MECHANICAL DESIGN FEATURES OF THE UNILAC

T. Niewodniczanski and E. Malwitz
Gesellschaft für Schwerionenforschung mbH
Darmstadt, Germany

Summary

The paper reviews the design of the mechanical components of the UNILAC as well as some results of prototype tests and of different technological approaches. Preliminary results on copper plating of the test cavities with Q values higher than 95 % of their theoretical value are discussed. Some data about the tank electroplating plant are given. The paper presents the mechanical design of the Wideröe and Alvarez structure and the single-gap cavities. Some details are given on the tank design as well as on the different versions of drift tubes. A general description of the cooling water system is included.

Introduction

After many years of design studies, prototype work, experiments with models and different technology-tests, the mechanical design of the UNILAC has been completed. Nearly all main components of the machine are already ordered and the assembling of the first accelerator part - the Wideröe tank No 4 - will start early in 1973. This cavity will be tested as the first unit of the whole machine under rf power at the end of 1973. Parallel to this activity the other Wideröe tanks, both Alvarez cavities and the single-gap cavity groups will be preassembled in the injector hall and afterwards moved into the accelerator tunnel. It is planned to finish the mechanical assembling of the whole UNILAC in mid of 1974.

Although the machine consists of many physically and mechanically different accelerating structures, its concept reflects the same design principles. This philosophy is based on the standardization of the sub-components (e.g. 112 Alvarez drift tubes are equipped with only 5 different quadrupole types) and the possibility of preassembling the individual cavity sections and the successive bolting together the vacuum checked and roughly aligned units into the final tanks. Furthermore, all the accelerating structures are made up from copper plated mild steel.

Throughout the machine gold-wire gaskets and Con Flat flanges are used as high vacuum seals and rf contacts. The application of gold wire as the main rf and vacuum seal between the tank sections, end walls and drift tube supports was possible due to the relative hard surface of the copper layer plated on the inner and front side of the tank sections.

The joining of the tank sections by gold wire gaskets enabled the reduction of the number of welding seams exposed to high vacuum to only one alongside the cavity. Although pretty good results have been obtained with vacuum tightness of the gold wire joints during many years of exploitation (5,6), the gold wire gaskets are backed up all over by soft vacuum volumes sealed off to the atmospheric pressure by elastomer seals. The end walls of the tanks in all three different accelerating structures consist of thin copper plated steel plates ("membranes") isolated from the atmospheric pressure by a soft vacuum backing.

The design of the drift tubes for the Wideröe and Alvarez structures follows principles of series production, which provide not only cheap industrial fabrication but also fast rebuilding of damaged units from a small variety of spare components.

Copper Plating Technology

As it was already described before (2,3,4), from the early beginning of the UNILAC project studies it was aimed to base the cavity design on the principle of electrolytically produced cavities. Initially the electroforming technique was envisaged and two single-gap cavities have been built for prototype evaluation. The results obtained (2) showed that although the physical properties of these cavities were excellent, the high cost of production, especially in the case of the 2 m diameter Alvarez tank sections, excluded this method.

Experience gained from an electrolytic processing program led to the decision of starting studies of different methods and approaches of copper plating technology. Although a much thinner copper deposit would be adequate for optimum rf conductivity (3) a copper thickness of 0.2 mm was chosen as a mechanically sound value.

The particular treatment was selected after a few years of studies using different bath types, and the products of several companies have been tested; e.g., for the main acid copper bath the performance of seven different organic brightening agents have been studied. Also different methods of electrolytic degreasing as well as different copper or nickel strike treatments have been evaluated.

For comparing different electroplating solutions small sample cavities of a diameter of 30 cm, with a resonant frequency of 767 MHz, as well as different flanges and plates have been copper plated. The prototypes were checked on their mechanical properties as: adhesion strength of the copper layer to the steel, outgasing characteristics, roughness of the copper surface, and on their electrical properties as: dc conductivity of the copper layer as well as Q-value of the sample cavities.

With the plating process described below it was possible to obtain copper plated sample cavities with following reproducible properties:

a) bright surface of the 0.2 mm thick copper deposit;

b) satisfactory sticking of the copper layer to the steel base;

c) outgasing rate of $1 - 3 \cdot 10^{-11}$ Torr·l·sec^{-1} cm^{-2};

d) smoothing coefficient (steel surface roughness to copper surface roughness ratio) ≈ 10;

e) good scattering of the copper deposit into holes and on the outer side of the cylinder as well as relatively small excessive deposits on the edges of the cylinder.

f) dc conductivity of the copper layer of 96 % IACS

g) Q-values of the sample cavities of about 96% of their theoretical value calculated for a dc conductivity of copper equal to 100 % IACS = $58 \cdot 10^{-7}$ mhos · m^{-1}.

Besides small cavities and samples also full scale components of UNILAC like a Wideröe stub line prototype (fig. 3) have been satisfactory copper plated.

The following copper plating treatment was chosen for fabrication of UNILAC components:

	Container No	Process	Solution
a)	-	degreasing with water vapor beam 10 kp/cm, 180° C	
b)	1	Electrolytic degreasing and rust removing	NaOH: 30 g/l Na_2CO_3: 40 g/l 5-10 A/dcm^2 50 - 60° C time: 4 min with polarity reversion
c)	2	water rinsing	
d)	3	sulfuric acid bath	5% H_2SO_4 or 10% HBF_4 20° C, 30 sec
e)	4	water rinsing	
f)	5	nickel strike	H_3BO_3 40 g/l $NiCl_2$ 90 g/l $NiSO_4$ 270 g/l Ni ion 80 g/l Cl ion 27 g/l main brightening agent 1 1/10000 Ah detergent agent 0,5 1/10000 Ah 50° C; pH=4; 10 min ; 3 A/dm^2
g)	4	water rinsing	
h)	3	acid bath	as d)
i)	4	water rinsing	
k)	6	acid copper bath (Cupatier-bath "80 L") x)	$CuSO_4 \cdot 5(H_2O)$ 220 g/l H_2SO_4 55 g/l Cu ion 60 g/l Cl ion 60 mg/l brightening agent "Cu 407" 1.5 1/10000 Ah smoothing agent "Cu 607" 1.5 1/10000 Ah detergent agent "807" 0.8 1/10000 Ah 25°C; 5-7 A/dm^2 air agitation 200 m^3/h cylinder rotation 7-36 rpm bath cooling 60000 kcal/h bath circulation 5000 l/h
l)	4	water rinsing	
m)	1	electrolytic degreasing	as b) without current time: 1 min
n)	2	water rinsing	
o)	-	hot water rinsing	

x) trade name of the supplier

For the plating of the UNILAC components (the biggest Alvarez tank sections are 2 m in diameter and are 2.6 m long) a special electroplating plant is being installed (fig. 4). The hall for this purpose has a floor area of 620 m^2 and has a 420 m^3 pit, a 12 V/10 kA rectifier and 7 containers with the volume of 18 m^3 each.

