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Publication Date
1985-10-01

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Accelerator & Fusion Research Division

Presented at the Workshop on the Construction and
Commissioning of Dedicated Synchrotron
Radiation Facilities, Upton, NY,
October 16-18, 1985

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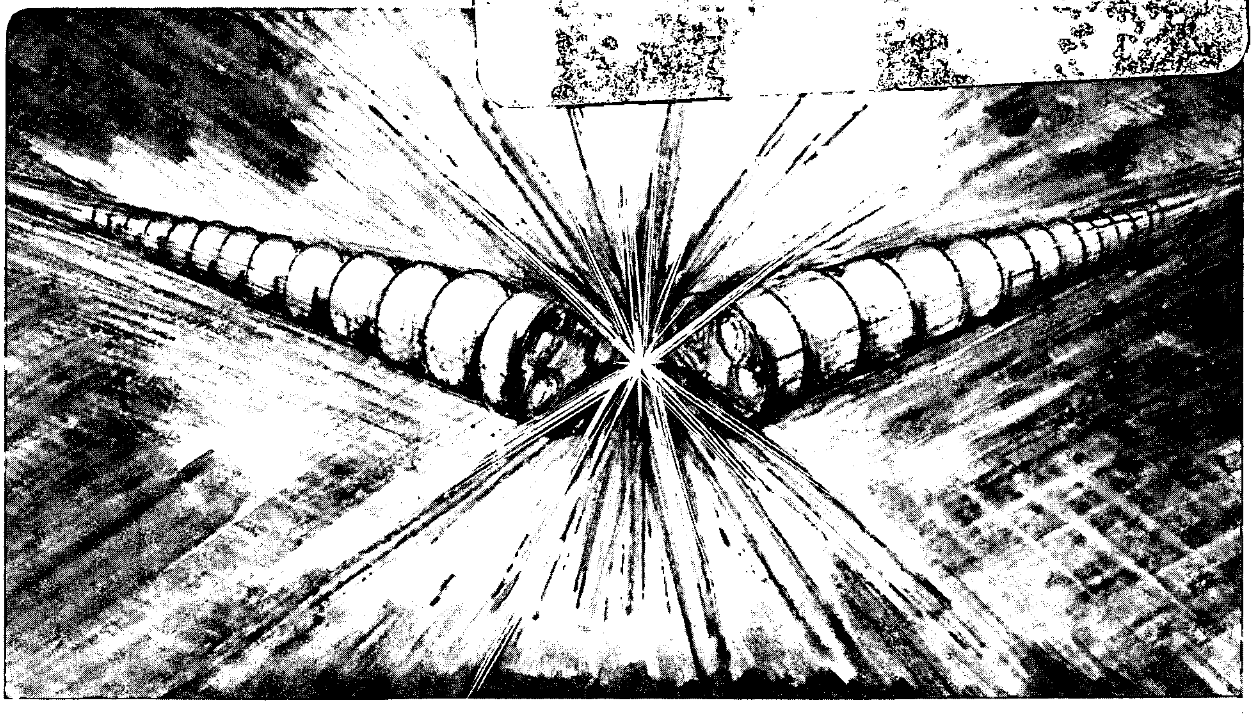

Prepared for the U.S. Department of Energy under Contract DE-AC03-76SF00098

A 1-2 GeV Synchrotron Radiation Facility at Lawrence Berkeley Laboratory*

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October 1985

INTRODUCTION

The Advanced Light Source (ALS), a dedicated synchrotron radiation facility optimized to generate soft x-ray and vacuum ultraviolet (XUV) light using magnetic insertion devices, was proposed by the Lawrence Berkeley Laboratory in 1982. It consists of a 1.3-GeV injection system, an electron storage ring optimized at 1.3 GeV (with the capability of 1.9-GeV operation), and a number of photon beamlines emanating from twelve 6-meter-long straight sections, as shown in Fig. 1. In addition, 24 bending-magnet ports will be available for development. The ALS was conceived as a research tool whose range and power would stimulate fundamentally new research in fields from biology to materials science (1-4).

