Applied Superconductor Technology Projects at SIN

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A pion treatment facility and international test facilities for fusion

Superconductivity - discovered nearly 70 years ago — is finally about to leave the physics laboratory. The complete lack of resistivity in some metals at low temperature appeared from the very beginning as a fascinating potential break through in electrotechnics. However, it is only about 25 years since this potential could be realized, at least on a laboratory scale, for the generation of high magnetic fields. The essential step needed was the discovery of "hard superconductors", alloys and intermetallic compounds with a relatively high critical temperature, able to remain in the zero resistance state even in the presence of a high magnetic field. Since then, the further development of superconductor technology has been closely related to the work in high energy physics laboratories, where the urgent need for the generation of high fields in large volumes (detectors and beam guiding devices) was paired with the available skill and flexibility for development work on the required scale. The gradual increase of industrial involvement in the field of magnet technology and refrigeration was stimulated by the potential application of superconductivity for energy transport and conversion (MHD), motors, generators, magnetic ore separation and even magnetic levitation for high speed transportation. All these applications were proved in the last decade to be technically feasible, but none of them seems to be economically competitive at present.

In the applications discussed below, the use of superconducting magnets represents the only solution to the given problems. First, the medical pion irradiation facility of SIN is described, which recently started operation. Second, the application of superconductivity to fusion reactors is briefly discussed, an area in which SIN is actively involved through a European and world-wide cooperative R & D effort.

Medical Facility at SIN

In the local treatment of tumours by radiotherapy, while the malignant tissue should be destroyed, optimum saving of the surrounding or infiltrated healthy tissue is of crucial importance.

Ideally, the irradiation method should guarantee the deposition of a homogeneous dose distribution in an arbitrary 3-dimensional volume inside the body. Preferably, it should have even a selective effect on the different cell systems or at least, not have a negative selectivity with respect to the healthy tissue. Such an effect is associated with oxygen and results in the radioresistivity of several tumours against conventional γ rays. Soon after their discovery, from both aspects negative pions were identified as hopeful candidates for radiotherapy.

It is only recently, however, that pion beams could be generated at the meson factories LAMPF (USA), TRIUMF (Canada) and SIN (Switzerland) with sufficient intensity for serious clinical trials. Of these, the most powerful and flexible pion facility dedicated to medical research has been developed and built over the past four years at SIN (Fig. 1)

Pi mesons are generated in a gas cooled Be or Mo pencil target placed in a 20 μA 600 MeV proton beam. The large acceptance (1st solid angle, $\pm$ 7% momentum band) optical system consists of two superconducting torus magnets of 5 m diameter. Each torus has 60 identical pancakes subdividing the pions into 60 identical beams. These beams leave the first torus parallel to the common axis of the tori, and after passing a shutter system are bent and focused back on to the axis, where the patient can be located.

The patient is partly surrounded by a cylindrical bolus, equalizing the penetration depth of the pions. Variations of pion momentum and motion of the patient can be controlled in such a way as to generate a homogeneous dose distribution in a practically arbitrary volume defined by the therapist. The dose outside the given contours can be kept negligibly small.

The superconducting ring magnets weigh roughly 7 ton each; their stored energy is 3.5 MJ. The coils are embedded in purposely shaped glass fibre epoxy plates, are epoxy impregnated and indirectly cooled by circulation of supercritical helium at 4.5 K, a method developed earlier for superconducting systems at SIN. The required current density in the coils is higher than 200 A/mm², a value only achievable with superconducting technology. These magnets are the biggest superconducting tori presently in operation.

