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Mechanical Engineering

Reports: Trips, Meetings and Procedures

TITLE

Foreign Travel Report for NASA and DOE - 1987

Itinerary and Summary

This report presents information gathered during my official travel to Europe. The travel was paid for primarily by the INFN Laboratory at Frascati, Italy, in connection with a collaborative effort on ASTROMAG. Secondary funding was provided by LBL and the Department of Energy. Some of the United States travel connected with a one-day meeting at the Goddard Space Flight Center was funded by NASA.

March 23 Left the United States to Frankfurt via a U.S. carrier.

March 24 Landed in Frankfurt, W. Germany. Traveled by train to Hamburg, W. Germany.

March 25 Meeting at DESY in Hamburg, W. Germany, with J. Susta, H. Mess, P. Schmuzer and S. Wolff concerning the HERA superconducting magnets and R.f. cavities. Discussions included continuous correction coils, the superconducting magnet and R.f. cavities for the HERA electron ring. Paid for by LBL and DOE. Traveled by sleeping car to Geneva, Switzerland.

March 26 Meeting with M. Morpurgo and P. Spillantini of CERN in Geneva, Switzerland, concerning the Italian two-coil toroid magnet design for ASTROMAG. Paid for by INFN, Frascati.

March 27 Meetings at CERN in Geneva, Switzerland, concerning the LEP superconducting insertion quadrupoles. Contacts: T. Taylor, P. Lebrun.

Meetings at CERN II in France concerning the LEP-2 experiment, LEP magnets and superconducting magnets for the LHC. Discussion included magnetization effects. Contacts: R. Perin, A. Asner, D. Hagedorn and D. Leroy. Paid for by LBL and DOE.

March 28 Morning meeting at CERN in Geneva, Switzerland, with P. Spillantini concerning various superconducting magnet configurations which could be used for large detectors for LHC and the SSC.

March 29 Traveled by train from Geneva, Switzerland, to Genova, Italy.

*This work was supported by the U.S. Department of Energy under Contract DE-AC03-76SF00098.

March 30 Meeting with people from the Ansaldo Componenti at their plant in Genova, Italy. Tour of the coil winding facility at Ansaldo to see the progress on HERA coils and a test LHC coil. Contact: F. Vivaldi.

Meeting with several people from Ansaldo in Genova, Italy, concerning the Ansaldo zero mechanical moment two-coil toroid magnet design. Contacts: F. Vivaldi, G. Scarfi, M. Grattorola, M. N. D. Romanini, F. Rosetelli and P. Spillantini. Paid for by INFN, Frascati.

Travel to Lucca and Firenze, Italy, by car from Genova, Italy.

Dinner meeting in Lucca with G. Ciancaglini, a consulting engineer who had designed and overseen the fabrication of copper calorimeter parts for the LEP-2 experiment.

March 31 Travel from Firenze, Italy, to Rome, Italy, by train.

April 1 Meeting at Frascati with people from INFN, Frascati, and ENEA, Frascati.

Meeting concerning the two-coil toroid superconducting coil design for ASTROMAG and what might be done by LBL, NASA and Frascati to bring this coil design to the same level as the strawman (HEAO) design. There were general discussions about the Italian role in physics for ASTROMAG. There was also a discussion about a 77 K superconductor made at ENEA, Frascati. Contacts: P. Spillantini, G. Basini, A. Codino and Marco Ricci all of INFN; and Mario V. Ricci, G. Pasotti and N. Sacchetti all of ENEA.

Paid for by INFN, Frascati.

April 2 Travel to Karlsruhe, West Germany, from Rome, Italy, by train.

April 3 Meeting and discussions with several people of the Kernforschungszentrum Karlsruhe (1/2 day).

Discussions included the successful test of the 19.35 T, 1.8 K hybrid magnet, fabrication of 105 K superconductor and discussions concerning a fountain effect pump for pressurized helium II internal cooled 1 T superconducting magnets. Contacts: F. Arendt, J. Erb, P. Turowski and A. Hofmann.

Paid for by LBL and DOE.

April 5 Returned to the United States from Frankfurt to Baltimore, Maryland, via a U.S. carrier.

April 6 Meeting at the Goddard Space Flight Center in Greenbelt, Maryland.

The meeting concerned what was learned from the Italians. There were discussions about a reduced scope ASTROMAG which could be launched by a delta rocket. Contacts: J. Ormes, J. W. O'Connor, M. Schein and S. Castles of the Goddard Space Flight Center.

Paid for by NASA.

Return to the West Coast during the evening.

Europe, Spring 1987

The value of the United States dollar has further decreased since my last trip to Europe in the summer of 1986. The Italian Lira has risen from 1,400 to the dollar to 1,290 to the dollar. (This should be compared to 2,000 to the dollar in 1985.) The German Mark is up from $0.49 in 1986 to $0.55 during this trip. The Swiss Franc is up from $0.60 in 1986 to $0.67 on this trip. Prices have changed very little in local currency. Germany experienced a slight negative inflation in 1986 due to the price drop in oil.

As a result of decreasing dollar values, the price of food seems higher. For example, in Italian restaurants everything is a la carte. If you order fish, you get only fish--no vegetables or potatoes (Northeastern Italy in the South Tyrol is an exception.) In Italy one can expect to pay from 4,000 to 7,000 Lira for an antipasto ($3.12 to $5.48). The pasta will run from 4,500 Lira to 8,000 Lira ($3.51 to $6.25) depending on the kind of pasta. Vegetables and salad will start at 3,000 Lira ($2.35) and go to 7,000 Lira ($5.48). Meat and fish dishes go from 9,000 to 25,000 Lira ($7.03 to $19.50). The house wine is still a bargain at about 5,000 Lira ($4.00) per liter; but coffee (espresso) might run as much as 2,000 Lira ($1.56). Then there is the charge for the bread on the table, 1,000 - 2,000 Lira ($0.78 - $1.56). One can eat in a pizzeria for less money, say 13,000 Lira ($10.15) for an individual pizza, a salad and a half liter of wine. Swiss restaurants are even higher; and German restaurants are in general much lower. However, one is not expected to tip 15 percent. The bargain of the century is a full meal at the Frascati canteen for 100 Lira ($0.08). This price was set in 1946 when Frascati was founded; by law it can't be raised. The Italians point out that lunch may be cheap, but the typical physicist at Frascati makes 1.5 million Lira per month (about $1200 per month). The food at the Frascati canteen is better than in most canteens including CERN and Saclay.

Transportation within Europe is expensive. The typical price for the train in Germany is DM 0.20 per kilometer (about $0.18 per mile) for second class. First class costs DM 0.30 per kilometer (about $0.27 per mile). Italian trains are a little cheaper. French trains are about the same, and Swiss trains are just a little more. Flights within Europe tend to cost 1.5 to 2 times the cost of first class train travel. If you are going to travel more than 2,400 km (1,500 miles) in 15 days or less, the first class Eurail pass ($280 for a 15-day pass) makes sense for an American, because one has all of the convenience and comfort of the pass while paying less than second class rail rates. The Eurail pass picks up most of the extra fare supplements for the special trains. The Eurail pass does not pick up seat reservation charges or sleeping car charges.

European trains, even the Italian trains, do run on time. They go from city center to city center (where one can find a hotel), and in many cases they do connect to the major airports (i.e., Dusseldorf, Munich, Frankfurt, Zurich). In many cities there are direct subway connections to the airport, but not in Rome. The French are trying to make their TGV system extend into surrounding countries. This is being met with resistance from some countries because of their own competing inter-city or rapido systems. The French TGV system extends all over Southern France. One can go direct from Geneva to Paris in about three and a half hours on the TGV. The German inter-city trains (not as fast as TGV, but plenty fast) run hourly from most of the major German cities. Some of these trains extend into Switzerland, Holland, Italy and Austria. Within Germany, the supplement is DM 4.00 ($2.20) for second class and DM 6.00 ($3.30) for first class (unless you have a Eurail pass). First class riders rarely have trouble finding a seat on a German inter-city, so it is usually not necessary to pay to reserve a seat.

This last winter has been one of the worst in the last 50 years. There was snow even in the Greek Isles, Turkey and Greece itself. The Alps have almost a record snow pack. (The Eastern United States has had similar cold and snow, while California has had 50 percent of normal rainfall and snowfall.) The skiing has been great in the Alps, with winter snow the last week in March and fresh snow even in early April. Two days before I entered Germany, there was about 5 centimeters of snow in the Ruhr. There was some of this snow left when I went to DESY in Hamburg. There was snow in Italy and Switzerland, and it was snowing in Austria. North of the Alps spring was quite far off. In Italy the fruit trees and forsythia had started to bloom a few weeks late. The 1987 winter was a hard one.

The drop in oil prices resulted in lower fuel bills in Western Europe despite the hard winter. This was not true in Eastern Europe where the price of Soviet oil is figured at a price which is the average world price for the last five years. The hard winter has forced Eastern European countries to trade goods to the Soviet Union which would normally be sold in the west. East German furniture is hard to find in West Germany, and last January the East German Mark suddenly tumbled on the West German currency exchanges. (West Germany trades in many of the East European currencies despite the fact that one isn't supposed to take these currencies in and out of the East European countries.) The East German Mark is normally bought for 0.16 DM ($0.088) and sold for 0.19 DM ($0.105). This rate of exchange (which is five to six times lower than the one for one official exchange rate) has persisted for the last 10 to 15 years. Last January the buy rate dropped to 0.09 DM ($0.05) and the sell rate dropped to 0.11 DM ($0.061). Apparently Romania, which was desperate for Western currency, sold all of their DDR Marks on the West German currency exchange. The hard winter resulted in some people making a killing in speculation on the DDR Mark, and to a lesser extent the Czech Kroner. Czech Kroners are normally bought for 0.05 DM ($0.028) and sold for 0.07 DM ($0.039) which is a factor of three below the official rate. (Not much of a change from 1977 when I was in Czechoslovakia.) Last January the Czech Kroner dropped somewhat along with DDR Marks.

It is interesting to look at the cost of electrical energy in Western Europe. Electricity in Germany is 0.18 DM plus 14 percent value added tax per kilowatt hour (about $0.113 per kwh including the tax). This is up from a cost of $0.033 per kwh in 1973 and $0.055 per kwh in 1978. West German electrical rates are comparable to rates in many parts of the United States. Swiss electricity prices are a little cheaper than German prices.

Regular readers of my foreign travel reports look forward to getting the gasoline prices in Europe, so I won't disappoint my readers. The gasoline prices by country as of March-April 1987 are listed henceforth:

1) Western Germany has introduced unleaded gasoline in two grades. Now there are five grades of fuel sold in Germany. The prices are as follows:

Regular leaded	0.92 - 0.94 DM/ℓ	($1.92 - $1.96/gal)
Regular unleaded	0.95 - 0.98 DM/ℓ	($1.98 - $2.04/gal)
Super leaded	1.00 - 1.03 DM/ℓ	($2.08 - $2.14/gal)
Super unleaded	0.98 - 1.02 DM/ℓ	($2.04 - $2.12/gal)
Diesel	0.89 - 0.92 DM/ℓ	($1.85 - $1.96/gal)

The prices above apply for self serve or partial full serve. There is really no such thing as full serve in Germany. The prices have hardly changed in local currency since the summer of 1986.

2) Switzerland has still not introduced unleaded gasoline. A sampling of Swiss prices is as follows:

Regular	0.89 SwFr/ℓ	($2.24/gal)
Super	0.99 SwFr/ℓ	($2.50/gal)

Swiss gas prices have gone up a little in local currency since the summer of 1986.

3) Italy has not introduced unleaded gasoline. The Italian gasoline prices with no variation are as follows:

Regular	1,230 Lira/ℓ	($3.61/gal)
Super	1,280 Lira/ℓ	($3.76/gal)
Diesel	640 Lira/ℓ	($1.88/gal)

In local currency there is no change from the summer of 1986. To keep people from cashing in on low diesel prices, a hefty annual car tax is put on diesel cars. It doesn't pay to drive a diesel car unless you drive over 15,000 kilometers per year. The gas prices are the same all over Italy.

4) Austria has not introduced unleaded gasoline. The prices in Austria (around Innsbruck) are as follows:

Regular	8.30 - 8.50 sch/ℓ	($2.49 - $2.55/gal)
Super	9.10 - 9.30 sch/ℓ	($2.73 - $2.79/gal)
Diesel	7.63 - 7.88 sch/ℓ	($2.29 - $2.36/gal)

Perhaps gasoline is cheaper near Vienna, but I doubt it.

It is reported by my friends with relatives in East Germany that DDR gas prices have jumped to the order of $5.00 to $5.50 per gallon. This is to discourage the excessive use of motor fuel which must be traded to the Soviet Union for goods which could bring in needed western currency. For comparison, gasoline prices at the Shell Station in College Park, Maryland, were $0.839

for regular, $0.899 for unleaded and $0.939 for super unleaded. (There is no discount for cash at Shell.) Bay Area gas prices can be as much as $0.10 lower per gallon for cash only. U.S. gasoline prices show a much higher variation than do those in Europe. The U.S. has missed the energy conservation boat as usual. It is unrealistic to expect political leadership in this area.

Before leaving the general topic of Europe in 1987, it is useful to discuss the subject of visas. The French require a visa of everyone except EEC countries and countries sharing a common border. (The only non-EEC country which applies is Switzerland.) This French anti-terrorist measure, which doesn't stop terrorists, is for local political consumption. (We know other countries which do that, too.) In any event, we Americans must get a French visa if we want to cross France or stay in France. The French (unlike a lot of countries) charge for the privilege of entering their country ($9.00 for a three-month visa and $15.00 for a visa good up to three years). Americans are advised to get a French visa if they are visiting CERN. We need a visa to cross from the Swiss site (CERN I) to the SPS site (CERN II). If you do not have a visa (I did not), get a ride with someone who has CD (diplomatic) plates on their car and hope that the French are lax that day. Lawrence Berkeley Laboratory people can get their French visa in one day by taking a picture (they say any picture will do), the cash, and your passport to the French Consulate on Bush between Grant and Stockton in San Francisco.