The procedures for construction projects funded by the DOE prescribe a sequence of stages and approvals. The process starts with a conceptual design of sufficient detail to define the scope of the project and to identify all the subsystems, so that a complete cost estimate can be prepared. Upon review and approval, the project is included in the Congressional budget request. If authorized by Congress, the project then proceeds with a preliminary design (Title I), final design and working drawings (Title II), and the construction phase (Title III). The conceptual design and associated cost estimate for the ALS have been completed and reviewed by the U.S. Department of Energy (DOE), but Title I activities have not yet begun. The focus in this paper is on the history of the ALS as an example of how a technical construction project was conceived, designed, proposed, and validated within the framework of a national laboratory funded largely by the DOE.

Major Parameters

The major parameters of the ALS storage ring are summarized in Table 1. Of special significance are the 12 long straight sections, reflecting the emphasis on wigglers and undulators as radiation sources, and the low value of the horizontal emittance. Low emittance values lead, in turn, to high values for the spectral brightness, especially for the radiation emitted by undulators. It should be noted that the parameters in Table 1 assume the choice of a specific mode of operation (with 250 bunches). Other modes we envision to be available will be characterized by

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*This work was supported by the Office of Basic Energy Sciences of the U.S. Department of Energy under Contract DE-AC03-76SF00098.