Mechanical Design of UNILAC

The accelerating structure of UNILAC consists of three main components: 4 Wideröe tanks, 2 Alvarez resonators and two groups of 10 single-gap cavities each (1).

In the case of Wideröe the coaxial-line structure with magnetic focussing in "outer" drift tubes, which are supported by the tank wall, was chosen (fig. 2). Contrary to the twin line structure, this solution makes the adjusting and the supply of DC current and cooling water to the drift tubes and quadrupoles simpler. The inner drift tubes without quadrupoles are screwed on the sections of inner conductor main line. The rf power coupling loops with domes as well the slug tuners are placed always in the last stub line of each Wideröe tank. For coarse tuning of the field pattern one can use shorting plates of the stub lines (fig. 5).All components of the Wideröe cavities, especially inner conductor main line, inner drift tubes and stub line shorting plates are cooled separately in order to control the thermal expansion.

In the case of the Alvarez structure each drift tube is supported by two adjustable stems. The two-stem design was chosen, after several experiments with prototypes, in order to minimize transverse mechanical vibrations. The rf end walls ("membranes") are similar to those used in the single-gap cavities. They are backed with soft vacuum and clamped on the cast iron spiders (fig. 6, 15). The rf drive-loops are isolated from the high vacuum by ceramic domes covered with a semiconductor layer. Besides the fine tuning with slug tuners, a solid bar is being used for the rough adjusting of the field distribution inside Alvarez cavities (10).

The design principles of single-gap cavities are nearly identical to those of the Alvarez structure (5, 6). The coarse tuning is provided by changing the gap length. In contrast to the half drift tube bodies, the quadrupoles inside can be adjusted transversally to the beam axis from the outside of the cavities (fig. 7).

Tanks

All tank sections are manufactured from mild steel being copper plated afterwards. The thickness of the tank walls (22 - 32 mm) makes it possible to machine Con Flat-flanges directly on the wall material. Contrary to other structures, the Alvarez tanks are machined conically (2.4 mm/m). The inner surface of both Alvarez and single gap-cavity tank sections have to meet tolerances ± 0.5 mm and a surface roughness less than 16 µm before the plating treatment. In the case of Wideröe structure, due to the relatively small loss of rf power on the cavity walls, the inner surfaces of the tanks are only ground. The cooling of the tank walls throughout the accelerator is provided by water jackets (3 - 5 mm thick).

Drift tubes

Drift tubes for the different accelerating structures are based on common design principles. Their fabrication technology as electron beam welding, vacuum brazing, copper plating of the stainless steel and monel, heli-arc welding etc, which was finally chosen after many experiments with prototypes, can be seen from the figures 9 - 14. OFHC is chosen all over. The mechanically stressed parts, like stems and flanges, are made mainly from copper plated monel.

The quadrupoles are positioned in the drift tube bodies by a tight fit of the yoke inner diameter to a shoulder cut into the drift tube caps. The material for the first eight quadrupoles of the Wideröe structure has a 20 kG/10 Oe quality in order to obtain field gradients up to 10.5 kG/cm. The iron for other quadrupoles has the quality 16 kG/30 Oe. Quadrupole apertures increase along the accelerator as follows: Wideröe tank 1 20-30 mm, tank 2 - 4 and Alvarez tank 1 30 mm, Alvarez tank 2 35 mm, and single-gap cavities 45 mm (4).

There is soft vacuum inside the stems and drift tubes. Flexible bellows on stems lie in the case of Alvarez structure outside the tank periphery (9). In Wideröe tanks they are inside the periphery and are water cooled.

The caps of the half drift tubes of the single-gap cavities have been made of pure aluminium explosion clad on copper. As the experiments with prototypes showed (7, 8), this material guarantees lower spark rate and x-ray level and shows better performance during conditioning and less tendency to surface contaminations as well.

Cooling system

The UNILAC cooling system is divided, on the primary side, into four different circuits according to the cooling medium quality (fig. 16).

For the cooling of the cavities and the copper drift tubes treated water will be used. To prevent corrosion, water quality will be adjusted to following specification:

pH value	9 - 10
electrical conductivity	< 100 µS/cm
hydrazin	25 - 30 ppm
ammonia	< 10 ppm
iron	< 1 ppm
copper	< 0.1 ppm
oxygen	< 0.02 ppm

The cooling system of magnets, which consists of stainless steel and copper, will have water of electrical conductivity lower than 20 µS/cm. For cooling of rf generators, where the cooling fluid must be fed by a short insulating path to high potential components water conductivity must be lower than 1 µS/cm.

The cavity water system provides cooling and close temperature control for cavity walls and drift tubes. Due to the different rf power losses in the structure during different operating modes (different accelerated ions, accelerating field levels and duty cycles) each cavity has to be cooled by an independent primary circuit.

Temperature of the inlet water in the cooling circuits is controlled to provide a constant mean temperature of 26 ± 1° C for the tank walls for different rf power levels.

The magnet and rf generator cooling circuits will have a central water processing plant and local ion exchangers.

All systems are equipped with plate heat exchangers only. The cooling water in the secondary system is protected against any interaction with oxygen.

Normally an open cooling tower plant will remove the heat load from the secondary circuit. However for full power operation modes of the accelerator, supplementary town water may be required on a few summer days.

Acknowledgments

The authors would like to express their appreciation to the engineering staff of the UNILAC-Project - to every colleague, who has contributed in designing, building and testing prototypes as well as preparing the production of the mechanical components for the UNILAC, and especially to pay tribute to Dr. Dieter Böhne, Project Leader, whose previous work is the basis for virtually all that is reported here.

We wish also to acknowledge the helpful advice, the generous exchange of engineering ideas and documents we got continuously in the past years from the BNL, CERN, LASL, LRL and NAL laboratories. We bear in mind that most of the technical solutions described here have been inspired by other members of the accelerator-builder community.

