Title
Fifth Annual Meeting of the Advanced Light Source Users' Association

Permalink
https://escholarship.org/uc/item/48s9c62s

Author
Lawler, G.

Publication Date
1993-10-01

LBL-34736
CONF-9208225
UC-411

Fifth Annual Meeting
of the
Advanced Light Source Users' Association

August 27–28, 1992
Lawrence Berkeley Laboratory

Organized by
ALS Users' Executive Committee

Lawrence Berkeley Laboratory
University of California
Berkeley, California 94720

October 1993

Prepared for the U.S. Department of Energy under Contract No. DE-AC03-76SF00098

LBL-34736
CONF-9208225
UC-411

Fifth Annual Meeting
of the
Advanced Light Source Users' Association

August 27–28, 1992
Lawrence Berkeley Laboratory

Organized by
ALS Users' Executive Committee

Lawrence Berkeley Laboratory
University of California
Berkeley, California 94720

October 1993

This work was supported by the Director, Office of Energy Research, Office of Basic Energy Sciences, Materials Sciences Division, of the U.S. Department of Energy under Contract DE-AC03-76SF00098.

Contents

Preface

A nearly completed Advanced Light Source (ALS) greeted the 170 people who attended the fifth annual meeting of the facility's Users' Association, held at Lawrence Berkeley Laboratory (LBL) on August 27 and 28, 1992. Anticipating the opening of the ALS in spring 1993, potential users came to learn about opportunities for making use of the world's brightest beams of ultraviolet and soft x-ray synchrotron radiation.

The program was introduced by the chair of the ALS Users' Executive Committee, Piero Pianetta (Stanford Synchrotron Radiation Laboratory), and began with a welcome by LBL Director Charles V. Shank, who announced a major change in ALS leadership, effective October 1, 1992. Jay Marx, ALS Director for the past six years, will leave to return to research as head of a new project combining high-energy and nuclear physics. Brian M. Kincaid, Deputy Director for Experimental Systems of the ALS for the past four years, will take his place at the helm. Shank praised Marx for his leadership of the ALS, calling it a "textbook project." He also had words of praise for Kincaid, who will have responsibility for completing the ALS construction project, running the facility when it becomes operational, and developing the scientific program.

Following Shank's remarks, William Oosterhuis of the Office of Basic Energy Sciences at the U.S. Department of Energy provided an overview of the funding climate for experimental facilities (beamlines and end stations) and for research at synchrotron-radiation facilities. Oosterhuis encouraged participants to be aggressive in submitting proposals despite the somewhat discouraging outlook for funding in these difficult budget times. He indicated that persistence in working with DOE program managers to develop proposals that respond to national needs and in assembling first-rate research teams to do forefront research would eventually be rewarded.

In his last talk to the user community, Marx gave a history of the ALS combined with an account of the facility's progress. He reported that the injector-accelerator system is operating routinely at full energy (1.5 GeV), with sufficient beam current extracted from the booster to fill the storage ring in a few minutes. The storage ring is close to being ready for its first injection of beam—an event scheduled for fall 1992.

Marx noted that five beamlines will make up the first complement on the ALS experimental floor. Three will deliver photons generated by undulators, and two will provide bend-magnet radiation. The three undulators, under construction at the ALS, include two with a 5-centimeter period and one with an 8-centimeter period. Assembly of the first undulator is nearly complete, and field mapping confirms that specifications consistent with a high-quality fifth harmonic have been met. The other two undulators will be completed soon after the first. By 1995, the ALS will have ten beamlines, including five with undulator sources.

Marx concluded by expressing his gratitude to the ALS staff for their hard work and support. Afterwards, Pianetta presented Marx with a commemorative photograph of the ALS and enthusiastically conveyed the good wishes of the users.

Marx's farewell was followed by a series of talks by ALS managers reporting progress in specific areas. Alan Jackson, Deputy Director for Accelerator Systems, described the commissioning of the booster and promised photons in April 1993. Kincaid spoke about the development of extremely refined water-cooled optics for ALS beamlines that meet or are better than the stringent specifications required to preserve the brightness of the undulator light and about the characteristics of the undulators, whose field-quality is more than sufficient for use of the fifth harmonic.

Fred Schlachter, ALS Scientific Program Coordinator, spoke of plans for a "user-friendly" facility with "one-stop shopping," where users can take care of check-in and all other institutional requirements at a single location. He discussed the progress of laboratory and office space for users, and provisions for ensuring user safety.

Philip Ross, Acting Scientific Director, described the scientific program established for 1993–1995. Ten participating research teams (PRTs) will operate beamlines during these first years after the ALS opens. He reported that a call for letters of interest was distributed to solicit responses from potential independent investigators—scientists not affiliated with a PRT who would like to conduct experiments at the ALS.

Guest speakers from the U.S. and Europe described their use of synchrotron radiation for electron and x-ray emission spectroscopy, emphasizing the extended possibilities offered by the ALS. Ingolf Lindau (MaxLab, Sweden) began the series of talks with the topic of high-resolution photoemission spectroscopy. Charles Fadley (LBL and University of California at Davis) described research using photoelectron diffraction, including observations of bond orientation in molecules on surfaces and identification of bonding sites. He also surveyed the prospects of photoelectron holography for accurate imaging of surface and near-surface atoms. X-ray emission spectroscopy was covered by Thomas Callcott (University of Tennessee), a spokesperson for a PRT that will be among the first to work at the ALS.

A series of presentations on spectroscopy and microscopy began the second day's program. James Samson (University of Nebraska) spoke on gas-phase spectroscopy experiments in which fluorescence was used to sort out Rydberg series in rare gases. In a talk about his work in spectromicroscopy, Harald Ade (SUNY Stony Brook, now at North Carolina State University) discussed plans for bringing scanning photoemission and scanning transmission microscopes with resolution as low as 10–50 nm to the ALS. Both James Tobin (Lawrence Livermore National Laboratory) and Yan Wu (IBM Almaden Research Center) described the use of magnetic circular x-ray dichroism for the investigation of magnetic materials. Wu spoke of an imaging microscope used with circularly polarized x rays that provides a spatial resolution of about 1 μm.

The last series of speakers focused on potential commercial applications of synchrotron radiation. Jeffrey Bokor (AT&T Bell Laboratories) talked about exploiting the near-coherent light from ALS undulators for interferometric testing of optics to be used in projection x-ray lithography. This technology holds promise for the production of a new generation of microchips with smaller features, but it requires soft x-ray optics and a means for testing them "at wavelength." Gene Ice (Oak Ridge National Laboratory) described the use of a bend-magnet microprobe for analysis of a wide range of materials with a spatial resolution approaching 1 μm. In his talk on protein crystallography, Sung-Hou Kim (Lawrence Berkeley Laboratory) described a recent study of a transmembrane receptor to illustrate the use of x-ray diffraction to determine the structure of proteins. He predicted a huge worldwide demand for beam time at facilities like the ALS that will enable rapid acquisition of high-resolution diffraction patterns. Edwin Westbrook (Argonne National Laboratory) ended the talks with a discussion of the need for large-area detectors in x-ray diffraction and described the ongoing development of CCD detectors that can satisfy this need.

Welcome to the Fifth Annual Meeting of the ALS Users' Association

Charles V. Shank
Director
Lawrence Berkeley Laboratory
Berkeley, CA 94720

I would like to welcome you to Lawrence Berkeley Laboratory and to the Fifth Annual Meeting of the Advanced Light Source (ALS) Users' Association. I know that you will be as excited as I am to see the progress we have made since last year's meeting. The ALS is close to operational readiness, and I expect that the next time I stand before you, five beamlines will be delivering photons to your experiment stations. We are well on the way to that milestone.

One thing I would like to discuss this morning is the motivation behind the coming change in ALS leadership and where that change will take the ALS in the future. Every committee that has advised me has recommended that the ALS should begin as a project and evolve into a scientific program and, furthermore, that the person who builds the project should ultimately be replaced by someone who will lead the scientific program. We have been extraordinarily fortunate to have had someone as capable as Jay Marx to lead the project phase. His leadership has made the project—as I have heard so often—a textbook case of putting together a large facility. So, for that, all of us here and myself owe Jay a great debt.

As we look now to the future, the scientific program will grow ever more important. I think we all agree that the success of the ALS will not be determined by whether we deliver photons on time, but whether the photons delivered allow all of you here today to conduct world-class science. So our focus must move in that direction.

As a result of these ideas, we set out to recruit new leadership for the ALS in anticipation of its becoming a program. We conducted an intensive search; I considered advice from the Users' Executive Committee; and, as a consequence of these activities, I am pleased to say that we have selected a capable person from LBL to take over this position. The new director of the ALS, as many of you know, will be Brian Kincaid. He is my first choice for the job. He has extensive background in the field, having begun his career as a synchrotron-radiation user. Four years ago, he came to LBL as the ALS Deputy Director for Experimental Facilities and built a team that has had enormous success in the design and development of insertion devices and beamline optics for the facility. I believe that he has all the qualifications needed to provide first-class leadership.

The ALS is a different kind of program from those established here at LBL in the past. We built the Bevatron and then the Bevalac, but these facilities were intended primarily to accommodate internal users, with some outside user component. The ALS is different in that, from its first day of operations, it will be focused on a broad user community—much broader than currently exists at LBL. So we must make this facility the easiest and most efficient place in the country to conduct research with synchrotron radiation. Not only do we expect the light source to work well technically, but we also expect that an infrastructure will be established to enable you to come and use this light source in a very efficient way. Brian is committed to making that happen.

In addition, the selection of research projects to be conducted here will make a great difference in determining whether the ALS is a successful facility—one that will continue to get high priority and funding from the Department of Energy—or one that will pass into oblivion. We must have a scientific program that is first rate.

In that area, I would like to express appreciation for what Phil Ross has done. In his capacity of Acting Scientific Director, he has made a large contribution to putting together a program that will allow us to have a very effective initial complement of activities at the ALS. My expectation is that Phil will be working with us in the future as we try to recruit a full-time head of the scientific program.

I have given you the broad outlines of our activity and would be pleased to answer any questions that might occur now or at a later time.

Report from the DOE

W. Oosterhuis
Department of Energy
Basic Energy Sciences

I am happy to be here, and would like to welcome you on behalf of the DOE. This is the advent period for the ALS as we anticipate the completion of the construction activities and the beginning of operations next spring. And I'm sure you are all looking forward to using the new experimental facilities!

Rarely has the construction of such a complex machine gone forward so smoothly. We should hope that all projects go so well. This excellent progress is due to the dedicated efforts of the ALS staff and especially to the leadership of Jay Marx.

Jay had the responsibility for bringing together a team of people to build the ALS and for working with them to carry out this job. They have done well. Speaking for those of us back in Washington (or at least in Germantown), we have really enjoyed peace of mind during the course of this project because of the competence of the ALS staff under Jay's leadership.

Now, as for the battle of the budget, FY93 does look like a very tough year. The DMS will probably have very little increase in its budget for research and operations of facilities. Nevertheless, we are committed to support for ALS operations as near the requested level as is possible.

We will support some initiatives for new beamlines. We (DMS, DCS, OHER) will make commitments for new beamlines, and I expect that other agencies, principally NSF, NIH, and DOD, will join with us in the instrumentation of the ALS. There will not be enough resources to do all the things that have been requested, but there will be funding available to do some of them. My point is that we (you and I) have to be in this effort for the long run. Persistence in seeking support is essential!

New, state-of-the-art beamlines will be necessary for us to see further, deeper things we have not seen before. That is why it will be worth the effort to secure the funding necessary to develop these beamlines, even though it may be frustrating and difficult.

It may even turn out to be a good thing that we can't support all requests immediately. In a few years, new developments that have not yet been conceived will emerge, and we will want to exploit them. For example, a few years ago, who would have predicted today's enthusiasm for circularly polarized photon beams? *That* capability will be available at the ALS from one of the next beamlines to be developed! Let me close by wishing you a successful users' meeting and offering the hope that as many of you as possible will be on the air in the coming year.

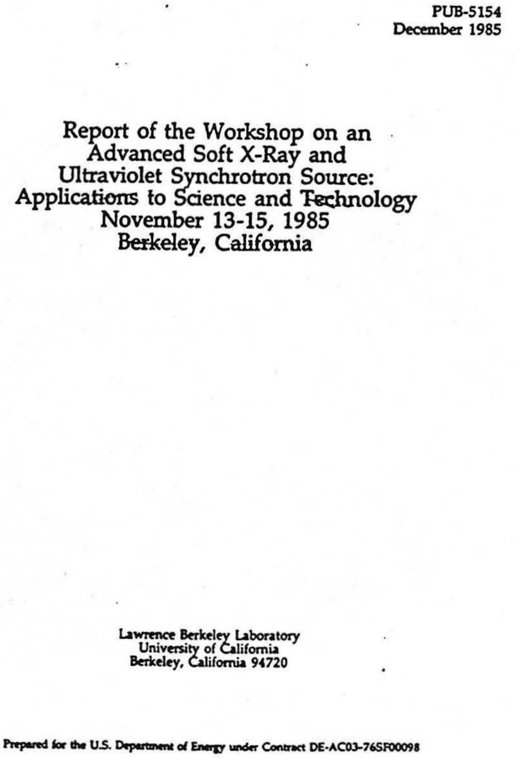
ALS Project Status

Jay Marx
Director, Advanced Light Source
Lawrence Berkeley Laboratory
Berkeley, CA 94720

This is the last time I will be speaking to this audience, at least as ALS Director. Instead of presenting an ordinary status report, I would like to look back at the history of the ALS and look ahead as well. The current status of the ALS will be included in this talk, but, in addition, I will use photographs that have been taken over the last few years to show you how the light source came about and where it is going.

At least for me, the ALS started in 1985—at a large workshop held here in Berkeley. This workshop brought together the user community to contribute ideas on what the major capabilities of the ALS should be (see Figure 1). Users representing many fields of science attended that meeting and provided LBL management and some of us who would be involved in building the ALS with a great deal of input. In fact, that workshop led to the parameters that drove the conceptual design of the ALS. For example, one of its results was a change in the optimized energy of the electrons in the storage ring from 1.3 to 1.5 GeV.

That occasion was the first time I met many of you. It was a time when I began to understand how important it is to have the scientific community provide continuing input to this project. That workshop led to a set of guidelines that allowed a group of people here at LBL to develop the ALS *Conceptual Design Report* (see Figure 2), which became the bible for those of us who were building the facility. This report was submitted to the DOE in July 1986, was reviewed in great depth, and finally led to the authorization of the first construction funding for the ALS in fall 1987. The effort to put the report together involved many people who are now part of the ALS team and many who have gone on to do other things. I want to mention Klaus Berkner, Max Cornacchia, and Malcolm Howells, who played major roles in this effort.



PUB-5154
December 1985

Report of the Workshop on an
Advanced Soft X-Ray and
Ultraviolet Synchrotron Source:
Applications to Science and Technology
November 13-15, 1985
Berkeley, California

Lawrence Berkeley Laboratory
University of California
Berkeley, California 94720

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

Figure 1. Cover page of workshop document.

PUB-5172 Rev.

1–2 GeV SYNCHROTRON
RADIATION SOURCE

Conceptual Design Report — July 1986

Lawrence Berkeley Labortory
University of California
Berkeley, California 94720

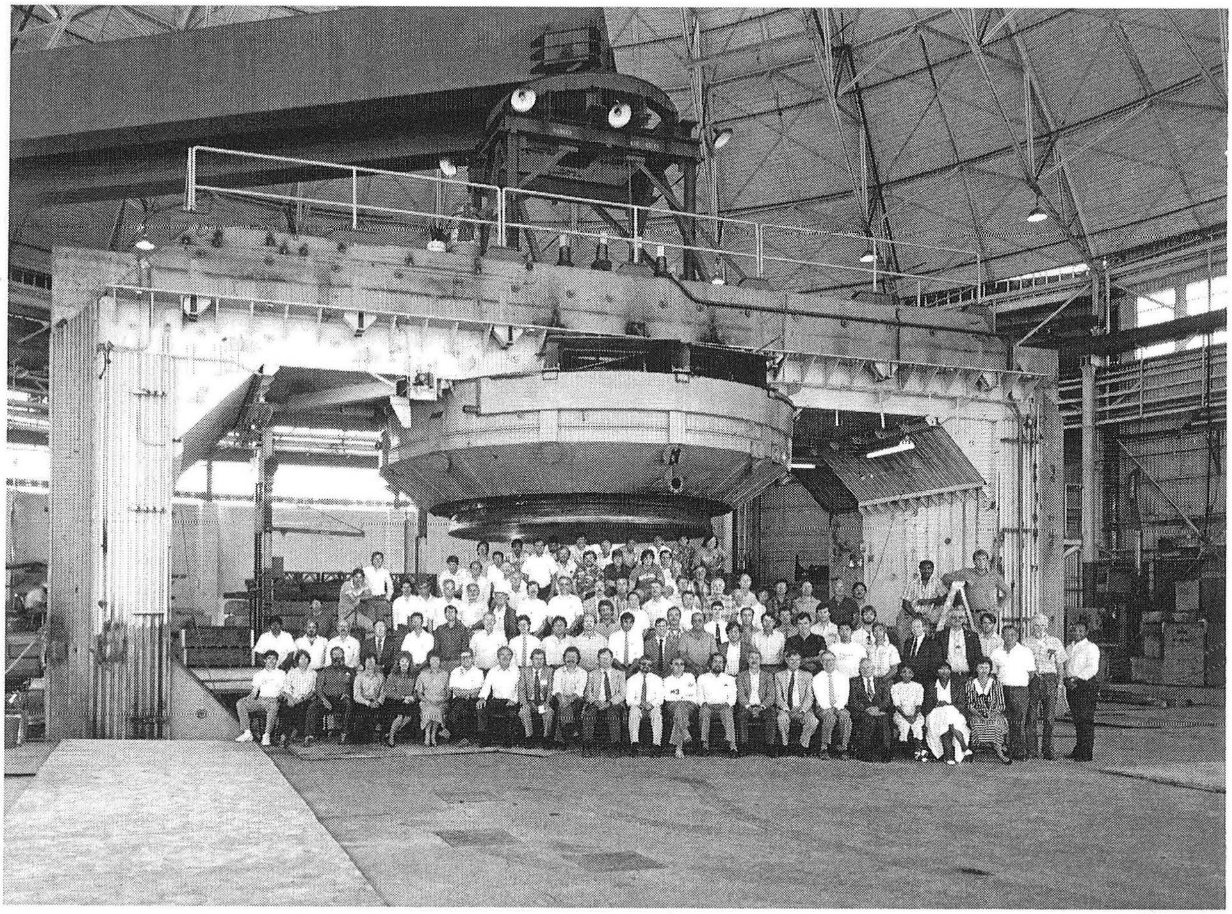
Prepared for U.S. Department of Energy under Contract No. DE-AC03-76SF00098

Figure 2. Cover page of Conceptual Design Report.

This first funding for the ALS was not the full construction funding. Congress authorized $1.5 million to get started on basic engineering designs. The first thing we did was to put together a team of people (see Figure 3).

The conceptual design of the ALS included the design of the building. In 1987, the ALS building was a model done by the architect (Figure 4), which you can now see in the lobby of the completed ALS building. Today, the building looks like this model except for the lack of a nice parking lot. The specifications called for a 1.5-GeV, full-energy injector under the dome and a 12-sided storage ring just outside the dome with the capacity for many beamlines from undulators, wigglers, and bend magnets (Figure 5).

The conceptual design specifications that were developed for the accelerator systems and which we still intend to reach are shown in Figure 6. The injector is a 50-MeV linear accelerator (linac) feeding a 1.5-GeV, 1-Hz booster that can fill the storage ring in a few minutes. The storage ring has an optimized energy of 1.5 GeV, although it can run from 1 to 1.9 GeV, allowing flexibility for user operations. We are aiming for a maximum current of 400 mA in multibunch operation and, of course, a very low emittance to allow us to produce the extremely bright photon beams that everyone wants. The time structure of the beams is also very important for experiments in which short-lived or transient systems are observed through time-resolved spectroscopic, scattering, or imaging techniques. We are trying to achieve a very short time structure and a decent beam lifetime.



CBB 887-3889

Figure 3. The ALS team in 1987 sitting in the gap of the 184-inch cyclotron inside the dome that now forms the center of the ALS building: Dave Attwood, Alan Paterson, Brian Kincaid, Alan Jackson, Ron Yourd, Klaus Berkner, Henry Lancaster, and Werner Ganz, among others, are seated in the front row. The team's first task was to get rid of the cyclotron, but the yoke, now used as a support for a large crane, is a permanent fixture in the building.

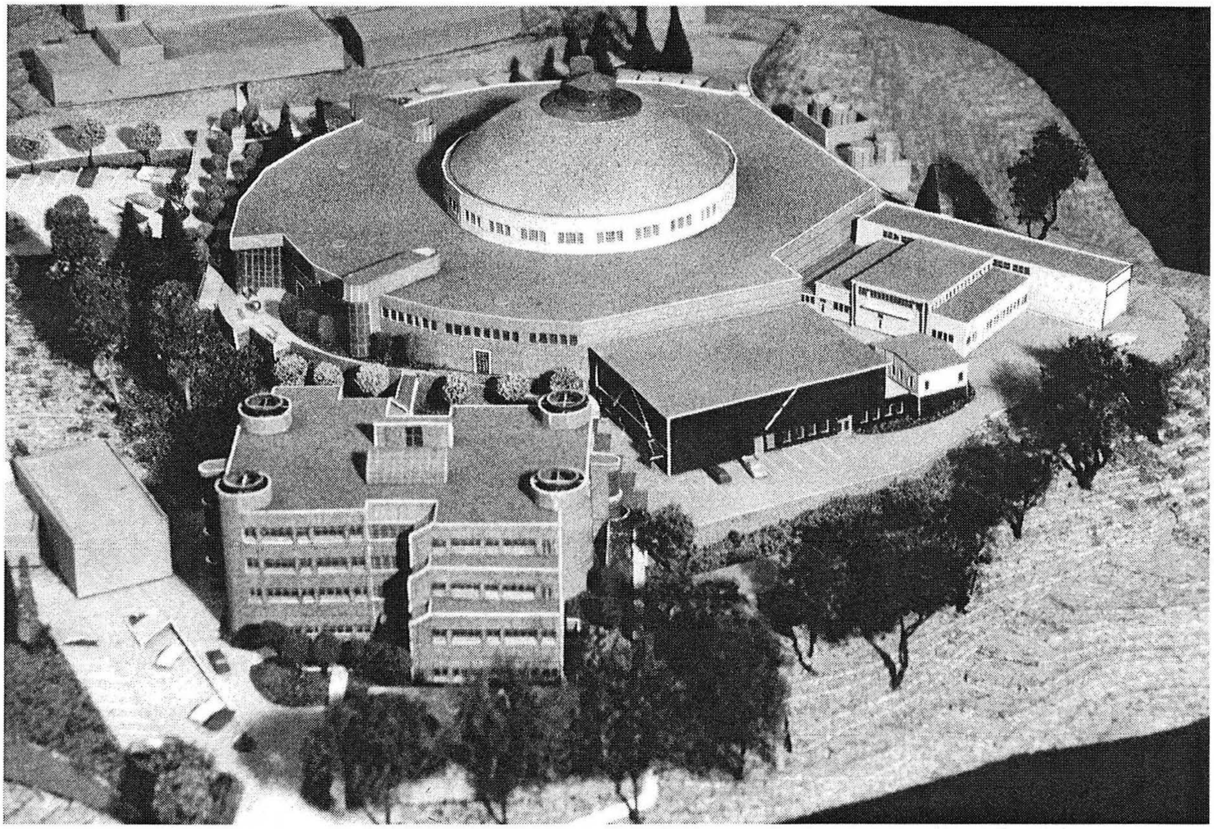


Figure 4. Model of the ALS.

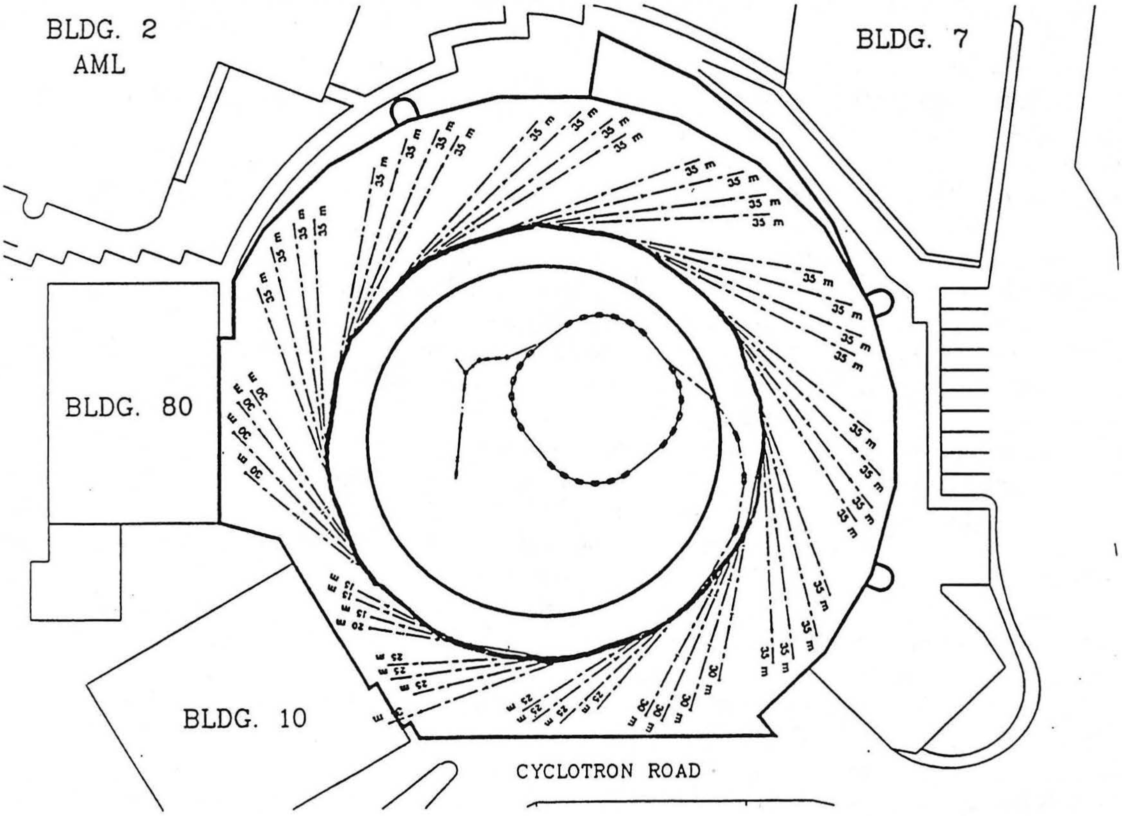
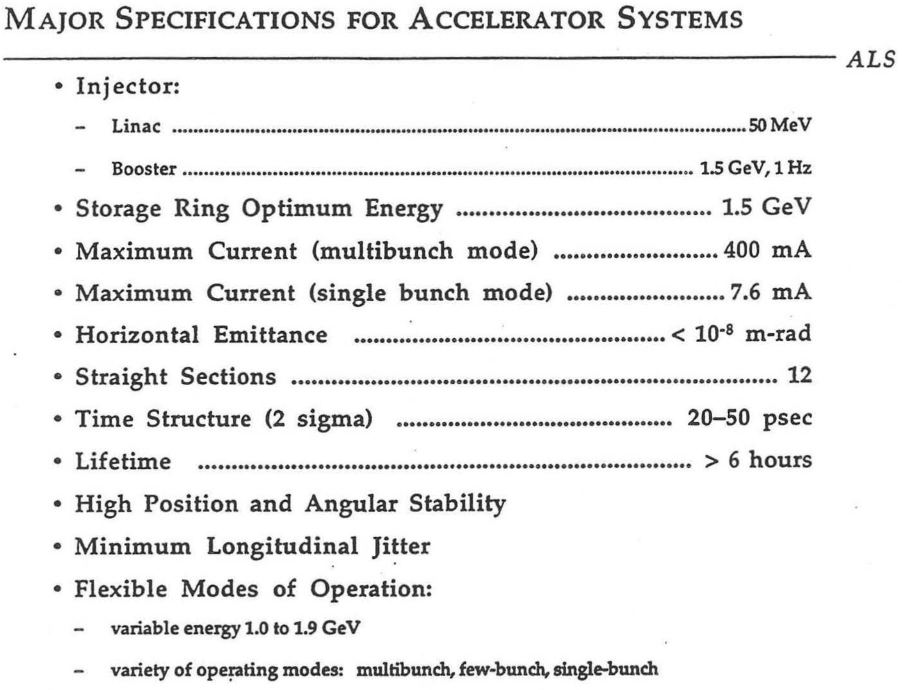


Figure 5. ALS plans showing injection system, storage ring, and potential beamlines.



MAJOR SPECIFICATIONS FOR ACCELERATOR SYSTEMS

ALS

• Injector:	
– Linac	50 MeV
– Booster	1.5 GeV, 1 Hz
• Storage Ring Optimum Energy	1.5 GeV
• Maximum Current (multibunch mode)	400 mA
• Maximum Current (single bunch mode)	7.6 mA
• Horizontal Emittance	$< 10^{-8}$ m-rad
• Straight Sections	12
• Time Structure (2 sigma)	20–50 psec
• Lifetime	> 6 hours
• High Position and Angular Stability	
• Minimum Longitudinal Jitter	
• Flexible Modes of Operation:	
– variable energy 1.0 to 1.9 GeV	
– variety of operating modes: multibunch, few-bunch, single-bunch	

Figure 6. Design specifications for accelerator systems.

Understood in the design is the concept that many beams are needed, not just those from insertion devices but also those from bending magnets. Figure 7 shows one of the 12 arcs of the storage ring, emphasizing the beam ports—one for the beam from an undulator or wiggler upstream and four for beams from bending magnets in the arc. Initially, we are developing beamlines from only the two center bending-magnet ports in each arc, those with the smallest vertical source size.

The next step, of course, was to try to get complete funding for the project. Success in obtaining funding was an occasion to celebrate (see Figure 8). I want to show this picture for two reasons. One is to acknowledge Dave Shirley's contribution to the ALS. The other is to show our style of parties and also my daughter Elena, who has grown up with the ALS. We have all grown up with this project. In fact, the ALS started much earlier than all of this.

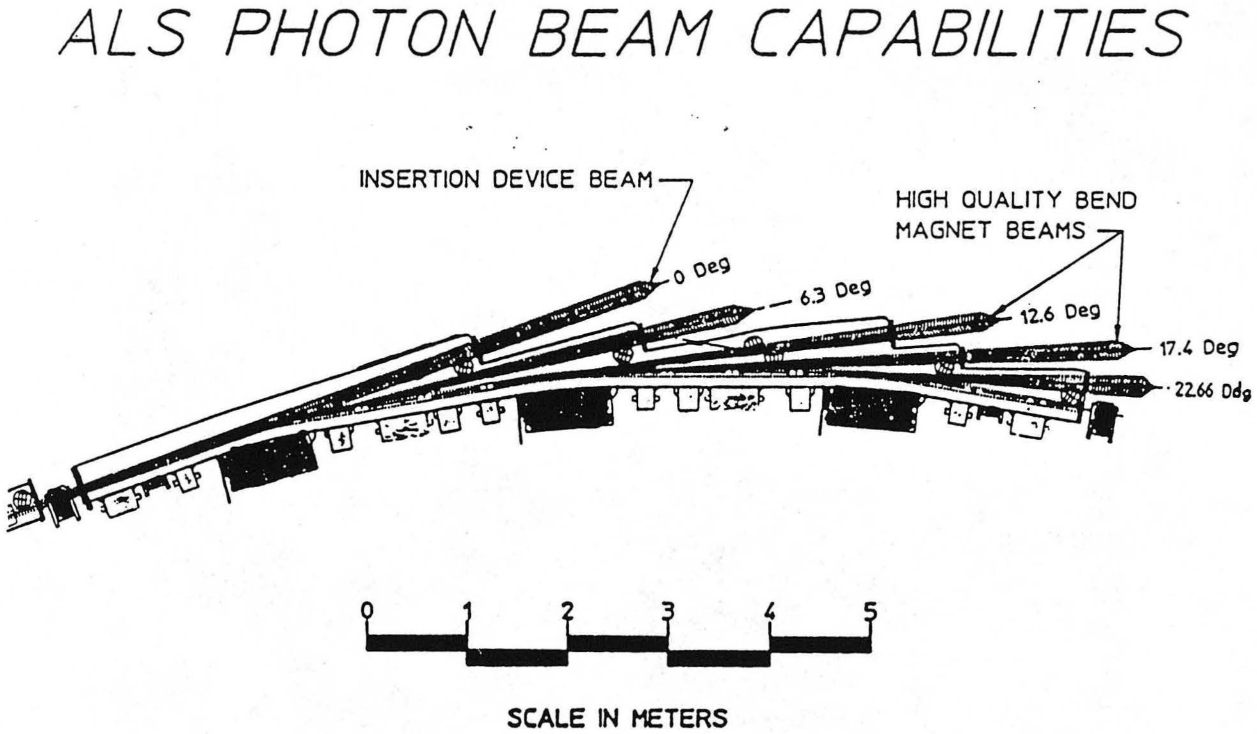
The ALS started with that domed building—the first built here at LBL (see Figure 9). It was built in 1941, I believe, on the present site of the ALS. In Figure 9, you can see the yoke of the cyclotron, which is still with us. Again, this is a time when there were no parking problems—the good old days.

In Figure 10, we jump ahead from 1941 to 1989, and things don't look much different. Of course, through the intervening years, there was a tremendous amount of research on the cyclotron. We spent a few years stripping it out, disposing of it, and beginning the construction of the annular addition outside the dome that holds the storage ring and the beamlines.

The next photograph (Figure 11) is an aerial view taken in 1989. You can see some of the complexities of the site, the dome, the adjacent buildings, and the future floor of the ALS experimental hall. The numerous buildings nearby made the site cramped and presented a challenge for the design, including the building adjacent to the experimental floor at 10 o'clock, which will actually be bulldozed in a few years to make room for a parking lot. When we started, it was a rectangle. We clipped off the corner so we could have a roundish site for the ALS—a complication that I knew nothing about when I joined this project. I've learned a lot.

Figure 12 shows the construction of the experimental floor. Much attention was paid to building a stable floor—with lots of rebar, concrete, caissons going down to bedrock, and so on. So we expect the floor to provide the stability that high-brightness experiments require.

While construction was going on, the team was watching over its progress (Figure 13): myself, Ron Yourd, Brian Kincaid, and Allan Jackson. I want to say something about Ron because many of you have not met him. He is one of the unsung heroes of the ALS—the project manager for the construction



ALS PHOTON BEAM CAPABILITIES

Figure 7. Arc sector of the ALS storage ring, showing beam ports.

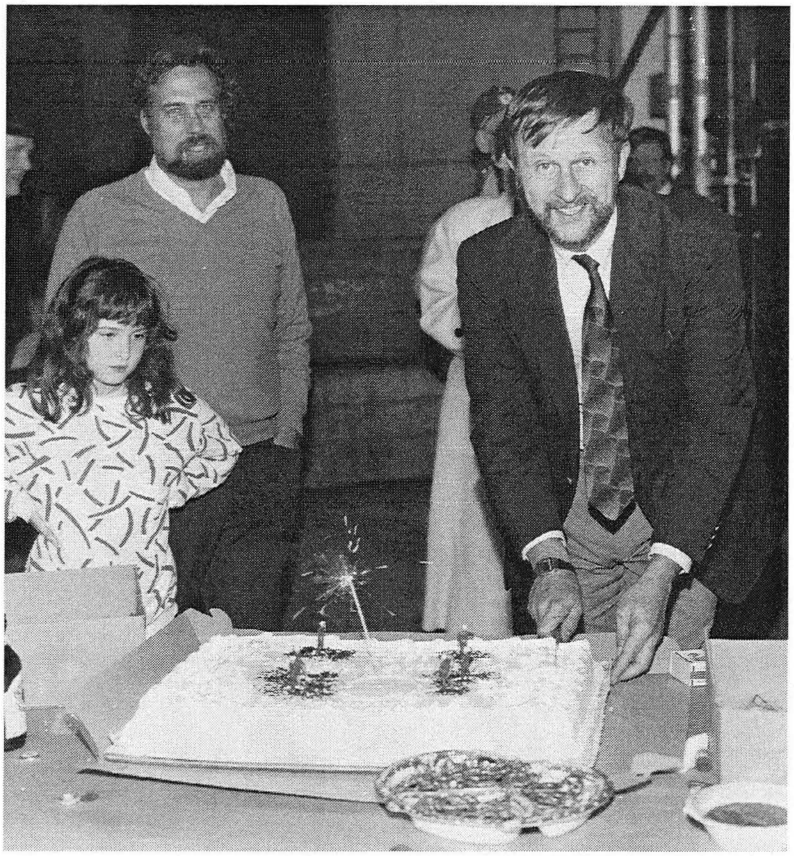
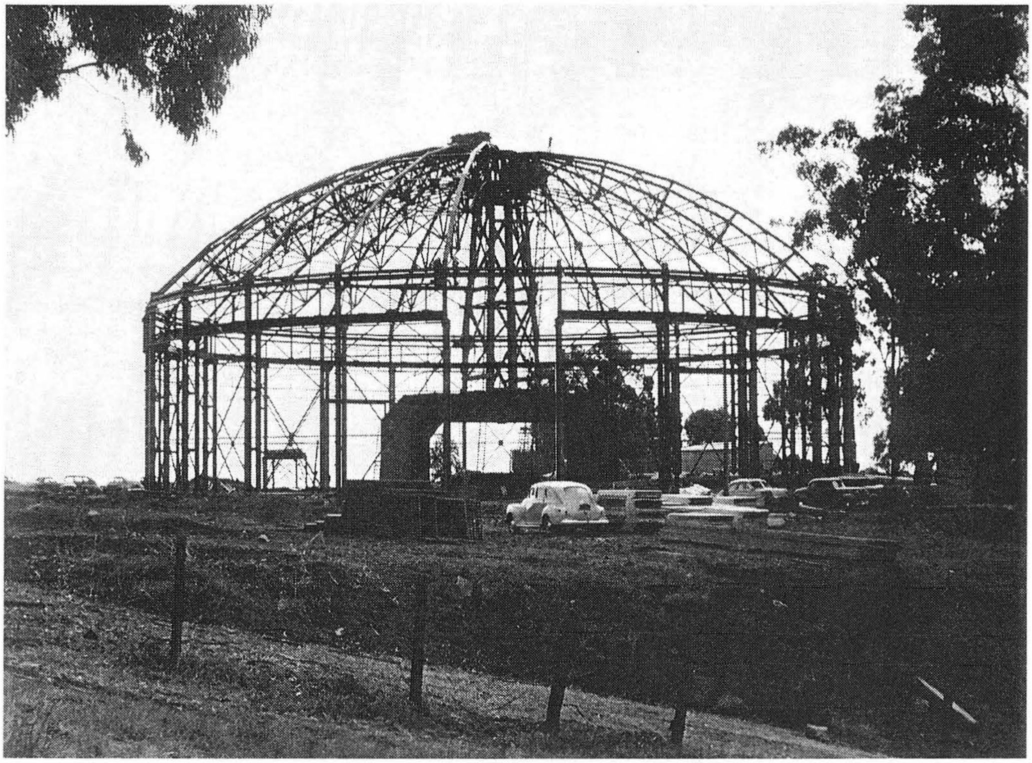
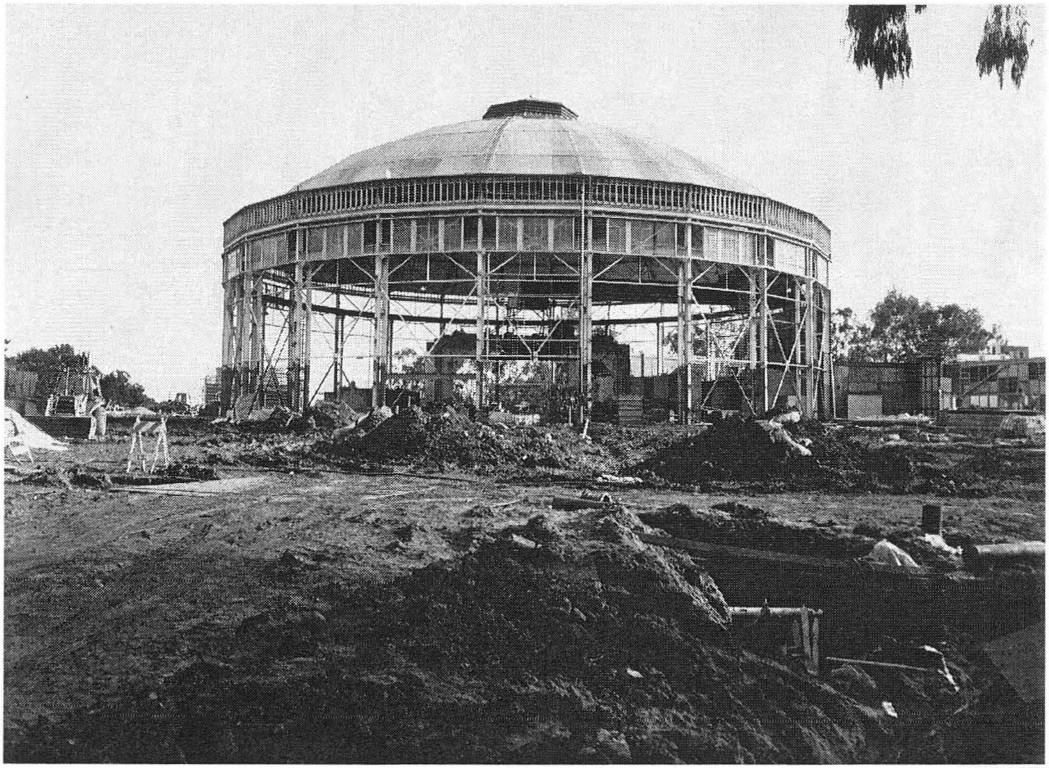


Figure 8. ALS celebration. Left to right, Elena Marx, Jay Marx, and David Shirley, former LBL Director.



