LBL--25778

DE89 002914

The Advanced Light Source at Lawrence Berkeley Laboratory

Max Cornacchia

Accelerator and Fusion Research Division
Lawrence Berkeley Laboratory
1 Cyclotron Road
Berkeley, Caliafornia 94720

August 1988

THE ADVANCED LIGHT SOURCE AT LAWRENCE BERKELEY LABORATORY

Max Cornacchia and the ALS Project Team
Lawrence Berkeley Laboratory
1 Cyclotron Road, Berkeley, CA 94720

1. Summary and Introduction

The Advanced Light Source is a national user facility for the production of high brightness and partially coherent X-ray and ultraviolet synchrotron radiation, which is now under construction at Lawrence Berkeley Laboratory.

The facility is based on a low emittance electron storage ring, photon beamlines and user support facilities. The lattice optics is optimized for undulator operation and can accommodate up to 11 insertion devices in the straight sections and up to 48 ports in the bending magnets. The nominal electron energy is 1.5 GeV, the horizontal emittance 10^{-8} m rad, the circulating current 400 mA in the multibunch mode of operation. The parameters are chosen to cover the photon spectrum from about 5 eV to 1 keV with undulators and up to 10 keV with wigglers. The choice of energy is dictated by the need to cover the above photon energy range with an undulator gap not smaller than 1.4 cm.

The facility is now in its second year of construction and is planned to be completed in late 1992 at a total cost of $98.7 million.

2. Performance and Applications

The unique features of the ALS are the sharp spectral peaks from undulators providing ultra-high brightness beams of soft X-rays. These beams are at or near the diffraction limit, are focusable to the order of 0.1μm and are broadly tunable. The short pulses (typically 30-50 psec at a repetition rate variable from 1.5 to 500 MHz) offer unique opportunities for new scientific applications. The facility is designed for flexible operation, with multibunch and single bunch options to provide flexibility for user requirements.

The complement of insertion devices proposed for the ALS cover the VUV and soft X-ray region in an orderly and overlapping fashion. Figure 1 shows the spectral brightness

---

This work is supported by the U.S. Department of Energy Research, Office of Basic Energy Sciences, Material Sciences Division, of the U.S. Department of Energy under Contract No. DEAC03-76SF00098.

as a function of energy for 4 typical undulators, one wiggler and the bending magnet. As a rough guide, we assume that the useful operating range of an undulator lies between the energy of the fundamental at the largest achievable K value (for a minimum magnet gap of 1.4 cm) and the energy of the third harmonic at K=0.5.

The combination of a low emittance electron beam, short pulses and the use of long undulators will produce laserlike radiation of unprecedented brightness at XUV photon energies. This will provide a unique scientific tool to a wide field of basic and applied scientific research. For example, the high photon flux and short pulses will allow biologists to study the time evolution of some dynamic processes in natural biological samples, chemists to follow the steps in chemical reactions and material scientists to carry out spatially and time-resolved photoelectron spectroscopy. The quasi-coherent nature of the radiation at photon energies below about 1 keV can be used to carry out various forms of imaging experiments on subcellular biological samples. The characteristics of the radiation are particularly suitable to the application of lithography for chip fabrication, since the high photon beam intensity in a selectable spectral range, the collimation and the small source size minimize the resolution-limiting effects of the lithography process.

3. Accelerator Design Features

3.1 General layout and storage ring lattice

The layout of the accelerator is shown in Fig. 2. It consists of an injection system (a 50 MeV linac and a booster that raises the energy to 1.5 GeV at a repetition rate of 1 Hz). The nominal energy of the storage ring is 1.5 GeV, but the design allows operation between 1.0 and 1.9 GeV. The performance goals of the storage ring are a low beam emittance, long beam lifetime and flexibility of operation. A list of parameters is given in Table 1. The lattice chosen for the ALS is a triple bend achromat (TBA) with combined bending and gradient magnets[1]. One unit cell of the structure and the lattice functions are shown in Figs. 3 and 4. The layout has 12 straight sections, each 6.75 m long. Of these, one is reserved for injection, one for rf (where a short undulator can also be accommodated), and the rest are available for insertion devices.