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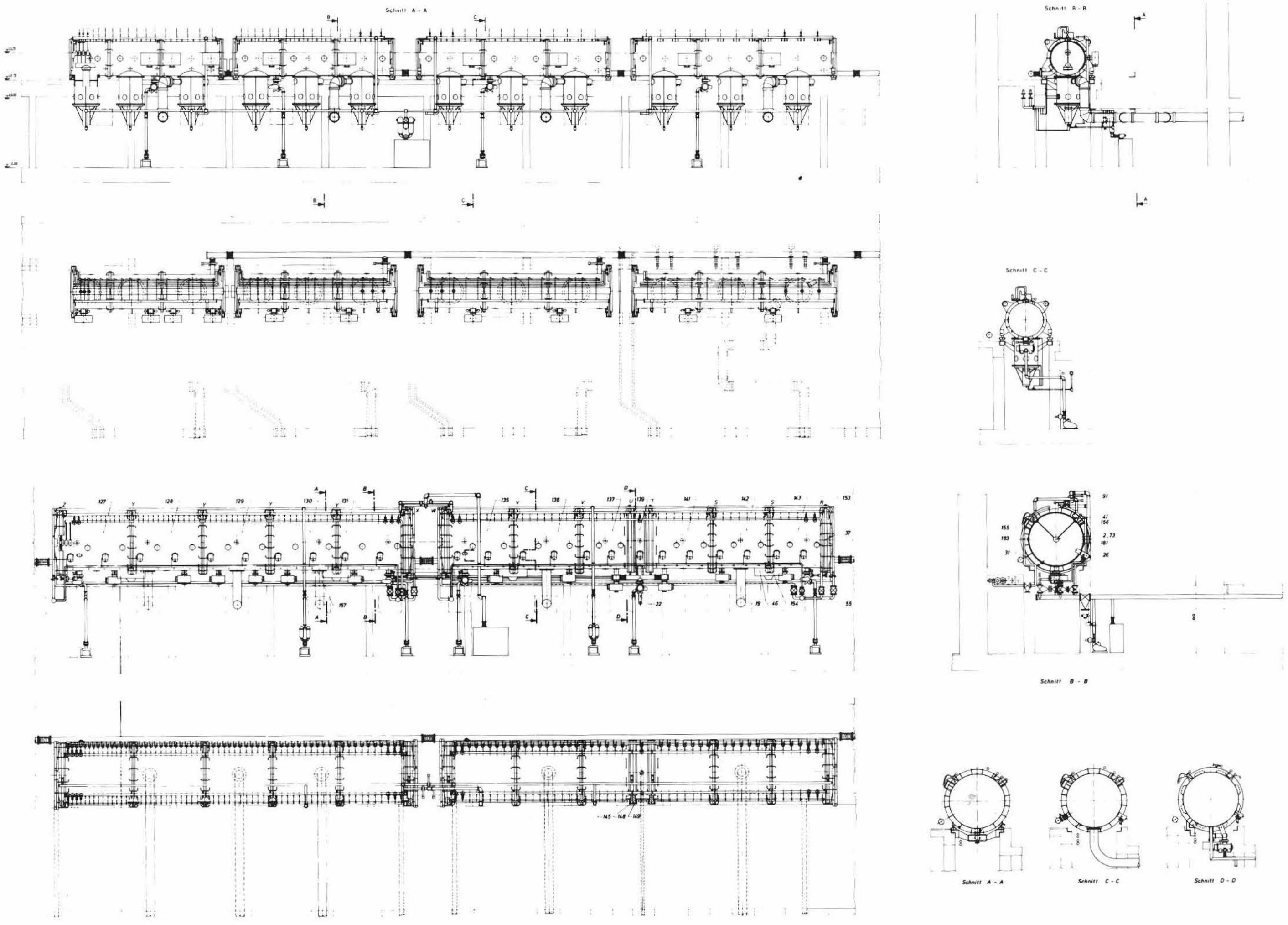
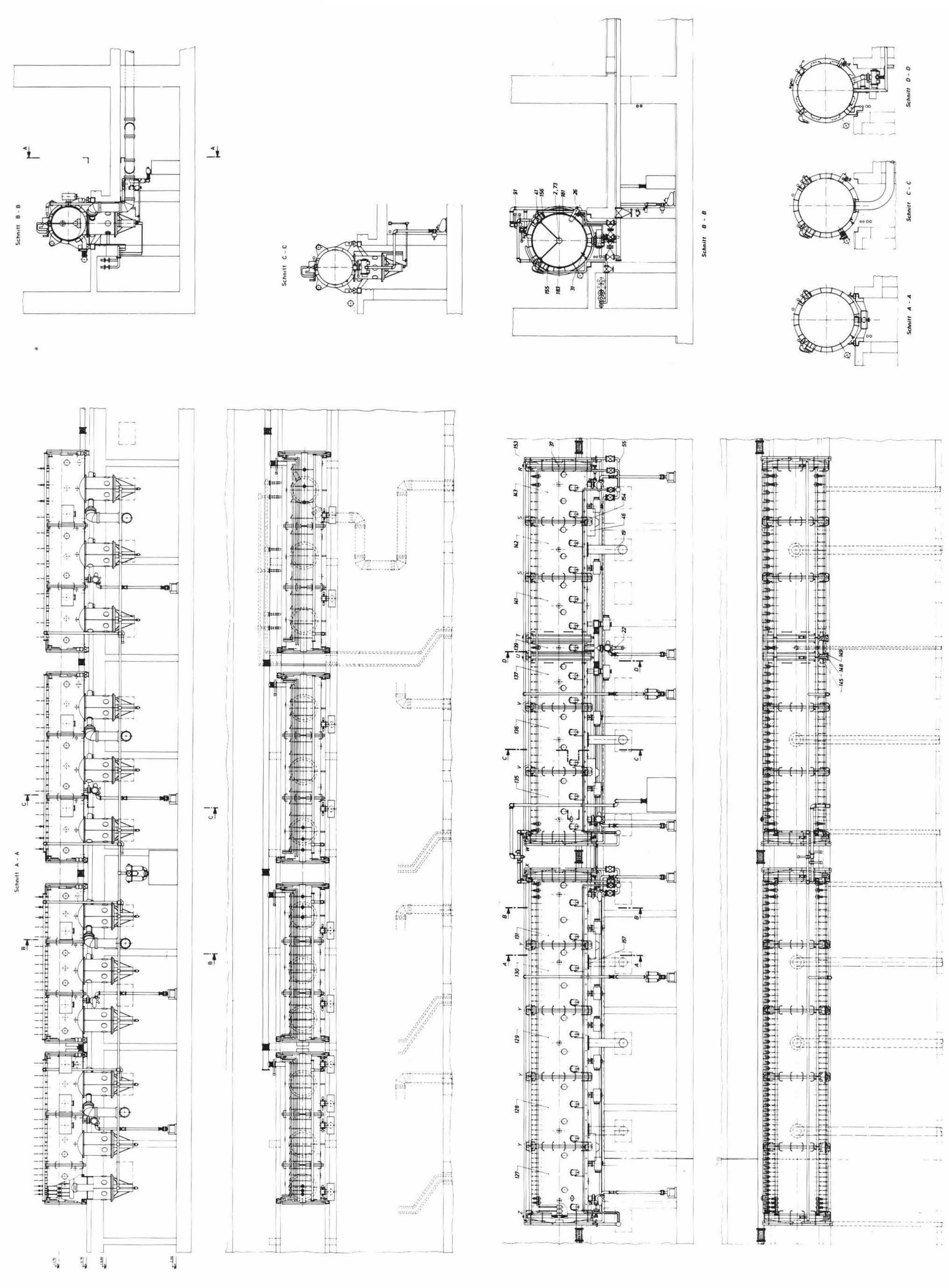