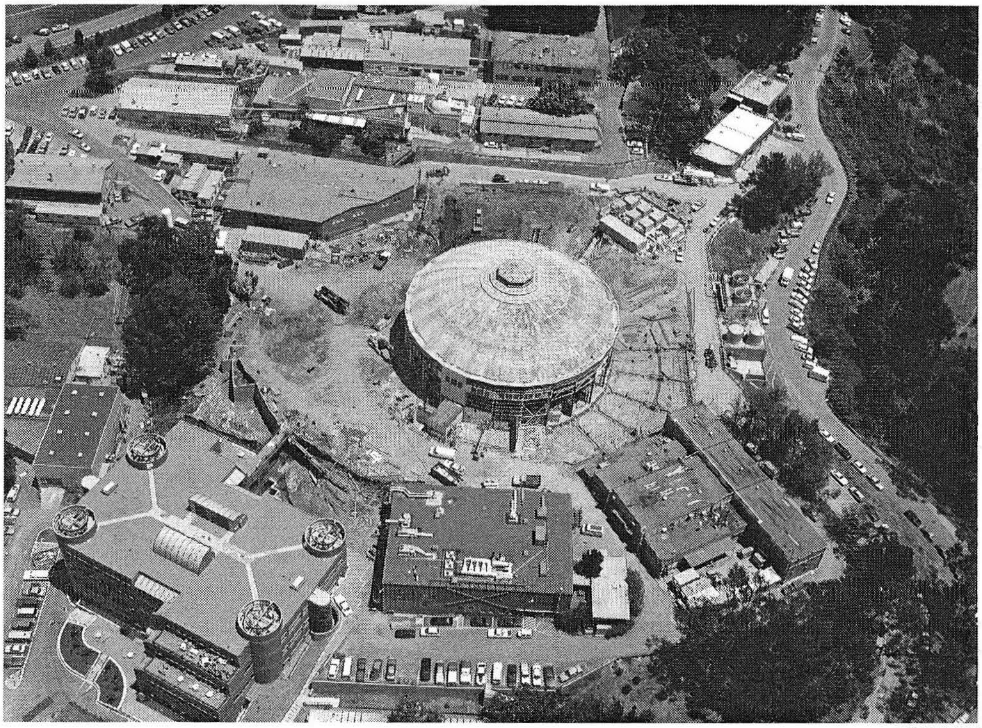
XBB 732-587

Figure 9. Construction of the 184-Inch Cyclotron in 1941 at the present site of the ALS.



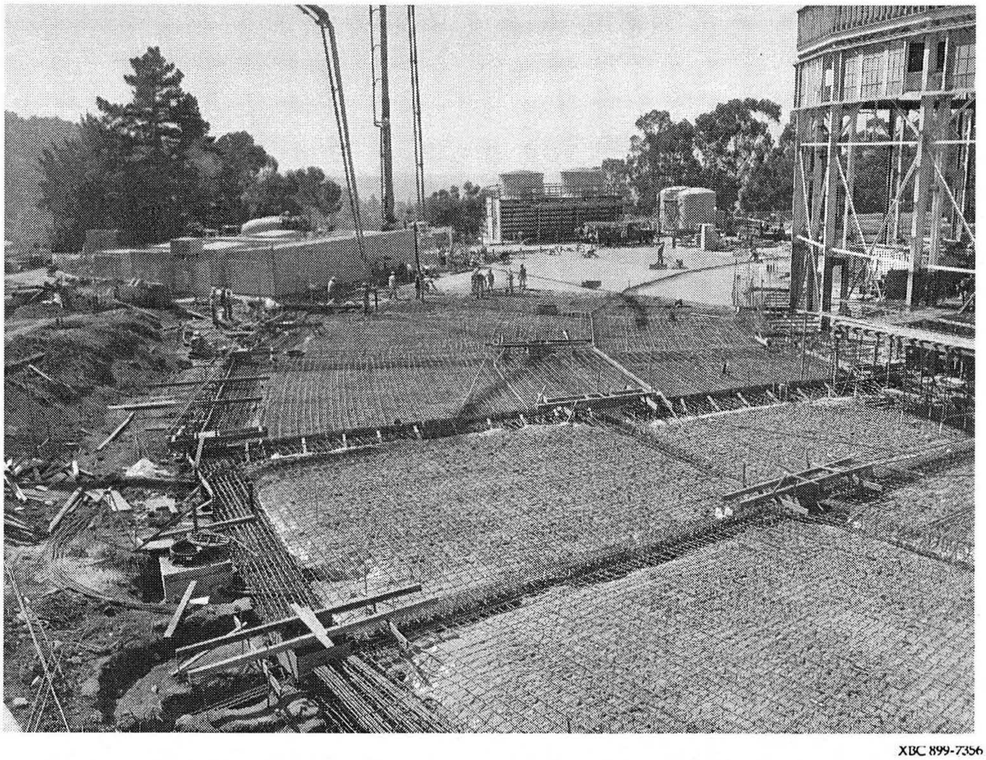
XBB 893-2539

Figure 10. Beginning of ALS construction. The cyclotron dome has been incorporated into the new building.



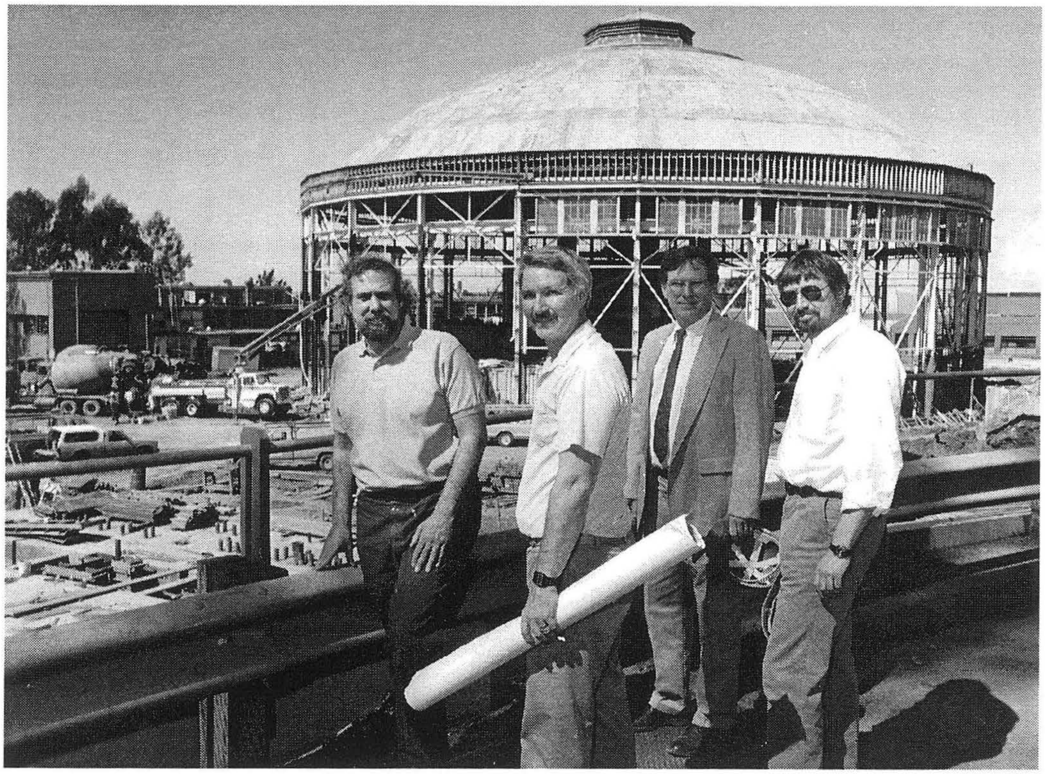
CBB 896-4518

Figure 11. Aerial view of the ALS building site early in the construction project.



XBC 899-7356

Figure 12. Construction of the ALS floor.



XBC 894-3012

Figure 13. ALS project leaders in 1989. Left to right: Jay Marx, Ron Yourd, Brian Kincaid, and Alan Jackson.

project. In fact, the ALS at various times has been described as the best managed project within the DOE. I sometimes get credit for that. Ron is the manager, and a lot of our success is due to Ron's superb management abilities.

During the construction phase, we have always had streams of interested visitors come and look over our shoulders. Even Admiral Watkins visited us (see Figure 14). At that point, we had the model and a construction site to show him—and a vision of what was coming.

The building grew. Figure 15 shows the site after the big earthquake in October 1989. When that quake occurred, the floor of the building was finished, and it happened to be the day when the first of the vertical columns was supposed to be installed. If they had been installed when that quake occurred, I think something very unpleasant might have happened. Fortunately, just at that time, construction had been delayed about a week, and the columns were lying on the ground; so there was no damage from the quake. Sometimes these delays are useful. I was in Washington when the quake occurred. It took six hours for me to receive a phone message to find out that both my family and my light source were okay.

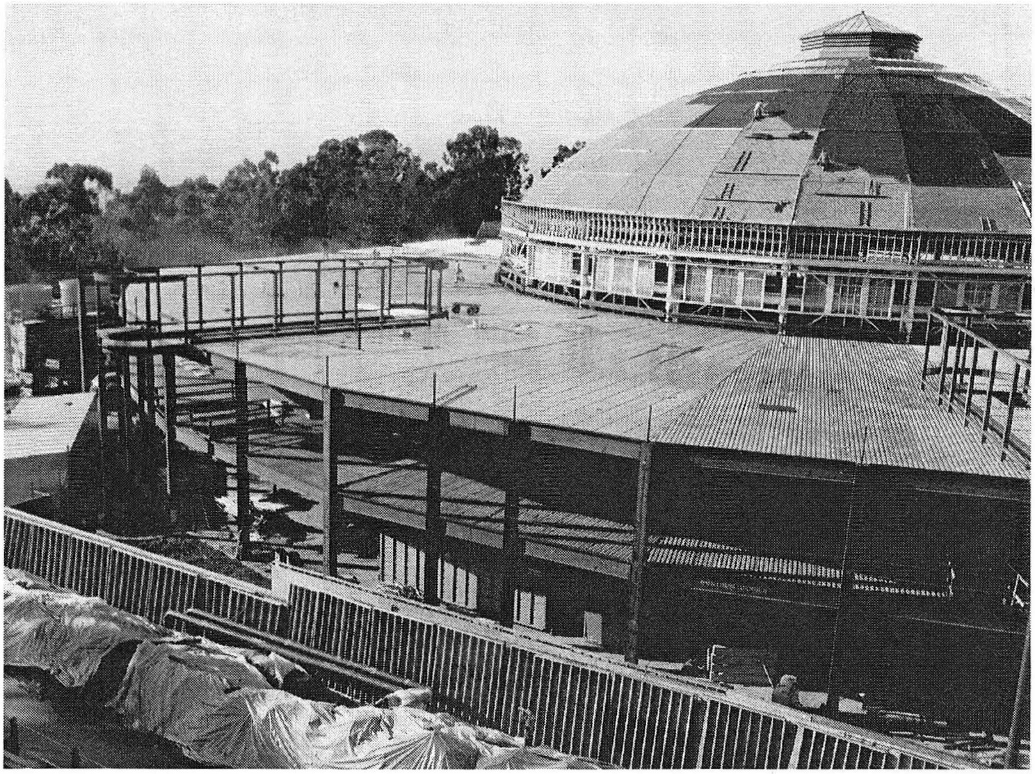
By 1991, the building was finished. Figure 16 shows it the way it looks now. You can see the dome, the hall for the storage ring and beamlines, and the crowded environment nearby—again, one of the real constraints we have had. At that point, the inside of the building was empty (Figure 17). The next step, of course, was to install the injector-accelerator system.

What I want to do now is turn to the injector and tell you that story (as shown in Figure 18). The injector is a full-energy 1–Hz system. The installation of the 50-MeV linac was completed, I believe, in early 1991, and the 1.5-GeV booster was completed about a year ago. We're now in the process of commissioning, and that has been a real success. I will say a few words about the commissioning later, but I want to leave some of the bragging rights for Alan Jackson.

The assembly of the injector went relatively smoothly; however, there were moments that made me nervous; Figure 19 shows one example, an accelerating section of the linac being lowered into its shielding enclosure. Figure 20 shows the linac, as it now stands, operating according to all of its specifications. The booster was more of a challenge in the following sense. We also had to fit it under

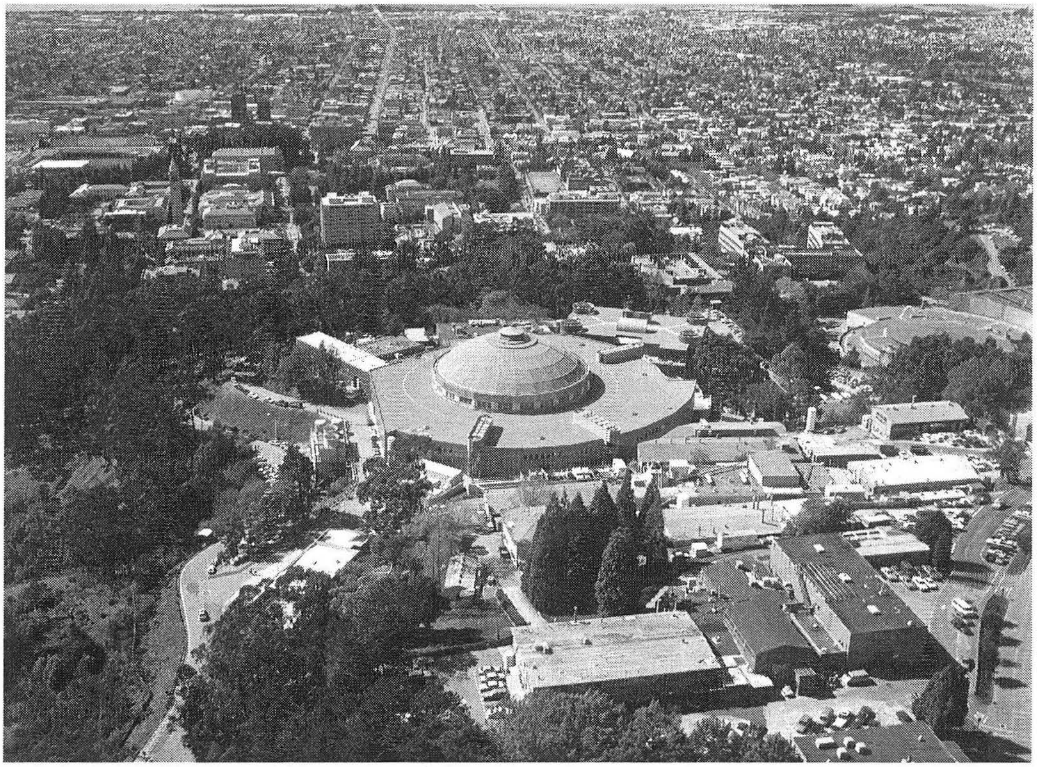
XBC 890-8591

Figure 14. Secretary of Energy Admiral James D.Watkins (second from left) visits the ALS.



XBC 901-561

Figure 15. The ALS building at the start of 1990.



CBB 913-1518

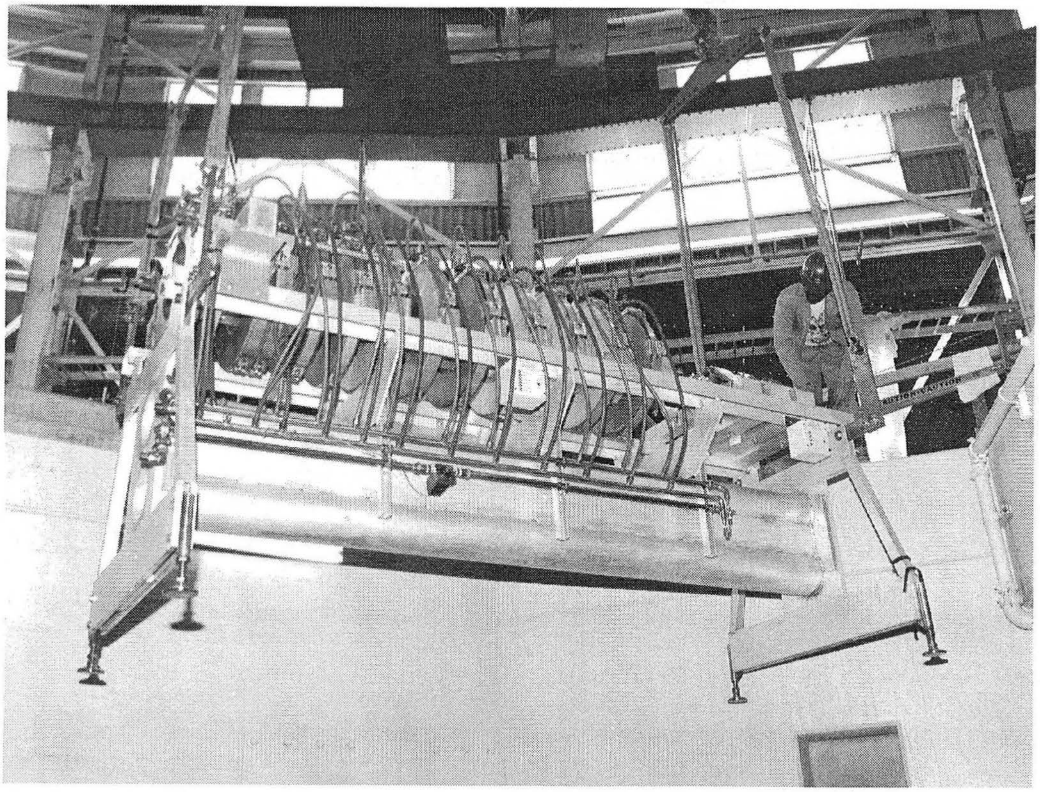
Figure 16. The ALS building was completed early in 1991, when this photograph was taken.

XBC 914-2771

Figure 17. In April 1991, the empty floor of the ALS building awaited installation of the injector-accelerator system.

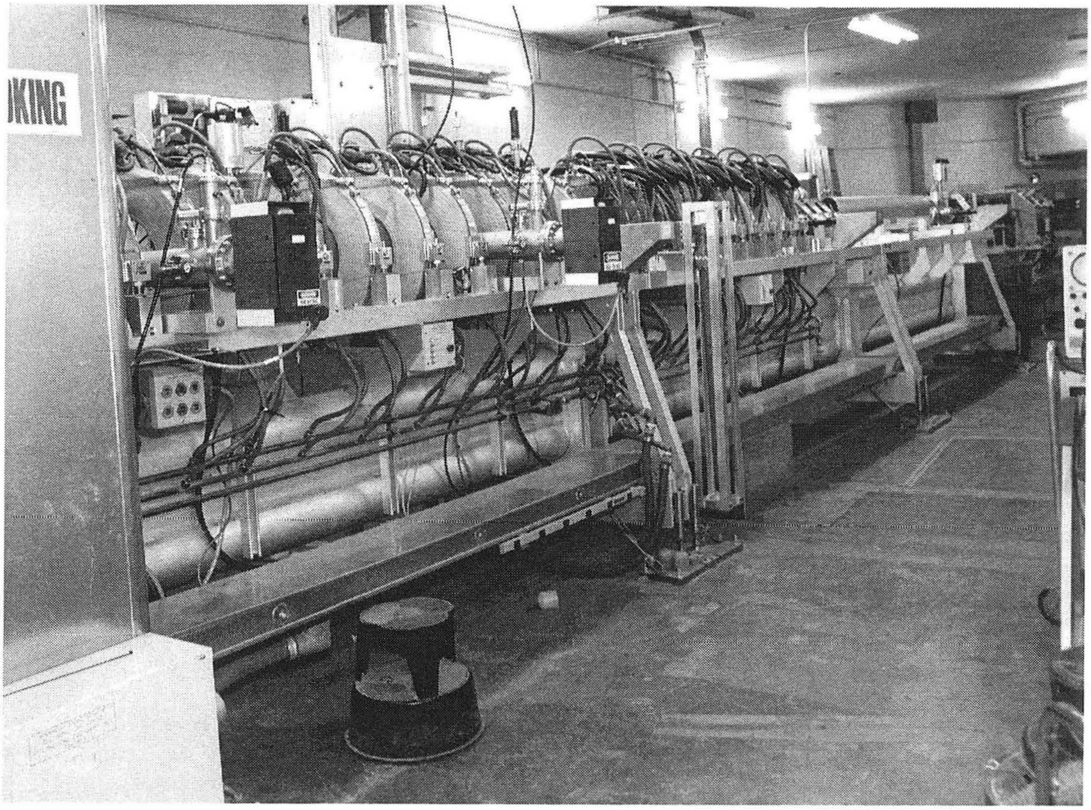
- **50 MeV Linac and 1.5 GeV, 1 Hz booster**
- **Installation of Linac completed early in 1991**
- **Installation of booster completed one year ago**
- **Commissioning in progress**

Figure 18. Injector-accelerator system milestones.



XBC 905-3885

Figure 19. An accelerating section of the linac being lowered into its shielding enclosure.



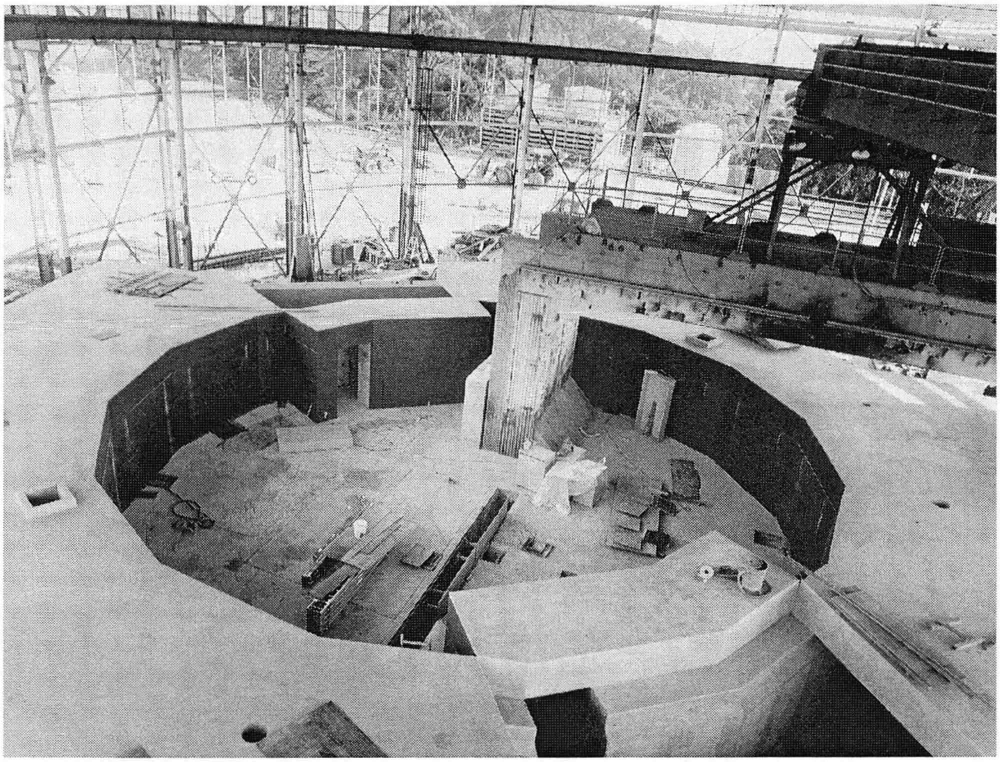
CBB 900-9336

Figure 20. The completed linac.

the dome. We had decided, for good reason, to keep the yoke of the old cyclotron; so the booster had to thread its way through the old yoke. Figure 21 shows the concrete shielding enclosure for the booster. The photo gives you a feeling of the booster's size and location. Outside the dome, you can see the construction on the experimental floor at this stage and the cooling towers of the ALS. The technical systems for the booster, the vacuum systems, and the magnets required a great deal of work by many people. In Figure 22, you can see our factory for assembling magnets on girders. This photograph gives a feeling of the complexity of things. Figure 23 shows another critical moment when one of the booster girders, fully loaded with vacuum chambers and magnets, was being brought under the dome to be lowered into its shielding enclosure. Once the booster girders were installed, a lot of work still had to be done: electrical work, plumbing, connection of power supplies, and a great deal of very precise surveying to get the booster in place, as shown in Figure 24.

During that time we had many visitors also. Figure 25 shows one memorable occasion when Chancellor Helmut Kohl of West Germany visited LBL and toured the ALS. The Chancellor, his wife, his translator, and Chuck Shank appear in the photograph.

The injector itself is a big success. Let me say a few words about its commissioning (see Figure 26). The linac works. It provides the beam required by the booster. It operates stably. Allan Jackson's team is tweaking it—improving it. As for the booster, we can now extract beam at full energy with enough current to fill the storage ring in a few minutes. That is what is required of the booster, and it really operates as we want. During the three-month period starting about last Christmas, we had a great time. We attained a major milestone each month. Last Christmas, for the first time, we accelerated beam in the booster to half energy. We had some power-supply problems to deal with. By the end of January, we had accelerated a few milliamps to the full energy of 1.5 GeV. During February, the current was increased. In early February, we reached half current and, by the end of February, full current. In March, we successfully extracted beam—enough to fill the storage ring in the required time. So the team has had from April until now to tweak the booster, to make it more robust, to try to make acceleration a turnkey

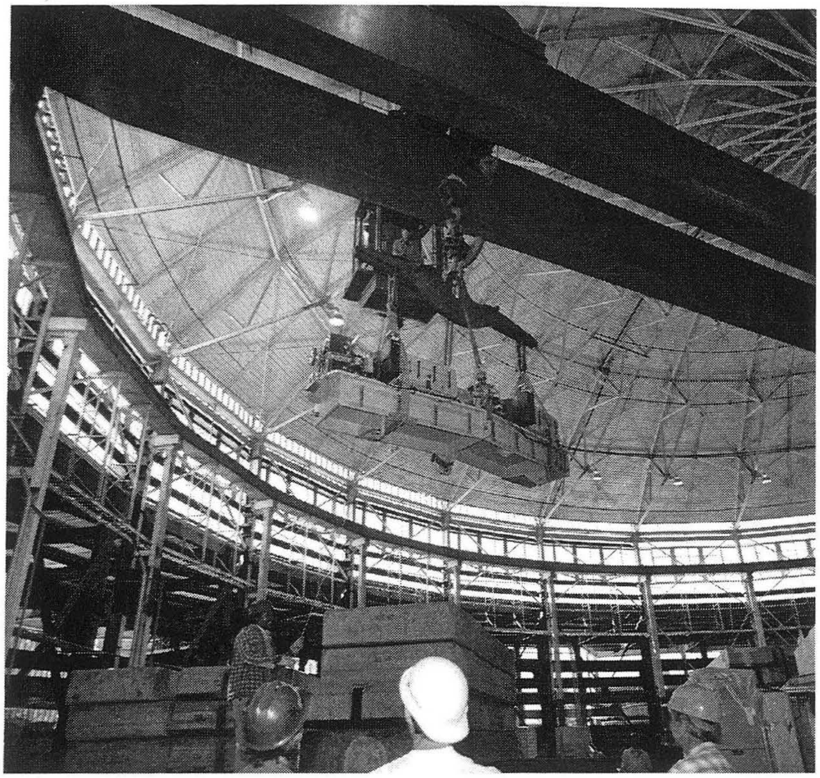


XBC 890-9357

Figure 21. Concrete shielding enclosure for the booster.

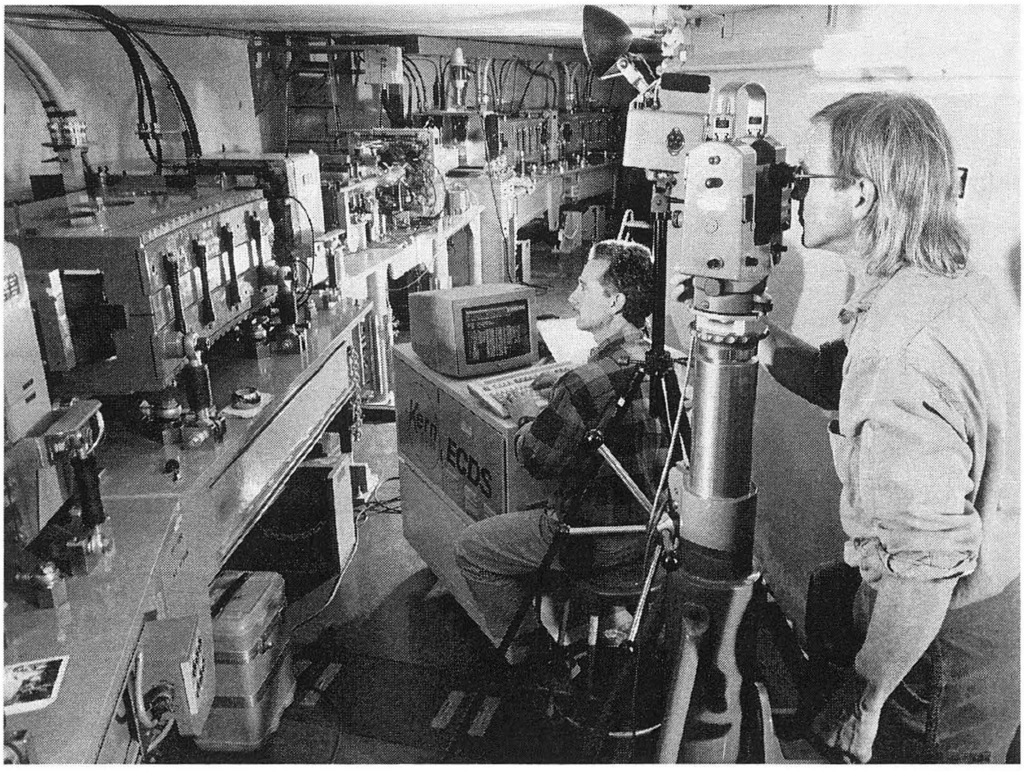
CBB 905-3863

Figure 22. Shop for assembling magnets on booster girders.



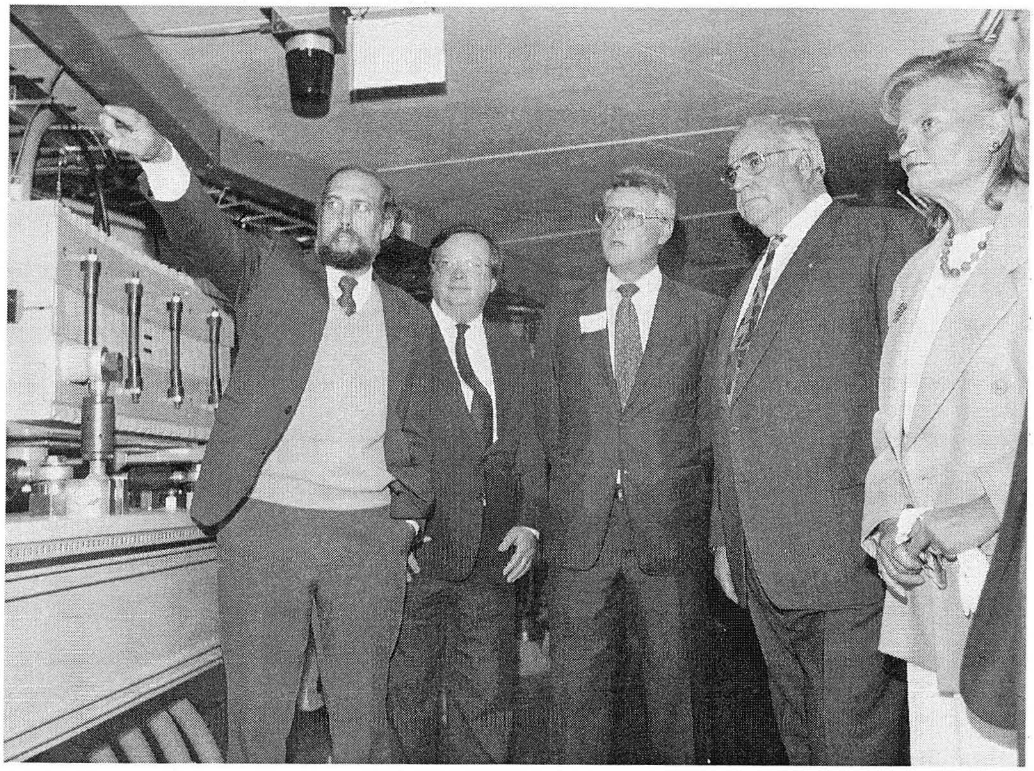
XBC 903-2764

Figure 23. A booster girder, fully loaded with vacuum chambers and magnets, is lowered into the shielding enclosure.



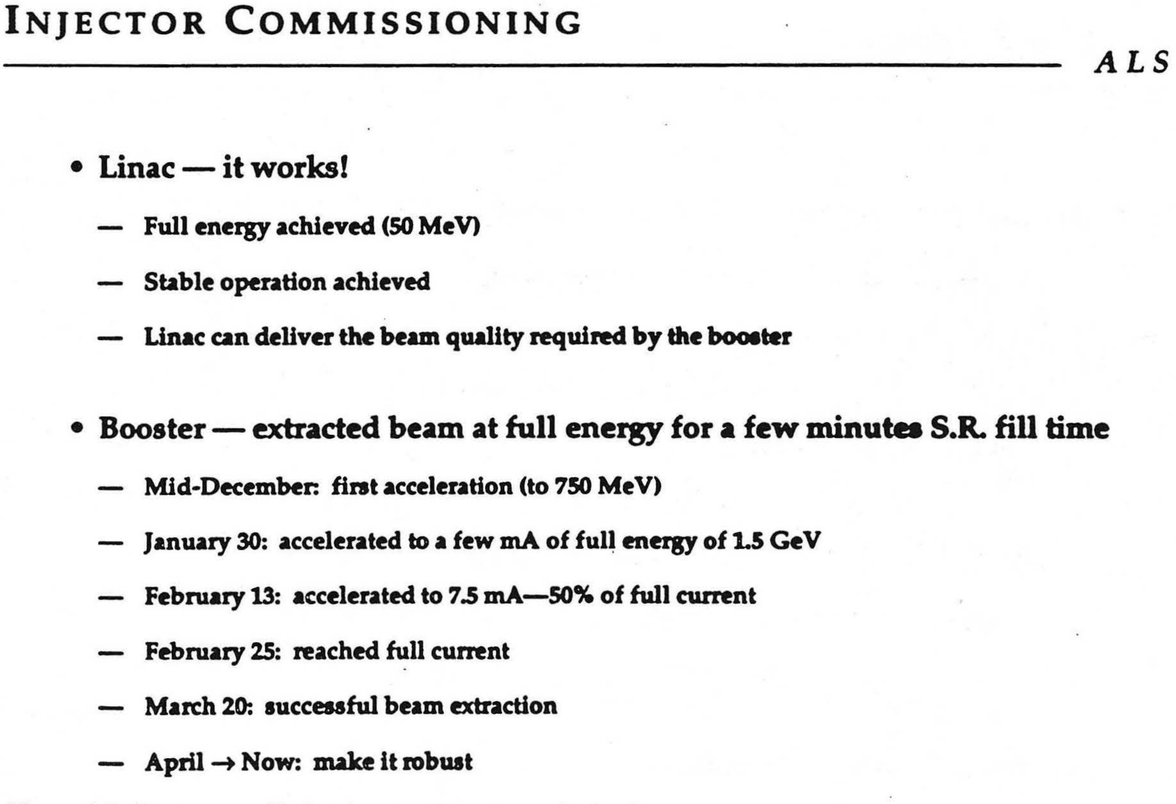
CBB 916-4950

Figure 24. Precise surveying was required to position the booster girders.



XBC 919-7465

Figure 25. Chancellor Helmut Kohl of West Germany tours the ALS. Left to right: Jay Marx, LBL Director Charles Shank, the Chancellor's interpreter, Chancellor Kohl, and Mrs. Kohl.



INJECTOR COMMISSIONING

ALS

- **Linac — it works!**
  - **Full energy achieved (50 MeV)**
  - **Stable operation achieved**
  - **Linac can deliver the beam quality required by the booster**

- **Booster — extracted beam at full energy for a few minutes S.R. fill time**
  - **Mid-December: first acceleration (to 750 MeV)**
  - **January 30: accelerated to a few mA of full energy of 1.5 GeV**
  - **February 13: accelerated to 7.5 mA—50% of full current**
  - **February 25: reached full current**
  - **March 20: successful beam extraction**
  - **April → Now: make it robust**

Figure 26. Progress of injection-system commissioning.

operation. I believe there was one occasion on which the booster went from a standing start to beam in about 4 minutes. So the injector is in great shape.

The storage ring is next (see Figure 27). I must confess, about three months ago, I had hoped to stand up here and announce first beam in the storage ring. The last few months have shown us that the final installation of the many subtle components of the storage ring just goes slower than one would hope. We haven't had any major technical problems; there's nothing that doesn't work. But the amount of work and the accuracy required has taken us longer than we had expected. We're now looking for first beam around October.

Let me tell you something about the storage ring and its history. It involved a lot of effort in assembling many, many magnets. Figure 28 shows thirds of sextupole magnets, which are very critical to the ring. They are very complicated magnets. Figure 29 gives you an idea of how a sextupole looks. There are also dipoles, quadrupoles, and steering magnets, all of which must be integrated with the ALS vacuum system—one of our most challenging technical developments.

Each arc of the ALS storage ring is based on one of the 10-meter-long vacuum chambers shown in Figure 30. The cutouts in the chambers are places around which the accelerator magnets can wrap and be close to the beam. The beam goes through a channel in the arc and produces synchrotron radiation. The ports through which the synchrotron radiation exits from the storage ring are also shown in this figure.

The vacuum chamber is made up of two pieces, top and bottom, machined in the aircraft industry. The raw material for making one of these, the top or the bottom, is a piece of aluminum. The chamber looks very nice in Figure 30, but requires a great deal of work to put together. Figure 31 shows the shop for assembling storage-ring arcs.

