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A 1.8 K TEST FACILITY FOR SUPERCONDUCTING RF CAVITIES

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ABSTRACT

To demonstrate the feasibility of superconducting RF technology for a high energy e+/e- collider, a research and development program has begun with collaborators from Europe, Asia, and North America. The immediate goal of the R&D program is to build and operate a 50 meter-long linac at DESY with 1.3 GHz superconducting RF cavities at a temperature of 1.8 K - 2.0 K and an accelerating gradient of 15 MV/meter. The refrigeration for the test system at DESY initially will have a capacity of about 100 W at 1.8 K, distributed among three test cryostats. In a second step, refrigeration will be upgraded to 200 W at 1.8 K in order to supply the 50 meter test linac. This paper describes the cryogenics of this test system.

INTRODUCTION

The study of electron/positron collisions in storage rings such as SPEAR, PEP (at SLAC), DORIS, PETRA (at DESY) or TRISTAN (KEK, Japan) has revealed much new information about the make-up of matter and the fundamental natural forces. Experiments of this kind are being continued in the storage ring LEP (CERN, Geneva). After the end of an upgrade program for LEP, the storage ring will reach its planned maximum energy of 2 x 100 GeV. High energy physicists would like to extend the studies to an energy region beyond LEP, to the center of mass energy of 500 GeV.

Storage rings for electrons at energies over 100 GeV become uneconomical due to the high synchrotron radiation. Therefore, high energy physicists are discussing new machines which permit the collision of high energy electrons and positrons out of linear accelerators, only with higher energy and more intense beams[1] than at the Stanford Linear Accelerator, where pioneering work has been done with SLC. In the framework of an international collaboration of more than 12 accelerator laboratories, the concept of a linear accelerator of superconducting high frequency resonators was developed: TESLA (TEV Superconducting Linear Accelerator).

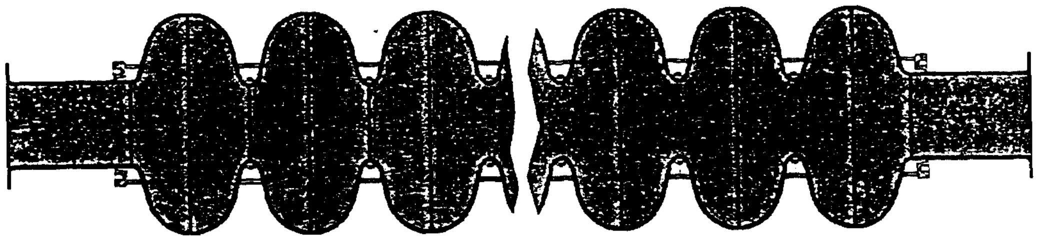

Figure 1. A 9-cell, 1.3 Ghz, superconducting rf cavity

PURPOSE OF THE TESLA TEST FACILITY

In order to prove that TESLA is overall technically realizable and competitive with other concepts, at DESY a research project, the TESLA Test Facility, has been established to test individual superconducting RF cavities and a 50 meter long prototype superconducting linac[2].

The use of superconducting high frequency resonators (figure 1) in a linear accelerator offers the advantage over normal components of lower losses in the walls of the cavities. This permits the use of a larger aperture, lower frequency, longer pulse lengths, and lower peak RF power requirements than with normal conducting accelerating structures.
Until now the disadvantage has been the high cost, and for a linear accelerator in accordance with the concept of TESLA these costs must be reduced. Of great importance in reducing the total cost is getting the maximum accelerating gradient per unit length. The goal is, through special high vacuum heat treating of the very clean niobium cavities[3] and the use of pulsed high frequency (HPP - High Peak Power processing)[4] to reach accelerating voltages of 20 - 25 MV/m in 1.3 GHz cavities. Furthermore, the costs should be reduced by having a large number of cells per cavity (9 cells) and an assembly of 8 cavities in a 12 meter long cryostat (see figure 2). The static heat loads and corresponding operating costs may be reduced through appropriate cryostat design[5]. Figure 3 shows a prototype cryostat design in cross-section.

In the Tesla Test Facility at DESY by the end of 1996 we hope to prove that these goals are attainable, and the groundwork for the construction of a linear accelerator with 2 x 10 Km active length of superconducting resonators will have been created.

