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Vol. 1 No. 1 Oct/1986

Light Source Report

Lawrence Berkeley Laboratory University of California

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NEWS OF THE 1–2 GeV SYNCHROTRON RADIATION SOURCE

Conceptual Design for the 1–2 GeV Synchrotron Radiation Source

Recent intensive efforts at the Lawrence Berkeley Laboratory culminated in June with a conceptual design report (CDR) for a 1–2 GeV Synchrotron Radiation Source. This report was favorably reviewed the following month by the Department of Energy (see page 2).

A CDR is a preliminary step to approval for construction of any major federally funded project. As a basis for review and planning, a CDR includes a self-consistent and credible facility design, a detailed cost estimate, and a proposed construction schedule. The conceptual design thus describes a thoroughly thought out and workable facility, but it also represents only the first step in arriving at a final design. Subsequent design refinements and a complete set of specifications will ultimately produce the detailed plans that actually serve as the basis for construction.

Results from research and development programs, as well as ongoing designer-user collaborations, will contribute to the evolution from conceptual design to preliminary design to final design. As an example, the design of the beam lines actually to be constructed will probably evolve during several more rounds of consultation with the user community and possibly the creation of partnerships that could lead to the development of more beam lines than currently proposed.

An artist's view of the facility is shown in Fig. 1. As described in the CDR, and as shown in Fig. 2, the facility consists of an injection system (comprising a linac and a booster synchrotron); a low-emittance storage ring that includes 12 straight sections and that is optimized at 1.5 GeV; five insertion devices (four undulators and a 2-tesla wiggler); five insertion device beam lines; and

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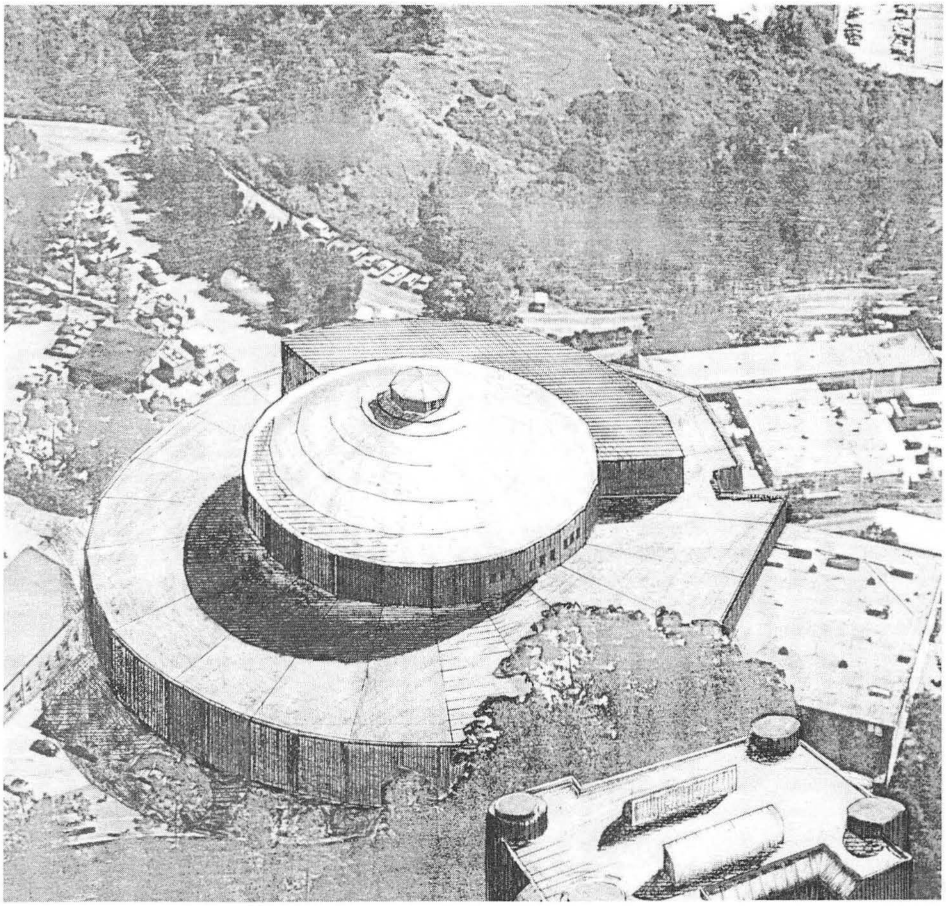

Fig. 1. *An artist's view of the 1–2 GeV Synchrotron Radiation Source at its hillside site under the dome of LBL's historic 184-inch cyclotron.*

From the Chairman, Users Executive Committee

The Users Committee welcomes the initiation of this newsletter, which is intended as a medium for keeping prospective users of the LBL 1–2 GeV Synchrotron Radiation Source up to date on recent events. The newsletter should also serve as a means for stimulating our participation in the ongoing process of design optimization, especially with regard to insertion devices and beam lines. The aim is thus both to convey news to our user community and to catalyze communication in the other direction, from users to designers. Our help will be needed to realize this aim. Articles on prospective experiments

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Light Source Plans Pass DOE Reviews

The 1–2 GeV Synchrotron Radiation Source project passed two significant milestones recently: the Validation Review, held in Washington, D.C., on June 26; and the Conceptual Design Review, held at the Lawrence Berkeley Laboratory on July 14–15. Both review committees examined the detailed project plans—including design, cost estimates, and schedules—and approved them essentially as presented.

