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Author
Paterson, J.A.

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Lawrence Berkeley Laboratory
UNIVERSITY OF CALIFORNIA

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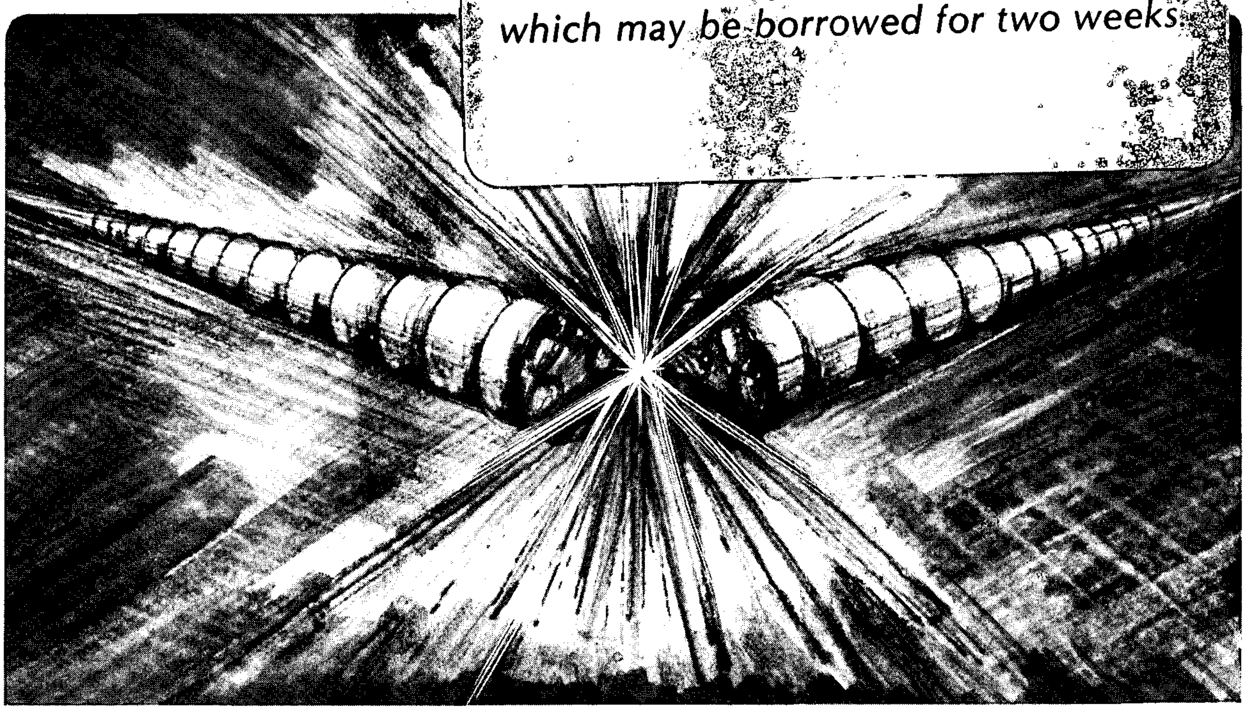

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DISCLAIMER

THE MECHANICAL BASELINE DESIGN OF THE COMMON LONG PULSE SOURCE FOR THE NEUTRAL BEAM SYSTEMS OF TFTR, DOUBLET III-D, AND MFTF-B*

J.A. Paterson, C.F. Chan, M.Y. Fong, G.W. Koehler, J.S. Sullivan,** R.P. Wells and D.P. Yee
Lawrence Berkeley Laboratory
University of California
Berkeley, CA 94720 USA

Abstract

The Common Long Pulse Source (CLPS) is designed to meet the differing long pulse neutral beam requirements of TFTR, Doublet III-D, and MFTF-B. The mechanical baseline design to meet these requirements is described along with supporting engineering data collected during the testing of the prototype LBL 10 x 40 Long Pulse Accelerator (LPA) and the Long Pulse Plasma Source (LPS). The CLPS is a scaled up design of the LPA and LPS and can be configured for 120 keV, 70 A D_2 non-focused, and, 80 keV, 80 A H_2 or 50 A D_2 with a 10 m focal length. The two configurations use identical major components, such as accelerator grids, supporting structures, insulators and plasma sources. The accelerated ion beam may be focused by canting the outer accelerator grid modules at an angle to the beam centerline. The optics of the intermodule beamlets which are produced as a consequence of this approach have been predicted analytically and the results are here presented along with the electrical field gradients and thermal calculations for the various components. A low technology plasma source back plate electron dump design has been adopted and the data collected during 10 x 40 LPA-LPS testing using a similar design are given and compared to engineering analysis of the new design. To aid in the establishment of the technical baseline, to assure the conformance to the restrictive space envelope for the source and associated hardware, and to define the user interfaces, a full-scale model of the CLPS was constructed. This model was assembled complete with all source mounted hardware which included water manifolding and plumbing. The baseline design has now been transferred to industry where the industrial version is now being manufactured by the New Products Division of RCA.

