BRIGHT PROSPECTS FOR A 1- to 2-GeV SYNCHROTRON RADIATION SOURCE AT LAWRENCE BERKELEY LABORATORY*

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INTRODUCTION

A 1- to 2-GeV Synchrotron Radiation Source was included in President Reagan's budget request for the 1987 fiscal year. The good news came a few months after a meeting of potential users demonstrated the interest in, and need for, such a facility, and it culminated four year's work on the project at Lawrence Berkeley Laboratory.

BRIEF HISTORY OF THE DESIGN

The design work for a 1- to 2-GeV light source at LBL began in early 1982. The basic concept was a source of ultraviolet and soft x-ray radiation that would make extensive use of wigglers and undulators. These special magnetic devices are characterized by transverse (i.e., perpendicular to the longitudinal momentum of the electron beam) magnetic fields of alternating sign, which impose an "undulating" trajectory on the electron beam. This results in the emission of intense

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radiation. In a wiggler, the distribution of the radiation is smooth and wide, similar to but much more intense than that obtainable from bending magnets and characterized by a higher value of critical photon energy. In an undulator (characterized by a weaker field), the interference effects of the radiation are important, and the synchrotron radiation is compressed in a series of narrow spectral peaks of extremely high brightness. This radiation is also very close to diffraction limitations and therefore has good coherence properties. Circularly polarized radiation can also be obtained from a crossed undulator.

The design work resulted in a Conceptual Design Report published in March 1983 and, in an updated form, in April 1984. The basic parameters of the machine were very close to those recommended at the recent users meeting. This meeting, the "Workshop on an Advanced Soft X-Ray and Ultraviolet Synchrotron Source: Applications to Science and Technology", was held on November 13-15, 1985, in Berkeley, California. It attracted over 200 scientists and engineers from various universities and research centers in the U.S. and abroad. A wide field of scientific disciplines was represented, all sharing the common goal of exploiting the high brightness and coherence that would be available from a new generation of light sources and insertion devices. Those in attendance divided themselves into six topical working groups: atomic and molecular science; biology and medicine; chemical dynamics; materials, interface, and surface science; industrial research and technology; and new techniques and opportunities.

At the end of the Workshop, the working group leaders met to discuss the optimum parameters for a facility that would meet their needs. There was agreement[1] on the following set of parameters, which, while presenting a challenge to the accelerator designers, appear to be within reach of the existing state of technology:

Beam Energy	1.5 GeV
Average Current	400 mA
Horizontal Emittance	$<10^{-8}$ π m-rad
Number of Straight Sections	12
Straight Section Length for Insertion Devices	6 m
Bunch Length (2 sigma)	20-50 ps
Beam Lifetime	>6 hours
High Position and Angular Stability	
Minimum Longitudinal Jitter	
Flexible Modes of Operation (0.75 to 1.9 GeV)	

The conceptual design for the 1- to 2-GeV Synchrotron Radiation Source is now in the process of being optimized and updated in preparation for the start of construction design in fiscal year 1987.

DESCRIPTION OF THE FACILITY

The 1-2 GeV Synchrotron Radiation Source will consist of an injection system (linac plus booster synchrotron), a low-emittance storage ring optimized at 1.5 GeV, several insertion devices located in the storage ring straight sections, and beam lines from the insertion devices and bending magnets.

Lattice Design and Beam Dynamics

One of the most important aspects of the storage ring is the lattice, i.e., the optical arrangement of bending magnets and focusing quadrupoles in the storage ring. A high photon brightness requires a high-intensity electron beam of very small emittance. The minimum horizontal emittance which is achievable in an electron storage ring depends on the lattice. For a small horizontal emittance, a small physical beam size is required at the bending magnets, where the beam is focused to a small spot by quadrupoles. Unfortunately, the unpleasant side effect of the strong focusing is a worsening of the chromatic properties and the reduction of the "dynamic aperture" and, ultimately, a poor lifetime of the stored beam. The design of the lattice is a sophisticated task, requiring a careful analysis of conflicting requirements. In the course of a reevaluation of the possible lattices for the 1- to 2-GeV Synchrotron Radiation Source, several options have been examined. The "triple-bend achromat" lattice was chosen for optimization because of its capability for flexible operation.

