THE PRESENT STATUS OF THE DARESBURY NUCLEAR STRUCTURE FACILITY

R.G.P. Voss,
Science & Engineering Research Council, Daresbury Laboratory, Daresbury, Warrington WA4 4AD, U.K.

Introduction

The last occasion on which a paper was presented to this series of Particle Accelerator Conferences was in 1973[1]. At that stage a design study had been completed for a tandem to operate initially at 20 MV and to be capable of development over several years to 30 MV, and a fully costed proposal had been submitted to the Science Research Council. Objections from local environmentalists to the proposed construction of a 70 m high tower in a fairly rural area led to a delay in obtaining planning permission. This was finally obtained, and full financial authorisation to proceed to the first stage of 20 MeV was obtained in early 1974.

Construction started immediately. The design of the key components was based largely on an extensive R & D programme within Daresbury Laboratory, and the actual construction was carried out by the Laboratory. Various reports[2,3] have given descriptions of the basic design philosophy and of the construction of the project. Delays were caused in the construction programme firstly by serious delays in the building and civil work, and secondly by problems encountered in the testing of the machine as a voltage generator, without tube, to approximately 30 MV. Construction of the machine is now complete, most parts have been commissioned, and the successful running of various ion beams for experiments began in late 1982. Very stable beams of excellent quality, with terminal potentials up to 18 MV, have been produced. Though at this early stage many difficulties remain to be resolved, no obvious limitation to the terminal voltage attainable has been encountered, and it is planned gradually to increase it in accordance with the requirements of the experimental programme.

Research and Development Programme

The design of the accelerator fell in to two parts. One was a question of detailed design based on known techniques and calculable properties. This covered aspects such as the ion beam optics[4] and associated equipment like focusing and bending magnets and beam diagnostics, the structural properties of the column[5,6], the vacuum pumping system, and the gas handling plant. The second part relates to areas where there is much less certainty: the behaviour of insulators, how to protect them, the properties of charging mechanisms, and of accelerator tubes and vacuum breakdown, how to operate a high speed computer-based control system in a hostile high voltage environment, etc. In order to try to establish a secure scientific and technical base for this second category, an extensive R & D programme was mounted, and this has continued throughout the life of the project. Extensive test equipment has been developed, including a 1.5 MV Van de Graaff generator, and a 1 MV Marx generator with a risetime of a few nanoseconds[7]. Once the basic designs were established, they were used to construct a pilot machine, for testing both the designs themselves and other components as they were designed. The pilot machine has a column 3 m long, and can attain voltages in excess of 10 MV as shown in figure 1.

With these test facilities detailed studies were made to choose the best insulator[8], and to develop effective methods of preventing damage to the insulators under discharge conditions[9]. The laddertron charging system was developed and tested extensively[10].

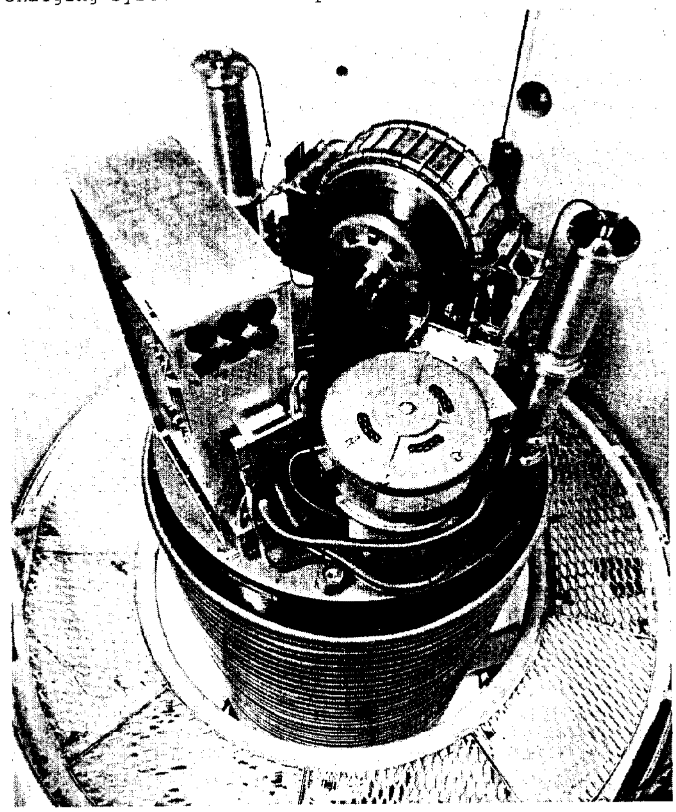

Fig.1. View of pilot machine with the terminal cover removed.

