SUPERCONDUCTING RF ACTIVITIES AT SACLAY: status report

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INTRODUCTION

This paper presents the RF superconductivity research and development work at Saclay for cavities designed for electron acceleration at 1.5 GHz. Improvements on diagnostics tools are presented together with recent work on a Nb TE 011 cavity designed for studies on surface resistance. An outline of MACSE, a short electron accelerator under construction, is given.

RESULTS ON SINGLE CELL CAVITIES

Several single cell cavities have been fabricated by hydroforming and electron beam welding of high purity Nb sheets of 2mm thickness (RRR $\simeq$ 180). The surface preparation consists of a chemical polishing (50µm) in a 1:1:2 solution of $HF:HNO_3:H_3PO_4$ followed by rinsing in demineralized, filtered water. Drying and assembling take place under a dust free laminar flow in a class 100 clean room. The final mounting on the cryostat vacuum system is made in front of a laminar flow.

During the past year 16 tests were performed using 5 different cavities.

Figure 1 gives statistics on these tests : a) surface resistance, b) onset accelerating field for electron emission, c) maximum accelerating field (the peak surface field Epk is given by Epk $\simeq$ 2 x Eac).

For fields Eac higher than 20 MeV/m, the limitation is always due to a quench. Temperature maps performed at a field level just before the quench in superfluid helium show no temperature increase. This systematic effect seems to indicate that this quench could be induced by multipacting . Calculations show that a two-point multipactor trajectory near the equator is possible at a field level of 24 ± 6 MeV/m. Similar effect has been observed at CERN at lower frequency [1].

We report below some observed effects of residual gases on surface resistance.

. During these tests we have sometimes obtained a large value of surface resistance, rapidly increasing with field. We suspect that this effect is due to a pollution of the Nb surface while the cavity is connected in the vacuum system of the cryostat , although the residual pressure is always in the 10^{-9} Torr range. A thermal cycle to room temperature has been observed to improve by an order of magnitude the surface resistance. Further baking at 500K under vacuum was also tested successfully on the same cavity (figure 2).

. A strong correlation has been observed between a helium leak during an experiment (most of the times located on RF feedthrough) and a reduced Qo during the next test (fig.3). On a particular test, during helium processing, the pressure inside the cavity was accidentaly increased up to 0.1 Torr (without RF) and immediatly pumped down resulting in a Qo degradation by a factor of 2 and a strong electron emission loading. After thermal cycle to 300 K the cavity could not recover its characteristics (fig.4).

RESULTS ON MULTICELL CAVITIES

A five cell cavity without coupler was tested and showed a maximum accelerating field of 6.5 MeV/m limited by electrons with a Qo value of 10^{10} at 1.8K..

A three cell cavity has also been tested . The maximum accelerating field was 16MeV/m (limited by electrons) obtained after two hours of He processing. In this test the onset for electron emission is 11 MeV/m. Qo is in excess of 10^{10} (fig.5).

Several multicells cavities are being manufactured and will be tested as a part of MACSE.

Nb/Cu DEVELOPMENTS

Two 1.5 GHz single cell Cu cavities were fabricated and coated at CERN [2] with Nb film of thickness 5 µm. The RRR was estimated to be of the order of 20. Figure 6 gives the Q(E) curves at 4.2K and 1.8K for one of these cavities. We observed a rapid increase of R_s with the applied field together with very strong field emission loading. The BCS resistance at 4.2K and the residual resistance were compared with the values obtained at 0.35 GHz and 0.5 GHz at CERN [3] and the ones obtained at 8.9GHz at CALTECH [4] for similar coating technics (fig.7) the BCS resistance scales as f^2 as expected. A similar scaling for the residual resistance seems to exist. In the next future we plan to measure , on the same cavity, values of the resistances on higher order modes, for frequencies ranging from 2GHz to 5 GHz. Studies are also planned using the TE011 cavity (see below).

IMPROVEMENT OF DIAGNOSTICS

Superfluid thermometry is routinely used for surface resistance diagnostics on single cell cavities and on the TE011 experiment. X-ray detectors are a very usefull tool for electron emission studies in single cell cavities.

. Superfluid thermometers have been operated for 1 year [5] and several rotating arms equipped with 13 thermometers have been built and used on single cell cavities. Fixed thermometers with improved efficiency are being implemented on the removable plate of the TE011 cavity.

A test chamber has been used to calibrate these thermometers by using a known power deposited on a Nb plate cooled by superfluid He. The main results are :

- reproducibility better than 30%
- overall resolution : 0.2mK
- thermal response : 0.3K/W to 4.2K/W depending on bath temperatue between 1.5 K and 1.8K.
- the kind of thermal bonding agent changes greatly the bath temperature dependance $\Delta T = T^{-n}$, values of n from n = 2 to n = 12 have been observed.