Fig. 1 General view of the Wideröe and Alvarez structures



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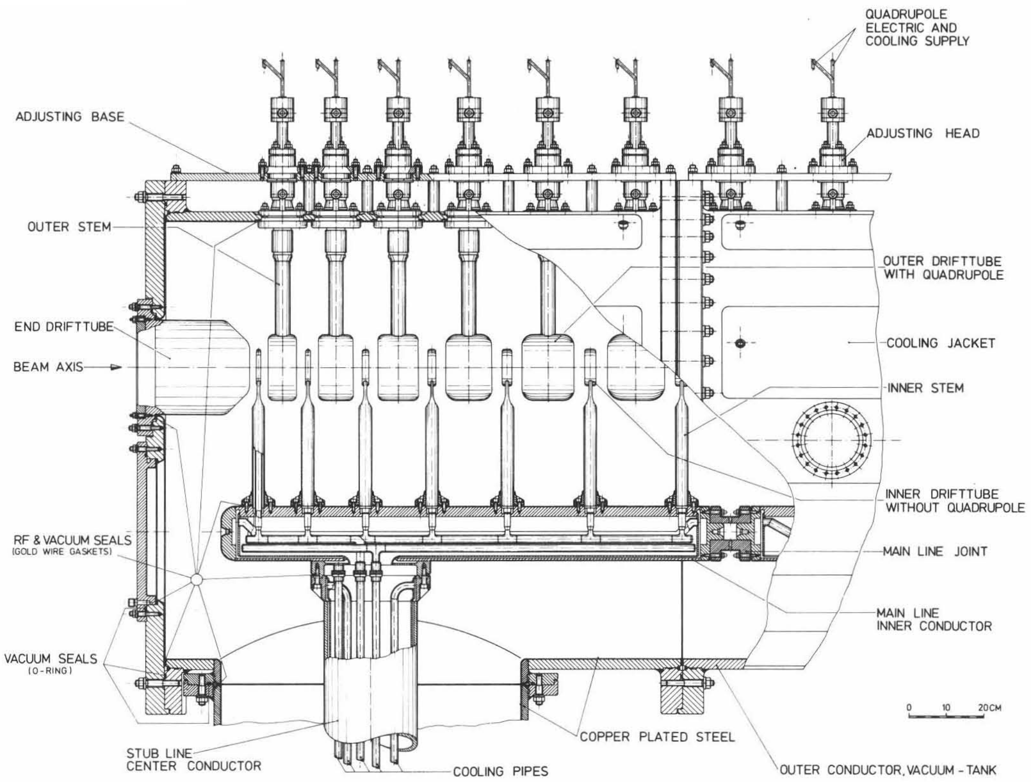