Visit to the Deutches Electron Synchrotron DESY, Hamburg, W. Germany, March 25, 1987

Hamburg, known for its eel soup and a form of Laubskaus (a Scandinavian mashed meat and potato stew with a fried egg on top), was cold and rainy with fog on the Elb. I went out to the Laboratory from the Othmarschen S bahn Station (two or three stops on the S3 S bahn line toward Wedel or Blankenese from the Hamburg Altona Railway Station. There is a direct bus from the Othmarschen S bahn Station to the Laboratory.

At DESY I met with J. Susta (who worked at the Lawrence Berkeley Laboratory up until 20 years ago), H. Mess, S. Wolff and P. Schmuzer. The topics discussed during my visit included information on engineering measurements on the HERA dipoles, temperature stability and temperature measurement, the new superinsulation system, quench detection and protection, the tunnel and experimental halls, correction coils, R-glass fiberglass, the HERA refrigeration system, and the superconducting R.f. cavities for the HERA electron ring.

a) The HERA Dipole Magnets

I met with H. Mess and talked with S. Wolff briefly on the topic of the HERA dipole magnets. S. Wolff was busy meeting with potential suppliers of the German dipoles. The decision on who the German supplier was to be was to be made on March 27, 1987. According to H. Mess, there were four serious candidate companies for the production of the HERA dipoles. Two of these companies are large industrial fabricators which have never made a superconducting magnet. The third is Euratom (essentially a branch of Siemans) which has made a number of superconducting magnets, but their track record on dipoles is not very impressive. The fourth is Brown Bovari Company (BBC) in Mannheim, Germany, which has made a number of the DESY test magnets; and BBC is the company which developed the cold iron fabrication technique used by the HERA group. (The people at DESY tend to downplay the important role that BBC had in developing the final design.) The selection is supposed to be made on the basis of price. The German magnet decision was made but not on March 27. BBC Mannheim got the contract for the German dipole magnets for HERA.

The whole German magnet selection process is disturbing. It is almost as if DESY did not want to give the contract to BBC. There appears to be almost a dislike of BBC at DESY which I cannot put my finger on. (There is a mutual distrust on the part of BBC as well. They feel, with some justification, that BBC technology could be bought by another German company by bidding the HERA job low.) My personal opinion is that BBC was the only qualified bidder for the HERA magnet, but I do not see all of the cards so it is a difficult judgment to make. Ansaldo in Italy will do the other half of the HERA dipoles (progress there will be reported later in this report), and a French company will build the Desport group designed quadrupoles.

I specifically asked H. Mess about instrumentation to determine stress and strain on the HERA magnets. I asked him if they have put strain gages on the aluminum collars or on the cold iron. He said there had been no strain measurements nor was there a reason to have any strain measurements. The attitude at DESY is that quench data was taken down to 3.8 K. The magnets have gone to short sample, so why measure the strain? It is claimed that the magnets do no train. H.C. Dustmann at BBC told me the same thing last summer. When one looks at the forces in the magnets which are designed for 4.68 T, it is not surprising that the magnet does not train.

b) Temperature Measurements and Stability

HERA plans to control the temperature in the ring to a short-term temperature stability of 10 mK. The SSC plans to regulate the temperature to 90 mK. I am not sure why HERA has chosen such a tight temperature tolerance, but they have. H. Mess is very much involved in the measurement of the temperature and its control.

I asked about temperature measurement. H. Mess stated that they have looked at several measurement methods. They have rejected the silicon diode because their accuracy is to about ± 100 mK instead of ± 10 mK. They talked to Lakeshore Cryotronics, but Lakeshore would not certify that their glass carbon resistor would meet the desired ± 10 mK accuracy. The sensor which has been selected is a carbon on alumina with copper sensor built by Positronika - a Dutch company.

Some measurements have been made on these temperature sensors. They appear to meet the required accuracy, but when one was exposed to radiation to the level of 10 million rads the sensor temperature readings changed by 14 mK. H. Mess did not say whether this was a systematic effect due to the radiation exposure or whether it was some kind of random drift due to other effects. I am inclined to think that Lakeshore Cryotronics was right in not guaranteeing that their sensor was accurate to 10 mK. I am not sure that the Positronika sensor is either.

c) Quench Detection and Quench Protection

H. Mess spent some time talking about the HERA magnet quench protection system. This has been a problem area because there was a magnet burnout in the first full length HERA magnet delivered from BBC. (The coil was fabricated by DESY, and the quench protection was also the responsibility of the magnet group at DESY.) As a result of last summer's accident, considerable work has been done on quench protection.

There are two separate types of quench detectors for HERA. The first involves comparing the resistance of the two coil halves to one another. If the two halves of the coil quench together, then the second method of quench detection is invoked. The second quench protection method involves comparison of the resistance of four magnets with one another. It is believed that the two methods used in conjunction with one another will be very reliable.

When the quench is detected, the following sequence of events is supposed to happen. 1) The power supply to the magnets is disconnected. 2) Current is shunted past the normal magnet through a series of cold diodes. 3) A capacitor bank is discharged into a heater to heat up and drive normal the rest of the magnets in the string. Since the quench programs have some uncertainty, the last step was felt to be essential even though the computer calculations suggested that steps 1 and 2 are sufficient for quench protection. I think HERA will find multiple capacitor banks will be expensive.

d) The State of the HERA Machine

I was taken to a section of the HERA tunnel where electron beam magnets have been installed. The first beam transport tests were being prepared. The section of Tunnel I was in was adjacent to one of the smaller experimental halls which has a ceiling height of about 20 meters. There are several levels of galleries for physics electronics which were next to the hall itself.

HERA is an 800 GeV proton ring which collides with 30 GeV electrons. The proton ring superconducting magnet requires a current of 5.0 kA to generate a design field of 4.6 T. (The short sample current is 6.5 kA which is equivalent to a central field of about 6.0 T. Hence, the magnet operates at 77 percent of critical field along the load line. This is conservative.)

The HERA tunnel is about 75 percent complete. Half of the tunnel has concrete walls, and somewhat less than half of the tunnel has services according to Joe Susta. In parts of the tunnel electron ring magnets have been installed. In other parts there are just the bus-bars and the water cooling circuits.

Fabrication of electron ring magnets is well under way. The test superconducting cavities for the electron ring have been tested, but construction of these cavities is some time off. The refrigeration plant construction is two-thirds complete. The superconducting magnets are behind schedule. The German supplier had not been selected. The Ansaldo first magnets are months late. I understand that work on the superconducting quadrupoles is proceeding o.k. I do not know where the magnets and R.f. cavities are in terms of the overall schedule, except I get the general feeling that things are late. The sense of urgency does not appear to be there, however.

e) HERA Magnet Continuous Correction Coils

I saw the HERA continuous correction coils and talked to P. Schmuzer about these coils, the problems with fabrication and the problems with the superconductor. The HERA continuous correction coils consist of a 5,830 mm long normal sextupole which is put on the 60.3 mm OD magnet bore tube (the vacuum wall), and a 5,785 mm long quadrupole which is used to change the tune of the machine as much as one full tune unit. Both magnets are of the $\pi/3N$ type. (The quadrupole has allowable multipoles of N = 2, quadrupole, N = 10, N = 14, N = 18 and so on. The sextupole has allowable N = 3, sextupole, N = 15, N = 21, and so on.) The quadrupole is outside the sextupole, and the finished correction coil package has an outside diameter of 67.0 mm.

The inner bore tube has an outside diameter of 60.3 mm accurate to 0.1 mm. The bore tube is 2.5 mm thick, and it appears to be quite stiff against buckling. The coils themselves are wound from superconducting strands which are 0.7 mm in diameter with 1,130 filaments about 14 microns in diameter. The conductor has a copper-to-superconductor ratio of about 1.8. The test coils were wound with superconductor provided by BBC in Switzerland, but the production wire is to be produced by a small Dutch company.

Since HERA is funded by a number of European countries, including Holland, all of the countries want to get involved in the machine in a "high-tech way". The Dutch want to provide superconductor for the correction coils. The SLE company was selected. This company is a garage-sized operation which unfortunately is not capable of producing good quality superconductor yet. The BBC conductor used in the test correction coil goes to critical currents of 340 A and 5.5 T and 4.2 K. The specification requires 250 A at 5.5 T and 4.6 K or 285 A at 5.5 T and 4.2 K. Some of the Dutch wire barely meets the critical current criteria. The conductor has considerable sausaging, and there are also inclusions in the conductor. It is hoped that the company can correct these defects. In the meantime, companies which can produce the conductor are barred and more time is wasted.

The insulation around the bore tube is 150 microns thick. It consists of 62.5 microns of glass, 25 microns of kapton and 62.5 microns of glass. The conductor insulation is a varnish like formvar; I do not know what it is. The insulated conductor has a tolerance of about ± 0.03 mm. The insulation between the coils consists of 100 microns of glass fiber and 50 microns of kapton. Outside the quadrupole coil is a similar insulation, and outside of that is banding which consists of glass fibers. The whole assembly appears to be pre-impregnated and cured. The outside banding diameter is 67 mm, and it is quite smooth. I do not know what the tolerance is for the outside dimension.

The HERA correction coils occupy only about two-thirds of the length of the dipole magnets. These coils are located in the region of the dipole where beta is the highest. It was felt that correction in the low beta region would not be very effective anyway. The stainless steel bore tube appears to be very stiff, even in the region where there is no correction coil. It appears that helium is not in direct contact with the bore tube under the coil. I do not know whether temperature control is a problem. I suspect not, because synchrotron radiation should not be a problem with HERA. The HERA bore tube is copper plated on the inside. It was difficult to find a company that could do this plating inside a 9-meter long tube.

The magnetic measurements of the test continuous correction coils are very promising. When the quadrupole was measured a dipole N = 1 was found. From that, the off-center distance for the measurement apparatus was found. The quadrupole N = 2 was as predicted, N = 3 and N = 4 were less than 0.0025 times N = 2. N = 5 was as predicted from the off-center calculation, it was also less than 0.0025 times N = 2. N = 6 was very close to zero. N = 7 and N = 8 were less than 0.002 times N = 2. N = 9 was small as predicted from the off-center calculation. N = 10 was the first strong higher multipole at 0.025 times N = 2. This was predicted. The higher multipoles were pretty much as predicted. The sextupole measurements showed multipoles which were of the order of 0.0025 times N = 3, except N = 2 (due to the measurement apparatus being off center) and N = 15 (which is the first allowable higher multipole). N = 15 was about as expected.

f) R-Glass Oriented Glass Fiber

Peter Schmuzer told me about a glass fiber I had never heard about. This glass fiber called R-glass is 50 percent stronger than E-glass and about 35 percent stronger than kevlar. Unlike kevlar, the R-glass does not change its modulus of elasticity as it cools from 300 K to 77 K or lower. The R-glass shrinks as it cools (along the fiber direction), kevlar does not.

The samples of R-glass I saw came from Vetrotex Saint-Gobain, a division of textiles of Saint-Gobain Industries, Quai des Allobroges, B.P. 86, F73001 Chambery Cedex, France. I saw samples of raw glass, which seemed quite robust, and samples of the impregnated glass with oriented fibers. This type of glass appears to be very attractive for use in the support bands for superconducting magnet cryostats.

A comparison between R-glass, E-glass, C-glass and kevlar is shown in Table 1. The chemical constituents of R-glass and E-glass are as follows: SiO_2 R-glass 60 percent, E-glass 51 to 55 percent. Al_2O_3 R-glass 25 percent, E-glass 13 to 15 percent. CaO R-glass is 9 percent, MgO R-glass is 6 percent, whereas E-glass has 20 to 24 percent of combined MgO and CaO. E-glass has 6 to 9 percent B_2O_3, R-glass has almost no B_2O_3. The R-glass seems to be a tightly controlled product.

g) The HERA Refrigeration System

The HERA refrigeration system consists of three helium refrigerators which are capable of generating 6 kw at 4.5 K and 20 kw at 60°K simultaneously. The three machines will be used to cool down the HERA machine. It is hoped that when the ring is cold that only two refrigerators are needed to keep the superconducting magnets cold. (The third machine will be kept in reserve.)

The HERA ring is fed with cold helium at one point on its circumference of 6 km. The flow circuits take single-phase subcooled liquid out 3 km in the region of the magnet coils. Two-phase helium (two circuits) is brought back through a hole in the magnet iron. (This hole is at one of the dipole poles. There is a second hole in the iron at a symmetric position on the other pole of the dipole. The second hole, which is to balance the iron magnetically, is filled with a plug to keep helium from flowing in that hole.)

Table 1. A Comparison Between R-Glass, E-Glass, C-Glass and Kevlar

	R-Glass	E-Glass	C-Glass	Kevlar
Elastic Modulus (Nm^{-2}) at 300 K	8.6×10^{10}	7.3×10^{10}	7.0×10^{10}	7.4×10^{10}
Elastic Modulus (Nm^{-2}) at 77 K	9.5×10^{10}	--	--	12.4×10^{10}
Density ($g\ cm^{-3}$)	2.55	2.6	2.5	≈ 1.8
Breaking Stress (Nm^{-2}) at 300 K	3.6×10^{9}	2.4×10^{9}	2.4×10^{9}	2.7×10^{9}
Elongation %	4.2	3.3	3.5	--
Diaelectric Constant at 1 MHZ	6.0 - 6.1	6.5 - 6.7	--	--
Diaelectric Loss Factor at 1 MHZ	19×10^{-4}	$15\text{-}20 \times 10^{4}$	--	--
Resistivity at 20°C (m)	$\approx 10^{13}$	$\approx 10^{13}$	--	--
Resistivity at 250°C (m)	$\approx 10^{11}$	$\approx 10^{11}$	--	--
Expansion coefficient at 300 K (K^{-1})	4×10^{-6}	5×10^{-6}	7.2×10^{-6}	≈ 0
Specific Heat at 300 K $J\ kg^{-1}\ K^{-1}$	≈ 840	≈ 840	--	--
Thermal Conductivity at 300 K ($W\ m^{-1}\ K^{-1}$)	≈ 1	≈ 1	--	--

Note: Aluminum has a density of 2.7 g cm^{-3} and a modulus of 6.9×10^{10} N m^{-2}. The expansion coefficient for aluminum at 300 K is about 22×10^{-6} K^{-1}.