3.2 Description of some accelerator components

Because of the bombardment of synchrotron radiation, the vacuum system represents one of the most challenging aspects of the design[2]. The arc vacuum chamber of is made of two halves of machined aluminum welded together. Figure 5 gives a view of a section of the vacuum chamber. The chamber geometry is such that the synchrotron radiation is intercepted by 96 photon absorbers lying outside the perimeter of the magnetic elements. The radiation emerges through a 1 cm slot that separates the chamber where the electron beam circulates from the radiation exit port. A titanium sublimation pump located underneath, and close to, the photon absorber intercepts most of the gas created by desorption. Modelling computations indicate that the designed vacuum pressure of 1 x 10^{-9} should be reached after an accumulated dose of 100 A-hr.

The storage ring magnets are of the C configuration to permit easy extraction of synchrotron radiation and to accommodate the vacuum chamber. The bending magnets are straight and contain a gradient component to focus the electron beam in the vertical plane. The design of the quadrupole and sextupole magnets are strongly influenced by the vacuum chamber geometry and installation. The sextupole magnets also contain horizontally and vertically dipole components (for orbit correction) as well as a skew quadrupole field. The laminated yoke is made of three sections, each incorporating two poles, to facilitate installation of the chamber.

Given the extreme sensitivity of the experimental apparatus to electron orbit movements, particular care is being taken in designing magnet supports that minimize vibrations.

The control system of the accelerator is based on a distributed, microprocessor based architecture that is bus-based and features parallel processing and a distributed data base.

4. Accelerator Performance Goals

The natural horizontal emittance at 1.5 GeV is 3.4 x 10^{-9} m rad. The predicted bunch lengths are in the region 25-50 psec (2σ values), depending on the charge per bunch. For multi-bunch operation the charge per bunch is small and the bunch length approaches the natural value (24 psec) determined by the lattice design and by the beam energy. As the current per bunch increases, as it may be required for single or few bunch operation, collective effects tend to increase the bunch length. The expected bunch length and lifetime under various conditions are given in Table 1 and have been reported elsewhere[3]. A beam lifetime of the order of 5-7 hours is expected, depending on the experimental conditions (undulator gap, charge per bunch, etc.).

The injection system is able to deliver to the storage ring single bunches or a train of bunches[4]. This flexibility allows the storage ring to be filled with any pattern, as it might be required by experimental conditions or in order to suppress ion trapping. The filling time for the multibunch case at the maximum design current (400 mA beam current) is less than 5 minutes.

The experimental conditions require a very high stability of the photon beam. For a throughput stability of 1% with a slit width equal to 2 standard deviations of the beam size image, the photon beam has to be stable to within 17% of one standard deviation. This corresponds to 6μ vertical positional stability for 10% coupling, implying a quadrupole stability better than 1μ for wavelengths of the order or smaller than the machine circumference. This degree of stability is not achievable without a look-and-correct procedure, and feedback systems will be used.

5. Insertion Devices and Beam Lines

The insertion devices are of the hybrid configuration, consisting of steel poles and permanent magnets. The minimum magnet gap, dictated by beam lifetime considerations, has been set at 1.4 cm.

Figure 6 shows the plan view of one sector of the storage ring with one beamline emerging from the port of one insertion device and four from the bending magnets.

It is envisaged that the insertion devices will be tunable, in the sense that the gap height, and hence the photon energy of the fundamental and other spectral peaks, can be scanned during data-taking. Because of the complexity of the feedback system and of possible cross talk amongst various interaction regions, some amount of "policing" by the machine control system will be required during this complex operation. A considerable operating experience will be required before this mode of operation can be fully implemented.

The design of the beam lines presents new challenges, particularly in the areas of optical fabrication tolerances and photon beam heating. The smaller source size requires tighter tolerances on the optical figure and finish. The photon beam power (up to several kW/sq. cm) has increased to the point where, in addition to tighter tolerances, optical components must be cooled to control thermal distortion and stresses.

One example of a possible beamline layout is shown in Fig. 7. Different wavelength regions are selected by rotation of the grating. Good focus is preserved throughout the scanning range by sliding the exit slit along the beam direction. The entire system will use only spherical optical surfaces.