The layout of one of the 12 superperiods of the storage ring is shown in Fig. 1. Each superperiod consists of a "dispersive region," where the bending occurs, matched to a straight section, 6.75 m long, reserved for undulators, wigglers, injection, radio-frequency cavities, and additional quadrupoles for special matching purposes. The straight sections are dispersion free, and the optics functions are optimized for high brightness.

The lattice of the 1- to 2-GeV Synchrotron Radiation Source achieves a very small natural emittance (4×10^{-9} π m-rad, rms value) with moderate focusing. This structure, called a triple-bend achromat because it incorporates three bending dipoles per superperiod, was first proposed by G. Vignola for a 6-GeV light source;[2] it replaces the Chasman-Green lattice originally selected for the 1- to 2-GeV Synchrotron Radiation Source. Optics and tracking studies have shown that the triple-bend achromatic structure offers greater flexibility and wider dynamic aperture than the original Chasman-Green type.

The 1- to 2-GeV Synchrotron Radiation Source will be the first storage ring where wigglers and undulators occupy a sizable part of the circumference. This fact presents the accelerator designers with a new set of optics and nonlinear dynamics problems, compared with those typical of more conventional storage rings.

The magnetic field of wigglers and undulators contain intrinsic linear and nonlinear terms. At LBL, we are engaged in a theoretical and computational study of the effects of these fields on the beam dynamics. Preliminary results indicate that the linear effects can be compensated for and that the nonlinear perturbations of the proposed wigglers and undulators are acceptable and should not pose a threat to the stability of the beam.

Vacuum System

A very important aspect of a storage ring devoted to the production of synchrotron radiation is the vacuum system. For a long lifetime in the presence of the reduced aperture of wigglers and undulators, a vacuum goal of 1×10^{-9} Torr in the presence of the beam is required. A major obstacle to the achievement of this goal is the desorption of molecules from the chamber walls. This is caused by photoelectrons, which are created by photons, hitting the walls. LBL has pioneered a new approach to this problem. Figure 2 shows the vacuum chamber configuration under consideration for the 1- to 2-GeV Synchrotron Radiation Source storage ring. The electron-beam circulation region is connected by a long, continuous slit to the adjacent pumping chamber, which also contains discrete water-cooled synchrotron radiation absorbers. The remarkable feature of this concept is that the gas is generated directly above the pump. Measurements and computations show that the presence of the antechamber has a negligible effect on the beam coupling impedance.

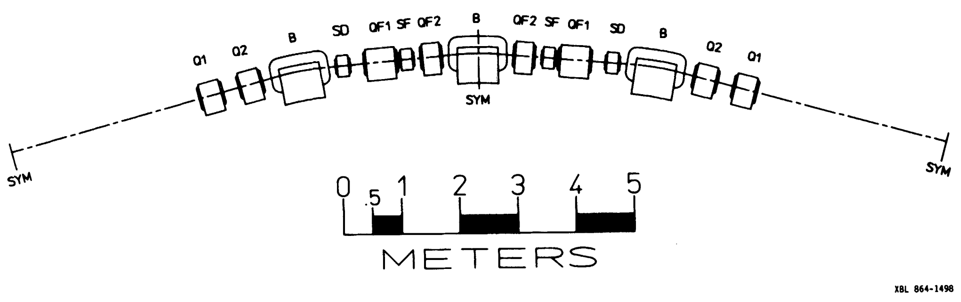

FIGURE 1 Latt'ce structure of one superperiod of the storage ring. The symbol B indicates combined bending and gradient magnets; Q1, Q2, QF1, and QF2 are quadrupoles; SF and SD are chromaticity sextupoles.