The most critical component in a tandem accelerator is usually the accelerator tube. Tube development work has been in progress at Daresbury since the early days of the project. There have been two main aspects to this work, one relating to the technical problem of producing an organic-free tube, the other being the physical processes which occur inside the tube, and how to control them to prevent them from leading to premature breakdown. On the first aspect, a long development programme led to the establishment of a highly reliable technique for bonding high-density alumina insulators to titanium electrodes.

The physical processes taking place inside tubes have been the subject of a series of experiments carried out on the various test facilities in the Laboratory. Topics investigated include single gap breakdown, multigap breakdown, the shape of the insulator, the type and the surface treatment of electrodes, the species and the energies of the ions taking part in microdischarges, and methods for suppressing microdischarges. The outcome was the very successful testing of 3 m of tube in the pilot machine. Conditioning was studied, it was confirmed that activity such as microdischarges in one section could be decoupled from other, neighbouring sections, and the tube was operated successfully at 6 MV.

A considerable number of papers have been published which relate to this tube work. Rather than list-

0018-9499/83/0800-2680$01.00© 1983 IEEE

ing many individual references, one reference is made to a comprehensive review paper[11].

Construction

Once the design of the basic components was established, construction of the accelerator could begin. Figure 2 shows the outline design. The 42 m column was constructed in lengths outside the vessel, using glass insulating legs manufactured in the Laboratory. Included in the column are the centre termminal, two long (1.8 m) dead sections, and four short (0.7 m) dead sections. The centre terminal is 4.5 m long. The first section of column was lowered into the pressure vessel and surveyed into position. The second section was then lowered on to the first, a special technique having been developed for avoiding stress in the glass insulators when assembling column sections, and when joining one column section to the next.

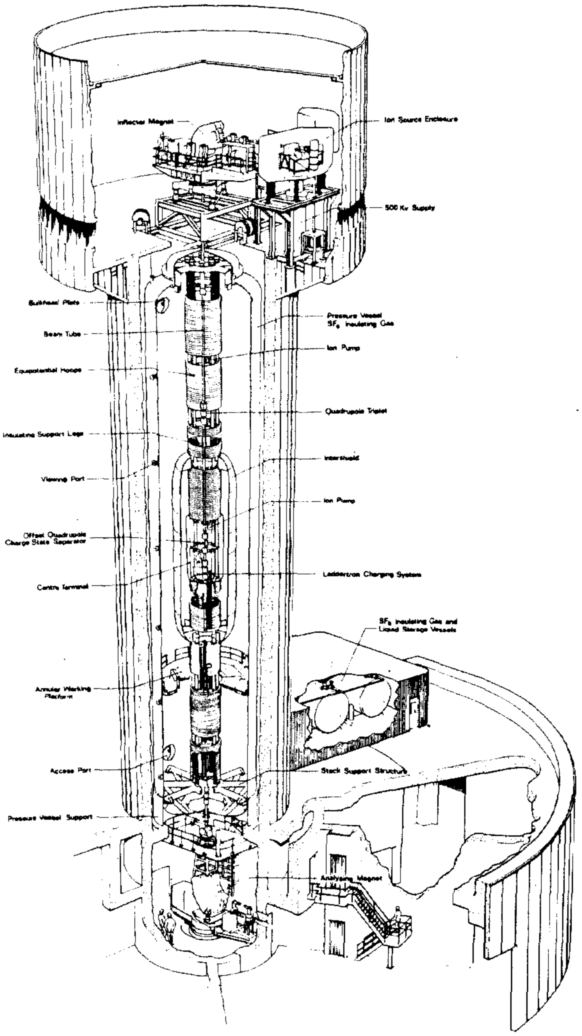

Fig.2. Outline design of the NSF.

The length of the column necessitates a considerable amount of equipment for focusing, steering and monitoring the beam, vacuum pumping stations, etc. Some of the equipmment and associated measurement of parameters are listed below.

Biased collimators with current readout,
X-Y slits,
column current measurement,
tube current measurement,
ion pumps, with pressure and temperature measurement,
terminal cryopump,
400 Hz alternators and their temperatures,
bulkhead bearings temperatures,
accelerometers,
power supplies and contactor switches,
shorting tape mechanisms,
magnetic quadrupole triplets and steering coils,
offset quadrupole charge state selector,
generating voltmeters,
Faraday cups,
stripper mechanisms.