Introduction

At the direction of the Office of Fusion Energy and under the management of the Lawrence Livermore National Laboratory (LLNL), the Lawrence Berkeley Laboratory (LBL) initiated a study to determine if a neutral beam source of a common design could be engineered to meet the differing needs of the major United States confinement experiments, namely TFTR, Doublet III-D and MFTF-B. As a starting point for this effort, there existed a LBL designed, fabricated and tested water cooled long pulse accelerator and plasma source, the 10 x 40 LPA and 10 x 40 LPS. The extraction area of this source was 10 cm x 40 cm; to meet the user needs, it was required that this be scaled up to 12 cm x 48 cm and that provision be made for the option of focusing. The design challenge was to meet the various and differing user needs with a common set of hardware. A significant constraint on the design was that no individual user need require a design detail that would increase the final cost of the assembly to the other users and thereby remove the cost benefits of commonality. The original 10 x 40 LPA design was developed to meet the specifications of the Advanced Positive Ion Source which included the constraint that no organic material be used. This specification resulted in a costly ceramic brazed assembly and the use of metal seals. No such requirement was imposed on the 12 x 48 CLPS and consequently, the opportunity of significant cost savings arose through design simplifications. Additional simplifications in the design of the 12 x 48 CLPS were also expected from an intensive value engineering effort and through the establishment of design data from the test program of the 10 x 40 LPA, in particular, the heat flux on the ion source back plate from back-streaming electrons. In April, 1984, a joint technical committee of LBL and the users was set up to establish a technical baseline design. Of particular concern at the outset was the extremely restrictive space envelope available for the source and associated hardware on the TFTR neutral beamlines and the pressurized SF_6 environment. The technical difficulties arising from these factors were resolved, and in May, 1984, the concept of a common design was deemed feasible. Final conceptual design approval for the LBL technical baseline design was granted in June, and a contract award made in August to RCA Corporation. Since the contract award, LBL has carried the prime technical responsibility for the 12 x 48 CLPS and the transfer of technology to industry.

User Requirements - Performance Goals

Table 1 lists the user requirements and performance goals of the 12 x 48 CLPS. This list was used to scale up the 10 x 40 LPA and 10 x 40 LPS to define the technical baseline design for the CLPS shown in section in Figure 1. The mechanical design of this assembly was driven by the premise that the scale up to 12 cm x 48 cm was a reasonable extrapolation from the previously successful LBL long pulse source designs.[1]

Accelerator Grid Design

The mechanical grid design concept adopted for the technical baseline design was the same as that used in the prior LBL long pulse accelerator designs, the details of which and the fabrication techniques used are reported elsewhere.[1,2] The need for increased extraction area was achieved by increasing the grid rail active lengths by 2 cm to 12 cm and by increasing the total number of grid rails. It was our engineering judgement that the increased rail lengths were still within the range available from manufacturers and that the grid deflections during beam operation would still be within those permitted to retain the optical quality of the accelerated beam. To check the latter assumption, a detailed thermal-structural analysis of the new grid design was carried out, the results of which are reported elsewhere.[3] The input to this analysis comprised the physical dimensions of the grid structures shown in Figure 1, and the extrapolated grid heat load data accumulated during performance testing of the 10 x 40 LPA,[4] a summary of which is presented in Table 2.

