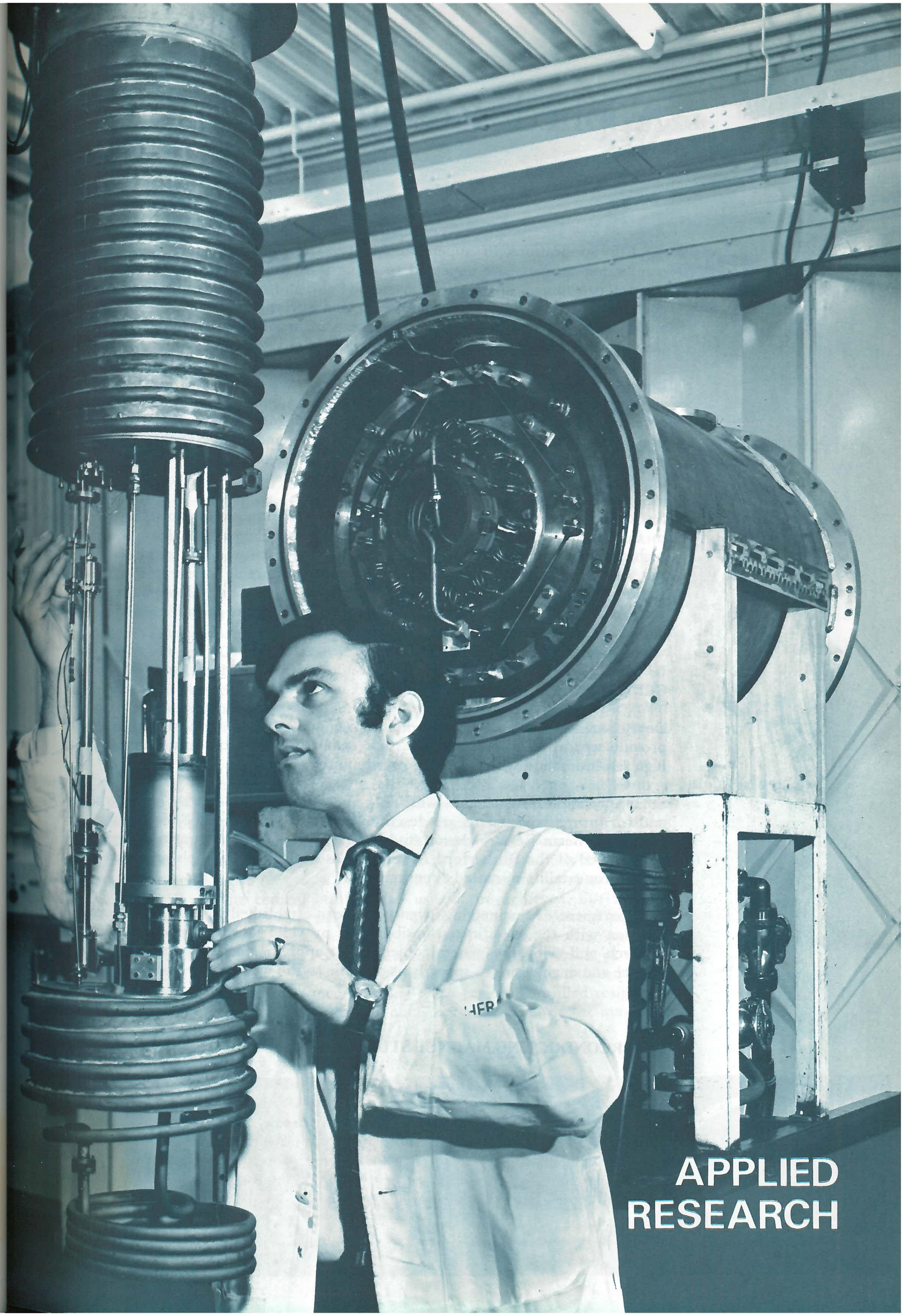


APPLIED RESEARCH

A cryostat assembly used for testing superconducting magnet coil systems.

Applied Research

A large part of the applied research in the Rutherford Laboratory is directed towards applications of superconductivity. During the coming decade superconducting magnets are expected to come into widespread use in high energy physics, providing more powerful magnetic fields and/or lower capital and running costs for bubble chamber magnets, beam transport, proton synchrotron magnets, and synchrotron power supplies. These can make possible definite advances in the experimental studies of fundamental particle physics.

Long term studies of possible accelerators to supersede Nimrod are under way, and, in line with the Laboratory's interests in superconducting technology, accelerators based on pulsed superconducting magnets have great attraction in this context. The design study of a 25 GeV Superconducting Synchrotron, which could replace Nimrod (a 7 GeV Synchrotron) in the existing Magnet Hall, is described.

Such a machine would give an extended return from our large capital investment in the whole Laboratory support complex, by providing a basis for home-based high energy physics in the 1980's. It could also constitute an extremely valuable pilot project for a future very high energy superconducting accelerator in Europe. In addition, it would open the way to further accelerator development by acting as an injector for a larger superconducting ring, should the scientific and financial climate become favourable for such a project.

In connection with new accelerator developments, the design status of the new CERN 300 GeV accelerator is summarised.

Development work on superconducting r.f. separators is presented. These will provide separation of secondary particle beams into their constituent types, with high resolution and with low r.f. power requirements.

Some special purpose magnets which have been designed to control particle beams and for future experiments are described. Other sections include the status of the High Flux Beam Reactor design study and descriptions of apparatus designed and constructed at the Rutherford Laboratory as engineering models or actual flight models for satellite mounted experiments.

A Department of Engineering Science has been established within the Engineering Division with the specific responsibility of providing direct support for applied research and with the general objective of applying technological advances in science and engineering as speedily as possible to the work of the Laboratory.

SUPERCONDUCTING MAGNET STUDIES

Following the successful development of composite filamentary conductors suitable for these applications, the emphasis is now on the solution of the remaining hardware problems, and the development of reliable and economic engineering techniques. In particular, considerable priority is now being given to the evolution of prototype pulsed magnets suitable for use in proton synchrotrons, which would enable the energy of the proposed European accelerator (initially 200-300 GeV) to be subsequently increased to over 1000 GeV.

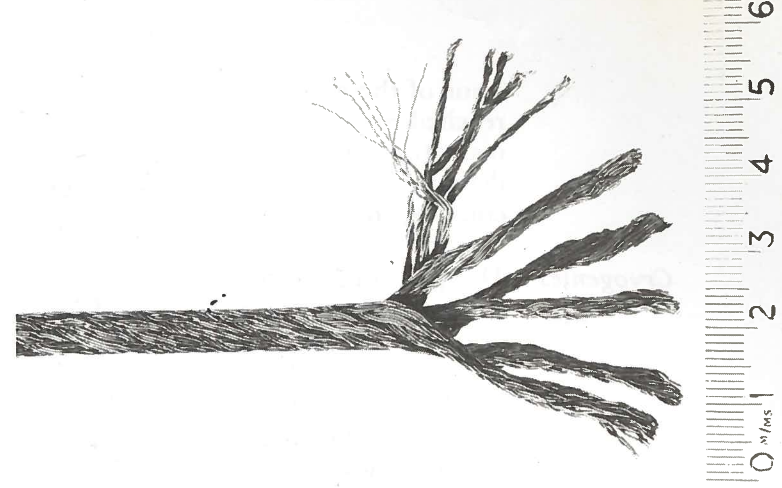


Figure 106. Compacted multi-strand cable.

Because of the importance and difficulty of the latter possibility, the scope of the programme has been widened during 1970 to include practical and theoretical studies of all of the problems associated with the development of pulsed superconducting magnets with the necessary degree of precision and reliability.

Conductor Development (Ref. 155)

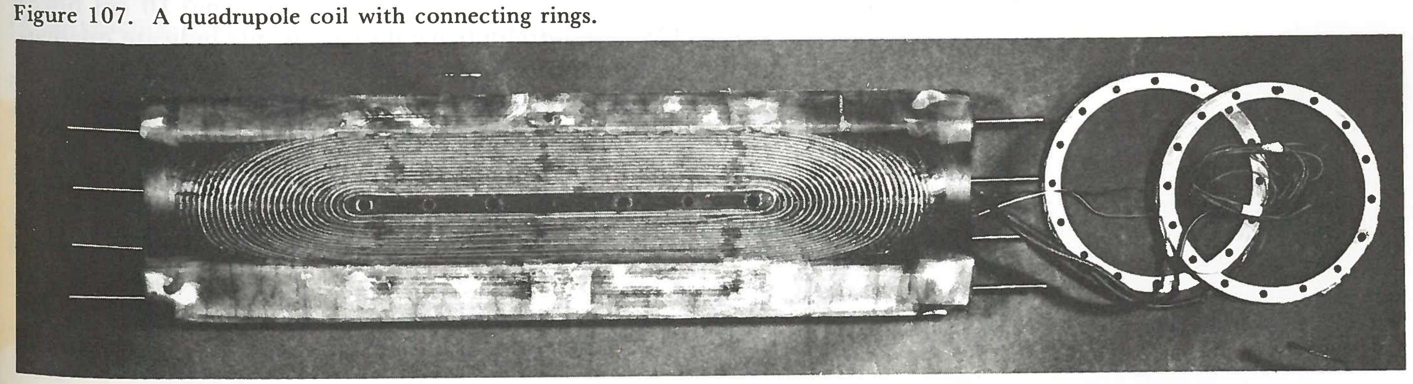
Work has continued on the development of NbTi conductors in collaboration with Imperial Metals Industries, and composites containing larger numbers of filaments and with better filling factors have been produced. Magnetisation measurements on composites containing both copper and cupro-nickel in the matrix, have given results in accord with theory. A new test rig is under construction which will allow future larger cross-section conductors (up to 10,000A) to be tested for critical current, stability, magnetisation, and a.c. loss, at rates of change of field up to 60 kG/sec.

An important problem tackled during 1970 has been the fabrication of the basic composites into compacted, fully transposed, multi-strand cables, capable of carrying currents in the 2000-8000A range. A cabling machine has been purchased and techniques developed for the manufacture of fully transposed systems containing up to 216 strands, with subsequent shaping into rectangular or square section to improve the packing and facilitate coil winding (figure 106). Further work is still necessary to completely eliminate wire breakage during the final compaction stage.

Coil Performance

The study of fully impregnated magnets initiated in 1969 was continued throughout 1970, the object being to determine how good a performance can be achieved and which impregnants are most suitable. The programme consists principally of tests on a series of separate quadrupole coils using a variety of impregnants, including filled and unfilled epoxy resins, waxes, and frozen liquids (figure 107). About 16 separate poles have now been tested. The principal conclusion is that at least 90-95% of the critical current can usually be achieved, but that the impregnant does have a considerable effect on the amount of initial 'training' necessary. The latter has been shown to be correlated with the mechanical strain energy created during fabrication and/or cooldown; materials incapable of storing appreciable strain energy (e.g. wax) or with low thermal contraction (filled resins) show least training, while coils incorporating crack resistant unfilled resins may sometimes require dozens of quenches and many cooldowns before the maximum current can be achieved.

Figure 107. A quadrupole coil with connecting rings.



Four of these coils were assembled to form a complete quadrupole, which reliably reached over 95% of critical current, giving a peak field of 40 kG in a 12 cm bore diameter, the coil current density being 27,000 A/cm^2. This is the first full-scale demonstration that simple fully-impregnated coil systems will be suitable for the construction of d.c. superconducting beam elements.

Cryogenics

The preceding tests were carried out with the coils immersed directly in liquid helium, whereas in practice indirect cooling techniques may be preferred (e.g. circulation of the coolant through adjacent tubes). To verify that the performance is equally good under these conditions the tests will be repeated in a horizontal cryostat cooled by supercritical or two-phase helium. Manufacture and assembly of the cryostat, together with auxiliary dewar, heat exchanger, and reciprocating pump, is now complete and the first magnet tests will be carried out early in 1971.

Comparative theoretical studies have been made of the various methods of employing liquid helium as a coolant: (i) two-phase, 1 atmosphere, (ii) single phase, supercritical pressures (iii) single phase, 1 atmosphere (sub-cooled), (iv) free boiling, with, in each case, the option of assisted or natural convection as an alternative to pumped circulation. In addition some small-scale experiments have been carried out to check the conditions under which oscillations in two-phase helium may occur.

Pulsed Magnets

Extensive tests on small solenoids during 1969 had already confirmed the basic suitability of filamentary conductors for pulsed magnets, and during 1970 the construction of prototype pulsed synchrotron magnets was initiated. A small dipole (35 kG, 30 cm long, 4 cm x 2 cm aperture) was constructed and operated satisfactorily with continuous triangular current waveforms at frequencies up to 0·5 c/s. In parallel with this, work began on a larger and more realistic dipole, length 40 cm, aperture 10 cm, designed to give 45 kG at 7,000A and 1 sec rise time. By the end of 1970 all magnet components and associated equipment had been manufactured and a trial section of the superconducting coil had been wound and tested. Some delay has arisen from the above-mentioned strand breakage problem in the compacted cable, but the complete magnet is still expected to be operational during the first half of 1971.

This magnet is fully impregnated but incorporates laminated copper mats to conduct the heat from the interior of the winding to the coolant. This technique is being compared with the alternative of internal cooling channels, in preliminary design studies for a proposed fully-realistic synchrotron magnet prototype.