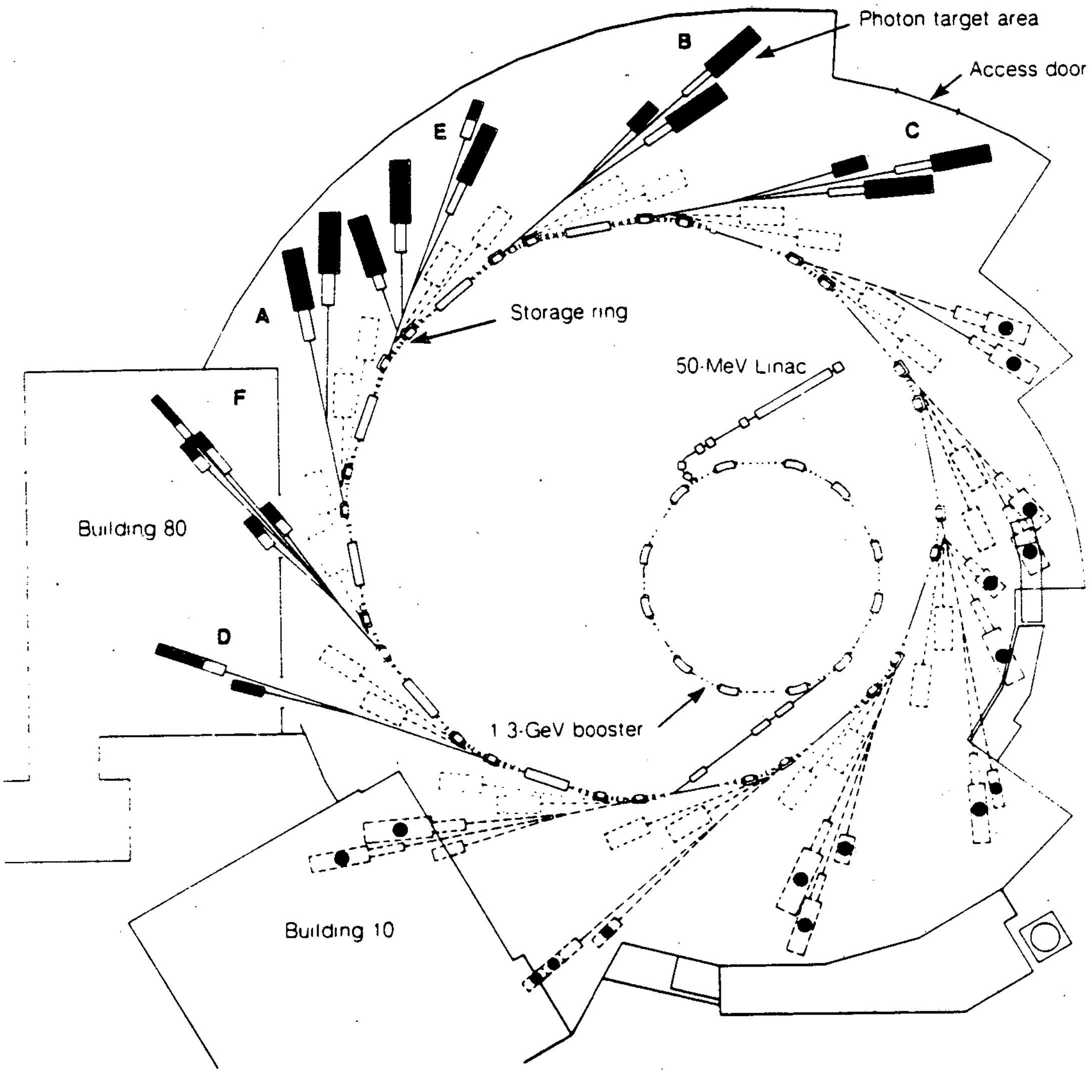

Fig. 1. Schematic of the proposed Advanced Light Source (from Ref. 1).

even shorter bunch lengths (along with reduced average and peak currents) and by higher peak currents (achieved by reducing the number of bunches).

As now envisioned, the ALS will be constructed initially with five or six insertion devices supporting a dozen beamlines. The spectral brightness of the radiation emitted by these devices is shown in Fig. 2, and a summary of their characteristics is given in Table 2. (The spectral brightness of undulators consists of a number of sharp peaks; the smooth curves shown in Fig. 2 represent the envelope of the maxima of the spectral peaks for each undulator. Furthermore, it is necessary to vary the undulator fields to scan over the photon energy ranges shown. For

Table 1. Design parameters for the ALS (from Ref. 1).

Parameter	Design value
Electron energy (GeV)	1.3
Average electron current (mA)	400
Peak current (A)	34
Bunch length (ps)	23
Horizontal emittance (π m-rad)	6.8×10^{-9}
Circumference (m)	182.4
No. of straight sections	12
Length of straights (m)	6

permanent-magnet undulators, the field strength is varied by varying the magnet gaps.) Finally, it should be emphasized that the characteristics of insertion devices and beamlines are, and should be, dictated by the needs of the research community. A synchrotron radiation users meeting scheduled for November 1985 may provide us with new information, leading in turn to changes in some of the parameters in Table 2.

Schedule and Cost

A later section is devoted to how a proposed conceptual design and the accompanying schedule and estimated cost are arrived at for a facility like the ALS. In the context of a technical description, however, it might be worth indicating our present vision of a construction schedule and cost for the ALS. Accordingly, Fig. 3 shows a proposed schedule, together with the

Table 2. Tentative parameters for the six insertion devices designed for the ALS. The U's denote undulators, the W's wigglers.

	U_A	U_B	U_C	U_D	W_E	W_F
Usable energy range (eV)	5-600	25-1500	75-3000	200-5000	0.1-10,000	1-20,000
Peak power density (W mr^{-2})	143	731	666	980	491	878
Spectral brightness[a] [photons s^{-1} mm^{-2} mr^{-2} (0.1% BW)$^{-1}$]	2.6×10^{15}	1.3×10^{17}	8.4×10^{17}	2.7×10^{18}	1.2×10^{16}	7.1×10^{15}
Coherent power in 1-μm coherence length (W)[a]	7.9×10^{-3}	1.6×10^{-2}	1.1×10^{-2}	7.4×10^{-3}	2.8×10^{-7}	1.7×10^{-8}

[a] Taken at the fundamental ($n = 1$) for undulators and at the critical energy for wigglers.