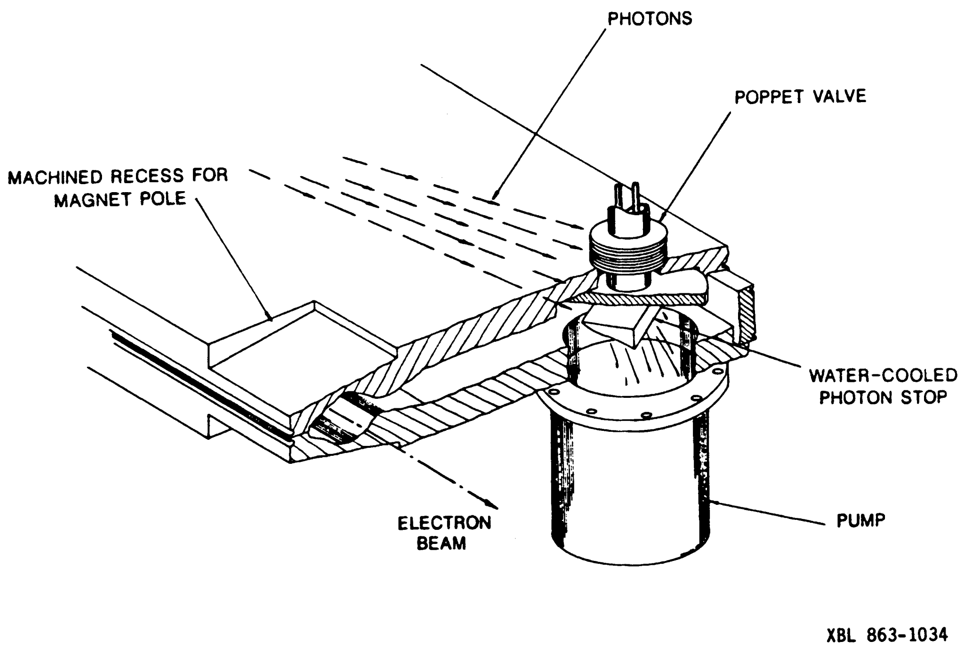

FIGURE 2 Storage ring vacuum chamber.

The injection system into the storage ring is currently under review. Several options are being considered. A likely layout is shown in Fig. 3. A 50-MeV linac injects the bunches into a booster, where the energy of the beam will increase to 1.5 GeV. Injection at the nominal operating energy of the storage ring is desirable for reasons of ease of operation and reproducibility of the experimental conditions. The storage ring has, however, the capability of accelerating electrons up to 1.9 GeV. For those experiments requiring operation at 1.9 GeV, the beam energy will be ramped from 1.5 to 1.9 GeV. The advantages and cost consequences of using positrons in place of electrons as a way to eliminate the problem of ion trapping in the storage ring are being studied.

To meet the needs of several categories of users, the design accommodates several combinations of insertion region optics and electron bunch structures. Short bunches are required by users in several areas; in biology, medicine, chemical dynamics, and materials and surface science, for instance, short bunches are needed to achieve short exposure times to permit dynamical studies. The 1- to 2-GeV Synchrotron Radiation Source will circulate bunches as short as 20 ps. Both multibunch (up to 250 bunches) and single-bunch modes of operation will be possible. The projected average circulating beam current for 250 bunches is 400 mA.

During operation, high positional and angular stabilities of the beam at the undulator and wiggler positions are very important. As an example, a positional stability of the order of 10% of the horizontal beam size is a performance goal. Sophisticated instrumentation and feedback systems will be required to guarantee this stability. Excellent reproducibility from fill to fill is also required.