Synchrotron Magnet Design (Ref: 60)

In parallel with the studies of magnet performance, theoretical and experimental work has been in progress on the problems of designing and fabricating coils which will have, and maintain, the degree of precision (typically 1 in 10^3) needed in a synchrotron. Analytical and computer studies have yielded suitable designs for the coil cross-section and for the coil ends, and have indicated the magnitude of the various winding tolerances which must be met. As a convenient, and inexpensive, way of studying these problems practically, a programme of field measurements has been initiated using low-field copper models at room temperature and also in liquid nitrogen to check thermal distortion effects. The manufacture of formerless coils to a very high accuracy has required the development of novel production techniques in the Laboratory workshops. Patent action has been taken on the processes involved. The first precision-wound dipole (90 cm long, 10 cm bore) has been completed (figure 108), and preliminary measurements indicate quadrupole (asymmetry) errors certainly no greater than 1 in 10^3 – an extremely encouraging result, since it is already within the typical tolerance requirements of a synchrotron. Development is now in hand to further the techniques to give greater accuracy and reduce manufacturing time. The coils so far produced have been hand-built, but a higher degree of mechanisation is envisaged in the form of improved jigs and fixtures.

Figure 108. The precision-wound dipole magnet.

Forward assessment of a number of synchrotron design problems has continued, both to assist the course of the technology programme and as a guide to future possibilities. A major item in this part of the programme has been a detailed study of a specific scheme for the construction of a 25 GeV superconducting synchrotron in the existing Nimrod Hall. This has clarified many of the injection, ejection, and lattice design problems, as well as indicating typical aperture, field, and rise time requirements. (See Superconducting Synchrotron Design Study page 146).

Other problems studied include estimation of tolerable field errors during resonant ejection, calculations of the degree of lamination required in iron shielding, studies of the feasibility of self-powered superconducting correction windings, and first assessments of the effects on magnet design of any requirements for rapid Q-shift (e.g. during transition). Subsequent studies will be oriented in particular towards problems associated with the possible conversion of a large European accelerator.

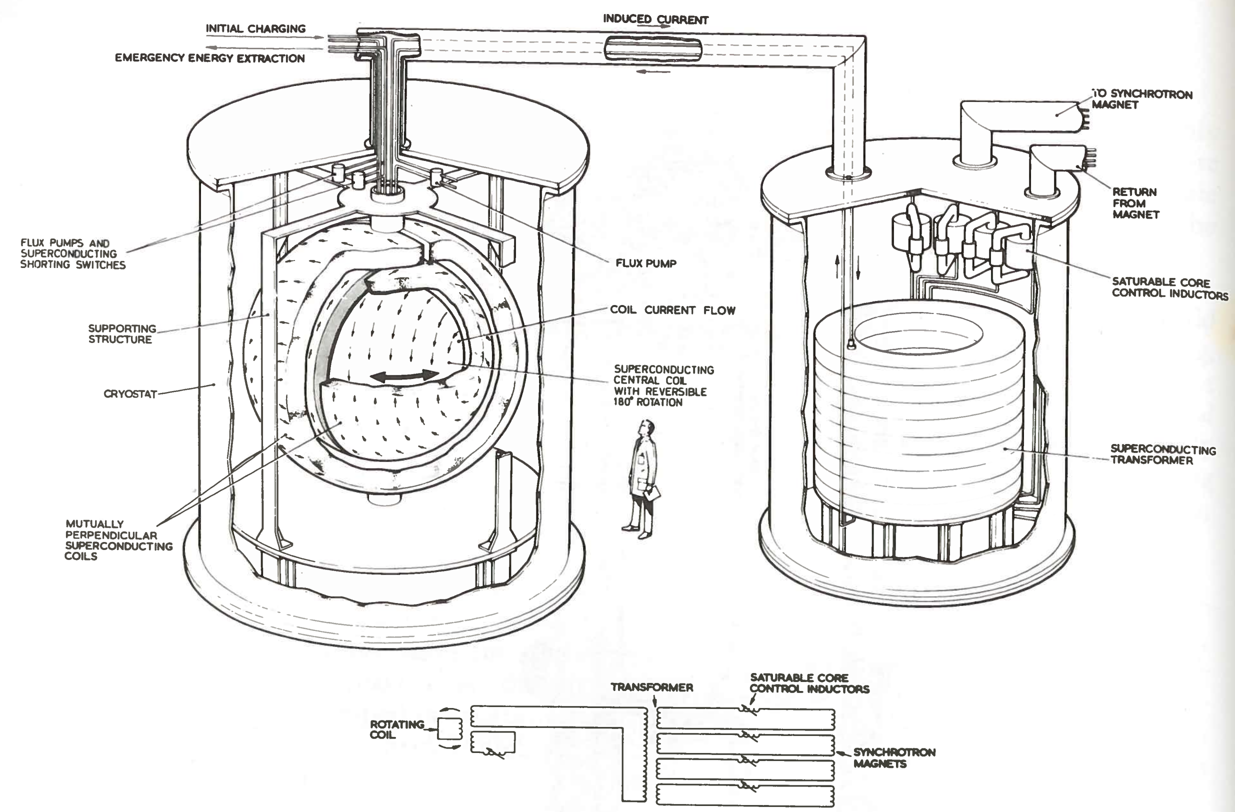


Figure 109. Artists impression of the proposed superconducting power supply.

Energy Transfer
(*Ref: 61, 168.*)

Further work has been carried out on the energy transfer scheme proposed as an alternative to conventional synchrotron power supplies. The principle was described in the 1969 Annual Report, and an artist's impression of a system capable of transferring 10^8 J is shown in figure 109. Preliminary calculations of coil design, stresses, a.c. losses, dynamic behaviour, and cost indicate that the full scale system could be both feasible and economic, and offers an attractive method of powering a future 1,000 GeV ($\sim$ 1,000 MJ stored energy) superconducting synchrotron.

In addition to continued theoretical assessments, it is proposed to simulate many aspects of the design and behaviour by means of a room temperature analogue, using electronic techniques to imitate superconducting behaviour in a copper model of the coil system. A preliminary analogue of this type has been operated successfully and a more realistic version is now being designed.

As a first step towards superconducting prototypes, a small low-field superconducting model has been designed (overall diameter 30 cm, peak field 5 kG, transferred energy $\sim 10^3$ J) and this will be constructed during 1971.

INSULATING MATERIALS FOR SUPERCONDUCTING MAGNETS

(*Ref: 152, 160, 161.*)

Research on insulating materials for superconducting magnets has a two-fold objective:

(i) The study of the behaviour of materials when cooled to very low temperatures.

(ii) The provision of insulating systems whose manufacture is technically feasible.

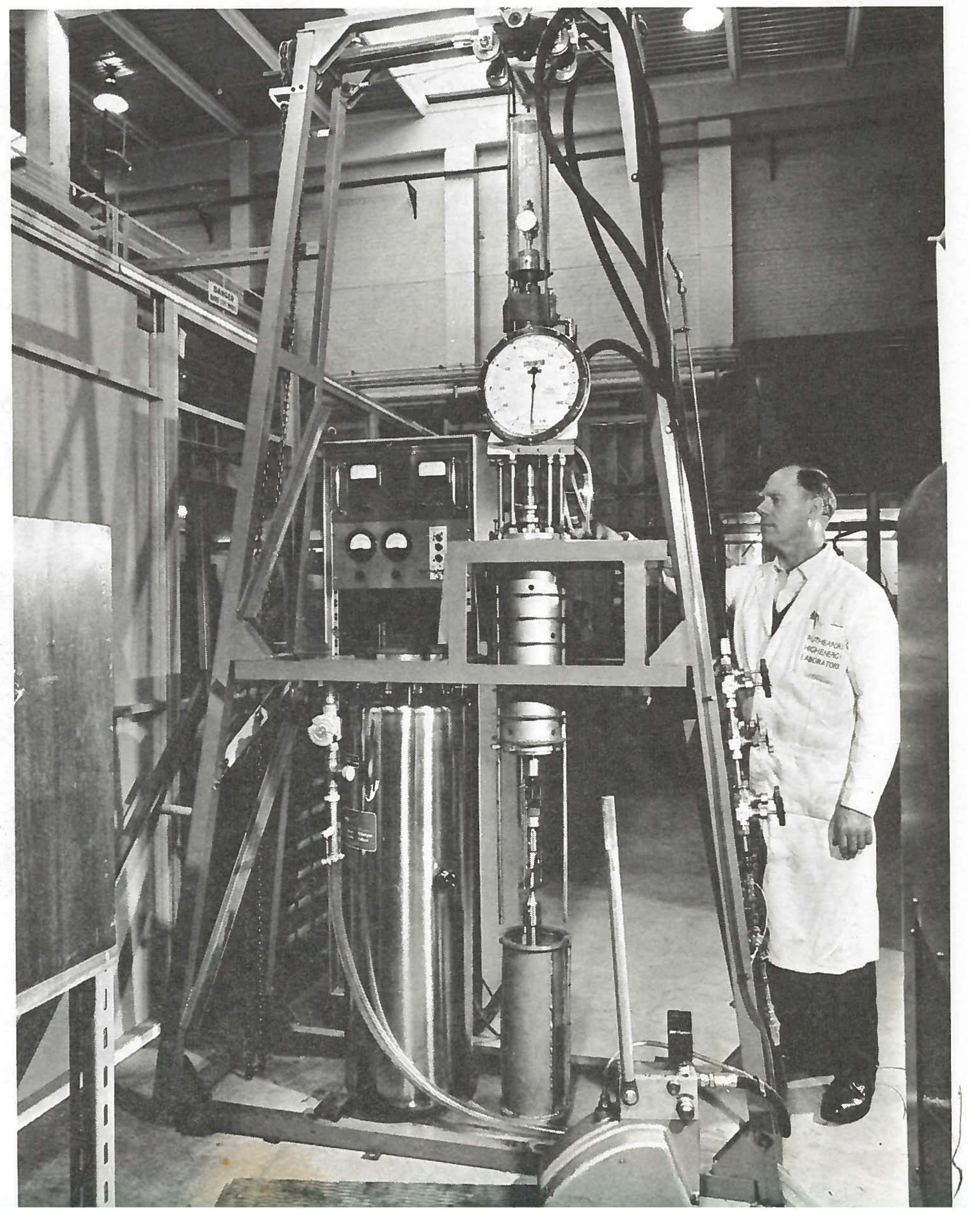
Most constructional materials undergo marked changes in their physical properties when cooled to temperatures in the cryogenic range. For this reason a continuous programme of physical testing of materials is being pursued and the equipment described in the 1969 Annual Report has been updated and improved.

The 450 kg test machine has been modified to improve the sensitivity of extensometer readings. Temperature monitors have also been included so that tests can be carried out in the range between room temperatures and 4°K. In addition, a testing machine capable of applying a force of 10,000 kg has been made fully operational and commissioning tests are in progress on apparatus used for measuring the thermal conductivity of materials at 4°K. A further improvement to the Laboratory's range of low temperature testing equipment has been the construction of a controlled environment cabinet, permitting specimens intended for mechanical testing on the 'Instron' machine (see figure 110) to be changed whilst eliminating contamination by air and water vapour and the loss of gaseous helium. This has enabled the test rate to be increased to 5 specimens per day on this machine and still provide full facilities for the recovery of helium.

Materials selection, including the development and evaluation of new resins and non-metallic composite materials, is an important aspect of the work associated with the Laboratory's programme on superconducting magnets. Tests have been carried out on the suitability of a number of epoxy resin systems for use as impregnants for magnets designed to operate at the temperature of liquid helium. The work programme has aimed at producing a system with good adhesion and suitable 'gel time' and viscosity characteristics. Attention is also being given to filler systems which lead to an improvement in radiation stability and strength, together with a lowering of thermal expansion co-efficients, without large increases in the Young's Modulus of the resin system.

The development and evaluation of application techniques for the encapsulation of magnets with filled and unfilled plastic materials is also being actively pursued.

Figure 110. The Instron test machine for use at 4°K.



THE PROPOSED HIGH FIELD BUBBLE CHAMBER

With capital approval for the proposed High Field Bubble Chamber (HFBC) expected during the first half of the year much effort was devoted to finalising the design. Studies on the design of the refrigeration and expansion system made in conjunction with industrial organisation were completed satisfactorily.

The research and development programme continued with the emphasis placed, as before, on the superconducting magnet, glass reinforced plastic bellows for the expansion system and the optical system. Short reports on this work are given below.

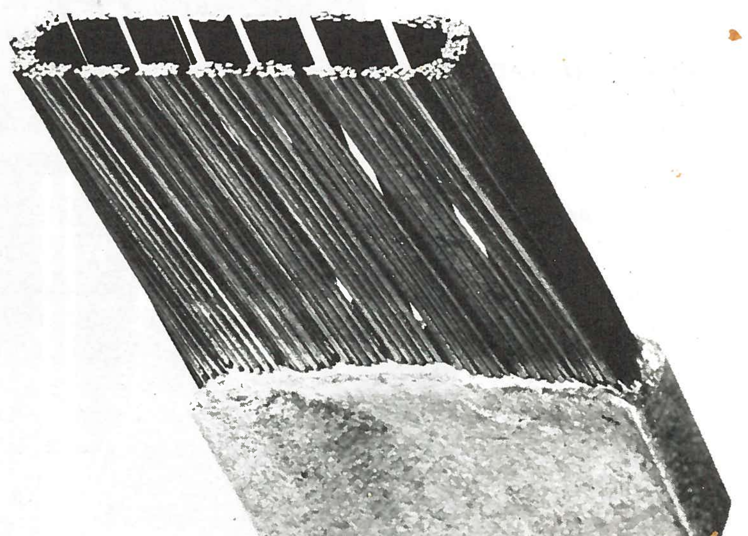
Although approval by Council for the project was obtained, the financial implications of possible British participation in the proposed 300 GeV Accelerator project at CERN led to capital approval being deferred. As a result the design work has been discontinued and the research and development programme reduced.