Figure 8 shows a proposed beamline for X-ray imaging with an undulator of period 3.65 cm. The system is designed to cover the range 23-68 Å at the fundamental and down to about 7 Å using higher harmonics. The line includes a spherical grating monochromator that has only one grating with 300 lines/mm and uses the source as entrance slit. After some power reducing apertures, the beam impinges on the grating, which must be water cooled. The instrument has two fixed output arms each with an exit slit providing a fully tunable source over the entire wavelength range. The wavelength is scanned by rotation of the grating.

The specifications for the actual complement of insertion devices and beamlines are now being defined based on input from the user community. The first undulator being designed has a 5 cm period and covers the energy range 50-1000 eV. Insertion Device Teams (IDT's) and Participating Research Teams (PRT's), will help to determine the optimum characteristics of the insertion devices and beamlines. Letters of interest leading to proposals for IDT's and PRT's are being submitted by the user community.

6. Status and Plan

The project is on track for completion in the fall of 1992, at a total cost of $98.7 million. The Linac will be commissioned in 1990. The booster and storage ring commissioning will start in November 1990 and 1991, respectively. The key personnel and organization is in place. The major accomplishments this year have been the completion of the conventional facilities detailed plan, the decommissioning of the 184-inch Cyclotron and the disposal of the shielding blocks that surrounded the Cyclotron. Significant progress has been made in detailed engineering design of magnets, vacuum system, rf, survey, and beam instrumentation. The first booster dipole magnet prototype has been constructed and tested.

7. References

1 A. Jackson, "The Magnet Lattice of the LBL 1-2 GeV Synchrotron Radiation Source", Proc. 1987 Particle Accelerator Conference, March 16-19, 1987, Washington, D.C., IEEE Catalog No. 87CH2387-9.

2 K. Kennedy, "Vacuum System for the LBL Advanced Light Source", LBL-25291 and Proceedings of the AVS Topical Conference on Vacuum Design of Advanced and Compact Light Sources, BNL, Upton, NY, May 16-18, 1988.

3 S. Chattopadhyay and M. S. Zisman, "Calculation of Collective Effects and Beam Lifetimes for the LBL 1-2 GeV Synchrotron Radiation Source", Proc. 1987 Particle Accelerator Conference, March 16-19, 1987, Washington, D.C., IEEE Catalog No. 87CH2387-9.

4 F. Selph, A. Jackson, and M. S. Zisman, "Injection System for the LBL 1-2 GeV Synchrotron Radiation Source", Proc. 1987 Particle Accelerator Conference, March 16-19, 1987, Washington, D.C., IEEE Catalog No. 87CH2387-9.

Table 1: Summary of Major Storage Ring Parameters[a]

Nominal energy (GeV)	1.5
Maximum circulating current, multibunch (mA)	400
Maximum circulating current, single bunch (mA)	7.6
Natural horizontal emittance (m-rad)[b]	3.4×10^{-9}
Bunch length (ps), (2σ), at maximum current	
Multibunch (ps)	28
Single bunch (ps)	47
Peak Energy (GeV)	1.9
Beam lifetime, half-time	
Gas scattering[c] (hr)	13.3
Touschek, maximum current	
Multibunch (hr)	14.5
Single bunch (hr)	6.6
Filling time	
Multibunch, to 400 mA (min)	2.1
Single bunch, to 7.6 mA per bunch (s)	16
Circumference (m)	196.8
Orbital period (ns)	656.4
Harmonic number	328
Radio frequency (MHz)	499.654
Peak effective rf voltage (MV)	1.5
Number of superperiods	12
Insertion straight section length (m)	6.75
Length available for insertion device (m)	5
Injection energy (GeV)	1.5
Betatron tunes	
Horizontal	14.28
Vertical	8.18
Synchrotron tune	0.0082
Natural chromaticities	
Horizontal	-24.5
Vertical	-27.6
Beta functions at insertion symmetry points	
Horizontal (m)	11.1
Vertical (m)	4.1
Momentum compaction	1.59×10^{-3}
Damping times	
Horizontal (ms)	15.3
Vertical (ms)	21.5
Longitudinal (ms)	13.5
Number of sextupole families	2

[a]All parameters at nominal energy unless otherwise noted.