Installation of the refrigerators was well underway as was the installation of the compressors (screw-type compressors) and the associated oil separation equipment. The installation of the refrigeration has occurred well ahead of the delivery of <u>any</u> of the HERA magnets.

The test magnets have been operated on their own refrigeration test loop. The first magnet had a heat leak much higher than expected (over a factor of five). Subsequent magnets are much better. The third and fourth magnets are expected to have heat leaks within the target range (about 5.0 W m^{-1} at 60 K and about 1.5 W m^{-1} at 4.5 K). It is not clear yet that HERA can be operated on two refrigeration plants.

The high heat leak in the first magnet has resulted in a redesign of the magnet cryostat. One of several changes made has been the use of an aluminum foil fiberglass superinsulation system rather than aluminized mylar and bridal veil netting. One of the reasons for changing the superinsulation is to make it more resistant to degradation due to radiation. The minus of the aluminum foil is that it must be applied so that it does no conduct heat from a higher temperature zone to a lower temperature zone.

h) The HERA Electron Ring Superconducting R.f. System

Joe Susta showed me three of the test cavities he and his group had built and tested. The HERA machine is an interesting one because the protons are bent using superconducting magnets, but they are accelerated and controlled using conventional R.f. cavities. On the other hand, the electron beam is bent with rather ordinary looking iron dominated dipoles with an induction of

0.173 T. The acceleration and control is done with superconducting niobium R.f. cavities operating at 4.5 K. The electrons need a lot of power from the R.f. in order to overcome the effects of synchrotron radiation.

The R.f. cavity structure consists of what looks like a pair of bellows with a straight piece in the middle. The length of the bellows can be changed to permit one to tune the cavity to the correct R.f. frequency. Since the electrons are relativistic above the transition energy, little or no tuning of the cavities is needed as the electron beam is injected and accelerated in the ring.

Two types of prototype cavities were built. One was cooled in a helium bath. The second was cooled with two-phase helium in eight parallel circuits. The HERA refrigeration people advised the group not to use a single two-phase circuit because the flow would not be stable. To test the hypothesis that two-phase flow is unstable, a test loop was built where liquid helium is forced through the circuit with eight up and down loops. The liquid helium was supplied from a 500-liter dewar. The test loop proved to be unstable except at very high flow rates. The trouble with the experiment is that such a test loop is always unstable. The same test loop would operate stability from a refrigerator or a helium pump if the flow circuit is done correctly.

The bath cooled R.f. cavity is made from pure niobium which is formed into a bellows structure, heat treated and tuned for R.f. operation. The cavity operated successfully, and it developed an acceleration gradient of 6 MeV per meter. The second cavity consisted of sheet niobium explosively bonded to sheet copper. The cavity was fabricated by welding both the copper and the niobium. Copper tubes about 20 mm in diameter were soft soldered to the copper after the niobium was heat treated. The cooling tube formed several parallel helium circuits which carry a mixture of liquid and gas from the refrigerator. This cavity developed 3.5 MeV per meter acceleration gradient.

Two-phase flow had nothing to do with the degraded performance of the second cavity. There was a hot spot in the cavity at a bend where the copper and the niobium were separated due to delamination of the copper from the niobium. This might have occurred during the heat treatment of the niobium. The two-phase flow was stable, and it did not cause temperature fluctuations (when it was run on the refrigerator) despite the fact that the cooling tube cross-sectional area was too large for the mass flow through the tube (by about an order of magnitude, perhaps even more). The liquid bath R.f. cavity was successful. The two-phase flow cavity was not so successful. The group is debating on whether to do more work on the two-phase cooled R.f. cavity.

Visit to CERN in Geneva, Switzerland, March 26-28, 1987

I traveled to Geneva from Hamburg, Germany, by a sleeper train. The cost of an international Schlafwagen berth was 55 DM ($30.25) in a compartment shared with up to two other people. (On European trains they mix the sexes, so you have no idea who you are going to share the compartment with.) An internal German sleeping car would be 44 DM ($24.20) for the same kind of second class berth. The berths have German-style feather beds, and there is hot and cold running water in the compartment which is very cramped.

Switzerland was cold and rainy (near Bern it was snowing). The snow level in the Jura near CERN was about 200 meters higher than the Lab. When the clouds rose on March 28, one could see a mantel of fresh snow on the Jura and on the mountains across Lake Geneva. At no time could the Mt. Blanc be seen. Between the constant clouds and smog in the Geneva area, the Mt. Blanc is rarely ever seen from CERN.

To old CERN hands there are two changes which must be remarked about. The first is that the X bus is no more. One now takes a number 15 bus from the square in front of the railroad station (Place Cornevain). The cost of the bus has gone down to 1.50 SF ($1.00) each way. The buses run every 10 minutes during the work day and every 20 minutes in the evening and on the weekends. It takes about 25 minutes to get from the station to CERN. One can get direct bus service from the airport to the station for about 3.00 SF ($2.00). There is no direct airport service to CERN.

The second bit of news has a ring of sadness to it. Tortella's Canteen will be no more as of July of this year. Tortella made a mint from CERN, and his canteen was an institution. Old CERN hands can remember when Tortella's was barely a shack on site next to the highway; he moved to the present site in 1971. He devoted less time to CERN and more time to collecting art, so he lost his CERN contract to a supermarket chain, Migre. The people at CERN do not expect the food to change (it could get better), because Tortella's has not been as good as it used to be.

The canteens at CERN (there are now three - two on the Swiss site and one on the French site) continue to be the gathering place where people drink coffee or other things, talk and read the myriad of newspapers for sale there in a dozen different languages. The French canteen is quite different from the two canteens on the Swiss site. (Tortella's, soon to be something else, is actually mostly in France.) It is quieter and cheaper (about 60 percent of the Swiss site canteens). The French canteen accepts only French francs, the Swiss site canteens accept only Swiss francs. That cup of coffee, the center of social activity at all of the canteens, costs 1.00 SF ($0.67) in the Swiss canteens and 2.40 Fr Fr ($0.40) in the French canteen.

The French visa is important to some at CERN. When the visa requirement went into effect last fall a number of CERN workers from non-EEC countries, including many with CD plates, were barred from going to work. So remember, you need a visa, you American terrorists, if you want to visit the SPS site canteen where you can get a cup of coffee for forty cents.

a) Discussions with M. Morpurgo Concerning ASTROMAG

I met with M. Morpurgo at the suggestion of P. Spillantini and the group at Frascati. Morpurgo had talked to the Frascati group and had no idea what his role might be in developing a design for the two-coil toroid magnet. In short, Morpurgo did feel he was qualified to take an active role in a design study. He agreed that he could act as an impartial reviewer of a conceptual design developed by a consortium of the Italians and myself. His role is to act as a reviewer who would advise the Frascati people as to the feasibility of a conceptual design developed elsewhere. Politically, he would be excellent in the role. He is well respected in the field of superconducting magnet design, and he is an independent Italian.

We talked about technical issues. He had read the ASTROMAG report I wrote on the strawman design. He is concerned as to whether a boil-off rate of 0.25 liters per hour (at 1.8 to 2.5 K) can be achieved. He had not looked at our calculations, so we talked about what is needed to achieve such low boil-off rates. After some discussion, he agreed it might be possible to achieve such low rates if the heat leak to the first shield can be minimized and if the support system is properly optimized. He realized that the magnets used in high-energy physics are usually not well optimized in either regard.

M. Morpurgo is not currently working in the field of superconductivity. He is working on conventional magnets for LEP and hopes he can get back into superconductivity in an active way. He suggested that I talk to R. Perin about superconducting magnets for the LEP tunnel, and he suggested I talk to someone involved with the LEP insertion quadrupole magnet. I did both, which will be reported later in this trip report. Morpurgo agreed to review any reports I generated on the two-coil toroid design and give me his comments. We chatted further on the improved support Italian science has been getting and how Carlo Rubia's Nobel Prize has brought a lot of that increased funding about.

b) The LEP Insertion Region Superconducting Quadrupoles

I had lunch with P. Lebrun and T. Taylor of CERN. We then went back to their Laboratory where we discussed and looked at the first of nine superconducting insertion quadrupoles to go into the ends of the experiment at the four experimental halls (used for experiments) at LEP.

The basic parameters for the LEP insertion quadrupoles is shown in Table 2. While the quadrupoles are designed for the Phase I operation of the LEP machine at 65 GeV, it is hoped that there is enough margin in the design to permit the quadrupoles to be used during Phase II operation when the electron energy is increased to between 80 and 85 GeV. The test magnet was built by Alsthom in France. The order has been given to them to build the other eight quadrupoles needed for the ring. The test magnet will become a spare should there be a problem with one of the other eight magnets. The total cost for the nine magnets is 6 million Swiss francs (about 4 million U.S. dollars).

Table 2. Parameters of the Superconducting LEP Insertion Quadrupoles

Magnetic Gradient for LEP Phase I	36 T m^{-1}
Magnetic Length	2 m
Good Field Diameter	100 mm
Warm Bore Diameter	130 mm
Inner Radius of Coil	90 mm
Outer Radius of Coil	120 mm
Peak Field at Design Current	4.5 T
Design Current for LEP Phase I	1625 A
Operating Temperature	4.5 K
Magnet Overall Mass	1500 kg
Magnet Cold Mass	1050 kg

The parameters for the superconductor, made by IMI in England, are shown in Table 3. The superconductor is a monolyth which is insulated by a varnish insulation (like formvar) and very thin kapton tape. The conductor and the coil are very similar to those used to make the ISR low beta insertion quadrupoles. These coils do not use cable, and they are cast in epoxy. The cast coils were supported by aluminum collars which have a larger thermal expansion coefficient than the coil package. The collared coil package is then pressed into the cold iron.

Table 3. Superconductor Parameters for the LEP Insertion Quadrupoles

Type of Superconductor	Nb-Ti
Copper to Superconductor Ratio	1.5 to 1
Conductor Dimension	1.8 by 3.6 mm
Number of Filaments	≈ 1500
Filament Diameter	≈ 45 μm
Copper RRR at 4.2 K	≈ 100

The test coil exhibited very little training. (None anywhere near the design current of 1,625 A.) The first training quench occurred at 1,975 A. After the quench, the magnet was taken above 2,000 A without training. (I do not know what short sample current is for this magnet.) This magnet is like the eight low beta insertion quadrupoles for the ISR train, very little despite the fact that the coils are completely cast in epoxy. The coils are tightly collared and well supported. The strain within the package under magnetic load is limited to about 0.2 percent. There is no liquid helium in the winding itself, but there is helium in the space between the coil and the cold bore tube, and there is helium in the crack between the coil and the collar. Despite the fact that most accelerator magnets are built with Rutherford cable with helium at the cable, there are other successful magnets which have been built using potted coil. The control of strain is very important in potted magnets.

The cryostat for the LEP insertion quadrupoles is a liquid bath cryostat which is to be supplied with helium from a Sulzer refrigerator. The design pressure for the cryostat helium vessel is 4.0 atmospheres. This permits one to quench the magnet and vent the quench gas back at the refrigerator rather than the LEP tunnel. The cryostat is unusual in that it has a horizontal neck rather than a vertical neck. The neck is completely horizontal (not tilted), and it comes into the gas space above the liquid. A horizontal neck in a bath cryostat has been tried in the MRI imaging magnet industry, but without success. This is the first horizontal (not tiled) neck cryostat I have seen that works.

The secret to the horizontal neck design is that there is no helium gas flow through the neck. The electrical leads and transfer lines are well insulated thermally. The leads themselves are rather like American Magnetics' leads, except there is no soft solder in them. The warm end of the neck has a 10-centimeter thick piece of foam. There is a series of tight fitting, close together stainless steel baffles. The spacing of the baffles is close enough so that convection cells are not set up. The heat leak in the cryostat neck is well under 1 watt.

c) Impressions of the L3 Experiment Conventional Magnet

The L3 magnet at LEP is probably the world's largest magnet. The magnet is 11 meters long and over 11 meters in inside diameter. (The coils are an octagonal shape with an 11-meter diameter.) The field can range from 0.32 T to 0.6 T depending on the insulation space between the large aluminum conductors. (I have heard two different values for this spacing. I am not sure which is correct.)

The conductor has a radial thickness of 0.6 m and a longitudinal thickness of 0.06 m. There are water cooling circuits on the outside of the conductor. This conductor will carry 30,000 A. The magnet pieces I saw were half turns which were welded together from smaller pieces. The half turns will be assembled and welded together in the tunnel in order to build up the turns of the magnet. The pieces I saw in the yard are rather impressive.

The iron return yoke for the L3 experiment will come from the Soviet Union. The return yoke consists of slabs of iron with a total mass of 8,000 metric tons (17.6 million pounds). The Soviets are also supplying germanium arsenide crystals, which scintillate even better than sodium flouride crystals. It is reported that the Russian germanium arsenide will be polished and shaped by workers in the People's Republic of China. Not only is the L3 experiment physically big (proportionally expensive), but there is a collaboration which matches the size of the experiment.

d) Discussions Concerning the Magnets for the Large Hadron Collider

The Large Hadron Collider (LHC) is a proposed proton-proton machine which is to go in the LEP tunnel. This proposed machine is designed with the idea that it will beat the SSC out of the cream of the physics to be done at the 15 to 20 TeV center of mass energy range. In order to achieve the goal of beating the SSC, CERN must act quickly, be successful in developing 10 T, 1.8 K Nb-Ti dipoles, or 10 T, 4.6 K Nb_3Sn dipoles, and there must be a major setback in the SSC such as lack of political will to build the SSC.