Project Director Klaus Berkner and LBL Plant Manager Don Eagling made presentations at the Validation Review, which was conducted by the Assessment and Validation Branch of the Office of Project and Facilities Management at the Department of Energy (DOE). Passing this review is a prerequisite for consideration of the Light Source for DOE's budget request for the 1988 fiscal year.

The Conceptual Design Review was an in-depth examination of all aspects of the project. The committee consisted of 14 DOE reviewers and five distinguished outside consultants. The committee was chaired by William T. Oosterhuis, who has been on detail to DOE from the National Science Foundation. Oosterhuis worked for L. Edward Temple, Jr., who directs the Division of Construction, Environment, and Safety in DOE's Office of Energy Research, and who has headed so many design reviews that they have been dubbed "Temple Reviews."

The consultants were Christoph Leemann of the Continuous Electron Beam Accelerator Facility (CEBAF), Newport News, Virginia; Marvin Weber of the Lawrence Livermore National Laboratory, Livermore, California; Tom Pawlak of the Fermi National Accelerator Laboratory, Batavia, Illinois; Ewan Paterson of the Stanford Linear Accelerator Center, Stanford, California; and David Lynch of the Department of Physics, Iowa State University, Ames, Iowa.

Results of the Design Review were overwhelmingly positive: after hearing 15 technical presentations by LBL physicists and engineers, the committee did not recommend a single significant change in the Light Source design. The committee did, however, make several important recommendations. Foremost was a call for additional funding for the research and development program for advanced diagnostic instrumentation, optical components for the beam lines, and engineering prototypes of the magnets, vacuum chamber, and rf system. The committee stressed that such an R&D program was essential to ensure that the proposed cost and schedule objectives would be achieved.

The committee also recommended that intermediate- and long-range plans be developed to handle large numbers of users, because ultimately the Light Source may accommodate approximately 250 users simultaneously. They emphasized the importance of one of the early goals of the project leadership—the establishment of a user liaison office, headed by a coordinator of research programs, to solicit, coordinate, and respond to input from prospective users.

The proposed project organization was considered appropriate for the Light Source. In addition to the coordinator of research programs, the project organization will include a construction project manager and two deputy project directors who report to Project Director Klaus Berkner. The deputy director for experimental systems will be responsible for the design specifications and commissioning of the insertion devices and beam lines; the deputy director of accelerator systems will have similar responsibilities for the injector and storage ring.

Because plans for the conventional facilities (Light Source building) were so well developed, the committee felt that the entire project could be advanced by three months if more resources than currently planned were put into the conventional facilities in 1987. They recommended that this be done.

Continued on page 3

X-Ray Optics Workshop Slated

In the summer of 1987, a workshop will be held at the Lawrence Berkeley Laboratory to give x-ray optics specialists the opportunity to study design strategies for the optical systems needed to take advantage of the special properties of the 1–2 GeV Synchrotron Radiation Source for various types of scientific experiments. The workshop will be entitled "New Opportunities in Optical Systems for Synchrotron Radiation" and will last two to three weeks. It is being planned by a local organizing committee chaired by Malcolm Howells of the LBL Center for X-ray Optics.

Participants will break into small groups to study such topics as new monochromator concepts, x-ray interferometry, linear and circular polarization, imaging systems, the role of multilayer reflective coatings, premonochromators, coherent x-ray systems, tomography, and more. The idea is to do serious calculations and in-depth studies, for which good computer facilities will be provided.

The program will begin with a two-day general meeting to which interested users will be invited. A presentation will be given on possibilities for future developments in x-ray optics, and prospective users will speak on potential beam line applications. The agenda will also include talks to provide a general update on the technical aspects of the Light Source project. Users will meet in small groups to discuss directions they feel are desirable for technical developments; written statements produced by these groups will be used as guidelines by the x-ray optics specialists during their deliberations in the ensuing weeks.

Howells expects that users and x-ray optics specialists will share ideas and learn from each other. He says, "When they hear the ideas of the optics people, users might see possibilities opening up that bring real scientific opportunities. Similarly, the optics people may be able to respond with appropriate developments when they hear about the users' dreams for the future. The dialogue could be very fertile."