Table 2 lists the anticipated maximum grid heat loads during normal beam operation at optimum per-

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**Lawrence Livermore National Laboratory, University of California, Livermore, CA 94550

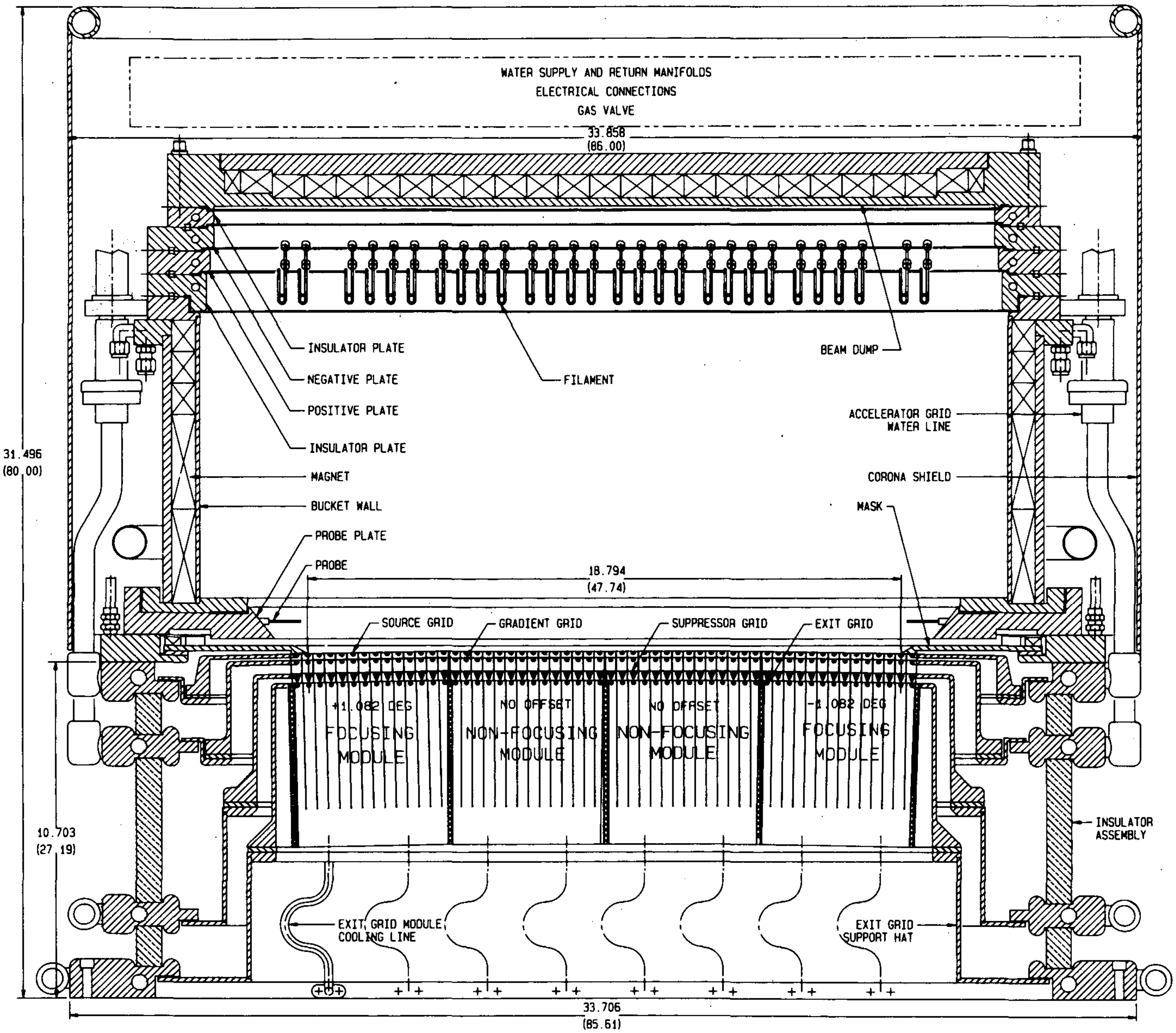

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Figure 1a 12 x 48 cm Common Long Pulse Source Side Elevation