Superconducting Magnet

Following the successful operation in 1969 of the RACOON I magnet designed to test the performance of the conductor first selected for the HFBC magnet, further conductor development has taken place. A final conductor configuration has been chosen which consists of 361 individual niobium-titanium alloy filaments embedded in a matrix of pure copper of cross-section 25 mm by 6 mm (see figure 111). The filaments are twisted about the longitudinal axis of the conductor with a pitch of 50 cm, to eliminate almost persistent magnetisation currents which would otherwise produce significant time dependent distortions of the magnetic field in the bore of the magnet. The conductor was developed and manufactured by Imperial Metal Industries (Kynoch) Ltd, working under contract to the Rutherford Laboratory.

A further test coil RACOON II has been built from this conductor to provide the evidence for final acceptance of the conductor for use in the 70 kG magnet of the proposed HFBC. The magnet has recently completed the first stage of its two-stage test programme. Operating fully immersed in liquid helium RACOON II was energised with currents up to 14,800 A and reached a peak magnetic field of 66 kG. This is believed to be the highest current at which a superconducting coil has yet operated. (The peak current density achieved in the conductor, almost 100 A/mm^2, can be compared with the 5 to 10 A/mm^2 at which copper conductors of typical water-cooled magnets run.)

Figure 111. The conductor of the RACOON II coil consisting of 361 niobium-titanium alloy filaments of about 0·3mm diameter in a copper matrix of cross-section 25mm x 6mm. The filaments are twisted about the longitudinal axis of the conductor with a pitch of 50cm to eliminate magnetisation currents.



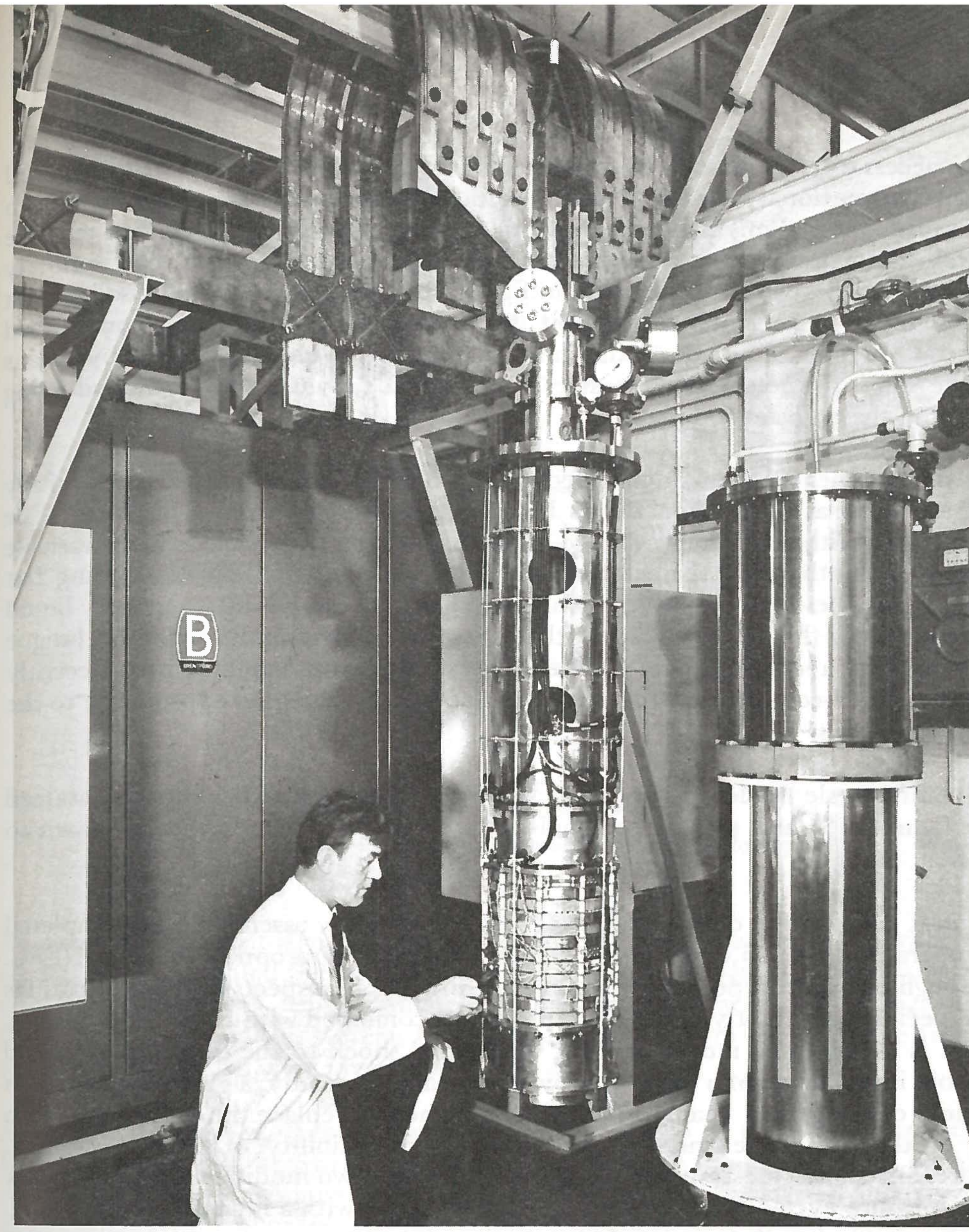


Figure 112. The RACOON II superconducting coil built to test the conductor for the magnet of the proposed High Field Bubble Chamber is shown connected to its 15,000A power supply.

RACOON II uses about 100 m of stabilised superconducting strip wound into six double pancake coils each of 25 turns. (See figure 112). In the HFBC magnet the conductor will operate at 7,500 A. The stable performance observed at currents of almost 15,000 A in the recent tests confirms that the conductor will have an entirely adequate margin of stability when operating at its design current. The twisted filament conductor ensures that magnetisation current loops set up within the conductor of a coil which is being energised will decay fairly rapidly. Measurements of the decay of such currents in RACOON II yielded a time constant of 40 minutes. In the HFBC application similar time constants are predicted. This means that the magnetic field distortions produced by these currents (which would persist almost indefinitely if twisted filaments were not used) will indeed disappear within the first hour after each energisation of the magnet.

The second stage of the RACOON II test programme is aimed at proving that the selected superconducting strip will also carry its design current of 7,500 A in a magnetic field of 84 kG, this being the peak field of the HFBC coils. For this test RACOON II in its own cryostat will be mounted within the bore of a conventional 50 kG water-cooled magnet at the Royal Radar Establishment, Malvern. When both coils are energised simultaneously it is expected that peak fields in excess of 84 kG will be generated.

It is necessary to support the superconducting magnet directly from the coil of the conventional magnet. Forces generated between the two magnets due to any radial or axial misalignment between the respective magnetic centres must be restrained to prevent any movement of the superconducting coil. The remotely operated wedges which can be seen in figure 112 transmit the radial misalignment forces to the conventional magnet by means of the specially constructed cryostat standing alongside. Axial misalignment forces are transmitted by means of the large diameter stainless steel tube which supports the superconducting coil from the cryostat top plate.

Expansion System

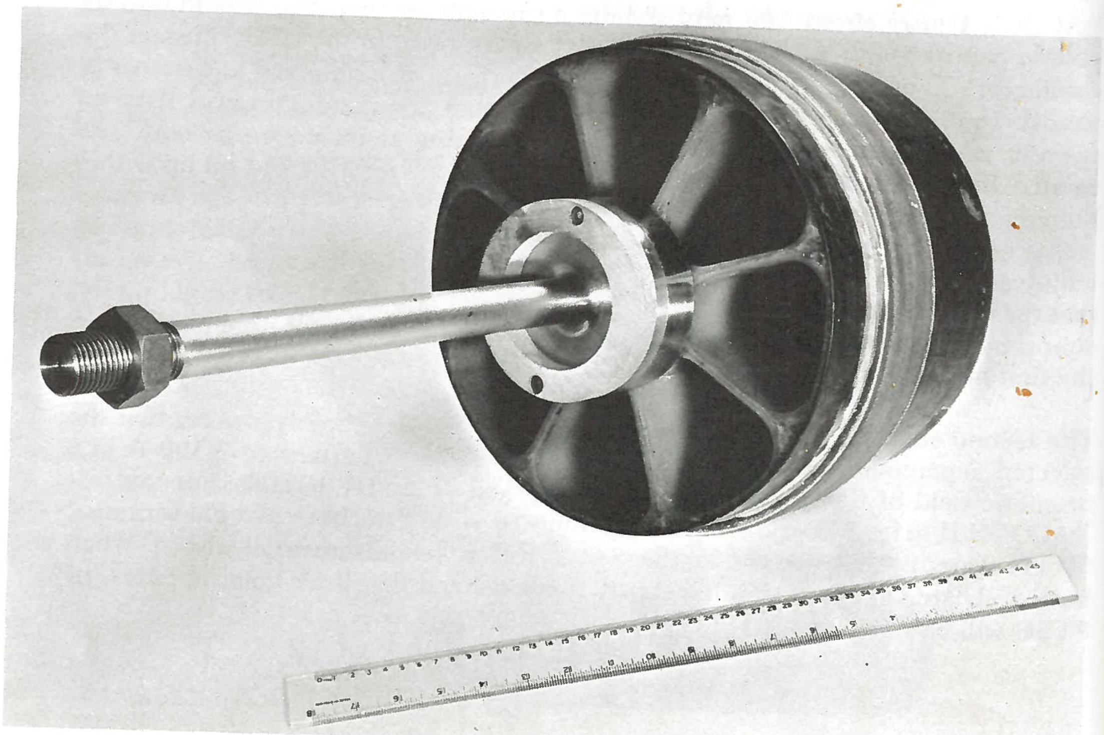
The development of glass-reinforced plastic bellows has continued successfully and as many as 20 million cycles have been completed with a one-fifth scale prototype, without failure. These tests have been performed with variable pressure at both room temperature and 78°K. Flexural fatigue tests using flat samples of the material have been carried out in liquid nitrogen and liquid hydrogen and the results indicate that there is no deterioration in the fatigue properties as a consequence of operating at the lower temperature. Recently attention has been directed towards manufacturing techniques appropriate to the full-size bellows.

A one-fifth scale model of the piston in glass-reinforced plastic has been obtained (see figure 113) and provisional cool-down tests have been performed down to 78°K.

Optics

The test programme of the prototype fish-eye window assembly was completed by operation for 15,000 cycles under conditions appropriate to the HFBC. Although the prototype performed satisfactorily in all respects two modifications have been tested. Firstly, a fused silica window combined with an invar 'spinning', which is designed to reduce the risk of thermal shock to the central heat shield window in the event of a main window failure and, secondly, a glued seal between window cartridge and chamber, which is designed to replace the standard indium seal of the prototype and thereby reduce the possibility of spurious boiling. Figure 114 shows the test piece incorporating these two modifications, which has been pressure cycled in the 10 inch bubble chamber with a liquid nitrogen filling. The mechanical performance of the components was entirely satisfactory. The nucleation properties of the glued seal will be tested in the fast-cycling bellows test rig now being designed.

Figure 113. One-fifth scale glass-reinforced plastic piston.