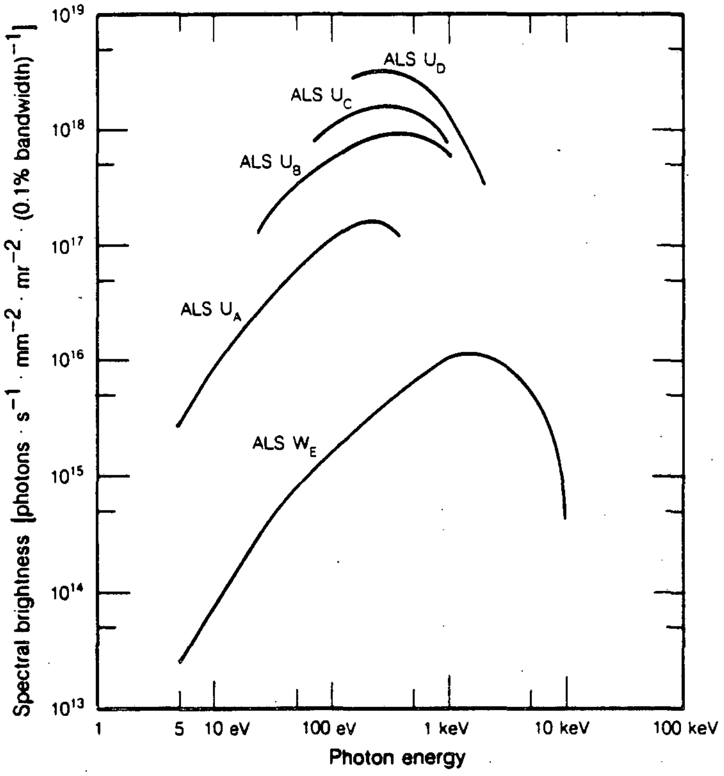

Fig. 2. Brightness curves for five of the insertion devices planned for the ALS, each as a function of photon energy. The brightness of the superconducting wiggler W_F is not shown. With a 1.9-GeV electron beam, the usable range of W_F extends to 40 keV.

estimated cost in 1987 dollars. Not indicated in the figure are the costs for preconstruction and concurrent R&D.

EVOLUTION OF THE ALS DESIGN

Background and Conceptual Development

As a framework for the following discussion, Table 3 shows a thumbnail history of the ALS proposal, from the background experience that underlay it to the present. The experience gained in our collaborative activities with the Stanford Synchrotron Radiation Laboratory (SSRL), in our partnership with the Stanford Linear Accelerator Center during the design and construction of the PEP storage ring, and in our pioneering work with permanent-magnet insertion devices were necessary underpinnings of the ALS proposal. Equally important were the perspectives gained in operating national user facilities such as the Bevalac and the National Center for Electron Microscopy, and the presence a first-rate staff that included physicists and engineers specializing in accelerator physics and technology