Figure 3 is an internal view of the column. It shows the stack legs, potential divider resistor chain, laddertron, drive shaft for the 400 Hz permanent magnet alternators, and a plexiglass tube carrying cold SF_6 for cooling purposes. In the centre is the accelerator tube, installed at a later stage.

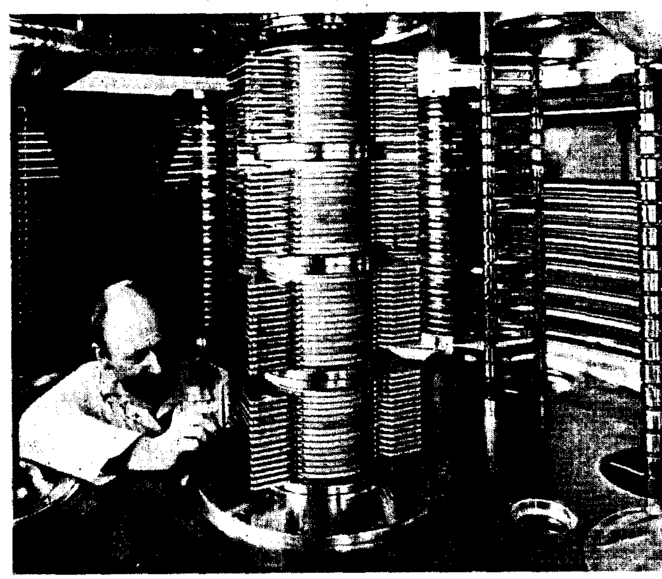

Fig.3. Internal view of column showing main components.

The gas plant has been fully operational for several years. A gas charge of 150 t of SF_6 is used, and the plant, like all other parts of the accelerator, is under computer control. From the television screen all valves are controlled and maintained, pumps and motors started and stopped, and all temperatures and pressures maintained. Appropriate alarm limits can be set on all parameters. Operation of the gas plant has been straightforward and easy. Operators have found the system easy to use. To date there have been 46 full pressure cycles.

Control System

The list above shows that there is a great deal of equipment inside the vessel, and consequently a fast and comprehensive control system had to be developed. It is based on a 5 Mbit/s serial data transmission system, using an array of minicomputers linked to a midicomputer, and interactive colour television displays. Inside the pressure vessel communication is by an infra-red light link. Each dead section has a microprocessor, and the total number of monitoring points is about 2000. The rate of scan will normally be about once every 10 ms, though at present a lower rate is being used because the midicomputer is not yet fully in use.

In principle, everything can be controlled by a light pen and one knob. A novel feature is that any analogue measurement can be brought up as a real time analogue signal on an oscilloscope at the control desk. This has been found to be an extremely useful tool during commissioning, in studying fluctuating processes occurring in the column.

During the high voltage tests there have been more than 500 sparks at high voltage levels. Throughout this rigorous testing almost no damage to the control system has been experienced, and it is believed that additional filtering has removed even that small probability.

Initial High Voltage Tests

In order to determine the basic voltage generating capability of the accelerator, the high voltage tests were carried out in three phases: first, with the column and terminal only, then with the intershield added, finally with the tube in position.

By May 1980 the machine was ready for the first phase of testing. High voltage tests were carried out at various SF_6 pressures. The voltage at which breakdown occurred was compared with predictions based on the performance of the Daresbury 10 MV pilot machine, giving an initial breakdown potential V of the form

$$V = 5.23\ p^{0.66}$$

This curve is plotted in figure 4. Each dot on the graph indicates the potential just before a spark occurs. Agreement with the predicted curve will be seen to be excellent. (In fact more than 200 discharges at high voltage took place and many of the points are superimposed.)

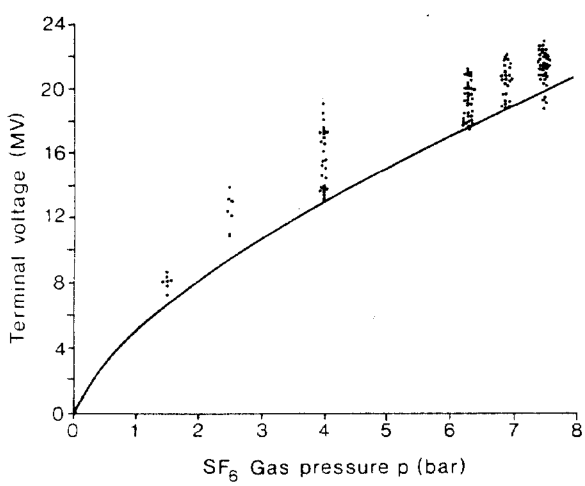

Fig.4. Predicted and observed sparking voltage as a function of gas pressure for machine without intershield.

