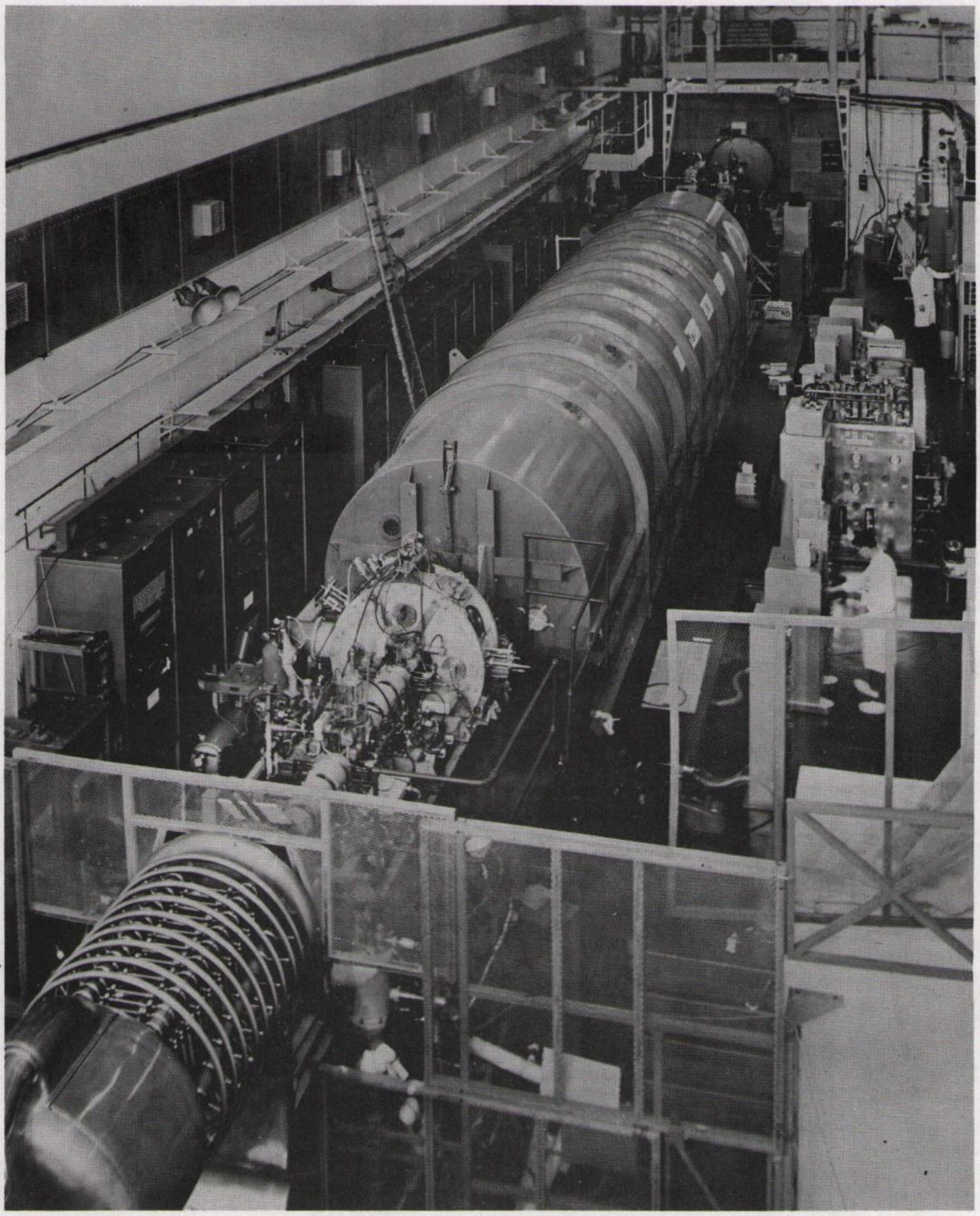
In these notes upon the injection system little mention has been made of the extensive, varied, and complex auxiliary equipment which is essential to such an installation. This includes power supplies of many types; vacuum, cooling and compressed air systems; direct and remote control facilities and safety interlocks, together with other protective systems for personnel and equipment. For this information reference should be made to the appropriate handbooks in this series.