[b]Defined as $\varepsilon=\sigma^2/\beta$, where σ is the rms beam size and β the amplitude function.

[c]10-mm vertical gap, 1 n Torr N_2.

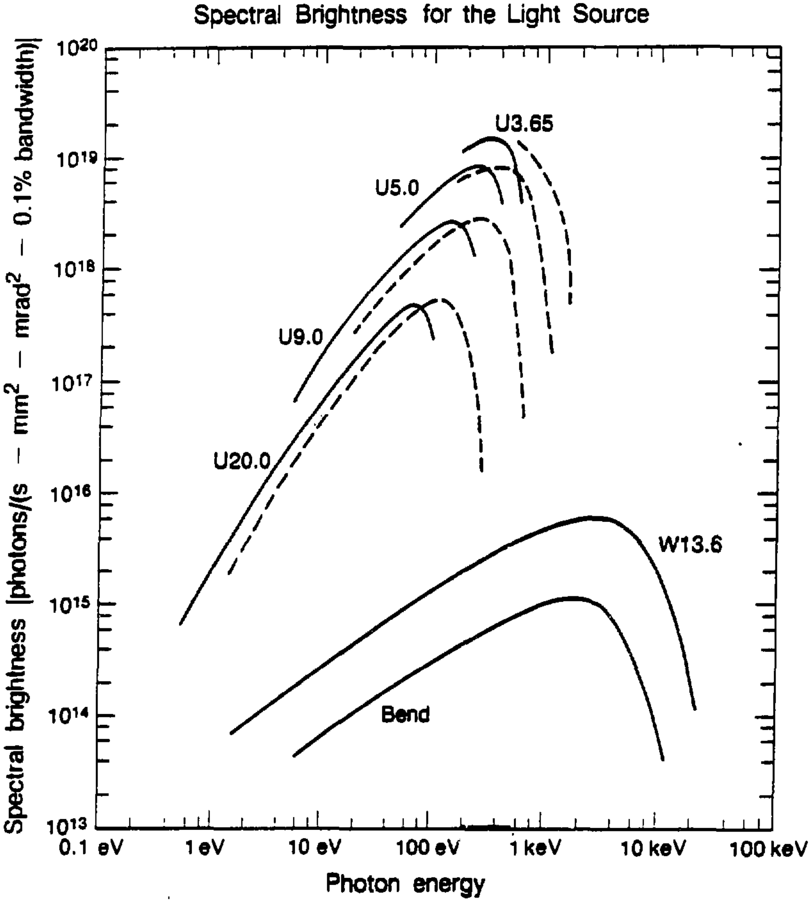


Fig. 1. Spectral brightness of radiation generated at the ALS.

- **For undulators, solid lines are the fundamental and the dashed lines are the third harmonic radiation**
- **E_e = 1.5 GeV, I = 400 mA, ε_x = 3.4x10^{-9} m-rad**
  ε_y = 3.4x10^{-10} m-rad