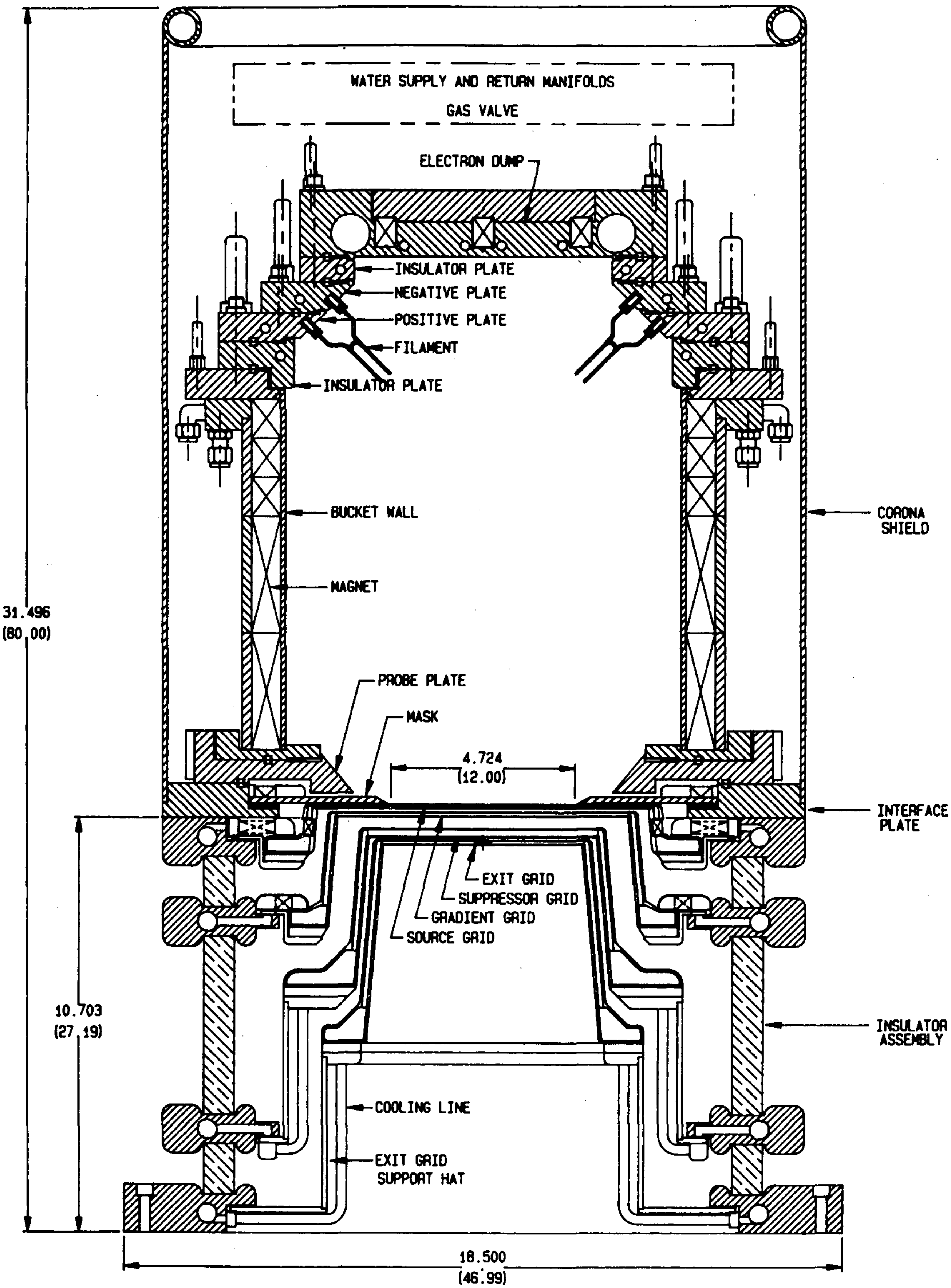

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Figure 1b 12 x 48 cm Common Long Pulse Source End Elevation

Table 3 Common Long Pulse Accelerator Field Gradients

Accelerator	Maximum Field Gradient (kV/cm)			
	Between Grid Rails		Between Grid Structures	
	1 - 2	2 - 3	1 - 2	2 - 3
10 cm x 10 cm LPA	67	126	65	125
10 cm x 40 cm LPA	89	130	83	115
12 cm x 48 cm CLPA	89	130	89	119

Grid Focusing

To minimize costs whilst retaining hardware commonality, the design offers the option of grid focusing through the facility to cant the outer grid modules at an angle to the beam centerline, 1.08° for a 10 m focus. This configuration is realized by the insertion of tapered shims which can be exchanged for parallel shims for non-focused beam operations. In the focused configuration, ions are accelerated in the inter-grid module slots between the outer canted modules and the center modules which are normal to the beam centerline. The optics of the two beamlets emerging from these slots were anticipated to differ from those from the other 51 slots and were consequently studied analytically to justify the adoption of the focusing technique. The results of this analytical study predicted acceptable performance and in fact indicated a slight reduction in beamlet divergence could be expected. Figure 2 shows the output from the WOLF[5] code run, showing a half-section through a beamlet in the intermodule slot and giving a beamlet divergence angle of 1.12°; this value may be compared to the 1.16° obtained for the other beamlets. This calculation was performed for a 4.8 m focus which is considerably less than any present requirement for the confinement experiments.