Numerical study on the influence of the different parameters and operating conditions of the thermometers has been carried up, using a code based on finite element MODULEF. This code simulates the experimental test assembly in a 2-D and axisymmetrical 2-D and will be improved to handle 3-D and transients effects [6]. It was established that the presence of the thermometer on the Nb surface alters the thermal properties of the Nb-He interface, resulting in a lower temperature rise than in the case where no thermometer is present. Figure 8 shows the temperature profile which is computed with and without thermometer. We conclude that the thermometer works rather in a thermal fluxmeter mode than in a normal temperature mode. Numerical simulation was performed using a schematic configuration of the sensor and the calculated temperatures were very close to the measured ones.

. X ray mapping of the cavity is obtained by an array of 15 BX66 diodes from Siemens mounted on a rotating frame. These diodes were calibrated by using a Van de Graaf which gives an electron beam of known current I and energy E (from 0.5 MeV to 2 MeV) hitting a Nb plate of 2mm. The diode was placed in liquid nitrogen for this measurement. The response of the diode was found to be :[7]

$$V \alpha\ I.\ E^{2.65}$$

The signal from a given diode for different values of the accelerating field is used to make FN plots ($V/Ea^{5.15}$ vs I/Ea) and to compute values of β of individual emitters.

Figure 9 shows the result for one of the best cavities tested. The temperature and X-ray maps were taken just before the quench, showing an electron trajectory and no heating on the rest of the cavity.

SURFACE RESISTANCE STUDIES

. We have built a cylindrical TE01n (n= 1,2,3) cavity in order to study the surface resistance R_s (f, T, B_{rf}) of bulk as well as superconducting films deposited on one demountable end plate of the cavity.

In the next months we will study, essentially on Cu substrats, sputtered Nb as well as reactively sputtered NbTiN films the investigation of which begun recently at CERN .

The localization of defects on the removable plate using sensitive thermometers in He II and the possible further identification of these defects via SEM and AUGER spectroscopy are the main goals of these experiments.

. The cavity (fig.10) is made of high purity Niobium (RRR180)

The main characteristics are :

- inner diameter of the disc = 110mm
- f(TE011)= 4.04Ghz ; f(TEO12) = 5.65Ghz
- 1mm Pb gasket located in a groove machined in the disc itself
- peripheric groove in the fixed end plate designed to shift away the degenerate TM111 mode by 50Mhz.
- variable coupling on one port with a possible displacement of the loop of 25mm ($3 10^5 < Qext < 3.10^{11}$)

For the first experiments 40 thermometers ϕ 10mm have been fixed with a thermal bonding agent on the plate under test; 88 new ϕ 6mm thermometers will be installed in the near future. The temperature mapping is performed by a scanning technique using relay multiplexers - the maximum offset voltage and noise of which is 2μV - and a voltmeter which gives an accuracy of 0.1 μV and a noise level of 0.2 μV for the 100 mv range and a 20ms integration time. The thermoelectrical effect is eliminated by inverting the DC current and a fast scanning of each sensor and bath temperature is performed in order to reduce the influence of the bath temperature on the thermometer sensitivity.

. Our first experiments were carried out with a 2mm thick RRR 180 Nb plate and an In gasket instead of a Pb one.

These measurements were made at the two frequencies of the TE011 and TE012 modes, and have shown an approximately f^2 dependance, both of the BCS part (T =4.2K) and the residual part (T =1.5K) of the surface resistance.

We have begun an investigation of the dependance of the surface resistance R_s on the maximum RF field level B_{max}, for a given mode in the cavity (fig.11).

A very few earlier investigations have pointed out that high purity superconducting surfaces can exhibit quite different behavior and some singularities, according to the value of B_{max}.

At low field values (typically $B_{max} < 5mT$) , we observed a significant increase of R_s as shown on figure 12.

This additional absorption has received an interpretation in terms of the so-called "magnetic-field induced surface state" [8,9]. This surface state is characterized by the existence of "skipping orbits" of normal electrons in the penetration depth of the magnetic field parallel to the surface, giving rise to a resonance in the RF absorption. In this model, it is essentially supposed that the resonance can occur only if a sufficient smoothness of the surface and a large mean free path as compared to the coherence lenght allow specular reflexion on the surface. The resonance peak should then decrease and even disapear with an increased surface roughness. It is infered that a carefull investigation of this resonance could help for a better undersanding of superconducting cavities.

The onset of this additional absorption is in agreement with theoretical predictions :

$$B_{max}=h.f/e.v_f.\lambda$$

(f = Rf frequency; v_f= Fermi velocity; λ = penetration depth) with usual values v_f= 3.5 10^7 cm/s and λ =460A ,this formula gives B_{max} = 1.4mT which is the observed value. It should be noted that in our cavity excited on a given mode, we observe a "plateau" in this absorption rather than a resonance peak. This is due to the fact that different rings with the B_{max} fiel are propagating along the surface when the field is increased.