The Intershield

The intershield is an intermediate electrode shown in figure 2, and is a device to enable a high terminal potential to be obtained with only a rather modest pressure vessel diameter. The effect of the intershield is shown in figure 5. The x-axis represents distance along the column, and the physical outline of part of the terminal, part of the intershield, and some of the column hoops are shown. The y-axis shows the radial electric field strength for various values of the terminal potential. The dotted curve shows the electric field strength for the case of terminal

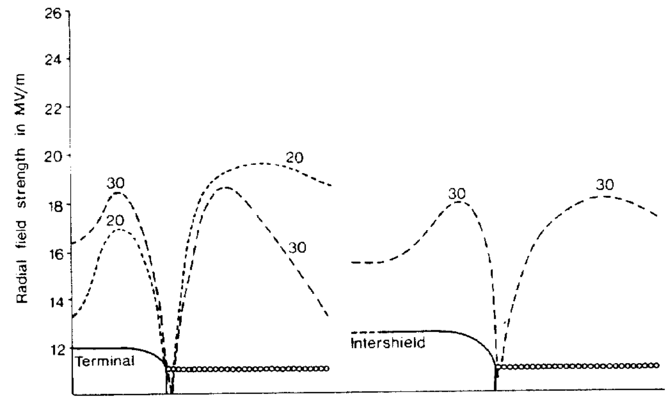

Fig.5. Radial electric field strengths for the NSF with and without intershield.
······· without intershield at 20 MV.
------- with intershield at 30 MV.

alone, with a terminal potential of 20 MV. It is clearly not a good electrostatic design, with very high fields on the hoops, but the accelerator is not designed to run without the intershield. The dashed curve shows the field distribution on both terminal and intershield, for a terminal potential of 30 MV. This field distribution is now very good, the various maxima in the electric field being equal in magnitude. The peak field with 30 MV on terminal is <u>less</u> than the peak field with 20 MV on terminal and no intershield.

The intershield is a cylindrical structure with ellipsoidal ends. It is 14.7 m high, and consists of highly polished stainless steel panels mounted inside and outside a light aluminium alloy frame. It weighs 10 t. A stage in its construction is shown in figure 6. Lengths of framework were assembled on a jig to ensure precise geometry and fitting, and covered with panels inside and out. All parts were numbered before dismantling and then reassembling inside the pressure vessel. On the left is shown the lower part of the frame attached to a dummy length of column. The attachment is made in such a way that no bending moment is transmitted to the column insulating legs.

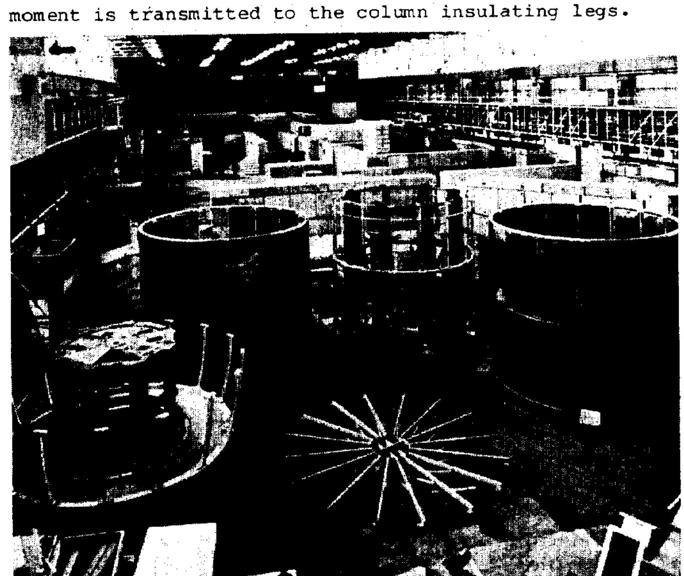

Fig.6. A stage in the construction of the intershield, showing various parts of the intershield including the lower frame fitted to a dummy length of column.