At the end of the workshop, each group of optics specialists will write up its findings for publication in a document to be distributed to all participants. The document will become an LBL publication and be made available to the Light Source user community and others who are interested.

Further information about the workshop will be provided in a subsequent issue of this newsletter.

From the Chairman . . .

Continued from page 1

with the Light Source are planned, and users' submissions in this category or in the form of guest comments will be welcome.

The Users Executive Committee has been in operation for two years; it was formed in late 1984 to provide *ab initio* users' input in the planning and design of the Light Source and to render support toward its realization. The need for third-generation sources and the exceptional scientific and technological potential of such facilities was clearly re-emphasized in the Workshop on an Advanced Soft X-Ray and Ultraviolet Synchrotron Source, organized jointly by LBL and an expanded committee and held in Berkeley in November 1985. In February of 1986, representatives of our committee and of the APS Steering Committee met to agree on suitable correlation of efforts to build both a 1–2 GeV ring and a complementary hard x-ray source based on a 6-GeV storage ring; these discussions resulted in the statement excerpted below. Also in February, our committee was represented at the Director's Technical Review of the conceptual design of the 1–2 GeV Synchrotron Radiation Source. Important milestones that followed were the Light Source's passing a Validation Review in Washington, D.C., in June and a Conceptual Design Review held in Berkeley in July. As described in the article "Light Source Plans Pass DOE Reviews" on page 2, these steps were prerequisites for consideration of the Light Source for the Department of Energy budget request for fiscal 1988. We can now look forward with some confidence to further progress towards the construction of the facility that we have been so eagerly awaiting.

Our committee met most recently on August 25 at LBL to be briefed on the status of Light Source planning and design and to chart the user organization's next steps. Our participation has been invited in a workshop on beam lines and x-ray optics being arranged by a committee headed by Malcolm Howells (see page 2). We further plan to arrange a series of small scientific conferences or workshops on advanced applications of soft synchrotron radiation in various fields, such as chemical kinetics, molecular physics, and microlithography. Details will be circulated in time for interested persons to make arrangements to participate.

Be sure to clip and mail the form on the back page of the newsletter to ensure your membership in the 1–2 GeV Synchrotron Radiation Source user organization. Your suggestions continue to be most welcome.

Bernd Crasemann,
Chairman,
Light Source Users Executive Committee

Reviews . . .

Continued from page 2

The proposed project schedule provides for careful coordination of the design, fabrication, testing, and installation of the various Light Source subsystems, so that each subsystem will be operating in time to test the next one. With the proposed budget profile, construction of the conventional facilities will begin in 1988. The entire project—injector system, storage ring, insertion devices, beam lines, and conventional facilities—will be completed at the end of 1992.

User Groups Endorse Two-Source Plan

President Reagan's budget request for fiscal 1987 included explicit reference to a 1–2 GeV synchrotron light facility at LBL and a 6-GeV light source at Argonne National Laboratory. In response to this welcome news, members of the synchrotron radiation community—represented by the user committees of both machines—joined in issuing a statement giving strong endorsement to the plan.

The user committees "enthusiastically endorse this plan and intend to work cooperatively to assure its implementation" the statement said. "We urge that the entire community join with us in fully supporting this exciting adventure."

The statement emphasized that "there is a pressing need, which has been recognized worldwide, to make synchrotron radiation from next-generation facilities available for scientific and technological research and development. These powerful new research tools, when integrated with a healthy and vigorous user community of scientists and engineers, will offer the United States vital scientific and technical input necessary to advance a broad spectrum of important technologies."

The statement noted that although synchrotron radiation extends over a wide range of wavelengths, research uses are grouped into two spectral ranges—ultraviolet and soft x-rays (in the 10 eV to 5 keV photon energy range) and hard x-rays (from a few keV to 50 keV and above). "Experimental requirements and optimal machine design parameters in these two ranges are substantially different," the statement pointed out. "In order to guarantee U.S. leadership in this field it is thus clear that two complementary next-generation synchrotron facilities should be constructed. . . ."

Bernd Crasemann, University of Oregon; Warren Grobman, IBM; and John Browne, Los Alamos National Laboratory, signed the statement for the 1–2 GeV Light Source user group; Peter Eisenberger and David Moncton of Exxon and Robert Birgeneau of MIT signed for the 6-GeV Source user committee.

Conceptual Design . . .

Continued from page 1

front-end components and controls for two bending magnet beam lines. The insertion device and beam line descriptions in the CDR present some useful ideas on how to build such systems for this facility, and they provide an indication of the scope of the insertion device-beam beam line program that can be accommodated within the proposed facility budget. Ultimately, we anticipate construction of 11 insertion devices, and 48 ports will be available for bending magnet beam lines.