Figure 32 shows the empty storage ring hall awaiting ring components. With the magnets and vacuum chambers ready, the next step was to assemble the ring. Figure 33 shows the first two vacuum chambers on their girders in the experimental hall. The second girder is being lowered by the crane. Once these chambers were in place, the next step was to install magnets. Figure 34 shows the sextupole magnets being installed onto one of the storage-ring girders, and Figure 35 shows one of the twelve storage ring arcs with all the magnets in place. If you tour the ALS today, you will see this very

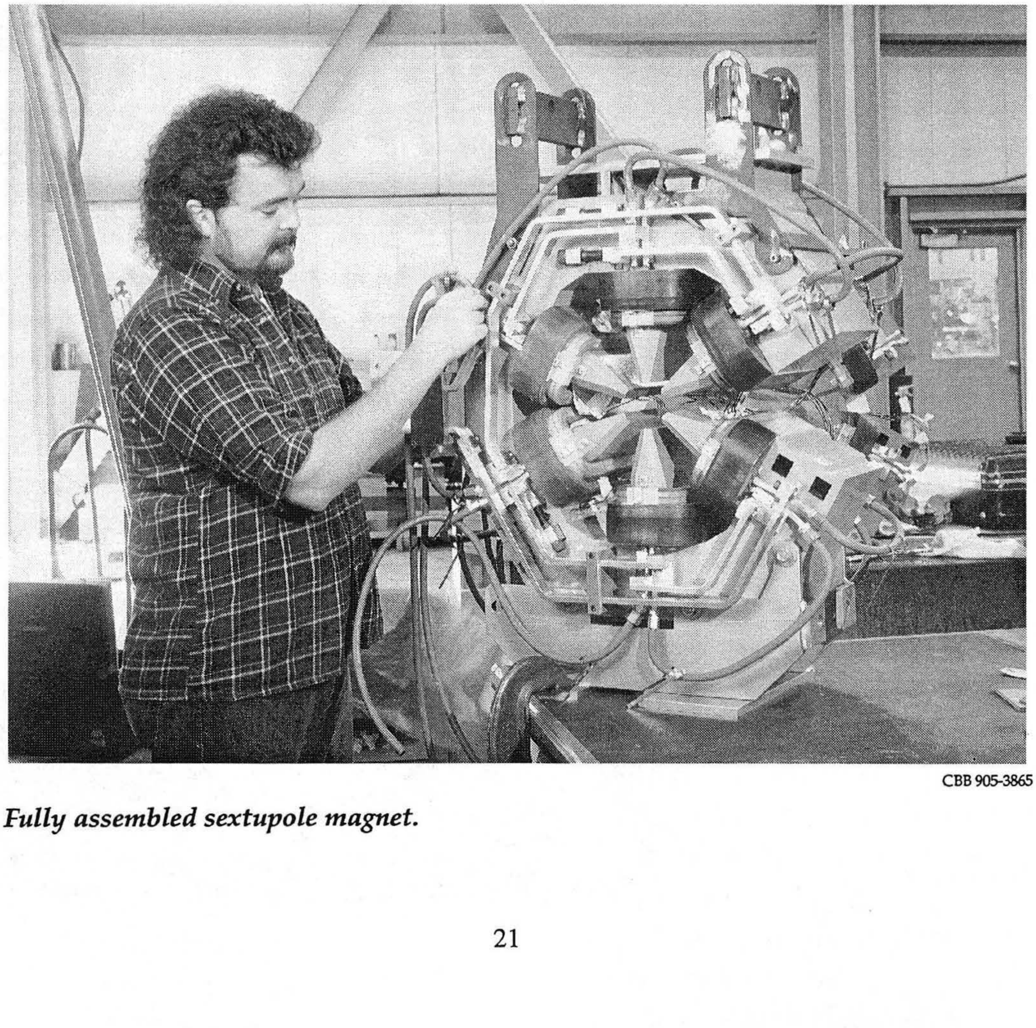
STORAGE RING

ALS

- **Installation progressing, targeted at injecting first beam in October**
  - **All arc vacuum chambers cleaned, pumped down, and in place**
  - **Magnet installation complete**
  - **Miscellaneous straight section hardware being installed**
  - **In-situ bakeout still to be done**
  - **Injection straight section to be installed in the next week or two**
  - **RF cavities in place; installation of waveguides almost complete**
  - **Electronics (power supplies, instrumentation, control system) will be ready**
  - **Shielding almost complete**
- **Tour will be best indication**

Figure 27. Storage ring progress.

Figure 28. Thirds of sextupole magnets awaiting assembly.



CBB 905-3865

Figure 29. Fully assembled sextupole magnet.

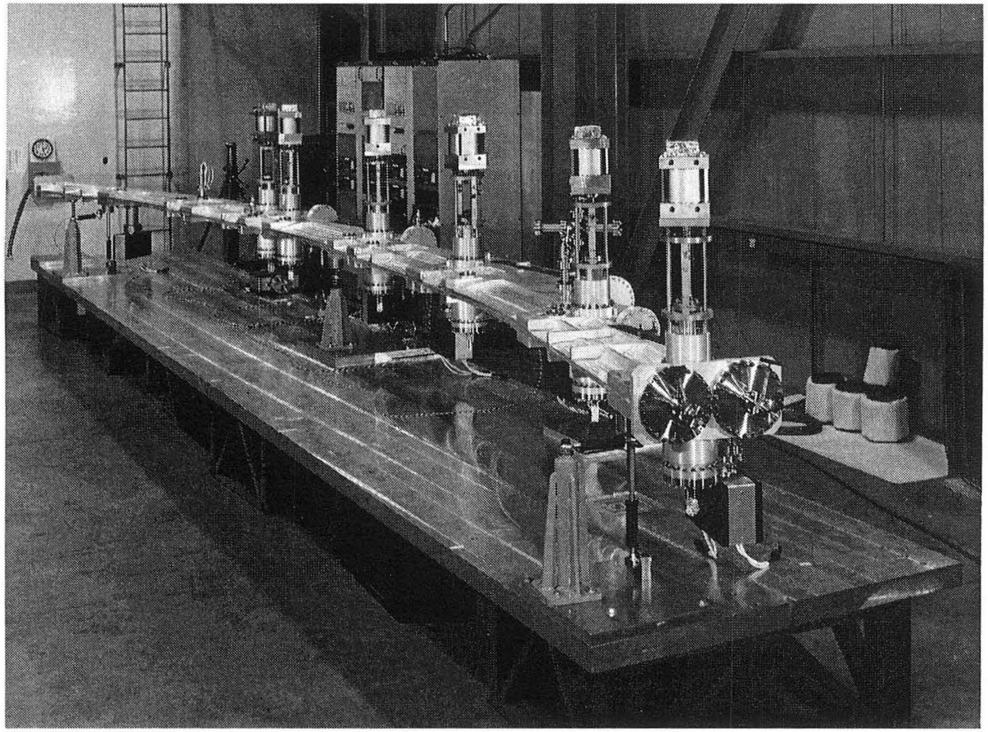


Figure 30. Vacuum chambers.

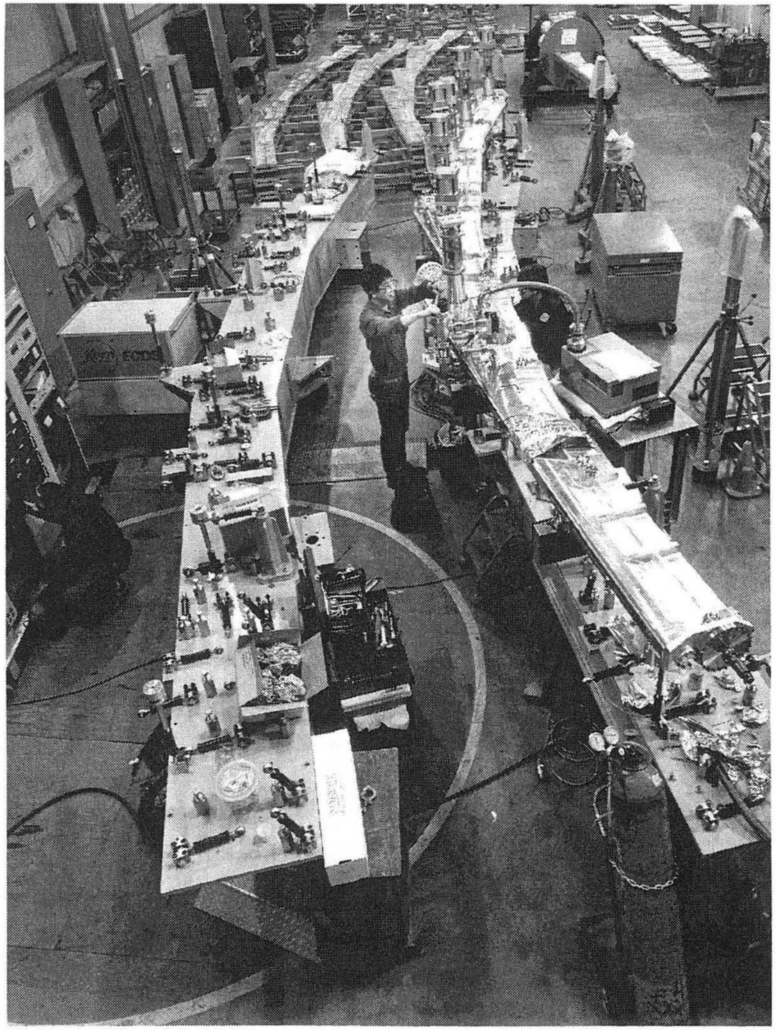
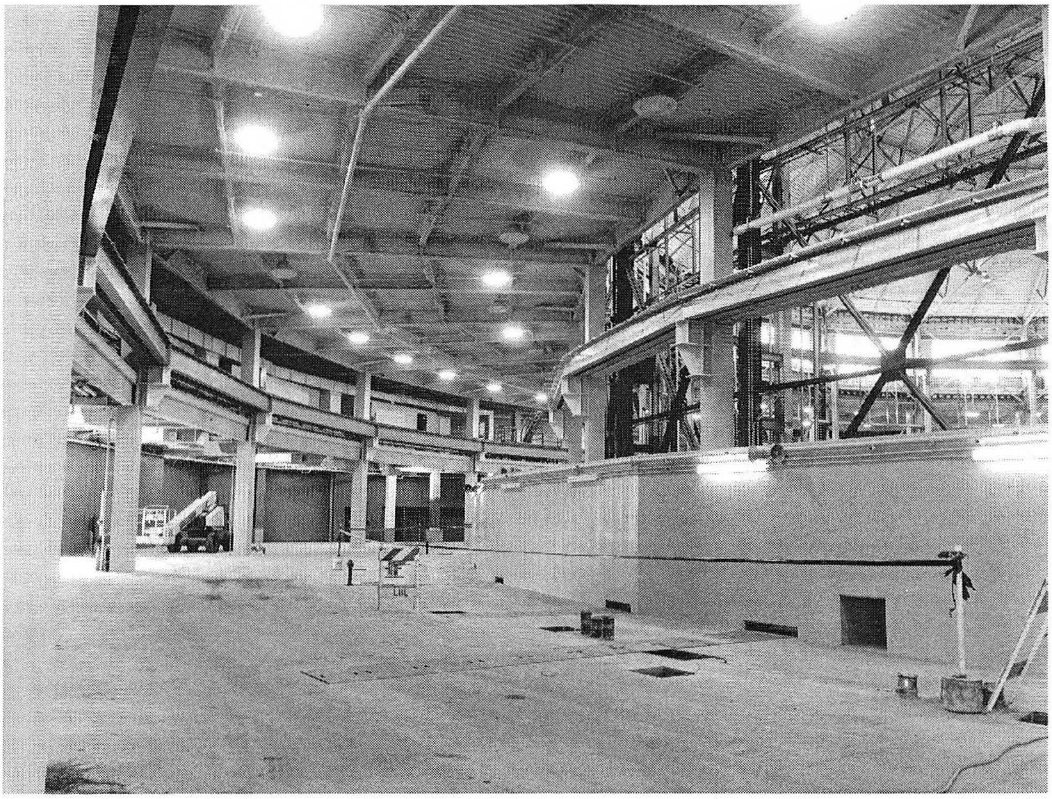
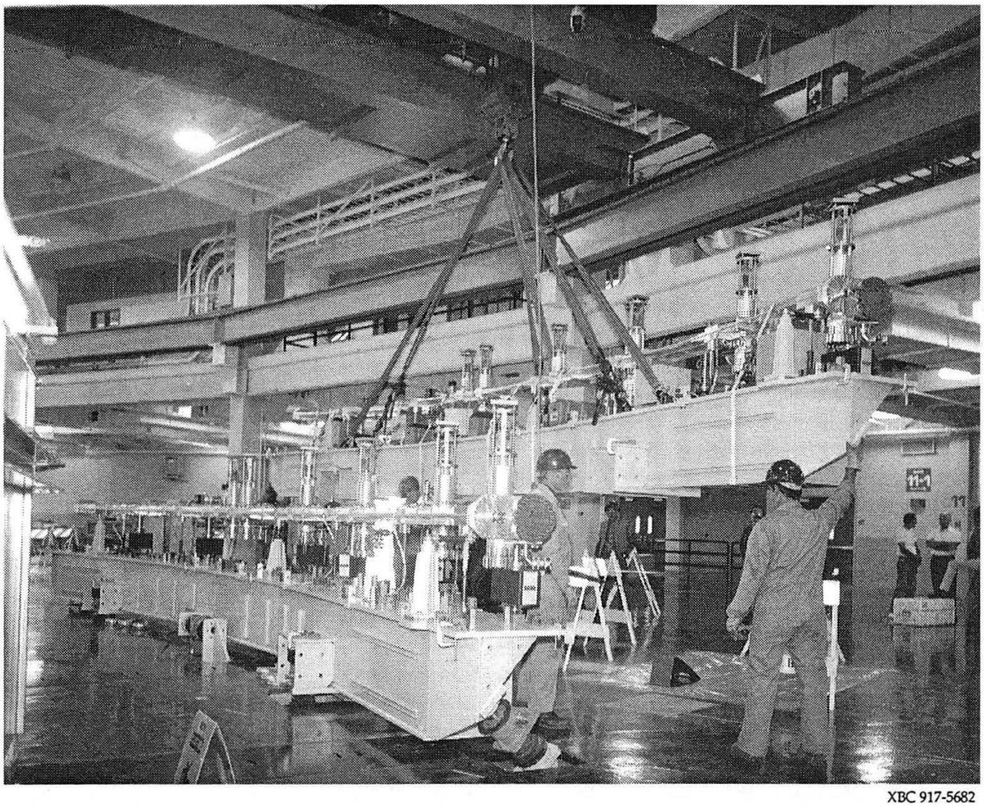


Figure 31. Assembling a vacuum chamber section.



XBC 9101-444

Figure 32. Empty storage-ring hall awaiting ring components.



XBC 917-5682

Figure 33. First two vacuum chambers on their girders in the experimental hall. The second girder is being lowered by the crane.

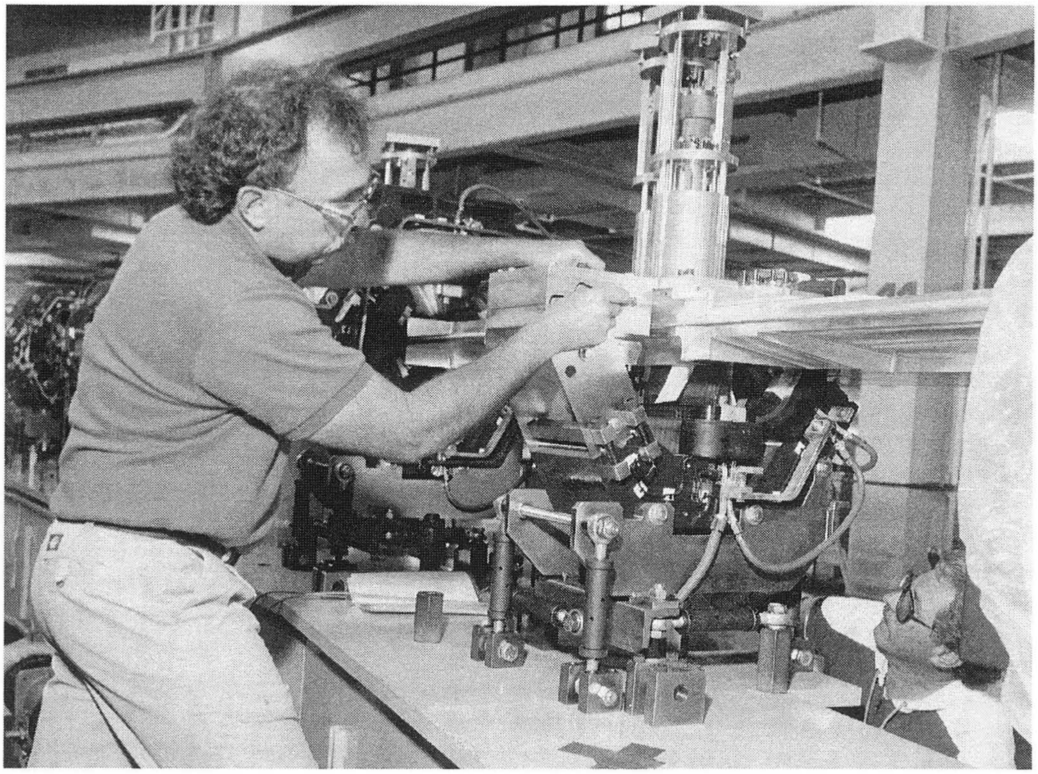
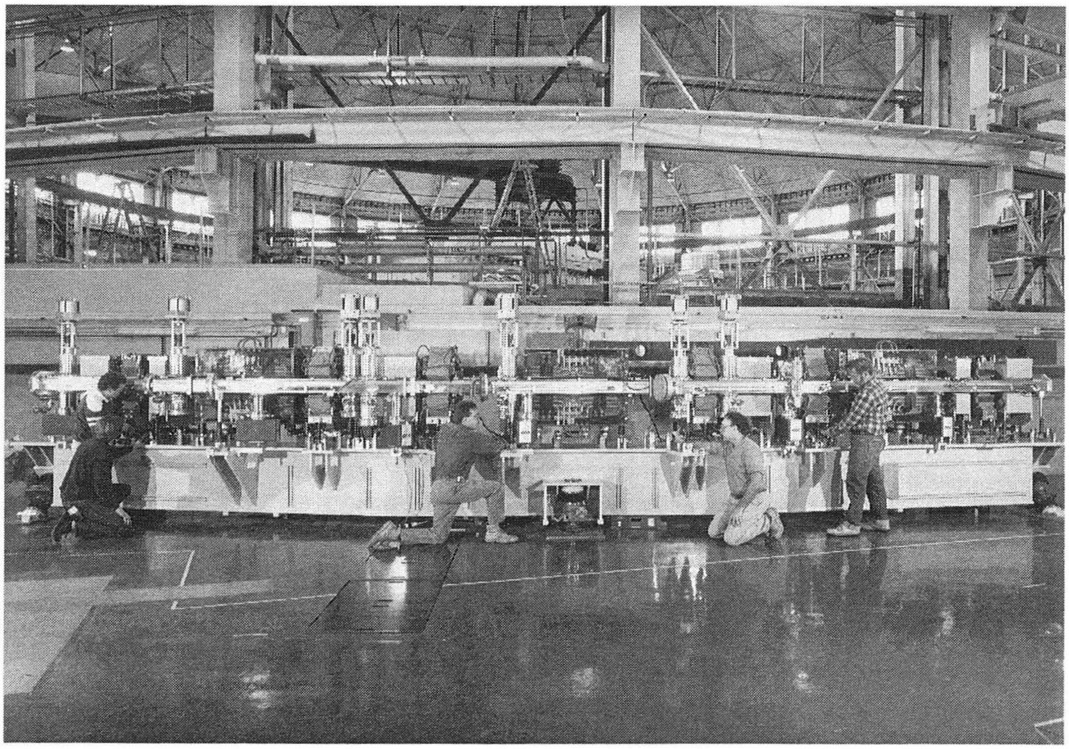


Figure 34. Sextupole magnets being installed onto one of the storage-ring girders.



CBB 9111-9380

Figure 35. One of the twelve storage-ring arcs with all the magnets in place.

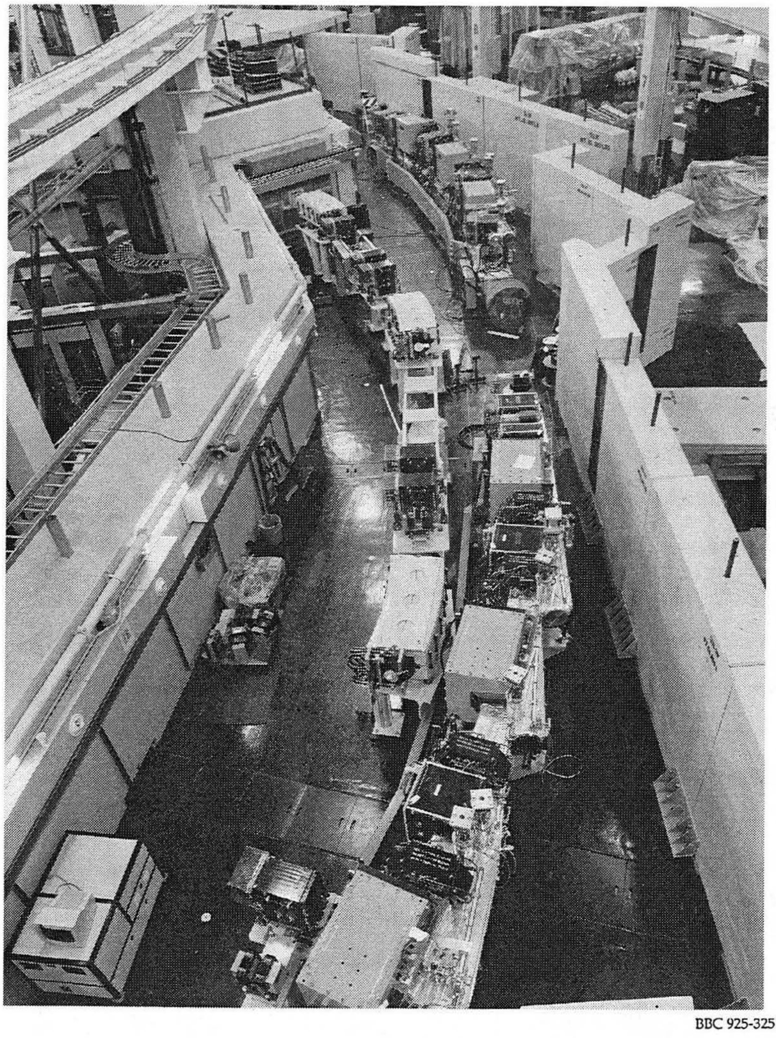
complex structure. I am still impressed by all the details people on the ALS team can keep together and do right. An undulator port and three bending-magnet ports are also shown in Figure 35.

After the chambers were in place, shielding was constructed. Figure 36 shows the shielding walls for the storage ring near the injection straight section. The ejection line from the booster delivers electron beam from the booster into the injection straight section.

With the roof on, the shielding wall appears as in Figure 37. You can see the ratchet design, which allows the beams to come out through ports perpendicular to the shielding wall. That shielding is now essentially complete.

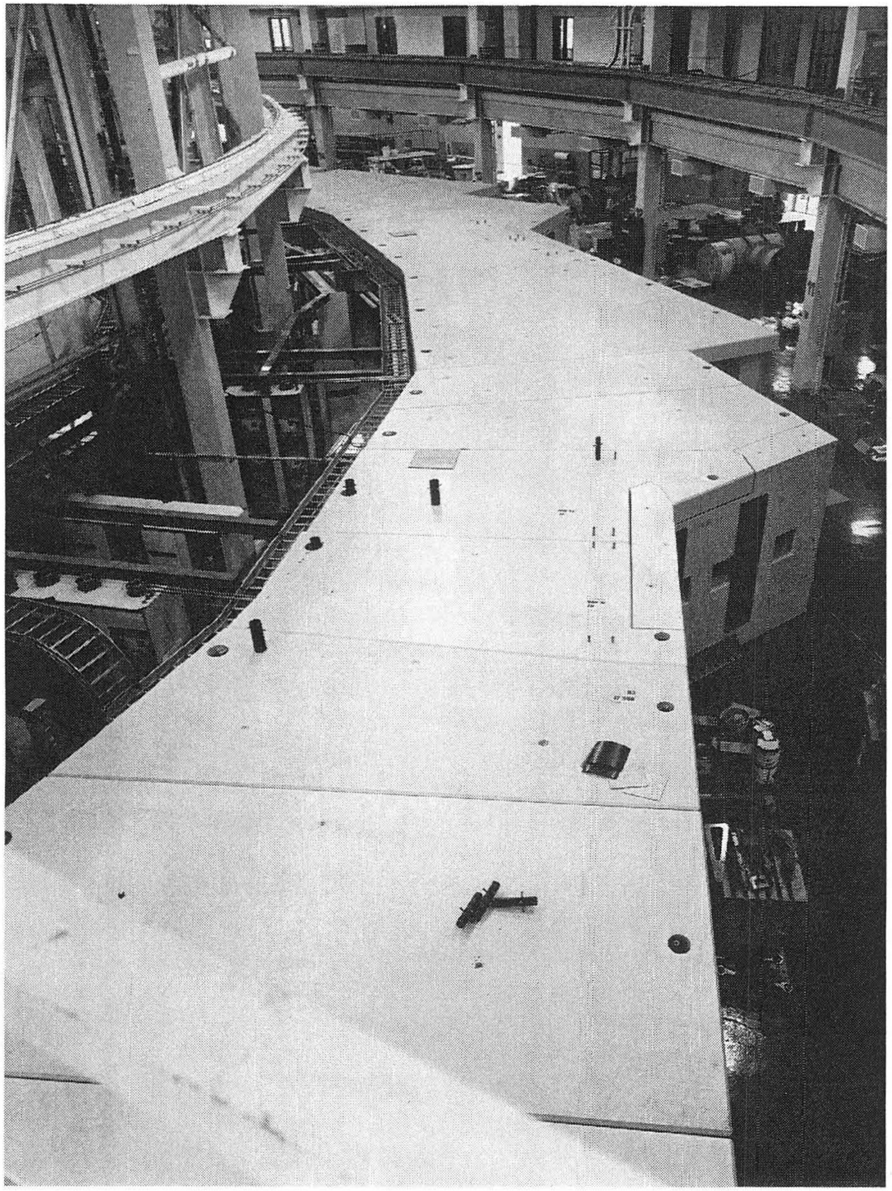
If you look through one of those holes in the shielding, you'll see the storage ring. Figure 38, which is on the cover of *Physics Today* this month, shows an undulator port and a number of bending-magnet ports.

Let me tell you where we stand with the storage ring. Basically, all of the arc chambers are in place, have been pumped down, and are under vacuum. All of the magnets have been installed, wired up, and provided with cooling water. We are working hard now installing miscellaneous pieces of vacuum hardware for the straight sections. Between the long straight-section pipes and the arcs, there are dozens of little coupling elements that are very tricky to install. Another thing we have to do is bake out the whole storage ring. Each piece that is installed has undergone bakeout separately, but contaminants that get into the ring when we couple the pieces together must also be baked out.



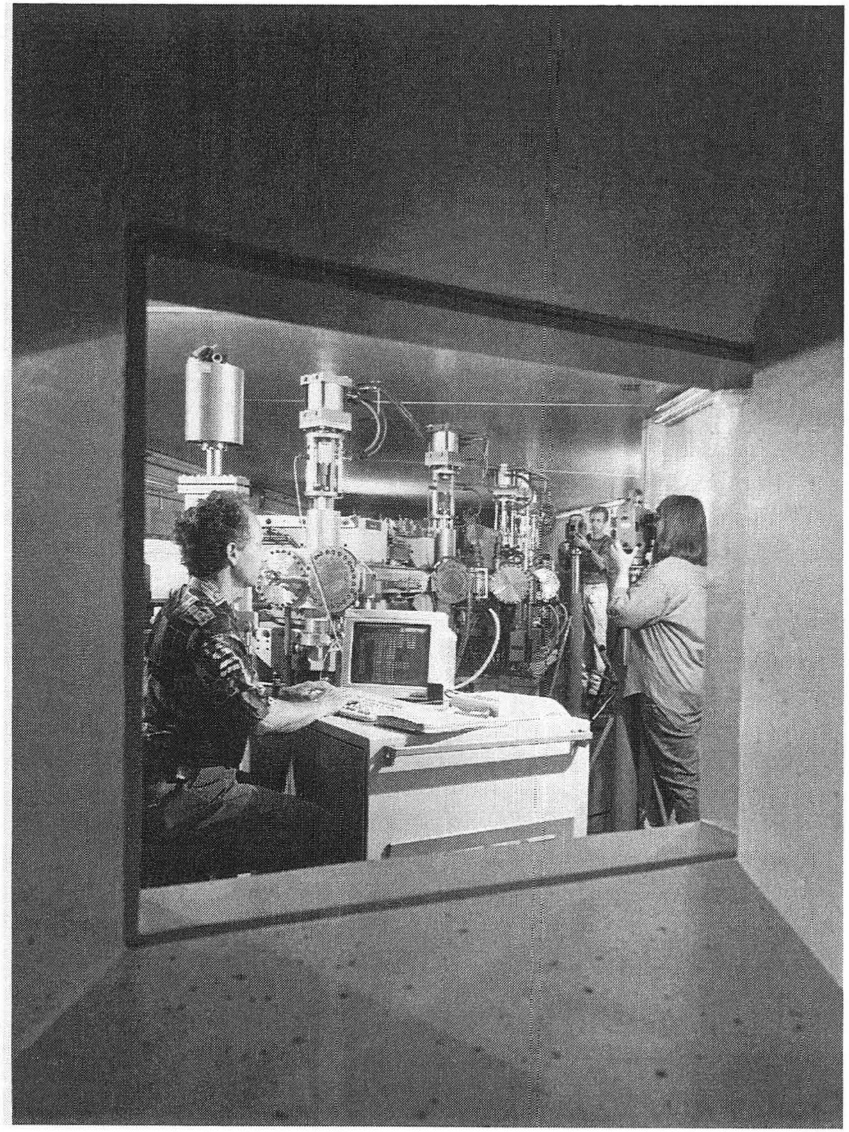
BBC 925-3251

Figure 36. The booster-to-storage ring transfer line emerges from the injector-accelerator system cave on the left to meet the storage ring. Concrete shielding walls have been erected.



CBB 925-3244

Figure 37. Storage ring enclosed by concrete shielding.



CBB 926-4525

Figure 38. View through the shielding wall shows a survey-and-alignment team at work on the storage ring . An undulator port and several bending-magnet ports can also be seen.

A large component that will soon be installed is the injection straight section, which is being assembled as a unit in the shop. The arc cavities are all in place, all of the electronic systems are going well, and power supplies are being tested.

The control system is going well. In fact, it's being exercised on a nightly basis for commissioning of the injector. The shielding is almost complete; we've assembled it all but have had to take away a few blocks to leave room to install large components such as the injection straight section.

I think those of you who go on the tour later will be very impressed with what you see. The message here is that the accelerator systems are going well. Come October, when we start to inject beam, then, of course, we will encounter new challenges.

Another part of the project that I want to discuss is experimental facilities—insertion devices and beamlines. Figure 39 is a viewgraph that Brian prepared for a summary talk he gave a few months ago. He described the state-of-the-art undulators and x-ray optics before the ALS project began and compared them to where we are now. Frankly, if I had seen this and understood it at the beginning of the project, I might have done something else. It really seemed like an impossible task, given the sizes of the magnetic field errors in undulators at that time. The best undulator was a factor of 2 worse than we needed for the ALS, given the small emittance of the beam. The length of undulators was generally about half the length of ours today. There were many issues that were not well understood. It was a real risk as to whether we could develop undulators to meet our needs, but in fact we have. Our first undulator is complete. It has been mapped, and it works.

The same is true of x-ray optics. We needed optics that could handle very high heat loads and meet very stringent tolerances. We also needed a metrology capability. As Brian would say, "If you can't measure it, you can't build it." A lot of effort went into metrology—providing metrology to vendors so they could actually study the characteristics of the optics they built. Brian will describe this in much greater detail.

As for construction activities in this area, we are building three undulators, two with 5-cm periods and one with an 8-cm period (see Figure 40). The first is complete, mapped, and waiting on the ALS floor, as you will see on the tour. Basically, it has all the specifications needed to give a high-quality fifth

STATE OF THE ART AT THE BEGINNING OF THE ALS PROJECT

ALS

- Undulators
  - 0.5% rms errors (0.25% or better needed)
  - 2 meter length (5 meter desired)
  - No complete theory errors and tolerances
  - Integrated multipole errors not controlled
  - Limited availability of quality permanent magnet material
  - Magnetic measurements needed improvement
- Optics
  - Difficult materials (CVD SiC, Zerodur)
  - No high heat load designs
  - Few vendors, long delivery delays
  - Aspheric optics not available with tight tolerances
  - 5 Å roughness needed, 0.8 μrad figure tolerance
  - Metrology in a primitive state

Figure 39. State-of-the-art undulators and optics at the start of the ALS project.

PROJECT STATUS – EXPERIMENTAL FACILITIES

ALS

- **Undulators (2 x U5, U8)**
  - **First U5 assembly complete**
    - Field mapping confirms that specs have been met and are consistent with high quality 5th harmonic
    - Analytic approach successful—undulators now an engineering science
  - **Second U5 and U8 work on schedule**
  - **Installation of undulators in ring (consistent with commissioning progress)**
    - November 1992, December 1992, February 1993
- **Beamlines (from U5 and U8)**
  - **Optics are a success story: mirrors in hand, grating blanks polished and ready for holographic ruling**

Figure 40. Status of ALS undulators and beamlines.

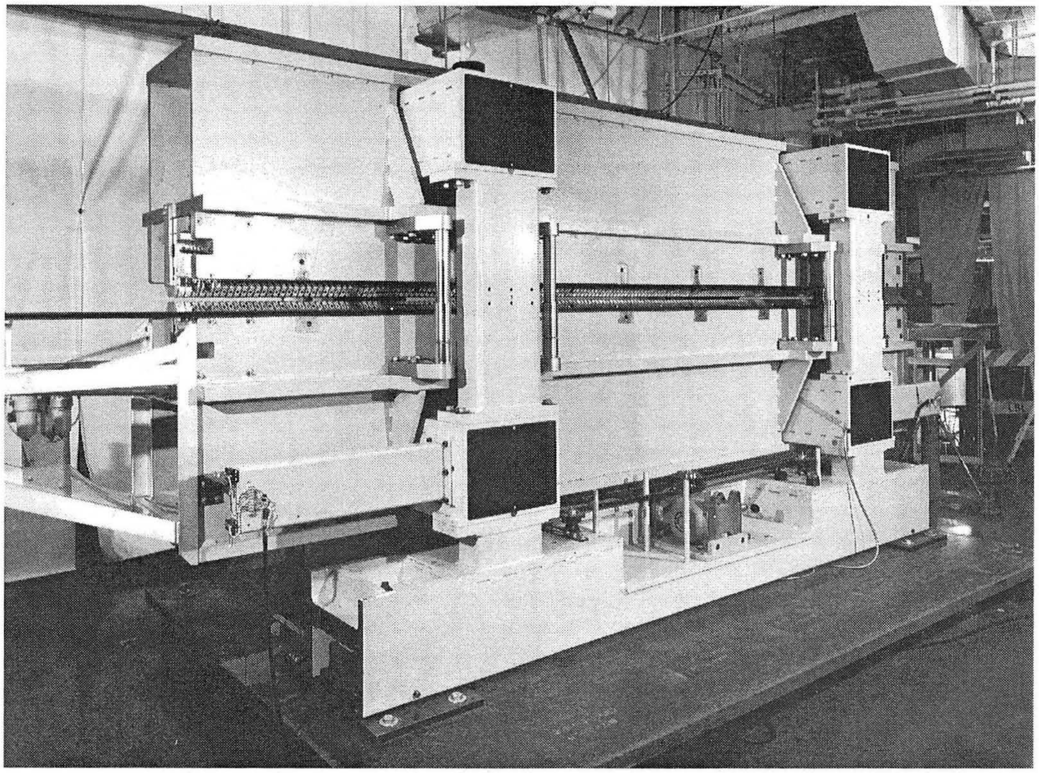
harmonic. In fact, it was assembled and did not have to be shimmed. An analytic theory developed with Klaus Halbach tells what the magnetic field errors are as a function of errors in the placement of magnetic blocks. This was the basis for assembling the undulator, so we feel that building undulators is now an engineering science rather than a black art. The other two undulators are on schedule. In fact, yesterday I saw the top half and the bottom half of the next undulator lying next to each other—two 5-meter-long sections. The next step is to take the top half, turn it upside down, and put it together with the bottom half. Each of the halves weighs about 20 tons. We are ready to install these undulators on schedule in the ring, assuming the commissioning reaches the point at which the accelerator staff is ready to study the effects of undulators.

The beamline optics are also a real success story. Wayne McKinney has done a fantastic job in working with industry, developing vendors, and obtaining the mirrors and gratings for the ALS beamlines.

Figure 41 is a picture of the first undulator. The massive support and drive system holds hundreds of poles and permanent-magnet blocks and enables the gap between the magnet arrays to be set with an accuracy of about 20 microns. The support structure resists more than 30 tons of mechanical force as the the top and bottom magnetic arrays attract each other.

Beamline components are now being built; I hope you will see them on the tour. Figure 42 shows a water-cooled grating blank, and Figure 43, a horizontal beam-defining aperture. Beamline front-end components are now being baked out, and a few are ready for installation. The undulators and beamlines being built by the project are moving along well.

Now I want to shift gears and look beyond the construction project. The first thing I would like to discuss is the beamlines that we anticipate having at the ALS—not just those the ALS project is building, but also those that are coming from elsewhere and those that are funded but not yet completed (see Figure 44). Clearly, one of our problems has been trying to find the resources to build an adequate number of beamlines to support this community. The situation once looked very grim, but seems much better now—not as good as we would all like, but let me tell you where it stands. Remember that the ALS has 12 straight sections. Two are occupied by accelerator hardware, so 10 are available for insertion

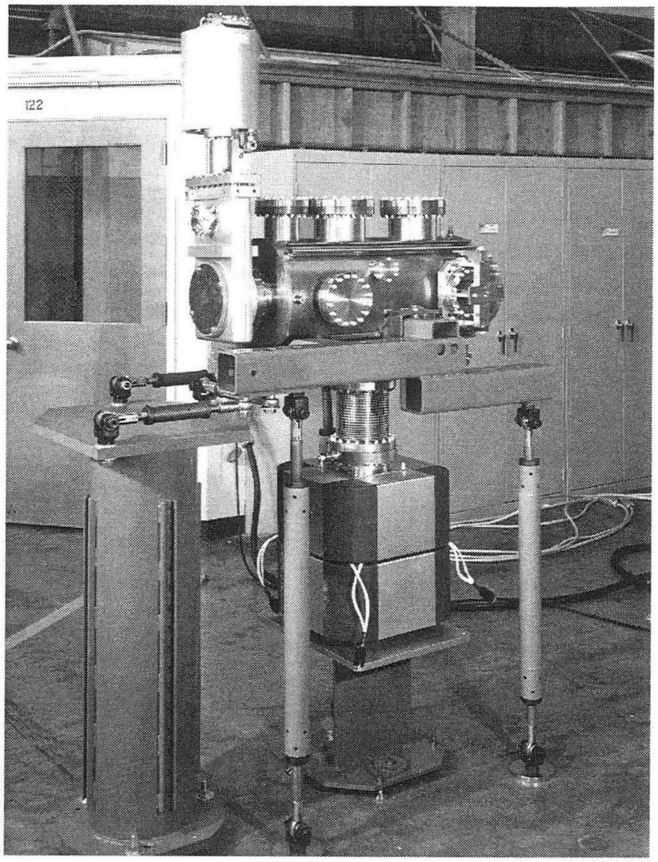


CBB 926-4172

Figure 41. The first 5.0-cm-period undulator built at the ALS.

CBB 915-3787

Figure 42. Water-cooled grating blank.



CBB 922-1331

Figure 43. Horizontal beam-defining aperture.