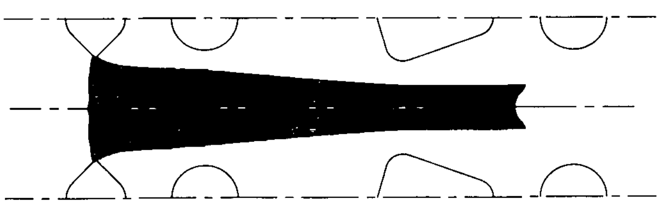

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Figure 2 WOLF Code Output for Intermodule Beamlet in Focused Configuration.

An important requirement of the focusing design was that the exit grid of the accelerator should be sealed off from backstreaming particles from the downstream plasma. The only open area permitted is in the active region of the grids. The design solution adopted to meet this requirement was to provide an overlapping tab on one edge of each exit grid module and a matching relief on the other edge. With this detail, the intermodule gaps are effectively sealed off for all grid configurations. This detail is provided on the exit grid only; all other grids will have openings at the intermodule locations. Openings in these latter areas have been present in previous LBL accelerator designs and have not resulted in adverse accelerator performance. As this is a new detail, however, the turn-on characteristics of the CLPS may differ from previous designs; this could result from the differing trajectories of ions as they are swept from the inter-grid volumes when the accelerator voltage is applied.

Accelerator Insulator

The accelerator insulator assembly forms the vacuum wall and is the basic mounting structure for supporting the water cooled grid assemblies. In addition, the insulator electrodes contain water passages that are used to distribute cooling water to the grid modules. The 10 x 40 LPA insulator is a weldment of titanium electrodes to brazed titanium to ceramic sub-assemblies, the details of which have been described previously.[6] This expensive assembly resulted from the APIS specification of bakeability and hard seals. No such requirements were imposed on the CLPS; thus, a cheaper design was deemed feasible. A trade study was conducted to evaluate the use of alternate materials and fabrication techniques with the selected design as shown in Figure 1. The technical baseline design shown uses Epon 826 epoxy bonded to stainless steel to form the assembly. These materials were chosen for economy and reduced technical risk over alternate materials. A significant simplification over the prior design is that the water passages are gun-drilled into the stainless electrodes and the electrode between the gradient and suppressor grids has been eliminated. The gun-drilling technique permitted the retention of end feeds for the cooling water, a facility required by TFTR due to space constraints. Since the establishment of this conceptual baseline design, RCA Corporation have expended considerable effort defining an optimal epoxy formulation and performing structural analysis and bond strength testing. The primary concern was the creep strength of the epoxy under slightly elevated temperature conditions. Following this effort, ABOCASI 50-3 and ABOCURE-17 were selected for the insulator material and HYSOL EA 9309 as the adhesive. The latter is the adhesive that was originally selected and used by McDonnell Douglas Corporation for the TFTR 0.5 sec sources.

Plasma Source

The 12 x 48 CLPS is a scaled up version of the 10 x 40 LPS. The design, fabrication and performance of which are described elsewhere.[4,7]

Filament Assembly

The filament assembly closely follows the general arrangement used for the 10 x 40 LPS; in particular, the filaments are in the same relative position to the back plate and side wall. Provision is made for insertion of up to fifty-six 1.52 mm diameter tungsten filaments along the 48 cm or long dimension of the source at positions where electrons backstreaming from the accelerator are thrown inwards toward the center of the chamber and away from the bucket wall. The gun-drilled copper filament plates that make up the assembly form a series of stepped surfaces which facilitate the mounting of the male multilam pin connectors for the filament and arc supply cables. The nesting of these plates on the vacuum side is such as to provide line-of-sight protection to the 0.03 cm thick mylar gaskets that insulate each plate from its neighbors. Vacuum is preserved using back-to-back O-ring grooves and each insulator is given an increased surface creep path for breakdown by providing matching reliefs in the surfaces of the plates. All plasma exposed surfaces of the assembly that are at cathode potential, and those of the insulator plates that float, are dull nickle plated to reduce the incidence of arc spotting, thereby reducing source conditioning time and improving reliability. Dull nickle was specified to preclude the incorporation of organic brighteners.