Although a descendant of LBL's original 1982 light source design, the current design clearly reflects the results of more recent thinking within the accelerator physics community, as well as the consensus enunciated at the November 1985 Users' Workshop as regards critical operating parameters. In particular, the storage ring lattice (the arrangement of bending and focusing magnets) has been completely redesigned in the past year, the nominal electron beam energy has been increased from 1.3 to 1.5 GeV, and the insertion devices and their associated beam lines have been reconsidered. The essential features of the design are the very low electron beam emittance, the long beam lifetime, the short bunch length, and the wavelength tunability and narrow bandwidth of the radiation.

The designers' responsiveness to the goals established by the November gathering can be judged from Table 1, which compares performance goals with the corresponding design parameters for the Light Source.

Storage Ring

Lattice Design. A small beam emittance is required for achieving a high photon beam brightness. The minimum horizontal emittance achievable in an electron storage ring depends on the detailed design of the lattice. To achieve a small emittance, a small horizontal beam size is required at the bending magnets. The beam must be strongly focused by quadrupoles to obtain this. The challenge is to accomplish this while maintaining good chromatic properties of the lattice and a large dynamic aperture. These goals led to a re-evaluation of the lattice used for the 1982 design.

In January 1986, a panel of outside experts met at LBL to discuss lattice candidates. The reviewers were Sam Krinsky and Gaetano Vignola of Brookhaven National Laboratory, Helmut Wiedemann of Stanford University, and Sergio Tazzari of the Frascati Laboratory in Italy.

Three of the lattice candidates were found to be "potentially equally interesting," which led to intensified study of these designs. Of these three, a "triple-bend achromat" (TBA) lattice was chosen, in part because of its capability for flexible operation (allowing the beam to be tuned independently in each straight section). Other considerations were its small emittance, good dynamic aperture, and relative insensitivity to magnet errors.

The TBA structure, incorporating three bending dipoles per achromat (thus its name), was first proposed by Vignola. Each single unit cell, or superperiod, has reflection symmetry around a central dipole and consists of a "dispersive region," where the bending occurs, matched to a straight section, 6.75

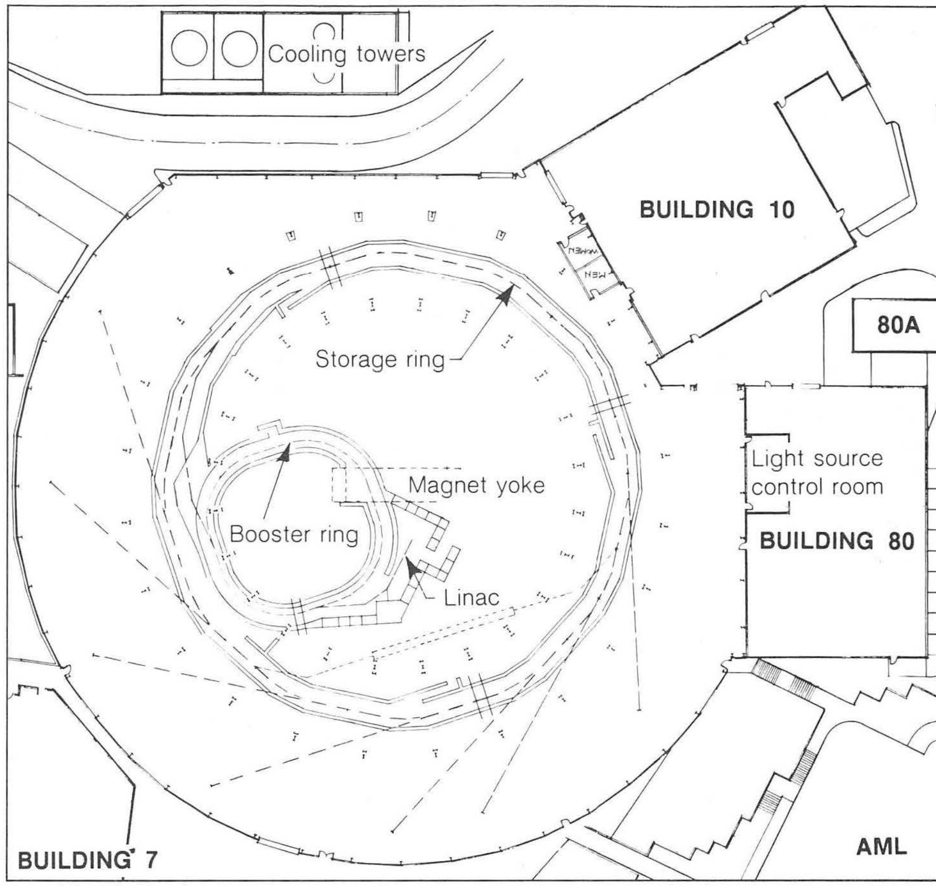

Fig. 2. A plan view of the 1–2 GeV Synchrotron Radiation Source, showing the injection system, storage ring, and seven beam lines. The plan will accommodate the future addition of an XUV free-electron laser, indicated by dashed lines inside the storage ring perimeter.