BEAMLINE SCORECARD

ALS

- 10 straight sections available for insertion devices
  - — 5/10 funded (insertion device and beamline)
    - – 3 by ALS, IBM (2 project beamlines – surface science and atomic/chemistry; IBM for surface science)
    - – 1 by DARPA (X-ray lithography)
    - – 1 by OHER (X-ray microscopy)
  - — 1/10 hopeful
    - – OHER (crystallography/spectroscopy)
  - — 4/10 by ALS Beamlines Initiative and CDRL
- Bend-magnet lines — 5 funded
  - — 2 from SSRL
  - — 1 microprobe from LBL
  - — 1 metrology from DARPA
  - — 1 soft x ray with circular polarity
- About $35M already invested/committed to ALS experimental program
- At least 10 beamlines (including 5 straight sections) for 1993–94 operations
- Beamlines Initiative critical to full utilization of ALS in late 1990s

Figure 44. Beamlines anticipated for first-phase scientific program, 1993–1994.

devices. At this moment, funding is available for five insertion-device beamlines, half the high-brightness facilities of the ALS. Of those five, three are being built by the ALS and IBM in the following sense. The ALS is building three undulators and beamlines to go with two of them. IBM is developing a beamline to go with the other ALS undulator. These three beamlines will be ready to start commissioning sometime next spring. Also a DARPA program in x-ray lithography is funding (1) an undulator beamline that will use holographic methods to study x-ray optics, and (2) a bending-magnet beamline for metrology. The construction of these beamlines has not yet started, but the check has arrived. These facilities will probably be available in about 2 years. In addition, the Office of Health and Environmental Research (OHER) at DOE is committed to funding another beamline for x-ray microscopy for the biology community. In summary, of the five insertion-device beamlines that I labeled as funded, three are being constructed now. The funds are available or almost available for the remaining two, which should be ready in 18 months to 2 years. In addition to these five, we hope for a crystallography beamline at the ALS sometime in the future, also funded by OHER. That accounts for six of the straight sections, but there are four left. These four, I hope, will be filled eventually by beamlines funded by what we call the "ALS Beamlines Initiative" and by the Combustion Dynamics Research Lab. The ALS Beamlines Initiative is very important to this community—and something we've worked very hard to develop and bring to DOE's attention.

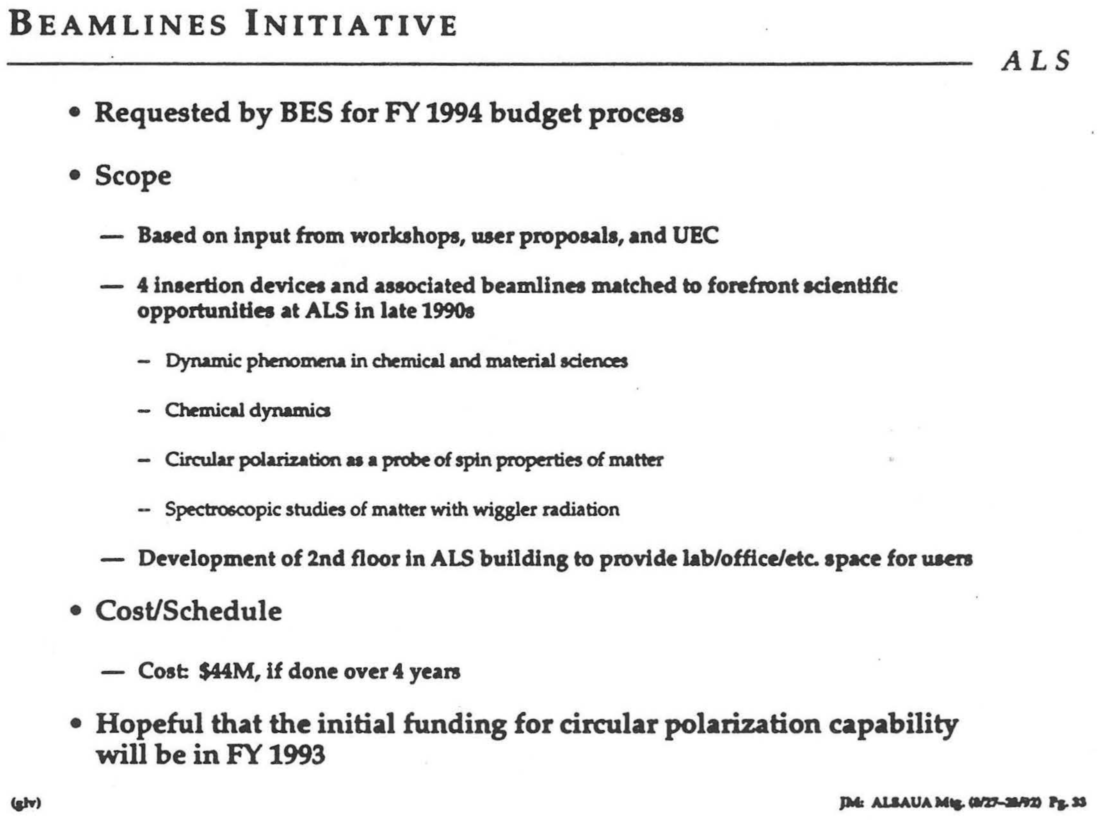
In addition to the insertion-device beamlines, five bending-magnet beamlines are funded and will be at the ALS sometime close to the beginning of operations. Two of these beamlines will be moved from SSRL. Also, a microprobe beamline is being developed by LBL's Materials Sciences Division; the metrology beamline, mentioned before, will be built with DARPA funds; and a soft x-ray beamline with circular-polarization capability is being developed by the ALS.

If you consider all these beamlines, the end stations, and other experimental hardware that have been funded by various agencies for users, it turns out that about $35 million has already been invested or committed to the experimental program at the ALS. I was surprised when we added this up. It's a very big number, representing a great deal of commitment and the ability to put a good number of beamlines on the air in the next year or two. Furthermore, as Bill Oosterhuis said, DOE and other agencies are committed to adding still more beamlines. That is why I want to say something about the Beamlines Initiative.

The Beamlines Initiative (Figure 45) is something that we've talked about for several years. We have called it Phase 2—a follow-on construction project to the ALS that will develop more beamlines and also complete the second floor of the ALS building to provide office and lab space for the user community. We have been working on this for many years, receiving input from workshops sponsored by the ALS, user proposals, and the users' executive committee (UEC). The net result was a proposal that went to the DOE last spring; in fact, the DOE requested us to submit it. It calls for the construction of four insertion devices and associated beamlines matched to forefront scientific opportunities, including the use of circularly polarized radiation as a probe of the spin properties of matter. It also includes a request for funds to develop the second floor of the ALS building for the user community. This proposal was very well received and has been reviewed for so-called "validation" as a project; that is, the financial people at the DOE examined the proposal to make sure the funding requested is the amount it will take to do the job. This amount is $44 million if the project were to be done over 4 years. It is not likely, in the current budget climate, that this proposal will be funded in fiscal '94 as a construction project, but we are hopeful that for this coming fiscal year, we will receive funds from the DOE to start building one of these beamlines, presumably the circular polarization beamline. So even though this project is waiting to be funded next year or the year after, DOE is so committed to it that they are going to try to find funds to start building part of this capability this year—and that's very positive.

When the project is completed later in the decade and the full complement of ALS insertion devices has been installed, it might look something like Figure 46. I want to show this picture to give you a sense of the range of science that we're anticipating: biology, crystallography, x-ray microscopy for biology, studies of coherent optics, materials surface and interface science, chemistry, atomic physics, chemical dynamics, chemical kinetics, more materials science, and soft x-ray lithography and circular polarization.

Figure 47 shows the second floor of the ALS in its current state. This is directly above the experimental floor—about 20,000 square feet that will be available for offices, lab space, and other important facilities for the user community. This area extends all the way around the ring. Imagine a



BEAMLINES INITIATIVE

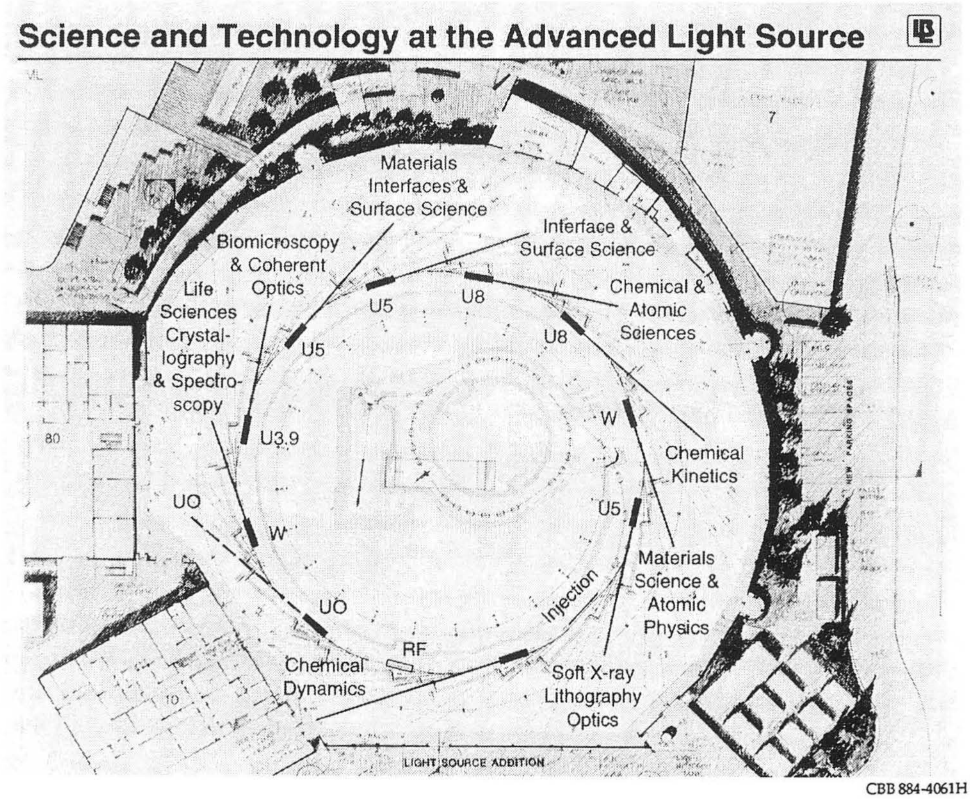
ALS

- **Requested by BES for FY 1994 budget process**
- **Scope**
  - — **Based on input from workshops, user proposals, and UEC**
  - — **4 insertion devices and associated beamlines matched to forefront scientific opportunities at ALS in late 1990s**
    - – Dynamic phenomena in chemical and material sciences
    - – Chemical dynamics
    - – Circular polarization as a probe of spin properties of matter
    - – Spectroscopic studies of matter with wiggler radiation
  - — **Development of 2nd floor in ALS building to provide lab/office/etc. space for users**
- **Cost/Schedule**
  - — **Cost: $44M, if done over 4 years**
- **Hopeful that the initial funding for circular polarization capability will be in FY 1993**

(glv)

JM: ALSAUA Mtg. (8/27–28/92) Pg. 33

Figure 45. Beamlines initiative proposal was made to the DOE.



CBB 884-4061H

Figure 46. The ALS will eventually have a full complement of 10 insertion devices with applications similar to those shown.


XBC 914-2762

Figure 47. Second floor of the ALS building has floor space of about 20,000 square feet that will be available for offices, lab space, and other important facilities for users.

hallway in the center and offices on the outer wall with views of San Francisco Bay. Completion of this space to meet your needs will cost about $7 million—funding that does not yet exist but is being sought as part of the Beamlines Initiative. These plans represent one effort we are making to try to meet the needs of the users.

In the last year or two, we in LBL management have been working hard to try to provide, even in these hard times, the kind of support facilities users will need (see Figure 48). Much progress has been made. We had a review yesterday with the UEC and talked about many of these items.

Specifically, we are moving very rapidly toward changing the administrative structure at LBL so that when users come to do experiments, they need not spend three days wandering around halls from office to office and climbing up and down hills. We will have a one-stop shopping arrangement that lets users go to one building, follow the "yellow brick road," and come out certified with all the necessary badges and cards.

Another big step is that we have found space near the ALS that is being refurbished as lab space and a vacuum-assembly area for initial users. This space—literally 10 meters from the ALS floor—will be available perhaps by October or November and will provide at least some of the laboratory facilities that the UEC said is essential for the initial groups of users. In the last few months, we have also found additional space that will accommodate other user facilities—offices, a shop, and a stockroom. Little by little, the space needed for users will be made available—I hope at the rate at which the user community grows.

Also, amazingly enough, we are making progress with LBL parking. Laboratory management realizes the severity of the problem and is considering changing the parking rules to try to reduce the number of cars on site. In the future, this measure will make it a little more feasible for users to come onsite and park. In addition, we will have some parking spaces near the ALS that will be reserved for users. There will not be enough for everyone, of course, but at least each PRT will have a reserved parking space. As a result, users will be able to run out to the hardware store and not spend an hour

USER NEEDS

ALS

- **LBL responding to needs for user support**
  - **Administrative simplicity: one-stop shopping**
  - **Lab space and vacuum assembly space for initial users based on UEC input**
  - **Other space being made available**
    - **Space suitable for offices**
    - **User shop**
    - **ALS storeroom**
  - **LBL parking regulations changing to reduce LBL cars on site**
  - **Increased hours of shuttle service**

Figure 48. The ALS management and LBL are providing for the needs of users.

looking for parking when they return. We're making incremental progress on many of these things, but the derivative is very high. Fred Schlachter, in his talk later, will discuss these issues.

I will finish the formal part of my talk with a summary about ALS construction (see Figure 49). The construction project is now about 95% complete. As I've said, the injector complex is a success and meets the specifications. The storage ring commissioning—our next big challenge—begins in about six weeks. Brian will tell you about the success of the undulators and x-ray optics for the beamlines—something we're all proud of. The scientific program, as you know, is focused on first light next year. If all goes well, we might even see some undulator light early next year. That is the the end of my formal talk.

On this occasion, I would like to make a few personal remarks. There are a few things I want to say to the community. The years ahead are going to be difficult times for funding. We're all aware of that; we read the newspaper. One very important thing for the whole synchrotron-radiation community to do in these hard times is to work together. I'm from another community where I've seen the success of doing so. If a community can work together, avoid criticizing each other, and present a unified front in Washington during times when budgets get tight, there are real chances of getting substantial funding. I've started to see some progress in the synchrotron community. There have been meetings among facility directors and representatives of the user committees from all of the DOE facilities. In fact, a unified plan for funding facilities in a healthy way is being put together now and will be presented to the DOE. That is a really big step—truly important because, instead of fragmenting along big-science/small-science lines or soft x-ray/hard x-ray lines, we are working together and using the clout that we have in a coherent way. That is something I really applaud, and I'd like to see it continue. I know Brian will work very hard in that direction.

I also wanted to echo Bill Oosterhuis' comments. There are people in Washington, Bill among them, and also Iran Thomas and Lou Ianniello, who are committed to funding synchrotron radiation. They have constraints, but really want to work with the community. They want to produce beamlines, fund end stations, and fund research. They are good people to work with. The community must avoid being disappointed by proposals that have been turned down and write better proposals. Work with these men

- **Construction about 95% complete**
- **Injector complex working, meets specifications**
- **Storage Ring commissioning begins this fall**
- **Undulator fabrication and X-ray optics for beamlines are a big success**
- **Scientific program focused for first light next year**

Figure 49. ALS construction summary.

and submit your proposals. Give them the ammunition to demonstrate the scientific excitement and backing for synchrotron radiation. It's going to be a frustrating time and, in some ways, we will all have to "outstubborn" the system.

I also want to take a little time to thank a lot of people. I spent six years with the ALS—one of the most meaningful things I have ever done. The ALS has been built by a team of about 200 people, and I can't thank them all. They have been great to work with. But there are a number of key people whom I want to thank individually. First, there's Ron Yourd. Ron has really managed this project from the beginning. There's Brian Kincaid, whom you all know. There's Alan Jackson, who has led our accelerator team; Alan Paterson, our lead mechanical engineer; Henry Lancaster, our lead electrical engineer; and Werner Ganz, the person responsible for our conventional facilities, the building that we have. There are many other people who have made this possible.

We have had tremendous support from LBL management. During this project, LBL has had two directors, Dave Shirley and Chuck Shank. They have been behind us all the way, and their support has made a huge difference in these hard times. Klaus Berkner, whom many of you know, has been part of the ALS from the very beginning. He is now head of Operations for the Laboratory and has been fighting for us behind the scenes all the time. The DOE people have worked constructively with us and have helped us make this project happen—Bill Oosterhuis, Lou Ianniello, and Iran Thomas, and also Bob Pankhurst and Phil Roebuck who watch over us for the local DOE.

Lastly, I want to thank the users. I came into this business with no knowledge of synchrotron radiation; I'm a high-energy physicist. I honestly didn't know much about your science. One of the great things about the last six years is that I have learned a lot of new science. I have also made many new friends and colleagues. I want to thank you for that.

I would also like to say that I think the ALS is blessed to have a leader like Brian. He will have the energy, drive, and vision to lead this project into its scientific phase in a good way. He has worked with me for four years. I have gotten to know him very well, and I have complete confidence in him. He has asked if I would loiter around a bit for the next few months as an advisor to him, and I am going to do that. One thing on which we will work is the connection of the ALS with the DOE. This is an area in which I have much experience, so we will work together to ensure a smooth transition with the DOE, as well as in all other respects.

Accelerator Commissioning

Alan Jackson
Deputy Director for Accelerator Systems, Advanced Light Source
Lawrence Berkeley Laboratory
Berkeley, CA 94720

Let me start this talk with an accelerator physicist's view of our facility. There are no buildings, no shielding, some beamlines in their rudimentary form, but three accelerators. We have a 50-MeV linac accelerator that injects into a 1.5-GeV, 1-Hz booster synchrotron. Collectively called the injection system, the two together are used to fill the 12-sided storage ring, which consists of 12 straight sections alternating with 12 arc sectors embedded in a lattice of bending and focusing magnets (see Figure 1).

In the storage ring, one complete straight section is occupied by injection equipment and another by equipment that generates oscillating radio frequency (rf) fields to accelerate, or at least maintain the energy of, the beam. The 10 remaining straight sections will accommodate insertion devices.

With regard to the storage ring, I will start with the bad news and go on to the good news. Depending on what you have heard about our start date for the first injection of electrons into the ring, we are somewhere between 3 and 10 months late, and I'm going to tell you why. The impression I want to leave is that our problems have not been caused by a single aspect of the storage-ring systems; they result from technical challenges across the board. I will give you a representative sample of some of those challenges.

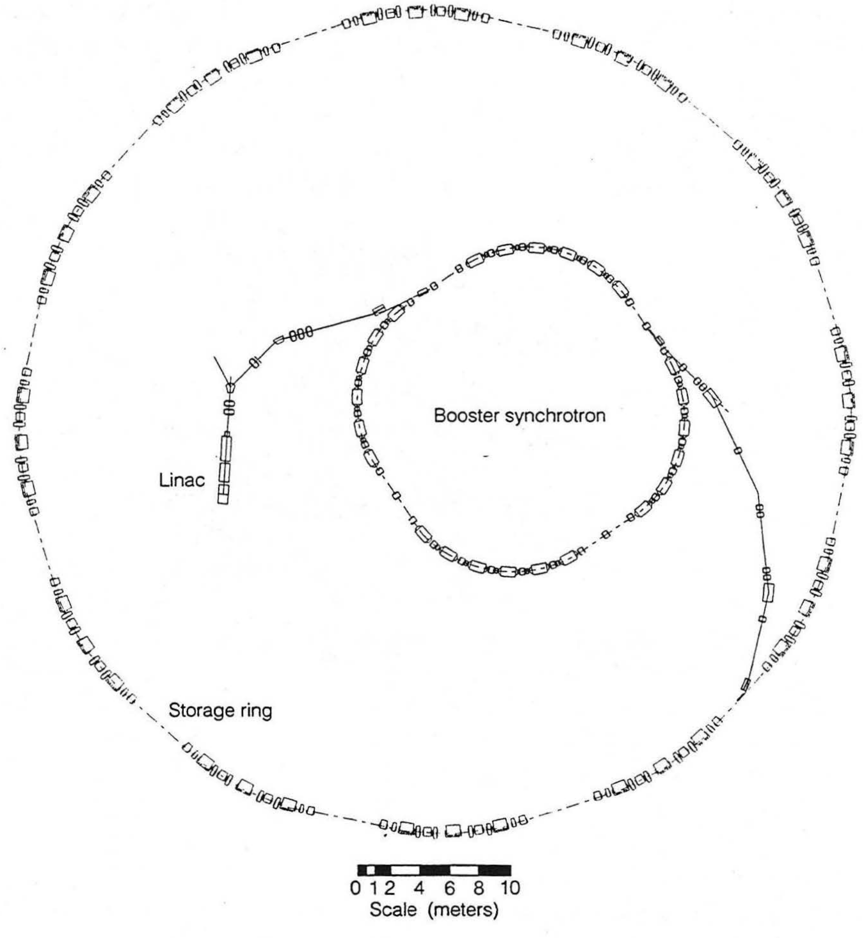
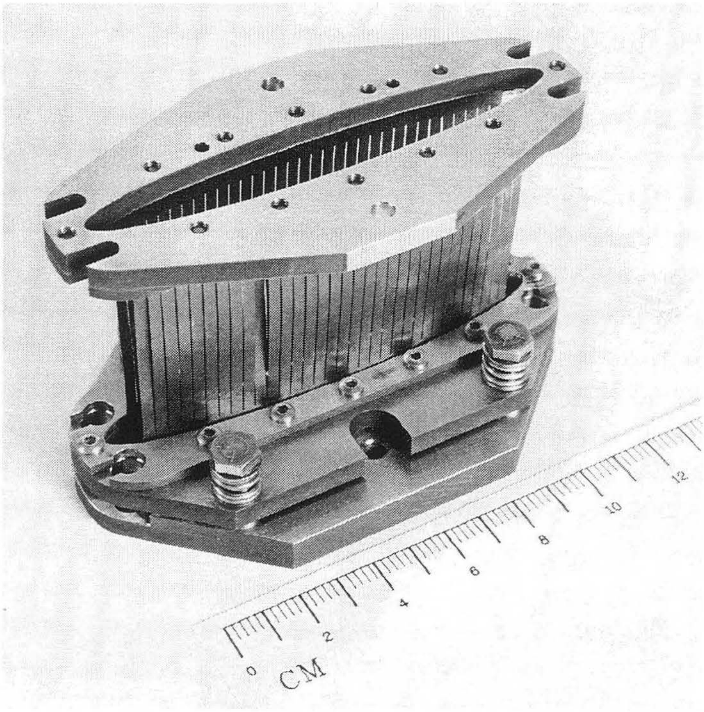


Figure 1. The accelerator physicist's view of the ALS: linac, booster synchrotron, and storage ring.

First, we have encountered unscheduled administrative requirements. The ALS will be the first major system to go through the DOE's new start-up program, which includes an operational readiness review. Such activities make great demands on the time of our engineers and technicians, who would otherwise be building equipment. Also, we have had to do a great deal of work on modifying and improving the products of some of our vendors. This was a management decision. We could have sent these products back to be fixed by the vendors, but the impact on the schedule would probably have been worse than that suffered by actually making the products work in-house. Again, this effort takes engineers' time that should have been spent installing the storage ring and making it work.

In addition, we have had changes in the design of some components at this late stage of the project. Figure 2 shows the small piece of equipment that has most recently caused problems. This is one of 48 flex bands used in the vacuum system to compensate for the expansion and contraction of the huge straight sections of aluminum vacuum chamber. Those of you who are materials scientists know the coefficients of expansion of aluminum and understand what a few degrees of temperature change means in terms of the resulting motion—all of which must be taken up by these small flex bands. Wrapped around each flex band is a bellows, which compresses during bake-out. All the little strips of the flex band are pushed together, but when restored to operating temperature, the flex band once again becomes smooth. These fragile devices must also withstand temperature reductions. They are just the most recent of our technical challenges.

Also we have had some unpredicted changes in our survey and alignment caused by temperature changes. The ALS building is temperature-controlled, but the temperature control was not turned on until recently. Although we tried to predict how the complicated arrangements of girders and vacuum chambers would move after survey at the higher operating temperatures, everyone was surprised to find out that these complicated structures did not go where they were expected to go. Therefore, we raised the temperature of the building to operating temperature and are realigning the girders, vacuum chambers, and magnets, to their tolerances of 150 microns, at the nominal operating temperature of the machine.



CBB 928-6625

Figure 2. One of 48 flex bands in the storage ring. A flex band fits inside each bellows allowing expansion and contraction of the ring due to temperature changes while maintaining a smooth inside surface to prevent distortion of rf fields.

Another challenge has been supply problems. The digital-to-analog converters that go into the intelligent local controllers (ILCs) of our control system are late. We have 100 in hand, but if we were trying to commission the machine now, it could not be done. We could only commission parts of the equipment because these ILCs are an integral part of the system.

The personnel safety system is not complete—neither the shielding nor the interlocks that keep personnel from exposure to hazards. A large part of that problem is due to the new administrative demands mentioned before. Because of the sensitivity of the personnel safety system, the design engineer has had to spend much time working with the people who are conducting our safety reviews. This effort has delayed the issue of job orders to the electrical maintenance staff and to installers who would otherwise have made progress installing the system.

The rf system isn't ready, mainly because of a near-bankrupt vendor who was building a power supply. We took possession of all the parts that belong to us, but must now build the power supply ourselves. This will take more time, because we lack the staff necessary to do that kind of thing.

The bottom line is that, despite these problems, we are meeting all the technical requirements for the components of the storage ring (and for all other ALS components). We are not cutting corners. We may not be coming on line with a fully commissioned machine in April 1993, but at least it will be a good machine.

Now let me turn to the injection system. I'll come to the bottom line first. We now have an injection system operating to specification, despite the fact that we spent a great deal of time on equipment—modifying it, making it better, making it work. We have had only two significant equipment failures. One was the dipole power supply, a large power supply that powers all the bending magnets and the booster. The second was the transformer that isolates the 120-kilovolt electron gun from ground. We have had problems with cracked cases on those transformers, which the manufacturer is now correcting.

What does it actually mean to have an operating injection system? We can now say that we have demonstrated performance in all aspects of the technical specifications. We routinely operate at 1.5 GeV. In spite of problems with power supplies, which are being fixed, we have been operating night after night over the past 4 months at 1.5 GeV. We can operate in multi-bunch mode and single-bunch mode. In multi-bunch mode, we have about 70% injection efficiency into the booster—from the linac output at 50 MeV through the full acceleration cycle in the booster. This is good news for several reasons. Our shielding was built to accommodate these kinds of numbers—actually, a little lower injection and acceleration efficiencies. It means that our shielding is in very good shape. In single-bunch mode, we have close to 100% injection efficiency. We can inject a single bunch from the linac into the booster. I say "close to" because we have been doing this only for the last couple of weeks. We have 100% extraction efficiency from the booster. That statement has a question mark behind it because the monitors we are using to measure the 1.5-GeV beam are not absolute. We have calibrated monitors, but there is a question about that calibration. If the extraction efficiency is 100%, the storage-ring filling rates should be 1 mA/s in single-bunch mode and 4 mA/s in multi-bunch mode. Since our goal is 400 mA, we should be able to refill the machine from zero in something less than 2 minutes. Again, all these aspects of performance meet our specifications.

Now I want to discuss some of the accelerator physics. Figure 3 shows one quadrant of the booster. It has four-fold symmetry. It is a very simple FODO lattice, giving fairly smooth amplitude functions around the machine. The curves in Figure 3 come from our models of the machine. The goal of much of the accelerator physics is to show that the machine actually works like our models. We have many tools and methods for investigating this.

The first thing I want to show you is that we are not hurting for lack of signal. Many problems in doing accelerator diagnostics are caused by difficulties in measuring what is actually there. On the lefthand oscillogram in Figure 4, the signal represents the individual bunches separated by 8 nanoseconds at the 25-MeV level in the linac. This is 1 volt per division. We have 8-volt signals to look at.

In addition, many diagnostics operate through our control system. We can measure the closed orbit in the machine—the orbit that the electrons want to follow. It should go right through the center of the pipe, but because of magnet misalignment and rotations and differences between dipole-magnet fields around the magnets, the orbit never follows that ideal. You can perturb the orbit by attaching a correction magnet and then measure the orbit's distortion. We have had excellent agreement between

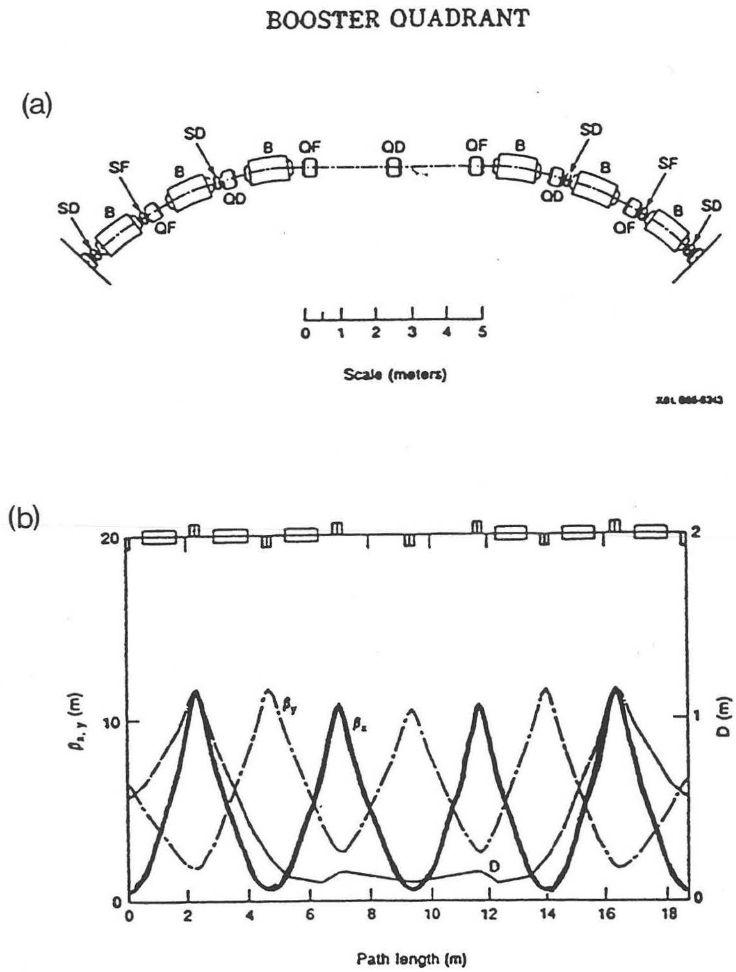


Figure 3. (a) Schematic of booster quadrant showing alternating focusing and defocusing magnets. (b) Amplitude functions derived from modelling.

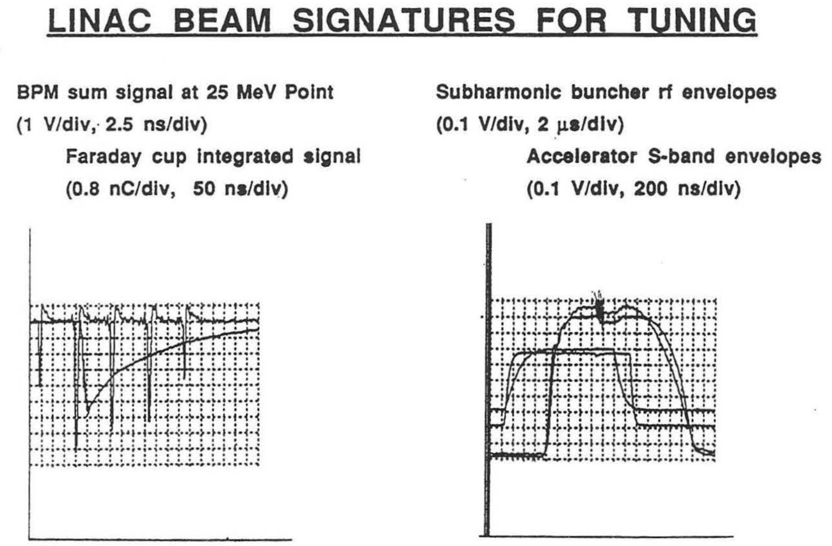


Figure 4. Diagnostics for monitoring the electron beam show substantial signal strength.

what we expect to find in terms of closed-orbit distortion and what we actually measure. Figure 5 shows the closed orbit measured in real time when we perturb small steering magnets in the same types of position at four positions around the booster. All of these curves should look the same but be displaced by one square for each quarter of the circumference of the booster. These measurements agree to better than 4% with our models.

Another thing we can do with the machine is measure the betatron tunes, fundamental parameters in any accelerator system. Figures 6 (a) and (b) show raw data of the beam position on a turn-by-turn basis, measured at one position as the electrons go around the booster. We can further analyze these data and measure the oscillation frequencies (or tune). Again, these results, shown in Figures 6 (c) and (d), agree to within 4%.

The electrons not only oscillate transversely but also longitudinally, in what are called synchrotron oscillations (see Figure 7). You can see that the agreement between the measurements (two crosses in the figure) and the theory is excellent. Again, this gives us confidence that the model of our machine is correct and that we understand the machine.

We tried to correct the deviation of the closed orbit from the ideal. This is done with correction magnets. There are two interesting things about the data shown in Figure 8. Plot (a) represents the uncorrected closed orbit around the machine—the 75-meter circumference of the machine—and shows how the orbit varies from its ideal position. With no correction at all, we have maximum deviations of

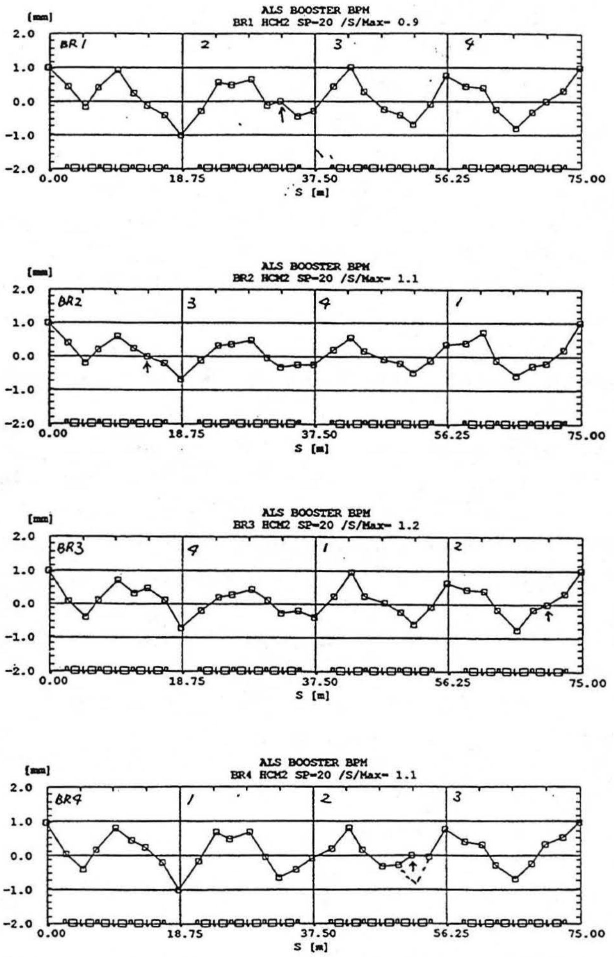


Figure 5. Real-time closed orbit measurements taken after perturbing steering magnets at four positions around the booster.

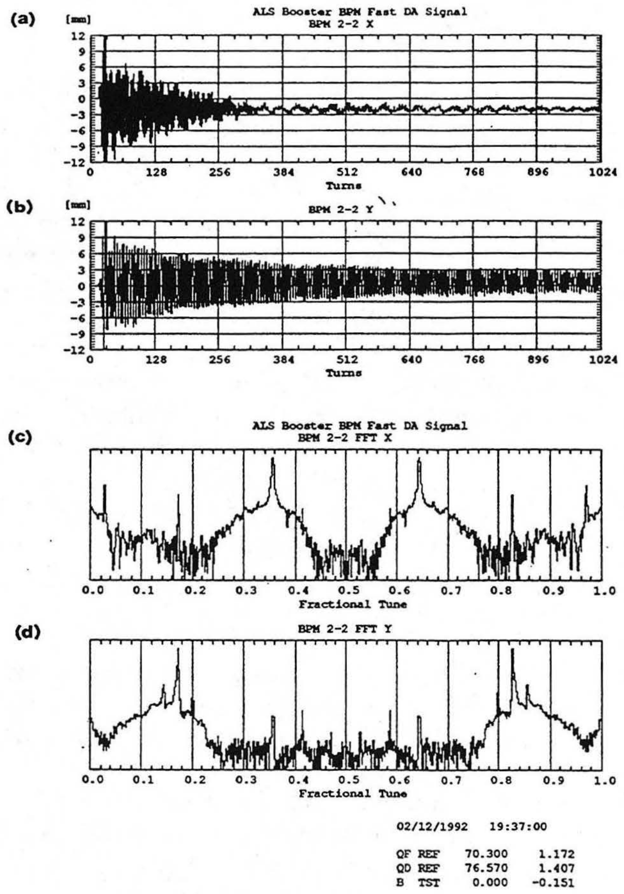


Figure 6. (a) and (b) show raw data of the beam position on a turn-by-turn basis, measured at one position as the electrons circle the booster; (c) and (d) are plots of the oscillation frequencies (or tune) of the electron beam.

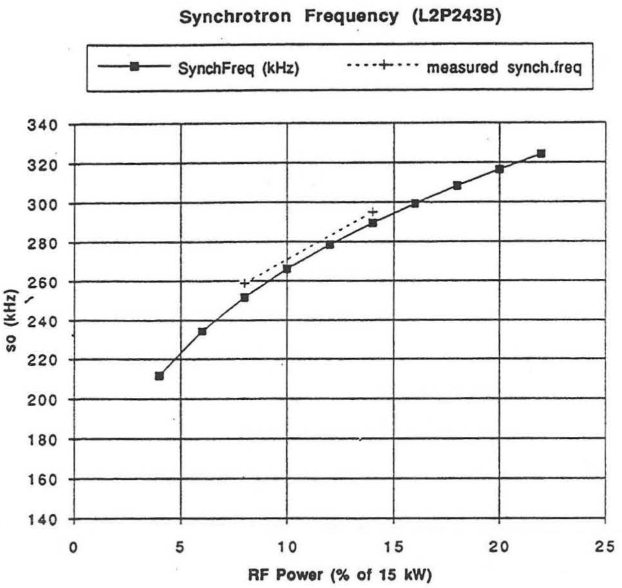


Figure 7. Synchrotron oscillations versus rf power (modeled and measured).

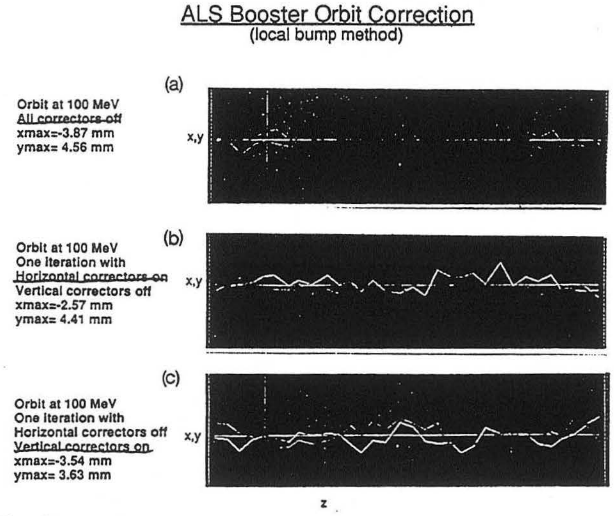


Figure 8. Correction of closed orbit in the booster: (a) uncorrected closed orbit; (b) closed orbit with horizontal correction; (c) closed orbit with vertical correction.

less than 5 mm from the ideal—a testimony to the accuracy with which the magnets have been built and placed on orbit—except for one problem. When we correct the horizontal orbit as shown in Figure 8 (b), we find that on average it is displaced by about 1 millimeter from where it should be. We couldn't explain that until we did a survey of the storage ring area and discovered that one of the normalization parameters used in the survey of the booster was incorrect, resulting in a booster radius larger by 1 mm than it should have been. Sure enough, this error was corroborated by the beam.