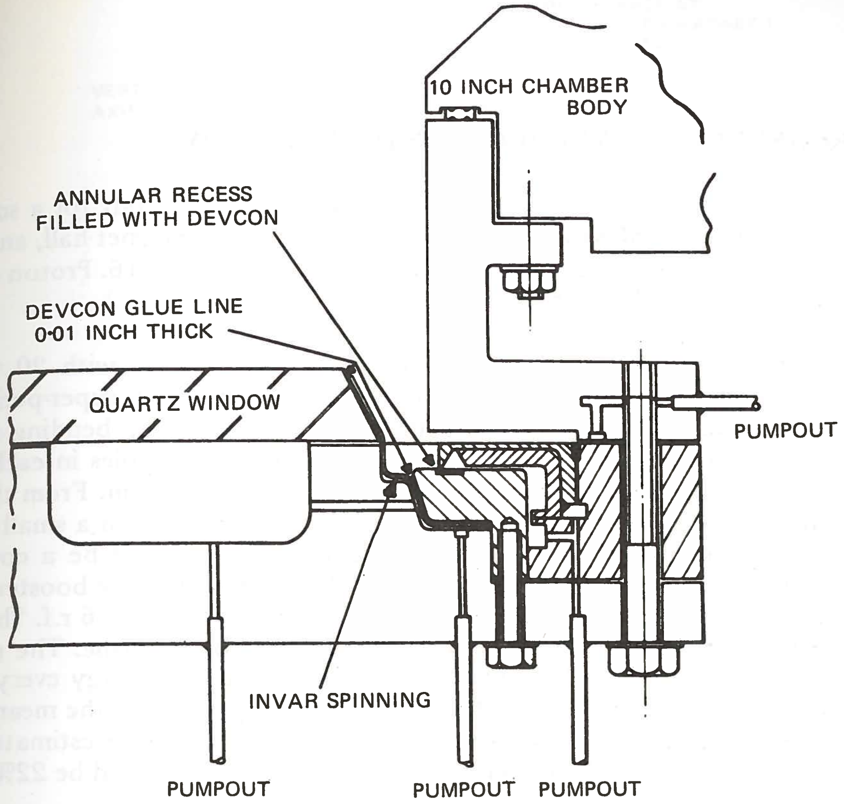


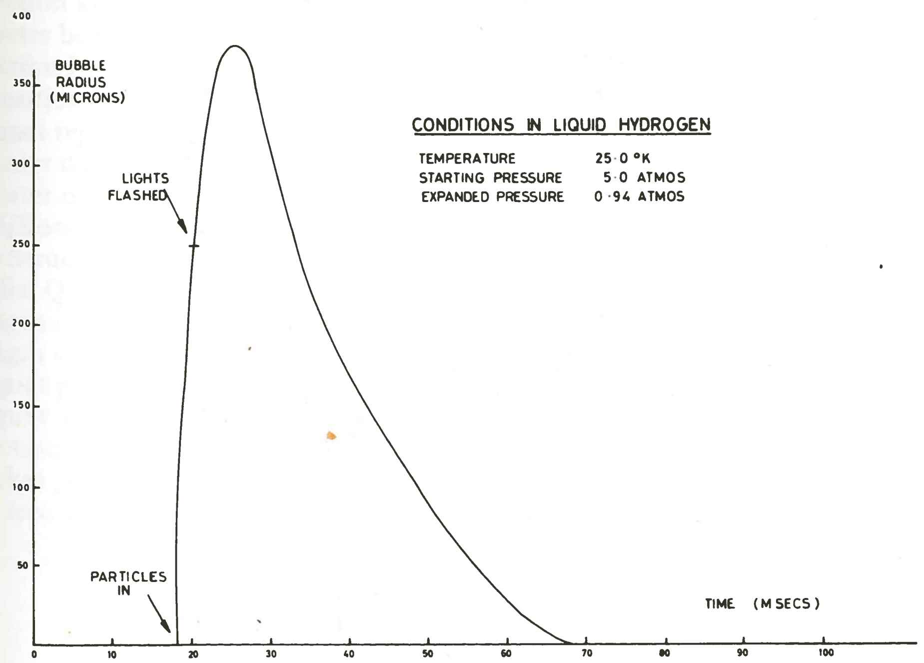
Figure 114. Window assembly incorporating an invar spinning and glued seal between window cartridge and chamber.

An experimental prototype camera designed for operation at up to 10 exposures/sec has been assembled for testing. Extensive tests of photographic emulsions have also been carried out using simulated bubble chamber tracks with a bright field (Scotchlite) illumination system. Conditions appropriate to the complete fiducial volume of the HFBC were investigated.

Computing

A number of new programs have been developed, two of particular interest are BUBBLE and NIFE. BUBBLE calculates bubble size as a function of time throughout the expansion-recompression cycle from the time of nucleation and has been of considerable use in predicting the conditions associated with fast cycling, where the time for bubble recompression is very significant. Figure 115 shows the variation of bubble size in the HFBC when operating at 10 expansions/sec. NIFE has been developed to calculate the dynamic stresses in the bellows and is based on a finite element method.

Figure 115. Bubble growth and recompression curve for 10 expansions per second operation of the HFBC, with a chamber expansion period of 40 milliseconds.



SUPERCONDUCTING SYNCHROTRON DESIGN STUDY

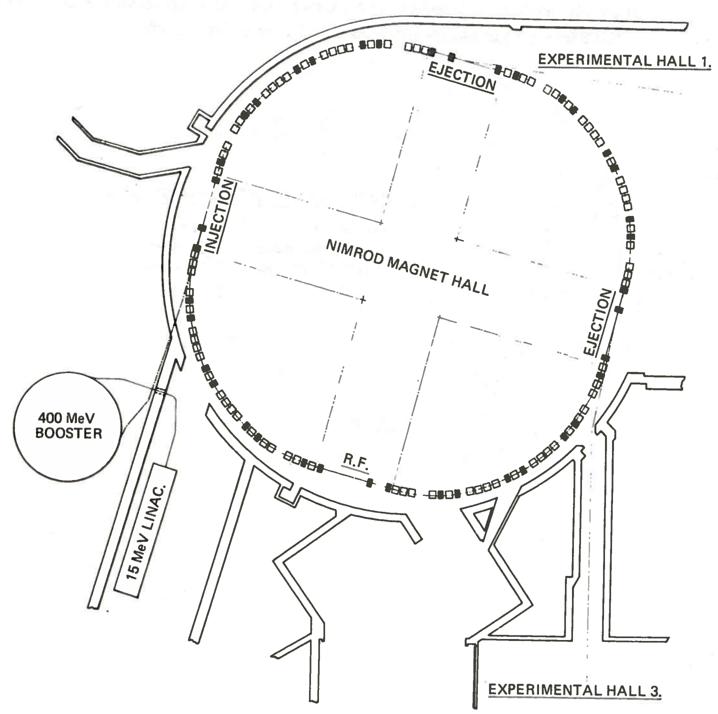
During 1970, a detailed theoretical design has been carried out for a superconducting synchrotron (SCS) which would fit in the Nimrod magnet hall, and which would use the existing Experimental Halls 1 and 3: see figure 116. Proton energies of about 25 GeV could be achieved.

The design incorporates a separated-function doublet lattice, with 20 focusing periods, divided into 4 super-periods: one period within each super-period contains a long straight section of 6·05 m, created by omitting bending magnets from an otherwise normal focusing period. The two quadrupoles in each period are 0·5 m long, and the bending magnets are in units of 0·95 m. From the existing 15 MeV linac, protons would be accelerated to 400 MeV in a small booster synchrotron, one quarter the radius of the SCS. This would be a combined-function machine using conventional iron-cored magnets. With the booster cycling at 20 cycles/second, 12 booster bunches would be transferred into 6 r.f. "buckets" in the SCS. Injection would take place in the vertical phase plane. The resulting SCS flux would be 1·5 x 10^{13} protons accelerated to full energy every 6·75 s. With a 0·75 s injection platform, 2 s rise time, and 2 s flat-top, the mean proton flux would be 2·2 x 10^{12} protons/second. Taking a conservative estimate for the effective spill time, 75% of flat-top, the effective duty cycle would be 22%.

With 60 kG peak field in the SCS bending magnets, the proton momentum would be 21·84 GeV/c: the corresponding gradient in the quadrupoles is 6·32 kG/cm.

The mean radius of the machine would be 27·85 m, and the bending radius 12·09 m. The diameter of the beam aperture (good field region) would be 11·6 cm, achieved with the aid of closed orbit control. The machine would be particularly well equipped with diagnostic, control, and monitoring devices. Figures 117 and 118 illustrate the processes of injection and ejection respectively. Injection requires the use of 2 fast kickers of 50 ns rise time. At ejection, the Q = $4\frac{2}{3}$ resonance is induced to send protons across a thin magnetic or electrostatic septum upstream of the ejection long straight: in the long straight section itself, they cross a series of magnetic septa of increasing thickness, to emerge at an angle of about 95 mrad. The efficiency of the process should be over 95%. Tables 16 and 17 list the major booster and main ring parameters.

Figure 116. Layout of a superconducting synchrotron which would fit in the Nimrod Magnet Hall and which would use existing Experimental Halls 1 and 3. The filled-in blocks are quadrupole magnets.



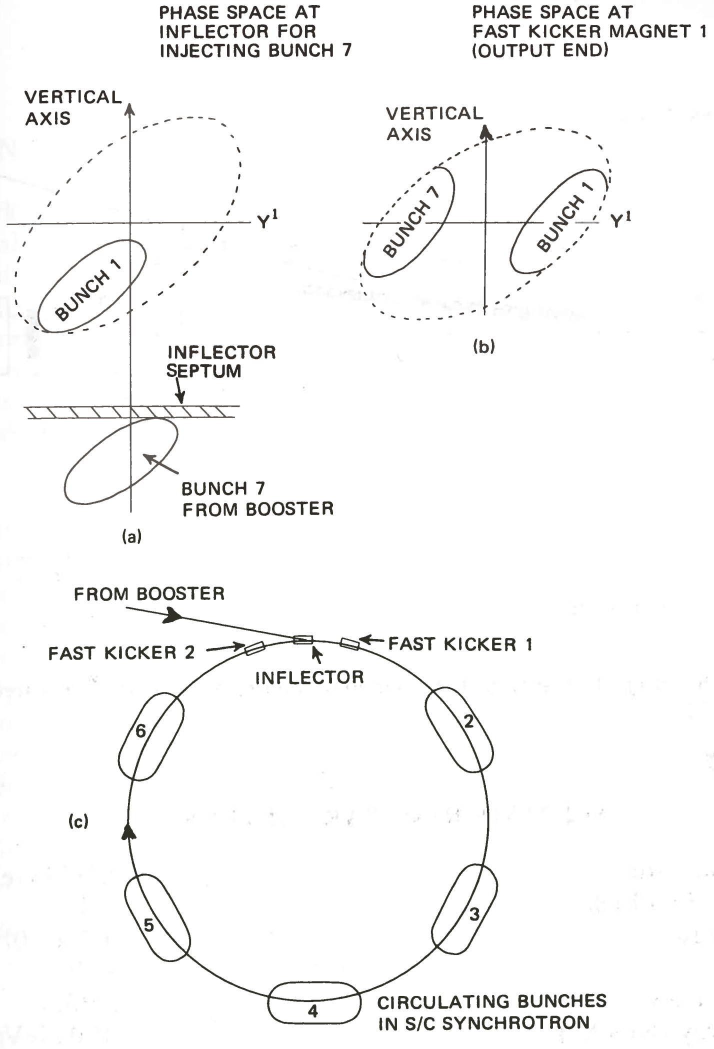


Figure 117. A 2-turn vertical injection system for a superconducting synchrotron. (a) The phase space diagram shows the relative vertical positions of particle bunches 1 and 7 at the thinseptum inflector magnet as bunch 7 from the booster is about to be injected. Fast kicker magnet 2 is used to adjust bunch 1 prior to this. (b) shows the phase space diagram for bunches 1 and 7 as they leave the fast kicker magnet 1. Successive pairs of bunches i.e. 2 and 8, 3 and 9 etc. are treated similarly. (c) The relative position of the first six bunches in the synchrotron magnet ring as bunch 7 is about to be injected.

Table 16

400 MeV BOOSTER PARAMETERS

Injection kinetic energy	15 or 50 MeV
Booster beam intensity (protons per pulse)	1·5 or 3 x 10^{12}
Ejection kinetic energy	400 MeV
Transition kinetic energy	680 MeV
Magnet repetition rate	20 Hz
Booster circumference	43·747 m
Booster orbit radius	3·361 m
SCS/Booster circum. ratio	4
AG Structure (CF)	8 (FO_1DO_2)
Radial Q, Vertical W	1·81, 1·77
Length of straights	1·33 m, 1·50 m
Length of magnets	1·32 m
Magnet profile parameters	1·30 m^{-1} (D), 1·00 m^{-1} (F)
Magnet apertures (vert., rad)	8·89 cm, 17·0 cm
Ejection kicker rise time	127 ns
Bucket phase space area	0·1 eV second
RF frequency range	1·21 to 4·89 MHz

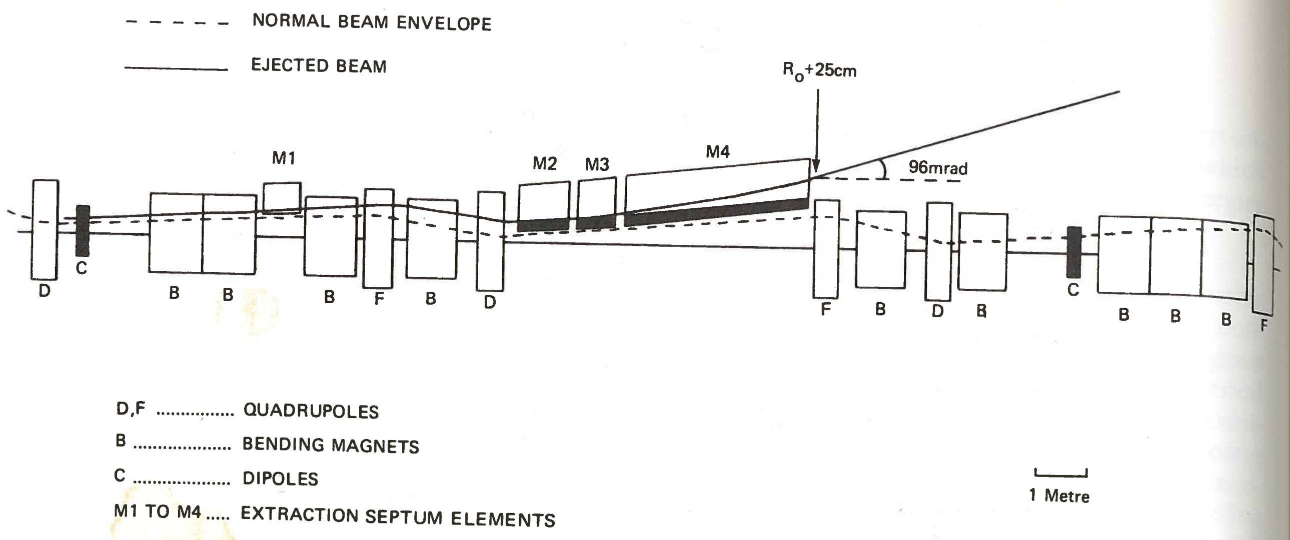


Figure 118. A beam ejection system for a superconducting synchrotron (theoretical extraction efficiency ⩾ 95%).