At much larger magnetic fields we observed a minimum in R_s around 25 mT followed by a rapid increase up to the breakdown field of 49mT as shown on fig.13. This behavior was also observed in previously reported works [8,10]. Experiments are in progress to clear up this behavior.

OTHER STUDIES - FUTURE DEVELOPMENTS

Fundamental studies on field emitted electrons and surface resistance of superconducting materials are being developed. They include :

. An experiment for DC field emission on small samples with localisation of emitters, under construction.

. Pulsed RF processing of single cell cavities will be tested with a 1.5 Ghz klystron delivering a power of 5kW. With a pulse length of 1 to 5 milliseconds and the use of a variable coupler, an accelerating field of up to 35 MeV/m can be reached.

. A special cavity, resonating on the TM020 mode, with a dismountable plate is being installed for studies of RF field emission. This cavity was designed in collaboration with the University of Wuppertal.

. A magnetron sputtering set up is now available at Saclay. It is used to study Nb films deposited on copper. Work is under way to study thin films of NbTiN. A laboratory is equipped to measure basic properties of thin films like critical temperature, RRR and thermal conductivity.

MACSE

An R&D facility for superconducting electron accelerator technology

A prototype cryomodule with 4 superconducting cavities will be implemented in the ALS tunnel after shut down. This programm will embody a new injector (100 μA continuous beam), a superconducting capture cavity, and beam diagnostics for intensity, position and energy dispersion. A cryogenerator system will supply 100 watts, 1.8 K, cooling power. Five klystrons locked in phase and amplitude will provide 5 kw continuous power (See fig. 14).

First beam is expected by the end of 1990 and tests are scheduled for 1 year. Three different sets of cavities and cryomodules will be successively assembled and tested.

Further developments include a high intensity injector a new type of klystron.

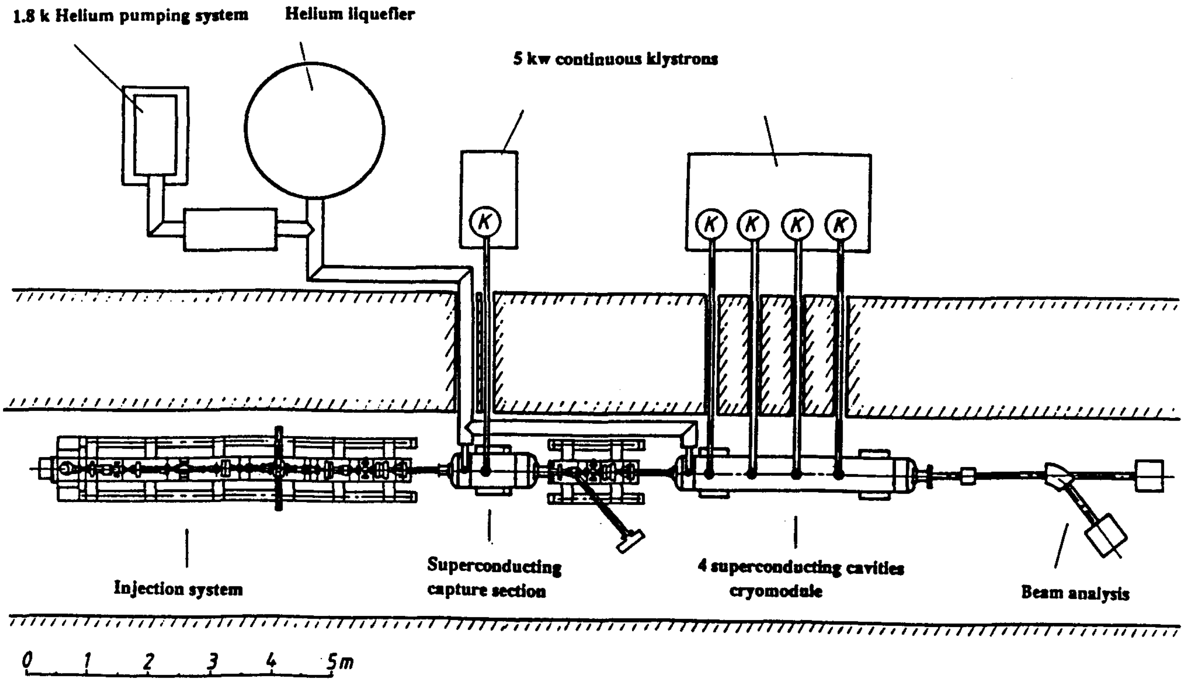
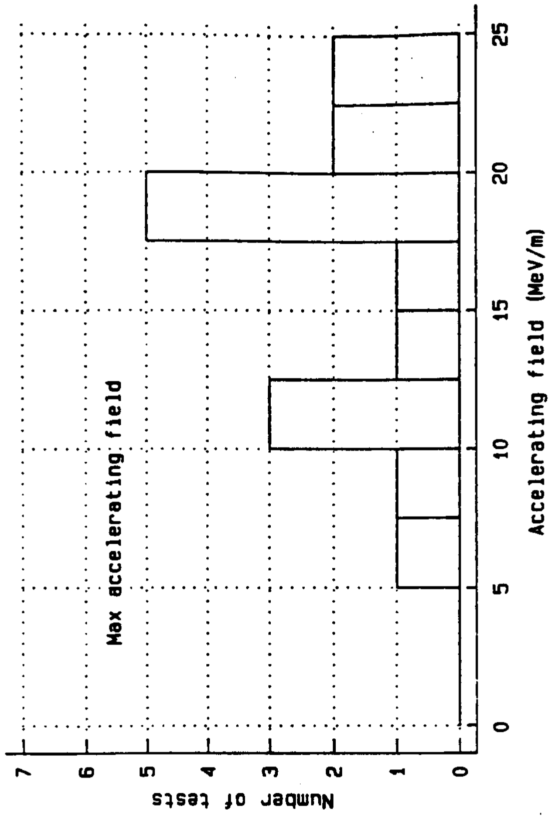
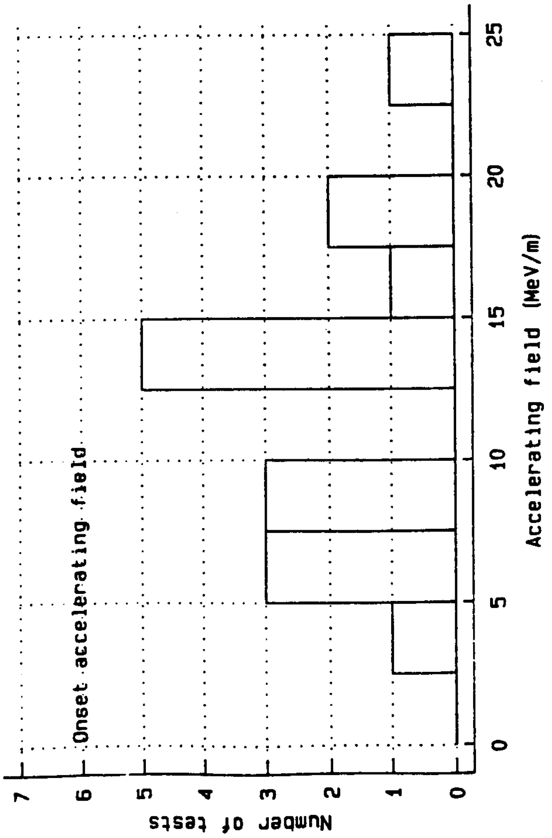