LIST OF DIAGRAMS

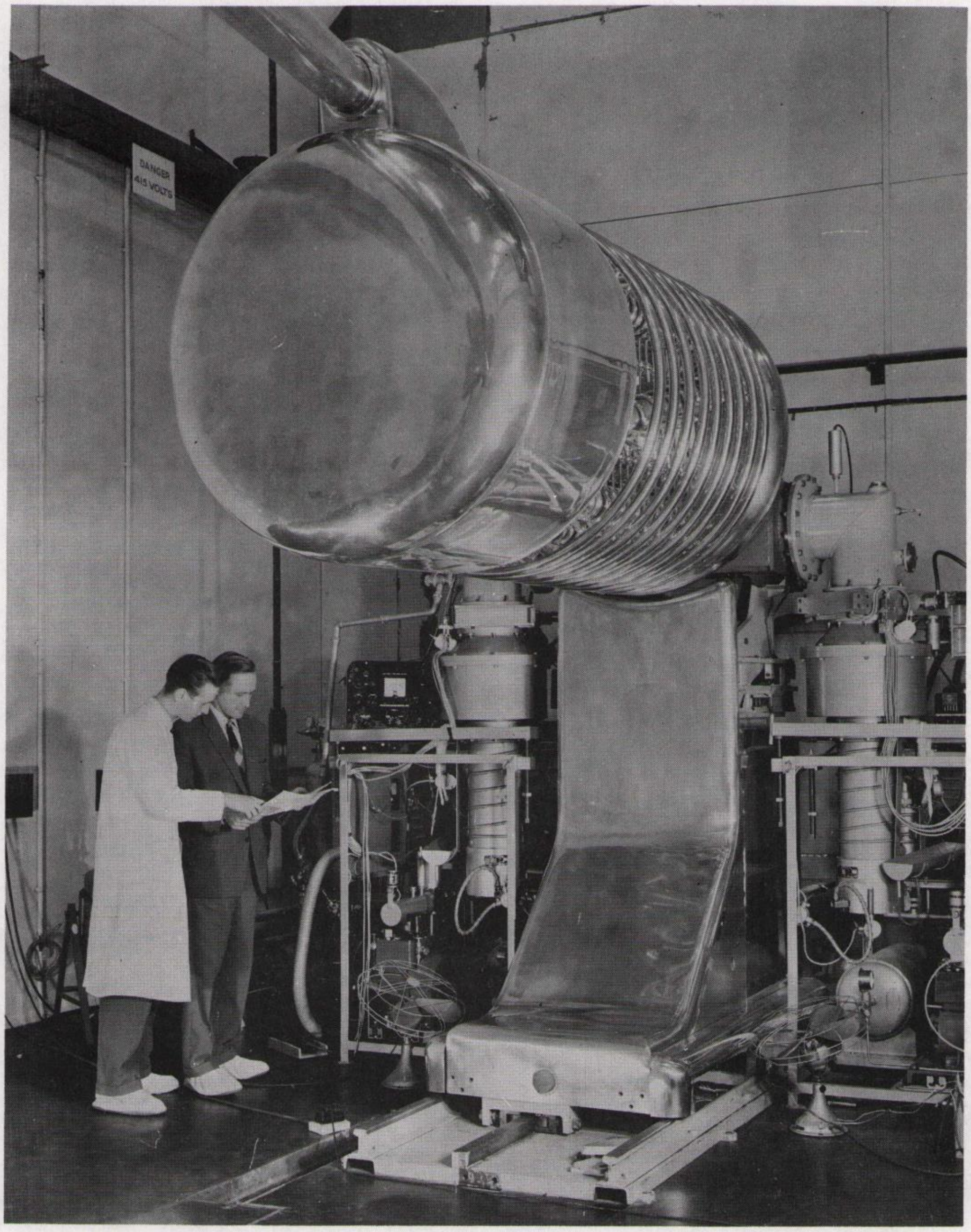


THE INJECTION SYSTEM
