EXTREME ULTRAVIOLET AND SOFT X-RAY DIAGNOSTICS
OF HIGH-TEMPERATURE PLASMAS

Annual Progress Report

Prepared by

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ABSTRACT

The following reports the results of the research program at this laboratory from June 1, 1975 through mid February, 1976. The report discusses in turn the four major research areas of this program: diagnostic studies of CTR plasmas, laboratory spectroscopy and calibration at short wavelengths, theoretical computation of transition probabilities for highly ionized atoms, and instrument development for short wavelength studies of CTR devices. Using existing instruments, diagnostic studies are under way at Versator and Elmo Bumpy Torus. A facility has been completed for the sensitivity calibration of spectrometers down to $300 \text{ \AA}$ as complete units. The development of computer programs necessary for transition probability calculations is ninety per cent complete. An f/20 forty cm focal length concave grating spectrometer has been constructed utilizing very high vacuum techniques to reduce contamination of plasma devices and calibration sources such as SURF II at NBS. New designs for grazing incidence monochromators have been developed.

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I. INTRODUCTION

The initial start up period for the contract of approximately eight months has been used to achieve several goals. A team of personnel has been assembled. In addition to four staff scientists, six graduate students and three postdoctoral fellows are working on the program. Practical experience with existing instruments on CTR machines has been obtained and this experience is being applied to development of new instrumentation. New conceptual designs suitable for very short wavelengths have been developed and are being investigated further. The laboratory capabilities are being extended to very short wavelengths. The computer programs necessary for accurate calculations of transition probabilities and photoionization cross sections have been developed.

II. DIAGNOSTIC STUDIES OF HIGH TEMPERATURE PLASMAS

Instrumentation and expertise existing at the initiation of this program has been used for diagnostic studies of magnetically confined plasmas in toroidal geometries. Three ultraviolet spectrometers have been used in the study of light plasma impurity atoms. The three spectrometers together cover a range from $\approx 400 \text{ \AA}$ to $2500 \text{ \AA}$ and have been calibrated to measure absolute levels of radiation. This absolute calibration allows for measurement of the amount of energy radiated from the plasma and more importantly allows one to use the ultraviolet radiation to measure local electron temperature and to study the evolution of impurities during the plasma discharge.

In the past seven months work in this program has centered around preparation of the instrumentation and performance of experiments in the field. Absolute sensitivity calibrations against NBS photodiodes and the wavelength calibrations of the remotely controlled instruments have been made. The instrumental packages have been tested in the lab and in the field. The initial field testing was done for the two vacuum instruments on FM-1 at PPL and for the third non-vacuum spectrometer both on FM-1 and RECTOR, the small research tokamak at M.I.T. The most extensive work done so far has been an impurity study on the other small research tokamak at M.I.T., VERSATOR. Analysis of the experimental data is currently in progress. Two abstracts based on preliminary results have been submitted to the Spring '76 APS meeting.

Work in the next few months will concentrate on modeling and on gaining radial information about impurity evolution and on further experimental investigation of the incompletely understood disruptive instability which was much in evidence in the VERSATOR and which strongly affects the ultraviolet radiation levels. Similar impurity studies on the M. I. T. tokamak ALCATOR will begin in the late summer using the new 40 cm instrument described in Section V.

A cooperative experiment with N. Lazar of ORNL has been designed in order to measure the impurity density and distribution in Elmo Bumpy Torus. The first experiment will measure the spatial distribution of emission in the 1150-2200 Å spectral region. Strong spectral lines are expected from H I, C I - C IV, O I, and Al II - Al IV. The experimental equipment is essentially complete and the measurements will be made upon completion of the generator repair at ORNL.

III. LABORATORY SPECTROSCOPY AND CALIBRATION

The laboratory work here has been done primarily in support of the instrument development and calibration of instruments for studying plasmas at other laboratories.

A. Calibration Equipment. Instruments which are calibrated as a unit are more reliable than those whose sensitivity is determined on the basis of a piecemeal evaluation of individual components. A special facility to perform such calibrations down to $1150 \text{ \AA}$ already existed at this laboratory (see Appendix A). As part of this program we have constructed a new facility for calibrating instruments down to $300 \text{ \AA}$ which permits the same high precision calibration available with the far UV facility. It employs metal vacuum seals, high purity traps and avoids the use of vacuum contaminating components so that the instrument under calibration will not be contaminated.