Voltage Testing with Intershield

The intershield was installed and the machine ready for the next stage of high voltage testing by November 1980. This began well, with the terminal quickly reaching 19 MV, at a gas pressure of 4 bars absolute, without a spark. However, it became clear that at higher gas pressures the voltage attainable did not increase as expected. The curve showing the voltage at which sparking was expected to start as a function of gas pressure is shown in figure 7. As in figure 4, each dot represents the voltage just before a spark occurs. The expected increase of voltage with pressure is seen not to have been observed.

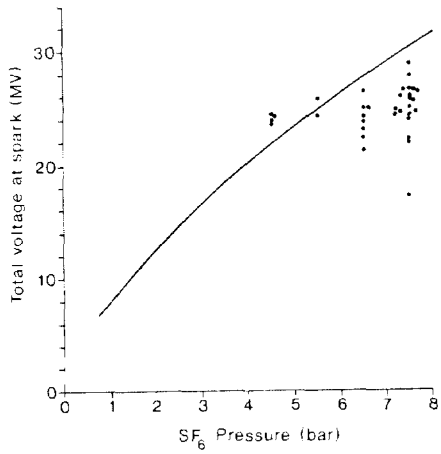

Fig.7. Predicted and observed sparking voltage as a function of gas pressure for machine with intershield.

Detailed studies were made of the electrical discharges, the distribution of currents in the column, and of the laddertron performance. These suggested that the limit was set not by the radial electrical field but by breakdown along the axis of the column, yet in the pilot machine the laddertron, drive shafts, and column structure itself had all been run to axial voltage gradients far in excess of those encountered in the NSF.

One possible factor did come to light. The pilot machine has very little heat input, and its normal operating temperature is about 25°C. In the NSF, temperatures in excess of 30°C can be reached. Available data on insulating materials suggested that this small increase could not account for the difference in behaviour. However, a test rig to study the properties of the monocast nylon used in the laddertron and drive shafts as a function of temperature was set up, and the pilot machine was modified to allow it to be heated. A wide range of different experiments[12] was carried out, leading to a determination of a dependence of voltage performance on temperature far stronger than anything expected. If the laddertron is run at a fairly high temperature, and the voltage gradient is gradually increased, surface breakdown across the nylon links begins. This effectively turns the links into partial conductors, and in extreme cases the whole machine will discharge down the laddertron, sometimes breaking it in the process. The dependence of leakage current across a monocast nylon link on temperature is shown in figure 8.

Once this effect was established, the laddertron was put back in the NSF, and subsequent high voltage tests were made only after circulating and cooling the gas for many hours, to reduce the temperature to about

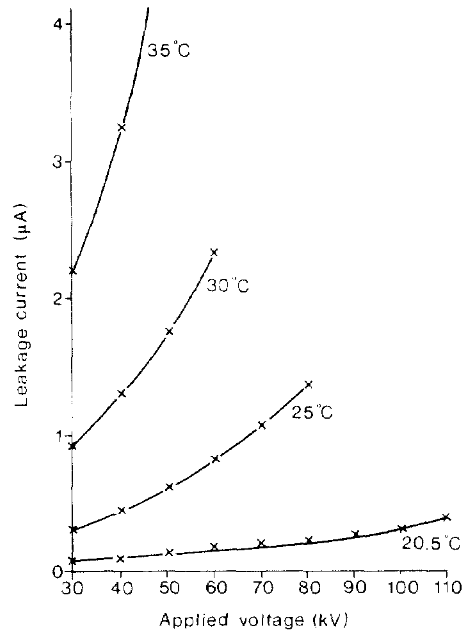

Fig.8. Dependence of leakage current across a monocast nylon link on temperature.

20°C. Under these conditions the whole machine was tested to 29.3 MV. Throughout these tests no trouble with sparking along the laddertron was observed, though occasional breakdown along nylon drive shafts occurred. This set the limit on the voltage attainable, and the problem is under investigation.

Figure 9 shows the column current distribution during one of the high voltage runs, when the terminal potential was 26.13 MV.

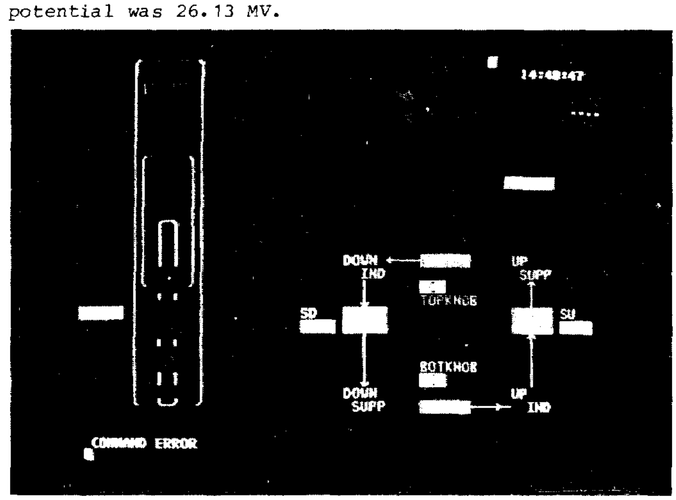

Fig.9. Column current distribution with terminal potential at 26.13 MV.