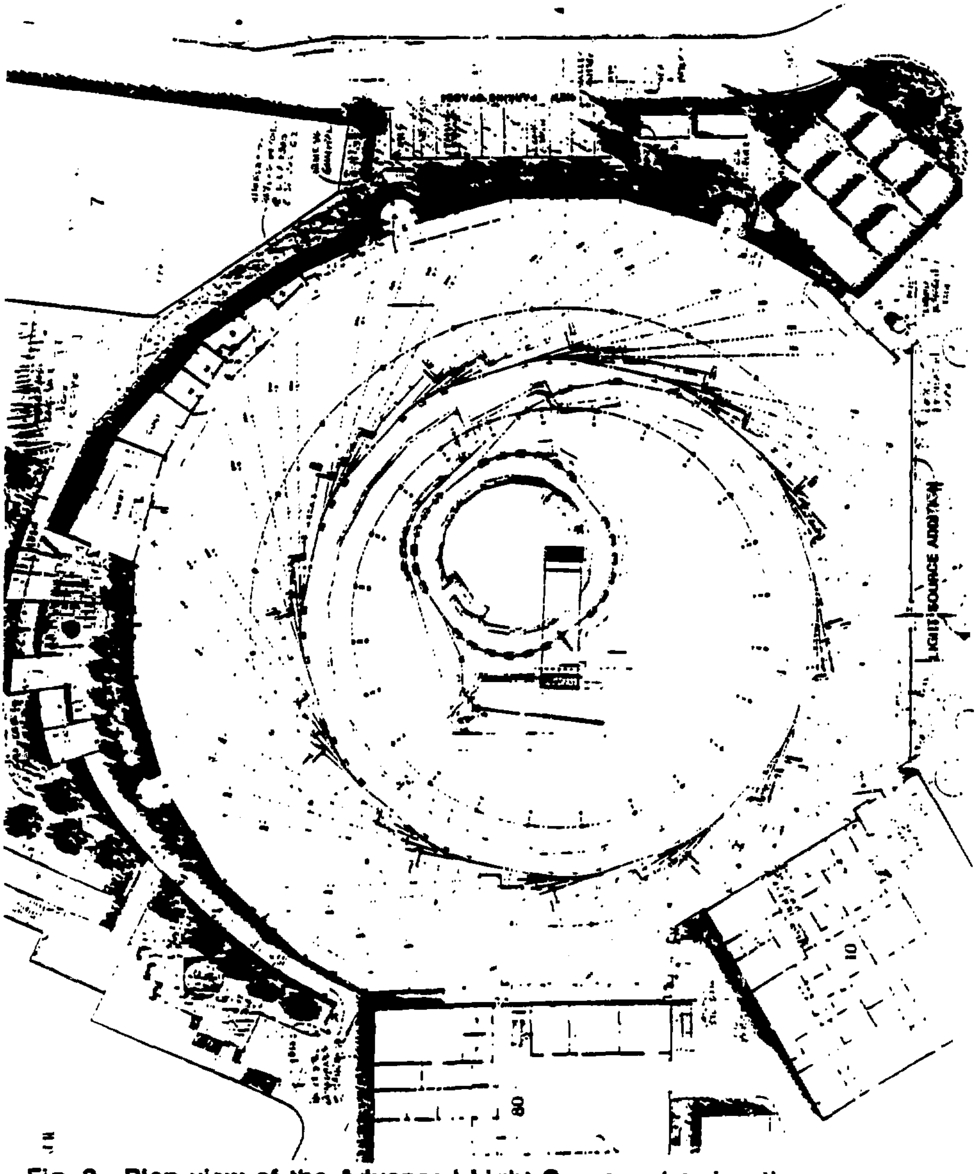
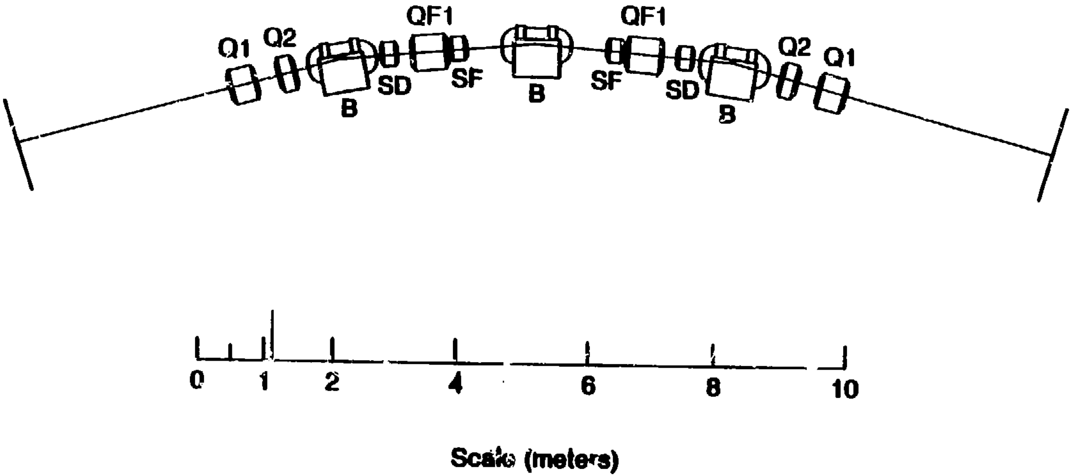