The calibration technique is basically identical to that described in Appendix A. Light from a high power windowless discharge tube illuminates the entrance slit of a 40 cm focal length (see Section V. B) concave grating pre-monochromator. The output of the monochromator is focused by an intermediate concave mirror onto the entrance slit of the monochromator under test, the slits of the instrument under test are set in the wide open position to avoid occultation of photons in the incident beam, and the f number of the incident beam is made large so that only

a small area of the grating is illuminated. The number of monochromatic photons in the incident beam can be measured by tilting the intermediate focusing mirror so that the output beam from the premonochromator falls on a calibrated photomultiplier tube. The photomultiplier can be calibrated before and after the instrument calibration by placing an NBS calibrated photodiode in the plane of the test spectrometer entrance slit and comparing its output for the strong lines of the light source with the output of the PMT. The photodiode is intermittently recalibrated at NBS. The intermediate mirror can be adjusted to illuminate different portions of the test instrument entrance slit, and the test instrument can be tilted about a point in the center of its entrance slit to illuminate any area of the grating of the test instrument. In this way a map of the slit and the grating can be obtained to determine the optical uniformity and the average optical properties of the grating and the detector of the test spectrometer at a large number of wavelengths. Based on our experience with the long wavelength facility, this equipment is expected to be extremely useful, not only for instrument sensitivity and wavelength calibration but also for individual evaluation of optics, gratings and detectors. The facility described above has been completed and is now in service.

This program requires the evaluation of grating transmissions and mirror reflectivities on a routine basis. A reflectometer has been constructed for this purpose. Mirror coating reflectivities and grating

transmissions, both classically ruled and holographic, are being measured.

B. Spectroscopic Sources. Stable CW sources with emission lines at short wavelengths and sources with pulsed time profiles similar to those of tokamaks are necessary for calibration. To this end, both a Penning discharge and a pulsed hollow cathode are under study. The Penning ion discharge utilizes crossed electric and magnetic fields to enhance the stage of ionization and hence the short wavelength emission. The source is being evaluated using the one meter grazing incidence instrument which was also constructed during this period (Section V). The pulsed hollow cathode uses a current pulse superimposed on a 200 ma dc discharge. Examination of the spectra shows an enhancement of higher ionization states. This indicates that in addition to testing time response, the source will be useful at shorter wavelengths.

As the spectroscopic techniques improve, it will be possible to determine the shape of spontaneously radiated line emission as a function of time. Relatively little work of this type has been done or high resolution transient spectroscopy of non-equilibrium sources similar to those employed in CTR. In order to investigate the spectroscopic problems and associated plasma modeling problems, the time resolved line emissions from a pulsed capillary discharge in argon

are being studied. The discharge occurs in a quartz capillary, 2 mm in diameter and 45 cm long. A steady current through the capillary of 100 - 400 ma is maintained between a co-axial impregnated tungsten hot cathode and a molybdenum anode. A 40 μ s in duration rectangular current pulse of 10 - 40 ma is superimposed upon the steady current at 50 pulses per second. This discharge is believed to have some characteristics similar to pulsed CTR machines, that is, equilibrium is not achieved during the pulse, the gas is rapidly heated by the pulse, (the gas density is low ($<10^{14}$ /cc), the ionization fraction is high, there are substantial gradients in plasma properties over distances comparable to a mean free path of the particles, and wall effects may be important. Analysis of the measured line profiles is underway and will be completed this spring.

IV. THEORY

The goal which we set for ourselves during this contract period was to develop the computer programs necessary to carry out accurate calculations of transition probabilities and photoionization cross sections in highly ionized atoms. This goal is at this writing, about 90% fulfilled. Among the programs we now have working are a multiconfiguration relativistic Hartree Fock one and a non-relativistic multiconfiguration Hartree Fock one. We also have programs for the calculation of relativistic transition probabilities in all gauges, and for calculation of non-relativistic photoionization cross sections. The program for calculation of non-relativistic transition probabilities, including the effect of the spin orbit interaction, should be finished within a few weeks. Our only uncompleted objective is a program for continuum relativistic wave functions, so that relativistic photoionization cross sections can be calculated. This should be accomplished before the end of the contract period.