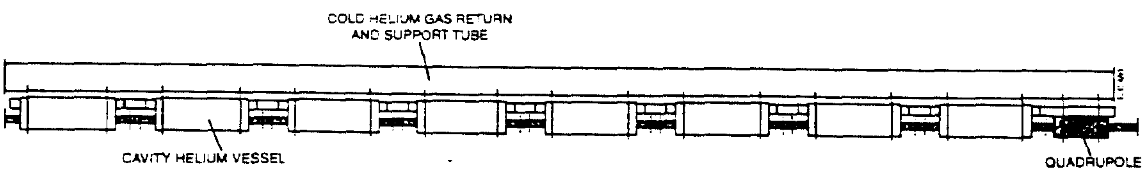

Figure 2. A side view of 8 cavities (one in each helium vessel) in one cryostat.

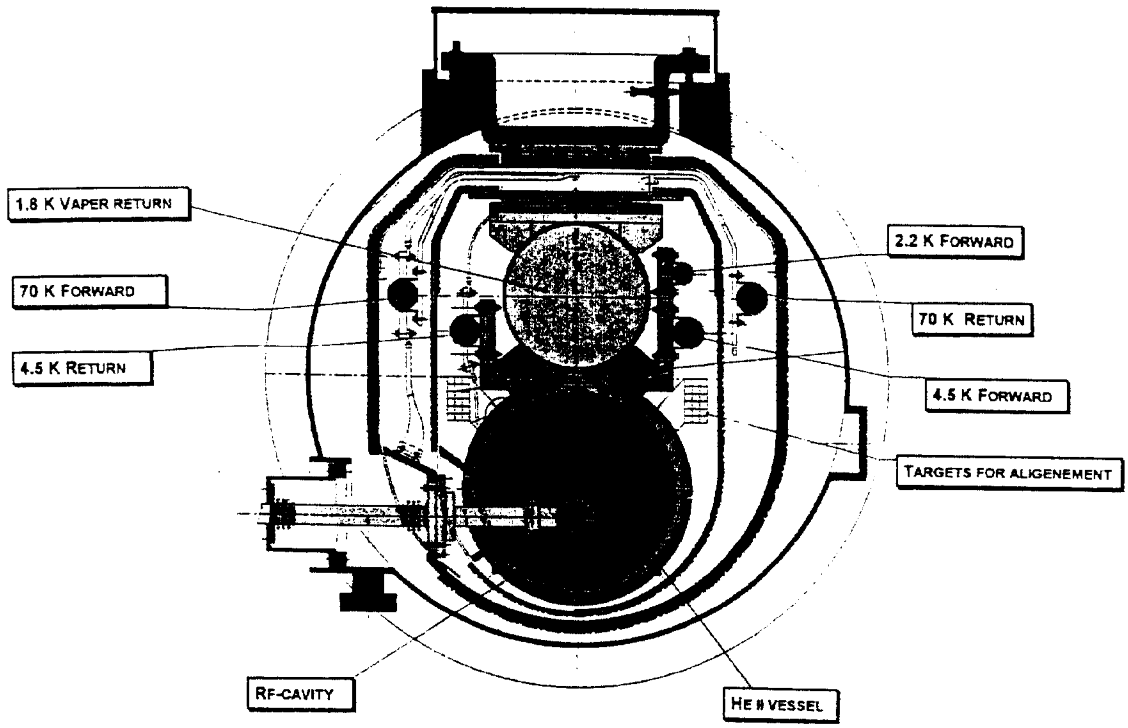

Figure 3. Cryostat cross-section at an rf cavity and input coupler.

FIRST STAGE OF THE 1.8 K FACILITY

The construction of the 1.8 K system takes place in two stages. Since the experiments first of all begin with the tests of single 9-cell cavities, it is enough in the first phase of the test operations to supply one horizontal and two vertical cryostats. Single 9-cell niobium cavities will be tested in a 1.8 K bath in the vertical cryostats. Then, after assembly into its helium vessel, the cavity and its helium vessel are tested at 1.8 K in the horizontal cryostat. Figure 4 shows a block diagram of the cryogenic components for the first stage of the Tesla Test Facility.

For the vertical test cryostats liquid helium at 1.8 K is needed. The horizontal cryostat requires 1.8 K liquid and 4.4 K helium for a thermal radiation shield and intercepts. Cooling of 80 K radiation shields and thermal intercepts in the test cryostats is by means of liquid nitrogen.