fig 14. MACSE : A SUPERCONDUCTING ACCELERATOR TEST FACILTY AT SACLAY





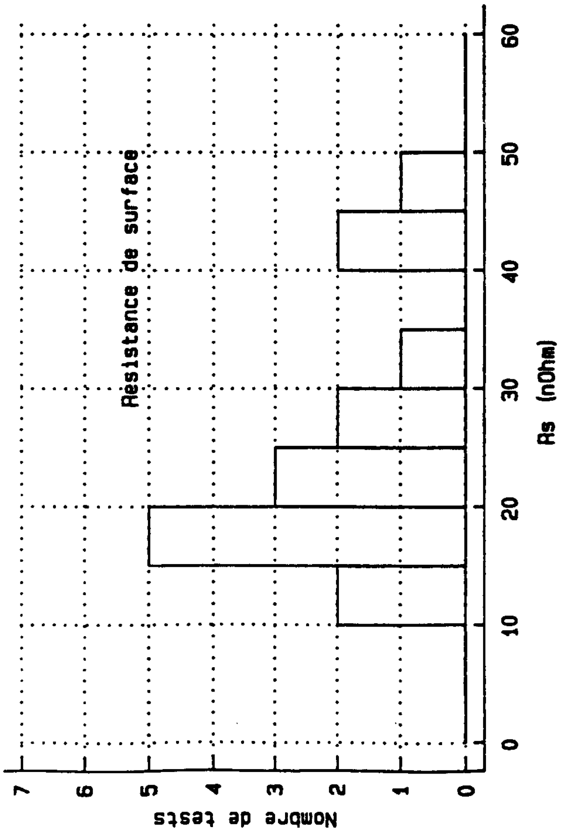


fig.1 - Statistics on single cell cavities

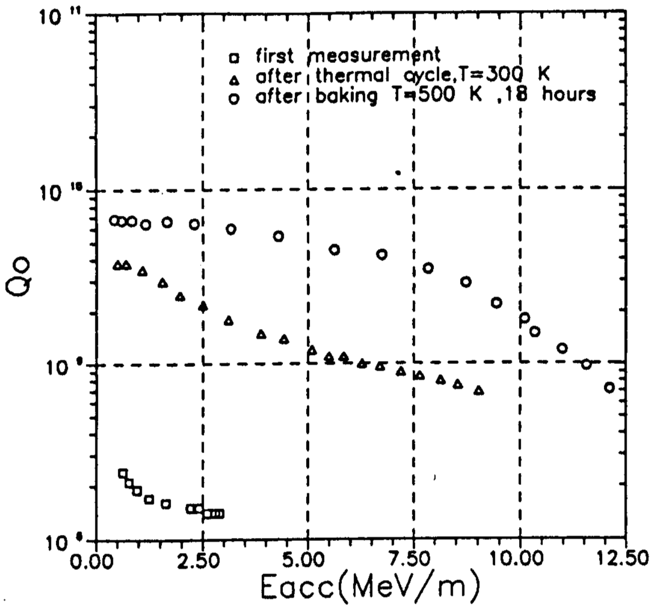


fig.2 - Influence of thermal cycle

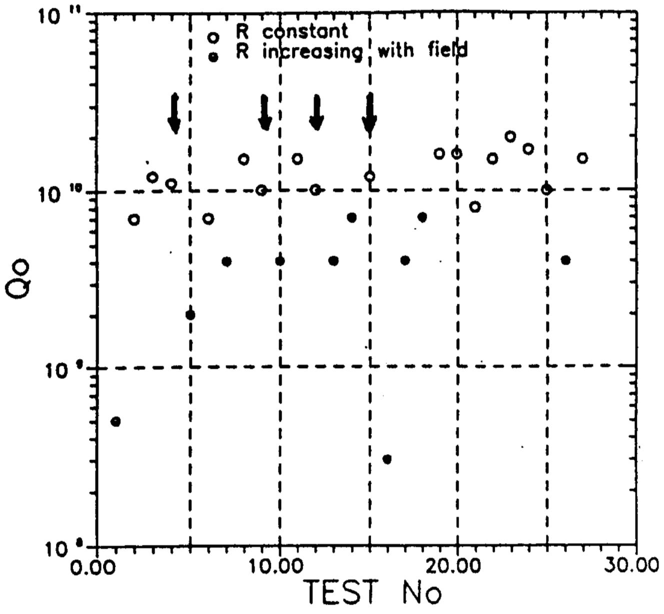


