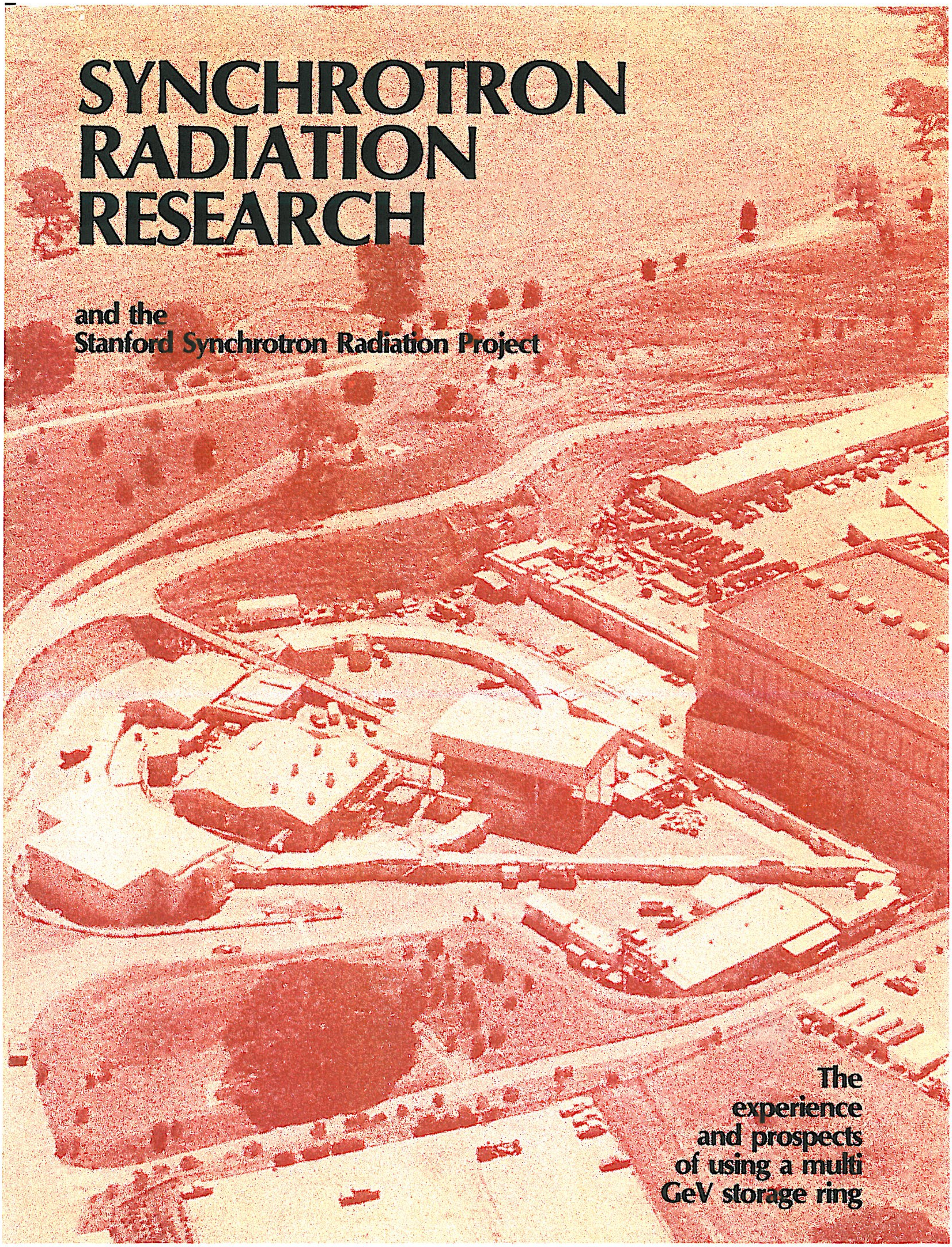
SYNCHROTRON RADIATION RESEARCH

and the Stanford Synchrotron Radiation Project



The experience and prospects of using a multi GeV storage ring

IV. PRESENT SSRP FACILITY

4.1 HISTORY AND GENERAL DESCRIPTION OF SSRP

Written and Compiled by H. Winick, Stanford Synchrotron Radiation Project

SSRP is a national facility for multidisciplinary research utilizing synchrotron radiation from the storage ring SPEAR at the Stanford Linear Accelerator Center. To document the capacity of this facility, detailed descriptions have been published.[202–205] Figure 39 is an aerial view of the SLAC accelerator and research yard showing the SSRP building adjacent to SPEAR in the lower right. Figure 40 is a closeup view of the SPEAR ring and the synchrotron radiation laboratory building. SSRP was initially proposed by S. Doniach (currently Director) and W. Spicer (currently Consulting Director). H. Winick is Deputy Director, A. Bienenstock is Associate Director, and I. Lindau is Scientific Coordinator. In addition to their role at SSRP, these personnel are all faculty of Stanford University.

Advice on basic policy matters and review of the general laboratory program is provided by a Science Policy Board (SPB). The original members of this group (1973) were J. Baldeschwieler, Chairman (California Insitute of Technology), F.C. Brown (Xerox Corporation and University of Illinois), S. Buchsbaum (Bell Laboratories) and D.A. Shirley (University of California at Berkeley and Lawrence Berkeley Laboratories). In 1976 J. Baldeschwieler and F.C. Brown left the board and A. M. Sessler, Chairman (University of California at Berkeley and Lawrence Berkeley Laboratory) and A. Rich (Massachusetts Institute of Technology) were added. The Science Policy Board reports to the President of Stanford University.

The Director of SSRP receives advice on individual experimental proposals from many outside referees and also from a Proposal Review Panel (PRP). The original panel members (1973) were N. Ashcroft, Chairman (Cornell University), D.E. Eastman (I.B.M.), M.F. Hawthorne (University of California at Los Angeles), R.P. Madden (National Bureau of Standards), G.A. Somorjai (University of California at Berkeley) and L. Stryer (Yale University). In 1976 L. Stryer left the panel and C. Cantor (Columbia University) was added.

First discussions about a synchrotron radiation facility at SPEAR took place in 1968 between W. Spicer and W.K.H. Panofsky. First design concepts were later developed by S. Doniach, J. Baldeschwieler and W. Spicer. A pilot project, funded by Stanford University and the NSF, started in 1971. Beam was extracted for one experiment in July 1973 by I. Lindau and P. Pianetta.

SSRP was funded as a national facility by the National Science Foundation in July of 1973 and the first experiments began operation in May 1974. Rapid construction of the research facility was due largely to extensive assistance from SLAC with funding through the NSF. This work included engineering design by SLAC mechanical, electrical, and electronic engineers; fabrication by SLAC electronic and mechanical shops; assembly, chemical cleaning, installation and alignment by the appropriate SLAC groups–particularly the SPEAR vacuum group; and design and supervision of the construction of the laboratory building by the SLAC Plant Engineering Department. The capabilities of SLAC in these areas continue to be vital to the SSRP programs in general and the Beam Line II program in particular.

Five monochromator systems for Beam Line I were operational in less than one year due largely to major assistance from twelve scientists in conceiving, designing, producing, and testing these systems. These monochromator systems are now part of the SSRP facility and available to all qualified users. Salary and travel support for these outside scientists, plus much of the cost of the monochromator systems, were provided by their respective institutions; through private funds in the case of industrial laboratories and through government grants in the case of the others. The institutions responsible for this initial support were the Bell

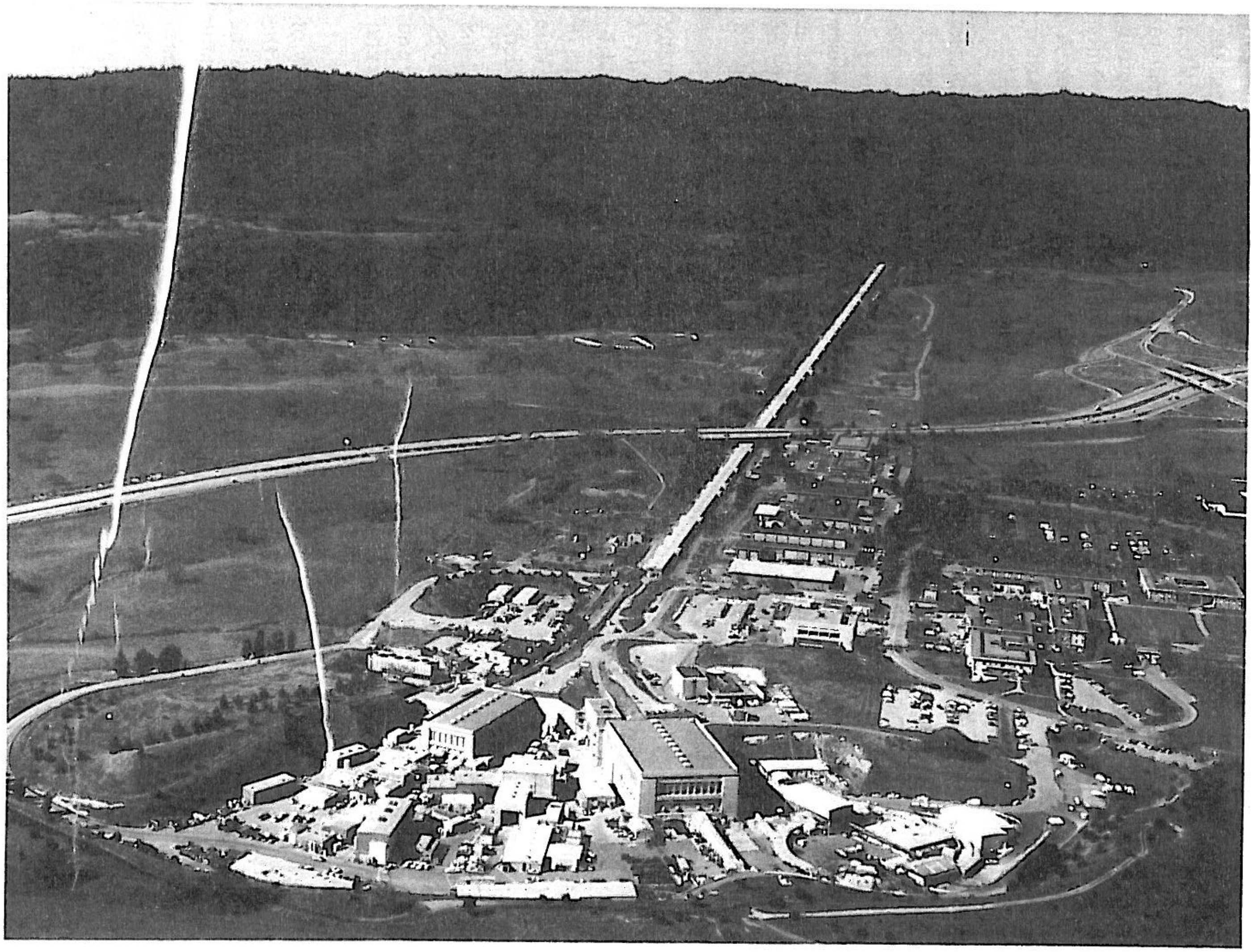


FIG. 39 **Aerial View of SLAC Showing Two Mile Linear Accelerator and Research Yard, Including SPEAR and SSRP Laboratory.**

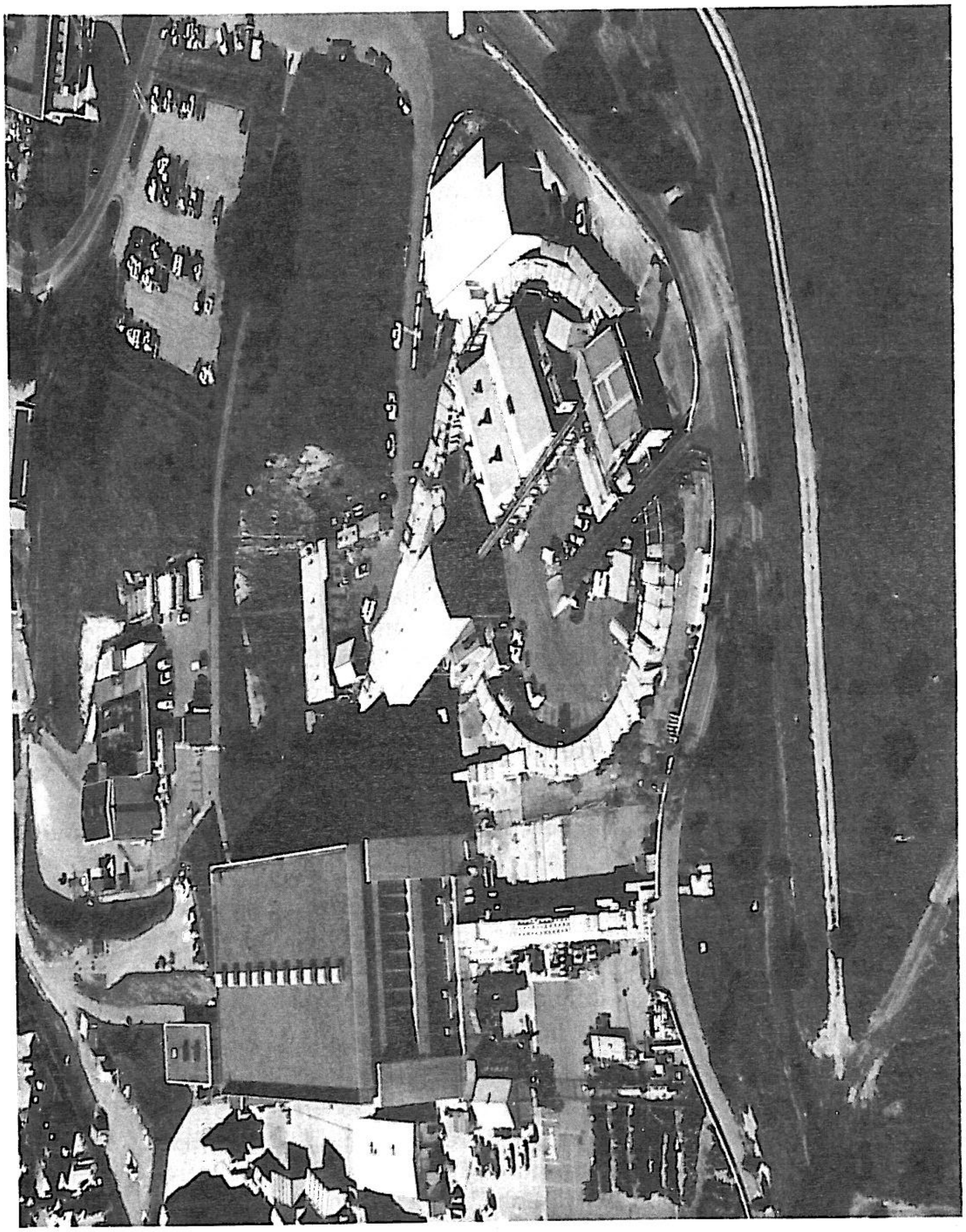


FIG. 40 **View of SPEAR and SSRP Building**

Laboratories, the California Institute of Technology, Stanford University, the University of Washington, the U.S. Navy Michelson Laboratory at China Lake, and the Xerox Corporation.