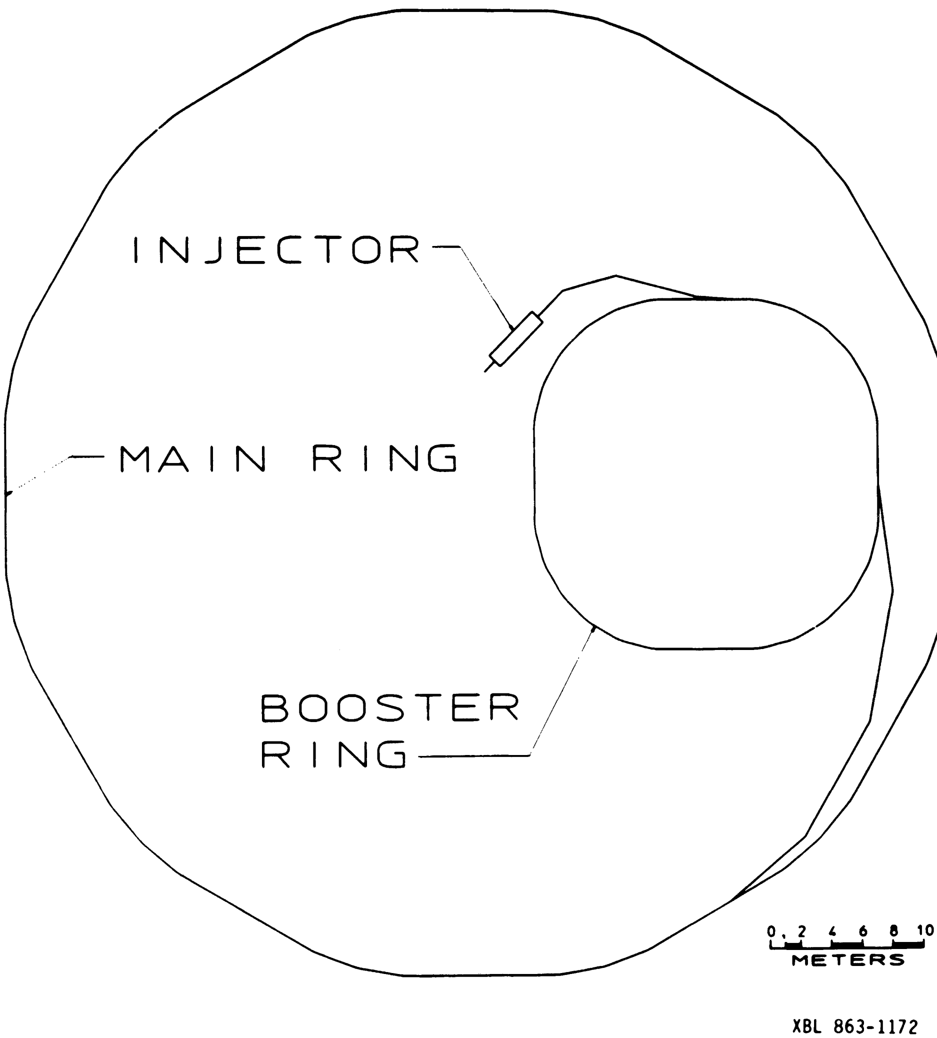

FIGURE 3 Schematic layout of the accelerator complex geometry, showing the injector (electron gun, bunching section, 50-MeV linac), the booster, the storage ring, and the transfer lines.

Several possible types of wigglers and undulators have been considered for the 1- to 2-GeV Synchrotron Radiation Source. There are 12 straight sections in the storage ring (of which 3 will be fully or partially occupied by the rf system, the injection system, and special beam diagnostics). A set of possible insertion devices is being considered, differing in period length, peak field, and number of periods. They are shown in Figs. 4 and 5, which depict the large photon flux and spectral brightness achievable at this facility, covering a photon spectrum from 4 eV to about 1 keV. The curves labeled with U's reflect the performance of the undulators, whereas W_E and W_F denote wigglers. Note the two-order-of-magnitude increase in the photon flux of wigglers, compared with that achievable from the bending magnets. Ultimately, a total of 48 beam lines will exploit the light coming from the bending magnets, thus making the facility accessible to a very large number of general users. Figure 6 shows the layout of the 1- to 2-GeV Synchrotron Radiation Source with its full complement of beam lines.