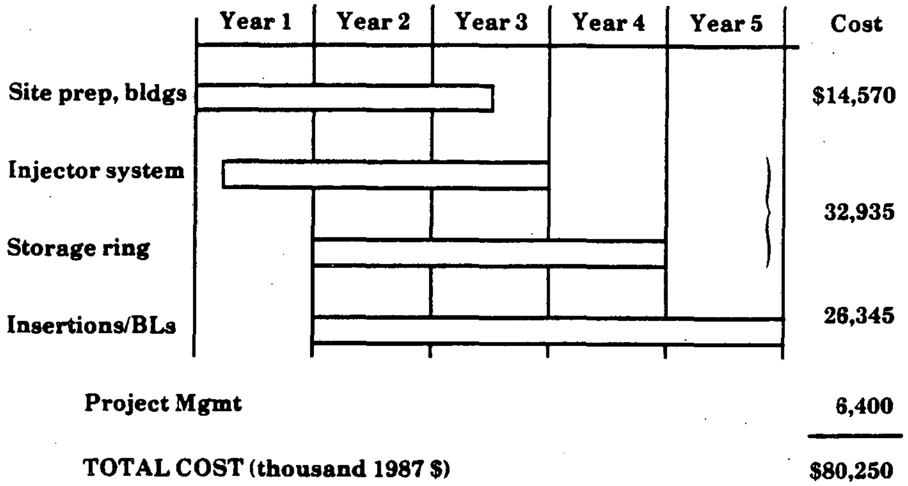

Fig. 3. Proposed construction schedule for the ALS, showing the cost (in 1987 dollars) of each major component. The schedule and estimated cost shown here reflect an initial complement of four undulators and one conventional hybrid wiggler.

and in x-ray optics and beamline development. In addition, a clear perception of the need for a dedicated synchrotron light source based on insertion devices had emerged among LBL scientists who had been involved with synchrotron radiation research since the early days of the Stanford Synchrotron Radiation Project (the forerunner of SSRL).

In early 1982, a team of physicists and engineers began a preconceptual study aimed at laying the groundwork for a more comprehensive design effort. The group's efforts concluded with a draft proposal for a source optimized in the soft x-ray region of the spectrum. As part of this proposal, we established the basic ring parameters, completed preliminary designs for the storage ring lattice and for dipole and quadrupole magnets for the storage ring, and developed a plan for conventional facilities to support the storage ring, beamlines, and experimental areas. Following publication of this preliminary report in July 1982, a more formal and more intense effort began, culminating in November with a draft conceptual design (5), which served as the basis for the first of two reviews by the Construction Management Support Division, part of the DOE's Office of Energy Research.

The Conceptual Design

Even in its draft form, the conceptual design report addressed the design of a complete facility, including a more refined design for the storage ring lattice; a detailed design for the injector; revised designs for the dipole, quadrupole, and sextupole magnets for the storage ring,

Table 3. Summary history of the ALS.

Date	Event
Related activities	
1974	Research began at Stanford Synchrotron Radiation Project; collaborated in design and construction of PEP storage ring
1979-1980	Designed and built $SmCo_5$ insertion devices
1981	Began work on LBL/Exxon beamline
1984	Created Center for X-Ray Optics
ALS design	
Early 1982	Began preconceptual design work
July 1982	Completed draft proposal
November 1982	Completed draft conceptual design report (Preliminary Design Handbook)
March 1983	Published five-volume Conceptual Design Report
April 1984	Updated design and published The Advanced Light Source: Machine Description and Background Material
1985-	Design optimization continues
Validation	
November 1982	First DOE construction review
January 1983	Director's technical review
April 1983	Second DOE construction review
May 1983	ALS/SSRL Users Workshop; DOE Validation Review
November 1985	Synchrotron radiation users workshop planned at LBL

plus magnets for the booster; a design for a conventional vacuum system incorporating distributed ion pumping; control and power system designs; detailed designs for six insertion devices, each with at least two beamlines; and plans for required building modifications, utilities, user experimental areas, and shielding. By this time, the R&D that should precede and accompany construction was also identified. Significant preconstruction effort was seen going into insertion devices and beamline elements, controls and instrumentation, pulsed magnet design, and the accelerator physics of high-current, low-emittance beams. In summary, all of the facility components were identified in sufficient detail to document the comprehensive cost estimate.

Following a period of review and refinement, a Conceptual Design Report (6) for the ALS was published in March 1983. An important step along the way was a technical review in January, commissioned by LBL Director David A. Shirley. Committee members included respected accelerator physicists from U.S. and European laboratories; the chairman was Ewan Paterson of the Stanford Linear Accelerator Center.