GENERAL ARRANGEMENT

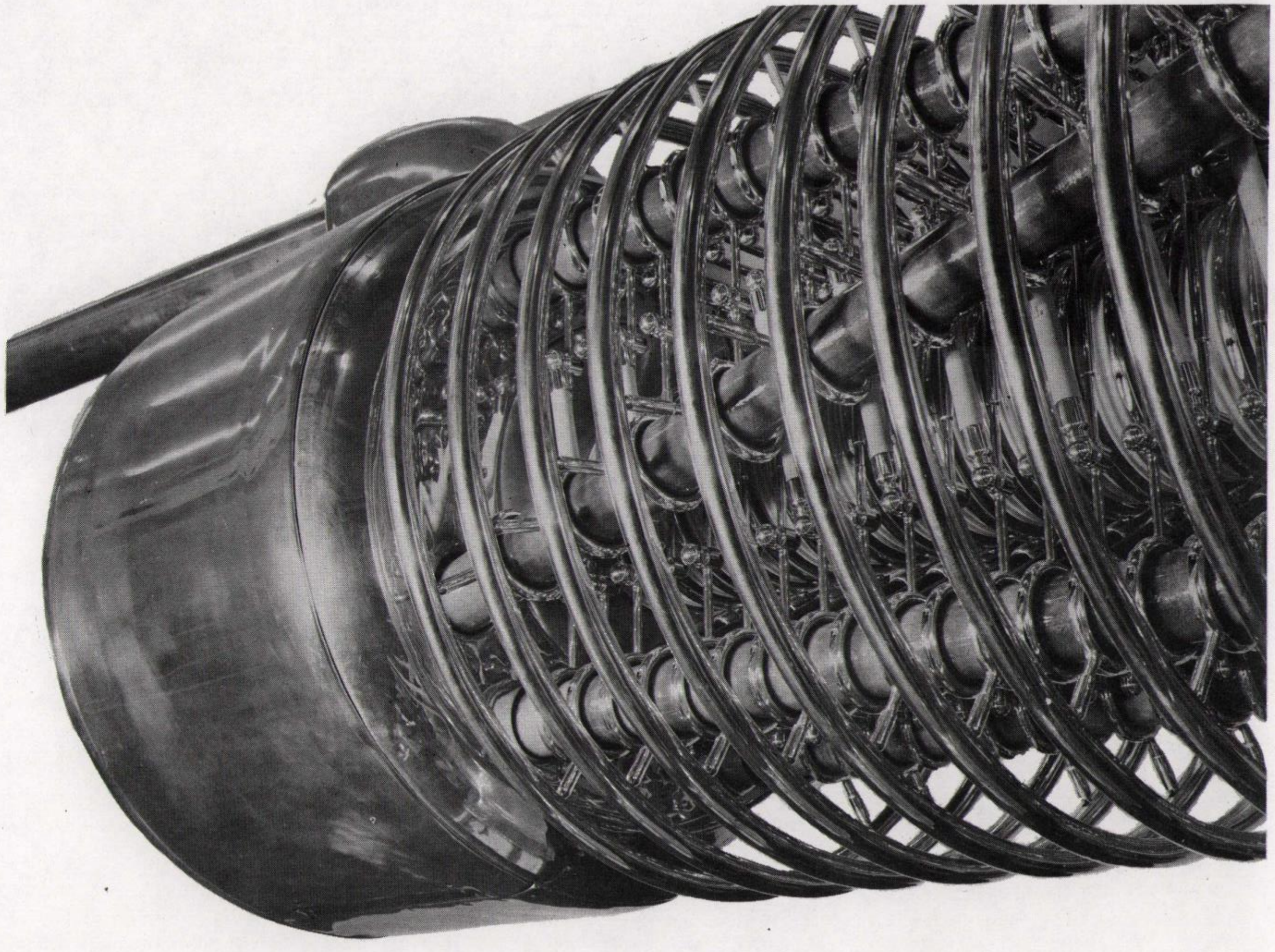
NM 2/00/1 Fig. 1.