Table 17

SCS MAIN RING PARAMETERS

Maximum Momentum	25·38 GeV/c
Maximum Bending Field	7 T
Protons per Pulse	$1{\cdot}5 \times 10^{13}$
Cycle Time	6·75 s
Ejection Efficiency	>95%
Injection Energy (Kinetic)	400 MeV
Field at Injection	0·267 T
Transition Energy	3·82 GeV
Aperture Diameter	0·12 m
Stored Energy	51 MJ
Circumference	175 m
Circumference Ratio	2·3
Mean Radius	27·85 m
Bending Radius	12·09 m
Maximum Quadrupole Gradient	63·2 T/m
Number of Focusing Periods	20
Number of Superperiods	4
Number of Betatron Oscillations per Revolution: Q_H, Q_V	4·8, 4·85
Resonant Q Value	4·66
Phase Advance per Period	86·4°
Maximum β Value	13·7 m
Effective Length of Bending Magnets	0·95 m
Effective Length of Quadrupoles	0·5 m
Length of one Period	8·75 m
Length of Long Straights	6·05 m
RF Frequency : Injection	7·32 MHz
: Ejection	10·26 MHz
RF Harmonic Number	6
Number of Pulses Injected	12
Injection Platform	0·75 s
Peak r.f. Volts	54 kV
Average Power in Beam	30·5 kW
Length of r.f. Cavity	2 x 2·0 m

EUROPEAN 300 GeV ACCELERATOR

Design work on the proposed European 300 GeV has culminated in the Project B* proposal. The essence of the proposal is to build the 300 GeV proton synchrotron and its laboratory adjacent to the present CERN site at Meyrin, Geneva. This enables major capital facilities of the existing laboratory to be used as an integral part of the 300 GeV programme. For instance, the CERN 25 GeV accelerator will be used as the injector for the 300 GeV machine and the West Hall of CERN as its first experimental area. This reduces the cost of the 300 GeV programme and allows research to start several years earlier than would be expected otherwise.

A design study has been carried out by the '300 GeV Machine Committee', under the direction of Dr. J. B. Adams, and 14 Working Groups with Machine Committee members as convenors. Only 3 people were employed full-time on the design, the rest of the work being done by staff from CERN and national accelerator laboratories on a part-time basis. The Rutherford Laboratory has taken a full part in the study, having 3 members on the Machine Committee and 15 people contributing in a major way to the work of 8 of the Working Groups, viz. magnet system, magnet power supplies, vacuum system, control system, radiation protection system, ejection, experimental areas and general equipment and buildings. Each Working Group has produced a chapter of a design report published by CERN for the 300 GeV Machine Committee.* The first chapter, a separate volume, is a summary of the design.

* Report MC/60. A Design of the European 300 GeV Research Facilities. CERN, December 1970.

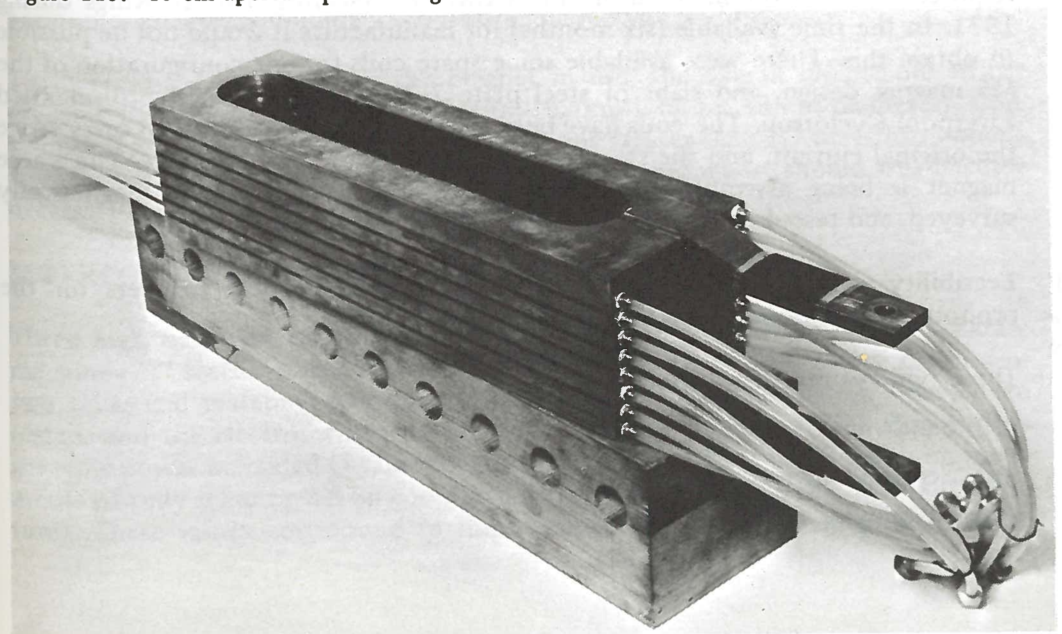
SPECIAL PURPOSE MAGNETS

High Field Pulsed Magnets

Approval has been granted, in principle, for the mounting of a Λ hyperon experiment at CERN during 1971, using the equipment developed at this Laboratory during the last few years.

Two complete magnet assemblies, each with one spare coil, are available and tested. The coils are of the type shown in figure 119, with a bore of 40 cm. The coil illustrated has been tested for more than 120,000 pulses at 70 kG. Improvements have been made to the water-cooling and containment systems as a result of experience gained in tests during the year.

Figure 119. 40 cm aperture pulsed-magnet coil.



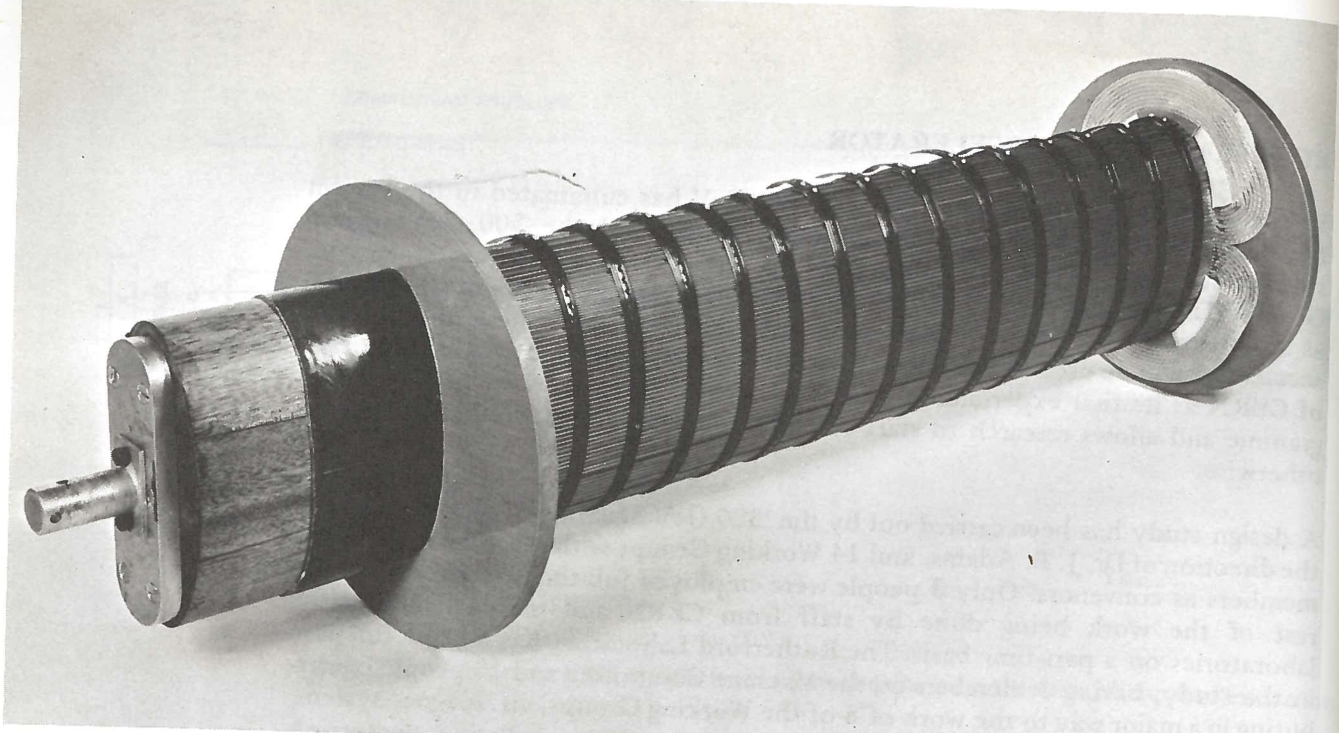


Figure 120. 30-turn flat-top field pulsed magnet during construction.

Beam Switching Magnets

The fast-rise, flat-top field pulsed magnet developed for beam switching, consists of a remote pulse-forming network feeding a magnet coil constructed within the walls of a 1 cm thick vacuum flight tube. With 20 kV anode drive voltage, a large triode drives 300 A in the 1 mH 30-turn coil, within 25 μs of command, and for up to 1 ms, depending on requirements; the pulse may be terminated earlier by a signal derived from the beam.

By linking the two sets of coil conductors in parallel, the rise-time may be halved at the expense of deflecting field. Figure 120 shows such a coil during assembly around an elliptical mandrel.

Magnet Trigger Systems

Development of the fast switchgear for a variable 20-70 kV pulse-forming network for stepmagnets and similar switches has continued, using avalanche transistors, thyratrons and sparkgaps. The emphasis is on reduction of total delays between a command signal and the establishing of a precise current of up to 20,000 A in an iron- or ferrite-cored magnet.

M5D Sepctrometer Magnet

A magnet, corresponding to our standard M5 spectrometer magnet design, is required for an experiment using the CERN Intersecting Storage Rings during 1971. In the time available (six months) for manufacture it would not be possible to obtain this. There were available some spare coils for one configuration of the M5 magnet design, and slabs of steel plate 7·75 in thick from the dismantled Liverpool Cyclotron. The coils have been modified to up-rate them to carry twice the original current, and the steel plate utilised to form a 50 ton yoke. The whole magnet is being assembled in Experimental Hall 2, and will be magnetically surveyed, and tested ready for dispatch to CERN by mid-March, 1971.

CERN 300 GeV Special Purpose Magnets Study

Feasibility studies have been carried out of special purpose magnets for the proposed new European accelerator.

Three types of magnets were considered:—

(i) Sandwich magnets

(ii) Septum magnets

(iii) Dividing magnets

The design of some of these calls for current densities in excess of 100 A/mm^2, and consequently very high heat transfer rates. The proposed construction allows for the use of inorganic insulation by known techniques. (Some of the septum magnets in use in Nimrod beam lines have current densities of 150 A/mm^2).

M11 Spark Chamber Magnet

The heavy liquid bubble chamber magnet has been dismantled and is now being re-built in Experimental Hall 3 as a spark chamber magnet. Modifications will make this magnet as versatile as possible for future use as a general experimental facility. In the present assembly three coil pancakes have been removed to give an aperture of 31 in with a field of 10 kG. This magnet yoke has been modified to enable the original hydraulic jacking system to be used in conjunction with the existing magnet transporter, to enable the 200 ton magnet to be moved for positional and alignment reasons. A turn-table is under construction to give small angular move-ments (±5°) of the magnet during experiments. The rotating part will slide on PTFE pads and accurate position will be obtained by a hydraulic ram system. Trails were done with PTFE pads suitably loaded, to ascertain the static and dynamic friction of this system. The static friction was found to be almost identical to the dynamic friction, thus accurate angular positioning should be possible.

Handling gear has been built to enable the magnet to be dismantled expeditiously to change the size of the gap and to introduce experimental apparatus.

Magnet Field Survey Equipment

The semi-automated magnetic field survey unit mentioned on Page 91 of the 1969 Report is being modified in line with user recommendations when it is hoped that the overall errors in surveys due to the unit will not exceed ± 0·2%. The modified unit will be used in surveying the M5 magnet for use at the CERN Intersecting Storage Rings and the M11 spectrometer magnet.

SUPERCONDUCTING QUADRUPOLE LENS

Superconducting magnets offer particular advantages in their compactness and high magnetic field for use in beam-lines. Such applications will be investigated by studying the performance of a commercially manufactured quadrupole magnet initially under test conditions and then in an actual beam-line.