The Large Hadron Collider has been studied for some time, but there has been no experimental work which is directly applicable to the LHC effort. The two storage rings which will carry 8 TeV protons require a central magnetic induction of 10 T. This means that the superconductor must operate at a field approaching 11 T. (CERN claims a peak field of 10.7 T in the conductor, but this low field rise may be difficult to obtain.)

I discussed various aspects of the LHC and the SSC magnet design with R. Perin, A. Asner, D. F. Leroy and D. Hagedorn of the SPS superconducting magnet group. The areas of discussion included: magnet design, conductor specification (niobium-tin at 4.2 K versus niobium-titanium at 1.8 K), proximity effect and associated magnetization, and some general problems having to do with the fabrication of high-field magnets.

The magnet design is currently in favor of 26 turns of 17,000 A cable on the inner layer and 48 turns of 17,000 A cable in the outer layer. The inner coil inside diameter of the proposed magnet is 5.0 cm. The inner coil design has four blocks on the inner layer with 4, 4, 3 and 2 turns respectively. The outer coil design has two blocks with 7 and 17 turns respectively (see

Figure 1). The proposed iron location is at a radius of 10 centimeters. The coil is surrounded by an aluminum collar, and that collar is in cold iron which is within a stiff aluminum tube. The iron pieces are separated by a slot at the poles when the magnet is warm. The slot closes as the magnet is cooled down from room temperature.

The inner layer cable would be a Rutherford-type cable with 26 strands which have a nominal diameter of 1.29 mm. The strand would have 15 micron diameter filament (they would like to reduce this to 5 microns if they can) in a copper matrix with a normal metal-to-superconductor ratio of 1.6. The overall dimension of the trapezoidal inner layer cable with its glass-kapton insulation would be 2.20/2.64 x 17.30 mm. (The inner radius thickness/outer radius thickness by the radial thickness as the cable lays in the magnet coil.) The outer layer cable would be a Rutherford-type cable with 40 strands with a nominal diameter of 0.84 mm. The strand would have 14 micron diameter filaments (the goal is 5 microns) in a copper matrix with a normal metal-to-superconductor ratio of 1.6. (Note: There is no significant reduction of filament diameter in the outer cable, nor is there an increase in the copper-to-superconductor ratio.) The overall dimensions of the trapezoidal outer cable would be 1.44/1.81 x 17.30 mm with insulation. CERN proposes that the outer cable be a soldered cable. The inner layer cable should carry 18 kA at 11 T; the outer cable should carry 18 kA at 8.5 T.

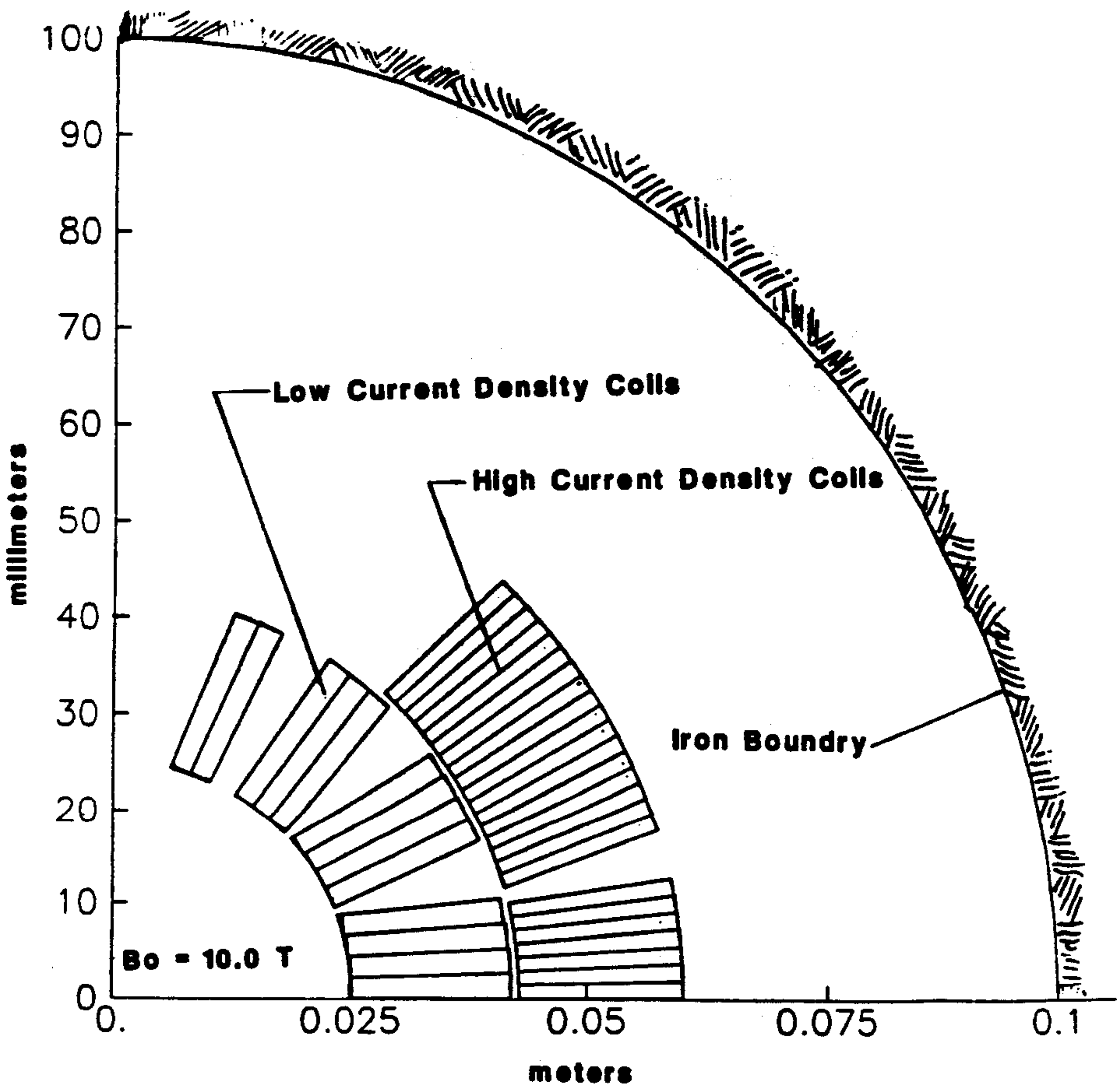
Because the desired central field is 10 T, two options for the superconductor are being looked at. The first is a niobium-tin multi-filamentary conductor with a design current density of 1,300 A mm^{-2} at 4.2 K and 11 T. The second conductor is a multi-filamentary niobium-titanium conductor with a current density of 1,300 A mm^{-2} at 1.8 K and 11 T. (This translates out to a current density of about 2,500 A mm^{-2} at 4.2 K and 5 T based on extrapolation of measured data.

The niobium-tin conductor is an ambitious one with three manufacturers being looked at. Vacuum Schmelze is proposing a modified bronze conductor. BBC is proposing an internal diffusion conductor, and ECN is proposing a conductor made by some sort of a powder metallurgy technique. I was given no information on any of the conductors, except that the superconductor critical current must be 1,300 A mm^{-2} at 4.2 K and 11 T over <u>all</u> of the filament area. The LHC group did not tell me about any niobium-tin conductor tests they have done. It is my impression that considerable conductor development is needed for either the niobium-tin or the niobium-titanium conductor.

The magnet development program calls for the construction of four prototypes to be built by European industry. The first one-meter long prototype which had been ordered from Ansaldo uses a modified HERA-type conductor (a Rutherford cable with dimensions of about 1.3 x 12.5 mm). The conductor is niobium-titanium produced by Vacuum Schmelze. The magnet is supposed to produce a central field of 1.8 T when it is cooled to 1.8 K. Ansaldo is three months late, as of March 27, 1987, in the delivery of this magnet. (From what I saw at Ansaldo, CERN will be lucky if they get the magnet only one year late.) The second one-meter long prototype, which is to be produced by Elin, an Austrian company, is designed to produce a field of 10 T at 4.2 K. This magnet is to be wound with unreacted niobium-tin. (I do not know the details of the size of the conductor or who was supposed to make it.) The unreacted conductor will have a glass-mica insulation which CERN has

Figure 1

LARGE HADRON COLLIDER
10 TESLA NIOBIUM TITANIUM
DIPOLE CROSS-SECTION



used in some test magnets. The magnet will be reacted at 700° C and potted. This magnet is also months behind schedule. The third prototype is to be a two in one, one-meter long prototype using a niobium-titanium conductor at 1.8 K. The contract for this magnet has not been let, nor has engineering work been done except for conceptual work. The fourth prototype is to be a two-in-one magnet, 9 meters long, using four HERA coils. This prototype is supposed to produce 7.5 T at 1.8 K. The design of this magnet has only started, as near as I can understand.

The injection field into LHC is to be 0.5 T. There is a very real problem with the field generated by circulating currents in the superconductor. Until I talked to the LHC group, I do not think they realized the possible extent of the problem. The LHC dipole has roughly three times as much conductor per unit length as does an SSC dipole. Even though the injection energy is 1.5 times higher than the SSC injection energy, the expected error at injection can be expected to be larger than it is in the SSC magnet. CERN proposes to correct out the sextupole using permanent magnet samarium cobalt sextupoles. They have not looked at the proximity coupling effect, A.C. loss effects or the effects of temperature variation in the conductor. They have not yet done enough lattice physics to know what the effects of decapole and other higher multipoles are. (If the physics calculations have been done, it has not filtered to the magnet group.)

We spent a lot of time talking about proximity coupling. This is a problem if they want to go down to 5 micron filaments in the conductor. We also discussed eddy current and eddy current coupling in the superconductor. This will be a problem because CERN proposes to use a soldered conductor in the outer layer. We also talked about the effect of H_{c1} on the field. The H_{c1} effect (like a surface current effect) will be be present, and it will be worse at 1.8 K and it will be worse for niobium-tin conductors. Such considerations may have an effect on LHC as to whether additional money has to be spent on the injection system. (There is a question of whether the LEP conventional ring is the suitable injector.) Factors not yet thought about could increase the cost of LHC.

Before leaving the topic of LHC, it is useful to discuss what CERN thinks is the role of LHC and how this might affect the SSC. The project will go before the CERN council in June for approval. The arguments for LHC are: 1) The SSC is very likely to be delayed for political reasons (the budget, a political fight over the site or a general revolt against the Reagan White House). This would leave the door open for CERN to beat the U.S. into this region of high-energy physics. 2) The LHC will be much cheaper to build than the SSC (1 - 1.5 billion dollars versus 4 - 6 billion dollars). This argument is based on two factors: the LHC will use the LEP tunnel; therefore, there is no site to buy or tunnel to build (an argument that Fermilab has been pushing for their site). 3) The LHC is based on HERA technology. The magnet aperture is similar to HERA, and the magnets are the same length.

The counter to the CERN arguments seem to be ignored. Some of these arguments are: 1) The magnets for LHC will have about the same amount of superconductor in them as the magnets for the SSC, despite the fact that the SSC center of mass energy is a factor 2 1/2 higher than LHC. 2) The concept for the magnets of the LHC is one of building many 10 T dipoles in a two-in-one configuration. A single 10 T dipole has barely been built in a short length. Two-in-one 10 T dipoles have never been built in any length. 3) The LHC concept requires either 1.8 K refrigeration or successful niobium-tin dipole magnets. There have not been very many niobium-tin dipoles built; this can hardly be considered a well understood technology. The 1.8 K refrigeration is also a relatively untried area (except for Toresupra). The cost of the refrigeration for LHC may well be nearly equal to the refrigeration cost of SSC. The input power requirements may also be comparable. (The factor of 2.5 in temperature makes up for the reduction of cooling length.)

When all of the problems are taken into account the cost of LHC may be higher than expected, and it will take time to solve a lot of the problems that will be encountered with high-field operation and/or 1.8 K refrigeration over long distances. In terms of hardware such as magnets and refrigeration, the SSC is well ahead of LHC. In terms of conventional facilities (except for the experiments), LHC is well ahead of SSC. CERN is not without its political problems. It is not clear that Great Britain will be willing to supply its share of the money for LHC (this could apply to other countries as well), and will physicists on LEP be willing to turn their experiments off early to install the LHC?

IF LHC is approved by the CERN council in June, the race will be on. The United States could well win the race, provided we do not delay the SSC too much or shoot ourselves in the foot by waiting for the "new superconductor". The CERN people I talked to about the "new superconductor" feel that it is probably not in the cards for the LHC. (I will temper that statement by saying "at this time".) Even though the potential saving in refrigeration is even greater (in a relative sense) than for the SSC. While people at CERN feel we should not waste our taxpayer's money, some of these people see that there is an issue of the United States' national pride. (These are the topics for discussion over coffee in the canteen.) Others at CERN felt that LHC might not be pushed so hard by people at CERN if the United States were not pursuing the SSC. (Call it a collective national pride as compared to our national pride.)

e) Magnets for Experiments for the LHC and the SSC

The previous topic of the LHC leads into the discussion of experimental magnets. Both the LHC and the SSC will require massive experiments requiring thousands of tons of iron and other components. LHC may be cheaper in this regard only because the center of mass energy is lower. The L3 experiment requires 8,000 metric tons of iron to return the flux, which would cost $10 to $15 million to build in the west (the iron alone, forget the detectors in this price). One group is considering an experiment for LHC which would require 27,000 metric tons of iron to return flux and filter out particles. (The iron alone might cost $50 million if the Russians do not donate it.) Such large masses of iron and such large detectors clearly require a rethinking of the use of heavy materials such as iron in detectors.

P. Spillantini and I spent the morning of March 28 discussing different methods for returning flux without the use of iron slabs. The magnet configurations which were discussed included: the toroid; solenoidal configurations which use two sets of coils so that the field falls off outside the winding very rapidly; and a configuration which produces no field at the center, then a field region, then no field on the outside.