An existing 900 W/ 4.4 K helium plant will be rebuilt and expanded to fulfill the need for 1.8 K and 4.4 K cooling. Supercritical helium (ca. 5 K, 3 bar) is taken from the 900 Watt plant and is carried through an already existing but easily modified distribution system to the cryostats. In the supply line of each cryostat (see the test cryostat schematic, figure 5) is a low temperature heat exchanger, which precools the incoming helium to about 2.2 K by means of counterflow heat exchange with the pumped vapor. An isenthalpic expansion into the low temperature bath is then carried out via a Joule-Thomson valve, and by regulation of the JT-valve the liquid level in the cryostat is held constant. The returning, low pressure helium vapor is warmed to about 3.5 K in the counterflow heat exchanger, and via an insulated transfer line, a collection box, and a helium heater it is carried to a large room-temperature vacuum pump assembly where it is compressed to 1.2 bar, and in the gas circuit fed to the screw compressors and the 4.4 K cryoplant.

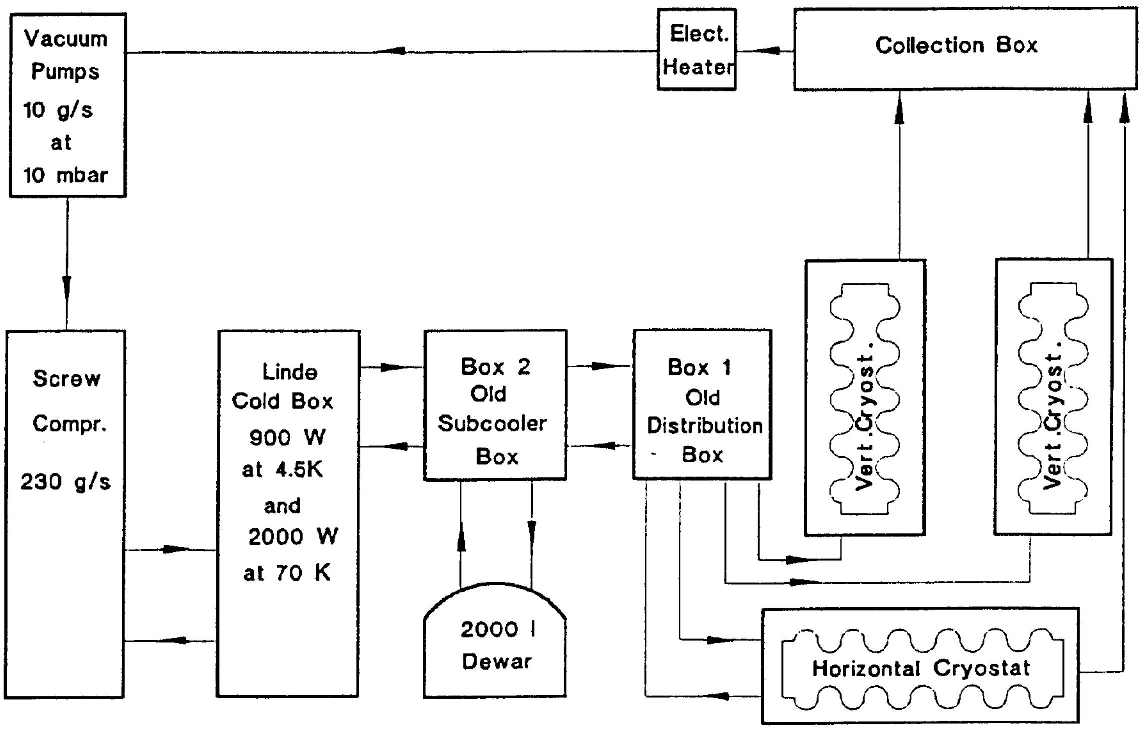

Figure 4. Block diagram of the first stage of the cryogenic system. Two vertical test cryostats and one horizontal test cryostat are operational.