By June 1976, there were 64 active research proposals, representing work from 33 different institutions, involving a total of about 135 research workers. Furthermore, 40 papers based on SSRP research had been published (or submitted for publication) in major scientific journals. User demand on the facility is increasing rapidly, as shown in Figure 41. SSRP primarily operates symbiotically on the SPEAR colliding beam program. There has also been some experience with dedicated operation of SPEAR for synchrotron radiation research (primarily three days in December of 1975).

The initial NSF grant of $1.2 million covered the construction of the building, one tangent beam line, control systems, interlocks, shielding, and some experimental equipment. It also covered the operations expenses from May 1974 through October 1974. The design, fabrication, and testing of five monochromator systems were largely provided by the outside sources mentioned earlier. The total cost to these other sources for this instrumentation development is estimated to be about $650,000.

Operations budgets of $475,000 for the period November 1, 1974 through October 31, 1975, and $531,000 for November 1, 1975 through October 31, 1976 were provided by the NSF. In addition, the NSF has provided $706,000 of construction funds for a second beam line and three x-ray monochromator systems. These funds also provide for an expansion of the laboratory building to accommodate this new beam line and for increased support facilities for experiments. This construction is currently being completed (June 1976). Also, approximately $20,000 has been provided through the Lawrence Berkeley Laboratories for development work on thinner beryllium windows and an improved beam splitter mirror on the 4° line.

Thus SSRP now has two operational tangent beam lines. The first accepts 11.5 mrad and has been operational since May 1974. It is shared by five simultaneous users. The second beam line, accepting 19.5 mrad, began operation in June 1976 with one channel-cut crystal monochromator. Two additional monochromators are under construction for the second beam line. More experimental stations are possible on both beam lines. Figures 42, 43, 44 show layouts of both beam lines and the complete SSRP facility.

The beryllium windows in both beam lines are now 500 microns thick, resulting in good transmission down to about 3.5 KeV. Thinner windows are being developed to reach photon energies down to about 2 KeV.

Each experimental station is equipped with a monochromator and a system of shutters, shielding, and interlocks, which permit user controlled access to each experiment without compromising the operation of the other experiments or the storage ring. All experiments operate simultaneously since each uses different portions of the beam. Acceptances of each experiment vary from less than 1 up to 10 mrad.

In addition to these two beam lines, another beam port has been used for studies in the visible part of the spectrum,[206] utilizing the excellent pulsed properties of SPEAR. This port was installed and is primarily used for diagnostic and monitoring purposes by SPEAR machine physicists. It consists of a plane beryllium mirror, located 2.4 meters from the source point, which deflects radiation radially outward through a hole in the concrete shield wall and into a small utility shed. The line, as now constructed, is limited to visible light because of the optics used. New lines, based on this simple idea, are now under consideration with upward deflection at angles from 6° to 90° and with optics that would extend the spectral range to 12 eV, with use of MgF_2 or LiF windows, or to even higher energies in a vacuum line complete with pumps, valves and a vacuum control system. The source point for these beams is different from the tangential beams (such as the present two beams utilize). Thus, addition of these large-angle beams makes available otherwise unused radiation. Also, because these new beams

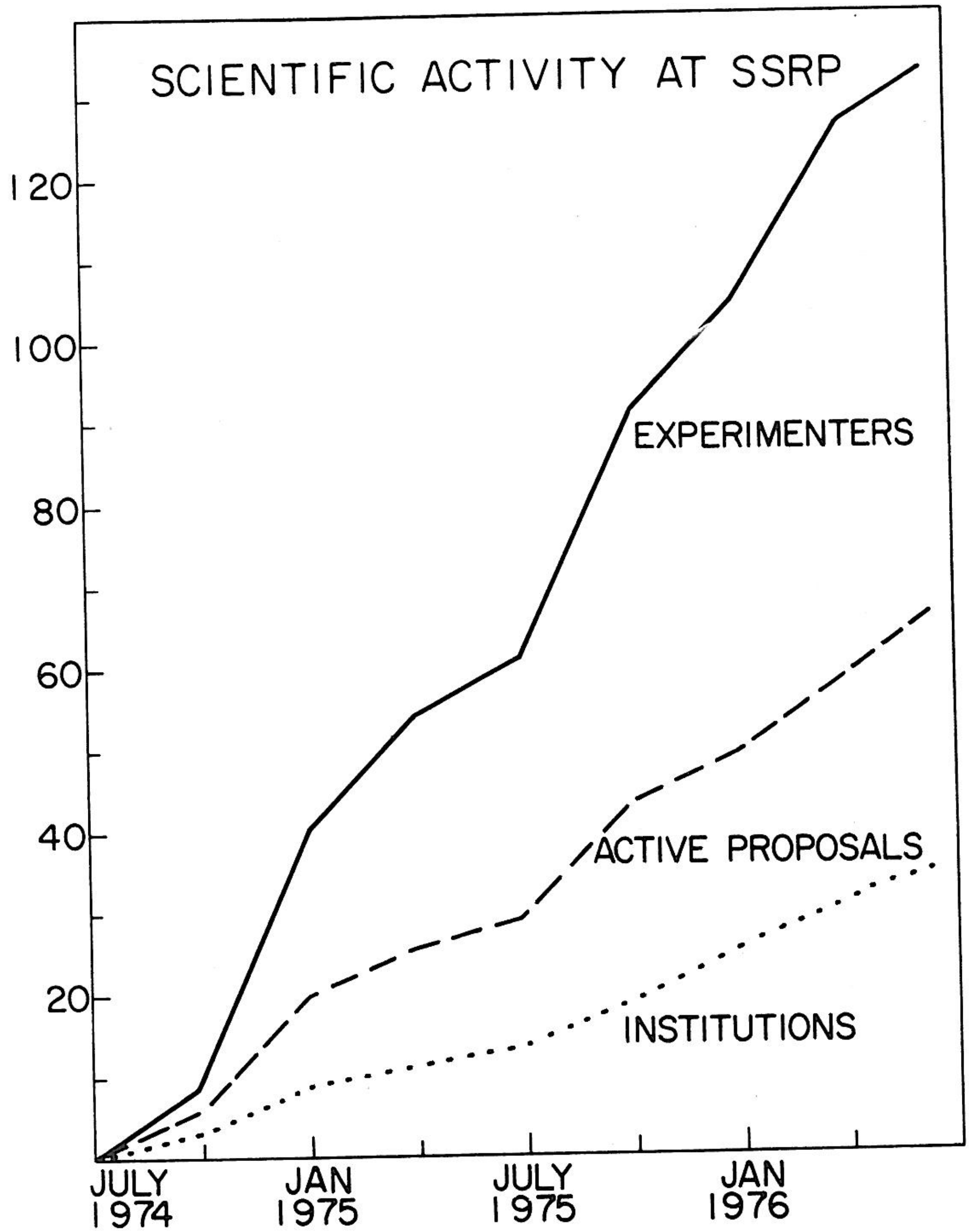


FIG. 41 **Plot Of the Number Of Experimenters, Active Proposals and Institutions Represented At SSRP Over Each 6-Month Period Since the Facility Startup.**