P. Spillantini has been an advocate of the toroid for a number of years. Such a coil would produce zero field along the beam, but inside the toroid the field would go around the beam like a ring. In a configuration he has studied, the zero field region might be 3.0 meters in diameter, and it would contain some sort of calorimeter. The outside diameter of the coil might be 15 meters (see Figure 2). Spillantini has looked at conventional coils consisting of conductors which are made from both copper and aluminum. The inside of the coil (the bars which go in a direction parallel to the beam) would be made from copper, while the outside and the radial sections would be made from aluminum. The toroid would contain from 8 to 12 such coils. There would be only a little flux leakage outside such a coil configuration. Such a coil might consume 12 MW and produce a field of the order of 0.5 to 0.75 T. The coil mass would be from 5,000 to 7,000 metric tons. The coil configuration could eliminate as much as 20,000 metric tons of iron. There probably are some attractive superconducting coil designs as well.

The discussion moved from toroids to solenoidal coils. I suggested double solenoid configurations, which are extensions of designs which have been looked at for MRI imaging magnets. One such design would produce a cylindrical-shaped region of a uniform solenoidal field which could be made longer than its diameter. Another design would be made using lumped coils, which would produce a spherical region of uniform solenoidal field (parallel to the axis of the beam). Both of these configurations would have a zero radial component of field along the beam axis, and there would be full access to the jets of particles which might form at low angles to the beam directions. Both of these configurations could be made with a uniform enough field to allow a TPC detector to be used. (The two-coil solenoid configurations are shown in Figure 3.)

The double solenoid coil could be designed so that the field falls off rapidly outside the outer coil. Some configurations which have been studied would have the field fall off at the rate of the radius to the -9 power. Since the magnets for an LHC or an SSC experiment must be large, it is not clear that they can be made completely superconducting. Both of the two-coil solenoid designs discussed could be made with, say, 5-meter diameter superconducting inside coils and, say, 10- to 15-meter diameter conventional water-cooled outer bucking coils. In either of the two solenoidal coil cases, it would not be unreasonable to consider fields as high as 1.5 to 2.0 T. In both of the two-coil solenoid designs, the iron used to return the flux could be eliminated. One could use earth or concrete (even heavy concrete containing barite) to filter out unwanted particles in place of the iron in the return yoke. Such an experimental configuration might be cheaper to build, and problems such as differential settlement might be eased.

Spillantini and I also talked about solenoidal magnets which have no field at the center. Such a magnet configuration would require two sets of coils if there is an iron return path. If there is no iron return path, three sets of coils would be required. It is not clear from my perspective as to what the physics advantage of such a configuration is, but it appears that such a magnet could be built. (It should be noted that the inner magnet of the set would have forces in a direction which is opposite from that seen in a normal solenoidal magnet configuration. As a result, it may be more difficult to make the inner coil of such a magnet thin because the magnetic pressure could cause buckling of the inner coil.)

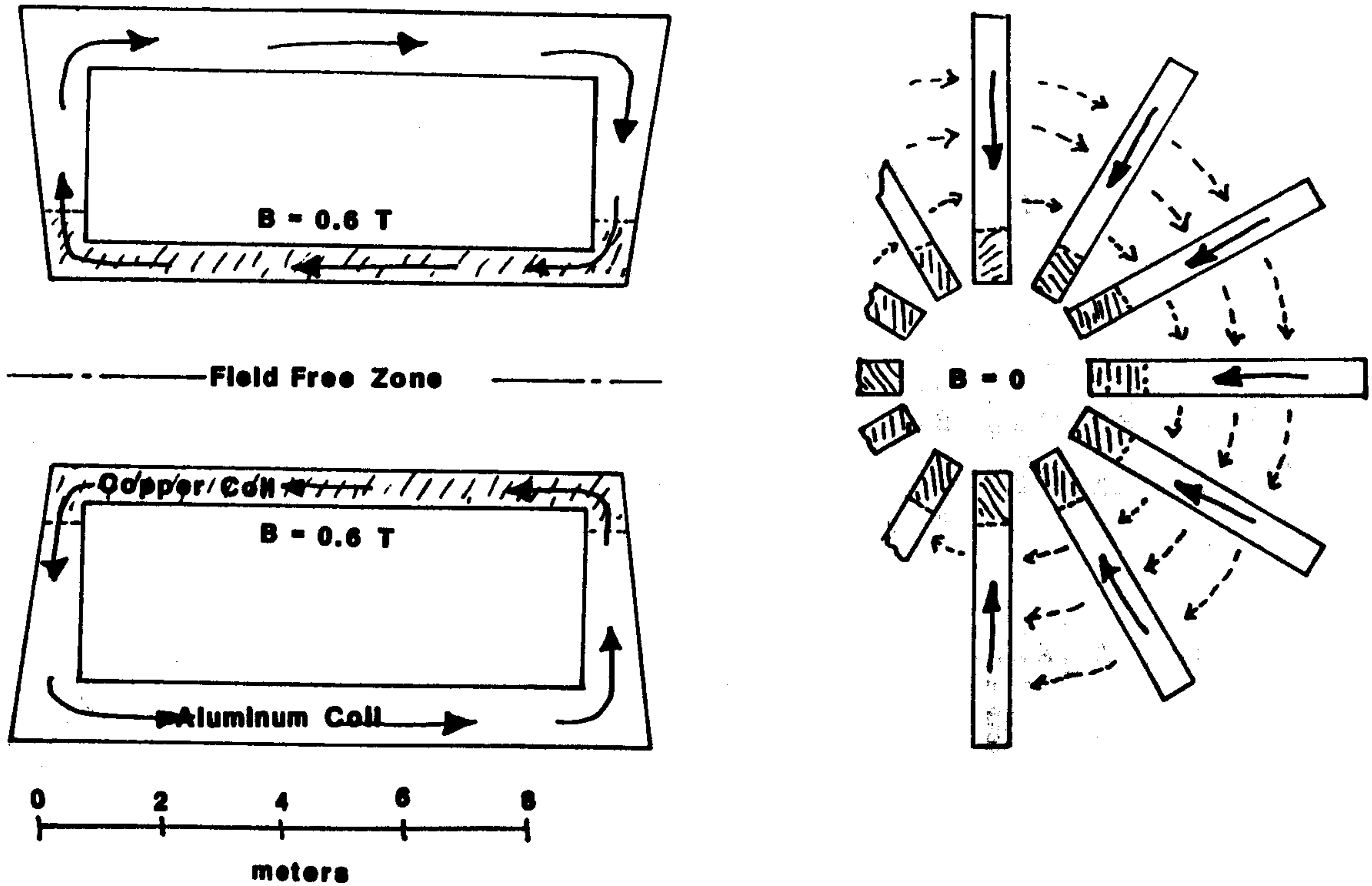


Figure 2

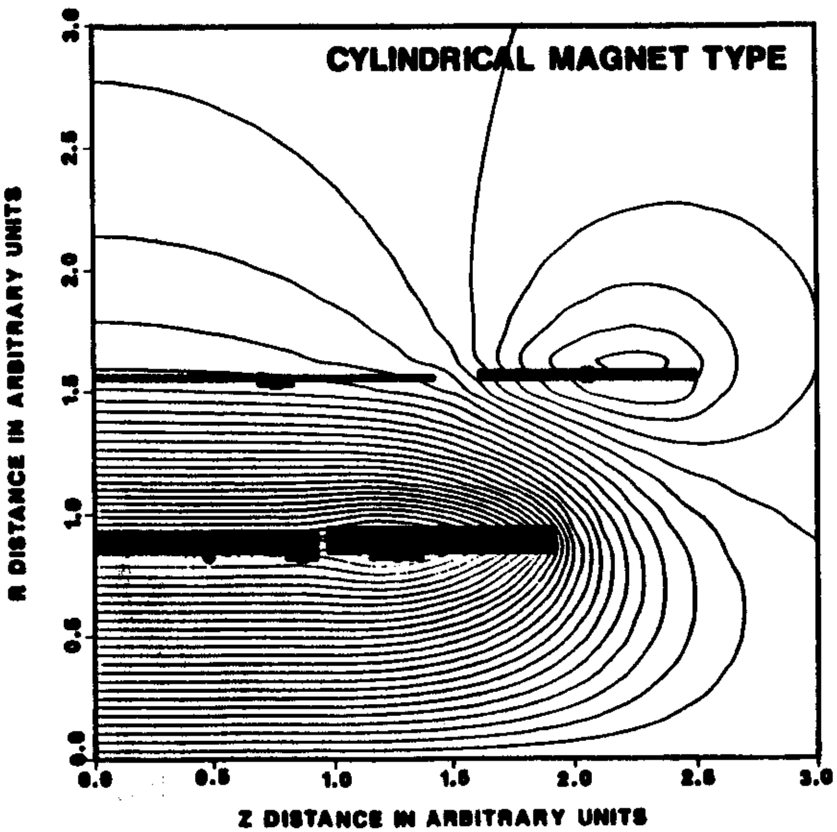
12 METER OUTSIDE DIAMETER CONVENTIONAL TOROID MAGNET

Figure 3

TWO TYPES OF ZERO NET MAGNETIC MOMENT SOLENOID MAGNETS

MAGNETIC FLUX LINE CONTOUR MAP

(LINES OF CONSTANT VECTOR POTENTIAL)



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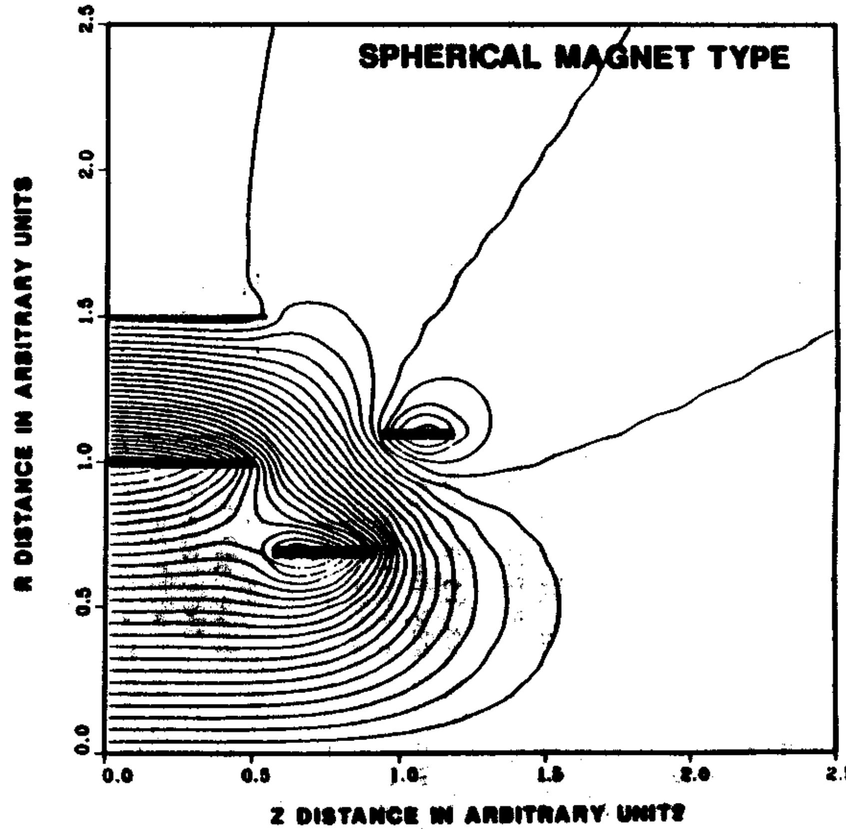


Visit to Ansaldo Company in Genova, Italy, on March 30, 1987

I traveled from Geneva to Genova by train (avoiding France) via Bern and Brig Switzerland, Milano, Verona, and Pavia, Italy. I arrived in Genova on March 29. Genova is a large industrial city which is Italy's largest seaport. Genova is not what one might call tourist mecca. Parts of the city do have very narrow streets which have a medieval feeling about them. The old fishing port south of the main part of the city is quite charming with some very nice vistas to the sea. One of the major sights to see in Genova is the cemetery. The cemetery has a lot of large, some rather garish monuments on the graves of prominent and not so prominent citizens of the city. In some cases, even poor families have put up large monuments in the cemetery.

Genova is a city of cats, you can see lots of them. Street newspaper vendors may have several of them on, in and about their stands. Genova's cats come in a variety of colors. They tend to be from striped to large spots in colors and from almost all black to calico. All of the city's cats tend to be short haired. The cats tend to be friendlier to visitors than the people are.

Genova is a city for fish and for pesto (a green pasta sauce made from basil, olive oil and pine nuts - some pesto may have cheese in it as well). The dish that one should eat in Genova is Gnocchi (a pasta made from wheat and potatoes) with pesto. Calamari can be gotten in Genova fixed six or seven different ways, from raw to deep fried; all are good.

My visit to Ansaldo was primarily to discuss the work that they have done on the two-coil toroid magnet system for ASTROMAG. In addition, I visited the Ansaldo manufacturing plant to see their progress on the HERA dipoles and the test dipole for LHC at CERN. I was taken around the plant by F. Vivaldi of the Ansaldo manufacturing group.

a) Conventional Magnets Wound in the Ansaldo

Ansaldo is an electrical machinery manufacturer which does a lot of magnet winding. Much of Ansaldo's work has been conventional magnets of various kinds. Ansaldo has been a supplier of conventional magnets to CERN, and the company produces toroidal and poloidal coils for fusion laboratories all over Europe. Ansaldo specializes in vacuum impregnation of their coils with various epoxide resins.

Ansaldo was building some of the LEP ring quadrupole magnets as well as building some of the coils for the LEP ring dipoles. The quadrupole coils consist of three turns per pole with a strip of aluminum between turns to carry the heat to a water-cooling circuit. The coils are glass and kapton insulated and are vacuum impregnated. Each coil is insulated from its pole. Each of the quadrupole poles are insulated from each other.