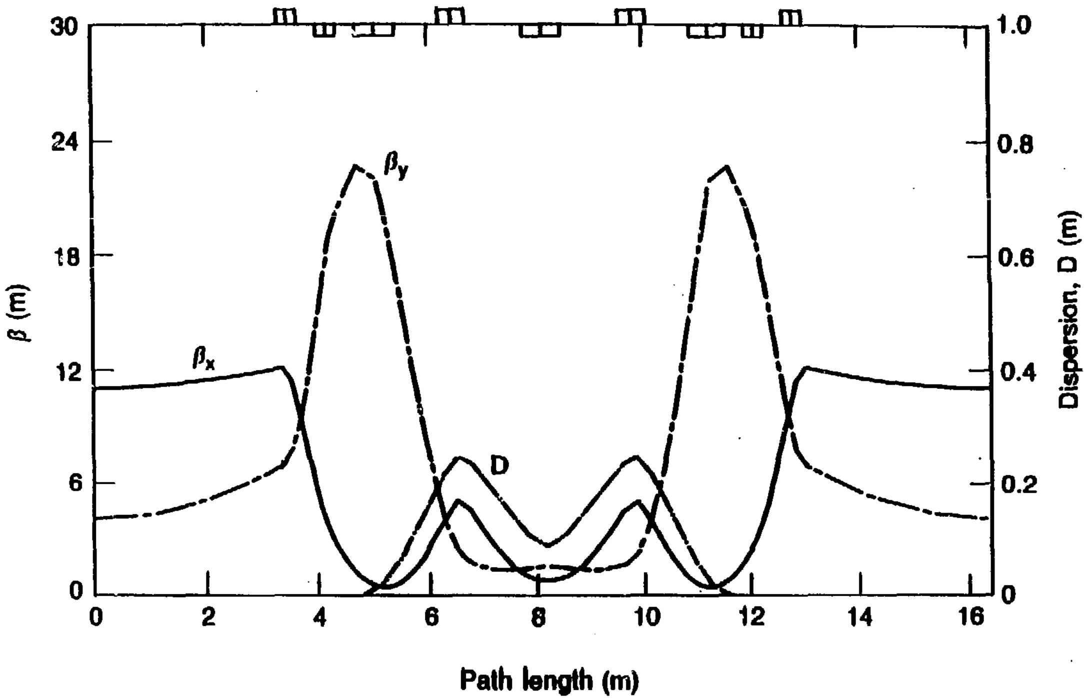