Fig. 2 Tank section of the first Wideröe tank

Fig. 3 Wideröe stub line prototype

Fig. 4 Inner view of electroplating plant during construction

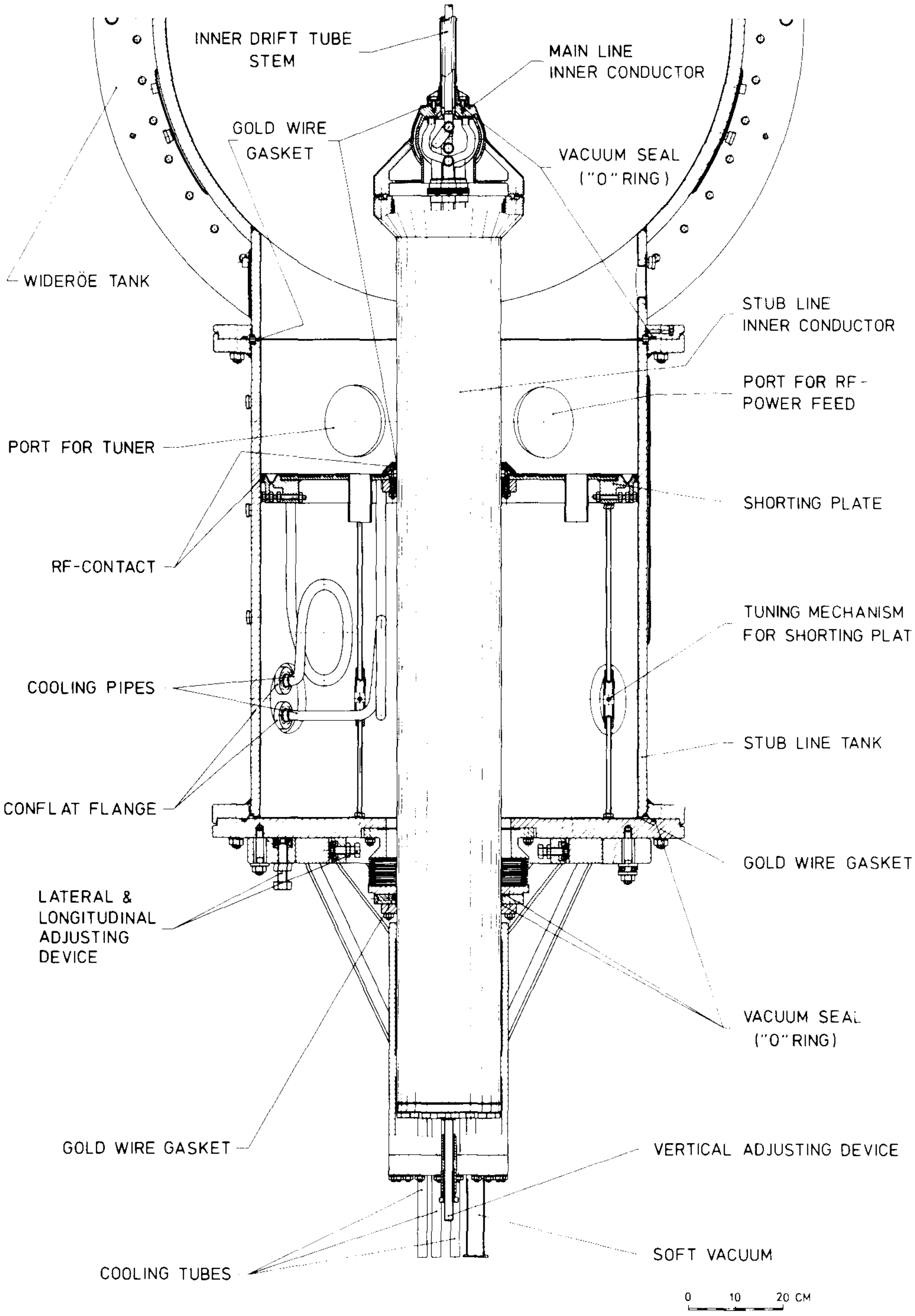

Fig. 5 Sectional view of the Wideröe stub line

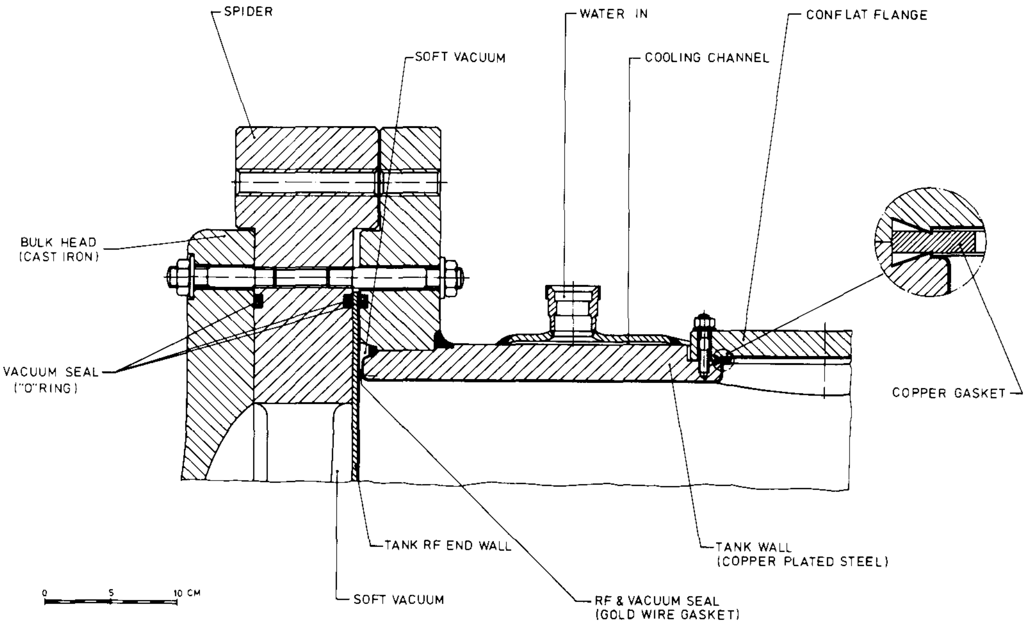