Just as the construction of the 1-2 GeV Synchrotron Radiation Source will require, in several aspects, a new level of ingenuity from the accelerator builders, so will the instrumentation for exploiting the radiation place new demands on its designers. The extraordinary performance of the source with regard to spectral brightness and time structure will create scientific opportunities which are almost entirely new and will need to be thought through from scratch. The time-resolved and coherence experiments belong in this category. One can also expect the development of a new generation of ultrahigh-resolution monochromators, as soft x-ray beams with greatly improved phase space properties become

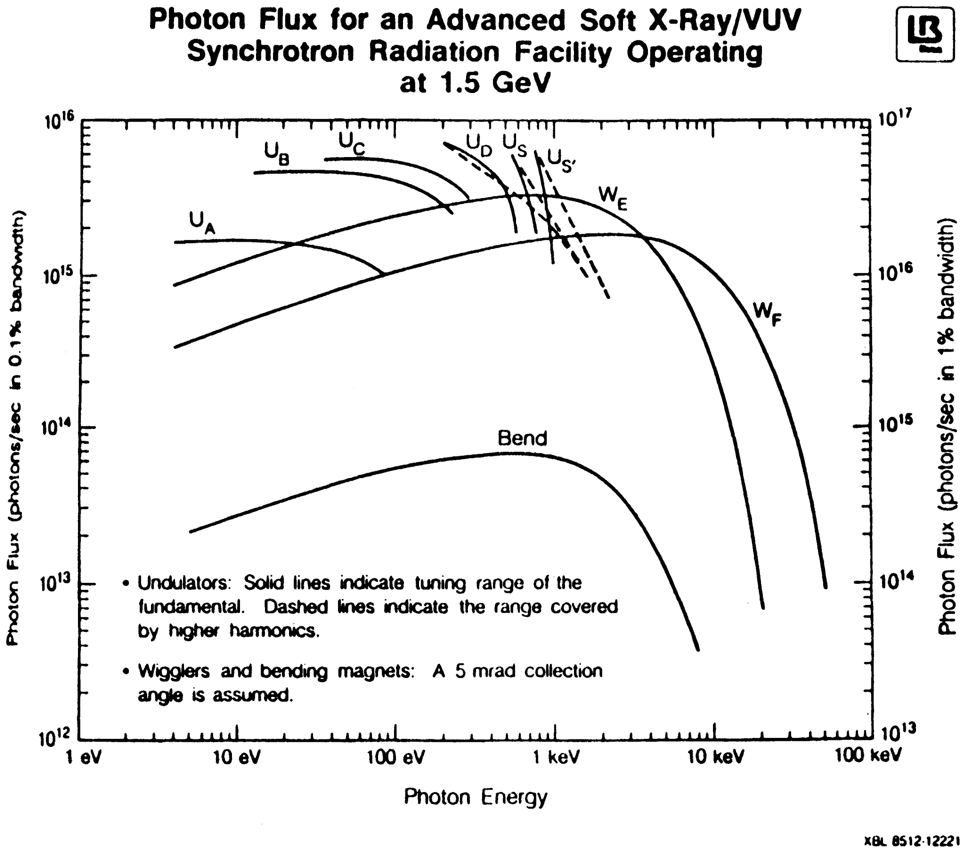

FIGURE 4 Photon flux for the 1- to 2-GeV Synchrotron Radiation Source operating at 1.5 GeV.