Table 1. Performance goals established by potential Light Source users, compared with machine design values.

	Performance goals	Design values
Beam energy, nominal (GeV)	1.5	1.5
Energy range (GeV)	0.75–1.9	0.75–1.9
Average current (mA)	400	400
Horizontal emittance, rms (m-rad)	$<10^{-8}$	4.08×10^{-9}
Number of straight sections	12	12
Straight section length for insertion devices (m)	6	6
Bunch length, 2σ (ps)	20–50	28–47[a]
Beam lifetime (hr)	>6	5–8[b]

[a]*Extreme values are for 250-bunch and single-bunch modes, respectively, at maximum current.*

[b]*Extreme values are for single-bunch and 250-bunch modes, respectively, at maximum current.*

meters long, reserved for undulators, wigglers, injection hardware, and rf cavities.

Bunch Length and Beam Lifetime. Apart from a low emittance, a long beam lifetime and short electron bunches were perhaps the most important design goals for the storage ring. In practice, the attainable bunch length is determined by the rf parameters and the constraints of the so-called longitudinal microwave instability. The influence of the longitudinal microwave instability is determined in turn by the effective impedance of the ring. On the basis of experimental evidence from the SPEAR electron-positron storage ring at the Stanford Linear Accelerator Center, it is expected that the effective longitudinal impedance will decrease for bunch lengths shorter than the pipe radius. As a consequence, assuming the validity of this scaling law, the predicted bunch length for the 250-bunch operating mode is about 20 ps for currents up to about 300 mA, rising to about 28 ps at 400 mA.

Beam lifetime is limited by a combination of two effects, Touschek scattering (large-angle intrabeam scattering) and gas scattering. The former is of particular interest, since it is most severe for short, high-current bunches with low emittance—precisely the properties we are striving for in the Light Source. Overall lifetimes for two operating scenarios are shown in Fig. 3. Multibunch operation meets the lifetime goal of 6 hours.

Vacuum System. The role of gas scattering in limiting beam lifetime depends on the gas pressure inside the beam tube. A major obstacle to the achievement of the Light Source design goal of 1×10^{-9} torr is the desorption of molecules from the chamber walls, caused by photoelectrons that are created by photons hitting the walls.

LBL has developed a new approach to this problem, as shown in Fig. 4. The electron beam tube is connected by a long, continuous slot to an antechamber, which contains discrete water-cooled synchrotron radiation absorbers. All synchrotron radiation either strikes one of these "photon stops" or passes out of the ring via a beam line port. The desorbed gas is generated at the photon stops, and it can be very efficiently pumped by concentrating most of the pumping capacity nearby. Measurements and computations show that the presence of the antechamber has a negligible effect on the beam coupling impedance; the slot effectively isolates the beam tube from the antechamber at frequencies below about 10 GHz.

Injection System

In the injection system (see Fig. 2), a 50-MeV linac injects the electron bunches into a booster, which increases the energy of the beam to 1.5 GeV and injects it into the storage ring. Injection at the nominal operating energy of the storage ring simplifies operation and enhances the reproducibility of experimental conditions. (For experiments requiring operation above 1.5 GeV, the beam will be further accelerated by the storage ring rf system.)

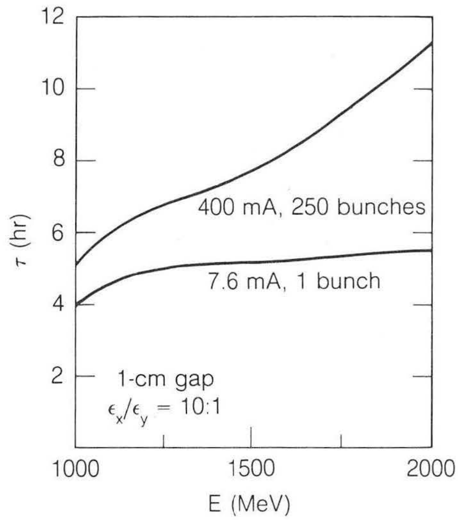

Fig. 3. *Predicted overall beam lifetimes for single-bunch and multibunch scenarios, assuming a limiting gap of 1 cm and the SPEAR scaling law.*

We visualize two different operating modes, each requiring a different injection scheme. The multibunch mode requires that the storage ring be filled to a current of 400 mA in approximately 250 consecutive bunches (out of a total of 328; the gap is needed to avoid ion trapping). In this mode, the storage ring buckets are filled by 126 repetitive transfers from the booster synchrotron, each transfer involving 50 electron bunches. For the few-bunch operating mode, we assume a current of 7.6 mA per bunch. Here, the bunches are filled one at a time. Filling times are 2.1 minutes in the multibunch mode and 16 seconds per bunch in the few-bunch mode. The few-bunch mode allows the machine to be filled with any pattern of regularly or irregularly spaced electron bunches.