fig.3 - Summary of tests
Arrows indicate He leaks

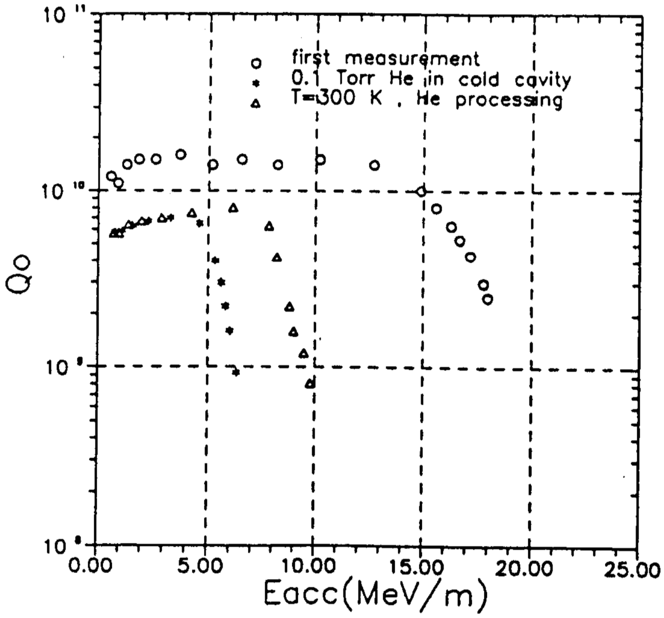


fig.4 - Degradation after He leak
in a cold cavity

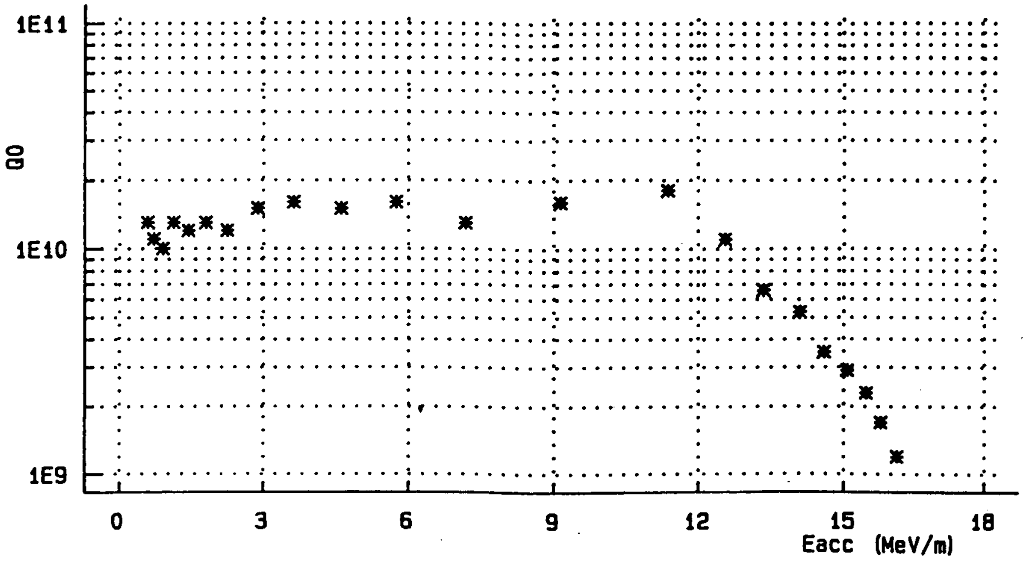


fig. 5 Q = f(Eacc) for the three cell cavity

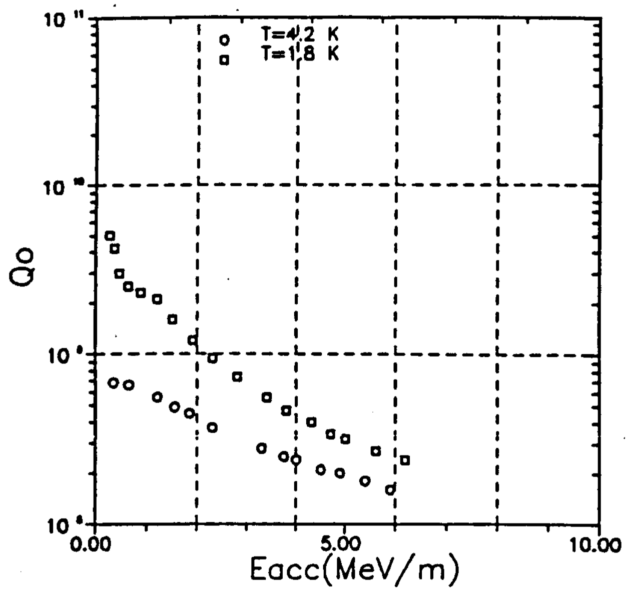


fig.6 - N/cu 1.5 GHz cavity