It was felt that these tests, completed in November, 1981, were most encouraging, and established the electrostatic limit of the accelerator to be comfortably in excess of the ultimate design aim of 30 MV.

Installation of Tube

The tube was installed and was vacuum tight under full SF_6 pressure by the end of 1981. Considerable associated equipment was installed and commissioned: ion pumps, beam scanners, slits, Faraday cups, pressure measurement devices, and the stripper foil changing mechanism. The various magnetic quadrupole triplets, steering coils, offset triplet charge state selector, and the power supplies for all these magnets were commissioned through the light link. Shorting tapes for tube conditioning were installed. During this period the injector was operated continuously for extended periods, for studying beam emittance, beam optics, and for establishing the parameters for the production of a range of ion species.

Initial Operation as Accelerator

Initial commissioning with ion beams started in May, 1982. Because of the delay to the programme caused by the high voltage test problems described above, the first priority was to produce a range of ion beams usable for experiments rather than to achieve the highest possible terminal voltage. Considerable experience has been obtained in conditioning tube, module by module, and in other aspects of high voltage operation. Without a beam 19.5 MV has been achieved. With a beam, beam optics, charge state selection, stripping, stabilisation etc. have been studied. Beams accelerated to date include ^{4}He, ^{6}Li, ^{7}Li, ^{12}C, ^{16}O, ^{17}O, ^{18}O, ^{29}Si, ^{32}S, ^{34}S, ^{36}S, ^{48}Ti and ^{48}Ca.

Beam transmissions as high as 90% have been obtained, and the energy stability for light ions appears to be better than 1 part in 10^{4}. In these early days of operation no attempt has been made to try for the highest possible voltage, but in recent months the requirements of the experimental programme have been met with a variety of terminal voltages including several weeks' operation in the range 17.7 to 18.3 MV. In this range no limitation to the terminal voltage achievable was apparent, and it is hoped to increase it in the near future to 20 MV.

References

1. N.R.S. Tait and R.G.P. Voss, "A National Nuclear Structure Facility for Britain", Trans. IEE Nucl. Sci. NS-20, p.163, (1973).

2. T.W. Aitken, B.S. Halliday, W.T. Johnstone, C.W. Jones, T. Joy, M.C. Morris, N.R.S. Tait and R.G.P. Voss, Nucl. Instru. and Methods 122, p.235, (1974).

3. R.G.P. Voss, Trans. IEE Nucl. Sci. NS-26, p.1459, (1979).

4. T. Joy, J.C. Lisle and W.R. Phillips, Daresbury Laboratory Report DNPL/NSF/R3 (1972).

5. J. Cook, N.T. Barrett, C. Massey, J.F. Dickie and T.J. Poskitt, "Static and Dynamic Mechanical Behaviour of the Stack of the NSF Tandem", Daresbury Laboratory Report DL/NSF/R16 (1977).

6. J.M. Leese, "The Mechanical Development and Construction of the Insulating Legs for the NSF Tandem", Daresbury Laboratory Internal Report DL/NSF/TM39 (1978).

7. T.R. Charlesworth and B.S. Halliday, "Two High Voltage Test Facilities at Daresbury", Daresbury Laboratory Internal Report DL/NSF/TM17 (1976).

8. T.W. Aitken and T.R. Charlesworth, "Surface Breakdown Studies of Glass in SF_6", Daresbury Laboratory Internal Report DL/NSF/TM11 (1974).

9. T.W. Aitken and R. Thorn, "Shielding Methods for Insulators and Other Components", Rev. de Phys. Appl. 12, p.1517 (1977).

10. T.W. Aitken and J.M. Leese, "Laddertron Developments", Rev. de Phys. Appl. 12, p.1391 (1977).

11. T. Joy, "The Development of High Gradient, High Vacuum Accelerator Tubes at Daresbury", Third International Conference on Electrostatic Accelerator Technology, p.87 (1981).

12. D.A. Eastham and P.S. Powell, to be published.