Insertion Devices and Beam Lines

Eleven of the 12 straight sections in the storage ring are available for insertion devices; one straight section is occupied by injection hardware. In each of these 6.75-meter-long straight sections (except one that is partly occupied with rf cavities), 6 meters is available for insertion devices. The conceptual design includes four undulators and

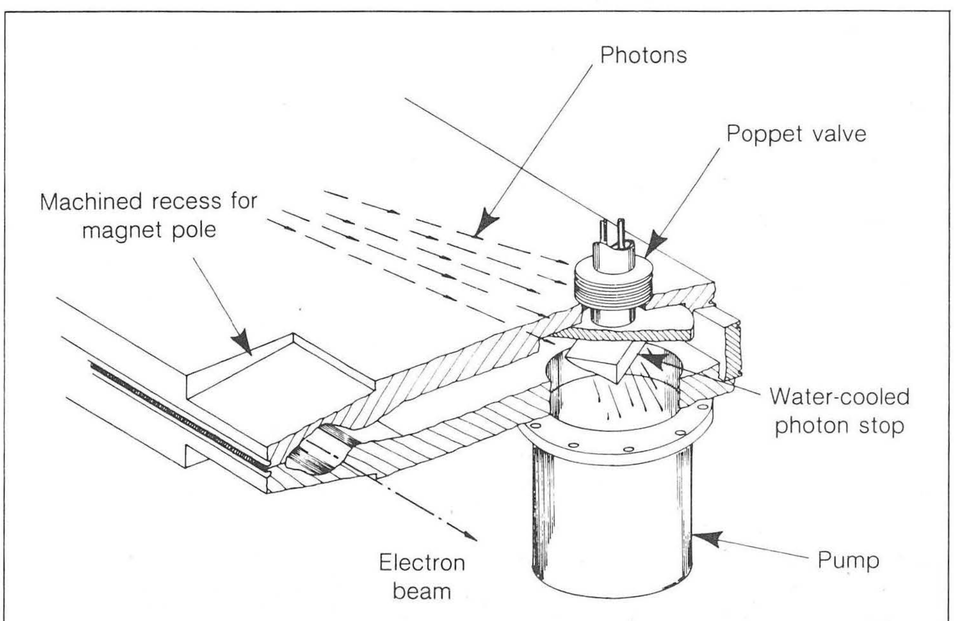

Fig. 4. *Cutaway view of the Light Source vacuum chamber, showing a photon stop and titanium sublimation pump.*

one wiggler, the characteristics of which are given in Table 2 and Figs. 5–7.

Undulators will be a major source of coherent short-wavelength radiation in the next decade. They are expected to reach far beyond the photon energies available with ultraviolet lasers. Indeed, undulators are strong candidates to serve effectively as the "soft x-ray lasers" of the early 1990s—that is, a strong source of spatially and temporally coherent x-rays.

The extraordinary performance of the 1–2 GeV Synchrotron Radiation Source, especially with regard to spectral brightness (Fig. 5), and coherent power (Fig. 6), provides opportunities for many new types of scientific investigations. Accordingly, the optical systems in the CDR were designed to demonstrate that extremely high spectral resolution can be obtained with systems that accept the entire photon beam.
The surface tolerances for these optical systems are around one microradian, which will require careful fabrication strategies. Nonetheless, we believe that these tolerances are well within existing

Table 2. Parameters for the initial complement of insertion devices chosen for the Light Source.

Name	Period (cm)	No. of periods	Photon energy range (eV)[a]	Critical energy (keV)
Undulators				
U20.0	20.0	23	0.5–95 [1.5–285]	–
U9.0	9.0	53	5–211 [15–633]	–
U5.0	5.0	98	50–380 [150–1140]	–
U3.65	3.65	134	183–550 [550–1650]	–
Wiggler				
W13.6	13.6	16	–	3.1

[a]The photon energy range of the fundamental and the third harmonic (shown in brackets) as K decreases from its maximum value to 0.5.