Fig. 2. Plan view of the Advanced Light Source, showing the beamlines emerging from the exit ports. The ALS will be housed in an enlarged version of the domed hall that was the home of the historic 184-inch Cyclotron.



XBL 8[illegible]6-6237

Fig. 3. One unit cell of the TBA structure.



XBL 866-6248

Fig. 4. Lattice functions through one unit cell of the TBA structure.

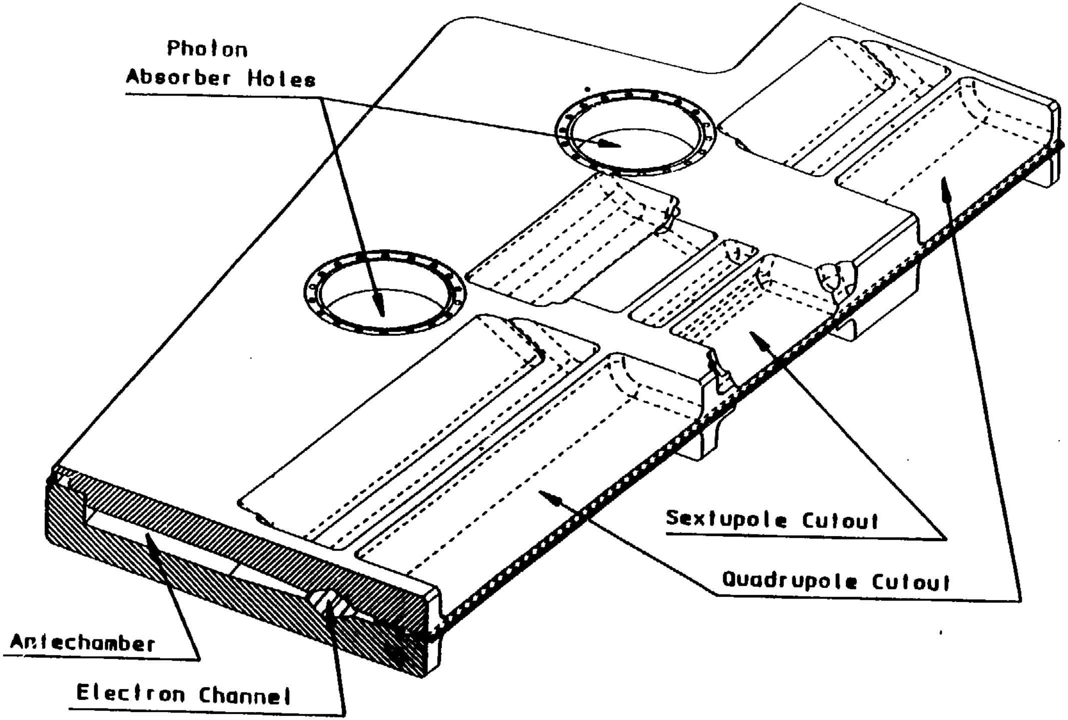


Fig. 5. Section of Vacuum Chamber.

XBL 885-1559

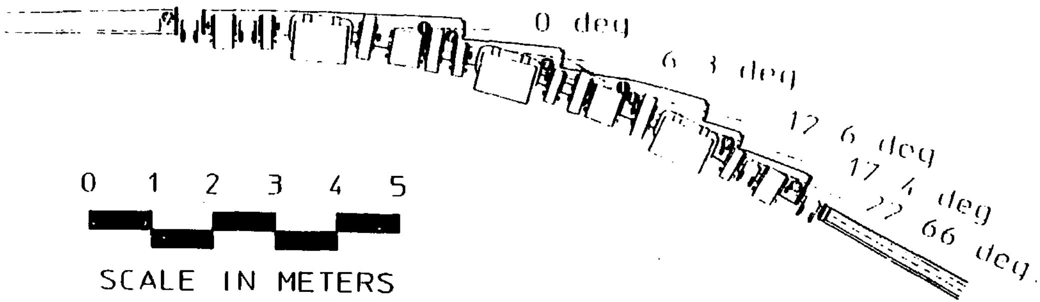


Fig. 6. Plan view of one sector of the storage ring, showing the port at 0° for the beams emerging from an insertion device, and four ports for beams emerging from bending magnets.