Bucket Wall Assembly

The arc chamber wall is formed by the bucket wall assembly which is an actively cooled all copper brazement. Samarium cobalt permanent magnets, with a pole tip field strength of 3500 G, are positioned around the bucket wall to form an axial line cusp arrangement as shown in Figure 3. As it is not possible to accurately predict the anode area available in this type of plasma source, the baseline design incorporates extra anode potential surface area on the plasma source mounting flange. This area may be adjusted by machining down the consequent protrusion into the source volume. Additional anode area may also be provided by shorting out the probe plate to the bucket wall, a scenario that may be adopted for hydrogen operation. The all copper assembly was selected for ease of manufacture and as TFTR will provide a pressurized SF_6 environment, a 3-dimensional finite element model of the assembly was deemed necessary to verify structural integrity. Highly localized stress concentrations were identified at the flange corners with peak stresses on the order of the yield strength of fully annealed copper. This result has required the dimensioning of the mating parts to be set so as to permit load sharing to the probe plate and to the filament assembly.

Electron Dump - Back Plate Anode

In the 10 x 40 LPS design, the source back plate, which serves as a dump for the backstreaming electrons from the accelerator, was a costly machined zirconium strengthened copper component. As a result of subsequent failure of this part during operation, it was decided to test a considerably simpler design concept. This opportunity arose due to the much reduced heat loads measured on this component and to a better understanding of the heat distribution. The new design used gun-drilled cooling passages close to the magnetic cusp lines, and performance tests on the 10 x 40 LPS using an instrumented plate of this concept verified the adequacy for application to the 12 x 48 CLPS. As shown in Figure 1, the concept was further refined by enlarging the outermost two cooling passages and using the resulting volume as a cooling water distribution manifold for the many source components. Peak heat fluxes on the 0.5 cm wide cusp lines were anticipated to be on the order of 1.4 kW/cm^2 during 120 kV, 70 A operation. These assumptions would lead to the temperature distribution in the back plate shown in Figure 4 for a 2 sec beam shot. The design limit of the peak temperature at the magnet is 150 °C, well above that predicted.

Subsequent to the specification of these design parameters, we have collected calorimetry data on the 10 x 40 LPA back plate. The extrapolation of this data to the 12 x 48 CLPS indicates cusp line fluxes of as high as 1.9 kW/cm^2 may be experienced depending on source gas flow. This power density can still be dissipated by the design through adjustments in the cooling water flow rates. The operating flow rates for the 12 x 48 CLPS will be established during first article accelerator testing at LBL.

Full Scale Model

As an aid to establishing the technical baseline, a full scale model of the CLPS was constructed complete with all source mounted hardware cooling water manifolding and associated plumbing. The completed model is shown in Figure 5. To assure that the final industralized units would meet the available space envelope, the proposed bulky quick disconnect double