Spectral Brightness for an Advanced Soft X-Ray/VUV Synchrotron Radiation Facility Operating at 1.5 GeV

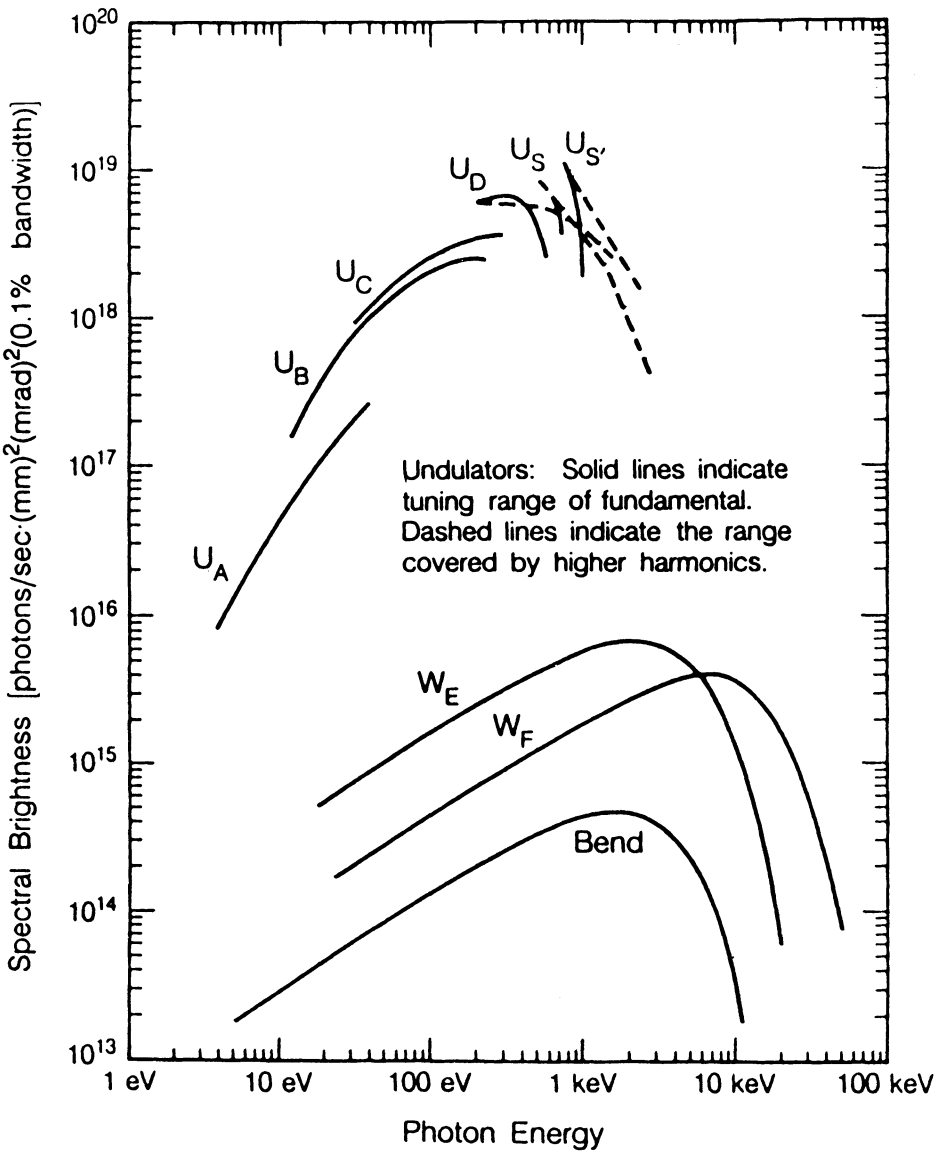

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FIGURE 5 Spectral brightness for the 1- to 2-GeV Synchrotron Radiation Source operating at 1.5 GeV.