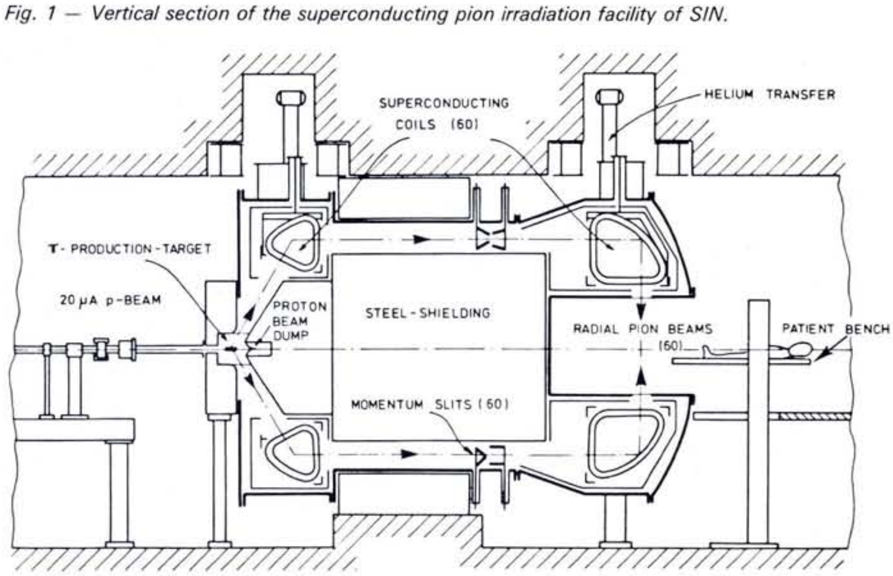
The "piotron" was first put into operation on 21 June, and the very first pictures of the dose distribution of the stopped pions proved its excellent performance (Fig. 2). The biomedical programme with the new beam will be started in October this year with dosimetry and radiobiology experiments.

Fusion Magnets

Today's ideas on fusion reactors are concentrated around two possible basic principles: inertial and magnetic plasma confinement. For the latter, different geometries are investigated, such as mirror, bumpy torus, tokamak etc. They all have the common need for large, high field, high current density magnets to keep the hot burning plasma more or less continuously in an equilibrium state.

Tokamaks with a DC toroidal main field are presently the most hopeful candidates for reaching ignition. Up to now, most experiments could only be performed in a short pulsed mode as long as normal conducting coils were used for generating the main toroidal field. JET is representative of the present size of experimental reactors, and studies for the next generation devices, such as JNTOR, clearly emphasize the need for superconducting main field magnets. The required peak field range of future Tokamaks is about 8 - 12 T with coil

Fig. 1 — Vertical section of the superconducting pion irradiation facility of SIN.



dimensions of about 10 m. The stored energy of such a system is of the order of gigajoules!

Needless to say, such magnets cannot be ordered off the shelf, but represent a formidable challenge to those involved in the field of superconducting technology. To overcome the missing orders of magnitude between present state of the art and fusion technology, several steps are needed, the first of which is a well advanced international project called the Large Coil Task (LCT).

Recognizing the urgent need for the development of superconducting technology for the next generation of tokamaks, the US Department of Energy initiated a project for the construction of a large superconducting torus. In the framework of the International Energy Agency, a collaboration was established with the participation of Euratom (represented by Germany), Japan and Switzerland, with the aim of demonstrating the feasibility and safe operation of large high field superconducting torus magnets.

In the LCT, which is built at Oak Ridge, six D-shaped coils 4.5 m high will be installed in a toroidal arrangement around a bucking post (Fig. 3). They should generate a peak field of 8 T, and will be tested under simulated tokamak conditions (external pulse field, nuclear heating). Three of the coils are contributed by the USA, with General Electric, General Dynamics and Westinghouse as coil contractors; the remaining coils are being developed by KfK-Siemens, JAERI-Hitachi and SIN-Brown Boveri.

The design concepts for the coils are different. Five of them are based on NbTi as a superconductor, a material with well advanced technology but a field range at its limit at 4^0 K and 8 T; one of the US coils is based on NbSn, a superconductor with potential use up to 12 T but extremely difficult to handle. Three of the coils are cooled by pool boiling, the others are cooled by force flow of supercritical helium. Conductor and structural design of the coils differ in several respects.

The Swiss coil concept is aiming at a high current density, low AC loss performance, based on a soldered cable conductor cooled by forced flow. Development and design were started in 1979 in close collaboration with industry, and the coil should be delivered to Oak Ridge with the other forced flow type coils in 1982. The common LCT test programme is expected to be finished in 1984. It will have a serious impact on the design of the breakeven generation of tokamaks.

As fusion power density is rapidly increasing with higher confinement fields, further development steps on a world-wide scale are in progress to extend the peak field capabilities of superconducting magnets to the 10 - 12 T level.