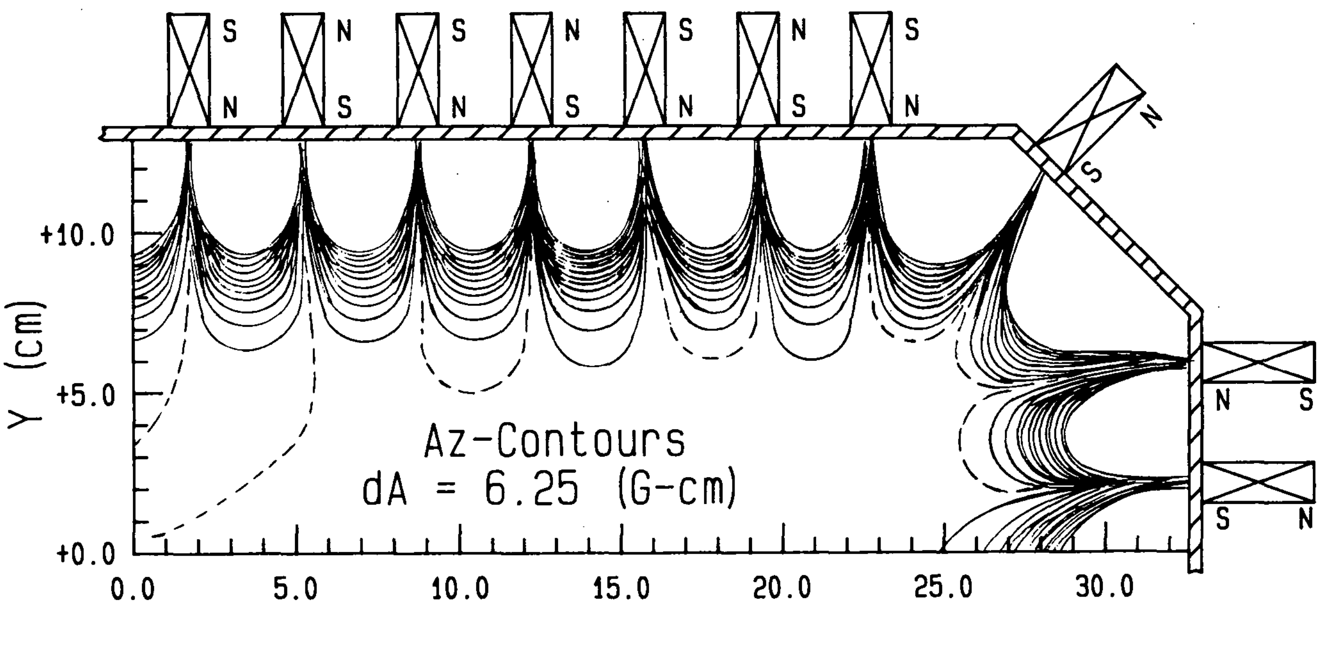

Figure 3 Plasma Generator Magnet Configuration

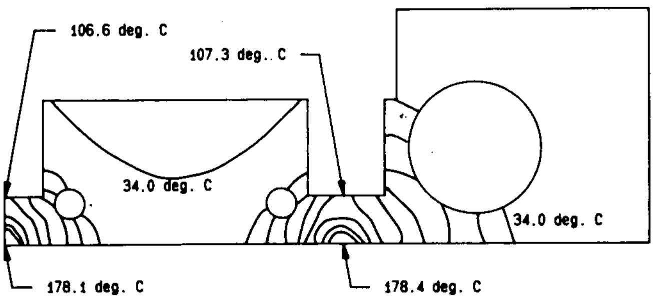

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Figure 4 Electron Dump Temperature Distribution, 120 kV, 70 A, 2 Sec.

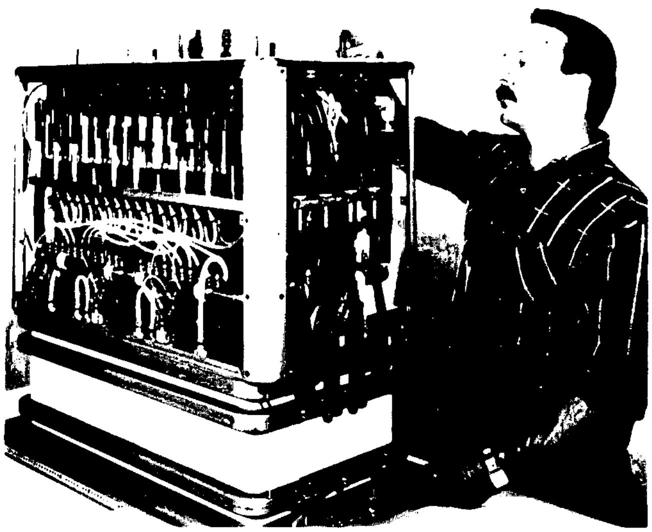

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Figure 5 Full Scale Source Model

shutoff water fittings were used along with manifolding and plumbing engineered to have acceptable flow and pressure characteristics. The facility for individual grid calorimetry was retained though the user requested single water supply and return lines would require thermocouple signal telemetry. The filament assembly had all proposed bolt hole patterns machined into the plates, thereby identifying many interferences early in the design. Bolt patterns were engineered for ease of filament assembly removal and complete plasma generator removal. The model also was an aid in defining the user interfaces; upon its completion, it was cycled through each of the users and is presently serving as a valuable training tool for the technicians at RCA.

Industrialization Status

The LBL conceptual baseline design described above has been undergoing the process of industrialization to RCA Corporation during the past year. The first article plasma generator was delivered to LBL in August, 1985 and the subsequent test program is described elsewhere.[4] By early November, 1985, the first article accelerator was in final assembly at RCA with delivery anticipated later in the month.

Acknowledgements

The authors wish to emphasize that the 12 x 48 Common Long Pulse Source represents the culmination of over ten years of intensive effort by the staff of the Magnetic Fusion Energy Group at LBL. The legion contributions, too numerous to individually recognize, are hereby acknowledged.

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