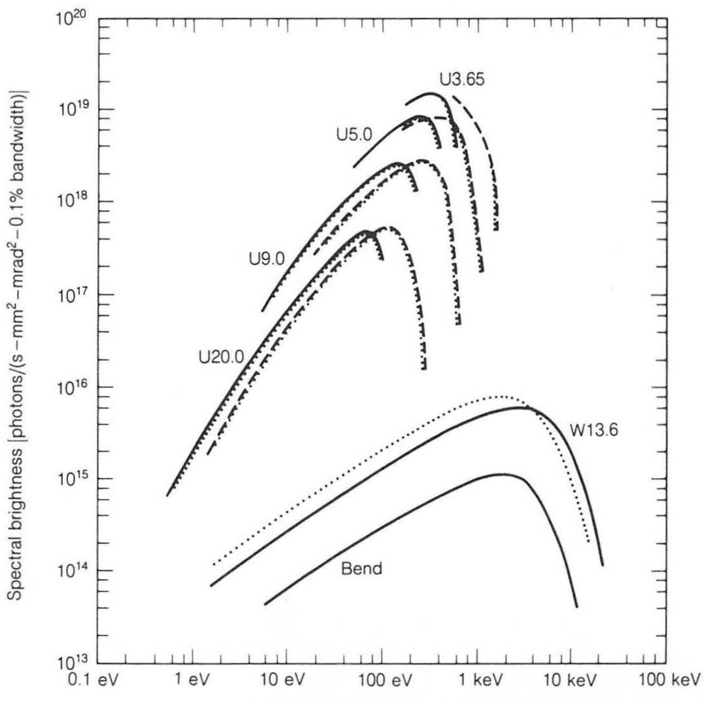

Fig. 5. Spectral brightness as a function of energy for the four undulators and one wiggler described in Table 2, together with the bending magnets of the Light Source. For the undulators, the tuning range is shown for both the fundamental (solid lines) and the third harmonic (dashed lines). The dotted lines show corresponding curves for spectral brightness at commissioning, when the minimum magnet gap will be 2.5 cm.

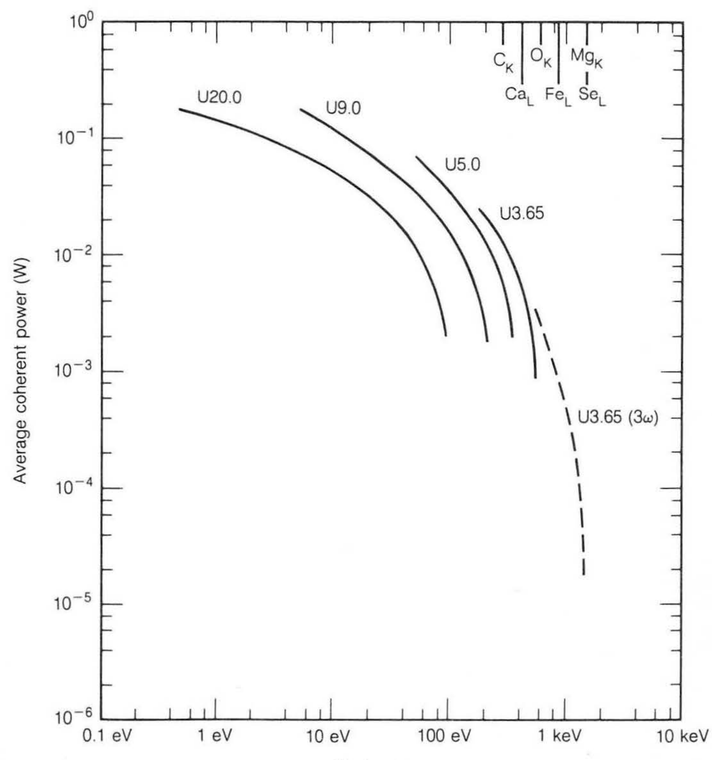

Fig. 6. Average coherent power as a function of energy for the five insertion devices of Table 2. Coherent power is defined as having full transverse coherence and a 1-μm longitudinal coherent length.