The findings of this committee had an important impact on the evolving design; indeed, they continue to influence our studies of accelerator physics issues. In general, they recognized that the design of a high-current, low-emittance storage ring "is a new emphasis in the accelerator art and much still has to be experienced and understood. . . . We recommend that an increased theoretical effort be applied to understanding the problems. . . ." In particular, they recommended further study of the consequences of high-current, few-bunch operation; wide-ranging efforts to better understand the problems of high-brightness rings; a reevaluation of the lattice design; further study of ion trapping and other effects that might increase the emittance or decrease the beam lifetime; more vacuum R&D; an exploration of injector options, including the possibility of using positrons; and a reevaluation of the performance parameters of the insertion devices.

The Conceptual Design Report reflected responses to several of the committee's recommendations, as well as the evolutionary nature of advanced facility designs. As examples, the storage ring lattice had undergone further revision, the magnet designs were still more detailed, the vacuum system had become a dual-chamber design to minimize the effects of radiation-stimulated ion desorption, the booster synchrotron had been considerably redesigned, and the characteristics of the insertion devices were now better understood.

Continuing Optimization

During the next year, LBL research on high-brightness storage rings continued, and the design of the ALS continued to evolve. In April 1984, The Advanced Light Source: Machine Description and Background Material was published (1). By now the pace of design change had slowed, but some changes still occurred: The dual-chamber vacuum system took on a slightly different configuration, the lattice was subtly altered, the magnet designs were a little different, and so forth. Indeed, scrutiny of the ALS design continues today. We are now looking at the impedance characteristics of the vacuum systems, positron-injection schemes, the issues of dynamic aperture and beam stability, and alternative lattice concepts.

ESTIMATING COSTS AND OTHER MANAGEMENT ISSUES

Cost Estimates

The evaluation of the cost of the ALS has been a consideration since preconceptual design activities began in early 1982, and an estimate appeared in the first design document--the draft Proposal for the Advanced Light Source. As the design evolved, the detail of the costing procedures increased, as did our confidence in the resulting estimates. For the first DOE construction review, the estimate was formalized in a seven-level work breakdown structure (WBS), an excerpt of which is shown as Fig. 4. The WBS is a systematic way of accounting for every component and activity by starting with the project as a whole, then dividing it into its basic elements, subelements, sub-subelements, and so on. In addition to the physical components of the facility and all fabrication, assembly, and testing activities, these elements include engineering, design, inspection, and administration (EDI&A) and contingencies. A detailed WBS is an essential ingredient in project planning and project management. It serves not only as a credible framework for estimating costs, but also as a convenient tool for monitoring and reporting costs and progress, once a project is under way. More importantly, for a project still at the proposal stage, it allows one to quickly assess the cost impact of design revisions.

For each WBS category, the estimate was of one of three types: a "comparative estimate," based on actual costs of similar components or systems; a "detailed estimate," based on well-defined scope, bill of materials, and fabrication processes; or a "conceptual estimate," when no detailed specifications existed. The contingency estimate for the complete project was derived from a contingency analysis for each WBS element, taking into account the relative confidence that could be placed in these three cost bases. Inflation data were compiled (and extrapolated) as part of the estimating process, especially in deriving comparative estimates based on earlier experience. In addition, care was taken to account accurately for prevailing labor rates in making detailed estimates.

The Project Management Plan

By the time of the second DOE construction review in early 1983, a draft Project Management Plan had taken shape (7), including the WBS as an integral part. This plan spelled out in detail the proposed management structure of the ALS, including the explicit responsibilities of all management personnel, together with the functional support roles of DOE