An order for a prototype superconducting quadrupole was placed with British Oxygen Company Ltd in June 1970, and is due for delivery in June 1971. The magnet will have a room temperature bore 12 cm diameter, gradient 6·5kG/cm, and an effective length 33 cm. By paying attention to the elimination of end effects, the magnetic length of the quadrupole is expected to be constant to a higher degree than previously achieved over most of the bore, and unwanted harmonics are correspondingly reduced.

To increase the flexibility of the magnet in use, the overall dimensions of the cryostat have been kept to a minimum, (62 cm long by 49 cm diameter). Con-sumption of liquid helium is expected to be not greater than 1.7 litres/hr in opera-tion. Provision for adding magnetic shielding is being made, should this become necessary under certain operating conditions.

SUPERCONDUCTING R.F. SEPARATORS

High Field Test Cavities.

Three high field test cavities have been made during the year: two of separate machined 'T' sections, and one of electroformed copper. Each cavity consists of two cells, end matching sections and short beam pipes. The first two have been tested, and the electroformed model is being tested at present. The first models gave low power unloaded Q-values of the order of 3 x 10^7 at 4·2°K, with improve-ments of only a factor 2-3 on cooldown to 1.85°K (the design operating tempera-ture). These values correspond to improvement factors within a factor 5 of the

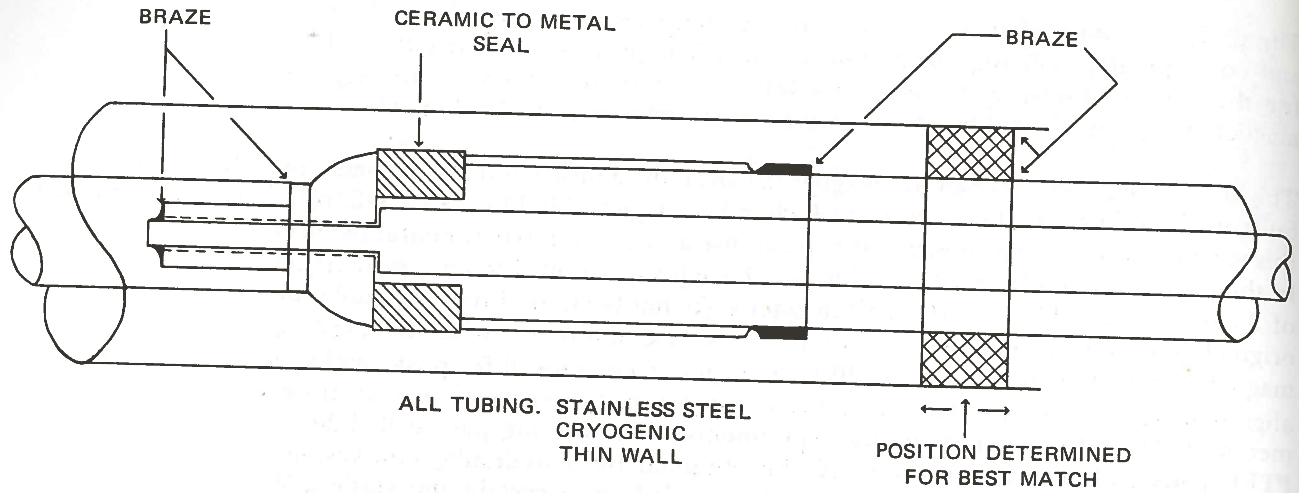


Figure 121. Details of a microwave window for operation at cryogenic temperatures.

theoretical value at 4.2°K, but worse by a factor 100 at 1.85°K. Possible causes for the relatively low Q-values are poor vacuum, quality of plating (which is particularly important under high electric field conditions), and imperfect joints. The lead-plating procedure has been improved in detail during the year, and was further checked by tests on an S-band TE011 Mode cavity. Over a wide range of plating currents, Q-values of the order of 10^{10} were obtained. The quality of the vacuum has generally been rather poor, but baking and the use of a new double sealed vacuum manifold should improve this for the electroformed model. The most likely reason for the low Q-values is the joint used on the model (each has 5 joints). The joint is a simple spigot type with a bolted flange, with which one cannot guarantee good lead-to-lead contact over the whole temperature range. This problem is avoided with the one-piece electroformed model. Tests are now being concentrated on this model.

New Plating Shop

The new plating shop was brought into use at the end of 1970. This incorporates many improvements over the old one, in particular conditions are cleaner, and handling is improved. The actual plating will be done with the cavity revolving round collapsible anodes. Glove boxes have been modified so that the plated parts are handled either under vacuum, or in an inert gas.

RF Components

Difficulties have been experienced with solid state strip line amplifiers at 1300 MHz. R.f. power for the separator system will now be provided by a conventional beam tube. Development of other strip line components has continued. A new microwave window for operation at cryogenic temperatures has been designed, and is shown in figure 121. The window proper is a standard feedthrough cylindrical insulator, which can withstand thermal shock (unlike the conventional planar window in coaxial line). The diameters of the conductors to and from the window are chosen to give the usual 50 Ω impedance, and the location of the terminating plane is chosen to give a match (typically voltage standing wave ratios better than 1.1:1 are obtained).

A new joint for the disc-loaded structure has been designed, which separates the function of providing a tight vacuum seal and making good lead-to-lead contact, as in figure 122. The indium is maintained under pressure by the cantilevered arm, to provide the seal, and the lead contact is maintained at the spigot. The joint has been immersed in liquid helium to temperatures below 2°K several times, with no sign of leak. An E010-E011 mode cavity is being made to test the r.f. properties of the joint.

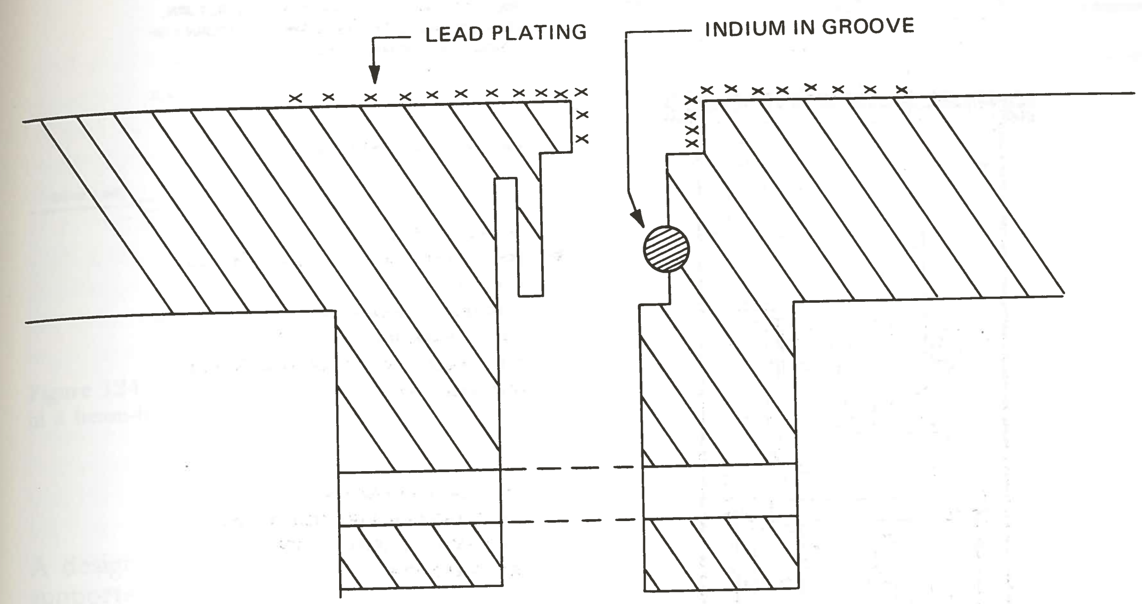


Figure 122. R.F. joint for operation at cryogenic temperatures.

Refrigerator Design

Operation of the proposed superconducting r.f. separators will require large scale production of super-fluid helium to fill the two cryostats (400 litre capacity) and maintain a refrigeration load of about 40 watts at 1·85°K. A secondary refrigerator to function in series with an existing 4·7°K refrigerator system has been designed.

The design is based on a modified 'Hempson process' utilising three counterflow and two pre-cooling heat exchangers along with two Joule-Thomson expansion stages balanced to give the best efficiency. The existing 4·7°K refrigerator will be adapted to supply liquid at 4·7°K and gas at 66°K for the five heat exchangers and further gas at 66°K to cool the heat shield along with the transfer pipe and cryostat heat shields. A 'Roots' pump will be added to the existing two stage vacuum pump and used to maintain the 1·85°K liquid vapour pressure and return this vapour back to the main system for recirculation.

Figure 123 shows the proposed design, features include

(a) a novel counterflow heat exchanger for the low pressure vapour cold return giving high efficiency and very low pressure loss. (Note:—a 1 Torr. increase in pressure loss would necessitate a 10% larger 'Roots' pump).

(b) tandem purifiers to allow continuous operation i.e. no 'down-time' required for regeneration of purifiers

(c) a method for the 1·85°K liquid extraction from, and the cold vapour return to, the bottom end of the refrigerator.

The latter feature creates many advantages over the normal top entry coupling schemes in respect to heat transport from the refrigerator to the cryostat vessels. For this a common 1·85°K liquid supply cold vapour return culvert type transfer pipe is proposed. This gives a common liquid level from the refrigerator to the cryostat vessels; one level control is therefore adequate. The extra liquid surface area in the culvert gives improved control stability. The high heat transfer rate of the superfluid liquid in the culvert reduces the temperature differential between the two cryostats. The heat losses of this composite transfer pipe including its coupling heat losses will be considerably reduced.

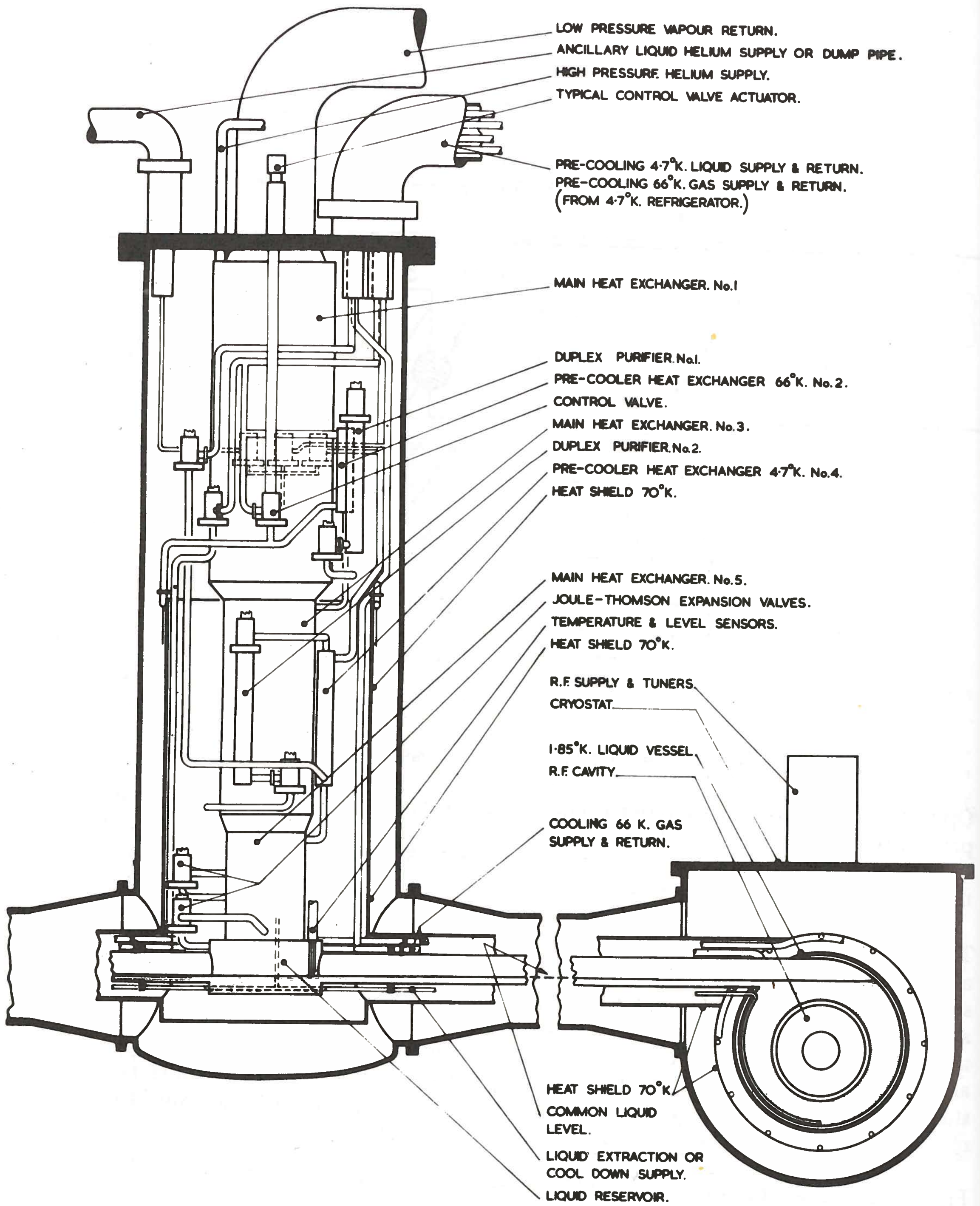


Figure 123. The 1·85°K refrigerator for the superconducting r.f. separators.