The new materials of the NbSn type to be used are extremely brittle, difficult to produce in the proper form and nearly impossible to handle in the usual way. New

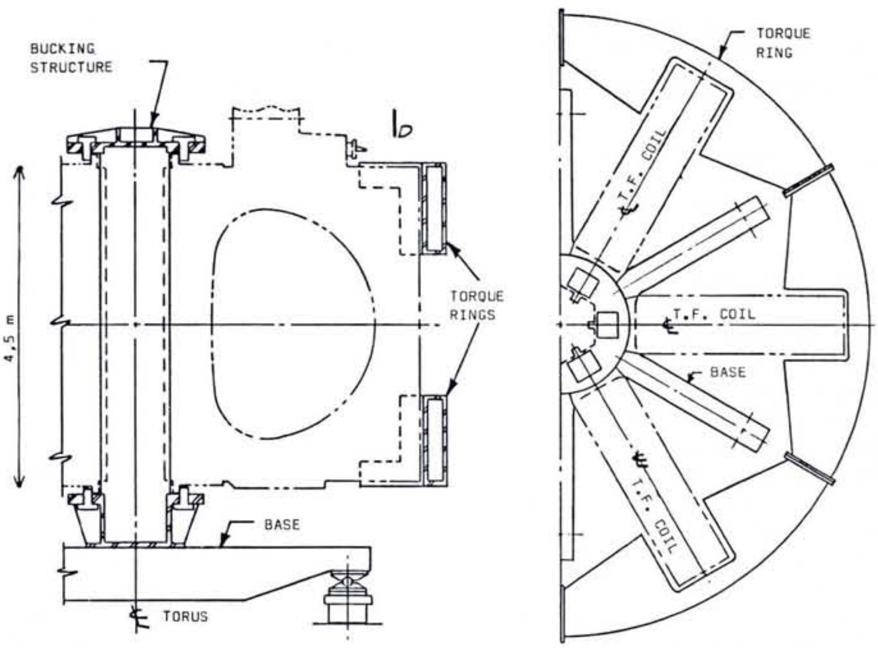
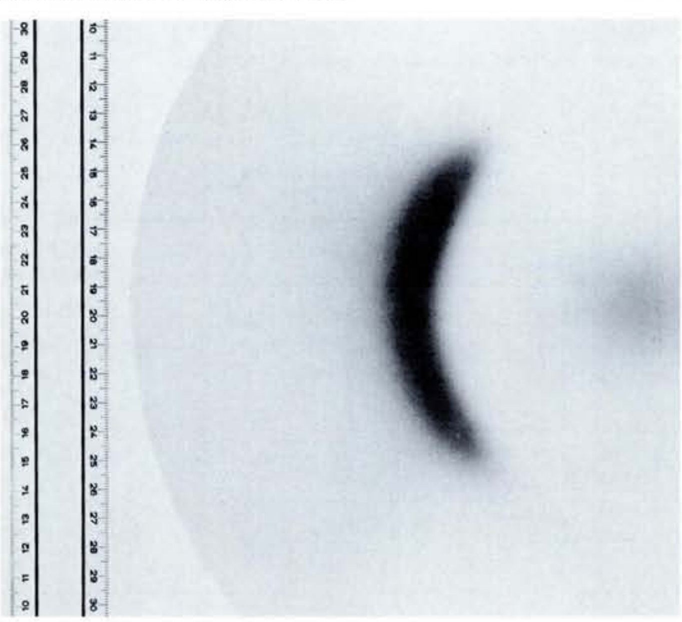
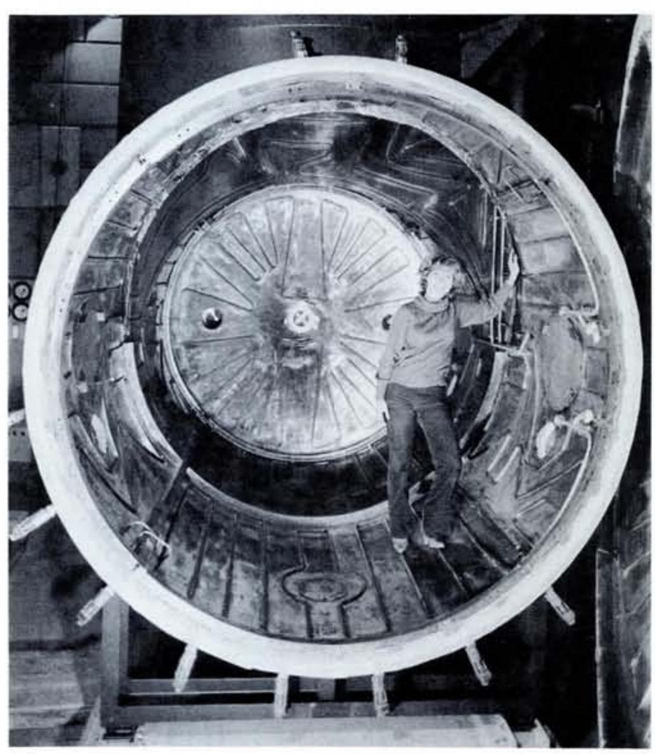