Three sets of fusion magnet coils were being fabricated at Ansaldo while I visited. The ENEA part of Frascati was having some D-shaped coils fabricated. These coils are about 3 meters high and 2 meters wide. Ansaldo routinely vacuum impregnated the coils in a temperature-controlled vacuum chamber which is about 4 meters in diameter. In addition to the D-shaped coils, Ansaldo was manufacturing some poloidal coils for Frascati. The toroid coils that Ansaldo was making for Culham were rather unusual. These coils are almost perfect rectangles with very square corners. These fully vacuum impregnated coils are about 1.5 meters high and 1.0 meters wide.

b) Superconducting Coils

F. Vivaldi showed me the HERA coil manufacturing facility and clean room in the plant. I described this facility in my last trip report for my visit to Ansaldo in August of 1986. I described the clean room in positive terms. However, the clean room in operation falls far short of its potential. The main entrance to the clean area has an anti-room where one puts on a white coat, white shoe covers, a white cap over the hair and white gloves. When one enters the Ansaldo clean area where the HERA magnets are to fabricated, one is struck by obvious contradictions. The sealed floor of the clean room had not been swept or vacuumed in some time. There were bits of dirt and wood on the floor. I watched as workers broke open a dirty wooden crate in the clean area. Splinters fell onto the floor; there was no effort to clean them up. The worst offense is the second door which leads directly into the area where the iron is to be put on the finished HERA coil assemblies. This area is as dirty as any area in the plant. There is no control of the flow of material between the two areas. After walking out of the clean area, I noticed smudges of dirt on the white jacket and lots of dirt on the boots. Is that the way a clean room is supposed to work?

Ansaldo is involved in the design and fabrication of a thin superconducting solenoid for the Zeus experiment at HERA. All I saw of this magnet were some samples of conductor manufactured by LMI of Florence. The conductor is a ten-strand cable which is co-extruded inside a piece of very pure aluminum which has an overall dimension of 4 by 15 mm. The ten-strand cable inside the aluminum has dimensions of 1.5 by 5 mm. The ten-strand cable of 1 to 1 copper to superconductor ratio is designed to carry a current of 10,000 A at 4.3 K and 2.3 T. (The design current for the Zeus magnet is 5,000 A at 4.3 K and 2.3 T.) The problem with the Zeus conductor is that the cable tends to separate from the ultra-pure aluminum when the conductor is bent over even rather large radii of curvature. Ansaldo is concerned about this conductor and whether it will be stable when it is wound into an indirectly cooled thin solenoid magnet.

Ansaldo is late in the fabrication of their first HERA dipole. What limited staff the Manufacturing Division has is devoted to solving the problems with the HERA dipoles. The winding machine bugs were worked out so that 9-meter long magnets can be wound. (This winding machine can easily be extended to 18 meters to permit the winding of SSC dipoles.) Four sets of HERA coils (enough for two HERA dipoles) have been wound with conductors produced by LMI. The collars were short free until the collars were applied and pressurized in the press. When the collars are released, the shorts go away. The short detection equipment Ansaldo is using detects the presence of shorts, but it does not detect where the shorts are. (The equipment, which uses a capacitor discharge ringing method to detect the existence of shorts, is well suited for production.) The HERA coil short problem has delayed the production of the first HERA dipoles, and it has delayed just about every other project Ansaldo is involved in. When I was there the cause of the shorts had not been found, except that the insulation was inadequate.

I looked at the small winding machine for the first LHC dipole. Ansaldo has been testing the machine using uninsulated soldered copper cable. The LHC dipole is already three months late in delivery. It is clear that the LHC dipole has had no priority. Ansaldo took the job as a development project with no money being paid by CERN. As a result, the staff that Ansaldo has is put on paying jobs first. CERN will be lucky if they get their first LHC one-meter dipole prototype only a year late.

c) The Meeting Concerning the ASTROMAG Two-Coil Toroid Magnet Design

The meeting at Ansaldo was attended by F. Vivaldi, a physicist on the superconducting magnet program; M.N.D. Romanini, Director of the Magnet Unit; G. Scarfi, a man from the commercial sales office having to do with magnets; F. Rosetelli, of the Ansaldo Research Division; P. Spillantini of INFN, Frascati; and myself.

It was clear from the beginning that Ansaldo has done no work on the two-coil toroid magnet since the December 1986 ASTROMAG Definition Team Meeting at the Goddard Space Flight Center. Ansaldo had agreed to do the study with no pay in order to develop new business. Unfortunately, the Research Division is also understaffed. Work for pay has taken priority over no-pay work. The Manufacturing Division is also short handed, and it has plenty of problems with HERA so it could not help.

F. Rosetelli and M. Grattorola have done most of the work that Ansaldo has done on the two-coil toroid. They did all of the basic work on the bending moment free design which P. Spillantini presented at the December meeting. F. Rosetelli gave me enough information to be able to work through the two-coil toroid design developed by Ansaldo and convert it to weight and size estimates which are needed in order to compare the two-coil toroid design with the HEAO design.

The bending moment free coil design developed at Ansaldo is shown in Table 4 and in Figure 4. The proposed Ansaldo design has approximately 10 percent of the maximum stress of either the double circle or the double D-coil configurations. (The maximum stress is projected to be 4×10^7 Nm^{-2}, about 5900 psi, in the coil cross-section proposed by Ansaldo.) The force between coils (tending to pull the coils apart) is about 3.4×10^6 N, about 750,000 pounds.

It is clear that the proposed Ansaldo coil design will have to be altered in order to bring the weight down in the design shown in Table 4. The proposed active coil mass of 1,500 kg could be reduced to about 850 kg. A careful look at the support structure between the coils will be required. For example, does one use hard aluminum, MP-35N or oriented fiberglass to support the 3.4×10^6 N force between the coils? Ansaldo has not looked at this problem. It is also clear that much of the work that Ansaldo has done can be used to estimate the mass and do other aspects of the two-coil toroid design so that it can be compared to the strawman configuration.

Table 4 Parameters for the Ansaldo Two Coil Toroid Magnet for ASTROMAG

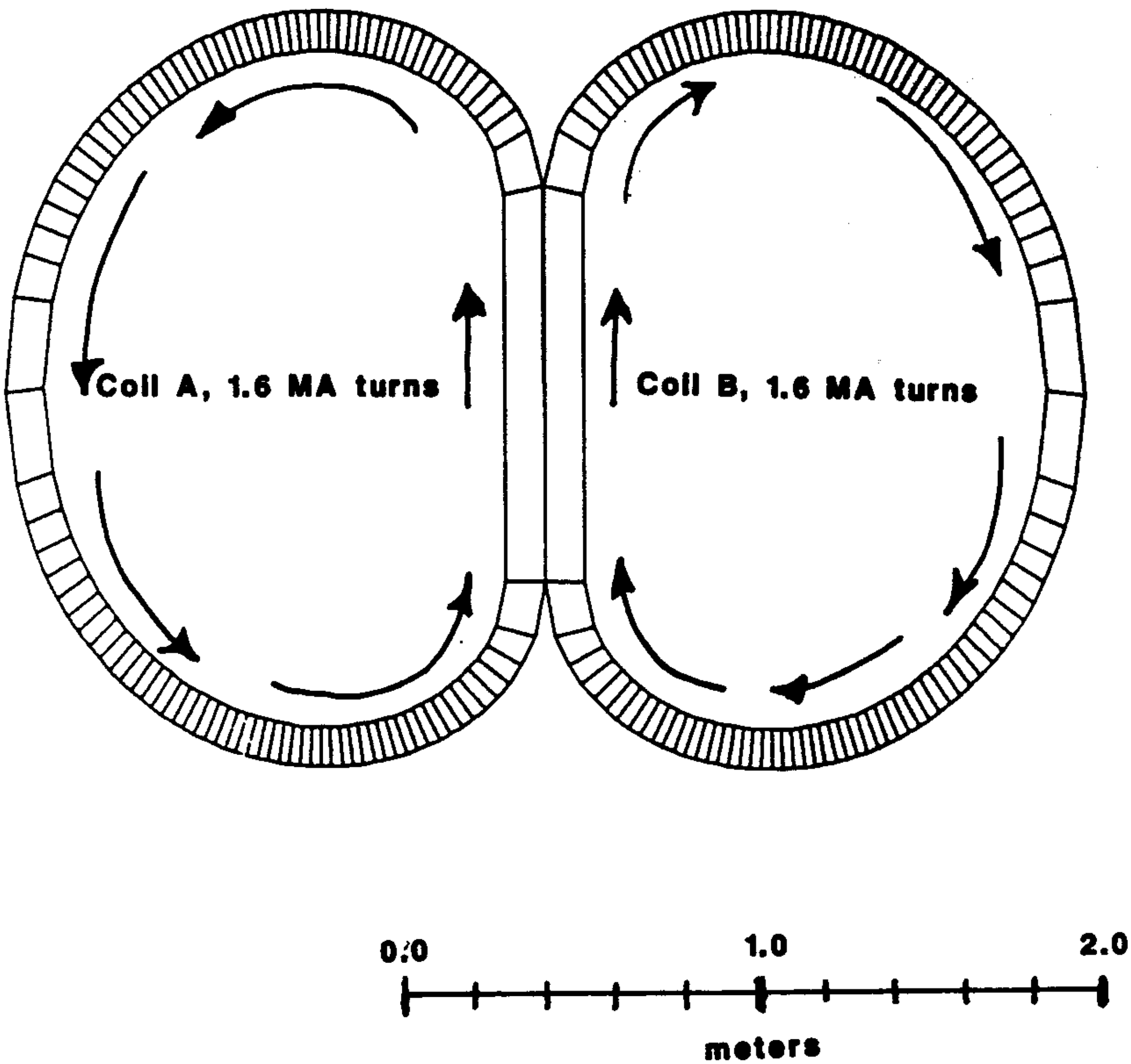
BENDING FREE COIL

NUMBER OF COILS		2
COIL OUTSIDE DIMENSIONS		1.55 x 1.88 m
TOTAL MAGNETIZING CURRENT		1.6 MAturns (per coil)
PEAK FIELD IN COIL		5.4 T
NUMBER OF TURNS		1344
DESIGN CURRENT		1190 A
CURRENT DENSITY OVERALL		66 MA/m^2
MAGNET ACTIVE COLD MASS		1500 Kg
SUPPORTING STRUCTURE (HARD ALUMINIUM)		150 Kg
CABLE COMPOSITION :		
	- S/C	13 %
	- COPPER	55 %
	- INSULATOR	25 %
	- FILLER + VACUUM	7 %
STORED ENERGY		12.5 MJ
STORED ENERGY WITH MAGNETIZING CURRENT OF 1.8 MA (per coil)		15.8 MJ

Figure 4

ANSALDO DESIGN
TWO COIL TOROID MAGNET

(COIL BENDING MOMENT IS ZERO)



Dinner Meeting with G. Ciancaglini in Lucca, Italy, March 30, 1987

I traveled form Genova, Italy, to Florence, Italy, by car with P. Spillantini. He had arranged a dinner meeting with G. Ciancaglini in Lucca to talk about solutions to problems on the L-3 detectors at LEP. G. Ciancaglini owns a small consulting engineering company in Lucca. P. Spillantini and others at INFN, Frascati, and CERN use his company to arrange for the design and fabrication of detector parts. P. Spillantini speaks very highly of G. Ciancaglini. For me, it was an opportunity to talk with an Italian consulting mechanical engineer.

On my trip to Lucca, I was able to observe some wonders of Italian engineering for myself. The ancient Romans were first-rate engineers. They invented the arch, and they were the road and bridge builders of the ancient world. Roman aqueducts and bridges still stand as a monument to their engineering talent. Some of the Roman bridges, aqueducts and roads are still being using after 2,000 years. Examples are the Pantheon in Rome, one of the bridges across to Tiber in Rome and whole sections of the Via Appia south of Rome. In fact, there are Roman bridges still in use in England, France, Spain, Portugal, Germany, Italy and other countries of the area.

While riding on the Autostrada from Genova to Lucca, I saw some modern Italian engineering. The coastal region around Genova is steep and mountainous with high cliffs jutting into the Mediterranean Sea. The coastline is scarred with deep valleys which go inland from the sea. The bottom of the valleys may have an elevation of 100 meters, while the ridges might have an elevation as high as 1,000 meters. Normally, one builds roads which follow the contour of the land. (They go toward the sea on the ridges, then follow the steep valleys inland, sort of like Highway 1 south of Carmel.) Freeway builders get around this problem by cutting through the mountains and filling the valleys.

The topography around Genova is too extreme for the cut and fill techniques normally used in the United States. The Italians solved the problem by using the bridge and tunnel technique. For the first 60 km south of Genova on the Autostrada, one goes through more than 30 tunnels and spans the valleys over 30 bridges. The Autostrada (a toll road, not a freeway) is at an elevation of 200 to 300 meters above sea level (sometimes a little higher, sometimes as low as 50 meters above sea level). From the bridges you can see the ocean as you span valleys with small villages in them. There were 7 tunnels over 1 km long. (The longest was 2.1 km.) There were another 10 to 12 tunnels that were 0.5 to 1.0 km. The bridges (mostly prestressed concrete arch bridges) were typically 300 to 500 meters long, with the longest approaching 800 meters. Of the first 60 km south of Genova, over half of it was either on a bridge or in a tunnel. It is interesting to note that the tunnel and bridge technique disturbs the land a minimal amount. The right away acquisition problem is probably greatly reduced by the use of this technique. Piero Spillantini told me that the Autostrada north of Genova was even more impressive in regard to the tunnels.

The city of Lucca is in itself an engineering marvel. Lucca is one of the finest medieval and early renaissance cities I have seen. Lucca is not found on most tourist itineraries, yet it is quite close to the cities of Pisa and Florence. Lucca is completely surrounded by a 17th century wall which is unbroken. In fact, the old city wall is separated from modern Lucca by the old moat and parkland. In size, Lucca rivals Carcossane in France and Rotenburg ab Tauber in Germany. Yet Lucca is almost forgotten as a place where tourists go. Within the 17th century wall are long stretches of 13th century walls which have 14th, 15th and 16th century buildings between these walls and the complete 17th century wall. Lucca is called the city of 99 churches. Around every corner is another church. They range from 8th century brick churches with small slit windows to 16th century churches with lovely stained glass. The finest church of all is St. Michaels. This church is built with multi-colored marble, and it has 100 columns up the front - each is carved in a different design using different colored marble.