We have applied our programs to a study of photoionization cross sections in the Ne, Ar, and Kr isoelectronic sequences. Here, we have demonstrated that use of a multiconfiguration Hartree Fock ground state very significantly improves the accuracy of calculated cross sections. Our results are of the same accuracy as those obtained from R Matrix calculations and better than those obtained from close coupling; since the multiconfiguration Hartree Fock method is

significantly simpler than either of these procedures, we feel that this is a very important result. Only the RPA and full many body perturbation calculations seem to be superior to ours, and they again, are significantly harder to carry out than the multiconfiguration Hartree Fock method. This simplicity of calculation makes it relatively easy to carry out reasonably accurate calculations along isoelectronic sequences.

We have also studied the effects of relativity on transition probabilities in the Li and Be isoelectronic sequences using a relativistic Hartree Fock technique. We have, in this case followed the sequences out to Li- and Be-like Uranium, respectively. In this work, we have used both the relativistic length and relativistic velocity forms of the dipole transition operator. To our knowledge, this is the first time that both operators have been calculated in one work, and it enables us to see clearly the effects of relativity. We find that in the Be sequence, the velocity matrix element is affected by relativity much more strongly than is the length matrix element. In the Li sequence, both matrix elements are about the same. These results seem to indicate that the primary effect of relativity, at least on these sequences, is to shrink the core so that the active electron sees a potential significantly different from that which would be predicted in a non-relativistic Hartree Fock calculation. These results all show strong deviations from the $1/Z$ extrapolated f values of Smith and Wiese for atoms more than about 22 times ionized, and thus demonstrate the necessity of using relativistic calculations at high Z .

V. INSTRUMENTATION

Six instrumentation projects were initiated during the past eight months with the following goals. 1) Evaluation in a CTR environment of the performance of spectroscopic technology developed for use in space. 2) Evaluation of grazing incidence mounts both conventional and novel from the standpoint of both simplicity of construction and the optical properties; i. e., spatial and spectral resolution, scattered light, etc. 3) Design and evaluation of multielement detectors for simultaneous spatial and wavelength resolution as a function of time. 4) The construction of new instruments which function well in a CTR environment and provide new tools for diagnostic analysis. The status of these projects are described below.

A. Existing Instruments. Over a number of years, this laboratory has evolved a number of instruments and techniques for UV and EUV measurements from platforms in space. In particular, two types of instruments, a 125 mm focal length Ebert and a 225 mm focal length normal incidence concave grating instrument appeared very attractive for immediate application to CTR. These instruments are small, less than 30 cm in length, and weigh about 1 kg. The detection photomultiplier is packaged integrally with a high voltage supply and pulse counting

electronics, and hence is much less sensitive than most systems to external noise. The wavelength drive is driven by a stepper motor permitting digital control; the spectral resolution is $\sim 1 \text{ \AA}$. The two available Ebert instruments with windowed detectors cover the range from 1150-2000 $\text{\AA}$ and 2000-2500 $\text{\AA}$. The concave grating instrument, with a windowless detector, covers the range from 300 to 1600 $\text{\AA}$ although the sensitivity drops sharply longward of 1200 $\text{\AA}$. To increase the sensitivity at longer wavelengths we have overcoated a windowless detector with CuI. To facilitate the use of these instruments to study CTR plasmas, a digital wavelength controller and high speed D-A's were constructed.

The long wave length unit has been absolutely calibrated with very high precision in the calibration test equipment (CTE) built in this laboratory for our space program (Appendix A). The shorter wave length spectrometer has been calibrated with moderate precision by adapting it to a commercial EUV vacuum monochromator and is being calibrated at present in the EUV calibration facility described in Section III.

We have measured the properties of the detector as a function of magnetic field. The gain stability is quite good up to 2 gauss and even at ~ 10 gauss changes by $\leq 10\%$. Thus magnetic shielding is required but need not be excessive. The instruments were shown to

work well at pressures of H_2 of 3×10^{-4} torr with no signs of optical degradation or increasing dark count due to corona. Experiments at FM-1 and Versator confirmed this.