Work is now proceeding to embody this proposed culvert type transfer system into the cryostat design, (see figure 123). Problems in design of control valves, level sensors, and sealing methods, all compatible with superfluid helium are being studied and various seals for superfluid helium are to be tested.

From a preliminary study of cryogenic control methods it is considered that the close tolerances of liquid level, temperature and pressure demanded for operation of the r.f. cavities, although difficult, can be achieved.

It is envisaged that the 1·85°K refrigerator when once set will give continuous operation without attention. Further study is being undertaken with the aim of reducing the operational attention necessary for the existing 4·7°K refrigerator plant. Figure 124 shows a typical layout of the r.f. separator in a beam line.

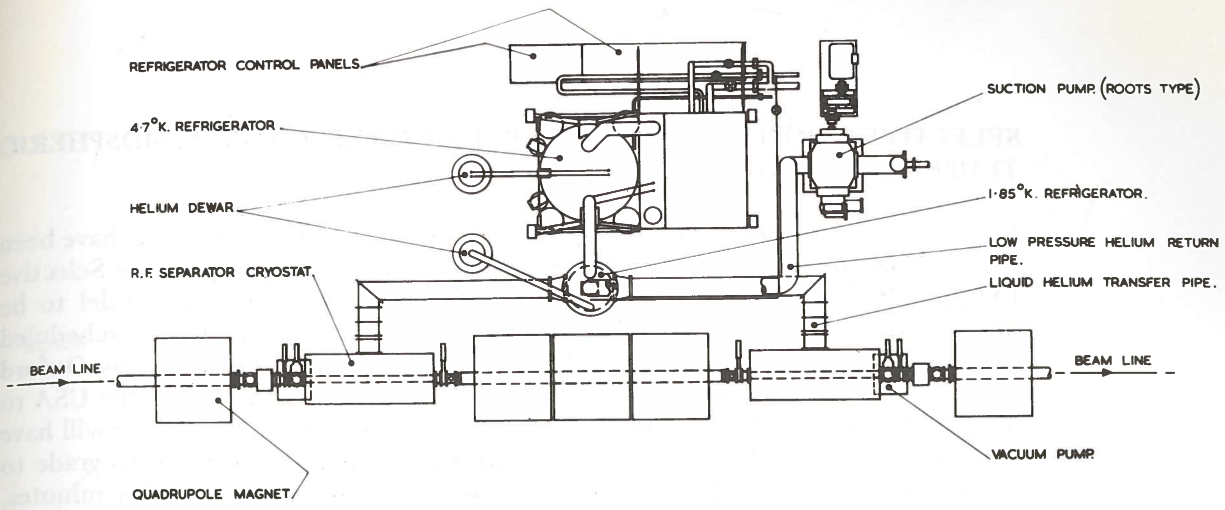


Figure 124. Proposed layout of the refrigeration equipment and the superconducting r.f. separators in a beam-line.

Cryostat Design

A design is completed of a cryostat to house the r.f. cavity. The cavity will be supported by the more rigid encompassing helium reservoir which in turn is supported by thin stainless steel wires to the outer vacuum vessel. The design of this support system, the attachment to the beam-line vacuum pipe and other connections such as r.f. tuners, r.f. power feed and helium vent line have been optimized to give adequate mechanical strength, minimum thermal distortion and minimum conductive heat influx.

A method of assembly of the cryostat has been planned so that the cavity is at all times kept under vacuum or purged with an inert gas to prevent contamination of the lead with which the cavity is plated.

In operation the cryostat will be mounted on a table that can be adjusted in all planes. This will be attached to a base of large mass and the assembly mounted on vibration isolators. Work is now in hand detecting and recording the frequency and amplitude of vibrations encountered in the Experimental Halls to provide information for the selection of these isolators. Operation of the r.f. cavity is susceptible to this type of disturbance.

When the r.f. separator is not operational, or when the helium refrigerator is not working, the cavity is kept below 70°K by cooling with liquid nitrogen fed through a standby cooling loop.

The separator has been designed so as to be suitable for transportation. In such circumstances the cavity and helium reservoir will be locked to the outer vacuum casing and the whole system will be transported either under vacuum or purged with an inert gas.

A design of vacuum system for both the cryostats and the beam line has been completed. Work is under way assessing the strength and permeability of certain coated melinex films to ensure the minimum ingress of contaminants into the cavity through beam-line windows.

Fast Shut-off Valve

In the beam pipe to the proposed superconducting r.f. separator, a rapid closing high vacuum valve will be required to prevent accidental contamination of the separator surfaces. In order to give the necessary protection the valve must close in a time of about 5 ms. The design of this 5 in valve incorporates some of the existing techniques which were developed for the 8 in and 4 in fast shut off valves, but also includes an electrostatic clutch in place of an electromagnetic device to operate the trigger system. A design study for this valve is proceeding.

SELECTIVE CHOPPER RADIOMETER EXPERIMENT FOR ATMOSPHERIC TEMPERATURE SOUNDING.

Since May 1969 a small team of engineers, draughtsmen and technicians have been working on the design, development and environmental testing of the Selective Chopper Radiometer engineering model. A flight version of the model to be manufactured commercially will be mounted on the Nimbus 'E' satellite scheduled for launching in the Spring of 1972. This experiment is a joint project by Oxford and Heriot-Watt Universities and is the only experiment from outside the USA to be included on this NASA meterological research satellite. The satellite will have a circular orbit of 600 nautical miles altitude and inclined at 80° retrograde to the equator in a sun-synchronous orbit with an orbit period of 107·4 minutes. This orbit permits viewing of all parts of the earth twice a day, once near local noon and once near local midnight.

The primary objective of the experiment is to observe the global temperature structure of the atmosphere at altitudes up to 50 km over an extended period of time. It will also make supporting observations of water vapour distribution and cloud cover and it should also be possible under appropriate conditions to infer the size and number density of ice particles in cirrus clouds. This information is obtained by selective measurements of infra-red radiation and the equipment is calibrated by views to deep space (3°K) and to a measured 'black body' radiator in the apparatus.

The apparatus, shown in figure 125, is mounted on the under-side of the satellite with one aperture facing earth. Two other apertures on the side of the housing view space. Radiation from the atmosphere is reflected by the calibration mirror and the off-axis paraboloid mirror on to the rotating chopper mirror. Radiation from space reaches the chopper mirror direct, but at right angles to the radiation from the atmosphere. The incident radiation is divided into four channels; the rotating chopper mirror, which is a circular disk with alternate quadrants removed, splits the radiation into two channels. Dichroic filters (beam splitters), which transmit one wavelength band but reflect other wavelengths, effect the final beam splitting. Due to the action of the chopper mirror the radiation in each channel consists alternately of atmospheric and space radiation.

Observations are made in sixteen spectral intervals utilizing only four detectors (A, B, C, D) by mounting four different filters on each of four disks. Each filter remains in position in front of a detector for 1 second, after which all four disks are rotated by 90° to bring the next filters into position, so that observations in all sixteen spectral intervals are made every 4 seconds. The four filters associated with detector A will give radiance information from 0 to 20 km altitude. The CO_2 cells associated with detector B will give radiance information from 20 to 45 km altitude. Some of the other channels have functions of measuring water vapour content of the atmosphere, determination of ice particle size and density in cirrus clouds and measuring reflected sunlight.

The calibration mirror is to be rotated about every 8 minutes to receive radiation from the 'black body' and in the opposite direction to receive space radiation for calibration purposes. This mirror also moves during the 4 second observation cycle to compensate for the motion of the satellite relative to the region of atmosphere under observation.

The technical problems which have been studied in the engineering model have included the use of dry lubricants for bearings and gears in ultra-high vacuum. The lifetime requirement of over 10,000 hours makes friction and wear the limiting factors for operation in outer space. To test the model under simulated space conditions a large vacuum test tank with nitrogen cooled targets has been designed and constructed. Other equipment simulates all the satellite commands and services and provides the logic and power circuits to operate the mechanisms of the apparatus.