When we visited the offices of G. Ciancaglini, I saw sections of the copper calorimeter which is being built for the L-3 experiment. The copper parts of the calorimeter are being built in extruded sections. These sections have to be very accurately made so that the gold-plated tungsten wires can be stretched down the grooves of the copper calorimeter parts. Unfortunately, copper extrusions can warp if the part shape is not right. These extrusions have a comb shape, sort of like the scallop of a castle wall. This shape is easily warped during the extrusion process. Apparently the first extrusion warped as much as 5 mm over the 10 cm span of the extruded part. The warpage problem was solved by adding small amounts of lead and zinc to the copper. As a result, the warpage was reduced to about 100 microns over the span of 10 cm.

G. Ciancaglini showed us plastic parts which hold the wires so that they are centered in the grooves in the extrusions over a length of about 2 meters. G. Ciancaglini found a small company which could make these parts for a fraction of what a large firm would charge. P. Spillantini felt that this engineer had saved Frascati about 1 billion lira alone on one experiment. About the dinner you ask; how about a Tuscano lamb and vegetable stew flavored with rosemary and garlic served with a 1978 Toscano Chianti Classico Riserva.

<u>Meeting with the People from INFN, Frascati, and ENEA, Frascati, April 1, 1987</u>

I was picked up at my hotel in Rome by Antonio Codino of INFN, Frascati, (the high-energy physics part of Frascati). With him was Giuseppe Basini, also of INFN, Frascati, who also lives in the city. The traffic was incredible. Codino was driving what he referred to as his Rome car, a Fiat 800 with all four fenders bashed. After going through Rome traffic, I can understand why the fenders were bashed. The drivers in Rome drive as if they own the road. They are very aggressive. If they were not, they would never get through the narrow streets or even the wide boulevards with three lanes in each direction with 5 cars abreast going in each direction. The flow of Rome traffic is accompanied by the bearing of horns, the shaking of fists and the remarks about the parentage of the other drivers on the road (with gusto). The traffic was made even worse by the fact that Rome had re-routed many of the downtown streets (creating many one-way streets) to discourage people from driving across the city. We traveled from my hotel, past the Forum, around the Coliseum, past the Arch of Constantine, to St. John by the wall, then out on to Via Appia. It took 45 minutes to get to the edge of Rome against the traffic. Coming into Rome from Frascati at 8:00 p.m. took even longer (Spillantini has a larger car).

a) The Meeting With INFN and ENEA

The purpose of the Rome meeting was to gather information and to determine who was to do the preliminary design work on the two-coil toroid magnet in order to insure that there is a fair hearing on the concept. It became quite clear that my role was going to be the collator of the information and that I would write the report which described the two-coil toroid magnet concept so that it could be compared to the strawman design. The following people attended the meeting in the Frascati, ENEA, conference room:

Giuseppe Basini - INFN, Frascati
Antonio Codino - INFN and Perugia University
Marco Ricci - INFN, Frascati
Piero Spillantini - INFN, Frascati
Giorgio Pasotti - ENEA, Frascati
Nicola Sacchetti - ENEA, Frascati
Mario V. Ricci - ENEA, Frascati

and myself. The high-energy physics and astrophysics interests were represented by INFN people. The superconducting magnet interests were represented by the ENEA people.

I presented a design concept for a two-coil toroid magnet which could be used to do ASTROMAG physics, and it would fit into the space shuttle. It was important to me to see what concept the Italian group had in mind for a two-coil toroid and where around the coil would the physics be done. The major criticism was whether or not the concept would work with helium II. Sacchetti told me about Hofmann's work at Karlsruhe. He wondered if the pressurized fountain effect pump proposed by Hofmann could be made to work. Frascati has done no work with helium II, so they were very curious about the scheme that was being proposed for cooling the coils in the two-coil toroid. We talked about experimental work being done at Goddard, and I told them I would contact Hofmann when I visited the KfK at Karlsruhe.

There was a discussion with the ENEA people about how one might calculate the force due to the two-coil toroids not being in the same plane. Since they are building a toroidal fusion machine, they said they can do the calculation with their computer codes. They agreed to calculate the force when the two-coil planes are tilted with respect to one another by angles of 1 m radian and 10 m radian. From these calculations one should be able to determine the force constant, and from that one should be able to determine what stiffness the support frame should have. ENEA agreed to do these calculations even if they do not have a formal agreement with INFN. We will try to set up a communications link between the ENEA, Frascati, and the LBL Vax computer. In the meantime, INFN and ENEA will try to set up a working agreement between the two halves of the Laboratory.

The INFN group is very much concerned about the politics of ASTROMAG and of other experiments which might be done in conjunction with NASA. The Italians do not know what their role in ASTROMAG will be. Their contribution to ASTROMAG will depend a great deal on what the Italian participation will be on the U.S. space station itself. They say that it is unlikely they can supply the magnet coil (due to a lack of money in their budget) unless a company like Ansaldo is already involved in other aspects of the space station. The Italian group at Frascati does want to participate in ASTROMAG physics and supply some of the detector regardless of who builds the magnet or, as I understand it, what magnet is finally adopted.

The INFN people and I agreed that Mario Morpurgo would make an excellent reviewer for the magnet design concept that I worked up based on the information I picked up from Ansaldo; ENEA, Frascati; and NASA-GSFC. The INFN group also intends to use their internal ENEA people as part of this review process. The INFN people and I agreed to have a preliminary two-coil toroid magnet design ready for review by ENEA and Morpurgo by the end of July 1987. We also decided who would be the joint authors of a paper to be given at the Magnet Technology Conference in September. The authors will be G. Basini, Marco Ricci and P. Spillantini of the INFN; A. Codino of Perugia University; F. Rosetelli of Ansaldo; and myself.

b) The High-Temperature Superconductor Work at ENEA, Frascati

On March 30, 1987 the ENEA, Frascati, superconducting group tested a barium yittrium copper oxide superconductor. The transition temperature for the material was 77 K. The drop in resistivity with temperature was described as being very sharp. (I do not know what this means exactly, because the transitions reported in the literature are not very sharp for these kinds of materials.) There were no Hc_1, Hc_2 or critical current density measurements made on the material.

I did not see the sample of the material which was still inside its test cryostat. I know nothing about the instrumentation or the cooling method used during the March 30th test. Mario Ricci described the material as a very brittle gray porcelain mass which has no resemblance to a useful superconductor. Mario Ricci, who is magnet oriented as I am, does not think the new material will be commercially useful for magnets any time soon. (Probably not for ten years except for some tapes made using a thin film technique.) Mario Ricci feels that magnet projects should not be delayed waiting for the new material to be developed.

Visit to the Institute fur Technischephysik, Kernforschungszentrum Karlsruhe, W. Germany, April 3, 1987

I traveled from Rome to Karlsruhe by train. I arrived in Karlsruhe in the rain. It had been raining there for nearly a month straight. Spring was still a long way off. Even the forsythia had not begun to bud. The Karlsruhe street car system has been extended out to Leopoldhafen, and it will soon be extended to the main gate of the Kernforschungszentrum. The fare to Leopoldhafen (about 12 kilometers from the main station) is 4.00 DM ($2.20) or four Streiffen. A Six-Streiffen ticket costs 5.00 DM ($2.75) from vending machines along the line. The town fare is 2.00 DM ($1.10) or two Streiffen from a Six-Streiffen ticket. Bay area people complain when bus tickets go up to sixty cents.

Before reporting on my Kernforschungszentrum visit, I will remark on this seasons hot electrical appliances which are being sold in the main Karlsruhe department store Herte on Kaiserstrasse. The hot item right now is a small 550 W microwave oven (less than 1 cubic foot) for 1,380 DM ($759). The other hot electrical item is the automatic tanning machine. (College students in the Pacific Northwest, where such things are popular, refer to it as "fake bake".) One pays 1,085 DM ($597) for a machine which does one side, or one pays 1,280 DM ($704) if you want a machine to bake both sides at once.

As it has been true for many years, in Europe you pay almost twice as much for appliances and electronic gear. An equivalent to a 25-inch TV monitor with stereo will cost 3,500 DM ($1925). This type of TV will do things not possible on American TV such as stock quotes, Aids hotline information, traffic information and weather being flashed on the screen (this information is transmitted by the TV station as some kind of a digital code, it is a public service), but the cost to the German consumer is high.

My visit to Karlsruhe turned out to be an interesting one. I learned about P. Turowski's success in producing 19.36 T within a 2.2-centimeter bore using a hybrid magnet at 1.8 K. I also learned about the 105 K superconductor made within the Institute fur Technische Physik (ITP), and I learned much more about pumping pressurized helium II through superconductor using the thermal-fountain effect. I talked with F. Arendt about his effort in setting up an institute at Karlsruhe similar to the LBL Applied Science Division, and J. Erbs talked to me about computer methods for keeping track of various materials at the KfK.

The rumor that H.C. Dustmann from BBC Mannheim is no longer in superconductivity is unfortunately true. H.C. Dustmann will be marketing sodium sulfur batteries for BBC. That Division will get a good worker, but unfortunately the superconducting magnet industry is losing one of its most innovative people. I think the BBC Mannheim magnet program will suffer for his leaving it.

a) The 19.35 T Superconducting Solenoid Magnet

Peter Turowski, the ITP and the Kernforschungszentrum Karlsruhe (KfK) now hold the world's record for field generated by a superconducting magnet. The magnet is really a hybrid magnet system that consists of four coils which are operated at 1.8 K from a pressurized helium II refrigeration system.

The outer coil is the Homer niobium-titanium, niobium-hafnium-titanium magnet built in 1981. This coil has an outside diameter of 720 mm and an inside diameter of 390 mm. The coil length is 630 mm. The outer coil will produce 11 T at 1.8 K. The second coil is a 290 mm diameter wind and react coil built with a well-ventilated 19-strand niobium-tin flat cable (4.8 x 0.8 mm) which is soldered to a copper coated pure aluminum tape stabilizer (4.8 x 0.6 mm). The first and second coils produce a field of 14.51 T at 1.8 K. The third coil is wound with $(Nb\ Ta)_3\ Sn$, and it has an inside diameter of 100 mm. The fourth coil is wound with $(Nb\ Ti)_3\ Sn$, and its inner bore diameter is 22 mm. The field inside the third coil is 17.08 T, the field in the fourth coil is 19.36 T. Both the inner two coils are built using the wind and react technique, then they are potted in bees wax to keep the glass fiber insulation in place. The outer coil pair is cryogenically stable while the inner coil pair is adiabatically stable.

The niobium-tantalum-tin ternary conductor used for the third coil was produced by Vacuumschmelze Hanau. The niobium-titanium-tin ternary conductor was produced by Showa Electric Wire and Cable Company in Tokyo.

P. Turowski told me that there is two fourth coils for the hybrid magnet. The second fourth coil has a bore of 55 mm rather than 22 mm. When the second fourth coil is used in place of the first fourth coil, the central field is 18.69 T instead of 19.35 T. Turowski tells me that the peak stress occurs on the inner bore of the third coil (where the field is over 17 T). The estimated stress at that point is 1.66×10^8 Nm^{-2} (24,100 psi). The elastic strain at the point is of the order of 0.16 percent, unless the outer layers of conductor contribute to supporting the force. The calculations at Karlsruhe suggest that there is very little support since even the outer winding of the coil is subjected to induction over 14 T.

The Karlsruhe hybrid magnet is an impressive achievement. Such a magnet could be used for NMR research as well as research on new superconducting materials. The ITP looks at the 19 T Homer facility as a tool for doing further research.

b) The Pumping of Helium II in a Pressurized Loop Using the Thermal-Fountain Effect.

The ITP at KfK has an interesting 1.8 K cooling for fusion reactor TF coils. The peak induction in such coils would be around 11 T, so a niobium-titanium conductor cooled to 1.8 K is an attractive option. It is proposed that the conductor be an internally cooled 16 kA conductor which is almost the same as the LCT/Euratom conductor.

The more expensive 1.8 K refrigeration is compared with the brittleness and mechanical sensitivity of the niobium-tin conductor. The group in the ITP of KfK feels that the use of ductile Nb-Ti conductor is an important advantage which outweighs the cost of the more expensive refrigeration. Since cooling at a temperature near 2.0 K is needed in order to use niobium-titanium or niobium-titanium-hatnium, it was decided that the unique properties of helium II could be used to circulate the helium through the internally cooled superconductor to insure cryogenic stability. A serious effort by A. Hofmann and his colleagues was made to develop a fountain effect thermal mechanical pump which could be used to circulate the helium II through the conductor. The pumping system proposed by Hofmann uses no moving parts or valves.

Hofmann's group built a test loop (see Figure 5 for a flow diagram for the test loop) which has a 35 mm diameter super filter (porous plug) which is made from 1.5 micron mean grain size alumina which has been pressed to the highest density. The super filter is 100 mm long. The warm end heat exchanger just outside the porous plug is 85 mm long, and it is composed of a 1,400 mm copper tube which has an inside diameter of 4 mm. The cold end heat exchanger is a finned copper tube which heat exchanges the pressurized helium directly with the bath at a temperature to which is at saturated pressure.