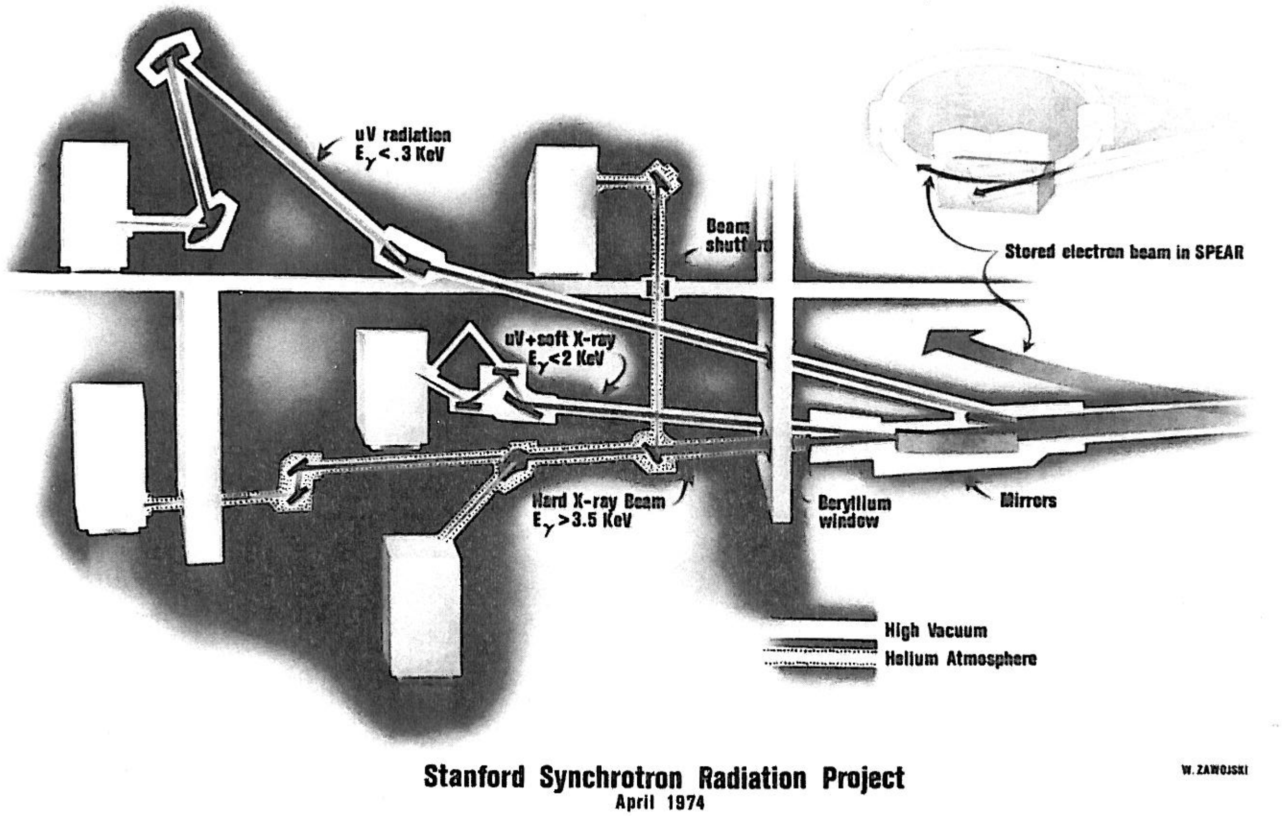


FIG. 42 **SSRP Beam Line I Layout Showing Five Monochromator Systems.**

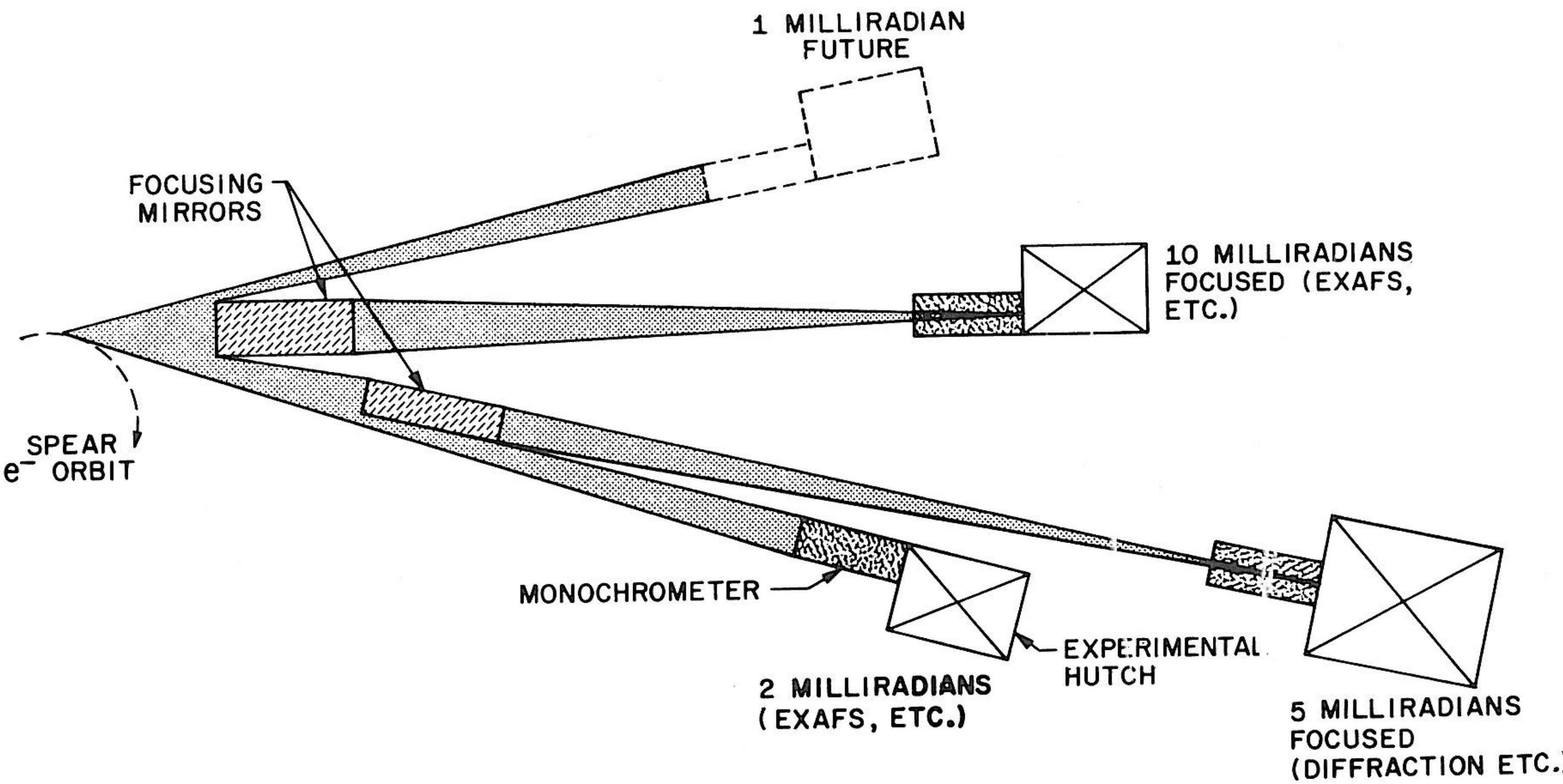


FIG. 43 **SSRP Beam Line II Layout Showing 3 X-ray Monochromator Systems Initially Planned.**

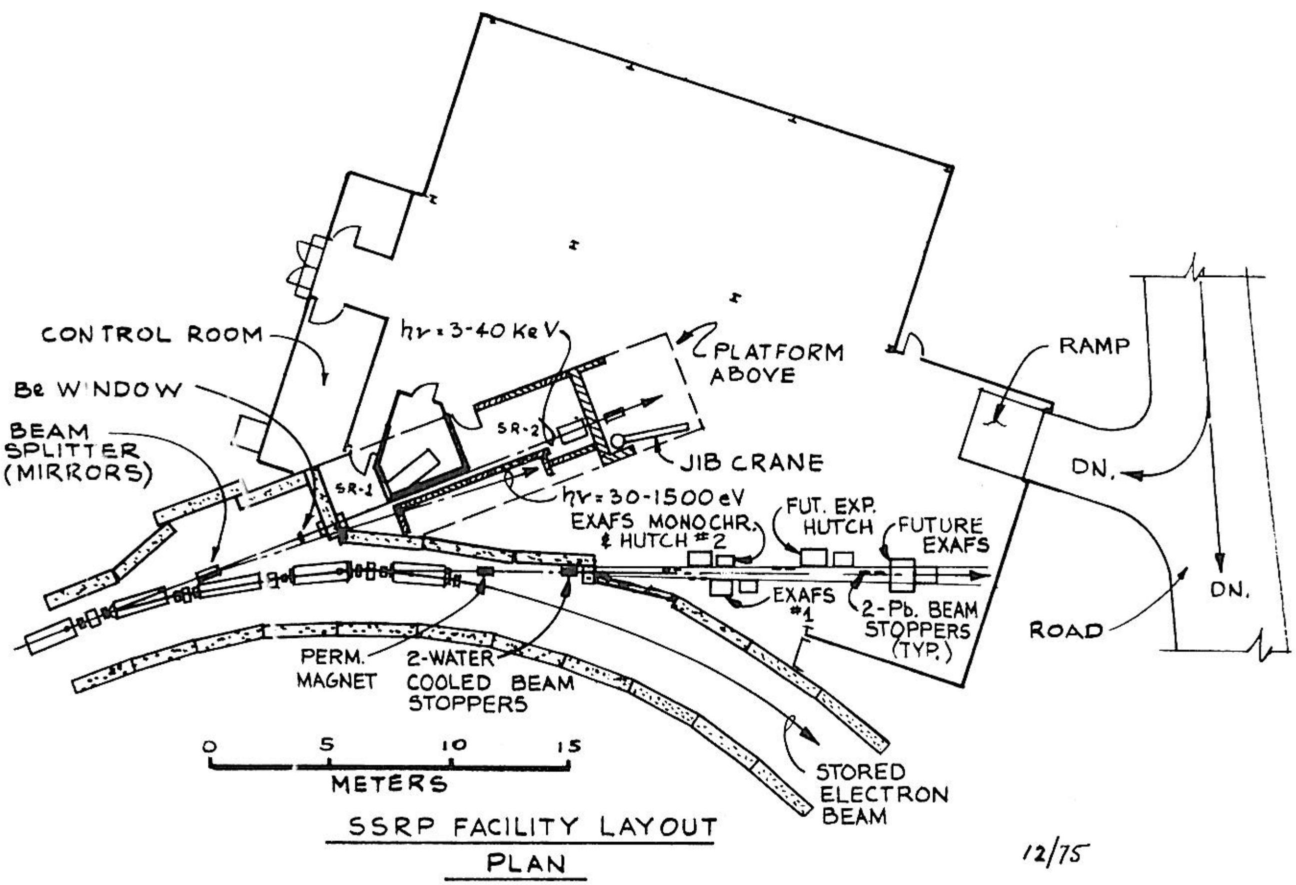


FIG. 44 SSRP Facility Layout

can be vertically deflected, it is convenient to direct them to a higher level experimental area, reserving the ground floor for tangential beam research areas. Thus SPEAR offers extensive XUV research capability based on beam runs that are essentially independent of the tangential beam runs required for x-rays. A schematic of two large angle beam lines installed in the same SPEAR straight section is shown in Figure 5 of this report.

Experience at SSRP has shown that beam splitter mirrors are very effective in providing VUV and soft x-ray flux while filtering out the harder x-rays. In addition, the deflection of the beam from the tangent line to the storage ring provides additional work space and decreases radiation hazards sufficiently to allow experimenters to work close to the beam line in a "hands-on" manner. Remote control of the beam splitter mirror is required, but not of the monochromator or the experimental equipment.

Figure 45 is a photograph of a 40 cm-long beam splitter mirror produced for SSRP by the U.S. Navy Michelson Laboratory at China Lake. The mirrors are made of highly polished copper and plated with platinum. Roughness of surfaces as low as 30 Å rms have been achieved.

4.2 BEAM LINES AND MONOCHROMATOR SYSTEMS

Five monochromator systems have been operational on Beam Line I since late 1974. They are part of the facility and available to all qualified users. Their descriptions are as follows:

A. 4° BEAM LINE - GRAZING INCIDENCE MONOCHROMATOR

F.C. Brown, Xerox Palo Alto Research Center and University of Illinois

The 4° Beam Line was designed to reflect 2 mrad of synchrotron radiation into an experimental area on the main floor. The wavelength range covered by the line as now instrumented is from 400Å to below 10 Å (30 to 1200 eV). The line has been implemented by the Xerox Palo Alto Research Center, together with the SSRP. Special mirrors were developed and manufactured by the Michelson Laboratories, China Lake, California. Surface roughness of the initial beam splitter mirror reduced response above 300 eV. A smoother mirror has now been installed, which has extended and improved the spectral response (Figure 46).

In this line, the vacuum ultraviolet and soft x-ray radiation is focused at 2° grazing incidence. Total external reflection is employed from smooth clean metallic surfaces with high atomic numbers (platinum and gold). In this way, an upper limit to photon energy is achieved that lies in the kilovolt range. State-of-art optics is involved and a number of significant advances have been made with the implementation of this system.

The optical system consists of a cooled, deflecting mirror M_o (6.4 meters from orbit), a grazing incidence ultra-high vacuum monochromator [16 meters from orbit (see Figure 47)] plus sample chamber optics. The entire line is continuously evacuated with ion pumps and is compatible with the vacuum in the storage ring. In general, components and materials are employed that have been specified by the SPEAR vacuum engineers. Special materials, such as dry lubricated bearings and thin film filters, have been tested by residual gas analysis or by diode desorption tests. Basically, the line is divided into regions A (SPEAR vacuum), B (monochromator and grating—separately pumped and isolated), and C (sample chamber—beyond 10-micron exit slits). Vacuum requirements in region C are considerably less strict than region A allowing ease of operation from a user's point of view.