The only problem areas are 1) To improve the time resolution, the maximum number of photoelectron events per time resolution element is being increased. The present pulse counting circuits have a maximum of 10^7 counts/sec. This will be increased to 10^8 counts/sec and fast electrometers which do not have the dead time limitation of pulse counting circuiting are being constructed. 2) Outgassing of H_2O and organic molecules is a problem, a not uncommon difficulty with diagnostic instrumentation. The source is not certain, but on the basis of a gas analysis study at SURF II at NBS, certain of the electronics are probably responsible. After ~ 300 hours storage in a vacuum of 3×10^{-7} torr at Versator, the outgassing was sufficient to seriously degrade the plasma. Cooling of the vacuum connector between the instrumentation and Versator to liquid N_2 temperatures removed the problem. As many diagnostics have problems of this type, the technique will be of some general use and we are studying it further in cooperation with the M. I. T. group. The proper solution, of course, will be to pinpoint the offending electronics and remove them from the vacuum.

In summary, only relatively minor problems are involved with the application of the spectroscopic technology to CTR. Based on this

experience it will be possible to ensure that such problems do not occur in the construction of instrumentation specifically designed for CTR. This is perhaps best exemplified by the 40 cm concave grating instrument described below.

B. Design of New Spectroradiometers. A number of new systems are needed in the field of plasma research to fulfill the following conditions:

- extension of grating spectroscopy to $10 \text{ \AA}$ at high optical efficiency;
- compatibility with super clean vacuum requirements;
- stability of absolute calibration;
- capability of spatial resolution;
- portability;
- ease of integrating with plasma machine systems;
- adaptability to two dimensional multiple element pulse counting detectors to provide simultaneous spatial and spectral readout.

1. E. U. V. Scanning Monochromator. During the first contract year our major instrumentation effort has been the design and construction of an $f/20$ - 40 cm focal length concave normal incidence grating monochromator with a scanning mechanism which both rotates the grating to provide spectral scanning and translates the grating along a line which bisects the

entrance and exit slits and passes through the center of the grating. The grating translation motion provides a means of accurately positioning the grating so that the slits are always on the Rowland Circle, thus providing spectral resolution which can be diffraction limited at all wavelengths. This method of providing a fixed slit, focusing concave grating scanning system is not new, being employed in several commercially available instruments. However, the design shown in Figure V.B.1.a incorporates compatibility, compactness, super clean vacuum capability and adaptability to two dimensional multiple element detector systems.

As shown in the figure, light from the entrance slit goes directly to the concave grating which focuses a spectral image on the exit slit. The external micrometer drive motor drives the sine shaft through a stainless steel bellows against a ball on the end of a follower arm on the grating assembly. The spring holds the ball against the sine plate and also holds the ball against the cam groove which is in a plate attached to the end plate. The wave length dial is directly calibrated in wavelength. The entire grating assembly is mounted on the end plate which seals to the vacuum housing with a metal "O" ring.

FIG. V. B. 1a - Optical Diagram of f/20-.4 meter Scanning Concave Grating Normal Incidence Spectrometer

The grating bearings, cam groove and sine plate bearing use dry metallic salt lubricant. The micrometer motor, precision screw and wavelength counter use machine oils but are external to the vacuum system.

The entrance slit is adjustable in width and height, the exit slit in width only. The mechanism for the slit adjustments are also made through stainless steel bellows and are thus external to the vacuum system, dry lubricant being employed on internal moving parts. The entrance slit is designed so that the only significant gas leak is through the slit opening, leaks along the slit faces being minimized by employing precision ground surfaces on all moving parts. Thus, for many applications no slit pre pump facility is required; the ion pump on the instrument will be able to handle the gas load. The detector housing is removable from the slit plate and is large enough in diameter to provide significant magnetic shielding very close to the detector. The focal plane area is large enough to employ a 5 mm high by 25 mm long multiple element detector in place of the exit slit and single detector.

With the 2400 groove/mm grating such a detector would provide simultaneous readout of 500 spectral elements over a 250 Å range and provide angular resolution along the slit of about 40 minutes of arc with an angular resolution of 4 minutes. Better angular resolution could be obtained if a curved ruling

(Type II) grating were used to correct for astigmatism.

Thus the instrument, as designed, is adaptable to anticipated improvements in the state of the art of gratings and detector systems.

We have constructed two complete spectrometers as described above, one for use with the EUV calibration facility described in Section III, the other for use in our field program. The two instruments employ a 2400 g/mm grating, the operating range of the units is 250 to 2000 Å, with fractional angstrom resolution over the whole range.