Figure 9 (a) shows what we see on a day-to-day basis. This is a multishot oscillogram, showing beam current of about 10 mA ± 10%. This current has since been increased to more like 15 or 16 mA, with the first few turns displayed here. Again, this is one of the strengths of the control system. From oscilloscopes on the floor, we bring those signals into the control room. Two completely different time-based oscilloscope pictures can be displayed on the same line.

Figure 9 (b) shows the electron-beam cross section as the beam comes out of the booster into the transport line. Figure 10 shows individual pulses, again spaced at 8 nanoseconds. The structure from the linac is preserved through the acceleration cycle and appears in the transport line. We have equipment that can accurately measure those profiles, and from the measurements, we can estimate the emittance of the beam. The result that we obtained for the transverse emittance of the beam (0.25 mm-mrad) is within 10% of the theoretical estimate. Again, this accuracy gives us confidence that we know what we're doing with the machine. And the coupling is less than 8%, well in line with what we predicted theoretically.

Before beam was ever injected into the booster, we obtained magnetic measurements from the dipole and quadrupole magnets. From that information, we learned that the current in the quadrupole magnets follows the acceleration of the rising current in the dipole magnets but that their fields do not track as they should because of remnant field effects. We predicted that imperfect tracking would cause a problem and put in place a linearity correction to fix it (see Figure 11).

Figure 12 shows a beam injected into the booster with step losses as the beam crosses different resonances, as predicted by the field measurements. The line represents slightly adjusted data from our model based on the magnetic measurements. The circles are actual measurements. Using these data, we were able to preprogram the quadrupole power supply to reduce that variation (see Figure 13).

Everything I have shown you would have been impossible without the control system. It is very flexible and working well. Figure 14 shows one of its inventors, Chris Timossi, sitting in front of the six screens that we use on a nightly basis. These are each connected with a separate PC.

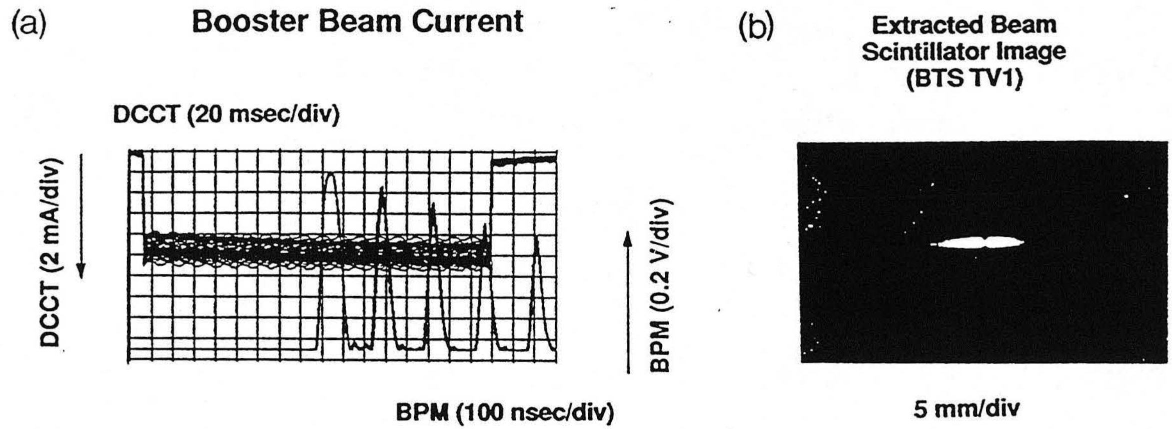


Figure 9. (a) Electron-beam current in the booster; (b) electron-beam cross section in the booster-to-storage-ring transport line.

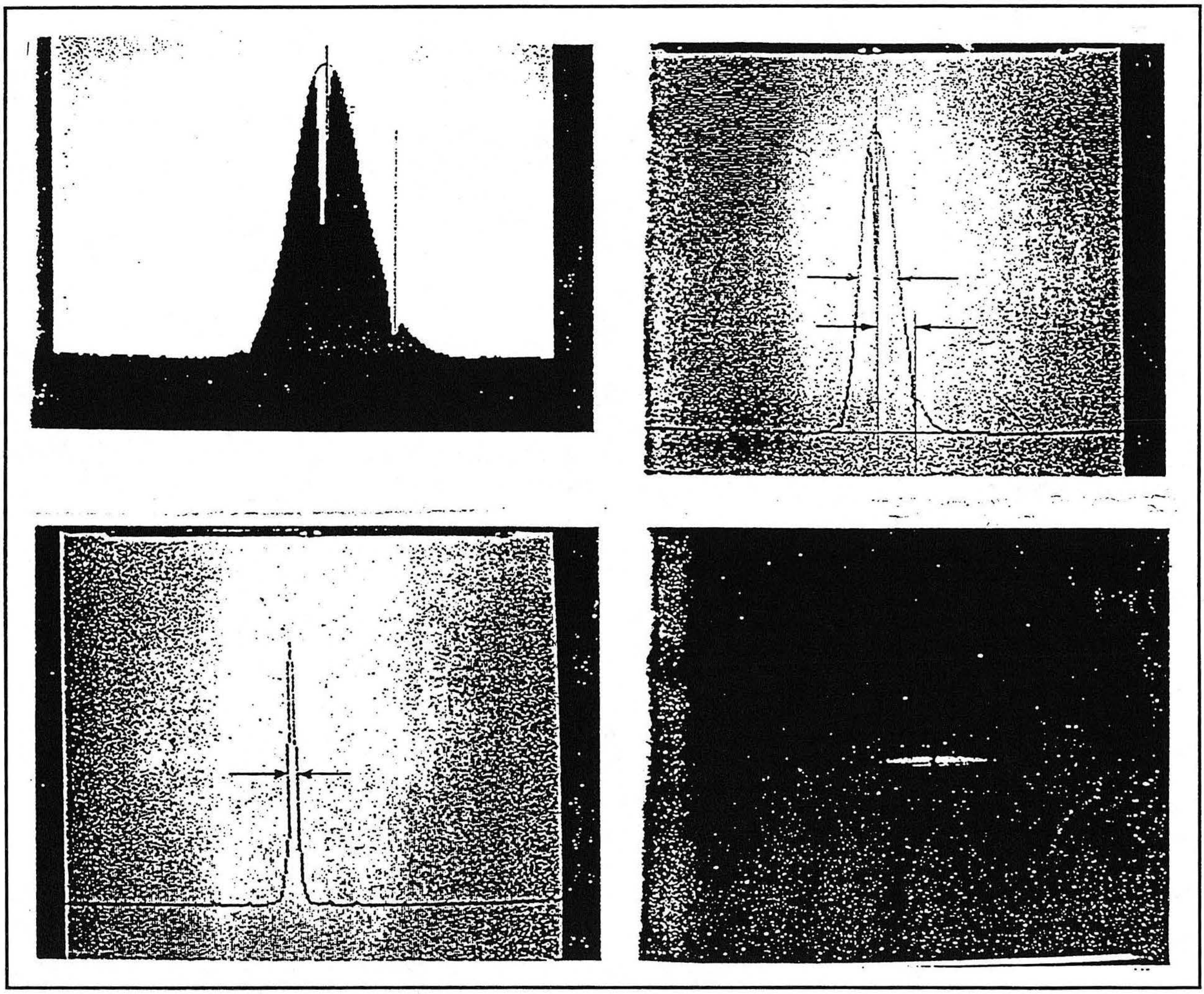
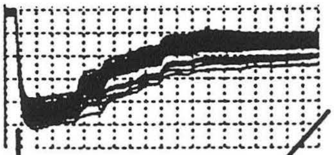


Figure 10. Individual electron-beam voltage pulses spaced at 8 nanoseconds.

Tracking linearity correction improves beam intensity

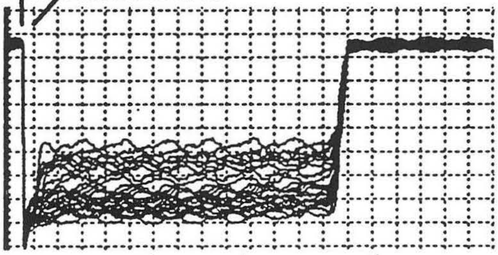
DCCT signal before the correction
vertical scale: 1 mA / div



horizontal scale: 0.5 ms / div
(data L04047, 920204)

DCCT signal after the Correction

vertical scale: 1 mA / div



horizontal scale: 10 ms / div
(data L04079, 920214)
(chkhd/booster/ramping/linearity correction/dcct signal)

Figure 11. Improvement in beam intensity brought about by correcting the tracking of the rising current in the quadrupole magnets with respect to that in the dipole magnets. Originally, the quadrupole current tracked the dipole current by a constant amount. The tracking was changed to a slightly off-linear course to compensate for residual fields in the magnets.

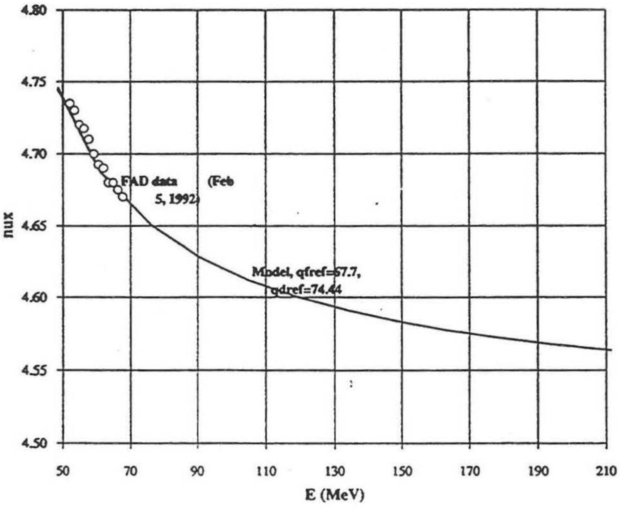


Figure 12. Predicted (solid line) and measured variation of the radial betatron frequency during acceleration.

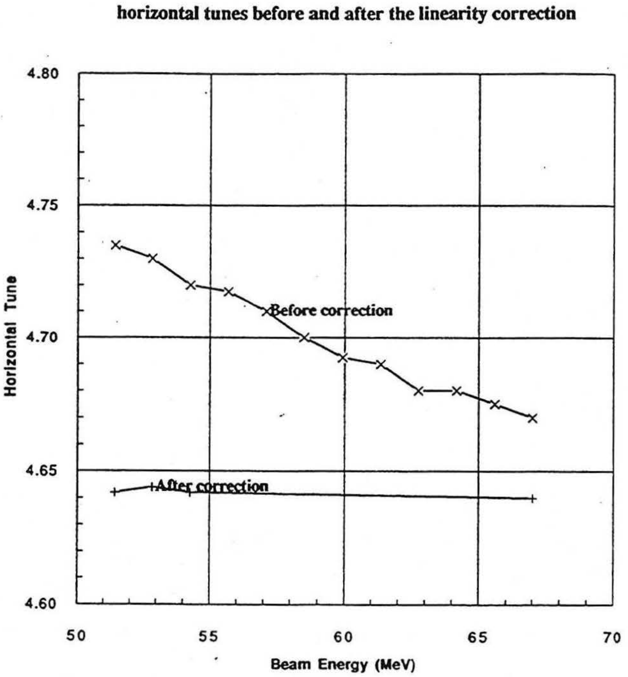


Figure 13. Radial betatron frequency before and after "linearity" correction.

Figure 14. View of the ALS control room. Chris Timossi is reviewing accelerator parameters.

Let me summarize by saying that the injection system is a well-understood machine. It is working well. It is working as it should. It has been an excellent training ground for our accelerator physicists, operators, and everyone else who has been helping on the night shift when the commissioning work is done. The storage ring may be late; however, we still promise by April 1, 1993, to have light from 1.5-GeV electrons shining right down the middle of the beam pipes.

Experimental Systems: Supersmooth Optics and Ultra-Precise Undulators

Brian M. Kincaid
Deputy Director for Experimental Systems, Advanced Light Source
Lawrence Berkeley Laboratory
Berkeley, CA 94720

This presentation describes the accomplishments made by the ALS Experimental Systems Group over the past few years. I think the group has achieved miraculous results in the technologies of undulators and optics.

The basic idea of the ALS storage ring is to produce beams using undulators. Figure 1 is a schematic of an undulator with permanent magnets in an array. The period of this array might be a few centimeters, typically 5. Electrons from the storage ring travel through the undulator and back into the ring. While in the undulator, they experience very small deflections, measured typically on the order of 10 µm, but rather large accelerations because of the high field in the device. If you think about an electron moving at the speed of light and its wavelength is 5 cm, the frequency of this motion—around 6 GHz—gets Doppler-shifted by the relativistic motion of the electron into the soft x-ray range, if you look in the forward direction.

Although the idea of an undulator originated at Stanford in 1950, the idea of a permanent-magnet undulator was conceived here at Lawrence Berkeley Laboratory (LBL) by Klaus Halbach. Figure 2 shows the world's first permanent-magnet hybrid undulator, which was installed at Stanford Synchrotron Radiation Laboratory (SSRL) in 1983—the Beamline 6 wiggler. Employing permanent magnets to energize steel poles, this device has been a real workhorse and is still in use.

Figure 3 shows one of the early drawings from the efforts of Halbach and Egon Hoyer, also of LBL. The magnetic-field flux comes from permanent-magnet blocks, flows into steel poles, and crosses the gap. Opening and closing the gap changes the field strength, which in turn changes the transit time of the electrons through the structure and thus changes the wavelength. Based on that idea, a revolution in synchrotron radiation is now in progress.

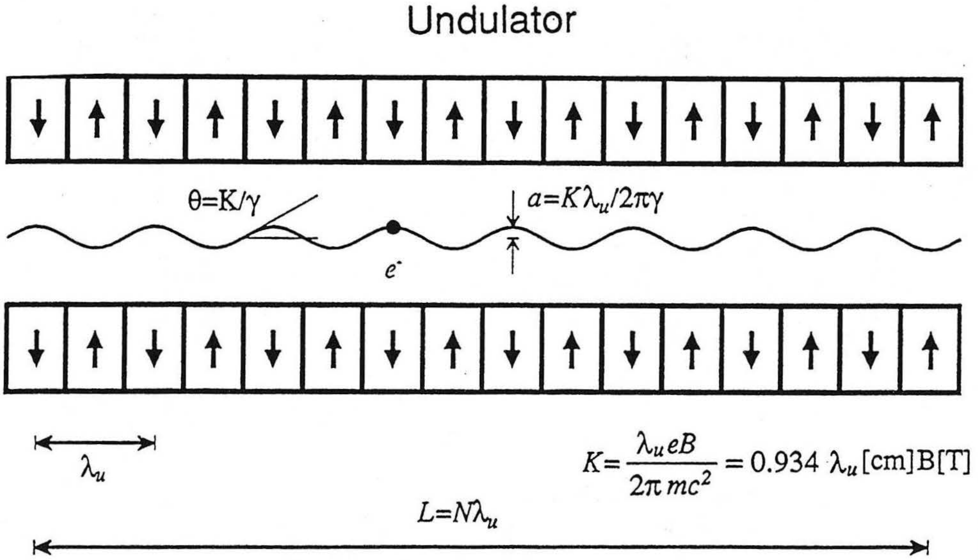
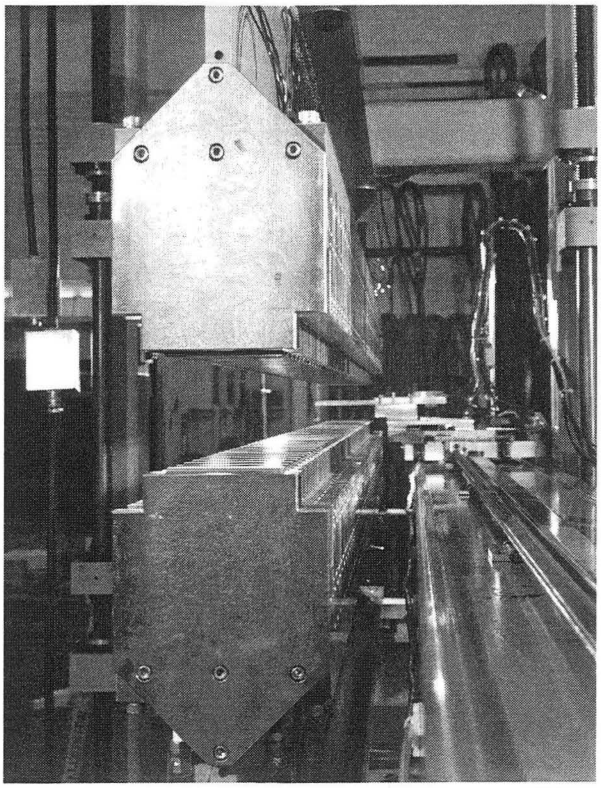
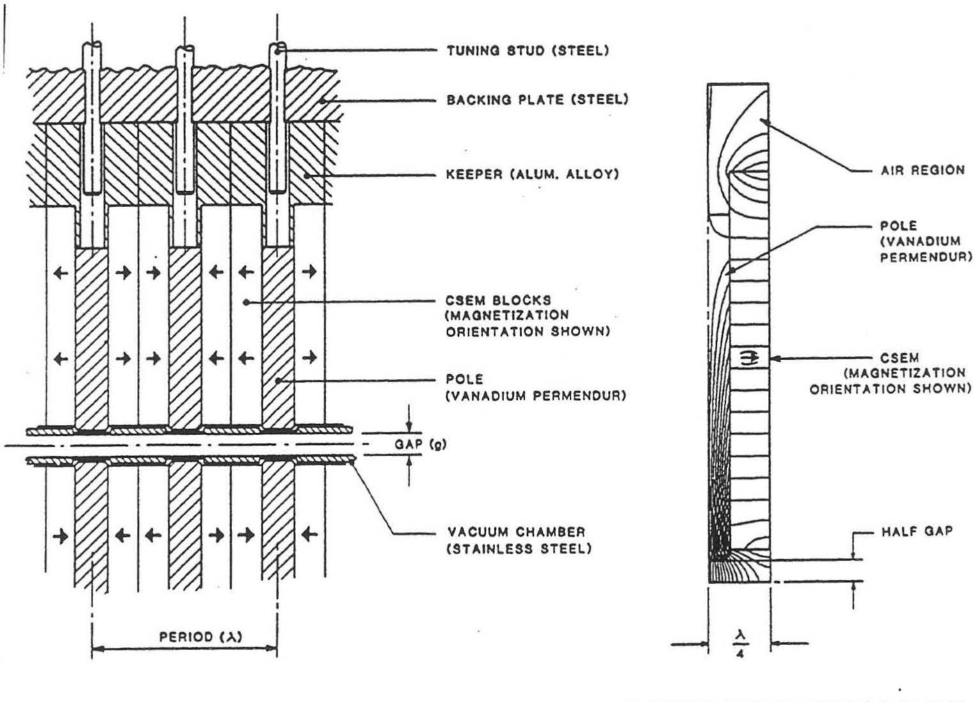


Figure 1. Schematic of an undulator. Arrays of permanent magnets of alternating polarity cause small deflections in the electron beam.



CBB 882-1446

Figure 2. Beamline 6 wiggler installed at SSRL is the world's first permanent-magnet hybrid undulator.



a.) ELEVATION CROSS SECTION

b.) QUARTER PERIOD MAGNETIC FLUX PLOT

CSEM–STEEL HYBRID INSERTION DEVICE

Figure 3. Early design for a permanent-magnet undulator by K. Halbach and E. Hoyer of Lawrence Berkeley Laboratory.

Earlier-generation machines started with bending magnets, which produce a broadband spectrum. These were circular machines, as shown on the left in Figure 4. Undulator-based machines have long straight sections; therefore, the ALS looks much more like the polygon-shaped structure on the right in Figure 4. Each straight section can accommodate a separately tunable undulator. The radiation spectrum that comes from an undulator, rather than being a broadband, x-ray light-bulb spectrum, is a tunable, partially coherent spectral peak. Producing this kind of light is the major purpose of the ALS.

The primary characteristic of this light is high brightness. The set of curves in Figure 5 was produced by S.L. Hulbert and J.M. Weber of Brookhaven National Laboratory (BNL). The curves labeled U8.0, U5.0, and U3.9 show that ALS undulator performance will be high on the scale of brightness, which is the critical parameter for all experiments involving microscopy, imaging, or coherent light. The curve labeled UA represents Advanced Photon Source (APS) undulator performance. These curves demonstrate why it is necessary to build both the ALS and the APS—because the curves do not overlap. The curve for the National Synchrotron Light Source (NSLS) X1 shows that it is probably the closest domestic competitor of the ALS undulators at this point.

At the beginning of the ALS project, there were only a few permanent-magnet undulators in existence. Figure 6 shows the field for one that I worked on at the NSLS. Although it is now used in the so-called U13 wiggler section, it was built as an undulator. The field has oscillations, a length of a couple of meters, and a period of 10 centimeters; it looks quite uniform. Gross errors are not evident, but when the data are analyzed, it becomes obvious that there are some strange errors in that magnet. If you do a least-squares fit of the ideal field and then remove the least-squares fit, the error fields remain (as shown in Figure 7). They are fairly large on the scale of the field that we had. The dotted lines in the figure indicate where the steel poles are. All of the errors seem to be between the steel poles, a characteristic that was not understood at the time (1987). It indicated that the design had some uncontrolled parameters.

Figure 8 shows another kind of error found in the magnetic field of an insertion device. This device, built at LBL by Egon Hoyer, Klaus Halbach, and their team, is the so-called Beamline 10 wiggler, which is also installed at SSRL. This figure shows the electron trajectory in dimensionless units. Three different electrons have been injected into the wiggler—one right down the middle of the magnet, another 6 mm to the right, and the third 6 mm to the left. The figure shows that the beam is getting a kick, resulting in a displacement. Effectively, there is a quadrupole moment in the magnet that shouldn't be there. If we

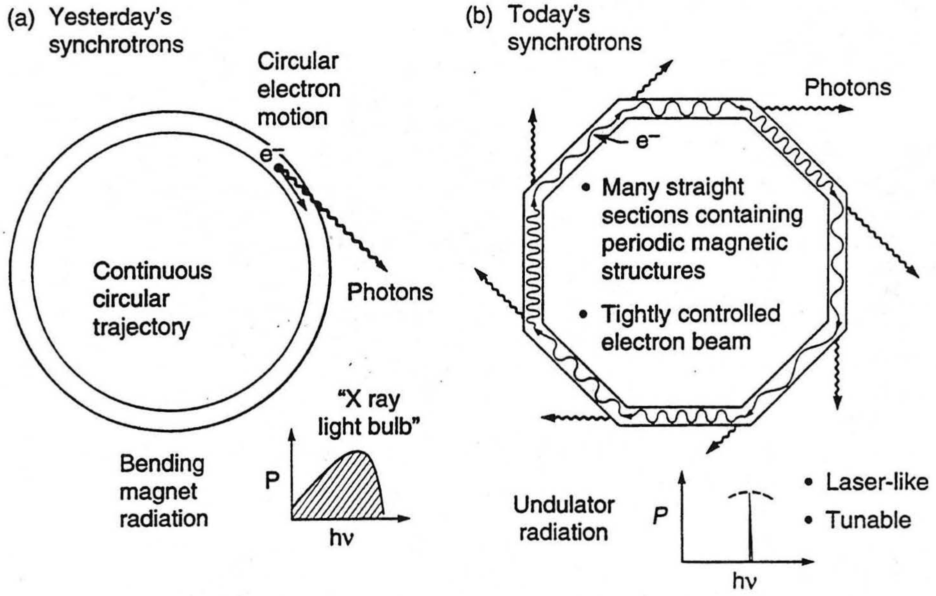


Figure 4. Earlier-generation synchrotron-radiation facilities (left) compared with third-generation facilities like the ALS. Straight sections in the newer facilities accommodate undulators, which produce partially coherent, tunable radiation.

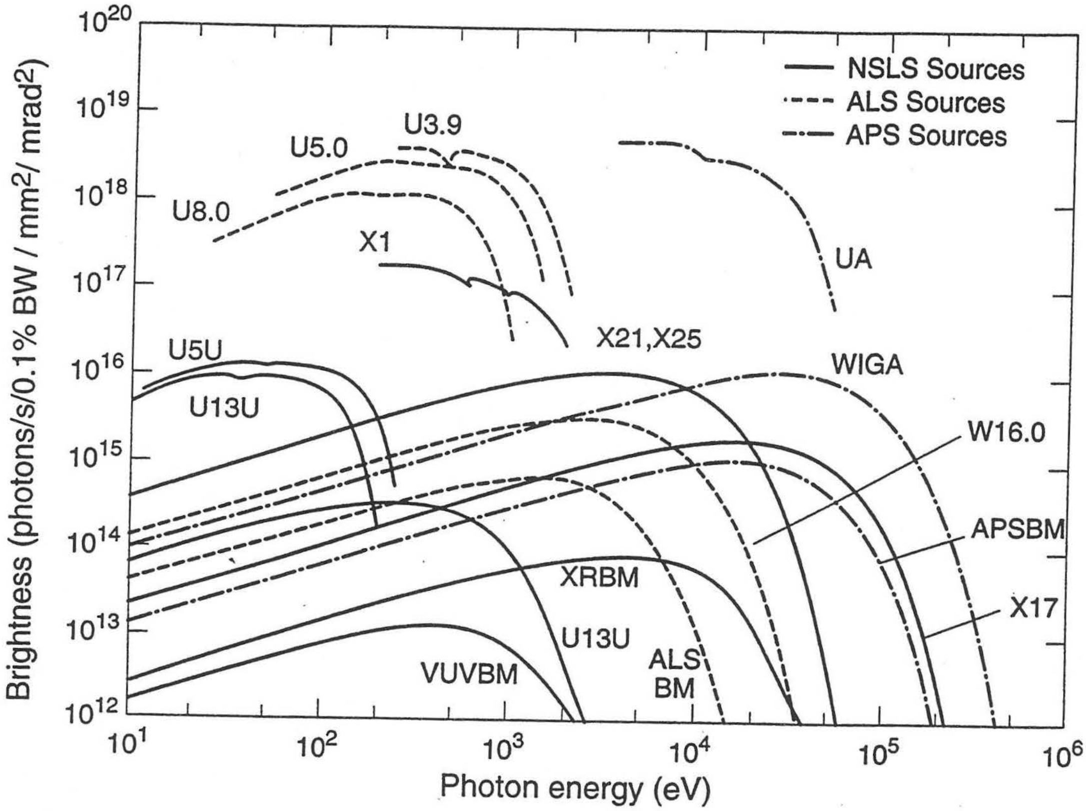


Figure 5. Brightness curves for synchrotron-radiation sources at the ALS, APS, and NSLS.

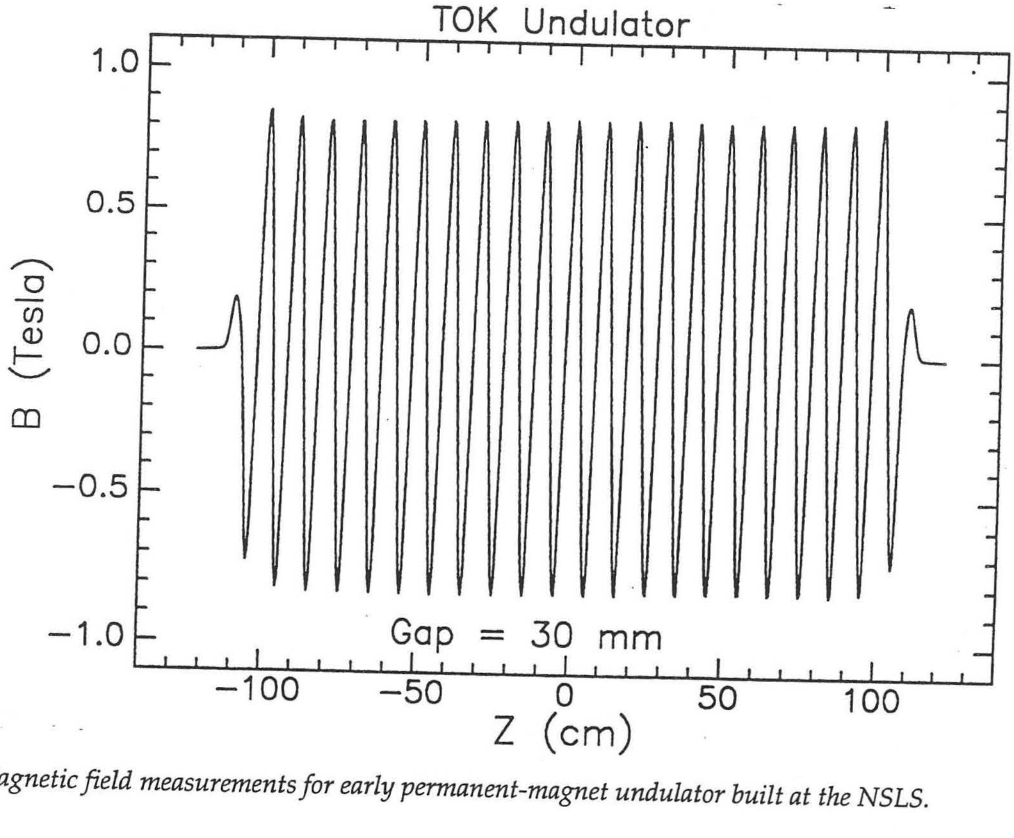


Figure 6. Magnetic field measurements for early permanent-magnet undulator built at the NSLS.

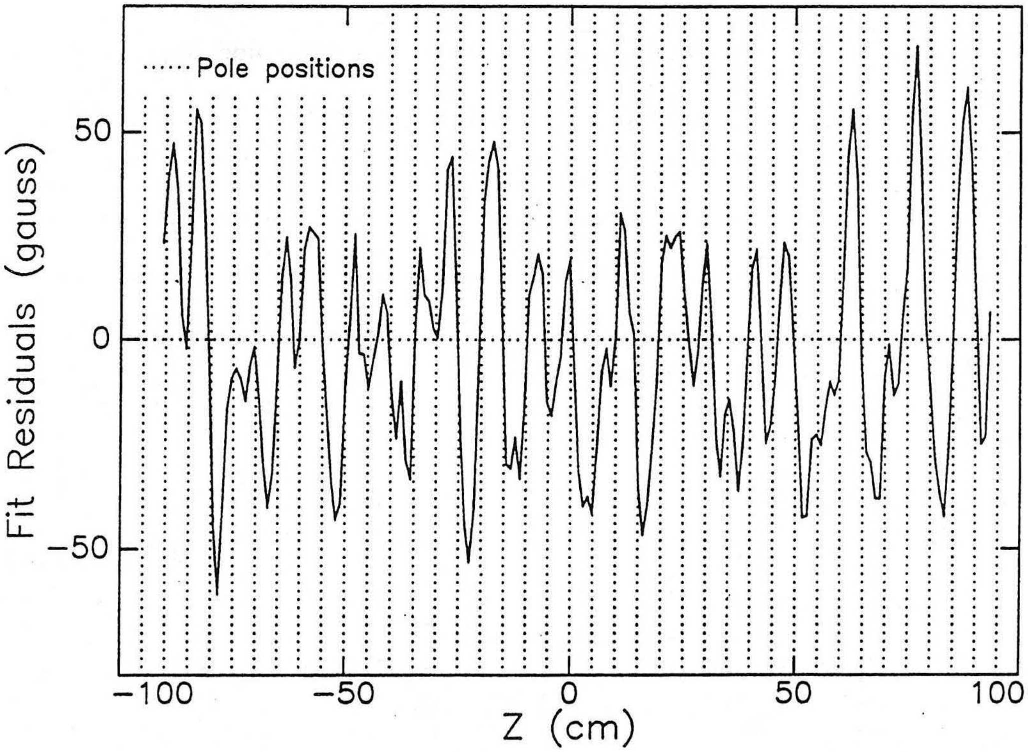


Figure 7. Errors in the magnetic field shown in Figure 6 became evident after data analysis.

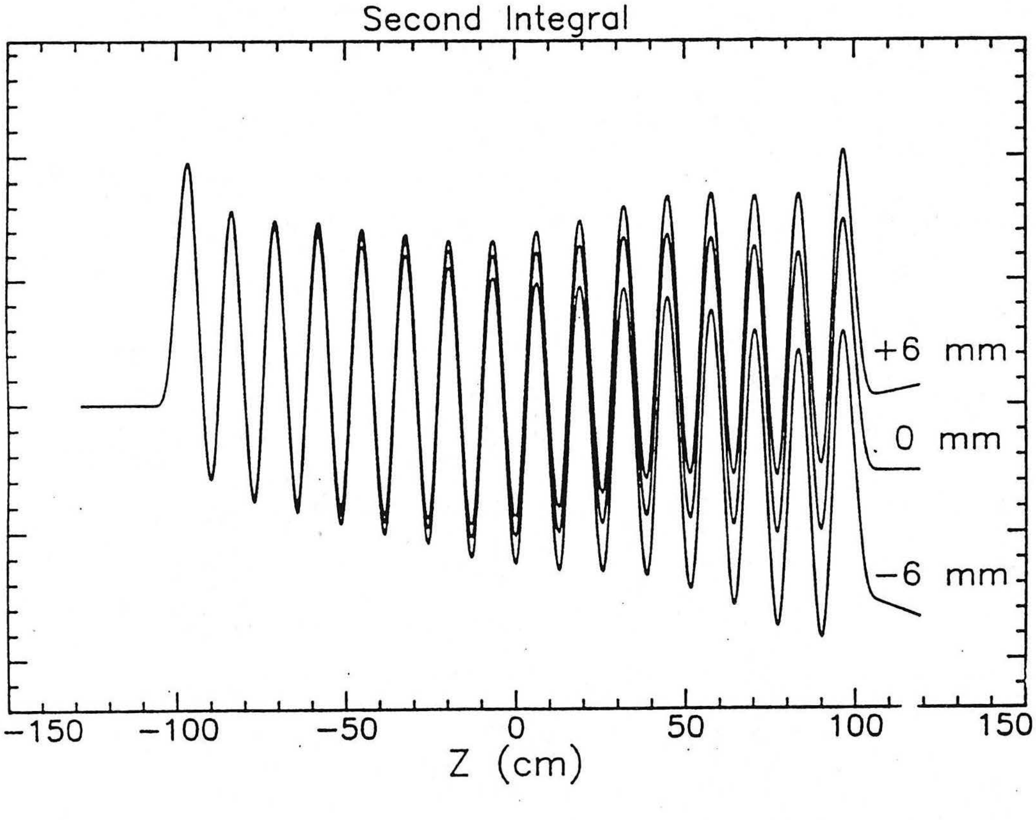


Figure 8. Measurements of the electron trajectory in the Beamline 10 wiggler at SSRL.

took this magnet and put it into the ALS, the machine would not operate. Figure 9 shows that if you do not have control over errors, the electron beam wanders off inside the undulator and that random walk spoils the spectrum.

Figure 10 (a) is a good example of a predicted spectrum from an ALS undulator, the fifth harmonic of a 100-period undulator like our U5 device. This shows the ideal 100% performance, a nice $(\sin x)/x$, transform-limited spectrum. Figures 10 (b) and (c) show what happens if you plug in the errors typical of the state of the art at the beginning of the ALS project. The result is like having only one-quarter of the beam current in the machine. Clearly, we had problems to solve.

When we started the ALS project in 1987, the state of the art for undulators was not advanced enough for our needs. At that time, errors of 0.5% were as good as one could expect, but we needed 0.25%. A length of 2 meters was the maximum so far achievable for a permanent-magnet undulator, but we wanted a 5-meter-long undulator in order to use longer straight sections for better performance. Furthermore, we didn't understand integrated multipole errors, permanent-magnet material was a kind of black art, and it was difficult to make magnetic measurements.

Part of the problem was solved in my group by Klaus Halbach, Bill Hassenzahl, and Roland Savoy. Figure 11 summarizes some of the kinds of errors that were treated by using an analytical theory. Figure 11 (a) is an example of a pole that has been machined incorrectly. This would produce a small gap error. Figure 11 (b) shows a permanent-magnet block that does not fill the space between the poles. This problem would cause extra field to leak out of the end of the block and cause an error. Figure 11 (c) shows a pole that is too thick, a problem that would cause the field strength to be too high. Figure 11 (d) shows the misorientation of a magnet block, which would obviously produce field errors.

Based on these error types, we developed a tolerance budget along with an analytical theory of errors. Table 1 shows the tolerance budget for a 5-meter-long undulator weighing tens of thousands of pounds—a giant piece of hardware. The pole positions have to be controlled to fractions of a mil. All machining

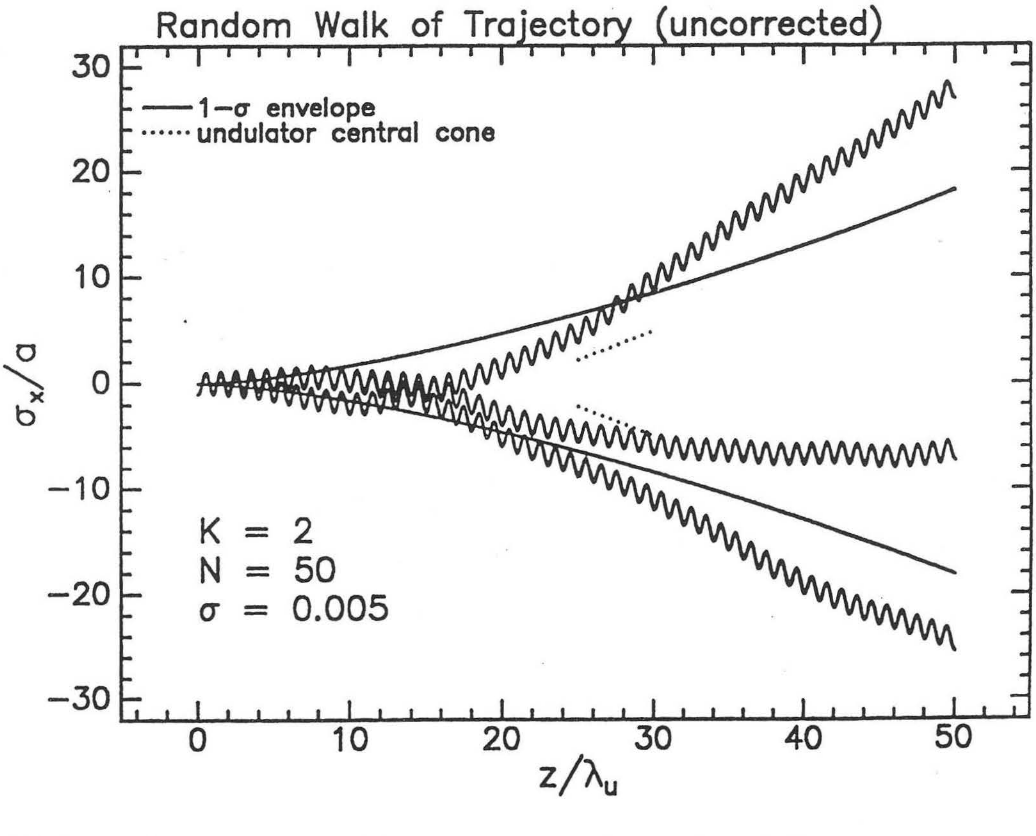


Figure 9. Electron trajectory errors caused by a magnetic error that displaces the beam.