Fig. 6 Alvarez tank termination

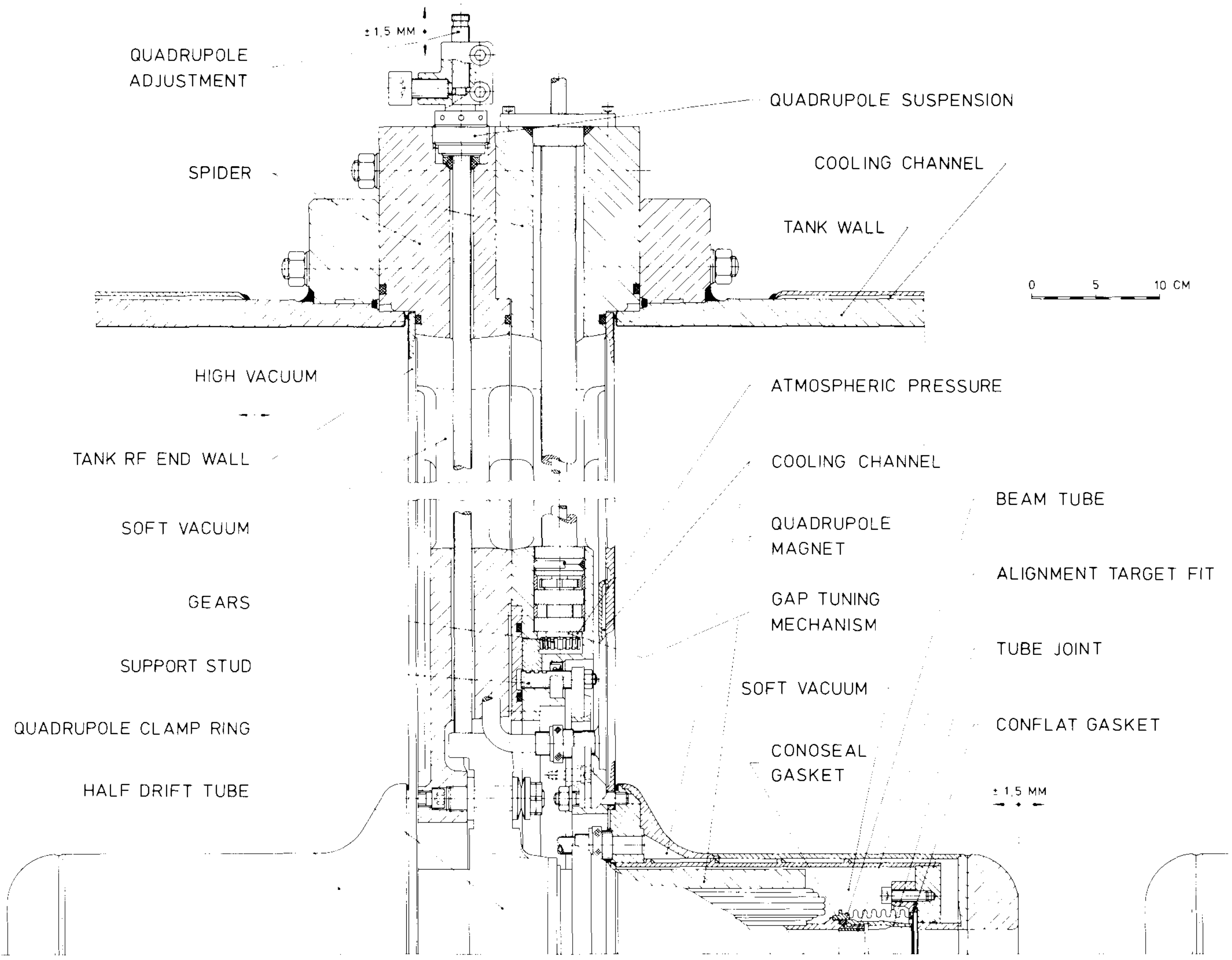

Fig. 7 Single- gap cavity intertank area

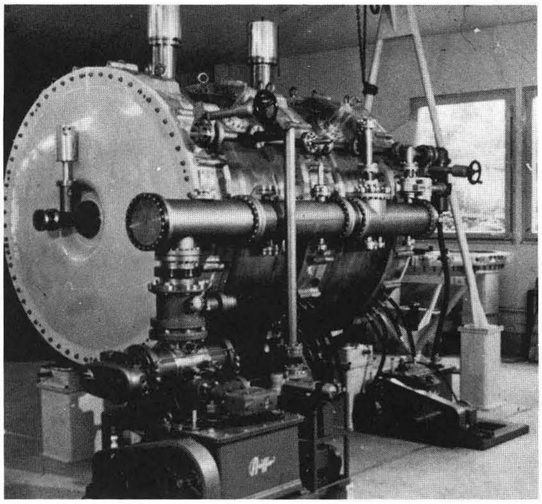

Fig. 8 Prototype of two single-gap cavities

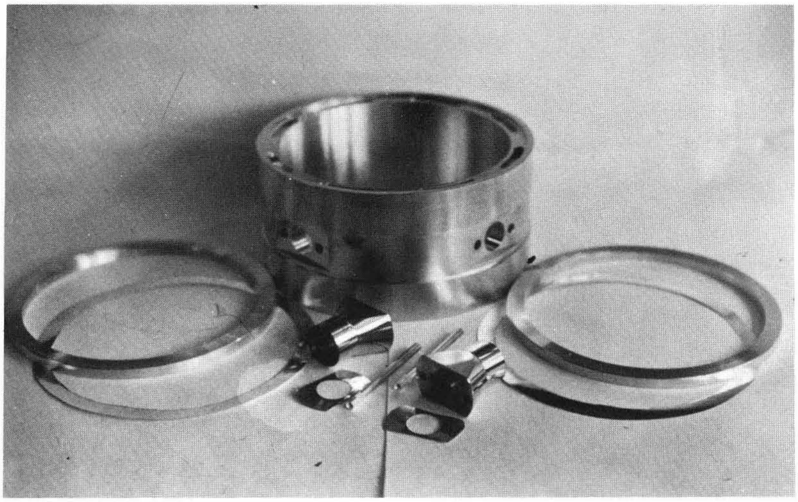

Fig. 9 Components of the Alvarez drift tube