2. Grazing Incidence Rowland Circle Instrument. A

conventional Rowland circle monochromator with a one meter radius of curvature grating has been constructed. The first tests with a hollow cathode discharge in Ne and the Penning discharge (see Section III) showed spectra down to below 150 Å with 0.6 Å resolution. The use of filters and more appropriate sources will give spectra to much shorter wavelengths. The monochromator is essentially a breadboard unit in which modifications such as moving the grating along the Rowland circle and mounting curved slits can be tried. If moving the grating on the Rowland circle is successful, the use of a

toroidal grating is planned. Simultaneous movement of the grating and exit slit will then provide stigmatic imaging of the entrance slit with moderate resolution ($\sim 0.5 \text{ \AA}$).

The instrument is essentially an experimental one designed for testing new concepts in instrument design and grating evaluation. Despite this, it still is quite rugged and sufficiently small to facilitate using at other laboratories. Thus, we plan to use it on Versator in the near future. The construction is such that, with minor modifications, the instrument will meet the stringent vacuum requirements for calibration at SURF II at NBS.

3. Grazing Incidence Double Monochromators. The instrument described herein is designed for the spectral range below $250 \text{ \AA}$. It employs two concave gratings used at grazing incidence, has entrance, intermediate and exit slits in fixed positions, and employs a single sine drive mechanism to rotate both gratings about axes at the center of the two Rowland circles. Auxiliary optical means are provided to adjust the gratings so that they are precisely on their Rowland circle. Conceptual design of this instrument is complete, detailed design will be completed during the contract period, and construction will start during the period; completion is expected in late 1976 or early 1977.

The instrument uses gratings with 2 meter radius of curvature with 170° between the incident and diffracted beams. The centers of the Rowland circles are separated by 17.23 cm. The entrance and exit slits are separated by about 60 cm with the intermediate slit at the midpoint. The f number of the monochromator is about $f/60$.

As shown in Figure V.B.3.a, each grating can be positioned between the entrance slit and the zero order by moving two sine plates along a single track which is at an angle of 10° to the line between the centers of the Rowland circle. The track direction is thus parallel to the central ray of the entrance beam when the gratings are in the zero order. The sine mirrors drive an arm on which the gratings are mounted to rotate the two gratings about the center of their Rowland circles.

The above relationships arise from the fact that there is a fixed angle between the incident and diffracted beam, and that that angle is very small. From the grating equation $\lambda = a(\sin \alpha - \sin \beta)$ expressed in the grazing angles $\alpha^1 = 90 - \alpha$, $\beta^1 = 90 - \beta$ and introducing the fixed angle $\gamma = \alpha^1 + \beta^1$.

$$\lambda = a [\cos \alpha^1 - \cos (\gamma - \alpha^1)]$$

$$\lambda = a [\cos \alpha^1 (1 - \cos \gamma) - \sin \gamma \sin \alpha^1] \quad (1)$$

A close approximation to this formula for small values of γ is

$$\lambda = A - B \sin \alpha^1 \quad (2)$$

where the constants A and B depend on the grating space and the value of γ .

Equation (2) demonstrated that a sine drive can be employed. Since α^1 is zero at the maximum wavelength, the plane of the sine plate must include the axis of rotation if the two sine plates were placed at the entrance slits, the planes of these plates therefore differ by the angle γ . To insure that both gratings rotate through the same angle for a given linear motion of the sine plates the direction of motion of the sine drive should make an angle γ with the line between the centers of the Rowland circle. This direction is along the incident ray in the first monochromator when the instrument is in the zero order.

As shown in Table V. B. 3. b the wavelength error introduced by the assumption that A (eq. 2) is a constant is less than 1/2% if γ is less than 10° . However, this error can be compensated for by a very small adjustment of the angles of the sine plates which introduces a compensating non linearity in the drive system.

TABLE V. B. 3 b

$$\lambda = 105.37 - 1205.9 \sin \alpha^1 \quad (\text{eq. 2}) \quad \gamma = 10^\circ, \quad a = 6944.94 \text{ \AA}$$

α^1	A	λ (eq. 1)	λ (eq. 2)
2°	105.44	63.35	63.29
3°	105.36	42.25	42.26
$3 \frac{1}{2}^\circ$	105.30	31.69	31.75

Because of blaze considerations and the overlapping order problem, the operating range of the instruments is limited to an angle of $\gamma/5$ to $2/5\gamma$ which calls for a blaze angle of about $\gamma/3$. These numbers are arbitrary but cannot be greatly exceeded. In our initial tests we will operate in the range shown in Table I. The vacuum techniques described in Section V. B. 1 will be employed with the double monochromator to provide a super clean system.