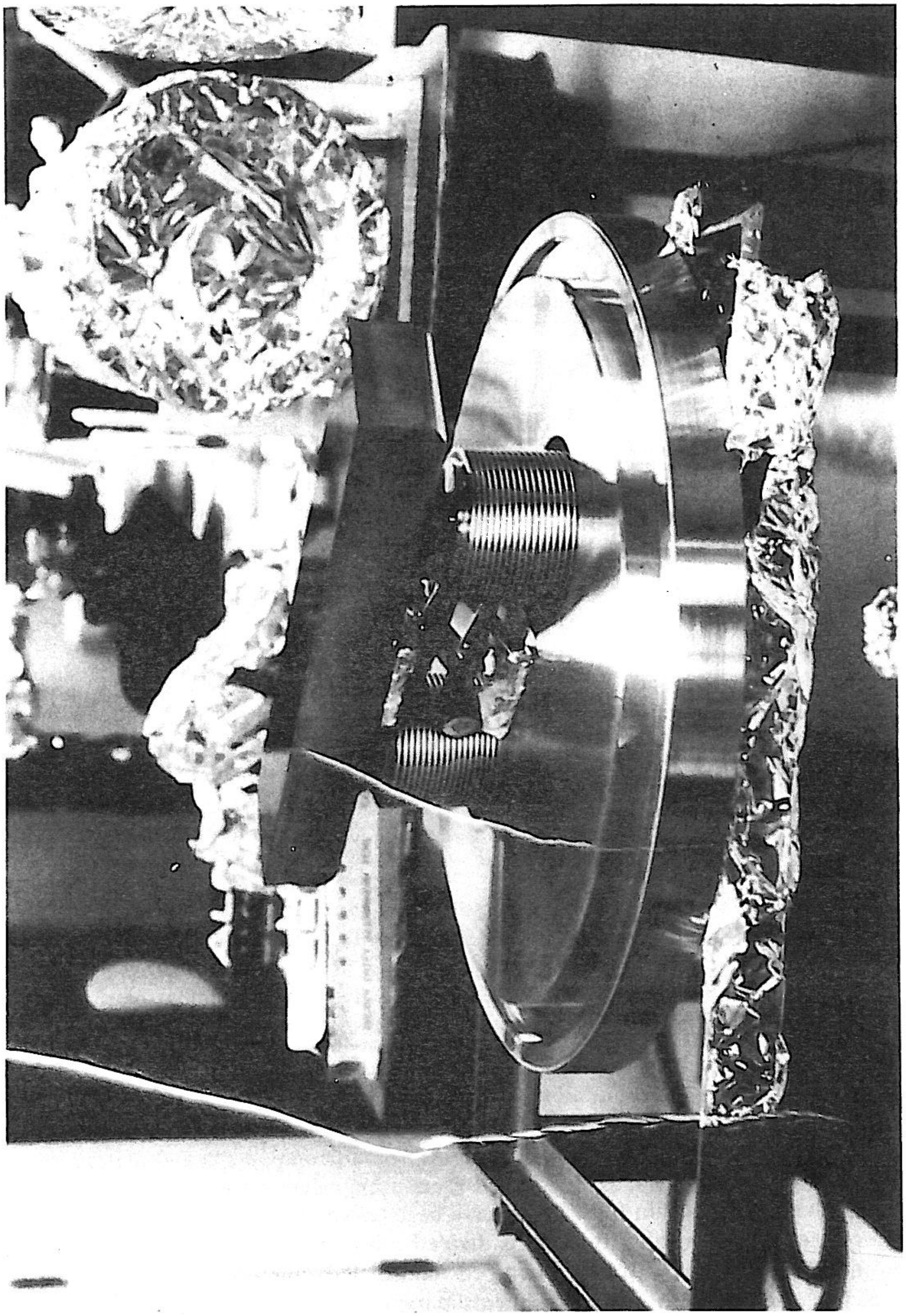


FIG. 45 **Beam Splitter Mirror—The Length Is 40 cm**

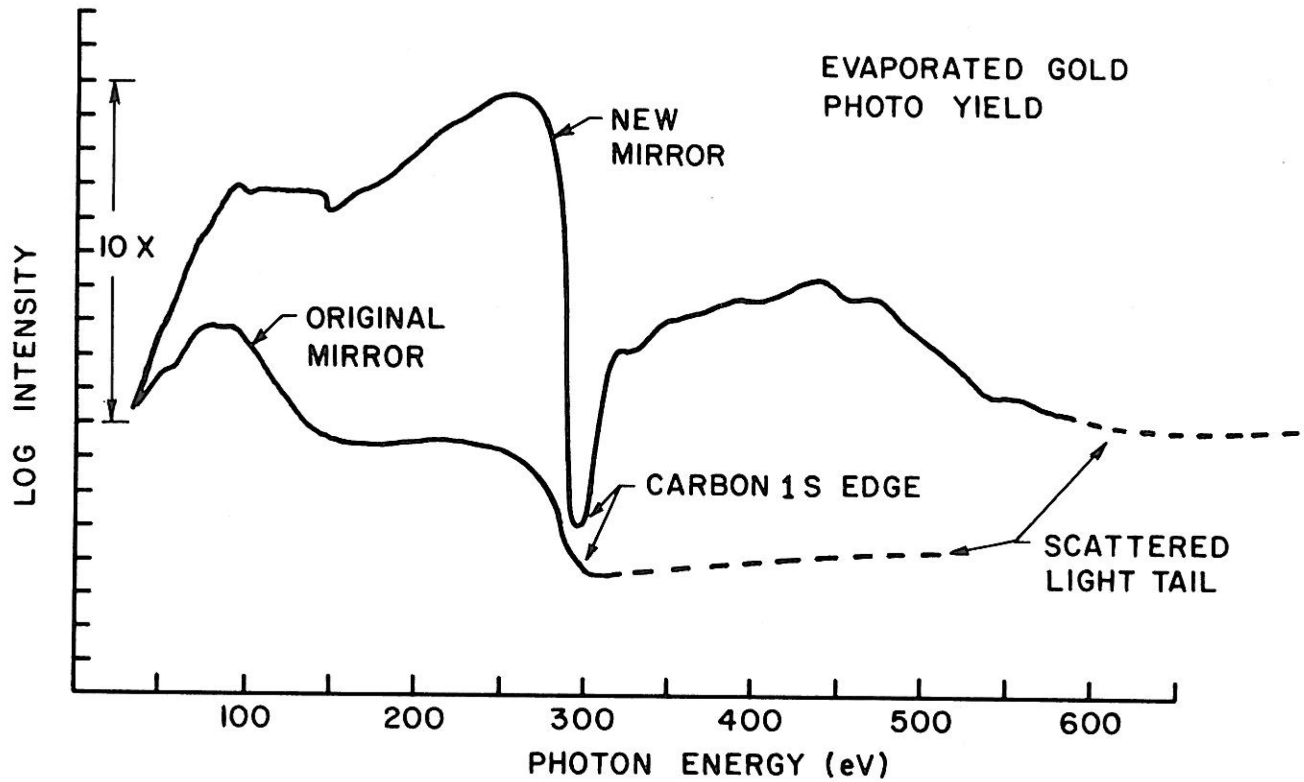


FIG. 46 **Evaporated Gold Film Photoyield Comparison Of New and Original M_o Mirror On the 4° Beam Line. The Data Is Taken With the M_2 Refocusing Mirror In Place. Note That the Total Flux Now Continues To Rise After the Carbon Edge. The Scattered Light Background From Zero Order Now Sets In Near 600 eV.**

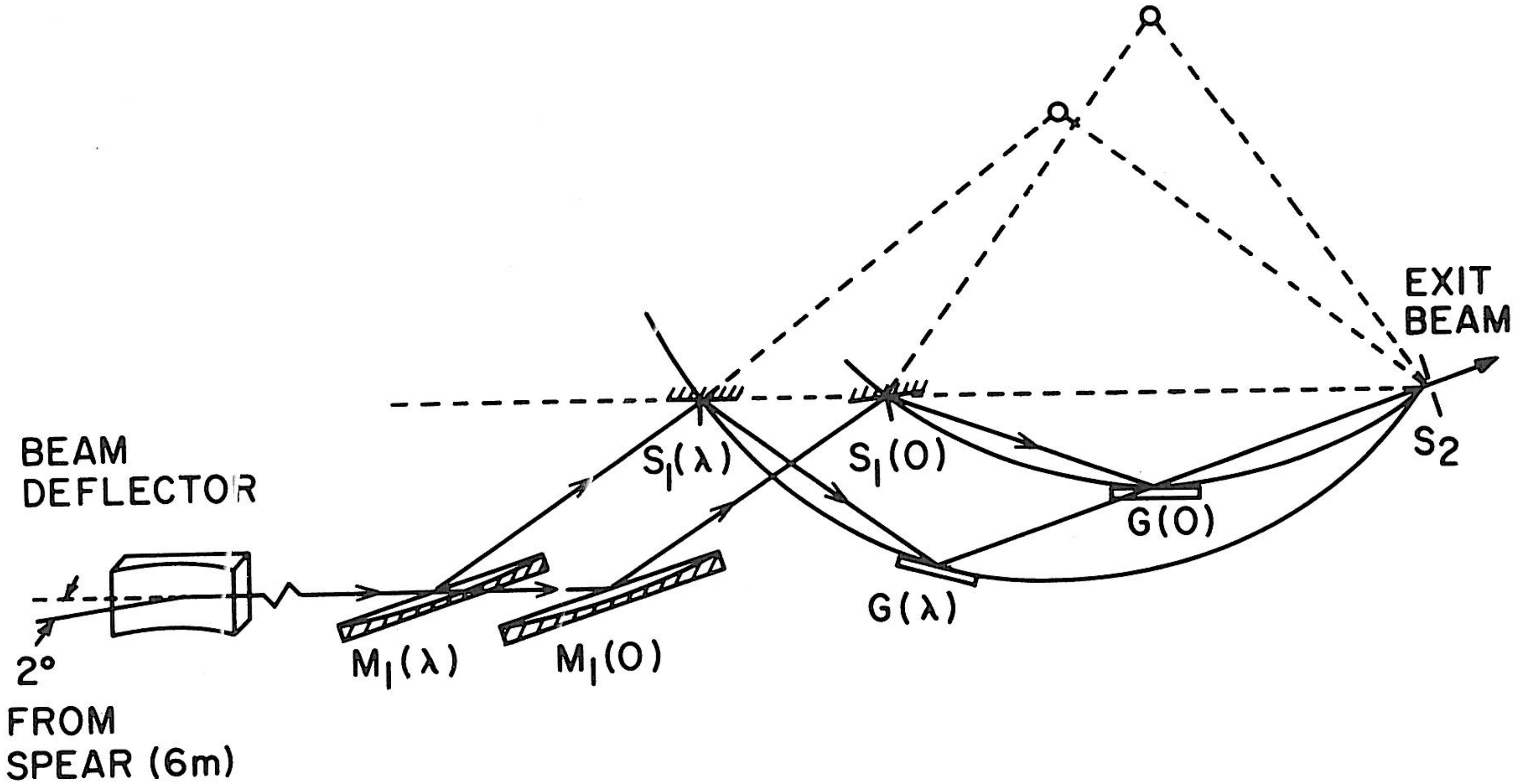


FIG. 47 4° **Beam Line Grazing Incidence Monochromator.**

The first mirror M_o (copper-platinum coated) has a spherical figure with 210 meter radius to focus the point in orbit onto the horizontal entrance slit of the monochromator located 16 m from orbit. It is maintained at about 30° C by either heating or cooling using thermoelectric devices. Cooling capacity to handle the full unfocused power of synchrotron radiation from SPEAR has been provided (200 W/cm^2). This mirror is inside the primary shielding wall but can be rotated and retracted under remote control.

The monochromator has been described by Brown, *et al.*[207] A drawing of the monochromator is shown in Figure 48. Its novel features include (1) scanning over a large range by means of toggle mechanisms and a precision air bearing; (2) fixed entrance and exit beams achieved by combining a Rowland circle-Vodar principle with a rotating mirror-entrance slit combination; and (3) all metal gasket, ultrahigh vacuum bellows construction. A vacuum of 2×10^{-10} torr was achieved before the grating was installed. The system normally operates in the mid 10^{-9} torr pressure range. The instrument is of rugged and durable construction and has high resolution and reproducibility.

A special valve has been developed to close off the exit slit of the monochromator when changing samples or accommodating different users. This is part of an ultrahigh vacuum sample chamber designed and built in the Physics Department at the University of Illinois. When the valve is open, a number of small samples or filters can be inserted in an intense monochromatic beam right at the exit slit of the monochromator. A mirror box with sublimator and ion pump is situated just downstream of this region. The exit beam can be highly focused at a point 1 meter from the exit slit by means of an adjustable toroidal mirror that is kinematically mounted in the mirror box. This design facilitates a variety of experiments, especially photoemission.

B. 8° BEAM LINE–NORMAL INCIDENCE MONOCHROMATOR

V. Rehn, U.S. Navy Michelson Laboratory, China Lake, California

The 8° beam line[208] is shown in Figure 49. The beam splitter mirror (M_o), which is located within the SPEAR shielding enclosure, is remotely positioned by three independent motors. Alignment is facilitated by the use of a mirror, view-screen system. A refocusing mirror installed after the monochromator exit slit reduces the spot size, resulting in an eightfold increase in flux density. One of four slit sizes may be selected without breaking vacuum. Significant polarization enhancement is achieved by selection of particular angles of incidence and by vertical deflection. This is described more fully in Section 3.2 of this report.

The photon flux available from this beam line is determined by three factors: SPEAR emission intensity, beam line acceptance angles, and beam line transmission. The emission intensity is essentially independent of SPEAR beam energy over the spectral range (4 to 70 eV) of interest here and, thus, is determined by the beam current. The solid angle of synchrotron radiation accepted is the product of the vertical (3.1 mrad) and horizontal (3.5 to 5.25 mrad, adjustable) acceptance angles subtended by the beam-splitting mirror M_o. The third factor, the transmission of the optical system, may be expressed as the product

$$T = R_o\ R_1\ R_2\ R_g\ E_g\ S\ D_g\ W\ ,$$

where R_i is the reflectance of the i^{th} platinum-coated, optical surface, E_g is the grating blaze efficiency, S is the entrance-slit function, D_g is the linear dispersion of the grating, and W is the exit slit width. From published values of platinum reflectance and typical values for the blaze efficiency ($E_g = 0.4$) and slit function ($S = 1$), we compute the transmission for $D_g = 8.33$ Å/mm and $W = 0.2$ mm to be 1.8% at 10 eV. Photoemission measurements on clean copper by A. D. Baer in June 1974, assuming a photoyield of 10^{-2}, set the value at $T = 1.2\%$. The absolute flux is about 1.7×10^9 photons per second per milliamp of beam current with a 2 Å band pass and 4.25 mr of synchrotron radiation. The normal-incidence reflections from the platinum-coated surfaces discriminate against the small fraction of light from SPEAR that is vertically