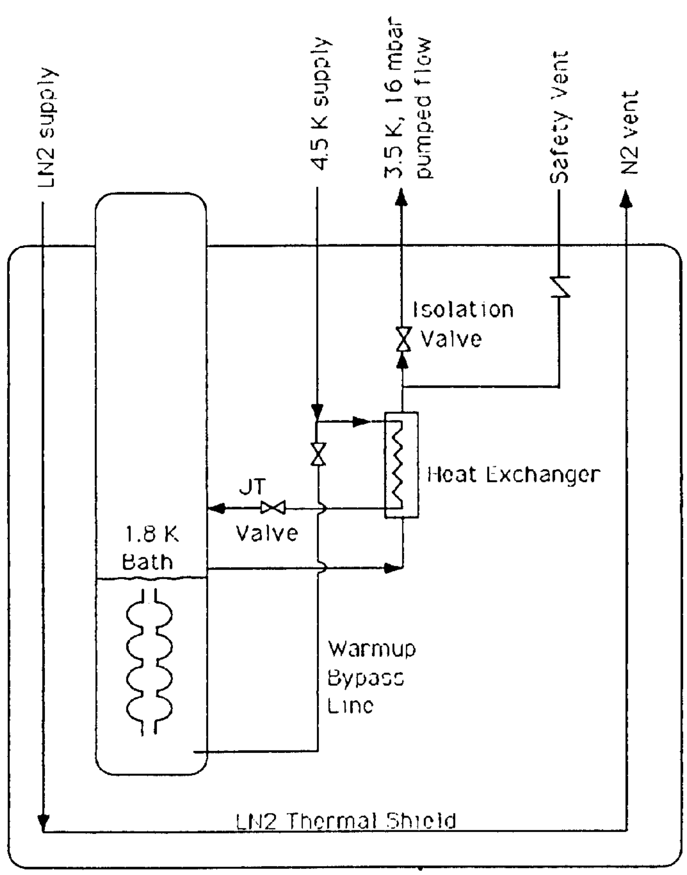

Figure 5. Vertical test cryostat schematic.

The helium temperature of 1.8 K corresponds to a helium vapor pressure of 16 mbar. The vacuum compressor assembly is sized for a maximum of 10 g/s helium at a suction pressure of 10 mbar. This flow specification corresponds to the requirements of the final stage of the 1.8 K facility. The suction pressure of 10 mbar is necessary in order to compensate for the pressure drop occuring in the heat exchangers and piping. The vacuum compressor assembly, consisting of three stages of roots blowers and one stage of rotary vane pumps, is manufactured by the Leybold company in Germany.

The cooling capacity available in the test cryostats results from the liquefaction capacity of the 4.4 K cold box and totals a maximum of 100 W at 1.8 K (at a maximum liquefaction mass flow of about 5 g/s). The static losses in the vertical cryostats, including the equipment necessary for the testing of the cavities, are estimated at about 10 W.
The remaining cooling capacity is available for the field and quality measurements, as well as the HPP processing.

It is possible to reduce the suction pressure of the vacuum compressors further, and thereby to operate the cryostats at temperatures less than 1.8 K with reduced cooling capacity.

THE MEASUREMENT PROGRAM IN THE TEST CRYOSTATS

In the vertical cryostats the maximum reachable field strength and the cavity quality should be measured with high frequency antennas for single cavities. To reach higher field strengths the cavities will be treated with high frequency pulses of high power. These may deposit large amounts of heat into the 1.8 K bath. The total heating rate can be controlled via the pulse repetition rate and will be limited by the 100 Watt cooling capacity at 1.8 K.

The limit of achievable field strengths, which in theory should lie at 50 MV/m, is in practice set by field emission of electrons on the inner surface of the cavities. These field emissions are caused by dirt and contaminants in the niobium. Field emission leads to local hot spots on the cavity walls and to the release of gamma rays. With the help of thermometers and photodiodes, temperature maps and gamma emission maps are made[3].

Before the installation of the cavity in the final cryostat module, in the horizontal cryostat further measurements are carried out on the cavity furnished with its own helium tank. The high frequency input coupler, the maximum reachable field in the RF cavity, and the cavity quality are tested. Unlike the test in the vertical cryostat, the quality measurement here can only be made through the cryogenic measurement of the losses, since the final high frequency input coupler does not permit an electrical measurement. Therefore, very high demands were set for the test of the losses: with a static load of 4 W, the dynamic load of about 1.5 W should be known with a precision of +/- 0.4 W. This measurement will be done by means of a precise measurement of the boiloff gas flow rate and the supply flow rate.