The flow apparatus was tested under various conditions. The tank temperature was varied from 1.6 to 1.9 K. The coil outlet temperature (the temperature at the outlet of the flow circuit in direct contact with the heat) was allowed to vary from 1.8 to 2.65 K. When the impedance was low, the flow

HOFMANN SUPERFLUID HELIUM PUMP WHICH USES THE FOUNTAIN EFFECT

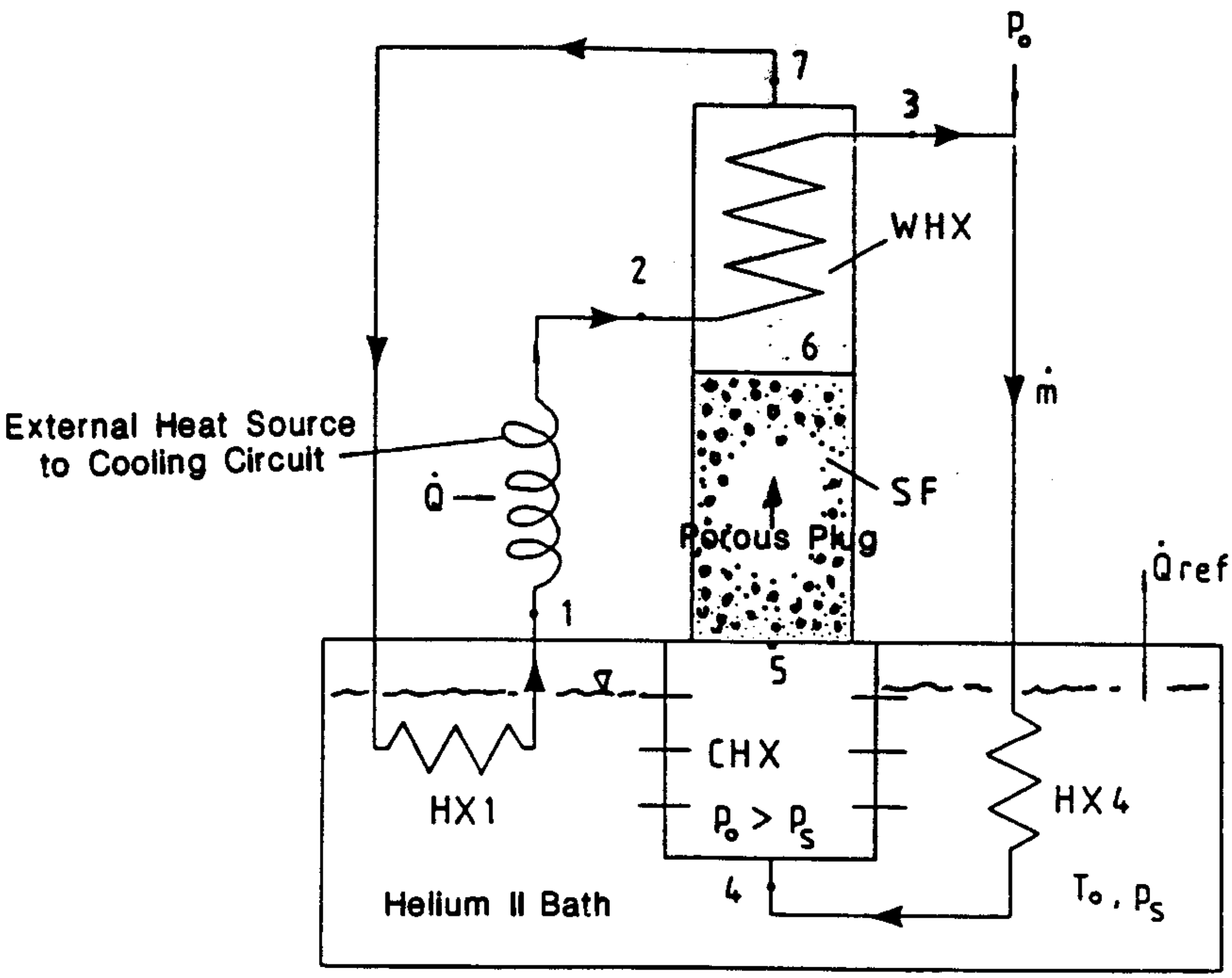


Figure 5 Scheme of the helium II cooling circuit with self-sustained fountain effect pumps. (SF: Superfilter, CHX and WHX: cold and warm end heat exchangers, resp.)

rate through the circuit ranged as high as 2.5 gs-1. The power which could be removed by the flow circuit was limited by the performance of the helium II refrigerator. One could remove 2.0 W at 1.6 K and up to 6.0 W at 1.8 K. Total cooling circuit length (from position 7 to position 5 in Figure 5) was 7,000 mm with an inside diameter of about 4 mm. Measurements were done at two different flow impedances. Hofmann stated that the measurement agreed quite closely with theory.

Hofmann's experiment shows that large amounts of heat can be removed using a thermal fountain pump on a pressurized circuit. The ASTROMAG cooling system requires only a fraction of a watt of cooling. The length of the cooling circuit is relatively short, and the hydraulic diameter of the circuit is large. As a result, the scheme tested by Hofmann's group at the KfK can be used to cool the ASTROMAG coils when they are remote from the helium II storage tank.

c) High-Temperature Superconductor

April 1, 1987, R. F. Lukinger of ITP of the KfK tested a sample of yittrium-barium-copper-oxide superconductor. (I was not given any information on the formulation of this superconductor.) The superconductor exhibited superconducting properties at temperatures as high as 105 K. The material appeared to be fully superconducting at temperatures below 102 K. R. Flukinger and his colleague are the second group at the KfK to report high-temperature superconductivity. Flukinger made the conductor to verify the measurements reported by C. Politis of another institute of KfK.

The method used by R. Flukinger was to levitate a piece of the oxide conductor off a permanent magnet. The piece of ceramic conductor was placed on the permanent magnet which was in a glass cryostat. Liquid nitrogen was added to the cryostat. The piece of ceramic floated above the permanent magnet. This suggests that Meisner flux exclusion has occurred. When the liquid nitrogen boiled away, the superconductor sample warmed up until it dropped back down on the magnet. The transition to the normal state occurred at temperatures in the range of 102 to 105 K. (W. Schaner and F. Arendt told me that there may be confirmation of partial superconductivity at temperatures as high as 240 K. This may be only a rumor.)

The ITP is excited about finding full superconductivity at temperatures above 100 K, but they do not see much effect in ongoing magnet work despite the political problems the discovery of high-temperature superconductor is causing. The people that have handled the new superconductor remarked that it is a long-long way from a practical conductor which can replace niobium-titanium or niobium-tin. The Flukinger sample is very brittle. They have no idea of what the sample's current carrying capability is, they think the critical current density is quite low (three or four orders of magnitude below what is needed for magnet construction). The general feeling of the ITP group at KfK is that the high-temperature superconductor might be useful in thin film applications such as superconducting electronics. Later applications might apply in the field of power transmission.

Visit to the Goddard Space Flight Center, Greenbelt, Maryland, April 6, 1987

My visit to the NASA Goddard Space Flight Center (NASA-GSFC) was for two purposes. I was to report on the progress which had been made by the Italian group on the two-coil toroid and on steps which will be taken to make a design study so that the two-coil toroid can be compared with strawman configuration of ASTROMAG. The second reason for visiting NASA-GSFC was to confer with S. Castles on the helium II cryogenic system for ASTROMAG.

a) Meeting with J. Ormes and J. O'Connor Concerning the Rome Meetings

I reported to J. Ormes and J. O'Connor about my meetings with Morpurgo at CERN, the people at Ansaldo in Genova, and the meetings with the Frascati people from INFN and ENEA. Since what happened at those meetings has already been reported in this travel report, I will not repeat what was said here.

Jon Ormes and I talked about what work should be done before the next ASTROMAG meeting which will probably be in late summer or fall of 1987. The tasks as I wrote them down are as follows:

1. The two-coil toroid design should have rough engineering done on it so that it can be compared to the strawman configuration (a two-coil HEAO type magnet).

2. There should be a report on the possible impact of the new superconductor technology on ASTROMAG.

3. I should look at a HEAO magnet configuration and experiment which could be launched on a Delta expendable launch vehicle.

The first task fits very well into the time table for which a design is developed and reviewed by the Italians. The second task can be done in conjunction with work I am doing on the SSC. The third task is motivated by the realization that ASTROMAG probably will not get on the space station before 1998 or the year 2000.

J. O'Connor gave me a copy of the Delta Rocket launch specifications, depending on the type of Delta one can put between 3,000 to 5,000 kg in a 300 km circular orbit. It has been suggested that I look at magnets with the following specifications: 1) maximum diameter is 2.36 m (about 8 feet); 2) the maximum mass for the experiment is 2,500 - 3,000 kg (perhaps 1,500 - 1,800 kg could be superconducting magnet, tankage, helium, insulation and vacuum vessel; this leaves 1,000 - 1,200 kg for physics detectors and associated electronics); 3) there would be no servicing in orbit, so the helium supply should last 2 years; and the support system should be designed for a cold launch.

Jon Ormes suggested that the magnetic field integral might be appropriate for the proton-antiproton experiment rather than the isotope experiment. The Delta launched magnet could be the fore runner to a larger space station to be launched about the year 2000. Jon Ormes suggested that one might look at a single-coil HEAO rather than a two-coil HEAO. It is clear that a number of options should be looked at for a low mass Delta launched magnet facility. At this time, we should not abandon the isotope experiment but instead calculate the kind of detector resolution that is needed to do the experiment with a lower mass, lower field integral magnet system.

There was some discussion of the new superconductor. Jon Ormes wants to know what his options are, but one can afford to take a wait-and-see attitude since the challenger explosion and the two-part space station proposed by the Reagan Administration appears to have forced a delay in a space station attached ASTROMAG. It is likely that the new superconductor will have no impact on ASTROMAG unless one of the following things happens: 1) there is a reliable 60-70 K refrigerator (this is possible for the space station but unlikely for a Delta Launch); 2) there is truly a near-room temperature superconductor which can be made into magnet wire (this would be a 240 K superconductor); or 3) liquid hydrogen can be used as a coolant for the superconducting coils (hydrogen is an unlikely coolant for a shuttle launched ASTROMAG; it might be possible for a Delta launched ASTROMAG provided there is suitable 40 K or above Tc conductor).

b) Discussion with S. Castles and M. Schein

Steve Castles and I talked about the helium II fountain effect pump proposed by Hofmann. Steve felt that helium could be pumped to the ASTROMAG coils without the extra heat exchangers found in the Hofmann experiment. Steve proposes that there be a porous plug between the helium tank and the coil. The helium II would be drawn from the tank through the plug. This helium II would in part be converted to helium I, and it would end up in the tank. Steve views the Hofmann pump scheme as a last resort.

The other area which Steve Castles and I discussed was the philosophy of coil down. My proposal to use a helium refrigerator to cool the magnet down is based on LBL-DOE experience on the use of helium refrigerators. NASA's experience and the experience of the aerospace industry is based upon cooling a helium system with liquid helium. The aerospace industry would not think about using 20,000 to 30,000 liters of liquid helium to cool something down and fill a helium tank. To the aerospace industry the cost of a refrigerator would be an unwarranted expense. Steve Castles suggests that we base our cooldown plan either on using liquid helium only or a combination of liquid helium plus helium gas cooled by heat exchanging with liquid nitrogen. The cryogenic system for ASTROMAG should reflect the NASA aerospace industry philosophy rather than the philosophy used at the DOE Laboratories.

c) Other Uses for Superconducting Magnets in Space

I was told about a conference on magnets in space at the Marshal Space Flight Center in Alabama. This conference is from September 15 - 17 this year. Other uses for superconducting magnets in space include: crystal growing, NMR spectroscopy, MRI imaging of animals and plasma physics experiments.

APPENDIX

This appendix consists of a biographical listing of papers I brought home from the various laboratories I visited. My itinerary, a summary of visits and the list of people contacted is included in the first section of this report.

Papers given to me at DESY:

S. Wolff, "Superconducting Magnets for HERA", DESY-HERA 1986-12, August 1986 based on a talk given at the 13th International Conference on High Energy Accelerators, Novosibirsk, USSR, August 7-11, 1986.

H. Kaiser, "Design of Superconducting Dipole for HERA", DESY-HERA 1986-14, August 1986, also given at the 13th International Conference on High Energy Accelerators.

PRE-IMPREGNES UNIDIRECTIONNELS STAATIPREG VERRE R. (This publication is in French and it describes the R-glass unidirectional fiberglass.)

PRODUKT-KENNBLATT, EIGENSCHAFTEN VON VETROTEX-TEXTIL GLAS. (A product brochure in German comparing E-glass, C-glass and R-glass products.)

Papers Given to me at CERN:

R. Perin, "Magnet Research and Development for the CERN large Hadron Collider", CERN SPS/86-9 (EMA), LHC Note 41, May 9, 1986. (This paper was presented at the ICFA Workshop on Superconducting Magnets and Cryogenics, Brookhaven National Laboratory, Upton, N.Y., USA, May 12-16, 1986.)

Cross-section drawing of the LHC dipole magnet coil showing conductors and iron boundary.

Papers given to me at Ansaldo:

A copy of Ansaldo viewgraphs which describe the circular coil solution, the D-coil solution and the Bending Free Solution for the ASTROMAG two-coil toroid magnet.

Papers given to me at ITP-KfK:

P. Turowski, T. Schneider, "19.3 T with a Superconducting Magnet", a research note for internal use.

P. Turowski, N. Brunner, S. Forster "A 12 T Nb-Ti Solenoid at 1.8 K with a Clear Bore of 290 mm in Diameter", presented at MT-9 in Zurich, September 9-13, 1985.

P. Turowski, A. Nyilas, M. Thoner "An A-15 Composite Conductor for a 15 T Insert Coil", presented at MT-9 in Zurich, September 9-13, 1985.

T. Schneider "Ausbreitung Normalleitender Zonen in Badgekuhlten, Supraleitenden Spulen". (A doctoral dissertation on the propagation of normal zones in superconducting magnets, November 22, 1985.)

A. Hofmann, A. Khalil, H. P. Kramer and B. Vogeley, "Considerations on Magnet Design Based on Forced Flow of Helium II in Internally Cooled Cables", contribution to the Intor-Report (November 1986). (This paper deals with the circulation of pressurized helium II through internally cooled superconductor using the thermal-fountain effect.)