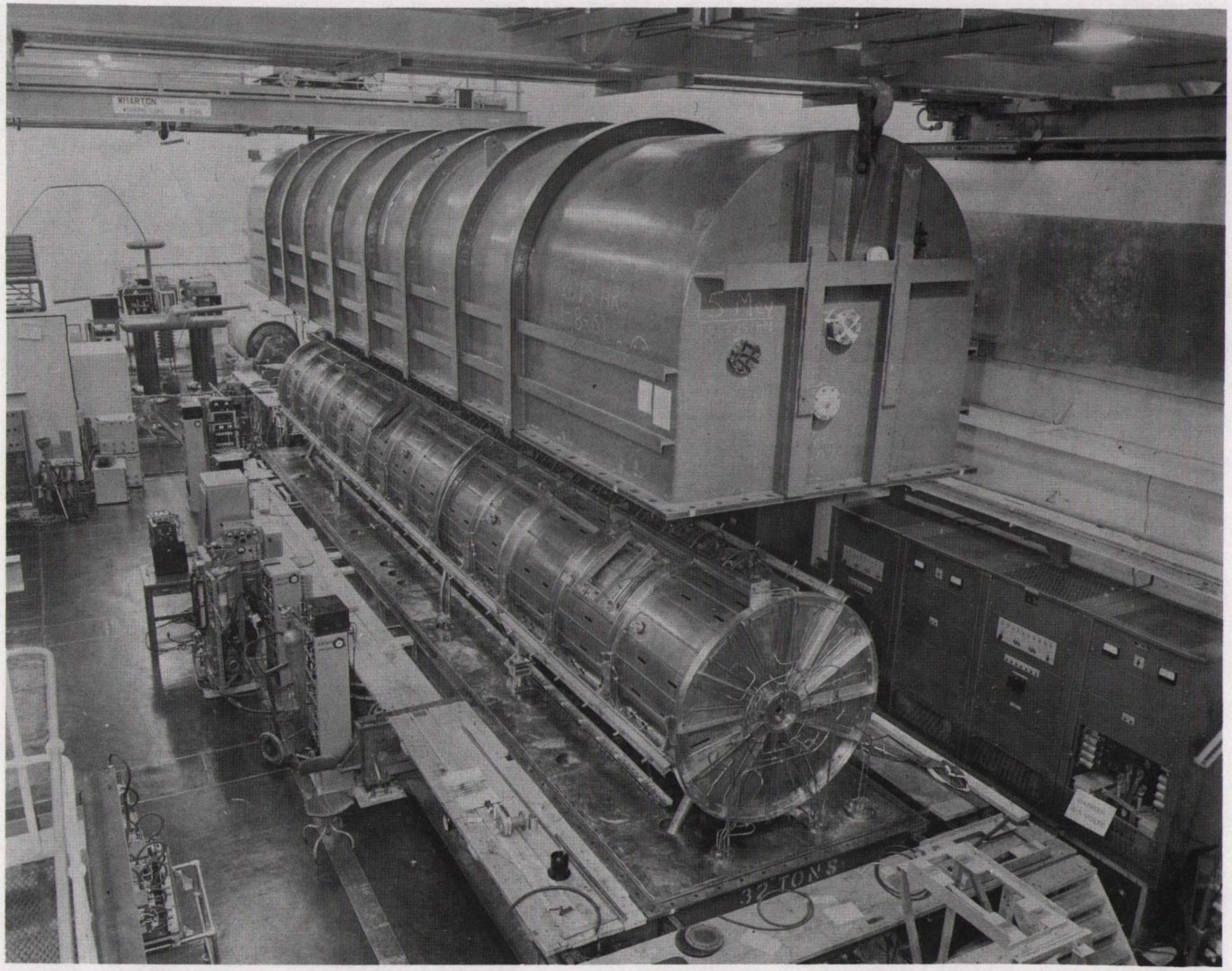
NM2/00/1 Fig. 2. VIEW OF THE INJECTION SYSTEM