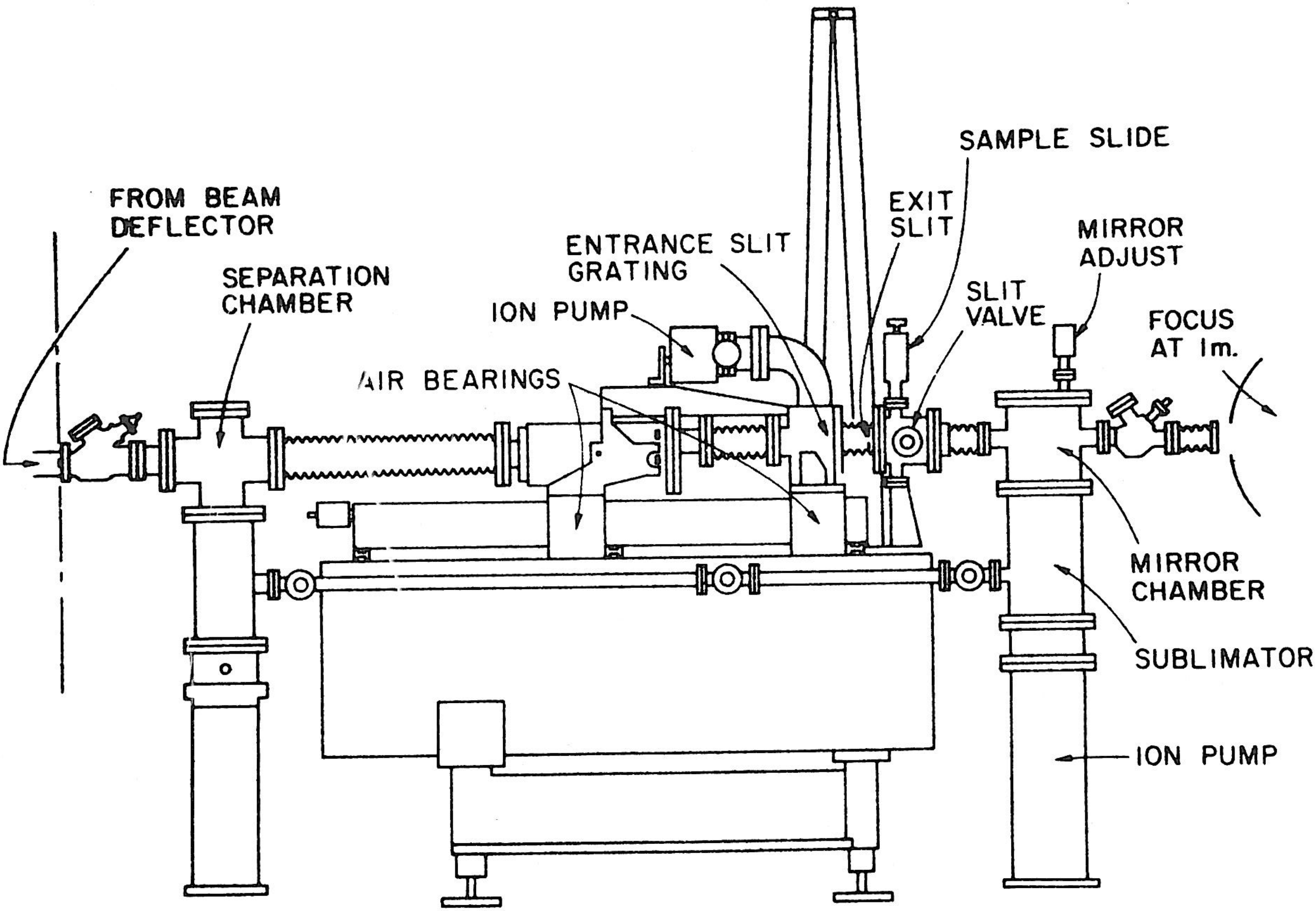


FIG. 48 **Drawing Of the 4° Beam Line and Normal Incidence Monochromator**

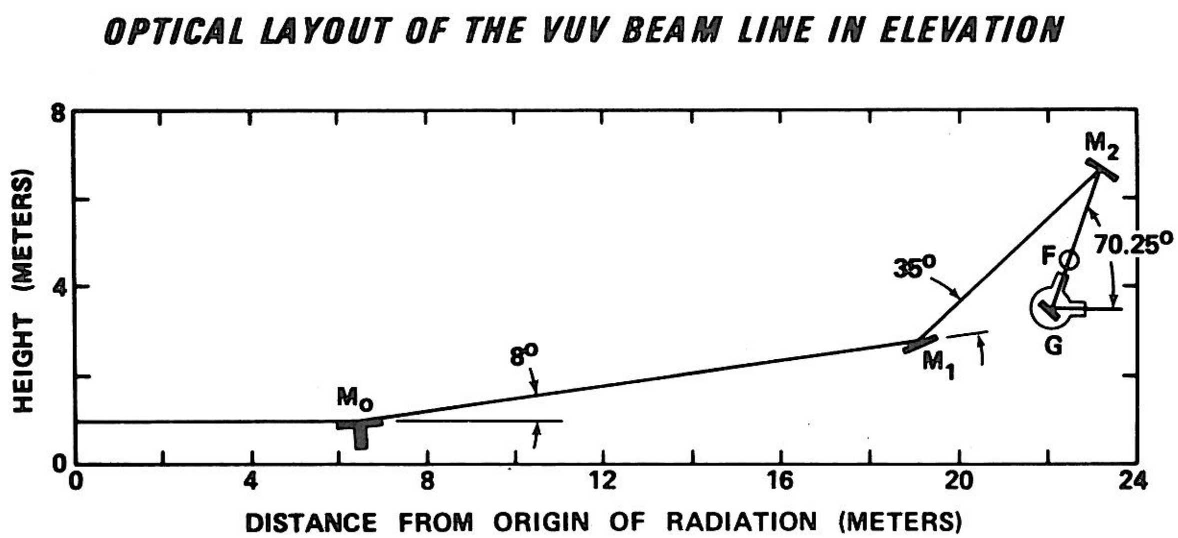


FIG. 49 Schematic Of the 8° Beam Line

polarized. This produces a polarization enhancement of a factor of 12 at the lower photon energies, resulting in a beam polarization of 97% or greater over the range of available energies. Preliminary reflectance data from platinum samples taken as a function of angle-of-incidence appear to confirm this enhancement.

Measurements of scattered light at the exit slit show that the fraction of unwanted light increases almost linearly from about 0.005 at 4 eV to about 0.02 at 20 eV. A sharp increase in scattered light occurs beyond this energy. The unwanted light results primarily from off-axis reflections of the zero order beam inside the exit arm of the monochromator. The $^1/_2$-inch diameter light pipe and detector in the reflectometer, some 15 inches beyond the exit slit, receives less than 1% of this scattered light.

The performance of the optical components in the line is near that of the theoretical expectations. We have measured the beam image size in the regions of the entrance slit and sample chamber where the cylindrical mirrors M_2 and M_1 focus the beam, respectively. The measured image height (Figure 50) of 0.18 mm at the entrance slit is less than a factor of two greater than the value predicted by the 0.097 magnification by M_2 of the vertical electron distribution in the SPEAR beam. Photographs of the beam at various distances from the exit slit (Figure 51) show the beam width to be in equally good agreement with values predicted from the design parameters of M_1 and the grating. The resolution of the monochromator with a grating having 1180 lines per mm and with 0.020 mm entrance and exit slit widths has been measured at the central image and at the 2536 Å Hg line. The value of 0.20 Å full width at half maximum is in good agreement with the calculated value of 0.198.

C. XPS BEAM LINE AND HIGH RESOLUTION X–RAY MONOCHROMATOR SYSTEM

I. Lindau, Stanford Electronic Laboratories and Stanford Synchrotron Radiation Project

The XPS monochromator gives a high-intensity, highly monochromatic x-ray beam[209] at a fixed photon energy of about 8 KeV (see Fig. 52). The crystal monochromator uses two flat Si[333] crystals in the parallel (nondispersive) mode. The first crystal accepts 0.5 mrad, or 6 mm (horizontally) of the radiation in the 0° beam line and diffracts it upwards at a Bragg angle of 45°. The total beam height is accepted, since the beam is highly collimated with little divergence. Thus, the diffracted beam forms an angle of 90° with respect to the horizontally incoming beam, and passes through a shutter system in the ceiling. The second crystal is positioned 2 meters above the first crystal (parallel), also at a Bragg angle of 45°, and brings the monochromatic beam to the horizontal plane. The first crystal is positioned inside the radiation shielding in the SSRP building. The shutter in the ceiling forms the entrance to the hutch containing the second crystal and experimental apparatus. A helium environment is used up to the second crystal. The crystal stages are provided with remote controls for position and angle. The crystal mounts are designed to allow for thermal expansion without disturbing the alignment. After having been exposed to the polychromatic x-ray flux for only a few hours the first crystal showed obvious discoloring, but no deterioration in diffracting properties was observed, even after several hundred hours of exposure. The monochromator is first aligned optically with a laser beam arrangement and then tuned to the rocking curve. The alignment is continuously monitored with a transmission ionization chamber after both the first and second crystals.

The source characteristics of the synchrotron radiation and its influence on the monochromator design will be discussed in detail by Pianetta and Lindau in a report now in progress. The main effect of the monochromator is to change the angular divergence of the incoming beam into an energy divergence according to the relation $dE = E \cdot \cot\theta \cdot d\theta$, which quite simply is obtained by differentiating Bragg's law, $\lambda = 2d \cdot \cos\theta$ and dividing by λ($d\theta$ is the divergence of the beam, E is the x-ray energy, and λ is the wavelength). The Si [333] crystals themselves have a small but finite diffraction width, which contributes to the overall energy

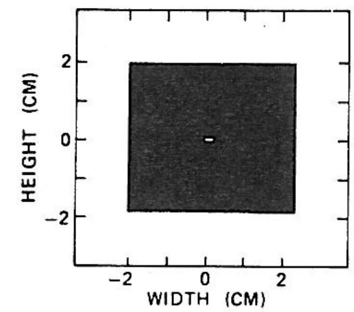


FIG. 50 **Image Height At the Entrance Slit Of the 8° Beam Line Normal Incidence Monochromator System.**

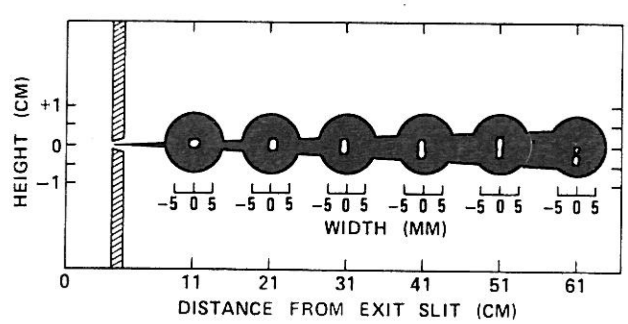


FIG. 51 **Beam Images At Various Distances From the Exit Slit Of the 8° Beam Line Normal Incidence Monochromator.**

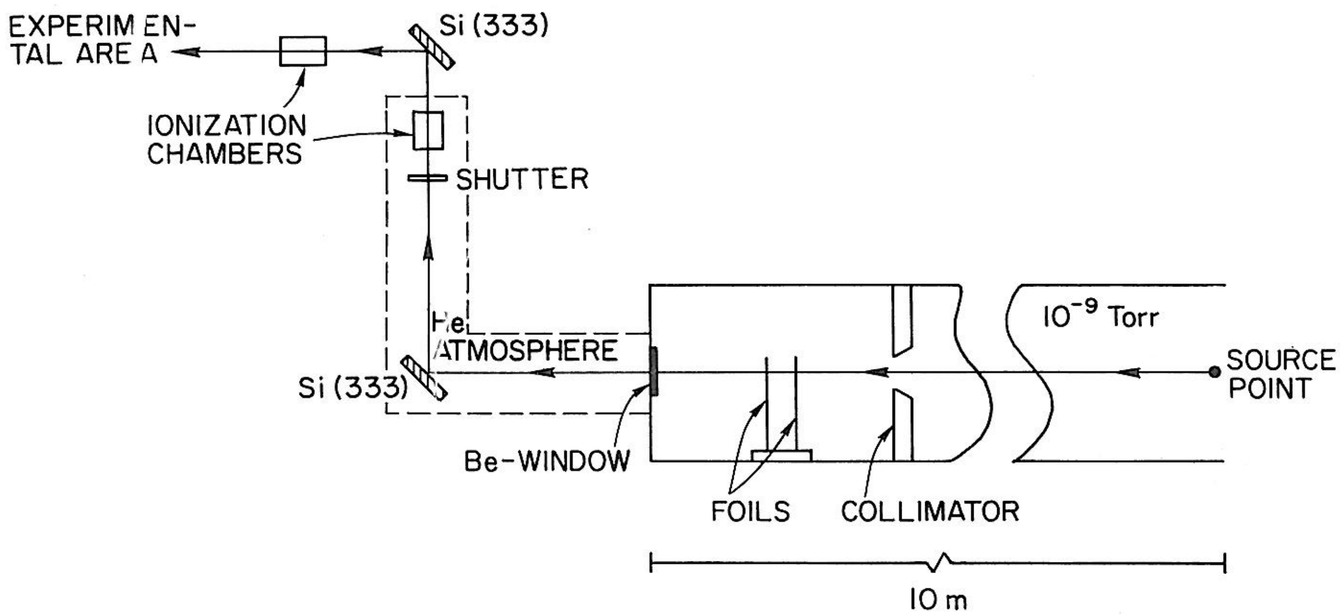


FIG. 52 **High Resolution, Fixed Energy X-ray Monochromator System For XPS Beam Line.**

spread of the monochromatic beam. This diffraction width is typically less than 10% of the beam divergence and, since it is added quadratically to the beam divergence, it will contribute less than 1% to the total divergence and can be neglected. A measured resolution of 0.1 eV at 8 KeV has been achieved with a 75 micron-high exit slit. The monochromator is presently operated with only the first Si[333] crystal to provide a well-collimated 8 KeV beam for small angle x-ray scattering.

D. BIOLOGY BEAM LINE AND FOCUSING MONOCHROMATOR SYSTEM

J. Baldeschwieler, A. Blaurock, R. Gamble, S. Samson, R. Stroud, N. Webb, California Institute of Technology

The biology beam line[210,211] utilizes 2.5 mrad of radiation and is shown schematically in Figure 53. It incorporates a 7 cm-long silicon crystal, cut at 8° 30′ to the [111] planes and bent to a logarithmic-spiral curvature, for horizontal focusing and monchromatization. A 120 cm-long, eliptically curved, float-glass mirror (see Figure 54) provides vertical focusing and elimination of harmonics. With SPEAR operating at 3.7 GeV, 20 mA in colliding beam mode, these optics produce a 0.5 mm x 0.5 mm focused beam with a flux of 4 x 10^8 photons/sec. The diffraction pattern of frog sciatic-nerve myelin obtained by using this system was compared to that obtained with a 300 watt conventional microfocus x-ray source and a toroidal camera. The new system shows a 190-fold gain in the integrated intensity on photographic film.

Vertical Focusing: The critical angle of reflection of 1.5 Å radiation from glass is about 14 minutes of arc. A two meter-long surface would be needed to intercept the full (7 mm) height of the beam. We only had a 120 cm-long sheet of float glass, which provided a 5 mm entrance aperture (height of interception) when in place. If curved cylindrically, a mirror of this length would show unacceptably large aberrations. Instead, the mirror was curved to an ellipse, which is capable of true point-to-point focusing. Aberrations resulting from the finite cross section of the source were reduced by focusing to the virtual x-ray source. The useful width of the mirror is about 5 cm, sufficient to intercept about 3.5 mrad of the radiation horizontally.