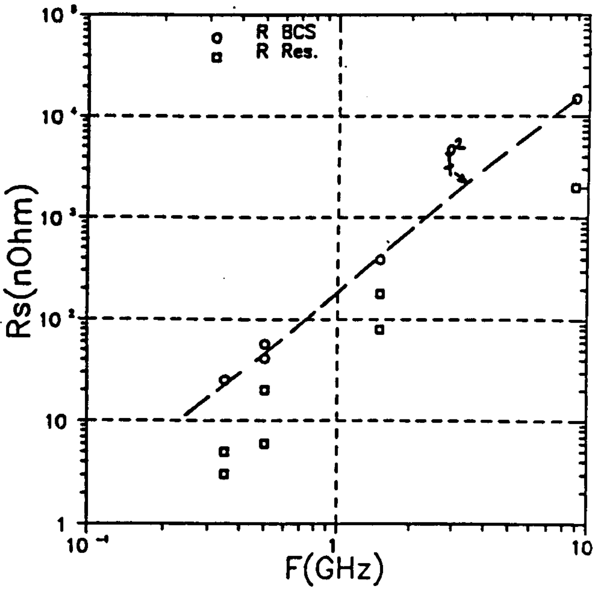


fig.7 - Resistance VS frequency for Nb/cu cavities

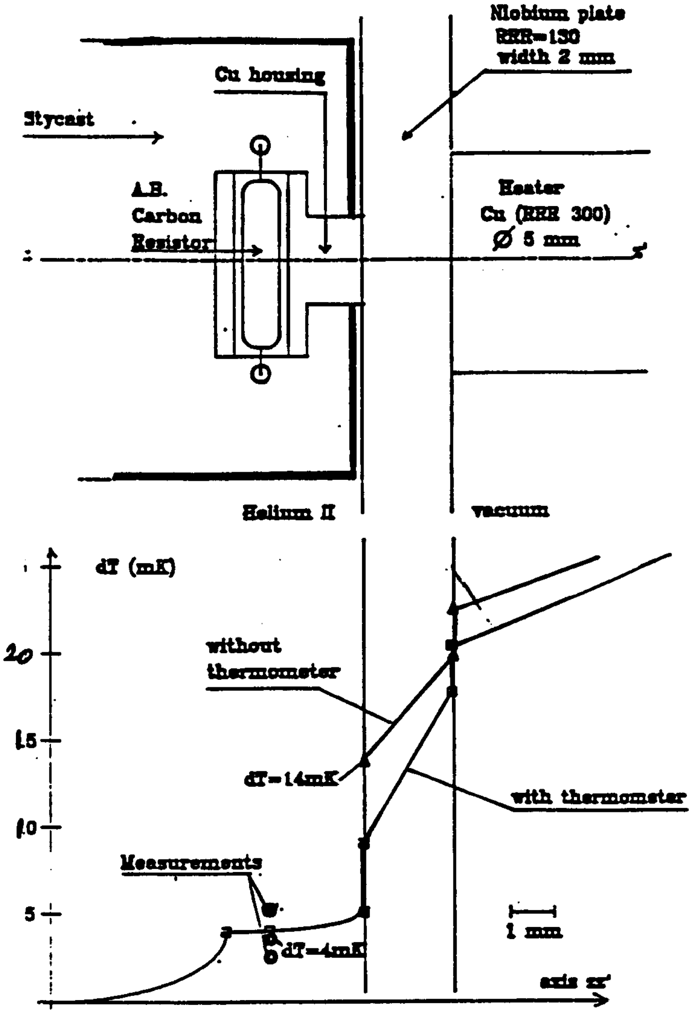
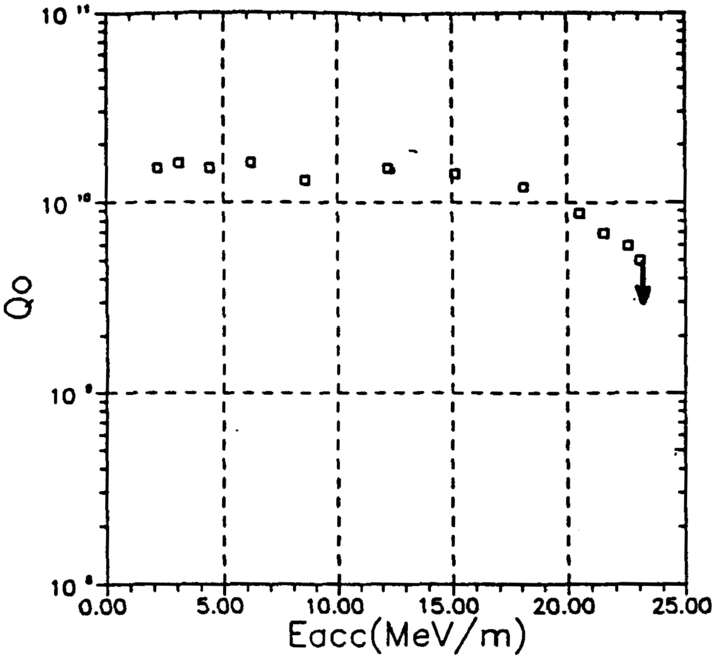


fig. 9. Temperature increase on the axis for P=1.73 mW (Tbath= 1.5 K)
(model calculations and measured values)