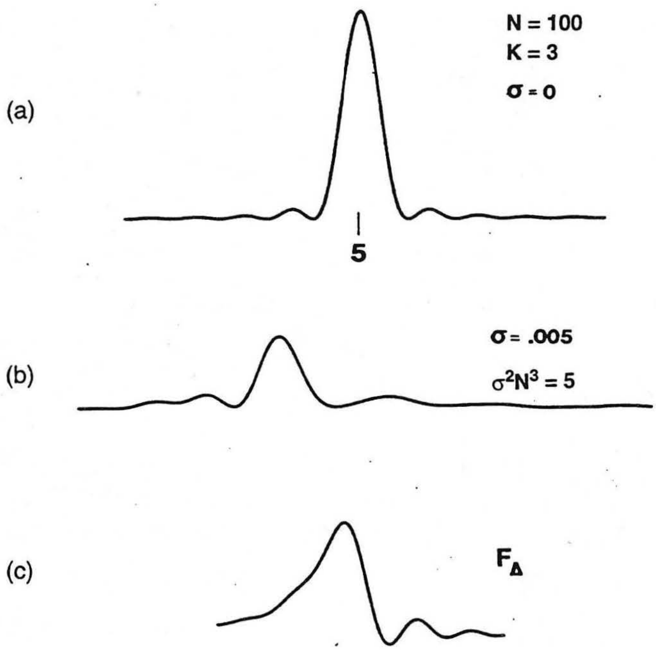
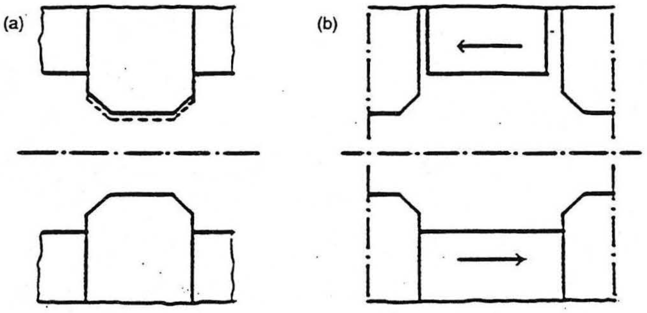
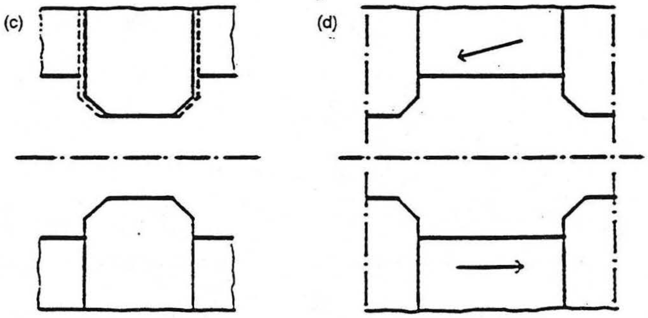


Figure 10. Magnetic errors in an undulator drastically affect the quality and quantity of synchrotron-radiation output.



Vertical pole motion

Spacing variation between pole and CSEM



Pole thickness variation

Easy axis misorientation

Figure 11. Classification of magnet errors that might be found in undulators: (a) vertical measurement of pole varies; (b) permanent magnet does not fill space between poles; (c) pole thickness varies; (d) magnet block is misoriented.

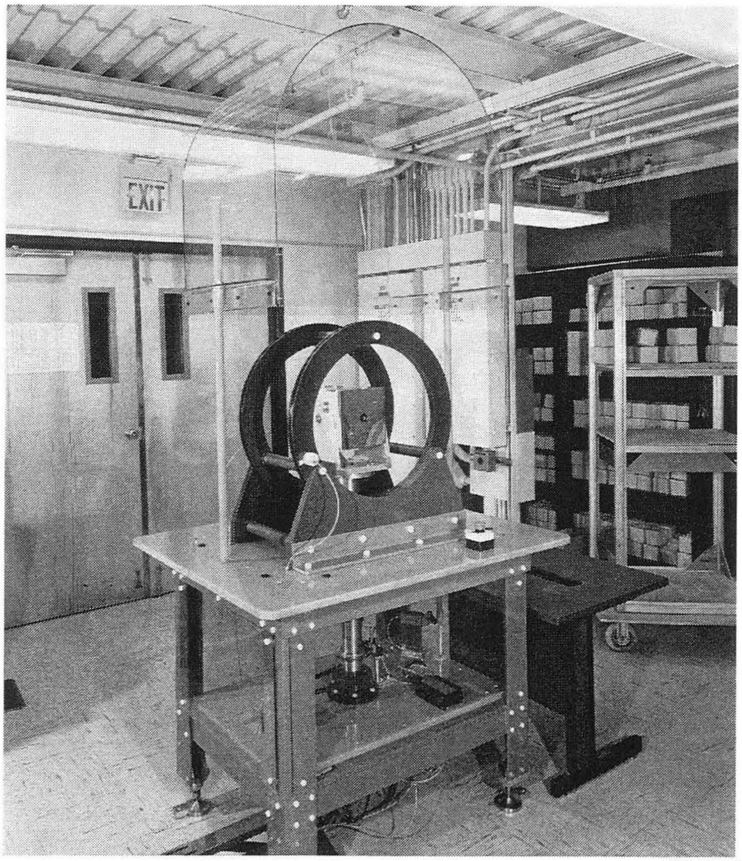
Table 1. Random error tolerance assignments.

Parameter	Tolerance	σ (%)
Vertical pole position	22 μm	0.06
Axial pole thickness	50 μm	0.03
Transverse pole width	100 μm	0.05
CSEM spacing difference	75 μm	0.06
Easy axis angle center block	1.3 degrees	0.16
Easy axis angle side blocks	2.3 degrees	0.16
Total field error allowed		0.20

tolerances have to be in the mil range. The permanent-magnet angles and orientation have to be controlled to an error smaller than what was available at the state of the art in 1987. So the total tolerance budget amounts to about 0.20% error. Staying within these tolerances was the challenge at the beginning of the project.

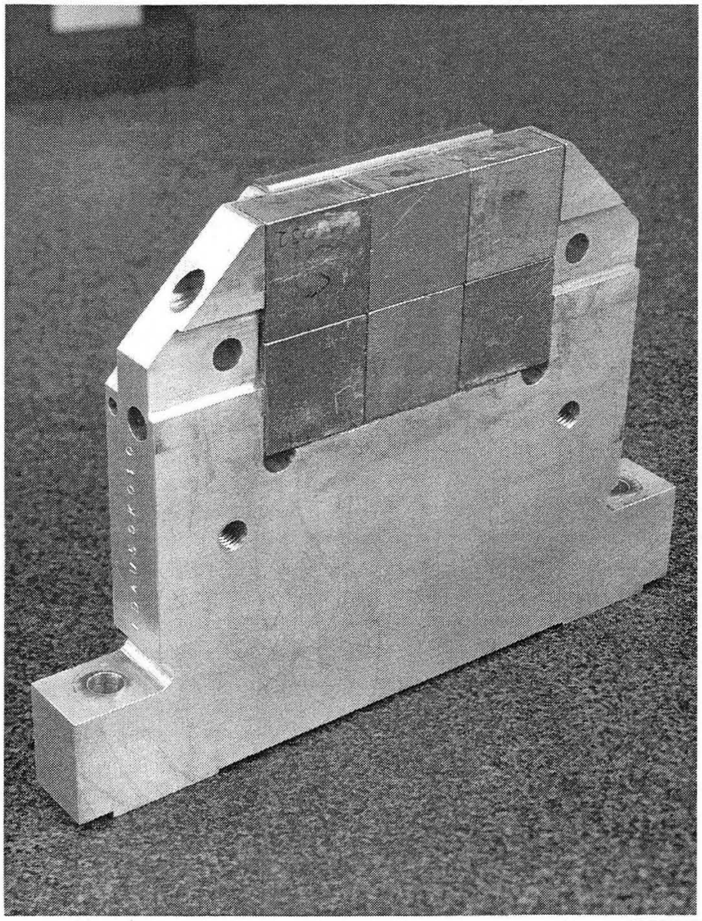
We started off by trying make the best possible measurements of the magnetic blocks. Figure 12 shows an automated system built by Hassenzahl and others at LBL and based on a Helmholtz coil. You put a magnetic block into the box, which spins around, inducing a voltage in the coil. The voltage measurement tells how strong the block is. We did that for over 5,000 blocks.

After magnetic measurements were completed, the blocks were glued to steel poles, and all were held together in an aluminum frame (see Figure 13). These pole assemblies were put together to create an



CBB 913-2043

Figure 12. Automated system for making magnetic measurements on permanent-magnet blocks.



CBB 913-1482

Figure 13. Pole assembly for ALS undulators consists of permanent-magnet blocks glued to steel poles and held together in an aluminum frame.

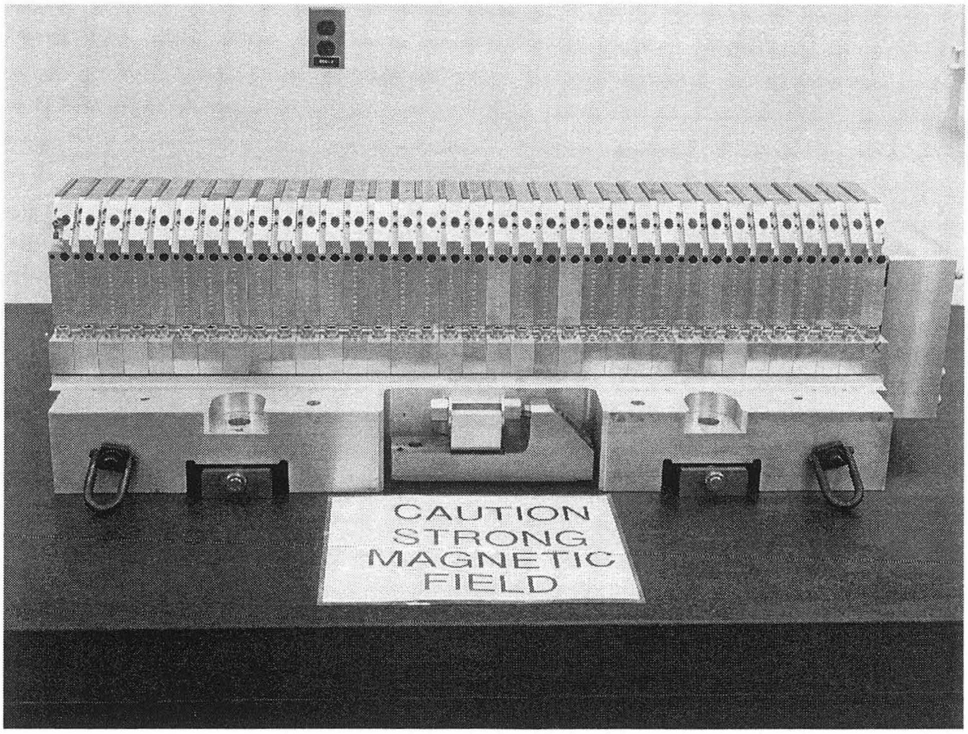
assembly section, as shown in Figure 14. The space between poles is 2.5 cm. Since a north pole alternates with a south pole, the magnetic period is 5 cm, and an assembly section is around 80 cm long.

The poles in these 80-cm sections must be very precisely aligned. Figure 15 shows some alignment work in progress, employing a laser interferometer. Ted Keppler is manually positioning the interferometer head, but the data are all being acquired by the PC in the background, which is running a spreadsheet program. Figure 16 shows the errors in terms of the pole heights. According to this figure, alignment for the poles (except at the ends) is within spec, which is basically a mil rms. Those at the ends have since been adjusted.

Following the pole-alignment process, the assembly sections were attached to two huge backing beams. These beams were then assembled into a large, very stiff support structure. Between these beams (and the attached arrays of magnet poles) runs a vacuum chamber, which will serve as the passage for the electron beam (see Figure 17). One magnetic pole array lies below, and one lies above the vacuum chamber.

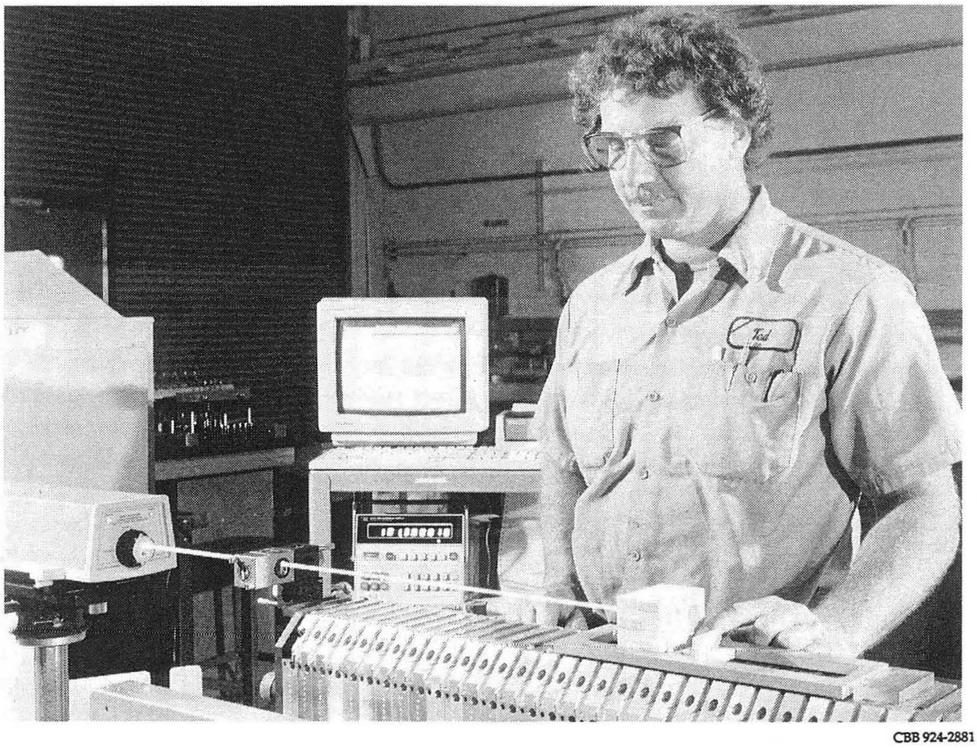
Figure 18 shows a 5-meter-long half-section of the vacuum chamber. This half has since been welded to a matching half. The slots in the chamber allow poles to fit through to achieve the smallest possible gap between the upper and lower magnet pole arrays.

The undulator is an exciting piece of hardware. We made field measurements on the device using an advanced Hall probe system, which we also had to develop ourselves. Figure 19 is a graph of these measurements showing 89 periods—a great many for an undulator. Most of the small variations seen in



CBB 9110-8709

Figure 14. Assembly section, consisting of 35 pole assemblies, is 80 cm long.



CBB 924-2881

Figure 15. An assembly section undergoing alignment by a system employing a laser interferometer and computerized data acquisition.

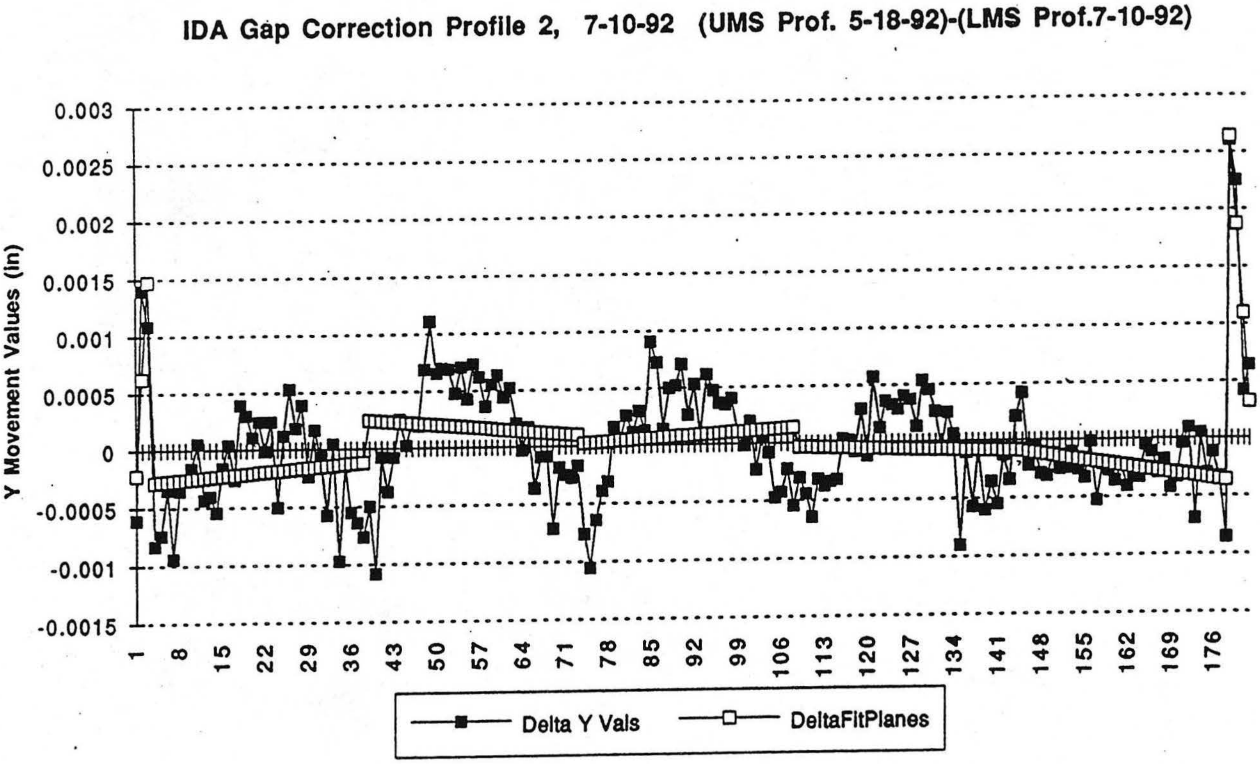


Figure 16. Results of assembly-section alignment. Pole-height errors are shown to be within specifications, i.e., no greater than 1 mil rms.

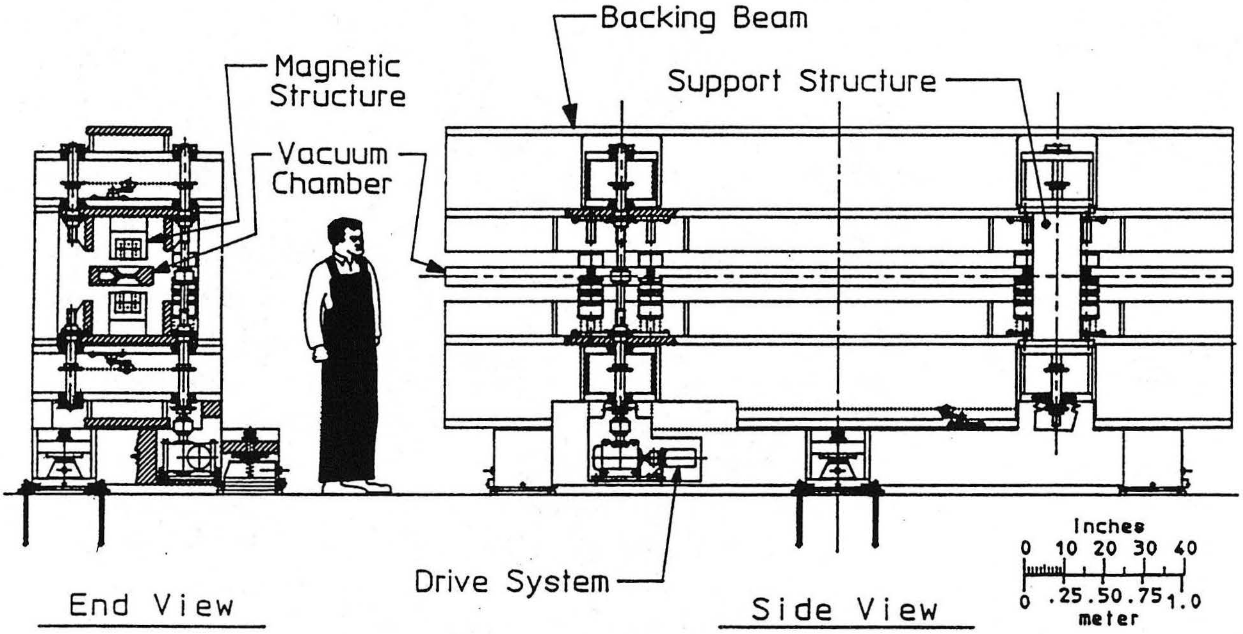
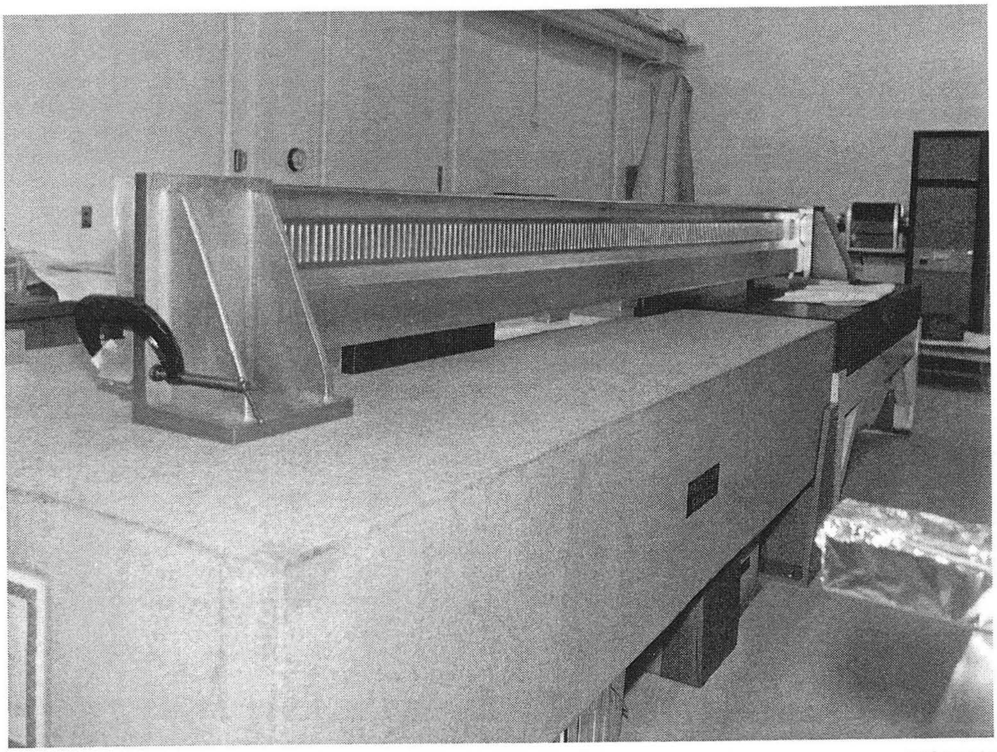


Figure 17. Diagram of undulator structure.



XBC 925-3659

Figure 18. Half-section of undulator vacuum chamber.

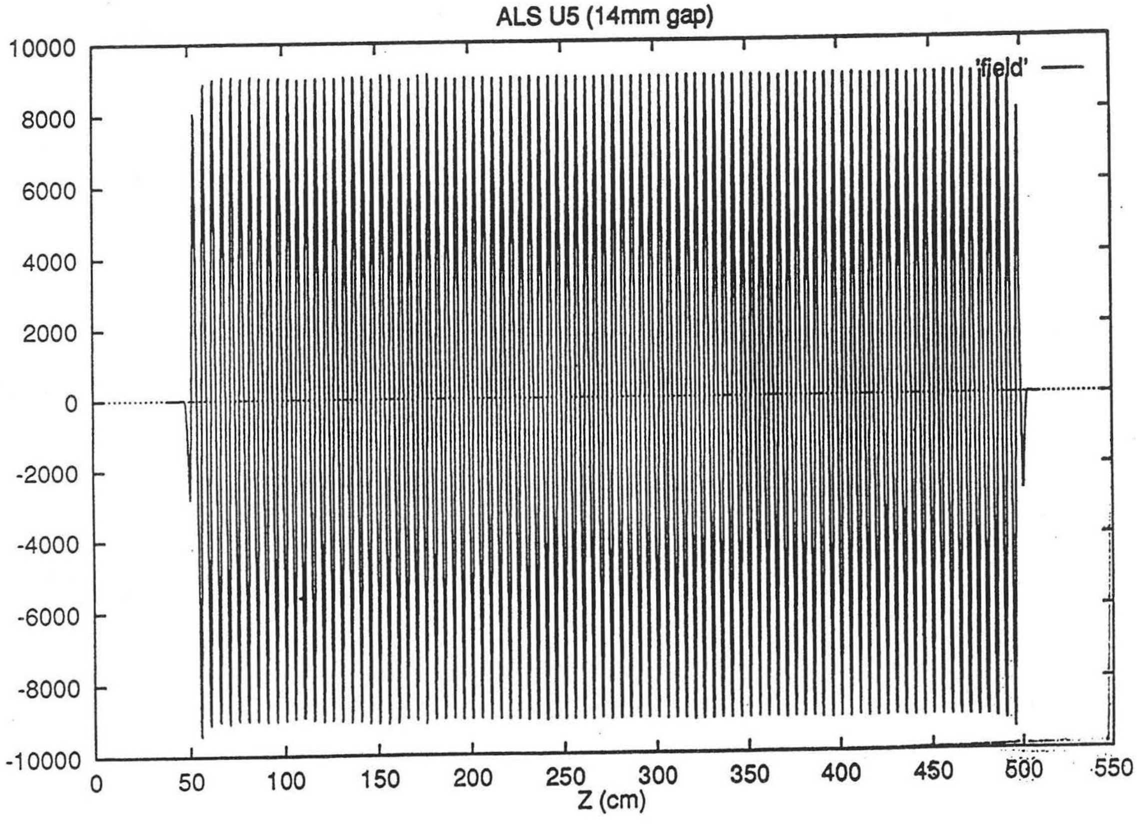


Figure 19. Magnetic measurements made on ALS U5 undulator.

the figure turned out to be artifacts of the graphics program; it's hard to get nonaliasing in the graphics. However, analysis of the field and subsequent computation of the electron trajectory from the results shows that the electron trajectory (Figure 20) is extremely good. The vertical scale in this figure is in units of wiggle amplitude, so 1 is 10 µm. The horizontal scale ranges from 0 to 5 meters; thus, in that distance (the length of the undulator), an electron will experience field-error-driven deviations of only about 10 µm.

Based on these data, we computed the expected spectrum. Figure 21 shows how the fundamental should look on axis. This is a calculated radiation spectrum normalized to what the ideal undulator would produce. The results indicate 99+% performance at the first harmonic. But what about the fifth harmonic? That is the critical test. Figure 22 shows that the performance is almost 80%—well above the 70% specification for this device. This is a nearly ideal transform-limited spectrum. As a result of our experience, building undulators now is an engineering science. The undulator is our first miracle.

The second miracle is our beamline optics—an even more amazing achievement. When we started the ALS project, the optics were a black art with many mysterious problems, for example:

- Difficult materials (CVD, SiC, Zerodur)
- No high heat load design
- Few vendors, long delivery delays
- Aspheric optics not available with tight tolerances
- 5-Å roughness needed, 0.8-µrad figure tolerance
- Metrology in a primitive state.

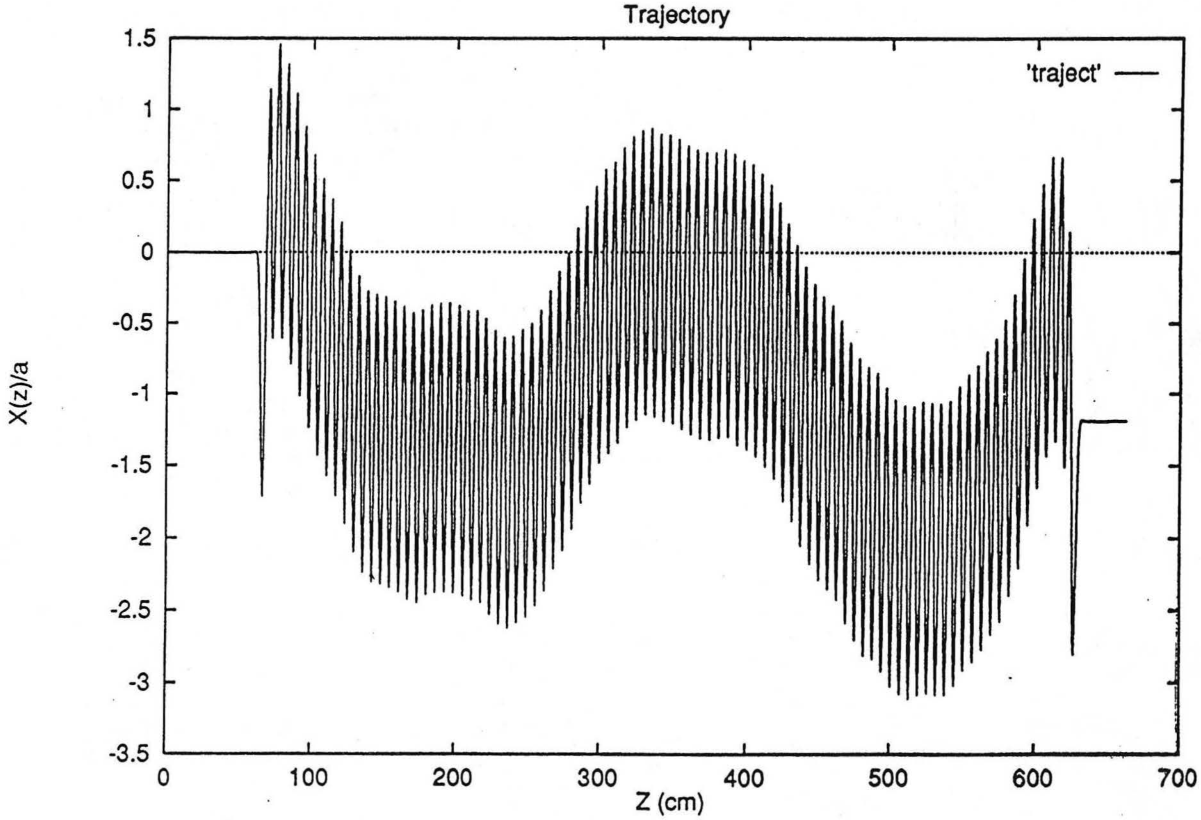


Figure 20. Electron trajectory derived from analysis of the data in Figure 21.

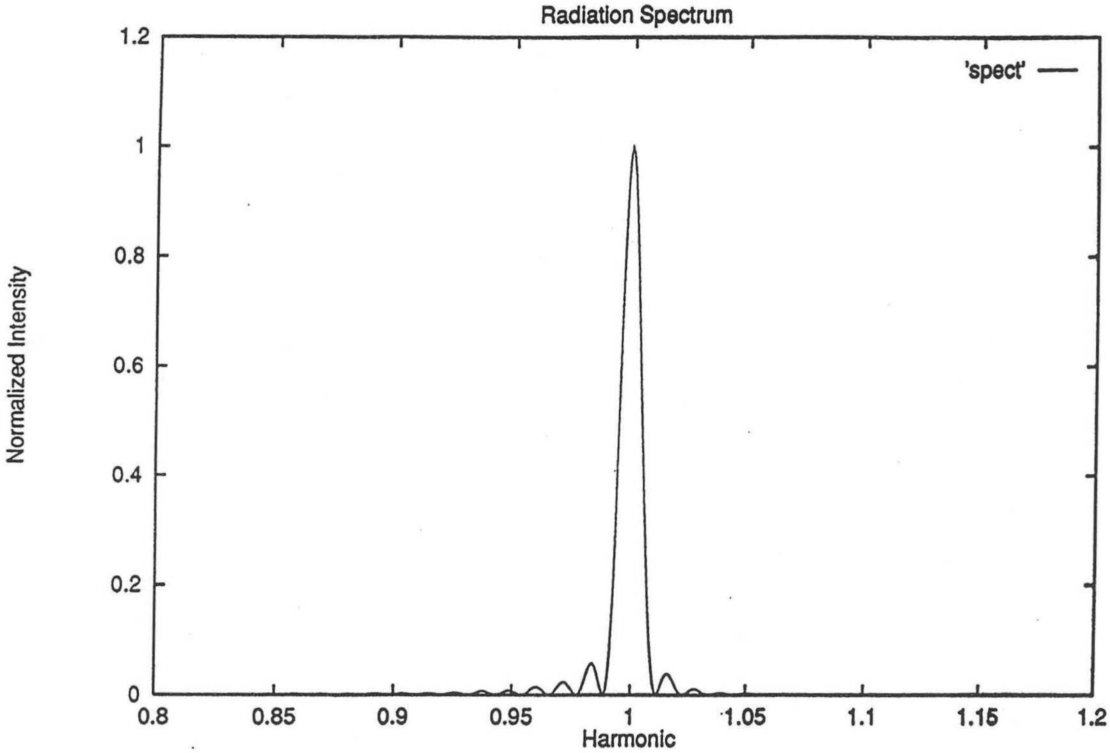


Figure 21. Computed synchrotron-radiation spectrum for first harmonic based on magnetic measurements indicates 99+% performance efficiency.

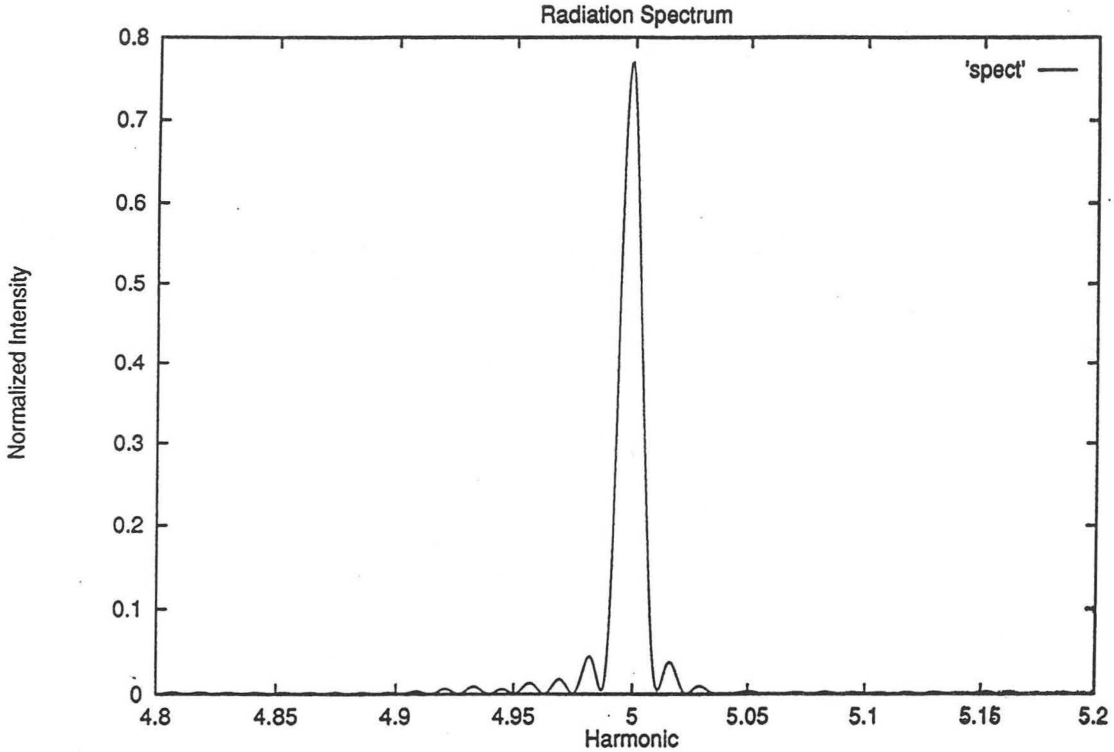


Figure 22. Computed synchrotron-radiation spectrum for fifth harmonic indicates almost 80% performance efficiency.

People didn't know whether or not to use silicon carbide, an unpleasant material to work with. Zerodur, another sort of glassy material possible to use, is also very hard to work with. Nobody knew how to handle the heat loads that would be produced by these big undulators. The vendors were a very few in number, and the delays in getting optics were very long. Furthermore, the optics you got very often were not what you wanted. At the beginning of the project, the vendors' customers were in a queue waiting for a grating or a mirror literally for years. We knew that aspheric optics were hard to make; so we tried to design systems using flats and spheres. As a result, we developed the spherical-grating monochromator design. We also knew that the surfaces would have to be very smooth and have a very good figure. The figure tolerance of 0.8 μrad is extremely tight—better than that for the Hubble telescope. The problem with the Hubble was that it was polished beautifully, but to the wrong figure. Not only have we polished our optics well, but they are polished to the *right* figure.

"If you can't measure it, you can't build it." This is a quote from Wayne McKinney, who has been in charge of beamline optics development. So, in order to build advanced optics, we had to develop advanced metrology. Table 2 shows the scope of the problem. The heat flux that will come from undulator beams at the ALS and at the APS is compared with various physical processes. The heat flux at the APS will be comparable to meteor-reentry heat flux at the meteor's surface. The ALS must contend with heat flux equivalent to that inside a rocket nozzle. This comparison shows why the APS and the ALS have a host of different challenges, a different parameter space. Many people think that building one synchrotron is like building any other, but it really isn't. The fact that we have solved our problems may or may not help the APS, and when they solve their problems, it may or may not be relevant to us.

Figure 23 shows the kinds of beamline optics we are building. The beamline for one of our 5-cm-period undulators (U5) has several components that must be water-cooled because they are subject to these extremely high heat loads: an adjustable horizontal aperture, a condensing mirror, the monochromator entrance slit, a spherical grating, and the monochromator exit slit. The beamline delivering photons from the 8-cm-period undulator (U8) has even one more water-cooled mirror.

What are the tolerances on these optics? Figure 24 shows the 1s → π* vibrational structure of nitrogen measured at 400 eV. These data were taken from Beamline 6 at Stanford, which employs a prototype of our monochromators. With the entrance slit set to 100 μm, you see a blob, but when the slit width is reduced to 10 μm, you start to see the vibrational levels. This indicates that there is science at a level of resolution beyond what has been generally available. Given a 10-μm slit and the fact that the beamline structure is measured in tens of meters, it is easy to see that we are dealing with angles on the order of microradians. This is the challenge in the optics business. How are all the parameters controlled? It is necessary to focus the light from a source to an image, an entrance slit, or an experiment perhaps 30 meters away. If there is a figure error, the beam goes to the wrong place. If there is too much surface roughness, the light scatters in all directions. (See Figure 25.) In addition to those problems, it is necessary to deal with kilowatts of power.

An important breakthrough came from Dick DeGennaro, one of the ALS engineers, who was seeking a material that would take the heat flux but would still maintain its strength. This is a material called GlidCop™, which was patented by the Glidden Paint Co. It is an alloy consisting of aluminum oxide

Table 2. Comparison of approximate heat flux levels in various processes.