The overall size of the float glass used is 120 x 30 x 0.5 cm. This sheet was kindly donated to the project by the Libby-Owens-Ford Company. It rests on eight shims of adjustable height (Figure 54) and is held down on these by eight lead weights, one above each shim. Only two of the weights are shown in Figure 54. The set of eight shims rests on a granite block having a flat and smooth surface (a so-called surface plate used in instrument shops).

The curvature of the mirror is defined by the heights of the shims relative to each other. These differ by only a few thousandths of an inch but are adjustable in increments of about 10^{-5} inches. Each shim was manufactured to the flatness and parallelism of about ± 0.0001 inches, which is comparable to that of the supporting surface plate. The accuracies needed to achieve the correct elliptical curvature were calculated prior to manufacturing.

The assembly is set to the critical incident angle and aligned to the proper position with respect to the x-ray beam by moving the entire granite block by means of remotely controlled motors located below the surface. The reflectivity of the mirror deteriorated by about 50% after one year of use and was replaced by a new sheet of glass.

Horizontal Focusing: The crystal plate is set to deflect the x-ray beam horizontally. It is bent to a logarithmic spiral, which provides good horizontal demagnification of the source. For conventional sources, this focusing geometry is preferred to a cylindrical curvature because it increases the effective source size.

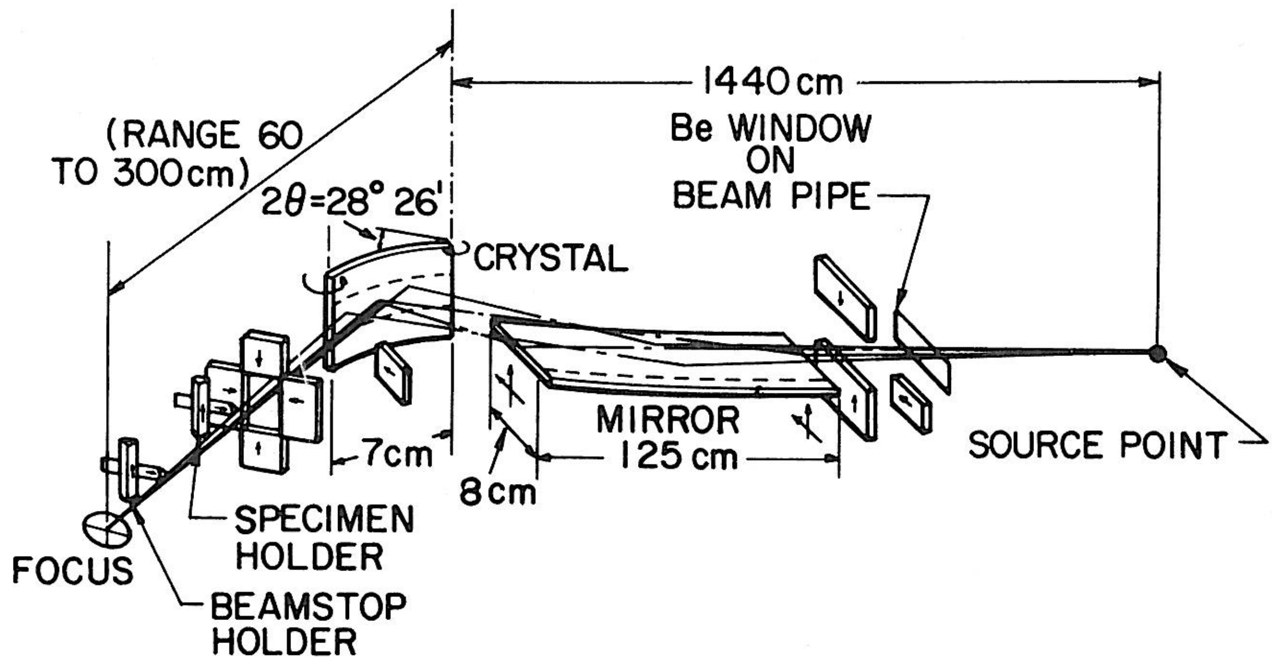


FIG. 53 **Schematic Of Double Focusing Mirror-Monochromator System For Biology Beam Line.**

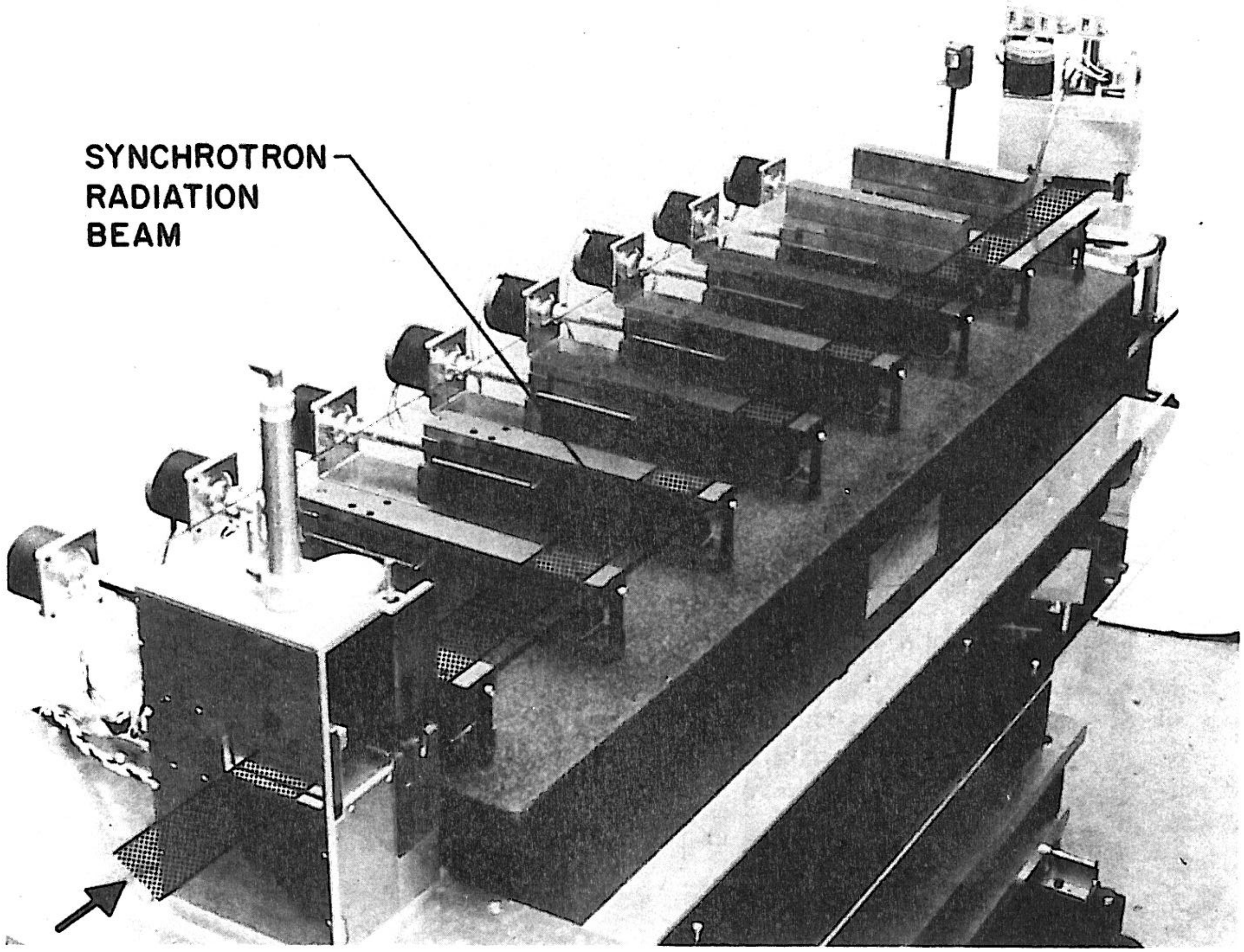


FIG. 54 **Photograph Of 1.25 m Long Grazing Incidence Focusing Mirror For Biology Beam Line.**

Demagnification obtained by the bent crystal is determined by the ratio of the crystal-to-source distance (1400 cm) and the crystal-to-focus distance (150 cm), which is in this case about ten to one. The crystal is cut asymmetrically to reduce the rate of convergence and, hence, the horizontal width of the beam at the specimen. Our system employs the silicon [111] plane. The crystal plate is cut 8°30′ to this plane.

The crystal-bending mechanism is positioned downstream of the mirror (Figure 53). The logarithmic-spiral curvature is achieved by applying separate and independent bending moments at the ends of the rectangular crystal plate. The system must remain clear of the radiation for other users. At each end of the crystal, a rigidly connected pair of rods is free to rotate under a linear push from a differential micrometer screw driven by a stepping motor. A horizontally-moving scatter guard is incorporated to shield off radiation scattered from the mirror and guard slits upstream.

E. EXAFS BEAM LINE AND CHANNEL–CUT CRYSTAL MONOCHROMATOR SYSTEM

Brian Kincaid, Bell Laboratories

The monochromator[212] is a channel-cut monolithic silicon crystal using the [220] Bragg reflection. Figure 55 shows the dimensions of the crystal and some important reflection angles. Good thermal conductivity, mechanical strength, superior radiation damage resistance, and availability in large single crystals from the semiconductor industry all make silicon a natural choice for the high intensity SPEAR x-ray beam. Monolithic design guarantees the crucial parallel alignment of the crystal planes necessary for this type of monochromator. There are no other critical alignment requirements in this design, allowing a simple crystal mount with a minimum of remotely controlled adjustments.

The parallel crystal arrangement is capable of high resolution because of the high degree of collimation of the synchrotron light. The energy resolution can be estimated by assuming that the SPEAR beam is just a very bright thermal source with no special optical properties. In this case, the energy resolution, as derived from Bragg's law, is

$$\Delta E \,/\, E = \cot\theta\,\Delta\theta \quad ,$$

where θ is the Bragg angle and $\Delta\theta$ is the angular divergence of the x-ray beam as determined by the source size, the slit height, and the distance from the slit to the source. Inserting the values for this experiment, a 1 mm slit 20 meters from a source about 0.5 mm high, using the [220] planes of silicon, one obtains a resolution of roughly 1 eV at 9 KeV, near the copper K-edge energy.

An added advantage of the parallel crystal arrangement is that the output beam of the monochromator is parallel to the input beam and is displaced from it by only an amount

$$\Delta h = 2d \, \cos\theta \quad ,$$

where θ is the Bragg angle and d is the spacing between the faces of the channel. This allows a simple tracking system to keep the output beam of the monochromator on a fixed spot on the sample, thus reducing sample nonuniformity problems. With proper choice of crystal dimensions, it is possible to scan a wide range of Bragg angles using only a single axis of rotation and to cover an extended range above that by translating the crystal up or down to allow the diffracted beam from the second crystal to clear the first crystal for large Bragg angles. All other monochromator designs require considerably more complicated motions of the crystals, the sample, and the detector, without significant improvement in useful resolution.

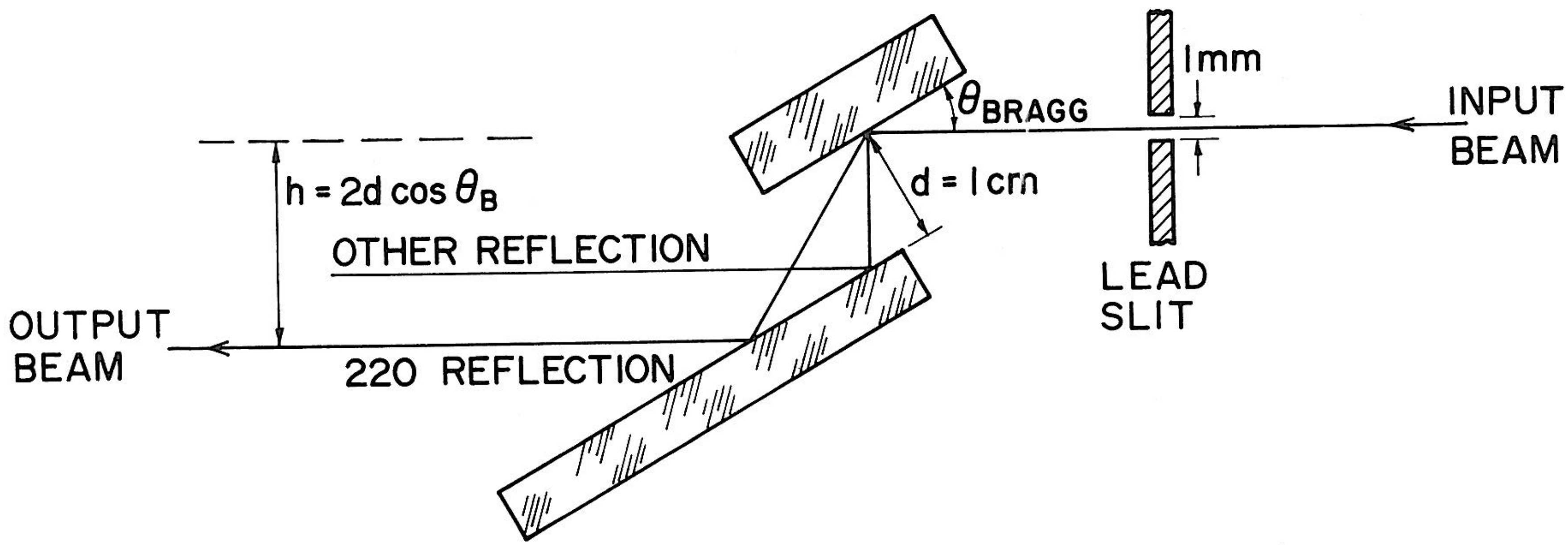


FIG. 55 **Channel Cut Silicon Crystal Monochromator**

A block diagram of the detector system is shown in Figure 56. The first ion chamber monitors the incident beam intensity and the second detects the radiation transmitted through the sample. The ion chambers are essentially gas filled capacitors through which the x-ray beam passes producing ion pairs. Electrons collected on one of the plates produce a current in the nanoampere range, which is converted to a voltage in a preamplifier. This voltage then drives a voltage controlled oscillator whose output frequency is measured by a dual channel gated scaler interfaced to the computer. The ratio of the contents of the scalers yields a number proportional to the absorption in the sample. The chambers are operated at atmospheric pressure using a gas flow system. Chamber 1, typically filled with a 90% to 10% neon-helium mixture, is 6 inches long, and chamber 2, typically filled with argon, is 12 inches long. Thus, only a fraction of the incident beam is absorbed in ion chamber 1 and virtually all the beam passing through the sample is absorbed in ion chamber 2. Entrance and exit windows are 6.5 micron aluminized mylar. The ion chambers have a large active area to minimize gain variation in response to beam position changes.