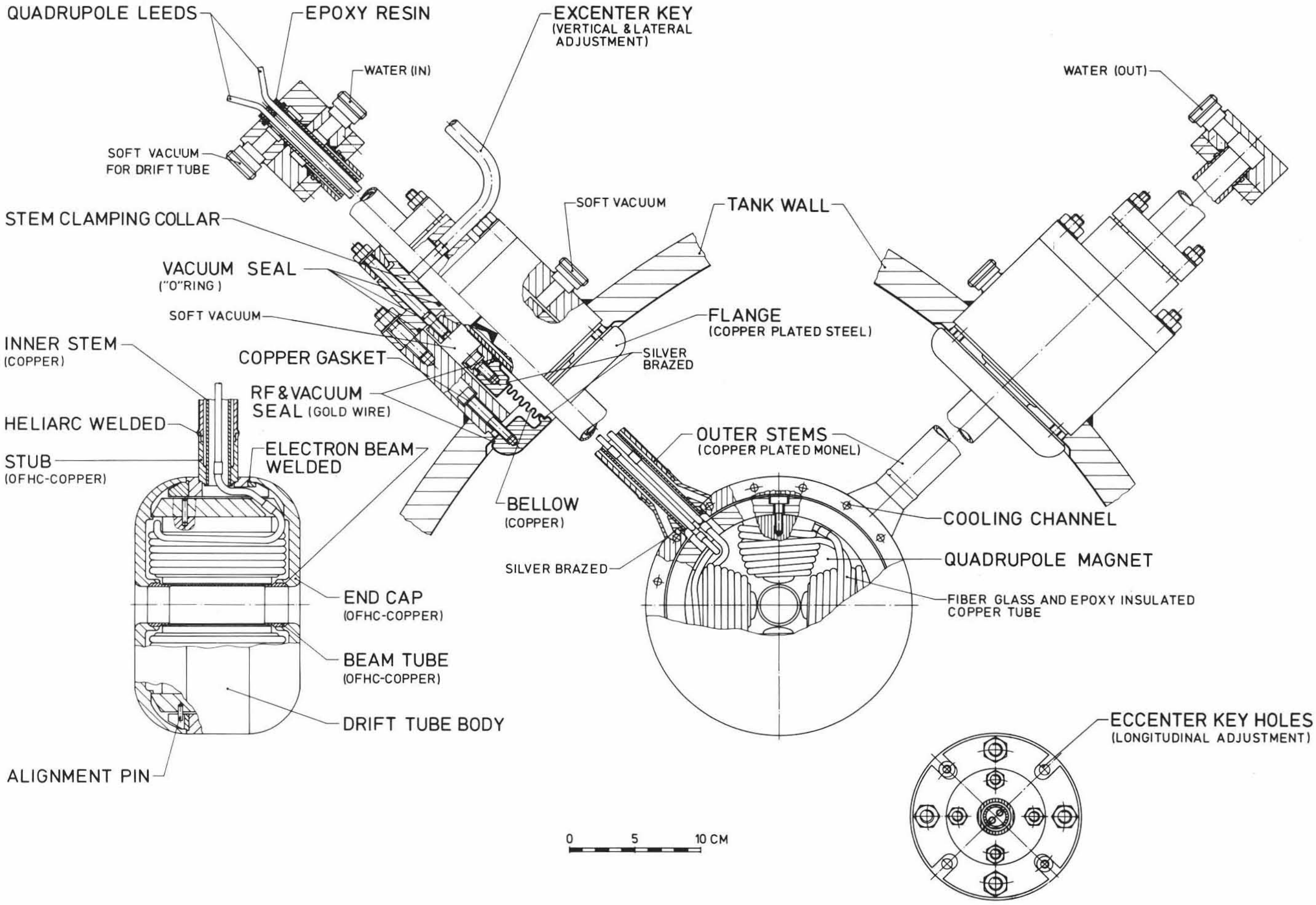

Fig. 10 Alvarez drift tube

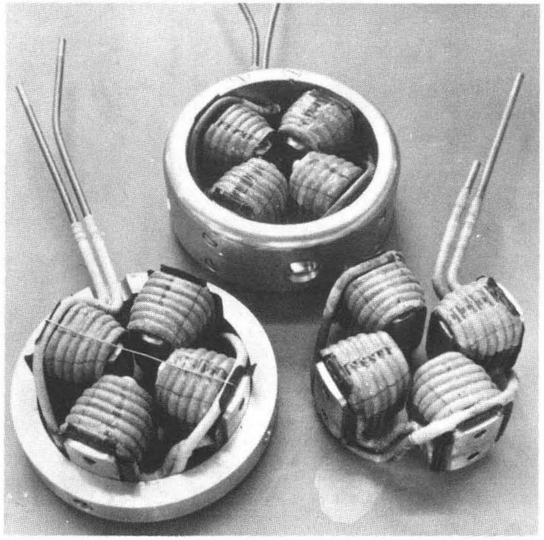

Fig. 11 Wideröe "outer" drift tube quadrupole prototype

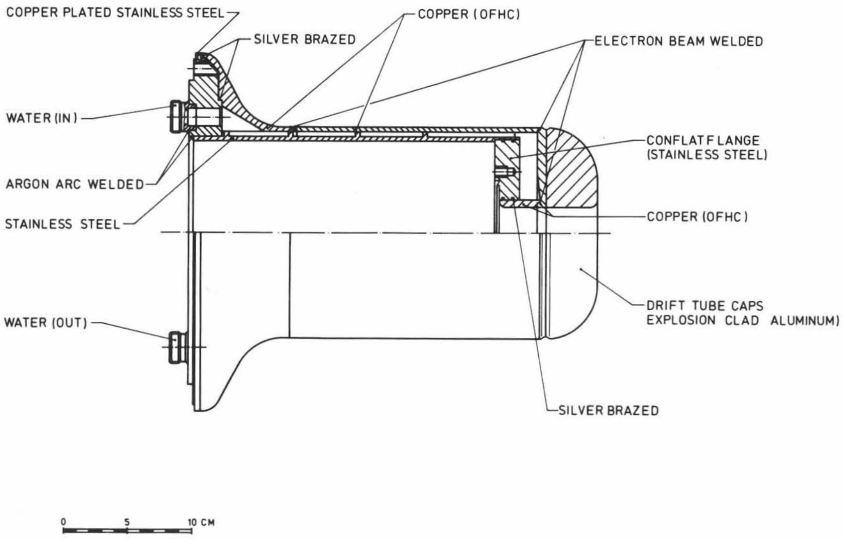

Fig. 13 Single-gap cavity half drift tube

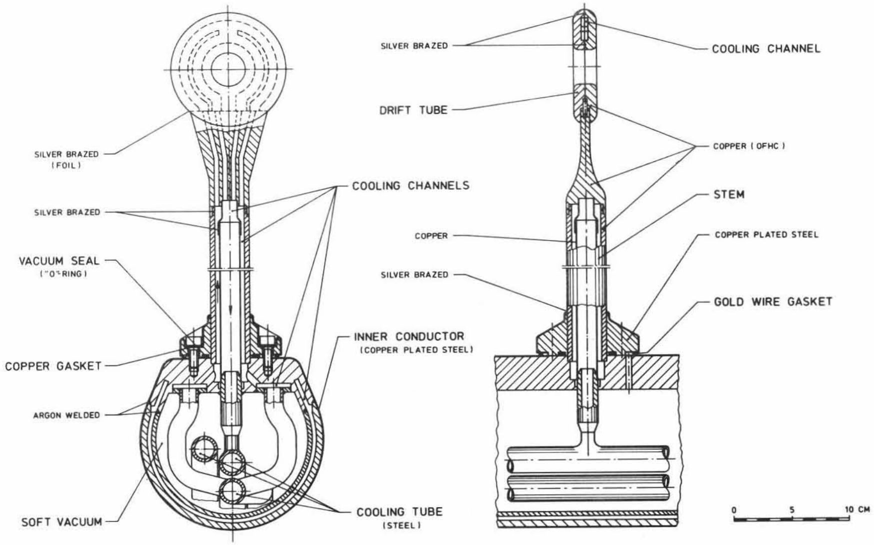