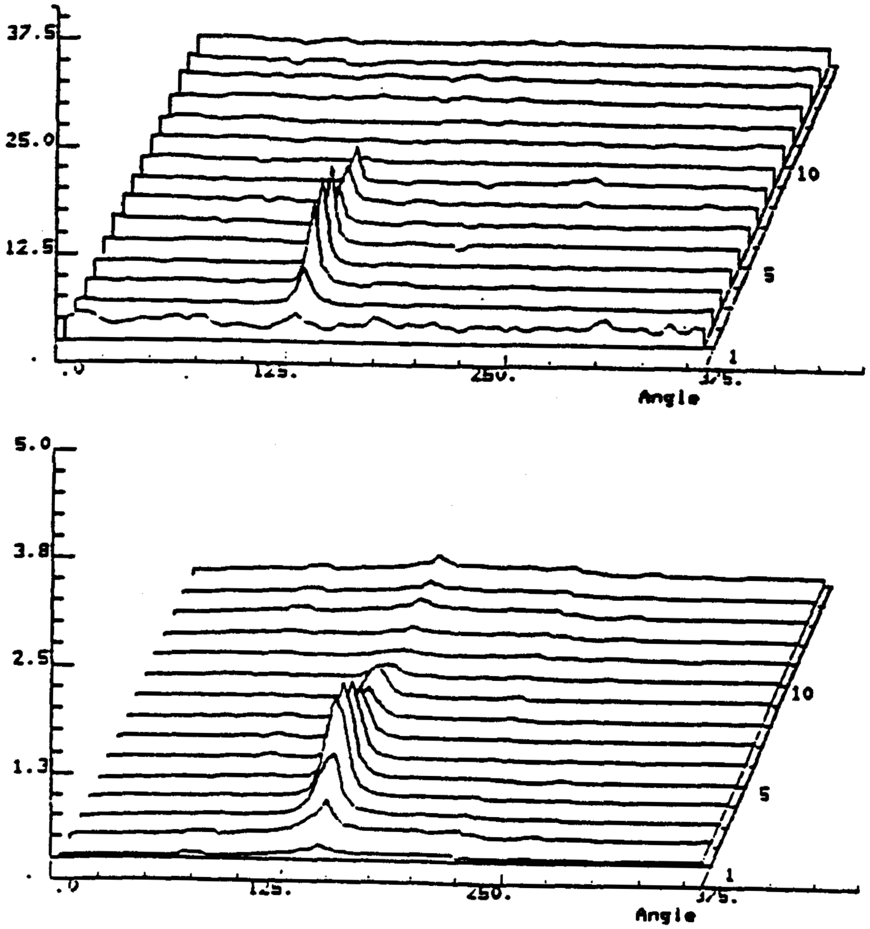


fig.9 - Temperature and X ray mapping taken at E_{acc} = 22 MeV/m

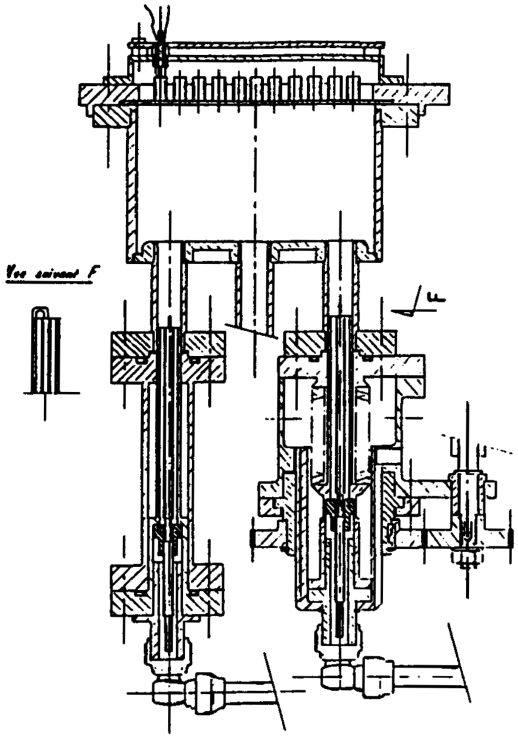


fig. 10 TE011 cavity

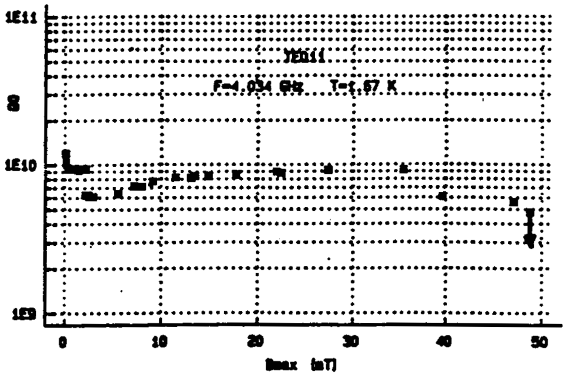


fig. 11 Q = f(B) for the TE011 mode

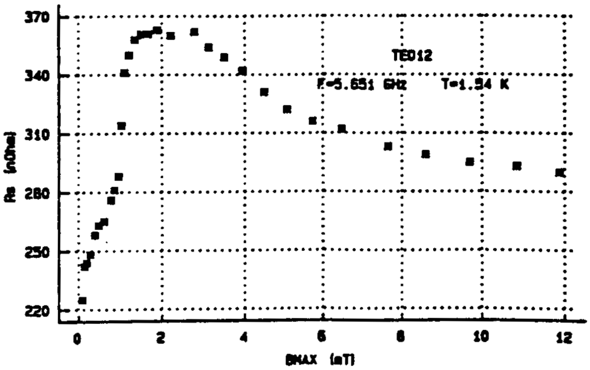


fig. 12 Rs dependance on low magnetic field (TE012)

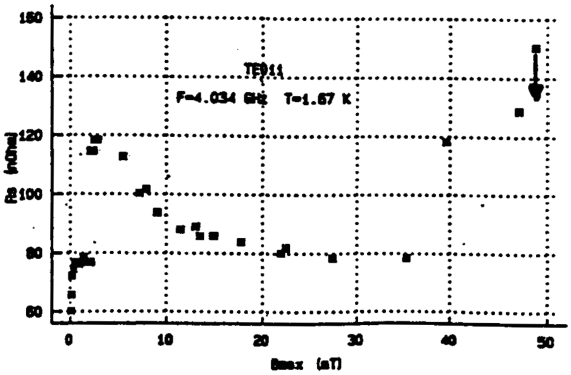


fig. 13 Rs dependance on magnetic field (TE011)

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