F. BEAM LINE II MONOCHROMATORS

One channel-cut silicon crystal monochromator system is now operating on Beam Line II. Two other systems are under construction which will also use a channel-cut crystal but will combine this with a focusing mirror to collect larger amounts of radiation. These systems are described in Section III. The entire beam line, including the monochromators, is being built to operate under vacuum. A pair of thin beryllium windows (initially with a total thickness of 500 microns) separate the storage ring vacuum from the beam line vacuum. Thinner beryllium windows now under development are aimed at achieving a total thickness of beryllium of about 85 microns(see Figure 57). Such a window would have good transmission down to about 2 KeV. At such low energies, evacuated beam lines are necessary since attenuation is excessive, even for helium, over a distance of several meters.

4.3 VERTICAL BEAM POSITION CONTROL

Because of the coupling between vertical electron beam displacement and vertical angle, very small variations in vertical electron orbit (<0.1mm) produce unacceptable changes in the position of the synchrotron radiation beam at the experiment. This is particularly true for x-ray experiments because of the small opening angle of the radiation at x-ray energies ($\theta_v \approx mc^2/E \approx 2 \times 10^{-4}$ at 2.5 GeV).

Experience at SPEAR has shown that the small changes in orbit from run to run and even the small drifts that occur during a run (both of which are acceptable for colliding beams) must be compensated at the synchrotron radiation source point.

This problem was anticipated in the design of the SSRP facility. A simple, accurate, and reliable system was developed in cooperation with the storage ring physicists and engineers, for reproducing the vertical position of the synchrotron radiation beam. The system consists of a pair of coils (actually trim windings on quadrupoles) that produce horizontal dipole fields. The coils straddle the synchrotron radiation source point and are spaced by about 180° (about 15 meters) in vertical betatron phase.

Powered in series, these coils produce a local orbit distortion in the vicinity of the source point with a small residual (<5%) elsewhere in the ring. A position monitor located in the synchrotron radiation beam run produces an error signal when the beam is off center in the vertical direction. This signal is amplified and fed back to the power supply for the orbit correcting coils. Thus, minute variations in the position of the synchrotron radiation beam are automatically compensated. The beam is held constant to within ±0.25 mm at 22 m. All experiments are initially aligned to accept a beam in the SPEAR median plane. The need for frequent alignment of experiments is eliminated.

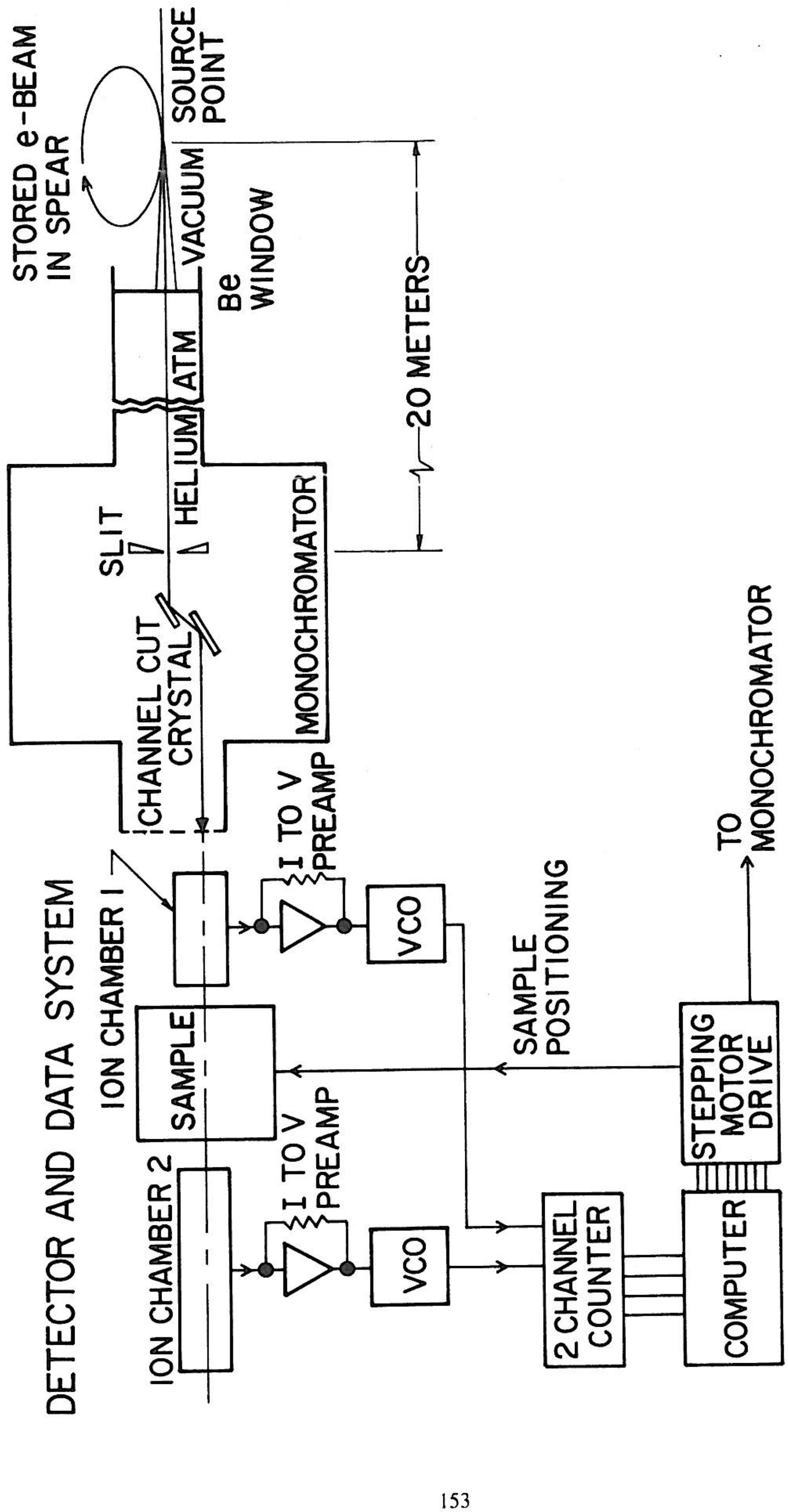


FIG. 56 **Block Diagram of EXAFS System**

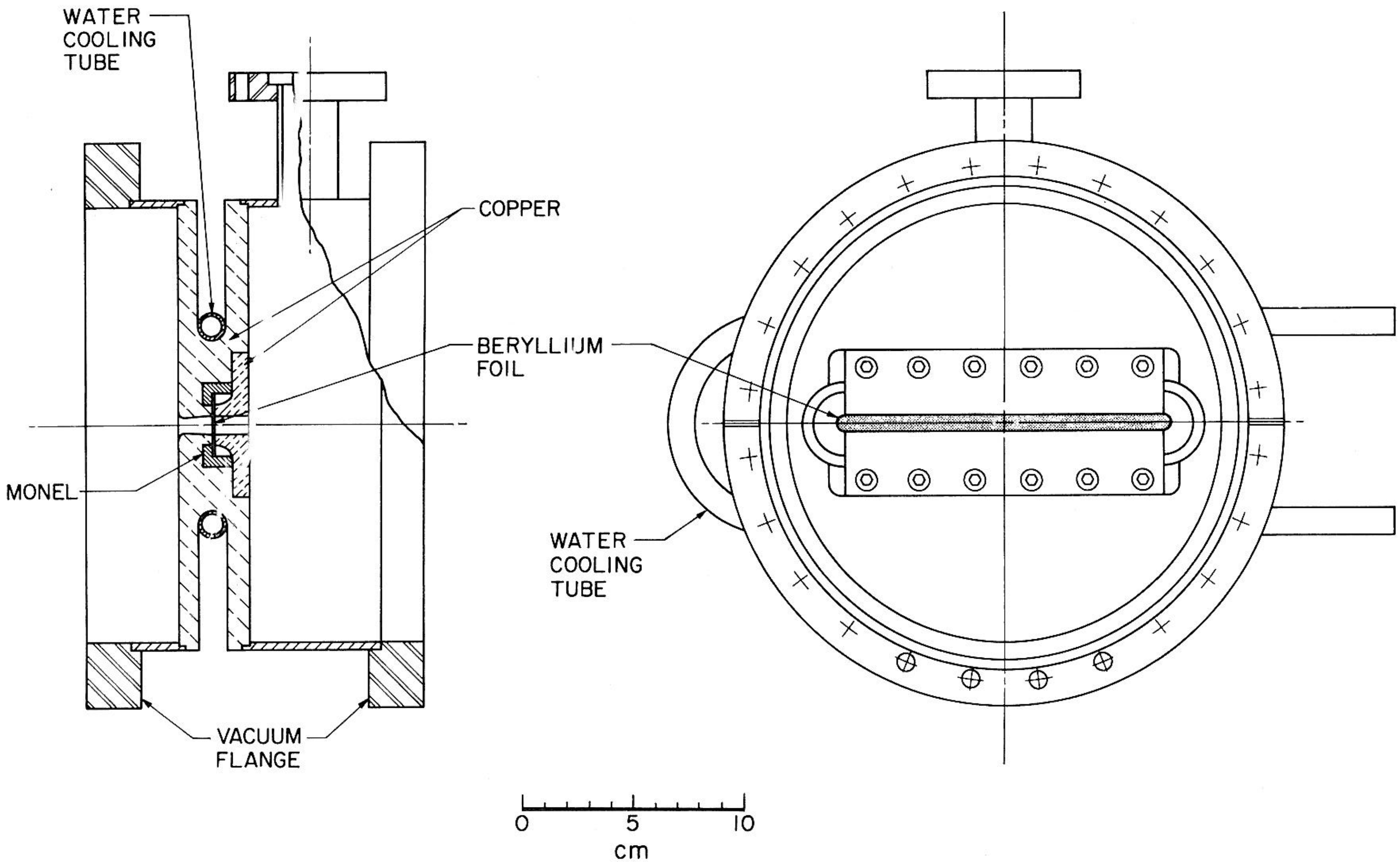


FIG. 57 **Beryllium Window Assembly**

The position monitor (shown in Figure 58) consists of a pair of copper photoemitting surfaces that are placed so that their leading edge is 6 mm above and 6 mm below the beam center line. The 12 mm gap between the plates is more than adequate to pass the x-ray beam. The UV radiation has a larger vertical opening angle and some of this will strike the copper plates causing photoelectron emission from the plates. The position monitor is placed downstream of the 4° and 8° beam splitter mirrors so it does not intercept any VUV radiation from these lines.

The photocurrent from the copper plates is collected and differentially amplified. The bipolar output voltage is used to control the current in the orbit correcting power supplies, nulling the position monitor signal and hence correcting the beam back to the median plane.

Compensation for differences in characteristics of the two plates is provided. The system is calibrated by positioning the beam on a fluorescent screen viewed by a TV camera. The image of the beam on the fluorescent screen is shown in Fig. 59.

4.4 VACUUM SYSTEMS AND CONTROLS

The beam line vacuum system is built to SLAC specifications[213] and is all metal and bakeable. All-metal gate valves can isolate the beam runs from each other and from the SPEAR vacuum system. A special all-metal, bakeable, fast-closing vane[214] is included in each beam line to minimize the effect of an abrupt loss of vacuum. This vane closes in about 20 msec. The system is designed so that synchrotron radiation in the main beam lines strikes only cooled surfaces.

With few exceptions (for example, beam splitter mirrors), all components were chemically cleaned and baked to 200° C before installation. Careful backfilling and purging with dry nitrogen is used during assembly and servicing of the vacuum system. In this way, bakeout is not required after initial installation.

The base pressure of the beam line vacuum system is 2×10^{-9} torr.

Ionization gauges and fast sensors[215] are used to detect leaks and desorption diodes[216] sense contamination. These devices are monitored by a vacuum control system that automatically closes valves in the event of vacuum problems. Under certain conditions (for example, water-cooling failure), the SPEAR beam is also dumped.

Figure 60 gives a block diagram of the vacuum control system. The vacuum system and control system have functioned well since operation started in May 1974.