SECOND STAGE OF THE 1.8 K FACILITY

Finished 9-cell RF cavities, which have been tested in their helium vessels in the horizontal test cryostat, will be assembled into a 12.2 meter long cryostat module consisting of 8 RF cavities, a superconducting quadrupole, beam position monitors, and various other instrumentation. The second stage of the TESLA Test Facility consists of the additional equipment to cool a string of four of these modules and a capture cavity, which together will form the main part of a test linac (see figure 6).

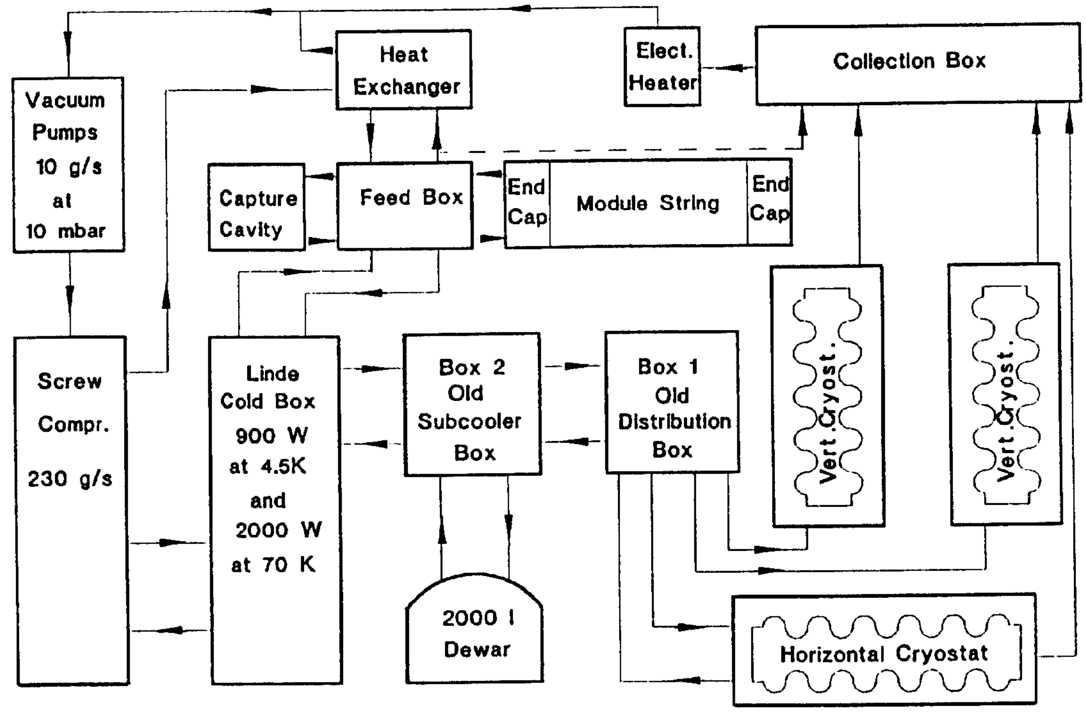

Figure 6 is a block diagram of the cryogenic system after the addition of the second stage.

The scheme for cooling the TESLA prototype modules in the test linac corresponds to the cooling process which is envisioned for a future TESLA linear accelerator. The cavities will be in a 1.8 K helium bath. Through this string of 4 modules, between the feed box and end box, a uniform helium level is maintained. The regulation of the JT valve in the entrance of the feed box follows via the measurement of the liquid level in the end box. The vapor returns back to the feed box via a 300 mm diameter return line, which at the same time serves as the mechanical support (see figure 2). The design of this return line and the other process lines is based on the later dimensions of TESLA. A cryogenic unit would have a length of 1880 meters in TESLA. Table 1 summarizes some of the parameters for TTF and TESLA.

The cryostat module has two radiation shields. Using the supply of the 4.5 K shield, one superconducting quadrupole per module will operate for beam focussing. The 70 K shield circuit cools an additional high frequency absorber in order to remove parasitic high frequency modes from the cavities (higher order mode losses). For the test of the 50 meter long linac consisting of the four cryostat modules including a beam injection system, the liquid production of the first stage of the cryogenic assembly is no longer sufficient. Cooling must be made available at three temperature levels. The heat loads for the 4 test modules and an injection module total about 80 W in the 1.8 K bath, about 90 W at the 4.4 K shield level, and about 430 W on the 70 K shield. Further losses appear in the transfer lines and supply boxes.