Process	Approximate Heat Flux (W/mm^2)
Meteor re-entry	100–500 (APS)
Fusion reactor components	0.05–80
Sun's surface	60
Commercial plasma jet	20
Interior of rocket nozzle	10
Fission reactor cores	1–2

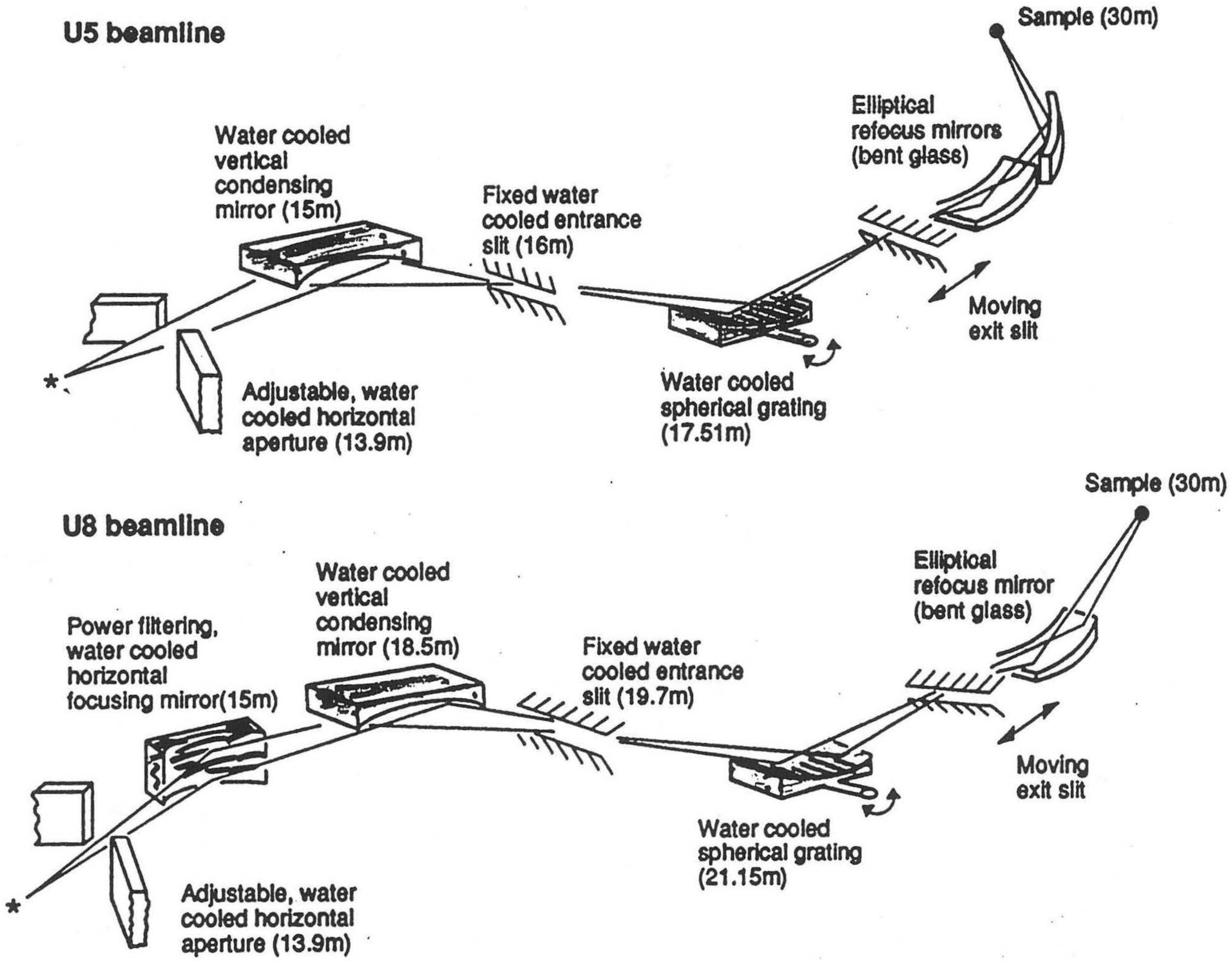
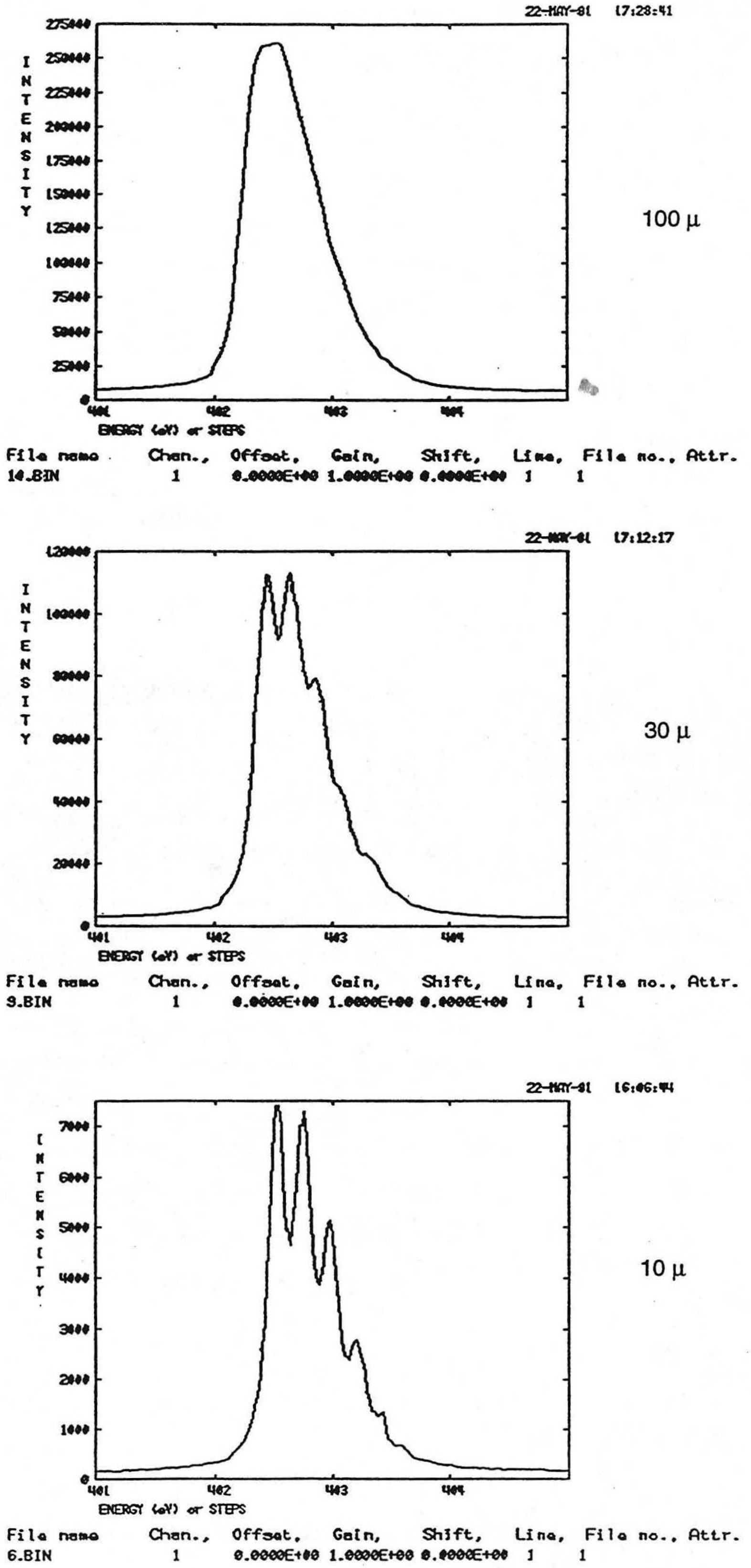


Figure 23. Diagram of optical components in ALS beamlines for the U5 and U8 undulators.

particles in a matrix of OFHC copper (see Figure 26). The aluminum oxide particles pin the grain boundaries, so that even though this material is fully annealed and fully strain-relieved (it has been put into an sintering oven), these grains prevent the boundaries from moving. Consequently, the material has the thermal properties of pure copper, the electrical properties of pure copper, but the mechanical properties of hard copper, which is not annealed. GlidCop™ is closer to stainless steel than it is to soft copper.

Using this material, the ALS engineering group put together the structure shown in Figure 27—a brazed, water-cooled grating assembly. (The grating grooves will be etched on its bottom surface.) One of the main features of this photograph are the water-cooling channels.

The next step is to coat the surfaces and polish them to achieve the right figure. The key players in that business are Dave Lunt and Wayne McKinney. These two people alone have created a whole new technology, starting with next to nothing. Optical surfaces are now a multimillion-dollar business worldwide in the synchrotron-radiation market. We coat these surfaces with electroless nickel and have them polished to an extreme smoothness using a process developed by Lunt. Figure 28 shows a trace of the surface roughness (measured in angstroms) after polishing. It was made with an interference microscope over a distance of 500 μm (i.e., 0.5 mm). The rms value of the signal is 2 Å, about the same smoothness as a glass of milk. (In fact, liquid surfaces are probably less smooth because of all the ripples.) Achieving this degree of smoothness—about a factor of 5 better than our specification—is now routine; it comes automatically with the polishing process. That is a big success—a miracle. There are people who claim this cannot be done, but we have the proof lying right here in front of me.



```
File name      Chan.,   Offset,    Gain,      Shift,     Line,  File no., Attr.
14.BIN          1       0.0000E+00 1.0000E+00 0.0000E+00  1      1
```

```
File name      Chan.,   Offset,    Gain,      Shift,     Line,  File no., Attr.
9.BIN           1       0.0000E+00 1.0000E+00 0.0000E+00  1      1
```

```
File name      Chan.,   Offset,    Gain,      Shift,     Line,  File no., Attr.
6.BIN           1       0.0000E+00 1.0000E+00 0.0000E+00  1      1
```

Figure 24. 1s → π^* vibrational structure of nitrogen measured at Kα with monochromator entrance slit width set at 100, 30, and 10 μm.

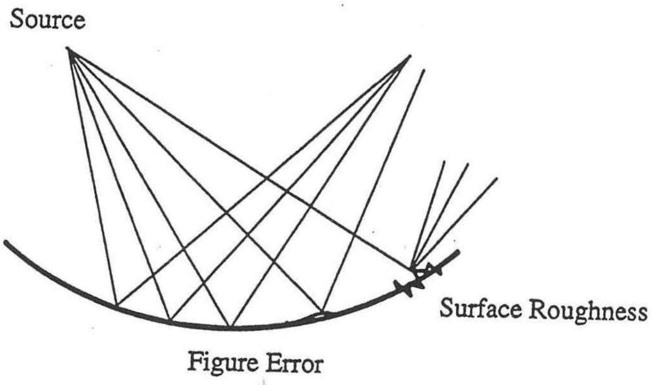


Figure 25. Effects of optical surface roughness and figure errors on focusing light.

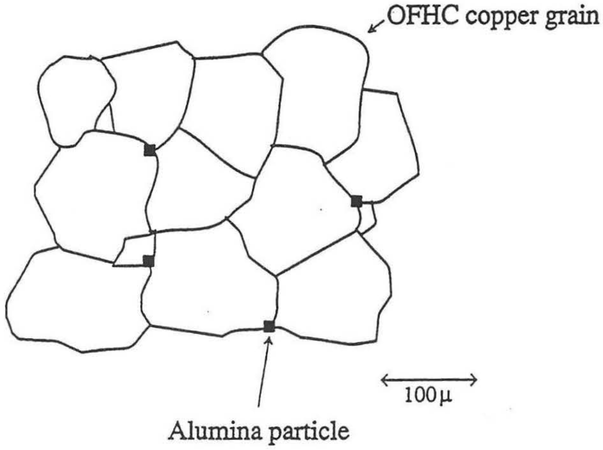


Figure 26. Structure of GlidCop™, a material used to make some ALS beamline optical components.

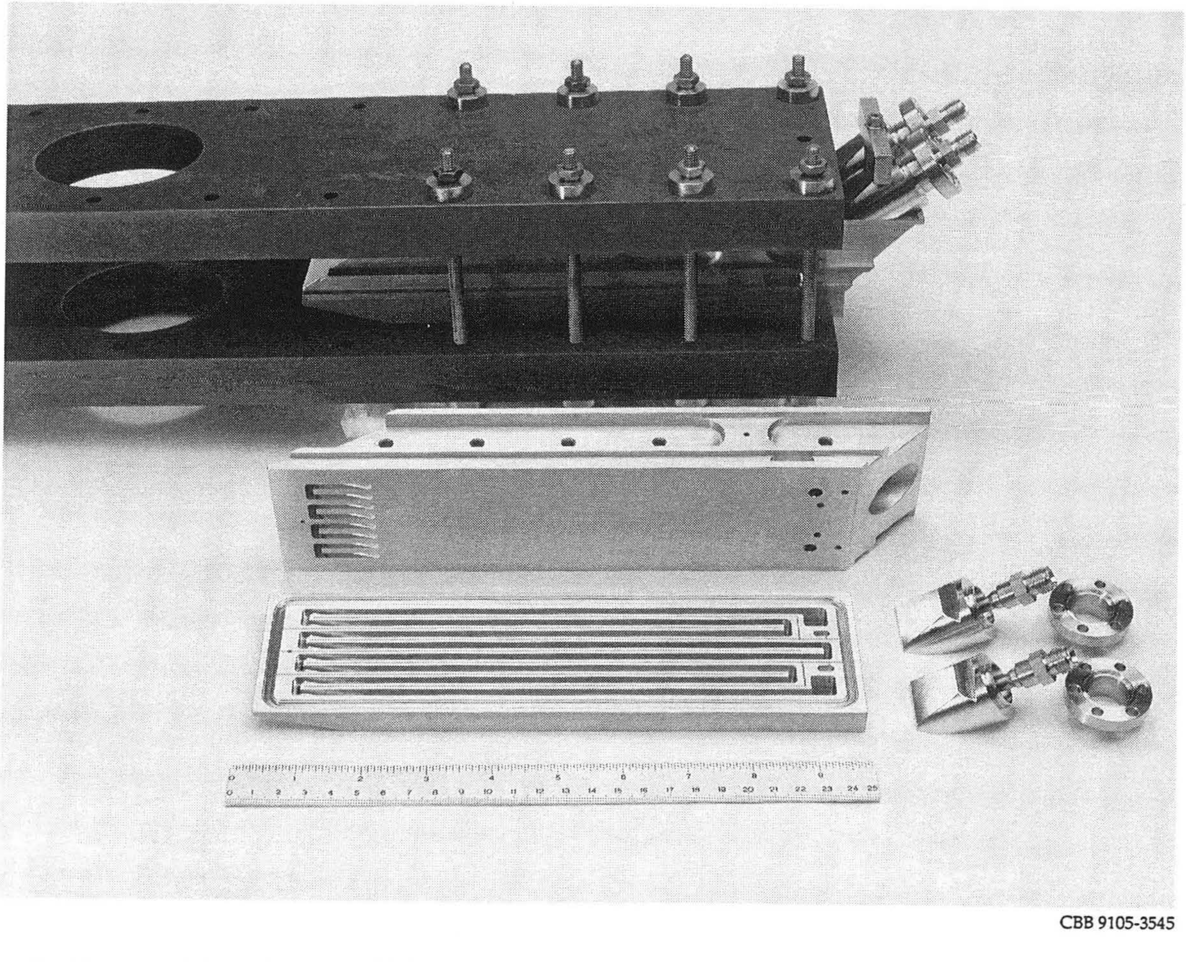
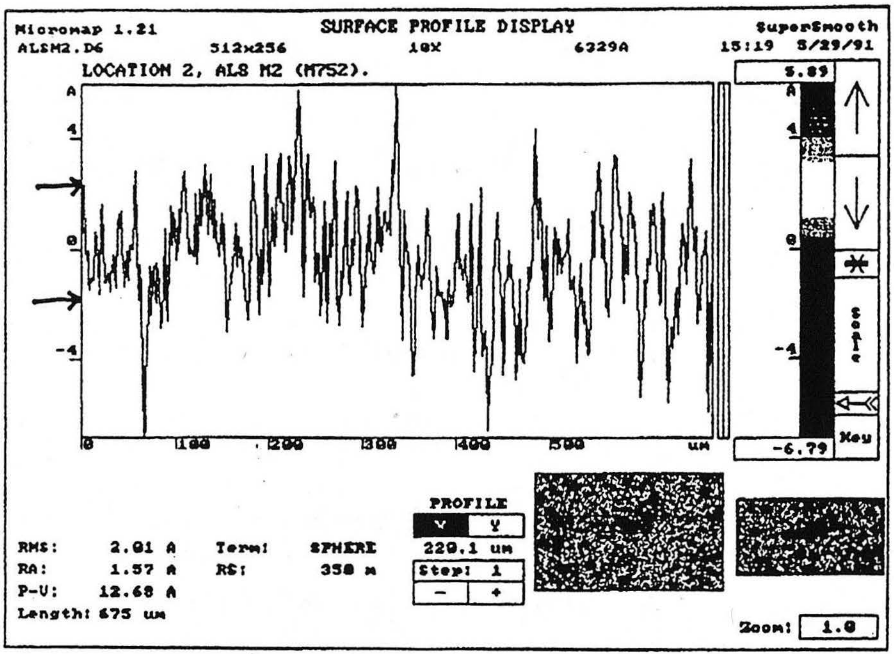

CBB 9105-3545

Figure 27. Water-cooled grating assembly for a beamline monochromator.


Micromap 1.21 SURFACE PROFILE DISPLAY SuperSmooth

ALSM2.D6 512x256 10X 6329A 15:19 8/29/91

LOCATION 2, ALS M2 (M752).

RMS: 2.01 A

RA: 1.57 A

P-V: 12.68 A

Length: 675 um

Term: SPHERE

RS: 350 m

PROFILE

229.1 um

Step: 1

Zoom: 1.0

- Achieved 2 Å roughness on ALS U8 Mirror
- Requirement for ALS mirrors is 10 Å rms

Figure 28. Trace of an ALS mirror's surface roughness (measured in angstroms) after coating with electroless nickel and polishing. Rms roughness value is 2 Å, five times better than the specification.

Once the surface is smooth, getting the right figure is the next step. The technology for achieving this is based on an idea from BNL. Peter Takacs of BNL developed a device called the "long trace profiler," and then Wayne McKinney and Steve Irick, on the ALS staff at LBL, made some major improvements in it. As a result, we are now able to measure the surface profiles of these optics. Figure 29 is a schematic of how this device works. It has an optical lever system and a CCD array that measures very small slope changes. Figure 30 is an example of results we obtained last year by using the long trace profiler to measure a 18-cm-long grating blank. In this example, the rms surface figure is within 1 µrad rms over about 160 millimeters. We actually have had better results since then.

Figure 31 shows one of the first ALS beamline mirrors—Mirror 1 on our U5 beamline. Its surface was measured by a different technique using conventional optics and found to have an rms slope error of 0.8 µrad, equal to our specification. Another mirror we measured later is better than our specification.

In summary, I want to say that the Experimental Systems Group has achieved miracles in two areas—undulators and optics. To get the high-brightness synchrotron radiation that we need, we had to create a completely new state of the art in these areas, and we have been very successful. I predict that when we open the ALS to users, the experimental systems are going to work very well.

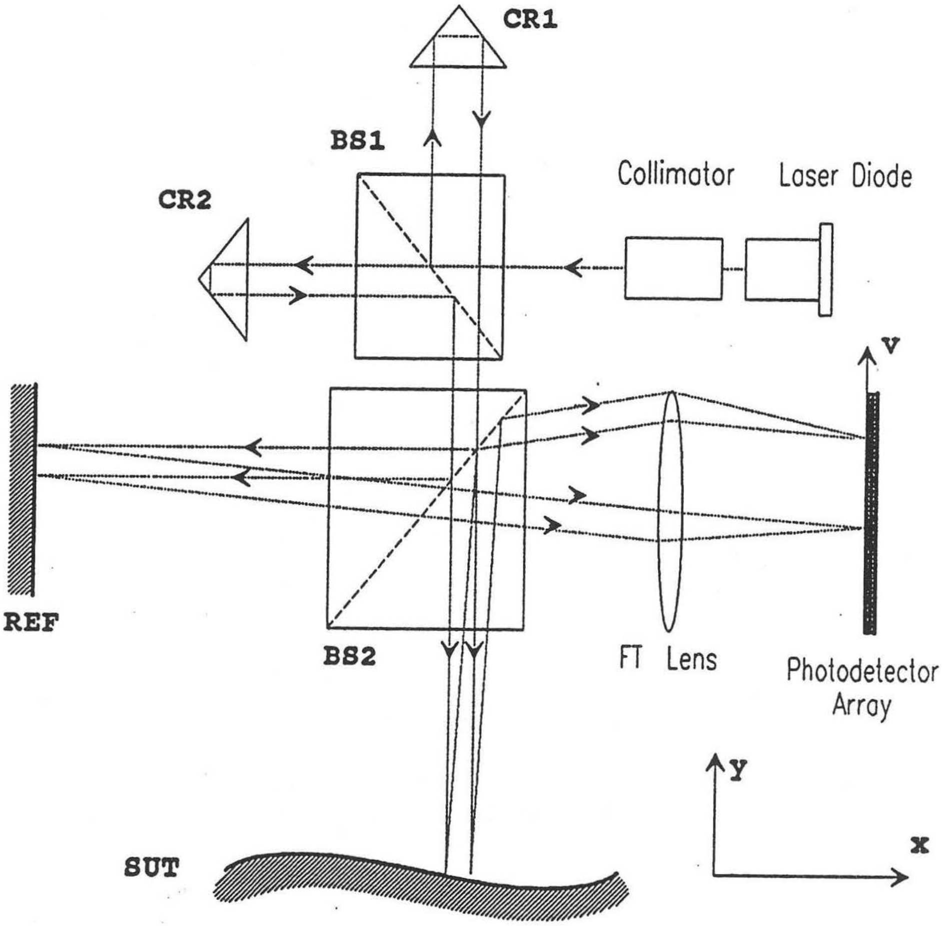


Figure 29. Schematic of long trace profiler used to measure surface figure of ALS optics.

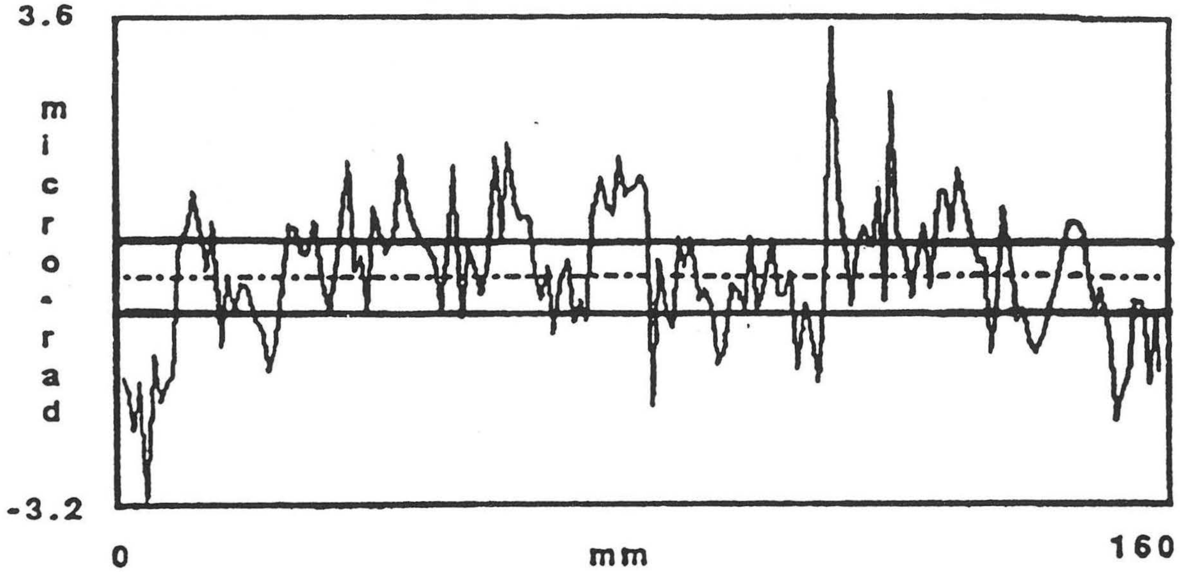
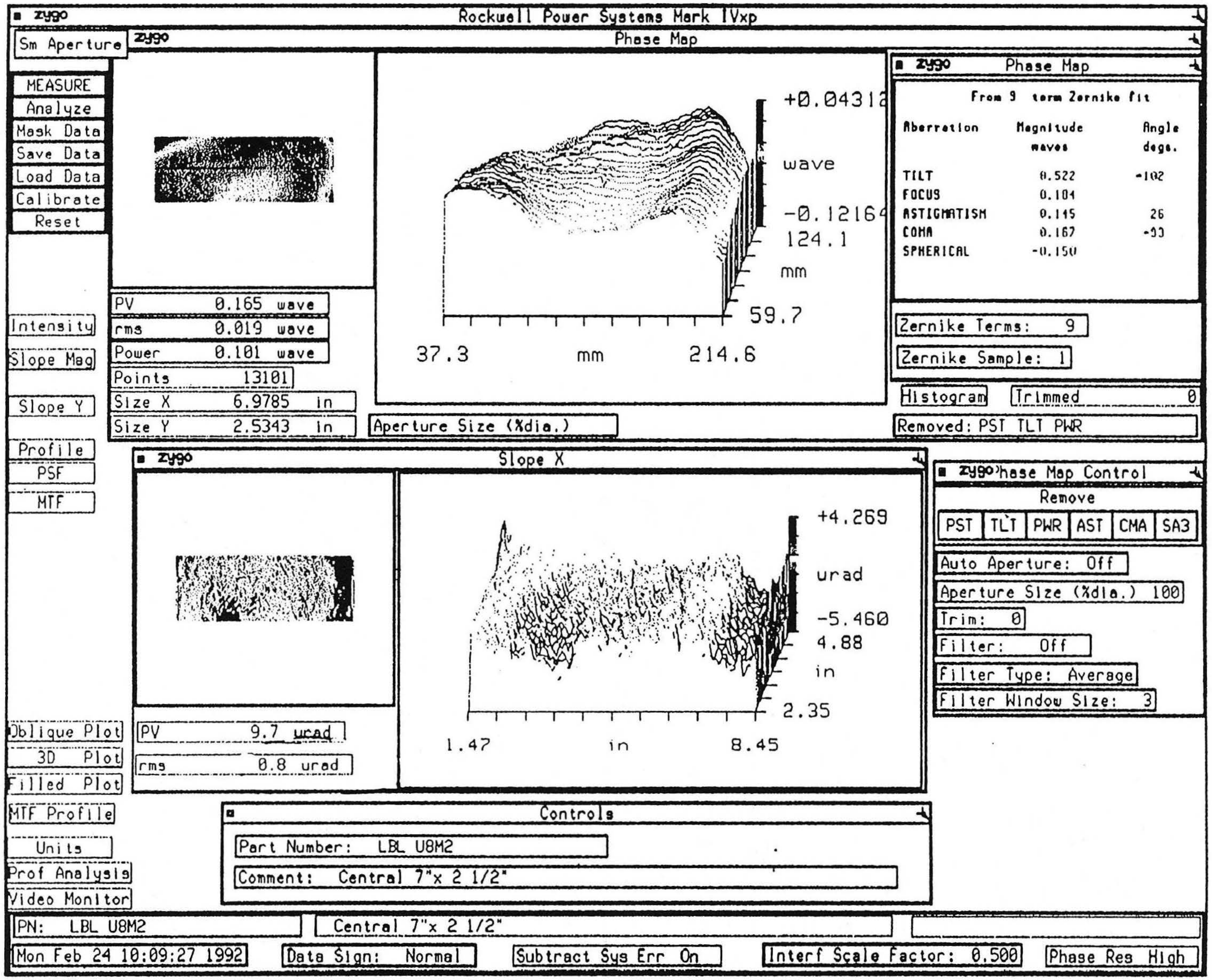


Figure 30. Results of figure measurements made by long trace profiler on a 18-cm-long, nickel-plated, spherical monochromator grating blank. The slope error of 1.0 μrad rms is due to the shape of the mirror and random errors in the measurement.



PV 0.165 wave
rms 0.019 wave
Power 0.101 wave
Points 13101
Size X 6.9785 in
Size Y 2.5343 in
Aperture Size (%dia.)

Phase Map

From 9 term Zernike fit

Aberration	Magnitude waves	Angle degs.
TILT	0.522	-102
FOCUS	0.104	
ASTIGMATISM	0.145	26
COMA	0.167	-93
SPHERICAL	-0.150	

Zernike Terms: 9
Zernike Sample: 1
Trimmed 0
Removed: PST TLT PWR

Slope X
PV 9.7 urad
rms 0.8 urad

Auto Aperture: Off
Aperture Size (%dia.) 100
Trim: 0
Filter: Off
Filter Type: Average
Filter Window Size: 3

Part Number: LBL U8M2
Comment: Central 7"x 2 1/2"

PN: LBL U8M2
Central 7"x 2 1/2"
Mon Feb 24 10:09:27 1992
Data Sign: Normal
Subtract Sys Err On
Interf Scale Factor: 0.500
Phase Res High

Figure 31. Results of measuring the surface figure of a beamline mirror. The rms slope error of 0.8 µrad met the ALS specification.

Planning for Users and User Services

A.S. Schlachter
Scientific Program Coordinator
Lawrence Berkeley Laboratory
Berkeley, CA 94720

My talk will cover topics that may seem a little mundane after all of the high tech you have just heard; but I think you will understand that these topics are very important: space, parking, user safety, and the user interface with the Laboratory.

Yesterday, the Users' Executive Committee (UEC) held a meeting, and I am going to give you a summary of the items we discussed. But before I start, I want to describe a little archeological work that we have done. Jay Marx showed you some pictures that went back to about 1940, but synchrotron radiation facilities may have been around long before that. On a recent trip to Rome, Brian Kincaid and I discovered what appears to be an ancient synchrotron radiation site (see Figure 1). Our best understanding is that the power supplies were in the center and that the injection came through the tunnel to the rear.

Strange as it may seem, the ALS project was planned and built without funds for user facilities or user space. If you know Lawrence Berkeley Laboratory (LBL), it may be hard to imagine how we will find space—parking space in particular—on the site. The difficulty is almost on the scale of achieving 2-Å surface roughness on optics, although maybe not quite as daunting technologically. If you disobeyed our instructions to take a shuttle and tried to drive here this morning, you learned how difficult it is to find a parking space. When we need space here, we can't just send in a bulldozer to level a few acres; we have to tear down existing buildings. So space is an extremely difficult issue.

We have developed a rather comprehensive plan for user services and, in doing so, tried to think of everything users might need. "User friendly" is such a cliché, but we are actually trying to achieve a

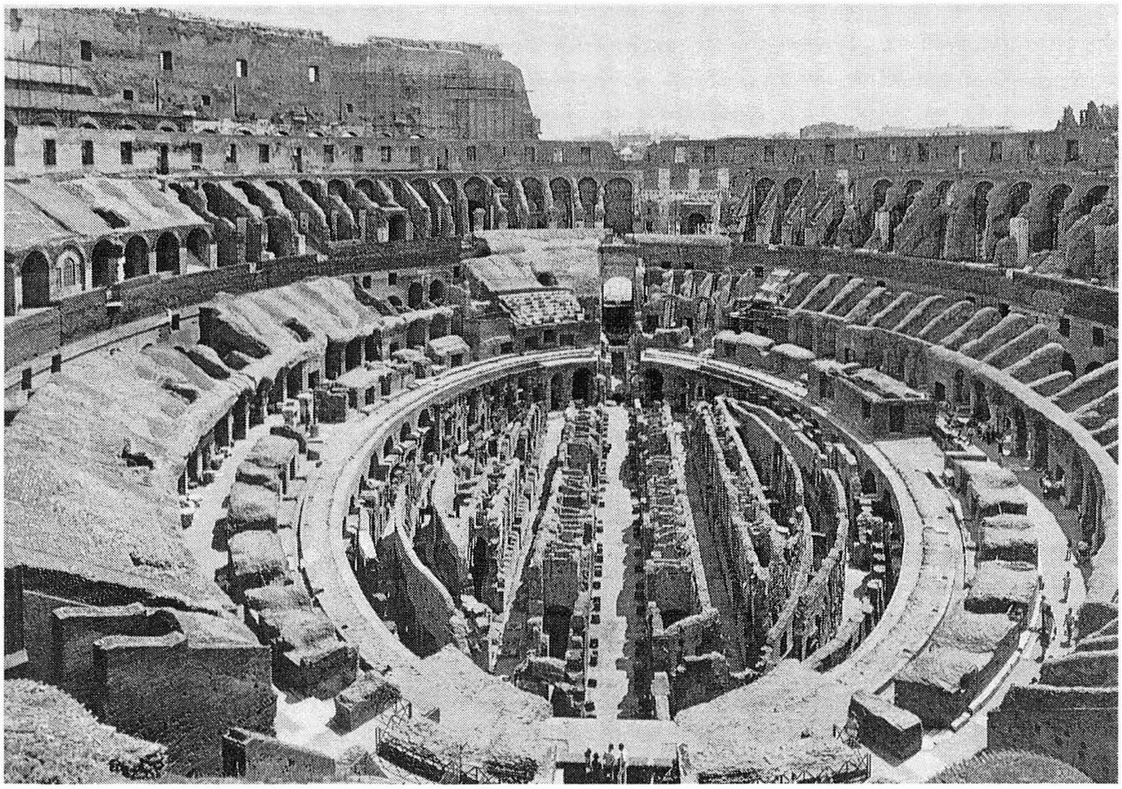


Figure 1. Ancient synchrotron radiation site was discovered in Rome.

user friendly facility. When I think about what *user friendly* means to me, the term would describe the service one receives in dealing with a competent airline. Someone has actually thought about the user interface, and when you call for reservations, the system works. You show up, get your tickets, and there is a seat for you. You take these things for granted until you fly an incompetent airline on which none of this takes place. Then you realize that the user interface is not so easy.

To us, *user friendly* means that we will provide the services you need to get your work done. We will also try to make it easier to do things right than to do things wrong. Because most people in this room are scientists, you know that if the badge office were closed on a weekend and you were to arrive on Saturday afternoon to do an experiment, you would be determined to get right to work on the experimental floor with or without a badge or training. You might be tempted just to go ahead and do it, if you could. Well, in the modern regulatory climate, we couldn't allow that. Therefore, we must have ways to accommodate you regardless of your arrival time. To do that requires money and staff; however, we are optimistic that we will be able to provide the staff and service required to make this happen.

We are doing a great deal of planning and coordination with user representatives. We meet with the UEC every three months, and over the years they have told us what they want us to do. I'll try to give you an idea of some of the things we have done to date.

Our first task was to talk with LBL management. We emphasized that there are differences between operating a light source and operating other kinds of user facilities that we have had at LBL—the Bevatron, the 88-Inch Cyclotron, the Electron Microscope, and so on. These differences stem from the fact that, at the ALS, users will be working in parallel rather than in series because every beamline gets photons at the same time. Consequently, the Laboratory will have more users on site at one time than ever before. Eventually, we expect to have as many as 100 users on site at any moment.

We discussed user needs with LBL management, for example, how users can take advantage of services available to LBL employees. LBL has many marvelous services—for example, shops, rigging, libraries, and so on—but coordination is necessary to make them accessible to users. Another issue is the standardization of databases. When you come to work at the ALS, a well designed database system is important so that you will not have to fill out numerous forms, all requesting the same information. Also, user training , which is required by the DOE, should be standardized, and training records should be integrated in a centralized system. Other issues we have been addressing are user parking, space and funds for user offices and labs, improving the LBL shuttle service, and streamlining accounting procedures for user accounts.

What we are aiming for is one-stop shopping—to organize things so that ALS users can check in at one location, take care of all administrative and regulatory requirements at the same location, and go right to work. The evidence that this is actually taking place can be seen as you drive into the Main Gate of LBL. The first building on the left beyond the guard gate is Building 65, which is now being converted to a visitors' center, and for which Fred Lothrop is responsible. The center will centralize many of the services that were previously scattered around the hill. You go in one door, you come out the other, and you have "User" stamped on your forehead, or a "user credit card" in your pocket, or whatever it takes to make you an official participating guest at the Laboratory.

As for the ALS organization, we will try to make our operations transparent to you. A user-support manager will be hired to serve as a single point of contact. It will be his/her responsibility to make the remainder of the infrastructure accessible.

I'd like to say a word about space. The following list was given to us in November 1991 by the UEC. It is a list of the facilities that they believe to be most necessary when the ALS begins operations, in order of priority:

Facilities Requested for ALS Users, 11/91

1. Cleaning room*
   Two fume hoods
   Storage area for solvents
   Storage area for acids
   Full wet chemistry lab facilities (water, air, etc.)

2. Vacuum assembly room*
   Two to three laminar flow benches running constantly
   Stereo microscope
   Spot welders
3. Gas storage and handling facility*
   Manifold for transferring gases under clean conditions
   Storage area for corrosive and flammable gases
4. Dust-free optical assembly area*
5. 3- × 3-meter or 3- × 6-meter area for handling biological samples
6. Access to office equipment such as copy machines (24 hours), fax, phone, and PCs or Macintoshes; computer access to networks*
7. Photographic darkroom*

The asterisk after an item on the list means that it will be ready when we begin operations. We are very pleased that LBL management has provided both the space and the money to build these facilities. Figure 2 is a sketch of this space, which is now being refurbished based on the desires expressed by the committee.

Before the refurbishing began, it looked a little bit more like Figure 3. This is the "before" picture. For the connoisseurs, this is actually Roentgen's laboratory in 1923. It reflects the state of the art in an x ray laboratory shortly after the turn of the century (just after x rays were discovered). The next time I talk to you, I'll have an "after" picture that will show the lab space now under construction, and I think it will meet your needs.

Figure 4 is a map that will give you some idea where user facilities will be located relative to the ALS (Building 6). We have some space for user facilities in Buildings 10 and 80, which adjoin the ALS

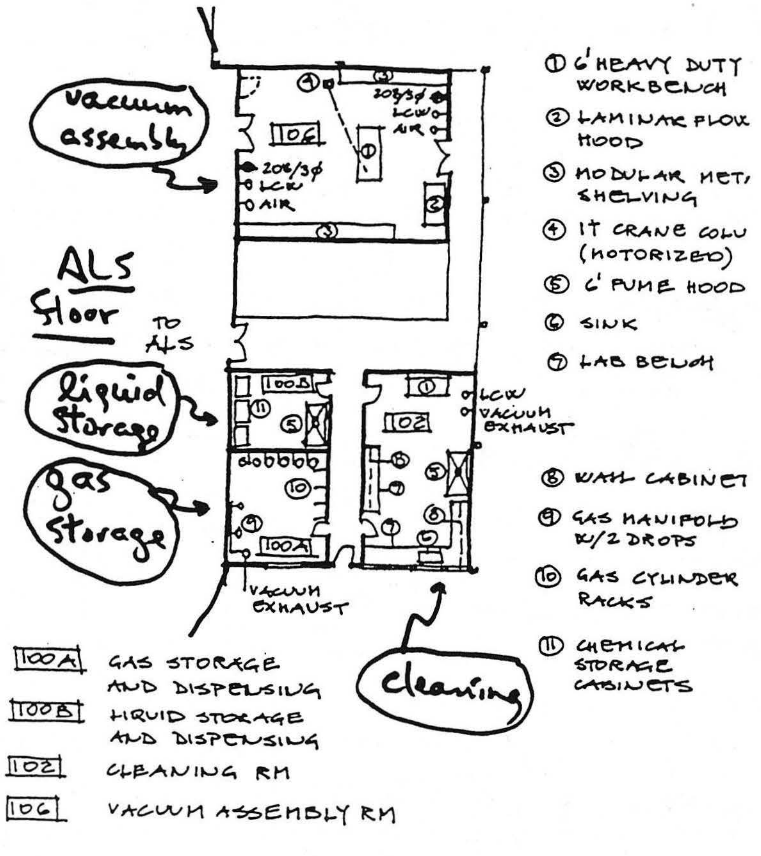


Figure 2. Space in Building 10 is now being refurbished for user facilities.

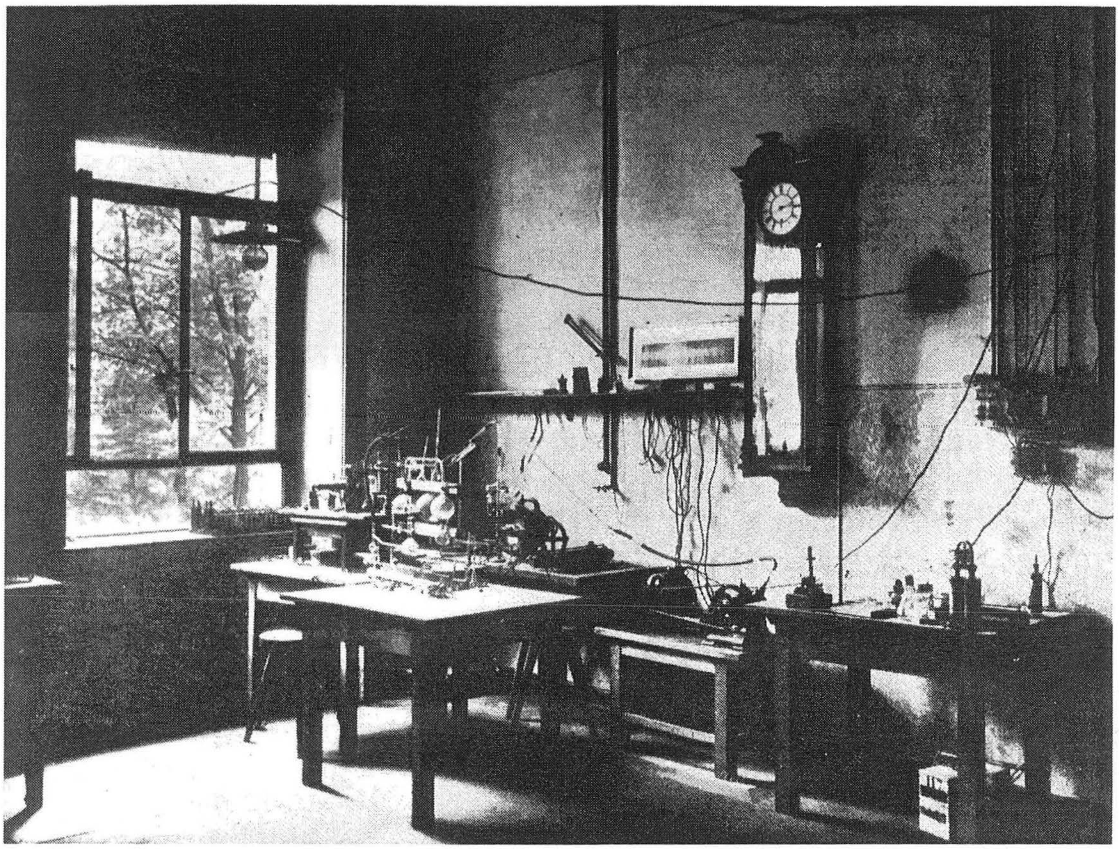


Figure 3. Laboratory used in 1923 by Roentgen, who discovered x rays.

building. We also will have space not far away in Building 53. In addition to the cleaning room, vacuum assembly room, and facilities for storing and handling gases and liquids, we will have user offices, an optical assembly area, a dark room, and a shop. Building 53 will house a library, offices, or perhaps an assembly area. This has not yet been decided.