Fig. 3 — Toroidal coil arrangement of the superconducting demo experiment LCT.

Fig. 2 — Dose distribution generated by 15 pion beams (below) inside a lucite cylinder at a depth of 13 cm.

Fig. 4 — Cryogenic enclosure of the SULTAN test facility (right) ready for installation of the 8 T background coils.





conductor processing techniques and a complete change of magnet fabrication methods are to be developed and tested on samples of practical size. Conductor stabilisation philosophies and structural problems have to be reevaluated, corresponding test facilities with adequate background field and cooling installations have to be set up.

Driven by their common interest, three European laboratories: CNEN (Frascati, I), ECN (Petten, NL) and SIN (CH) decided to coordinate their development efforts and to install a common high field force flow test facility at Villigen.

The programme envisages the use of different high field materials (NbSn, NbAl, VaGa) and the development of different conductor manufacturing techniques in collaboration with national industrial companies. Mutual information on structural, cooling and stabilization problems is agreed on. The test facility SULTAN (**Su**pra**l**eiter **T**est**an**lage) is presently under construction. The cryogenic system and supplies are contributed by SIN (Fig. 4). The 6 T outer section of the background solenoid is provided by CNEN, and ECN is responsible for the 8 T 1 m bore inner section.

First conductor loop tests in the new facility are scheduled for mid 81. A later extension of the facility to above 10 T by insert coils made of high field conductors is in preparation. Recently Euratom decided to support the efforts as an important part of its fusion technology programme.

EPS and UNESCO

Agreement has been reached between EPS and UNESCO for our society to be admitted to the Mutual Information Category of Relationship (Category C) as defined under UNESCO's directives concerning relations with international non-governmental organisations.

Conditions which have to be fulfilled for an organisation to be acceptable are that it is working in fields that are relevant to the work of UNESCO, that it concerns people from a number of different countries, that when it covers a particular geographical area, it can be regarded as representative of the relevant activities in that area, and finally that it is run by a representative international body. Clearly EPS fulfills all these conditions in a thorough manner.

Category C

Category C is a loose form of relationship, the essential obligation imposed on the collaborating organisation being limited to providing information to the Director-General of UNESCO on its activities which are relevant to UNESCO's programmes and objectives and to disseminating information to its members on UNESCO's programmes and achievements. No financial contribution is involved.

The principal formal advantages accruing, are the possibility that invitations may be sent to attend certain of UNESCO's meetings and the access given to UNESCO's documentation.

What is probably of much greater importance is the tidiness that will be introduced into the activities that EPS and UNESCO have been conducting in common for some time, not exactly sub rosa, but without the formal blessing of the organisation. These have concerned two main areas: education, with particular emphasis on the plans to promote teaching abroad through the Lecturer Exchange Scheme, and in the distribution of *Europhysics Education News*; publications: UNESCO twice has been host to European publishers of physics journals at the instigation of EPS.

However, this is only a beginning and now that the relationship has been formalised it is possible that opportunities for collaboration will multiply and there will be a growing area of common activity. UNESCO is not rich, but it does have some funds, particularly for bringing together people from distant parts. Already discussions have been held on how UNESCO might help in preparing the Seminar that the EPS Physics and Society Committee is organizing in Istanbul next year. This would seem to a promising beginning to a relationship that is hoped will be mutually beneficial.

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