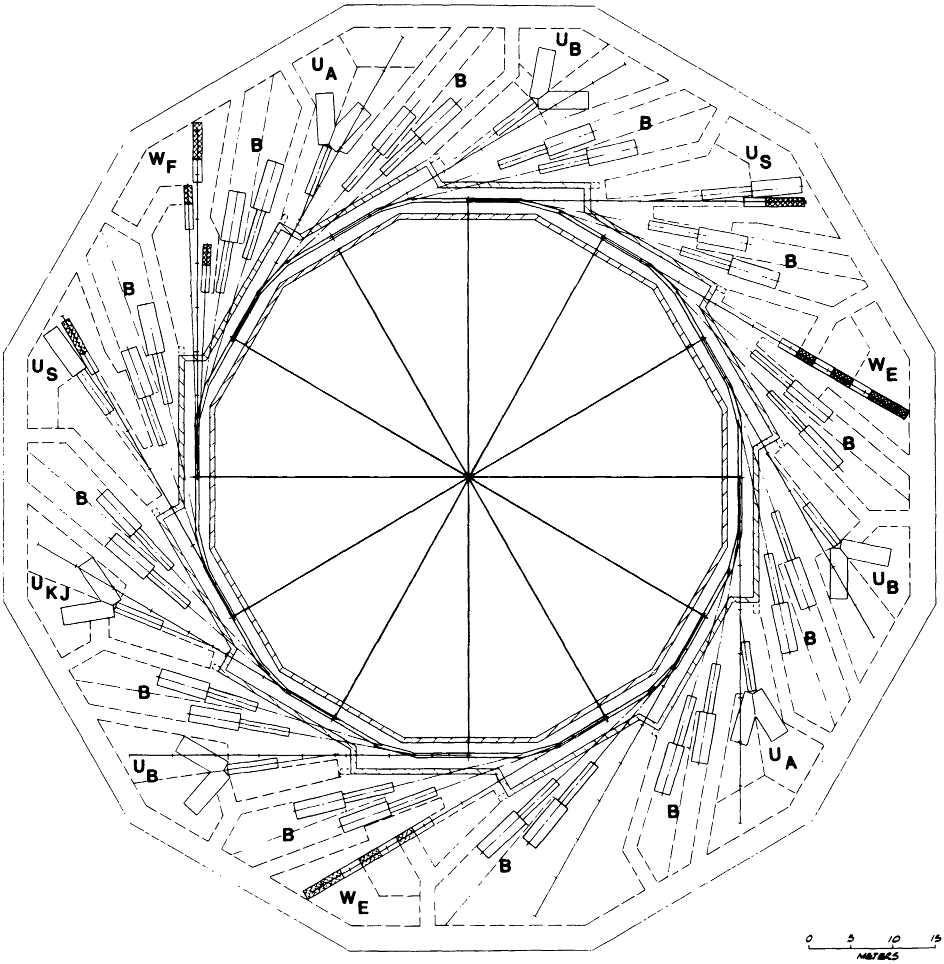

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FIGURE 6 Layout of the storage ring with its full complement of beam lines.

available.

All the beamline systems will have to be built with tolerances that are tighter than those in earlier machines, in order not to degrade the good geometrical properties of the beam. The optical designer will thus face the double challenge of achieving these tighter tolerances in the presence of an increased photon beam thermal load.

A Workshop on Optical Systems for a 1.5-GeV Synchrotron Light Source is being planned for the second half of 1986. The three-week Workshop will be held at LBL. Its purpose will be to study the technologies that might be applied to address the new problems in beam line design.

CONCLUSION

In addition to the advances in the quality of the radiation it will produce, the 1- to 2-GeV Synchrotron Radiation Source will break new ground in the number of users it will serve. Present plans call for 11 beam ports to be ultimately served by undulators and wigglers, and 48 to be served by bending magnets. Considering that all of these have the capability to be subdivided (branch lines) at least once, one can see that the 1- to 2-GeV facility and its user community will eventually become a multidisciplinary scientific institute of outstanding strength and diversity.

REFERENCES

1. Report of the Workshop on an Advanced Soft X-Ray and Ultraviolet Synchrotron Source: Application to Science and Technology, November 13-15, 1985, Berkeley, California, Lawrence Berkeley Laboratory PUB-5154, December 1985.
2. G. Vignola, "Preliminary Design of a Dedicated 6 GeV Synchrotron Radiation Storage Ring," Nucl. Instrum. Methods Phys. Res. A236, 414 (1985).