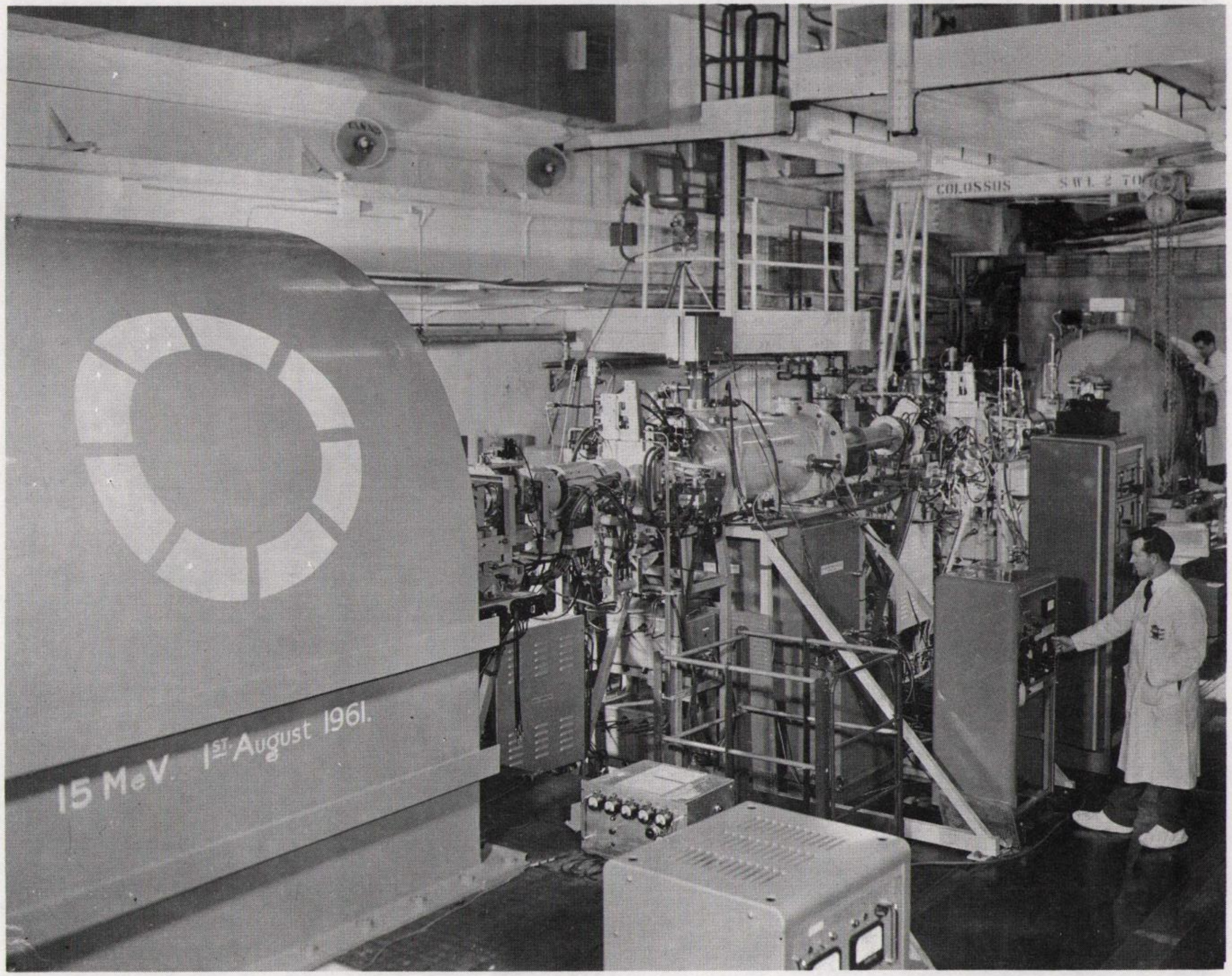
NM2/00/1 Fig. 3. THE D.C. GUN



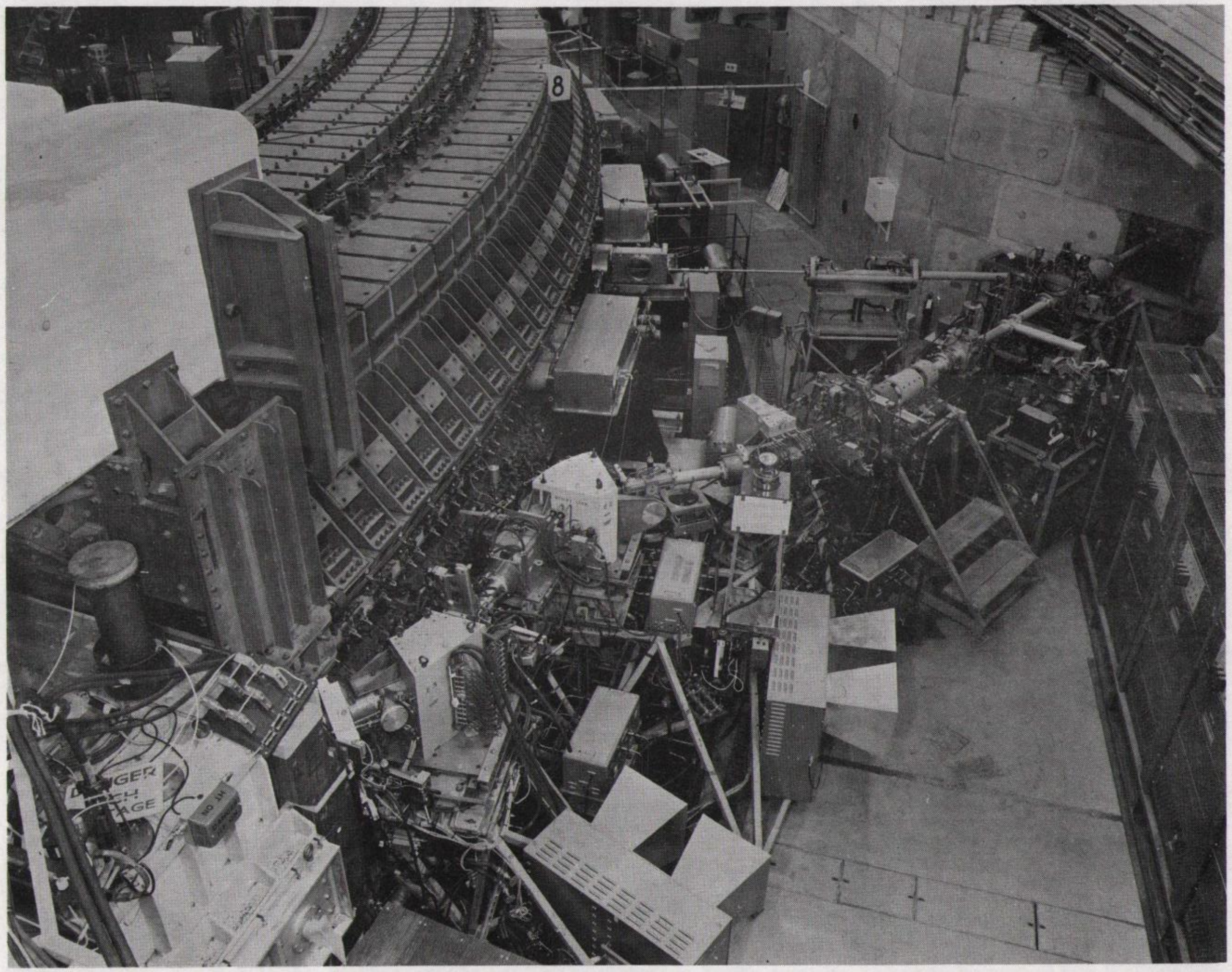
NM2/00/1 Fig. 4. ION SOURCE AND ACCELERATING COLUMN



NM2/00/1 Fig. 5. THE LINAC WITH COVER REMOVED



NM2/00/1 Fig. 6. VIEW OF THE HIGH ENERGY DRIFT SPACE



NM2/00/1 Fig. 7. VIEW OF THE INFLECTOR

Introduction to the Injection System

NOTE Figure 8 (Plan of the injection room and plant layout) is in preparation and will be issued at a later date.