There is a broad need for a double monochromator for the very short wavelength region. Besides its use as a diagnostic device, it can be used to evaluate optical components by the substitution method, and to determine the light scattering properties of optical components. It also provides an internal calibration means, since the measured output of the first monochromator can be used to measure the transmission of the second monochromator and vice versa.

The instrument is adaptable to multiple element detectors which can be placed along the Rowland Circle in place of the intermediate slit. Except for pinhole camera techniques, spatial resolution along the length of the spectrum cannot be achieved with a classical grating because

of the extreme astigmatism introduced by grazing angles. However, improved spatial resolution might be achievable with specially formed gratings employing curved rulings or aspherical blanks. Thus the instrument can be used as a single monochromator and is adaptable to use of gratings which are designed to reduce aberrations.

4. Stigmatic Grazing Incidence Plane Grating Monochromator.

Preliminary conceptual design of a stigmatic plane grating grazing incidence system is in progress and will be completed during the current contract period. Detailed design and construction cannot be initiated until the next period. Because of component costs and other development costs special funding will be required to proceed with this development as discussed in the renewal proposal.

The proposed instrument, as shown in V. B. 4. a employs 80 mm long sections of parabolic mirrors whose far edges are 500 mm from the focus of the parabola as both collimator and camera mirrors. The focal length of the parabolas is only about 1.25 mm but for a very small source the system shown can, of course, produce an aberration free monochromatic image at the exit slit, assuming no manufacturing limitations and for the proposed angles, very high optical efficiency would be anticipated.

**FIG. V.B. 4a- Stigmatic Grazing Incidence
Plane Grating Monochromator**

For an extended source, such as a 1 mm wide by 5 mm long slit, coma and astigmatism will degrade the image, as one might expect since the slit length is 4 times the focal length of the parabola. However, preliminary ray traces show that for such a slit the image quality is remarkably good, of the order of a hundred microns wider at the end of the slit image and negligibly broadened at the center. Astigmatism is parallel to the slit length and degrades only the spatial resolution, but only by one to two hundred microns. The dispersion of the spectrometer at 7.5 mm can be as large as $0.75 \text{ \AA} / \text{mm}$ providing a limited resolution of 1000 for a 5 mm long slit and much higher resolution with a shorter slit.

Parabolas of the type required are manufactured by computer controlled polishing engines and must be made in complete 80 mm long cylindrical sections, then cut in 30 mm wide pieces, 8 pieces being produced from one cylindrical section. These techniques have been developed for x-ray astronomy instrumentation. Preliminary evaluation indicates that the state of the art mirrors can meet the optical tolerance requirement for the present application.

Finalization of the design requires more detailed information about the quality of the polished surfaces, more detailed ray tracing to determine the three dimensional shape of the images and the effect of aparabolization of the mirrors. Development of the instrument also requires a study of means for adjusting and evaluating the system, including the effect of aberrations introduced by the plane grating when illuminated by a non flat wave front. Additional studies of the efficiencies of plane grazing incidence gratings and the techniques for ruling the proper groove shape on such gratings must be undertaken. Beyond monochromator design, the possibility of extending the field of view to provide limited spatial and spectral resolution, perhaps limited to line shape studies rather than wide spatial coverage should ultimately be studied.

As indicated above the final development and construction of the proposed instrument is beyond the financial scope of the present contract. However, the preliminary results are most promising. An instrument with these properties will have many important applications to plasma studies.

5. Multielement detectors. It is extremely desirable to measure several spectral or spatial resolution elements simultaneously. A very attractive device for this appears to

be the microchannel plate. As part of other programs in our laboratory we have studied the detection and gain stability of these devices over long periods of time and their applicability to ultraviolet spectrometers. The primary disadvantage of microchannel plates is the low maximum signal current of $\sim 0.2 \mu\text{a cm}^{-2}$. Discussion with the manufacturers indicate that orders of magnitude improvement are not to be expected unless we enter into a program of new glass development; a step which we do not feel is justified at the present time. Improvement on the order of a factor of three is expected with the appropriate thermal treatment. For the purposes of evaluation, we have purchased such plates and are in the process of evaluating the maximum signal currents. We are also evaluating solid state multi-plexers for reading out multiple anodes.

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