Fig. 12 Wideröe "inner" drift tube

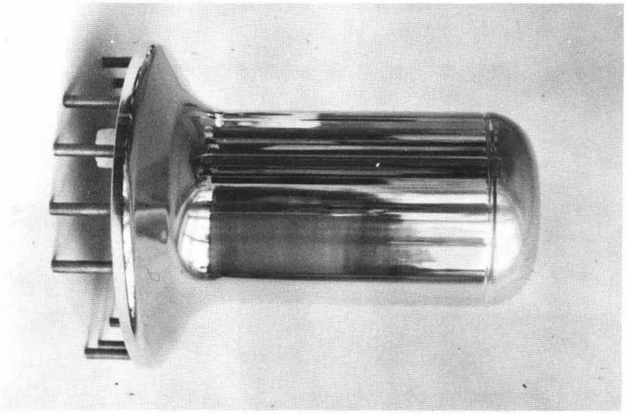

Fig. 14 Single-gap cavity half drift tube prototype

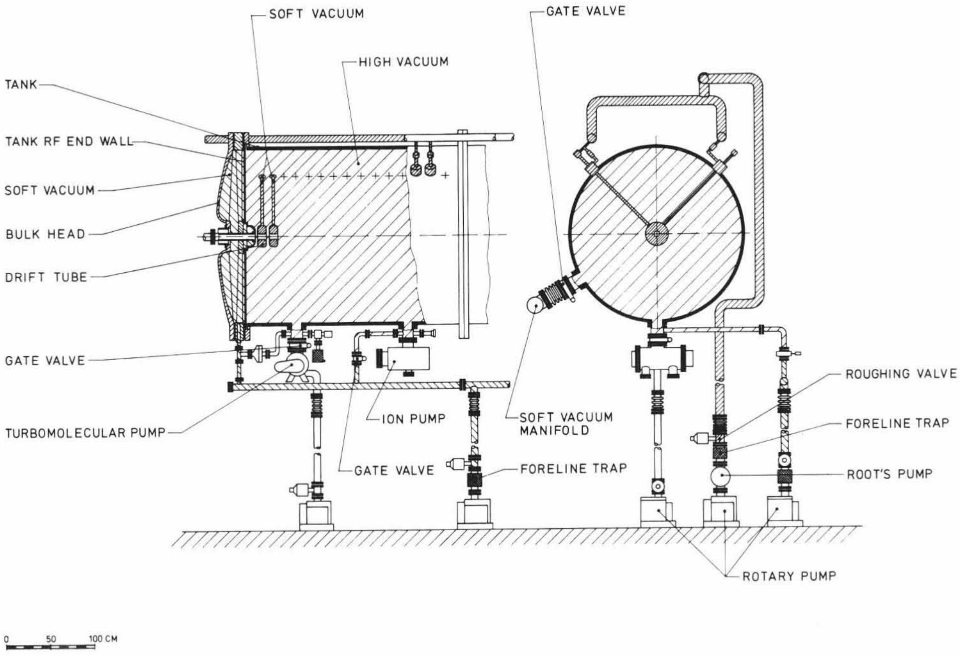

Fig. 15 Vacuum system of the Alvarez tank

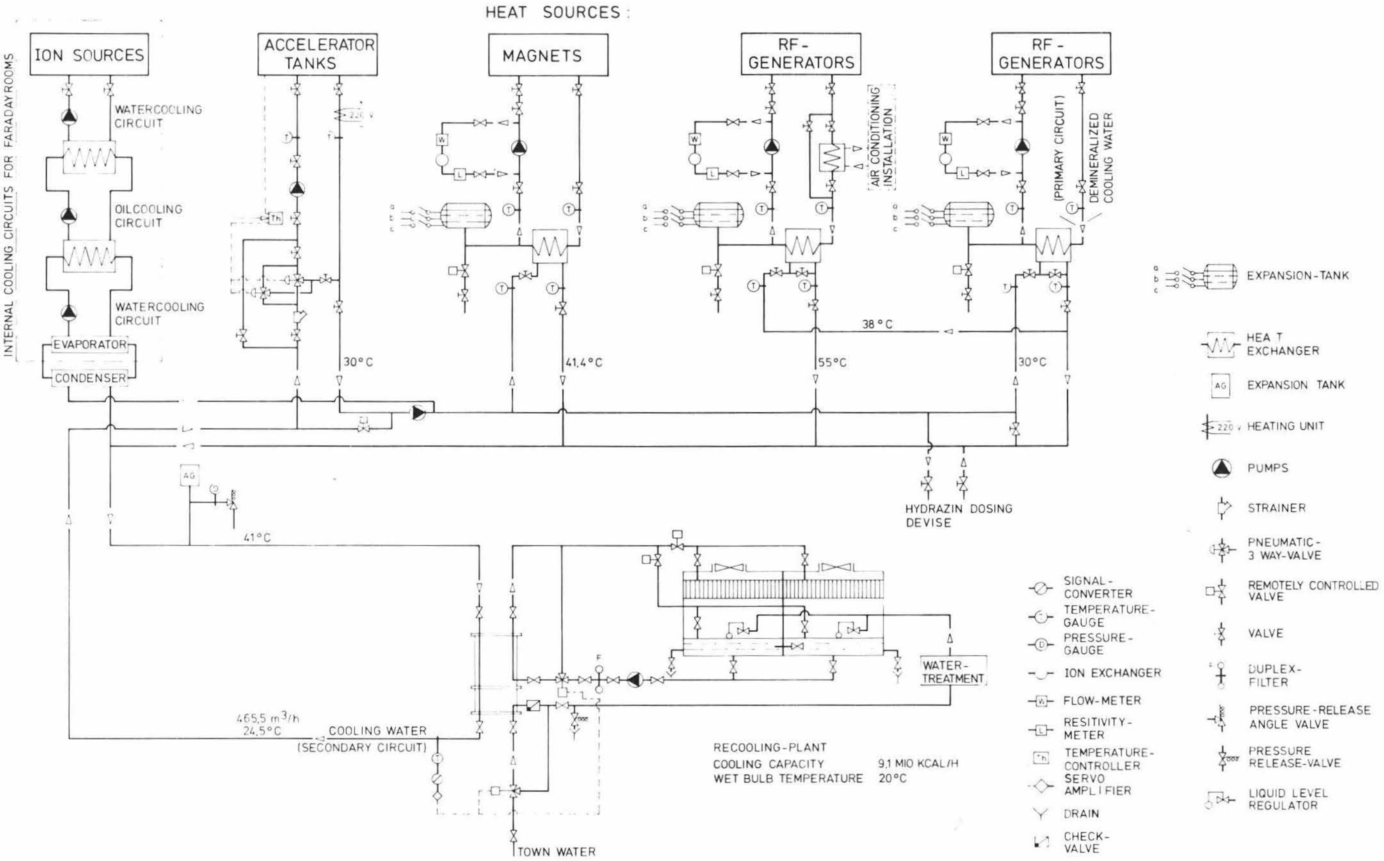

Fig. 16 Schematic of the UNILAC cooling system