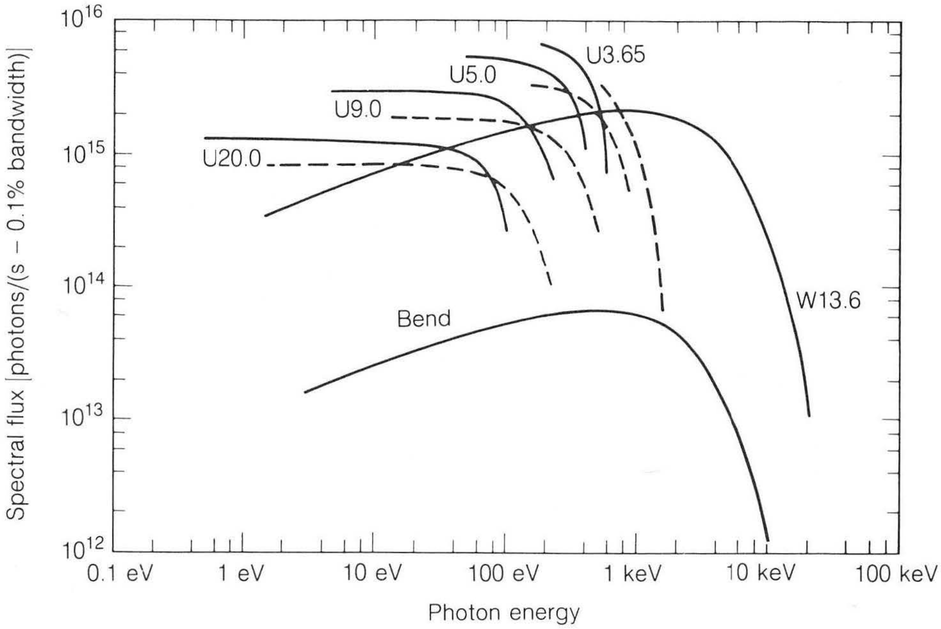

Fig. 7. *Photon flux curves are convenient for conceptualizing and planning new experiments. The curves shown above are typical of what can be expected from the Light Source undulators, wigglers, and bends. These curves do not take account of beamline efficiencies, which vary from one experiment to the next. For wigglers and bending magnets, a 5-mrad horizontal collection angle is assumed. For undulators, solid lines are the fundamental, dashed lines are the third harmonic radiation.*

manufacturing capability for the spherical and flat surfaces upon which all the beam line designs are based.

An important feature of the optical systems is their phase-space acceptance. We have shown that the phase-space properties of today's state-of-the-art monochromators are such that the entire beam can be accepted. As an example, we calculate that we will be able to deliver photons at the oxygen *K* edge with a relative bandwidth of 10^{-4}, without loss due to phase-space mismatch. The spectral ranges and typical resolutions of the insertion device beam lines included within the scope of the conceptual design are given in Table 3. In addition, the conceptual design includes front ends and controls for two bending magnet beam lines. (Advanced concepts for beam line systems will be considered next year at an x-ray optics workshop to be attended by both optics specialists and Light Source users. See page 2.)

Conventional Construction, Cost, and Schedule

The CDR also includes details regarding conventional construction, which entails, most importantly, modifications and additions to the building that now houses the 184-Inch Synchrocyclotron. Outside the scope of the CDR are current plans for 10,000 square feet of office and lab space in existing buildings to accommodate users of the first complement of experimental facilities. However, plans do include provision for 40,000 square feet of future office and lab space in the Light Source building itself. The planned facility allows for 40-meter-long beam lines.

The cost of the Light Source is estimated at $98.7 million, and commissioning is scheduled to be complete by the end of fiscal 1992. This schedule provides for "beneficial occupancy" of the building before the end of fiscal 1989, at which time testing and installation of the injector system will commence. Installation of the storage ring will follow in 1991, and insertion devices and beam lines will be installed and

The **Light Source Report** will keep you up to date on developments at the LBL 1–2 GeV Synchrotron Radiation Source. If you wish to continue to receive it, please let us know by returning this form, address label attached, to:

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Your name on the mailing list makes you a charter member of the 1–2 GeV Synchrotron Radiation Source user organization.

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Table 3. Summary of parameters for the five insertion device beam lines proposed for the Light Source.

Radiation source[a]	Max aperture H (mrad)	Max aperture V (mrad)	Spectral range [typical energy] (eV)	Energy resolution at typical energy (eV)	Monochromator type[c]	Estimated photon flux at typical energy (photons/s)[d]
A (U20)	1.8	1.8	0.5–30 [15]	0.00015[b]	5-meter NIM	5.5×10^{13}
B (U9.0)	0.57	0.57	5–200 [56]	0.0012[b]	10° SGM	1.5×10^{14}
C (U5.0)	0.185	0.18	50–800 [280]	0.024[b]	3° SGM	1.1×10^{14}
D (U3.65)	0.1	0.09	200–1500 [540]	0.076[b]	2° SGM	2.2×10^{12}
E (W13.6)	18.0	0.85	800–3500 [1840]	0.9	Crystal	
			3000–10,000		Vacant (suited to development as hard x-ray station)	

[a]*U = undulator, W = wiggler, (xx.xx) = period length in cm.*

[b]*For undulators, resolution is slit width limited with 10-μm slit.*

[c]*NIM = normal-incidence monochromator, SGM = spherical grating monochromator.*

[d]*Flux emerging from the exit slit at the typical energy (column 4), assuming 10% grating efficiency, at 400 mA in a 0.1% bandwidth. For the crystal monochromator, the flux is given for $\Delta\lambda/\lambda$ = 0.049% rather than for a 0.1% bandwidth.*

tested in 1992. Even allowing for a normal shakedown period, we are optimistic that we will see light of unprecedented experimental value before the end of 1992.

*Copies of the **Conceptual Design Report** are available upon request from the Accelerator and Fusion Research Division, Building 50, Room 149, Lawrence Berkeley Laboratory, Berkeley, CA 94720.*

The **Light Source Report** is published periodically at Lawrence Berkeley Laboratory for members of the 1–2 GeV Synchrotron Radiation Source user organization.

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