Therefore, with the help of an additional heat exchanger, shown in Figure 6, the cooling capacity at 1.8 K will be increased to 200 W (10 g/s). About 90% of the cooling capacity which is carried in the 3.5 K, 16 mbar, return stream is transferred in this heat exchanger to a counterflow stream of 14 bar, the process pressure of the 4.4 K cold box. (In the first assembly stage the cooling capacity of the 3.5 K, 16 mbar, stream is lost to the process through the heat added by a heater.) After an isenthalpic expansion to 1.2 bar, this counterflow stream returns to the compressors via the 4.4 K cold box.

Table 1.: General Data

		TTF-Cryostats	TTF-Linac	TESLA
accelerating gradient	MV/m	20 - 25	15	25
RF-frequency	GHz	1.3	1.3	1.3
number of RF-cells per cavity		9	9	9
number of cavities per module			8	8
total number of modules			4 + 1 injection	12 x 12 x16
total length of system vertical " " " " horizontal	m m	vertical ~ 2.5 horicontal ~ 2.0	50	31880
beam energy	GeV		~ 0.480	2 x 500
Refrigeration requirements (estimated)	K	1.8 / 4.4/ 70	1.8/4.4/70	2.0/4.4/60
vertical cryostats	W	10.0/ -- / 25.0		
horizontal cryostats	W	5.5/ 15/ 50		
module	W		21/ 19/ 100	
system	W	100/ 350/ 1000	200/ 350/ 1000	
system	kW			48.4/44.7/230

Table 2.: Refrigeration Data for TTF

cooling capacity at 1.8 K	W	200/100 *)
mass flow rate at 1.8 K	g/s	10/5 *)
inlet pressure to 2 K heat exchanger	bar	~ 3.0
inlet temperature to 2 K heat exchanger	K	~ 4.4
supply temperature to J-T valve	K	~ 2.2
return pressure from cryostats	mb	16
return temperature from 2 K heat exchanger	K	~ 3.5
heating power required	KW	~ 15 *)
return temperature from recovery heat exchanger	K	~ 275
expected heat exchanger recovery efficiency		0.85 .... 0.9
inlet pressure for warm pumping system	mb	~ 10 - 15
residual capacity at 4.4 K	W	~ 350
shield cooling capacity at 60 K	W	~ 1000

*) Without the 3.5 K/room temperature recovery heat exchanger (experimental stage 1), the reduced lower numbers are valid only. Return gas has to be heated from 3.5 K to room temperature. Since the operation mode is "liquefaction", almost no capacity at 4.4 K is available.

Except for the unbalanced mass flow in the supply and return streams of this heat exchanger, required due to the differences in the thermal properties of the two streams, and the cooling of some small current leads, no other liquefier performance of the system is required, whereas the system in the first assembly stage ran as a liquefier. Because of the small permitted pressure drop in the low pressure stream in the heat exchanger, and the therefore small stream velocity required, there are unfavorable conditions for the heat transfer and heat exchange. The above described heat exchanger therefore requires special engineering.

Parallel to the 1.8 K refrigeration described above, about 400 Watts of cooling capacity remain at a temperature level of 4.4 K in the 4.4 K cold box. Table 2 summarizes the planned refrigeration and liquefaction capacity for TTF.

THE MEASUREMENT PROGRAM IN THE TEST LINAC

Like in the horizontal cryostat tests, heat loads to the 1.8 K bath must be measured in order to quantify the dynamic losses of the RF cavities and understand their performance. It is also desireable to measure the static losses to the 1.8 K bath and the total losses to the 4.5 K and 70 K temperature levels. Therefore, careful flow and temperature measurements are planned at all temperature levels, as well as measurement of the boiloff flow rate from the 1.8 K bath.

THE SCHEDULE FOR THE TEST FACILITY

By the end of 1993 the first vertical cryostat should be brought into operation. The start of operation of the horizontal cryostat is expected in 1994. In 1995 the second stage of the cold facility with the low pressure heat exchanger should be finished. The operation of the test linac is planned for the end of 1996.

The construction of the cryogenic components of the test facility is shared among the institutes Fermilab (USA), INFN Frascati (Italy), IPN Orsay (France), CEN Saclay (France), and DESY (Germany).

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