4.5 RADIATION SHIELDING AND PERSONNEL PROTECTION SYSTEM

B. Humphrey, Stanford Linear Accelerator Center

To maximize accessibility to the radiation, shielding and a personnel protection interlock system were designed to permit access close to experimental equipment during all phases of SPEAR operation (filling, storing, and dumping of beam). Concrete, lead, and steel are used in sufficient thickness to guarantee that the highest possible radiation levels in occupied areas under worst case accident conditions are < 25 rad/h. Radiation monitors are set to dump stored beams and stop injection when radiation levels in occupied areas exceed 100 mrad/h.[217] A permanent magnet at 5.5 meters from the source deflects charged particles vertically so they cannot pass small vertical collimators and enter the SSRP building.

Protection against synchrotron radiation exposure is provided by thinner shielding (such as 1/8-inch steel sheets) adequate to attenuate the highest energy x-rays expected.

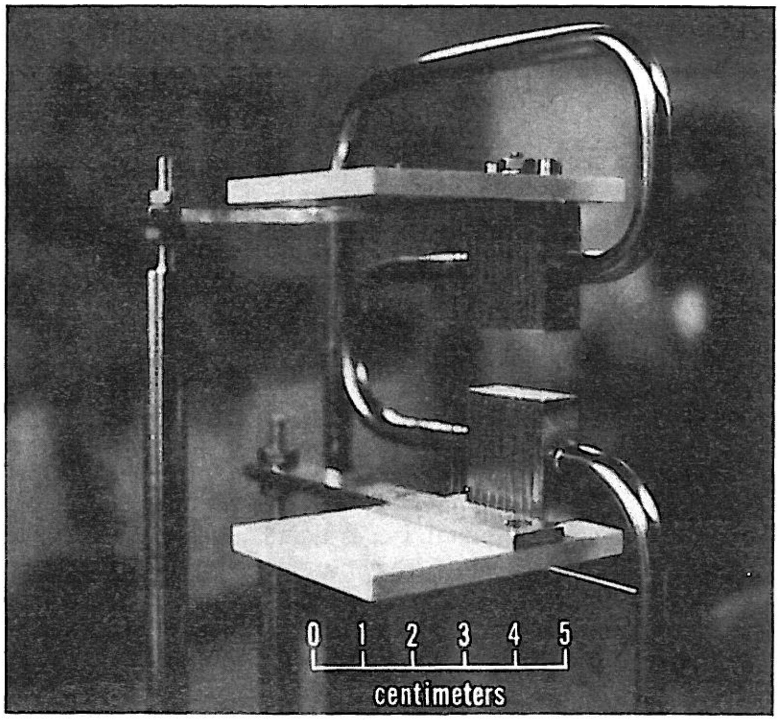


FIG. 58 **Synchrotron Radiation Beam Position Monitor.**

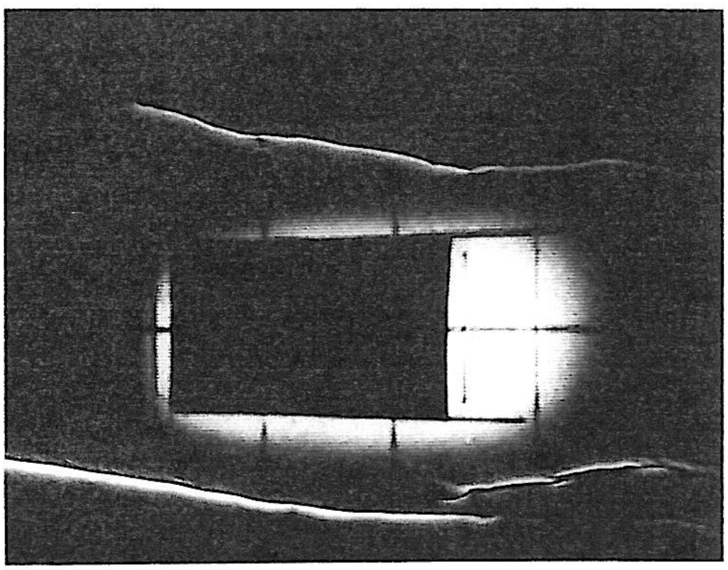


FIG. 59 **Image of the Synchrotron Radiation Beam on a Scintillation Screen at 22 m From the Source Point During Colliding Beam Operation. The Major Divisions On the Screen Are Spaced By 1 cm. The Black Rectangle Is a Cutout To Allow X-rays To Enter a Downstream Monochromator.**

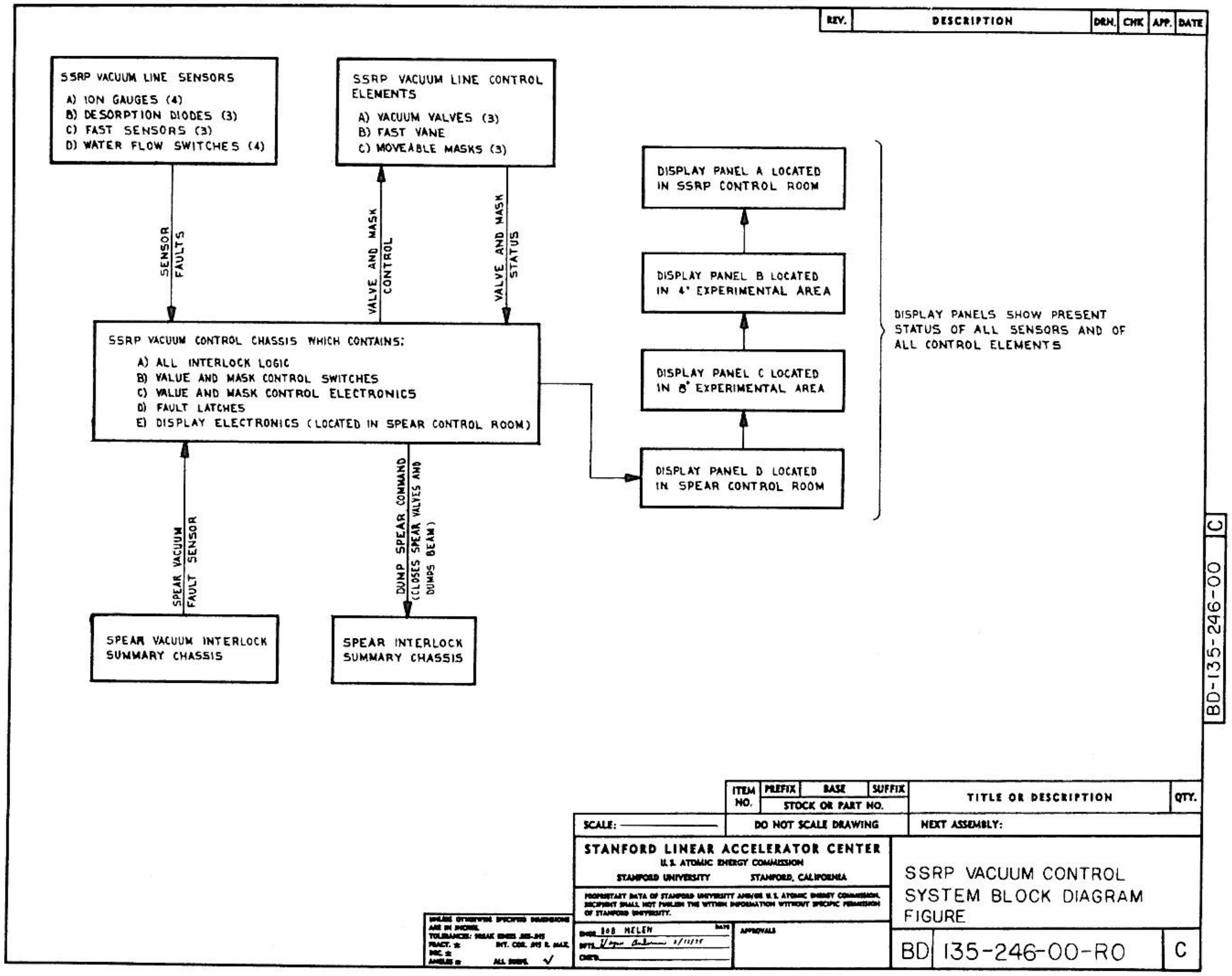


FIG. 60 **Block Diagram of Vacuum Control System.**

Access to the primary beam line area (along a tangent to the stored beam) is controlled by the SLAC operator in a standard manner used at SLAC. A pair of heavy shutters, each with redundant microswitches, must be inserted to block the beam before access is obtained. The SLAC operator logs the names of persons entering, observes the access on TV, and releases a key to open the door to the primary radiation area. All wiring to limit switches and key banks are in conduit used only for personnel protection circuits with the fewest possible cross connections within the system. Status panels are of the standard SLAC design. Telephone relays are used throughout and all circuits are hard-wired.

Beam splitting mirrors and diffracting crystals placed in the primary beam generate secondary beams that enter areas from which there is no direct view of the stored electron beam. Each experimental beam is provided with a pair of radiation stoppers. Secondary beam experimental areas are called hutches. Free space inside a hutch is inadequate for a person to be inside and still close the door. Thus, the problem becomes that of assuring radiation safety while providing convenient access to the interior of the hutch for purposes of setting up and adjusting detectors, samples and other instruments.

For the 4° beam line, only a minimal gate is required, permitting experimenters access to the monochromator and sample chamber through many openings in the gate with the beam on.

Early in the planning of SSRP, decisions were made in conjunction with the SLAC Radiation Committee to implement a self-monitored radiation area access control program. That is, each experimenter is permitted access to his hutch by means of his own control and interlock panel without requiring further permission from outside operators and independently of the condition of other synchrotron radiation secondary beam runs or of the SPEAR ring.

The Hutch Control and Personnel Protection Panel was designed on the basis of this requirement. This unit affords the experimenter the following control:

a. Beam Stopper Open/Close.
b. Ion Chamber Reset. Parallel-plate transmission ion chambers downstream of shutters are used in x-ray beams (which are not enclosed in vacuum systems) to insure that shutters have blocked the radiation.
c. Hutch Key Release (under safe conditions).

In addition, there is an On-Line/Off-Line keyswitch, the key to which is kept by SLAC Health Physics. In normal operation (On-Line) all interlocks are activated. When, from time to time, a hutch is disassembled this switch is turned to Off-Line after precautions are taken, and in this state only the Beam Stoppers remain as active interlocks.

The Hutch Panel receives inputs from the Stoppers (IN and OUT of the beam), from the Hutch Doors (OPEN and CLOSED), and from the Ion Chamber (OK or RADIATION ALARM). In addition, it keeps track of whether or not the hutch key is retained in the Solenoid Key Release Unit (a part of the Hutch Control Panel).

With this assemblage of status information from these external and internal sources, the Hutch Panel forms two separate and redundant interlock chains which, when violated (from, for example, Hutch Door being OPEN with radiation present or from several other possibly hazardous configurations), dump the stored beam and stop injection.

Similarly, the input status information is processed into a control signal which allows the experimenter to obtain the key to open his hutch door under safe conditions. If any of a number of unsafe conditions occur after this key is released, the Dump SPEAR interlock is tripped and the source of radiation eliminated.

The philosophy of design of the Hutch Panel embodies safety through redundancy. Relay logic (24 V) has been used throughout. Safety against failure has been achieved by creating interlock violations from any of the following: loss of power, uncabling, blowing of fuses, malfunctioning of single switches (for example, Hutch Door switches). Also, connectors are recessed so that electrical bypassing ("buggering") of interlocks is difficult.

Figures 61, 62, and 63 portray the system in two hierarchical levels. Figure 61 shows a block diagram of the SSRP experimental areas and associated devices. Figure 62 depicts the functional logics and status blocks that make up the interlocking of the Hutch Control and Personnel Protection Panel, the heart of the self-monitored radiation access system. Figure 63 shows the corresponding control block diagram.

This system has been in operation since May 1974 and has performed as expected.

4.6 EXPERIMENTAL SUPPORT FACILITIES

SSRP is developing a considerable general experimental support capability. The very extensive SLAC shops are also available to SSRP on a contract basis and have been extensively used for implementation of the beam lines.

A small, but fairly complete, machine shop is now operational in the new extension to the SSRP building. A lathe,* milling machine,* two drill presses,* two band saws, and two grinding wheels* are now installed. These machines are in regular use by SSRP staff in making modifications to experimental equipment and hutch enclosures, often during a 1 to 2 hour changeover of experiments on a beam line.

An electrical/electronics shop is equipped with general purpose electronic test and measurement equipment including scopes, digital meters, power supplies, TV cameras and monitors, and chart recorders. Also, two position-sensitive detector systems (one dimensional) complete with pulse height analyzers are available (one operational, one nearing completion) for use by experimenters.

A high vacuum shop now being set up will provide clean space for preparation of experiments on the vacuum beam lines and is equipped with a leak detector, residual gas analyzer, a test station and a variety of vacuum gauges and bakeout controls.

Also available for general use by staff and experimenters are a Cary 14 spectrophotometer and an Enraf-Nonius x-ray generator.

Under construction are a biochemistry laboratory room and an animal storage and specimen preparation room. These will be equipped with instruments, including a pH meter, centrifuge, analytical balance and a microscope. A photographic darkroom is under construction.

More specialized support services are available from SLAC on a paid basis. These include instrument calibration and repair, chemical cleaning, rigging, electronic fabrication, heavy mechanical and vacuum fabrication, vacuum welding and testing, precision alignment and vacuum installation. Extensive computer facilities at SLAC are also available to SSRP experimenters for off-line data analysis on a paid basis.

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*One of each of these items represent a donation by Stanford University.