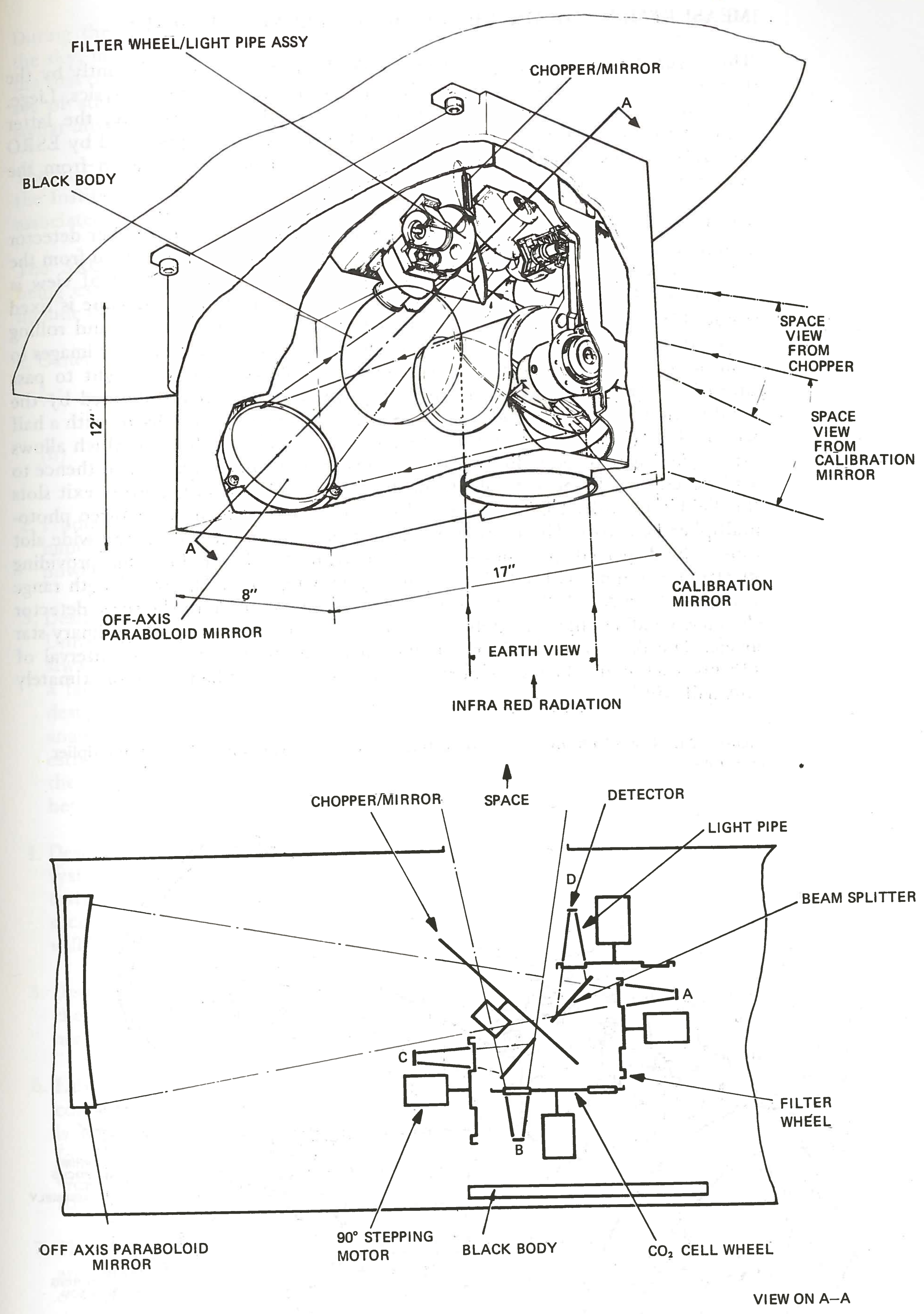


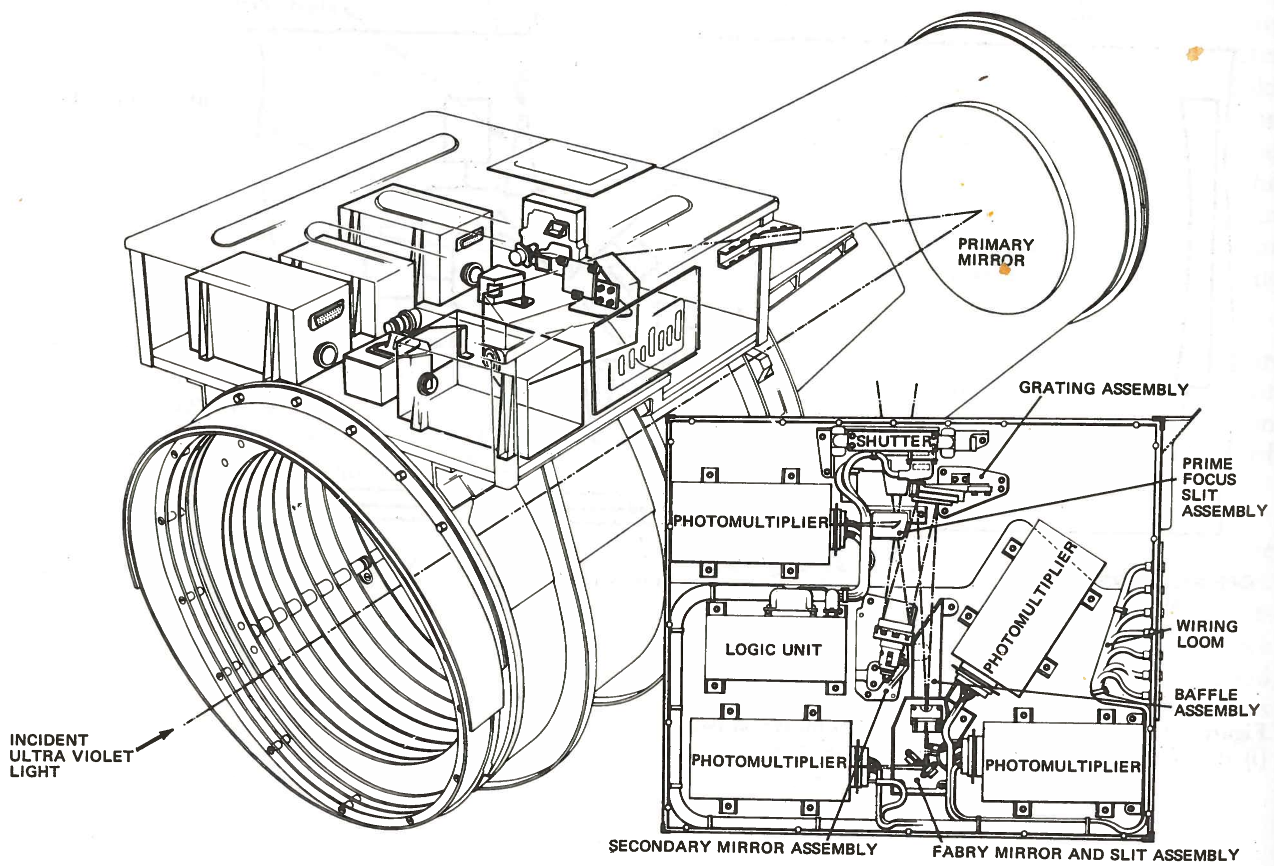
Figure 125. The selective chopper radiometer showing: (i) the general arrangement, (ii) view on A-A.

MEASUREMENT OF THE ULTRA VIOLET FLUXES OF STARS

The S2/68 Experiment for the ESRO TD1 Project was initiated jointly by the Royal Observatory, Edinburgh (ROE) and the Institute of Astrophysics, Liege. It is the largest of seven experiments on board the TD1 satellite, the latter being the largest and most complex scientific satellite so far produced by ESRO and is to be launched in February 1972. (The name TD1 is taken from the American launch vehicle used which is a Thor-Delta).

S2/68 is an ultra violet reflecting telescope with four photomultiplier detector channels, as shown in figure 126. Ultra violet light from stars is reflected from the off-axis Cervit primary mirror into the spectrometer box. The field of view is defined by slots in the focal plane of the primary mirror. The telescope is fixed inside TD1, the latter having a near polar, sun synchronous orbit and rolling about the sun pointing axis once per orbit. This motion causes the star images to scan across the focal plane slots. A narrow slot allows ultra violet light to pass through to the photometer channel, the passband of which is defined by the combination of photocathode and glass filter; it is centred on 2800Å with a half width of 400Å. Next to the photometer slot is a much wider slot which allows ultra violet light to pass through to an ellipsoidal secondary mirror and thence to a plane grating. Dispersed light from the grating falls on three narrow exit slots the light transmitted by these is reflected by Fabry mirrors into three photomultiplier detectors. The motion of the primary star images across the wide slot causes the dispersed spectrum to move across the fixed exit slots, thus providing spectrum scanning without the use of any moving parts. The wavelength range 1330Å to 2600Å is fully covered by the spectrometer, each of the three detector channels yielding approximately 20 data points for each scan of the primary star image. The data is in the form of photon counts in an integration interval of 148 ms, each count being the number of photons in a passband of approximately 35Å half width.

Figure 126. The S2/68 ultra violet reflecting telescope showing the four photomultiplier detectors.



During the six month lifetime of TD1, S2/68 will produce a complete scan of the sky, measuring photon fluxes of stars down to the 9th magnitude. It will be the first complete sky scan with one instrument and will yield a valuable consistent set of stellar fluxes. The data will be particularly suitable for studies of inter stellar ultra violet absorption and its distribution over the sky.

The SRC is responsible for the structure and optics of the instrument (S68) and the Institute of Astrophysics, Liege is responsible for the detectors and filters and associated electronics (S2).

The SRC project team is based at the Rutherford Laboratory, overall control being exercised by a Management Committee. The activities of the project team include the following:

1. General Project management involving such aspects as:
   (a) supervision of the industrial contract, with Hawker Siddeley Dynamics Limited,
   (b) liaison with Liege, European Space Research and Technology Centre (ESTEC) and Goddard Space Flight Centre, USA.
2. Production of detailed specifications for the telescope, optics etc. This is a very important aspect of the project management and requires considerable man-power.
3. Design of the stray light baffle system in conjunction with consultants at University College, London. This is particularly important because TD1 is always in full sunlight and the baffle system must attenuate the solar flux by a factor of at least 10^{14} to enable 9th magnitude stars to be observed. Initial design, based mainly on geometrical considerations, has been subjected to analytical treatment involving multiple ray tracing by computer to derive an estimate of overall system attenuation. By this means the attenuation due to the combination of spacecraft and telescope baffling has been calculated as better than 10^{16}.
4. Design and construction of devices for checking the alignment of the optical system of a development model of the telescope before and after vibration tests and during thermal vacuum tests. Thermal vacuum tests have been successfully completed and have shown that the alignment of the flight model will be within specification in the orbital thermal environment.
5. Design and construction of a portable monochromator-collimator unit for checking the optical performance of the finished telescope. This device is now nearing completion.
6. Laboratory calibration of the flight model. This will be done at ROE where a complex equipment is almost completed. A major component of this apparatus is a secondary standard photomultiplier used to scan the ultra violet beam used for calibration and measure its absolute intensity. This photomultiplier is itself calibrated absolutely against a thermopile in an apparatus constructed at the Rutherford Laboratory.
7. The implementation of a contamination monitoring scheme. The mirror coatings are specially made for use in the ultra violet and are susceptible to very thin contaminating films. A running check is being kept on the state of the mirrors during the 12 months between coating and launch by measuring the ultra violet reflectance of small sample mirrors which accompany the flight mirrors at all times and which were coated at the same time. A precision, vacuum reflectometer, at ROE, is used for reflectance measurements.

THE HIGH FLUX BEAM REACTOR

Prior to 1965 the National Institute for Research in Nuclear Science (NIRNS) supported the use of UKAEA reactors by University scientists for research into the properties of condensed matter. This arrangement was maintained by the Science Research Council (SRC) when it took over NIRNS and currently the SRC supports the work of some 100 scientists and research students in this field. Neutrons of around thermal energies have long been used in solid state physics and their use has been steadily extended in both solid and liquid state studies in chemistry and more recently in biology. For much of this work the special properties of the neutron – its zero charge, its mass, its magnetic moment – give it characteristics of scattering and penetration which lead to information which cannot be obtained in any other way.

It has been recognized for some time that to provide adequate support in future years for this important field, new facilities would be needed which would raise significantly the available beam intensities and provide more experimental space and more advanced research instruments. One possibility would be to build a 100 MW reactor giving a thermal neutron flux of $1{\cdot}5 \times 10^{15}$ n cm^{-2} sec^{-1} (maximum intensity available now in the UK is 10^{14} n cm^{-2} sec^{-1}). The Atomic Energy Authority (AEA) have already prepared a basic design for such a reactor, known as the High Flux Beam Reactor (HFBR), which it was hoped could be constructed as a joint AEA/SRC project. When it became clear that this joint approach was no longer possible, the Council decided to consider adopting the project as a purely SRC one. In May 1970 the Rutherford Laboratory was asked to prepare a proposal for a costed programme of detailed design and project planning which could be undertaken as the next stage of proceeding with the project. This proposal has been prepared with the assistance of the AEA which would be asked to carry out much of the detailed work of the project. It was submitted to Council in December 1970, but no decision has yet been taken concerning the adoption of the proposed project design programme.

As envisaged now, the reactor would be heavy water cooled and moderated using a core of highly enriched uranium 235 aluminium alloy fuel tubes. Twenty seven neutron beam tubes pierce the reflector to the high-flux zone around the core. In order to reduce the unwanted fast-neutron and gamma-ray components in the beams most of these tubes are placed tangentially to the core. Hot and cold neutrons are provided by beam tubes arranged to look at special sections of moderator maintained at the appropriate temperatures. A radial hole pointing directly towards the core provides a high intensity neutron beam having a high epithermal component. This beam hole can be aligned to a 300 m flight path for time-of-flight measurements. The twelve highest-flux holes are horizontal; eight high-angled and six low-angled holes and a sloping "through" hole give a somewhat lower flux. There are 17 irradiation holes in the reflector, and one in the core.

Figure 127 illustrates the present design of the reactor and some of the beam tubes. It would be located at the centre of a large containment building some 150 ft dia and 110 ft high with the main experimental floor extending from the biological shield to the wall of the building.

The whole facility could be constructed over a five year period at a total cost of about £20M. It would eventually require a staff of about 500 and would support some 150 university research scientists.

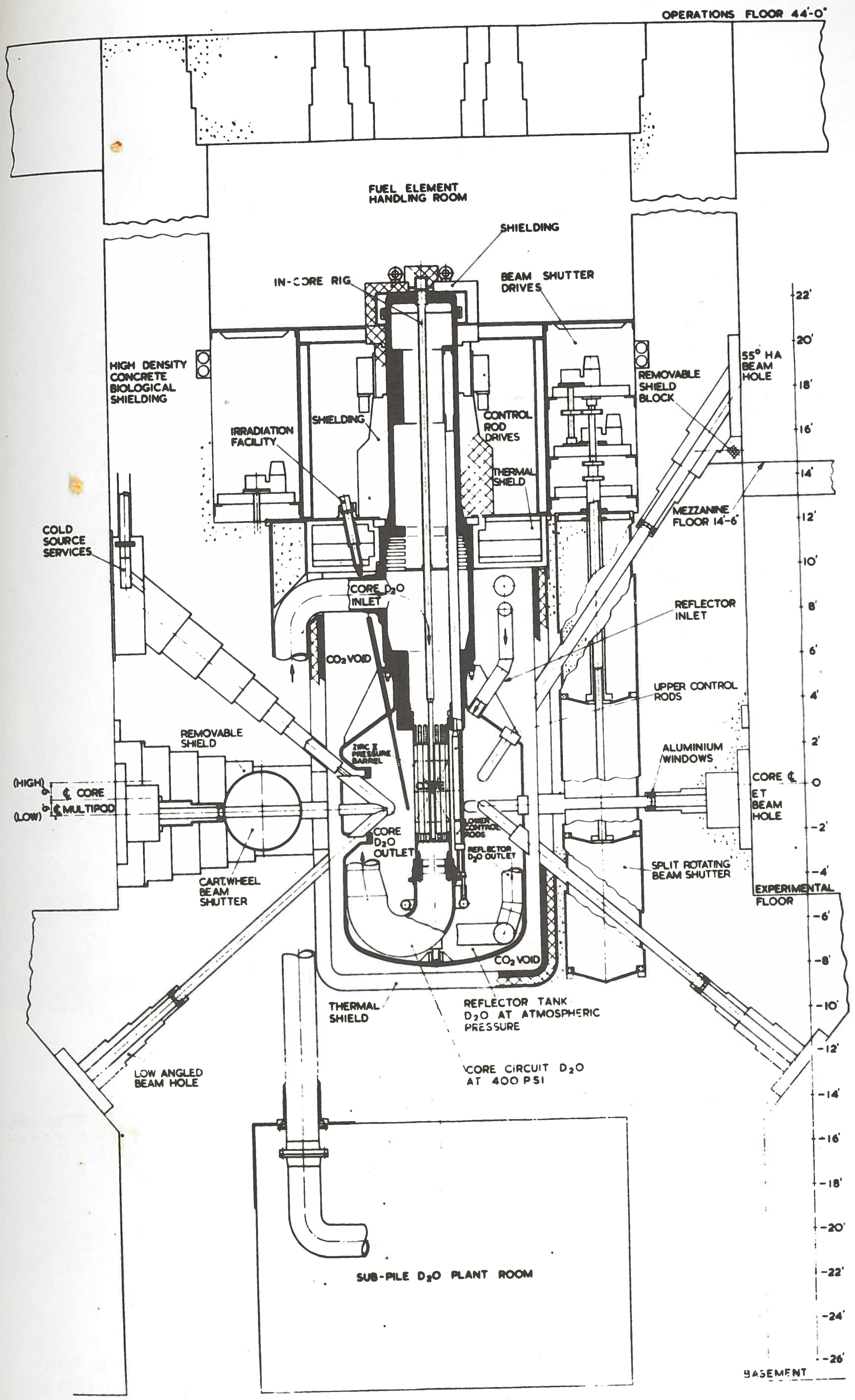


Figure 127. Sectional elevation of the proposed High Flux Beam Reactor. (Reproduced by courtesy of AERE Harwell).