XBL 868-2852

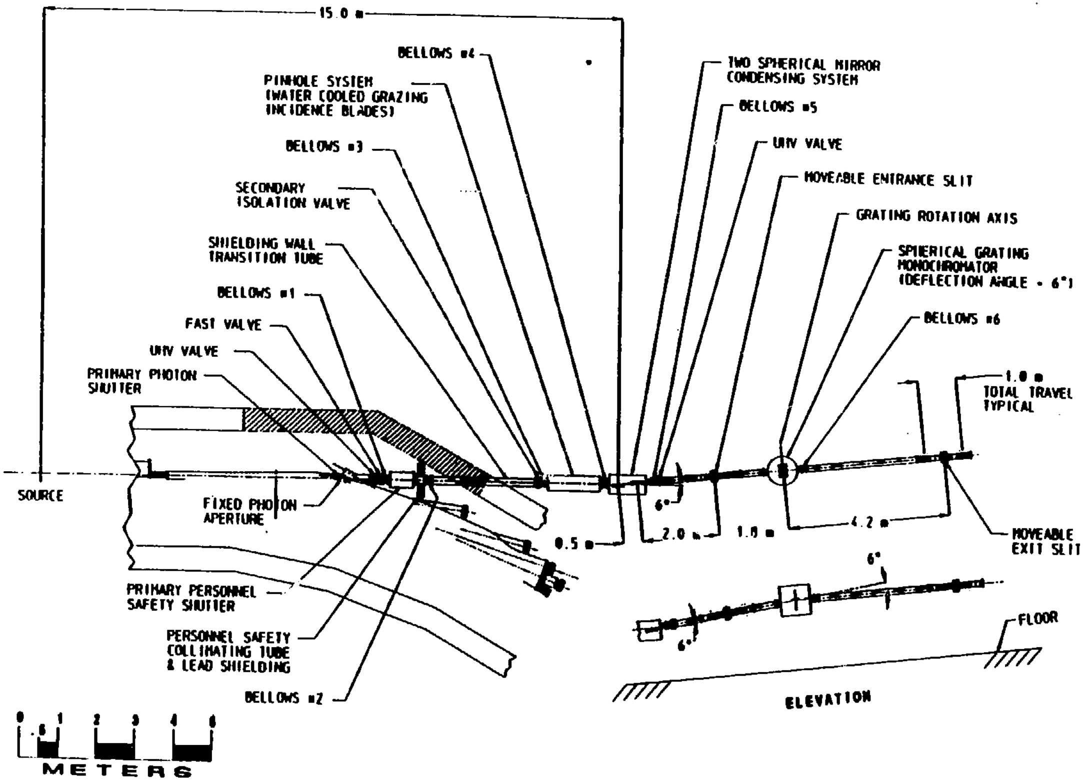
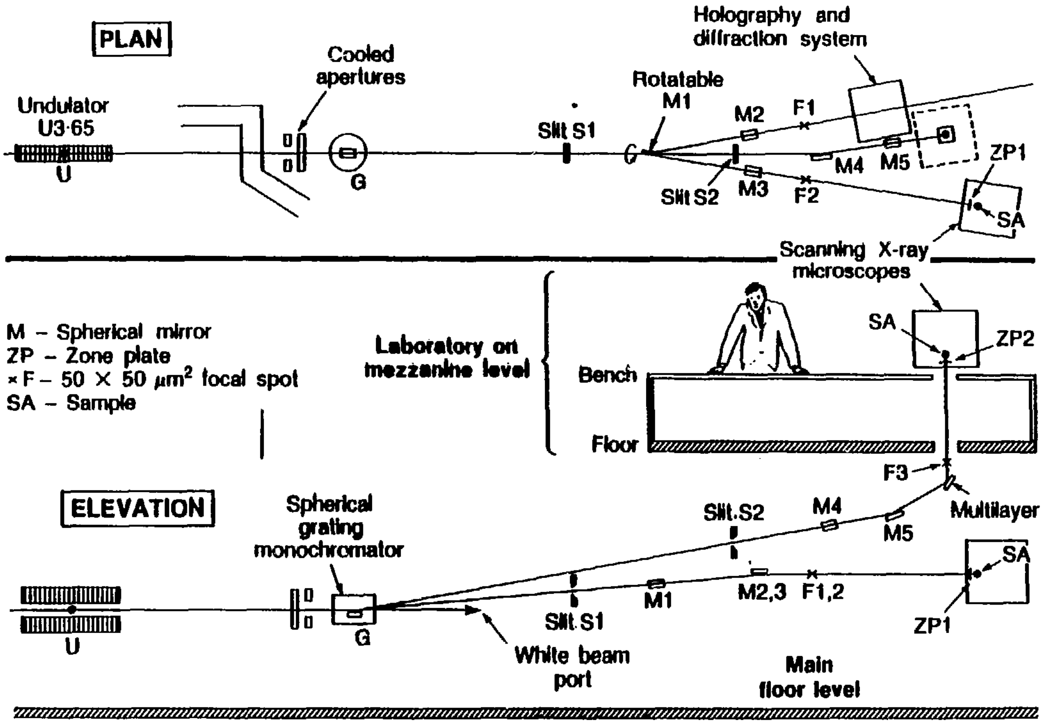


Fig. 7. Layout of a beamline from an undulator with 5 cm period and with a 3° spherical grating monochromator.

XBL 865-2044

PROPOSED ALS BEAMLINE FOR X-RAY IMAGING



XBL 884-8035

Fig. 8. Proposed beamline for X-ray emerging with an undulator for period 3.65 cm.