Level 1 2 3 4 5 6 7

		Cost Code
3.1	Accelerator Systems	5000
3.1.1	Storage Ring	5100
3.1.1.1	Ring Magnets	
	● Dipoles	5111
	· Fixtures	
	· Coils	
	· Yokes	
	● Quadrupoles	5120
	· Fixtures	
	· Coils	
	· Yokes	
	● Sextupoles	5130
	· Fixtures	
	· Coils	
	· Yokes	
	● Steering Magnets	5140
	● Stands & Supports	5145
	● Installation	5147
3.1.1.2	Ring Vacuum System	5151-5175
	● Vacuum Chambers	5151-5157
	· Dipole Chambers without Photon Exit	
	· Dipole Chambers with Photon Exit	
	· Quad Chambers Upstream of Insertion Devices	
	· Quad Chambers Downstream of Insertion Devices	
	· Quadrupole-Sextupole Chambers	
	· Spool Pieces	
	· Injection Chambers	
	● Pumping System	5161-5162
	· Roughing System	
	· Appendage Vacuum Pumps	
	● Installation & Miscellaneous	5171-5175
	· Isolation Valves	
	· Bellows	
	· Vacuum Baking System	
	· Installation	
3.1.1.3	Ring Survey & Alignment	5180
	● Monuments	5181
	● Liquid Level	5183
	● Survey Instruments	5185
	● Survey & Alignment	5187
3.1.1.4	Ring Magnet Power System	5210
	● Choppers	5211
	● 600 kW Power System	5212
	● 300 kW Power System	5213
	● Sextupoles Power Systems	5214
	● Trim & Steering Power Systems	5215

Fig. 4. Excerpt from the work breakdown structure prepared in 1982 for the ALS. The cost codes refer to detailed worksheets for each WBS entry.

offices. Reporting requirements were summarized, and a formal system of project review and documentation was defined. In addition, the management plan included a detailed schedule, keyed to the WBS, along with a summary logic diagram that linked the project elements in a logical, temporal order. Plans were also laid out for a computerized critical path network that would allow for detailed project monitoring, once it was under way.

By the fall of 1983, the management plan was augmented by updated quality assurance, safety analysis, and procurement plans, as well as an environmental assessment report (8).

USER WORKSHOPS

The ALS was conceived as a research tool of unique power, of far-reaching interest to a scientific community of biologists, materials scientists, physical chemists, and many others. Accordingly, we have made efforts from the very beginning to ensure that our concept of the ALS is in accord with the needs of a diverse user community. The first input was informal (but informed), coming largely from workers who already had research contacts with LBL scientists. But the process of soliciting feedback was refined as the design proceeded, and in May 1983, the three-day ALS/SSRL Users Workshop, attended by more than 200 scientists and engineers, was held at LBL. The stated purpose was "to focus on the science and technical aspects" of the ALS and the planned SSRL upgrade. Discussions centered around working groups organized to study beamlines, research applications of high-brightness beams (including chemical and biological applications, soft x-ray imaging, and x-ray lithography), and free-electron lasers (9).

The recommendations of the workshop included several of a general nature, such as those emphasizing the importance of "abundant, skilled user support" and year-round operation. These were valuable suggestions, and many have been explicitly addressed in our vision of a user-friendly facility. The more important recommendations, however, at least from our point of view as designers of the facility, were the specific technical recommendations that emerged from the workshop's working groups. Among the most important were suggestions to revise the initial complement of ALS beamlines and to develop new materials and designs for detectors and beamline components. The first of these was reflected in the revised design of undulators U_A and U_B, and the second is a continuing activity in the Center for X-Ray Optics at LBL.

Since the 1983 meeting, an ALS Users Executive Committee has been formed as an enduring link between LBL and the user community. This committee has continued to review and evaluate the status of the ALS project, and as a result of its initiative, a synchrotron radiation users workshop is scheduled at LBL for November 1985. The express purpose of this national workshop is to bring together a broad spectrum of users and to confirm, and update if necessary, our perception of their needs, including required wavelength ranges, power levels, pulse time structure, and beam-position reproducibility. With this information in hand, we can proceed with confidence to update the ALS conceptual design and to embark on the necessary preconstruction R&D.

ACKNOWLEDGMENT

The author thanks D. Vaughan for his extensive contributions in the preparation of this paper.

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