- **Offices (B10)**
- **Cleaning room and wet chemistry (B10)**
- **Vacuum assembly area (B10)**
- **Storage area for gases and liquids (B10)**
- **Optical assembly area (share with ALS staff)**
- **Dark room**
- **Shop (B53 or B16?)**
- **Library, offices, . . . (B53)??**

Figure 4. User facilities will be located near Building 6, which houses the ALS.

Among the services that the visitors' center will offer is a housing referral service. Although this service will not make housing more available, it will give users a way of accessing what there is.

Parking, on the other hand, is a more serious problem. (Incidentally, the ALS is not the only light source with a parking problem. Figure 5 shows one of our sister facilities where the cars are parked about three deep.) What is LBL doing about parking? Figure 6 is an article from Currents, LBL's weekly employee newspaper. It says, "Frustration long shared by LBL employees —lack of adequate parking." It would be nice to read further and find out that LBL is building a parking structure to house another thousand cars, but that is not what the article says. We don't have the money for that. What we are really doing is limiting the number of cars by reducing the number of parking permits issued. However, participating guests (i.e., ALS users) will be eligible to receive parking permits, and more spaces will be available. Furthermore, it appears that the Lab will dedicate 11 parking spaces to the ALS. This might not sound like a lot if you come from Argonne or Brookhaven, but here this is truly a miracle—almost as good as 2 Å. Of these 11 parking spaces immediately adjacent to Building 6 (see Figure 7), six will be assigned to the first six PRT leaders. The other five will be assignable by the users' office.

I want to cover one other topic very briefly today, and that is user safety. Paul Johnson, who is the ALS safety officer, and I have been working together for more than a year on how we will obey the DOE's rules about safety and how we will communicate the requirements to users who might come from facilities where the rules are different. Figure 8 is a cartoon from another laboratory. It is our business to keep this kind of thing from happening. Paul and I have visited various laboratories, and I'll show you some photographs of cases that we'd rather not have here.

One of my favorites is the power supply on a chair (Figure 9). When I went to take this picture, the leads from this power supply (the high voltage output) were going to a couple of terminals on which were taped a paper sign that said, "Danger, High Voltage." When the users of this apparatus saw me coming with a camera, they didn't disconnect anything. They simply took off the sign.

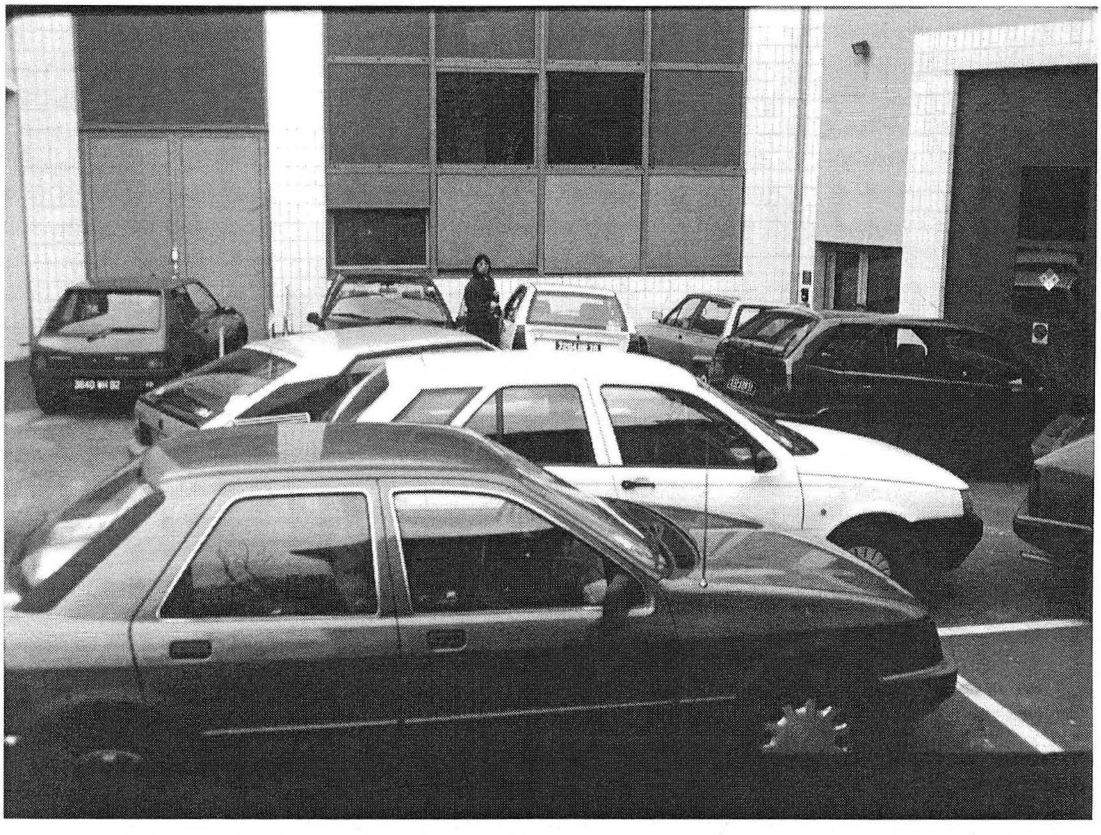
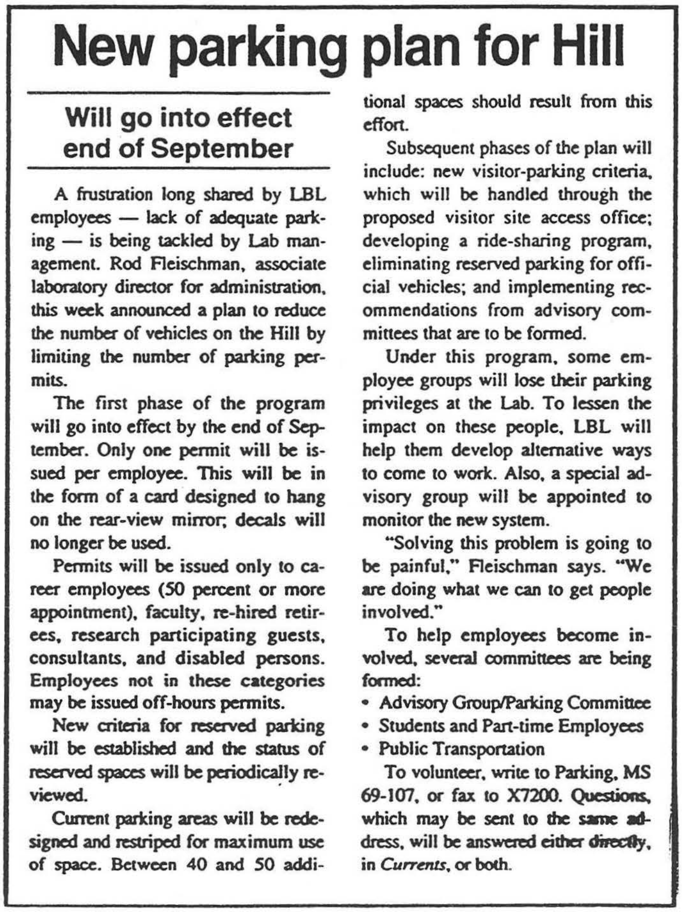


Figure 5. Cars are parked about three deep at a sister synchrotron-radiation facility.



New parking plan for Hill

Will go into effect end of September

A frustration long shared by LBL employees — lack of adequate parking — is being tackled by Lab management. Rod Fleischman, associate laboratory director for administration, this week announced a plan to reduce the number of vehicles on the Hill by limiting the number of parking permits.

The first phase of the program will go into effect by the end of September. Only one permit will be issued per employee. This will be in the form of a card designed to hang on the rear-view mirror; decals will no longer be used.

Permits will be issued only to career employees (50 percent or more appointment), faculty, re-hired retirees, research participating guests, consultants, and disabled persons. Employees not in these categories may be issued off-hours permits.

New criteria for reserved parking will be established and the status of reserved spaces will be periodically reviewed.

Current parking areas will be redesigned and restriped for maximum use of space. Between 40 and 50 additional spaces should result from this effort.

Subsequent phases of the plan will include: new visitor-parking criteria, which will be handled through the proposed visitor site access office; developing a ride-sharing program, eliminating reserved parking for official vehicles; and implementing recommendations from advisory committees that are to be formed.

Under this program, some employee groups will lose their parking privileges at the Lab. To lessen the impact on these people, LBL will help them develop alternative ways to come to work. Also, a special advisory group will be appointed to monitor the new system.

"Solving this problem is going to be painful," Fleischman says. "We are doing what we can to get people involved."

To help employees become involved, several committees are being formed:

- Advisory Group/Parking Committee
- Students and Part-time Employees
- Public Transportation

To volunteer, write to Parking, MS 69-107, or fax to X7200. Questions, which may be sent to the same address, will be answered either directly, in *Currents*, or both.

Figure 6. Article on LBL parking plan from Currents, the LBL employee newspaper.

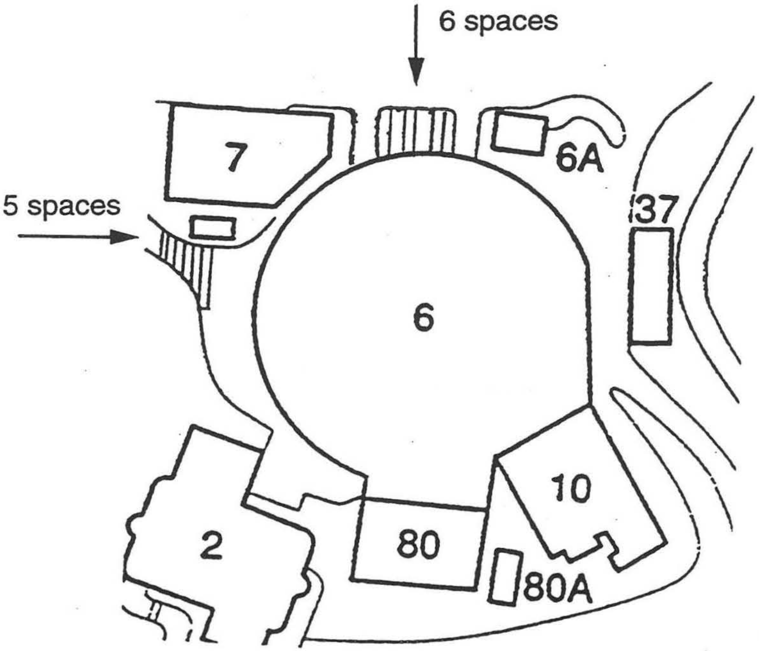


Figure 7. Eleven reservable parking spaces will be available alongside the ALS.

Figure 8. At the ALS, we are making every effort to avoid occurrences like this.

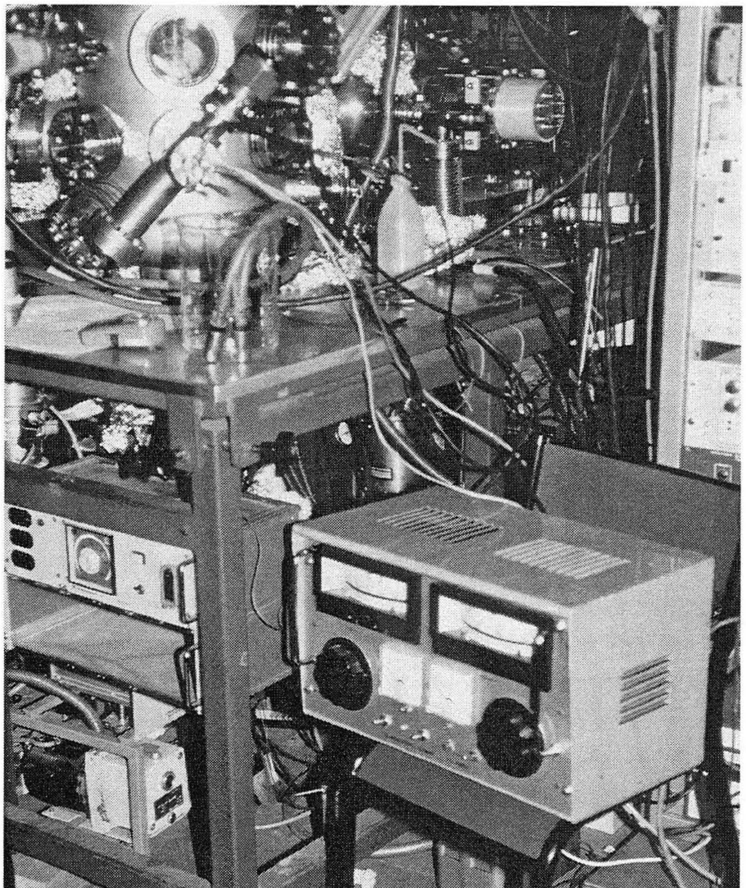


Figure 9. A power supply on a chair, photographed at another synchrotron radiation facility, is a sight you will not see at the ALS.

Figure 10 shows another case that I would rather not see at the ALS. My hand is in the photograph, which also shows a number of 110-volt terminals. If you happened to have one hand resting on anything that is grounded and you put your other hand here, you would have a disagreeable and potentially fatal surprise.

Paul and I have written a user safety plan that we hope will prevent problems from arising. We are trying to come up with mechanisms that make things safe and not rely on platoons of police who go around telling you what you can't do. The plan arose from a user safety workshop that Paul and Dennis Lindle organized last fall. Again, we consulted with the users to come up with a plan that is workable and user friendly.

Let me give you a preview of one aspect of the plan. Figure 11 shows the ALS Experimental Safety Form, which is based in part on the kinds of forms that other laboratories use. It is also based in part on our experience with our favorite bureaucracy, the Internal Revenue Service. I originally called this "Form 1040." The resemblance to the income tax form is due to a series of "schedules" (see Figure 12) that users fill out only if applicable. Users bringing hazardous materials to the ALS fill out Schedule A; those bringing lasers fill out Schedule C, and so on. The need to fill out a schedule for "top-heavy/unstable equipment" might not be obvious if you come from a more stable part of the country, but here we have seismic safety criteria. If you bring a huge device that sits up in the air on a couple of spindly legs, our engineers will run it through a Richter 7 and tell you whether it passes or fails—before it falls over on someone during a real earthquake. All of this plan is designed to help you to get your experiments approved and get on the ALS floor safely.

There are many other aspects to our interaction with users. I'll just mention a few here. We have a newsletter that is published periodically. It was scheduled to be issued in time for this meeting except that it was delayed to include news of the impending management change. It will be in your mailboxes

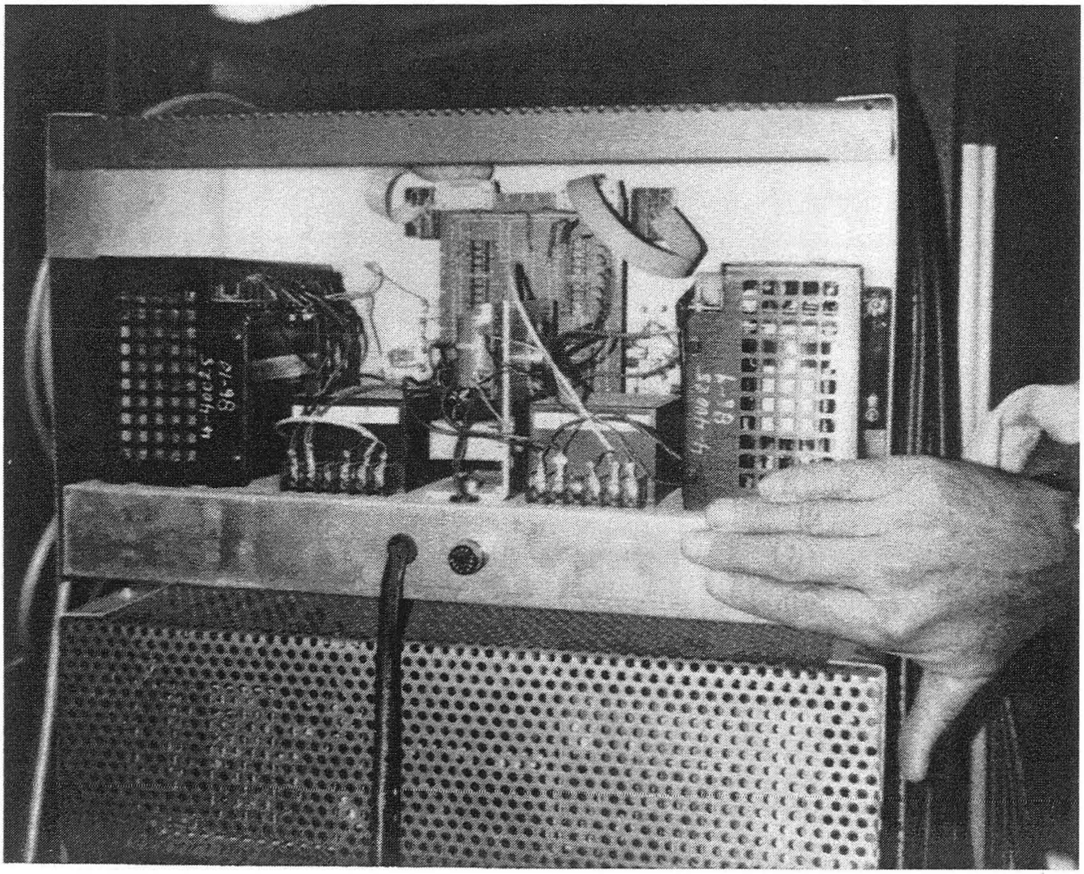
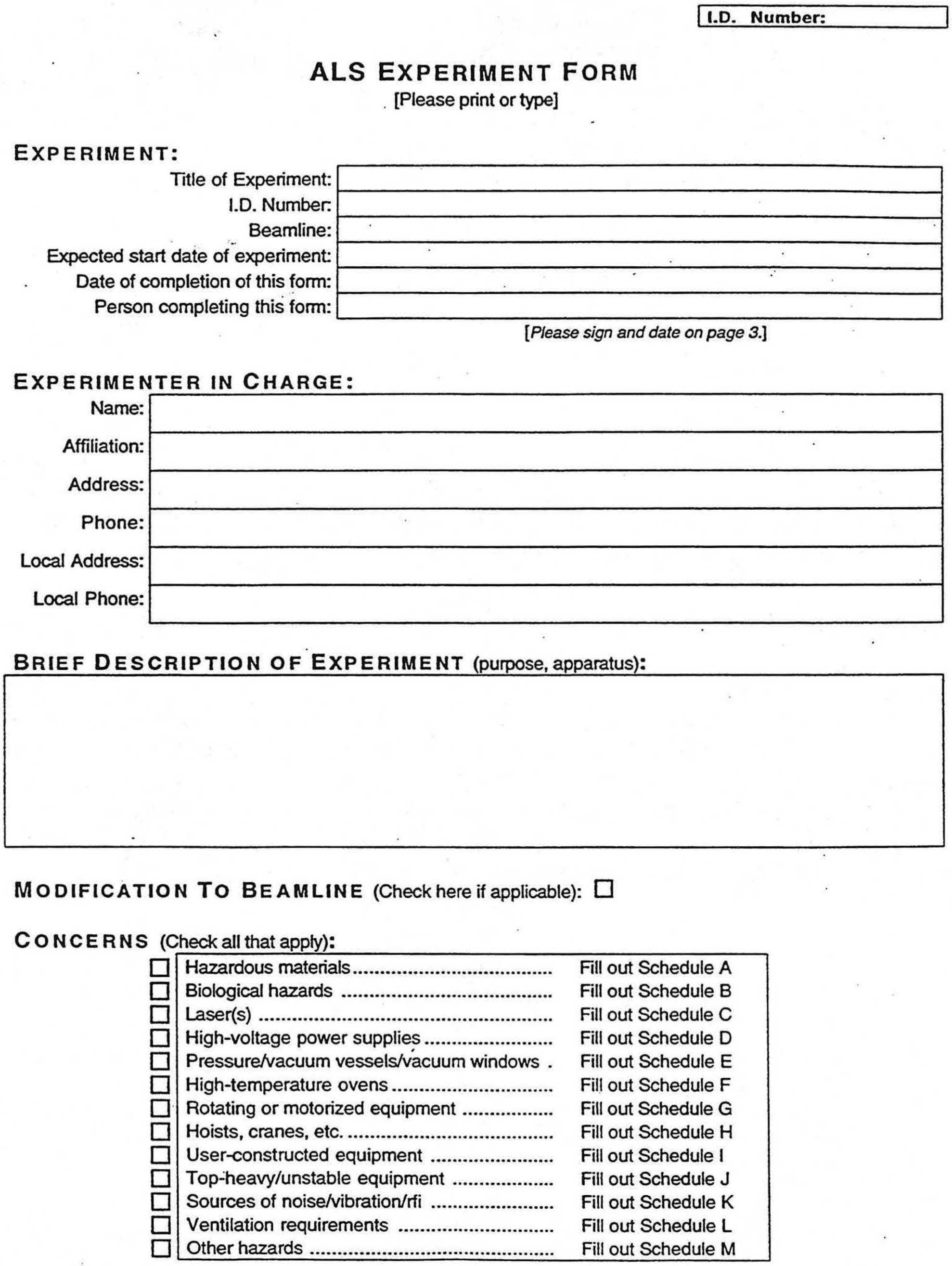


Figure 10. The hand in the photograph is resting on a piece of equipment, which contains a number of 110-volt terminals—a potentially hazardous situation that we wish to avoid at the ALS.



I.D. Number:

ALS EXPERIMENT FORM

[Please print or type]

EXPERIMENT:

Title of Experiment:

I.D. Number:

Beamline:

Expected start date of experiment:

Date of completion of this form:

Person completing this form:

[Please sign and date on page 3.]

EXPERIMENTER IN CHARGE:

Name:

Affiliation:

Address:

Phone:

Local Address:

Local Phone:

BRIEF DESCRIPTION OF EXPERIMENT (purpose, apparatus):

MODIFICATION TO BEAMLINE (Check here if applicable): ☐

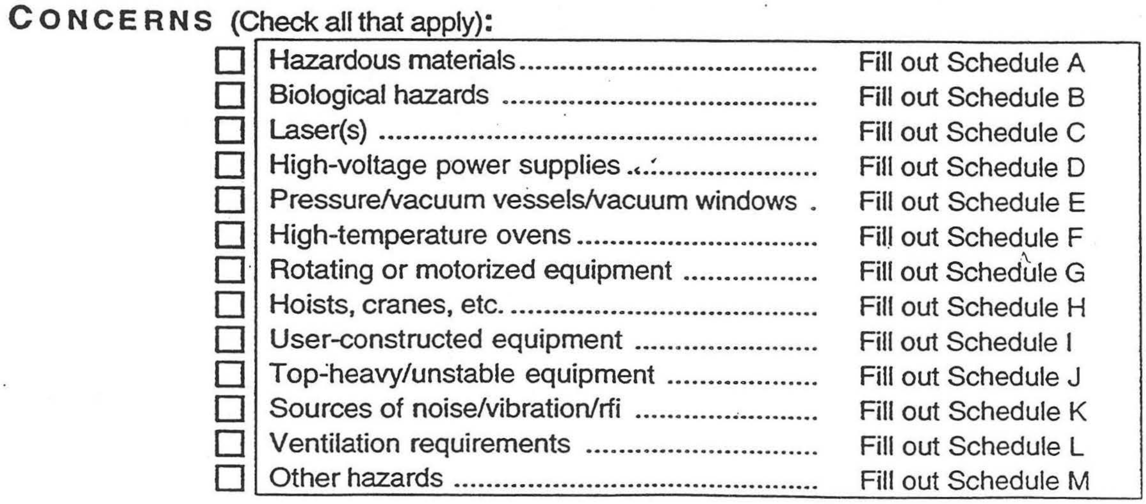
CONCERNS (Check all that apply):

☐	Hazardous materials	Fill out Schedule A
☐	Biological hazards	Fill out Schedule B
☐	Laser(s)	Fill out Schedule C
☐	High-voltage power supplies	Fill out Schedule D
☐	Pressure/vacuum vessels/vacuum windows	Fill out Schedule E
☐	High-temperature ovens	Fill out Schedule F
☐	Rotating or motorized equipment	Fill out Schedule G
☐	Hoists, cranes, etc.	Fill out Schedule H
☐	User-constructed equipment	Fill out Schedule I
☐	Top-heavy/unstable equipment	Fill out Schedule J
☐	Sources of noise/vibration/rfi	Fill out Schedule K
☐	Ventilation requirements	Fill out Schedule L
☐	Other hazards	Fill out Schedule M

Figure 11. Users will fill out this form for each experiment conducted at the ALS.

in a month or two. A new, very informative brochure about the ALS is being written. A user guide similar to the NSLS Guide to the Users Floor will be written. A guide to ALS beamlines for independent investigators has just been published.

I want to mention two committees closely associated with the ALS user program. The first is the Program Review Panel (PRP), which reviews proposals. Three new members are in the audience today—Chuck Fadley, Christoph Kunz, and François Wuilleumier. The PRP last met on February 8th and will meet again this Saturday, August 29. Those of you who have written new proposals have already heard from the PRP and will attend the meeting. The second committee is the UEC (mentioned earlier), which



CONCERNS (Check all that apply):

☐	Hazardous materials	Fill out Schedule A
☐	Biological hazards	Fill out Schedule B
☐	Laser(s)	Fill out Schedule C
☐	High-voltage power supplies	Fill out Schedule D
☐	Pressure/vacuum vessels/vacuum windows	Fill out Schedule E
☐	High-temperature ovens	Fill out Schedule F
☐	Rotating or motorized equipment	Fill out Schedule G
☐	Hoists, cranes, etc.	Fill out Schedule H
☐	User-constructed equipment	Fill out Schedule I
☐	Top-heavy/unstable equipment	Fill out Schedule J
☐	Sources of noise/vibration/rfi	Fill out Schedule K
☐	Ventilation requirements	Fill out Schedule L
☐	Other hazards	Fill out Schedule M

Figure 12. Users will check the hazard categories that potentially apply to an experiment and enter information on the corresponding forms, called "schedules."

meets every three months. Yesterday, the UEC conducted a review of the ALS user program. The committee also sponsors the Annual Users' Meeting.

In keeping with my role of managing user amenities, let me remind you that lunch is included in the registration fee. In order to encourage you to take the self-guided ALS tour, lunch will be served at the ALS building. A dinner will be held this evening at the Hong Kong East Ocean Restaurant, the restaurant where last year's dinner was held. The price is included in your admission, and you were given a ticket. Tomorrow's lunch is also included in the registration fee. To get your lunch tomorrow, you will have to go to Buildings 70 and 70A where we will have an industrial exhibit of vendor products related to synchrotron facilities. Be sure to go and look at the products on display.

Welcome to the ALS.

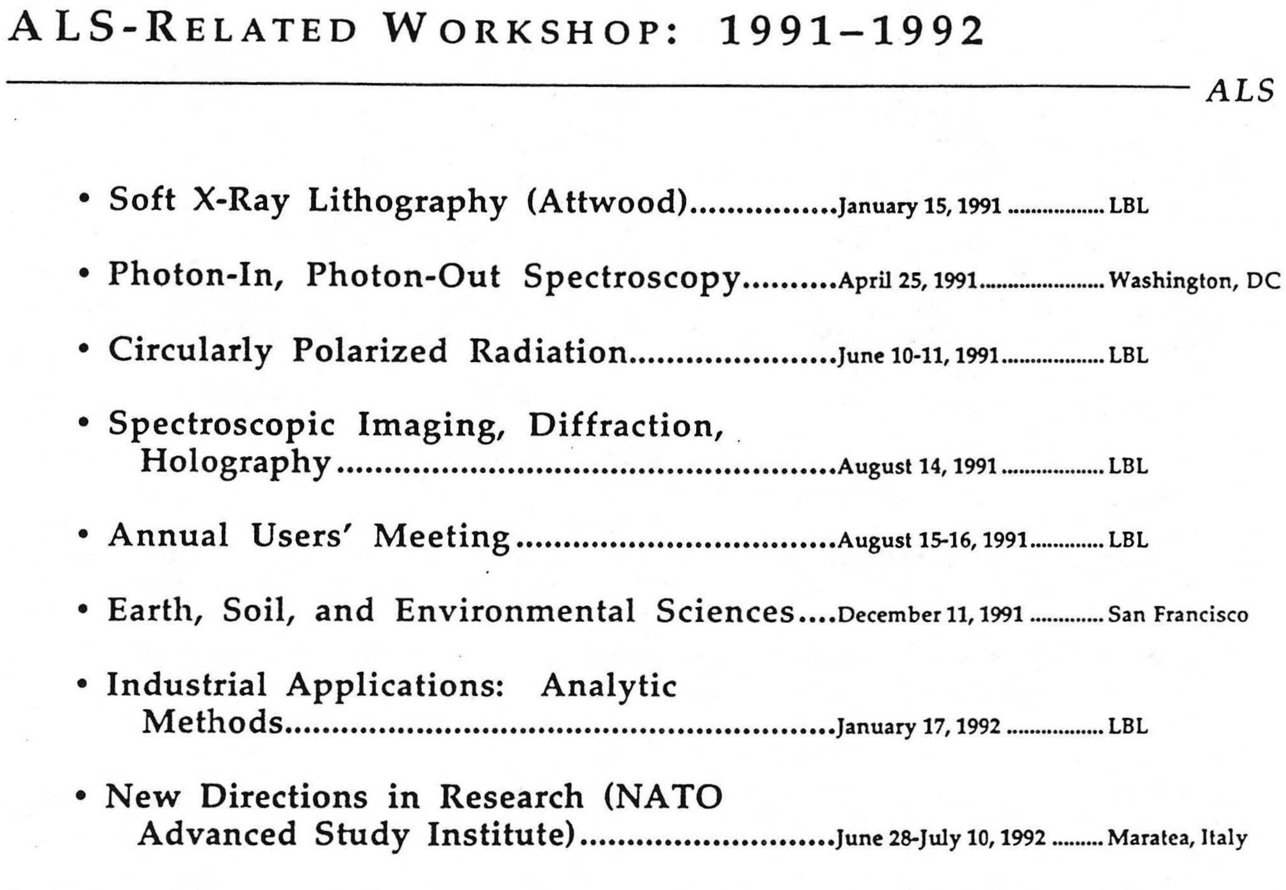
ALS Scientific Program

Philip N. Ross
Acting Scientific Director, Advanced Light Source
Lawrence Berkeley Laboratory
Berkeley, CA 94720

I am going to speak about the beamlines that we will have available for you to use during the first two years of ALS operations and about how you can come here to do science—to create the ALS scientific program. Many researchers who come will work as members of a participating research team (PRT), but many of you who want to work at the ALS are not members of PRTs, and I will talk today about opportunities for you as well.

Several of our PRTs originated at workshops organized to bring together potential ALS users who have interests in common; thus, workshops have played a very important role in developing PRTs for the initial scientific program at the ALS. Figure 1 lists some workshops that I want to call to your attention.

The X-ray Lithography Workshop, held at LBL approximately a year ago, led to the formation of a new PRT on x-ray lithography and an undulator beamline that we hope will be ready in 1995. Another important workshop, entitled "Putting Synchrotron Radiation to Work for Technology: Analytic Methods," was organized by Jo Stöhr (IBM–Almaden) and Fred Schlachter (LBL) and held here last January. Its purpose was to stimulate interest from industry in becoming involved with the ALS. Although we have received some critical questions from the DOE about the lack of industry participation, there was a very strong turnout for this workshop and a great deal of interest by industry in ultra-ESCA



ALS-RELATED WORKSHOP: 1991–1992

ALS

• Soft X-Ray Lithography (Attwood)	January 15, 1991	LBL
• Photon-In, Photon-Out Spectroscopy	April 25, 1991	Washington, DC
• Circularly Polarized Radiation	June 10-11, 1991	LBL
• Spectroscopic Imaging, Diffraction, Holography	August 14, 1991	LBL
• Annual Users' Meeting	August 15-16, 1991	LBL
• Earth, Soil, and Environmental Sciences	December 11, 1991	San Francisco
• Industrial Applications: Analytic Methods	January 17, 1992	LBL
• New Directions in Research (NATO Advanced Study Institute)	June 28-July 10, 1992	Maratea, Italy

Figure 1. Workshops organized to present information about conducting research at the ALS.

(electron spectroscopy for chemical analysis). A couple of end stations for ultra-ESCA are being developed for the ALS, one by Brian Tonner (University of Wisconsin).

I would also like to call your attention to a workshop on Synchrotron Radiation in Transactinium Research to be held at LBL on October 1–2. Its purpose is to examine the scientific program that might evolve around an actinide end station on the ALS 8-cm-period undulator (U8) beamline. This would be the first of its kind—the only "hot" end station at a synchrotron in the United States. The scientific interest in this is not only associated with the chemistry of actinides for environmental restoration and waste management, but it is also directed toward heavy fermion physics because most heavy fermion systems involve actinide elements; therefore, participants will hear about some very interesting condensed-matter physics.

A number of you attended the NATO Advanced Study Institute "New Directions in Research with Third-Generation Soft X-Ray Synchrotron Radiation Sources," in Maratea, Italy. This two-week summer school, held last June and July, was directed by Fred Schlachter. The proceedings of all of these workshops can be obtained by contacting Fred Schlachter's office here at LBL.

What I especially want to talk about today is the ALS Independent Investigator Program. When I looked at the registration list for this meeting, I saw that approximately half of the registrants are associated with PRTs and the other half are not. Presumably, those of you in the latter category are interested in doing research at the ALS in the next couple of years as independent investigators; that is, your work would be conducted independently of a PRT.

There are two types of independent investigators: those who would bring an end station from another synchrotron facility and those who choose not to bring one, but would like to do science here nonetheless. All of you should have received a letter from me in the last week—a call for letters of interest—sent for the purpose of sampling this community to learn how many independent investigators want to come to work on the first complement of beamlines in 1994. Following this initial call for letters, we will issue a call for proposals.

To assist independent investigators in submitting letters of interest and proposals, we have two resource documents. One is the ALS design document that describes the undulators and their beam characteristics. The other is a handbook, which we just produced, thanks to Gloria Lawler on Fred Schlachter's staff and members of the ALS Experimental Systems Group, Phil Heimann, Tony Warwick, Zahid Hussain, and Rupert Perera. This latter publication, entitled *ALS Beamlines for Independent Investigators*, describes the beamlines that will be available to independent investigators in the first few years of ALS operations.

Of the 10 beamlines expected to be in operation by 1995, four will be available to independent investigators: Beamline 7.0, which will be equipped with a spherical grating monochromator (SGM) and deliver photons from a 5-cm-period undulator; Beamline 9.0, another SGM beamline delivering photons from an 8-centimeter-period undulator; and two bending-magnet beamlines, one with an SGM and one with a double-crystal monochromator. Three of these beamlines—Beamline 7.0, Beamline 9.0, and the bending-magnet beamline with the SGM—we hope will be available to independent investigators in the fall of 1993.

If you would prefer to join a PRT, there is still time, or you can submit a letter of interest and a proposal for research as an independent investigator.

When you toured the ALS, you were not able to see where the end stations are going to be located. Figure 2, which shows the floor layout at the end of Beamline 7.0 (the U5 Beamline), gives you some idea. The refocusing optics can direct focused beam to several end stations. The circle at 30 meters from the source represents a permanently mounted end station, built by Brian Tonner, spokesperson for the PRT associated with this beamline. Presumably, this end station will be dedicated to small-spot ESCA. Another end station will be situated further back (at 31.1 meters from the source). If you were to come here as an independent investigator and bring your own end station to work on Beamline 7.0, this is where you would work. (Tony Warwick of the ALS Experimental Systems Group is the LBL contact for Beamline 7.0.)

Figure 3 shows Beamline 9.0 (the U8 beamline). Again, the beamline has refocusing optics. There are two possible end stations on the straight-through port. The straight-through beam will have a permanently mounted, permanently aligned differential pumping section for gas-phase experiments. It is totally dedicated to gas-phase experiments. The branch line at 30 degrees from the straight-through line

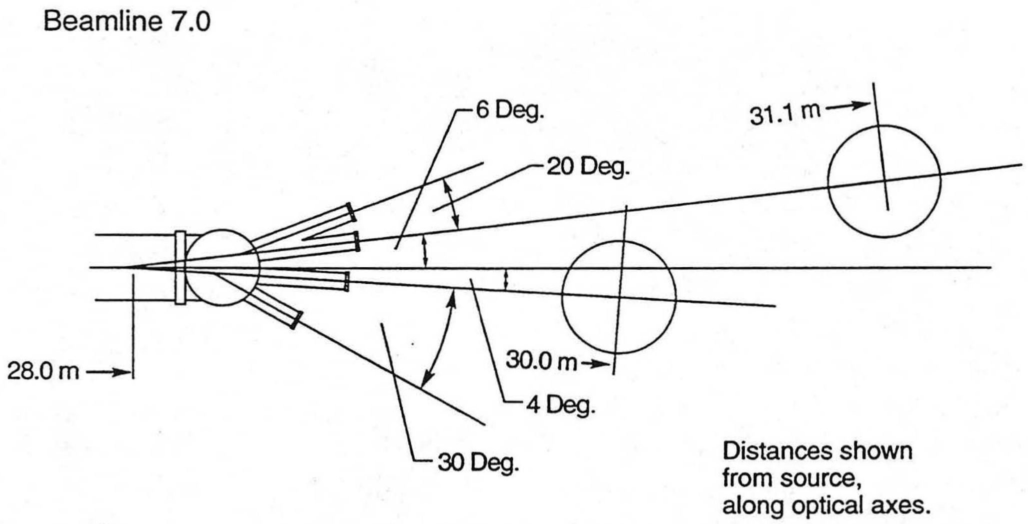


Figure 2. Floor layout of the experimental space at the end of Beamline 7.0.

will be used mostly for solid-state VUV experiments. (For information about conducting experiments on Beamline 9.0, contact Phil Heimann of the ALS Experimental Systems Group.)

A significant number of people have expressed interest in using end stations already installed at the ALS. There is an interest in a state-of-the-art electron spectrometer for doing ESCA. Most of you know Dave Shirley, who has left the University of California and has gone to Penn State. To accommodate his students who were left behind, we have negotiated with the director of the LBL Chemical Sciences Division to convert two of his vacuum chambers to ALS end stations. These are both state-of-the-art electron spectrometers. One we intend for gas-phase studies, and the other for condensed-matter studies. They are not very user-friendly right now; they are very much customized to the Shirley group. They will be made more user-friendly, will be maintained by the ALS staff, and will be available for use on Beamlines 7.0 and 9.0. The gas-phase end station will obviously be used mostly on Beamline 9.0. The condensed-matter, solid-state end station (see Figure 4) can be moved between the beamlines. This is a 6-inch-diameter spectrometer, with a mean radius of about 2 inches. It has a double-Einzel retarding lens and a modern high-speed counting position-sensitive detector. This spectrometer will be available to independent investigators on a proposal basis.

I want to get back to where we are going in terms of the ALS scientific program. What we know right now is that by 1995 we will have five insertion devices and five insertion-device beamlines. Of these

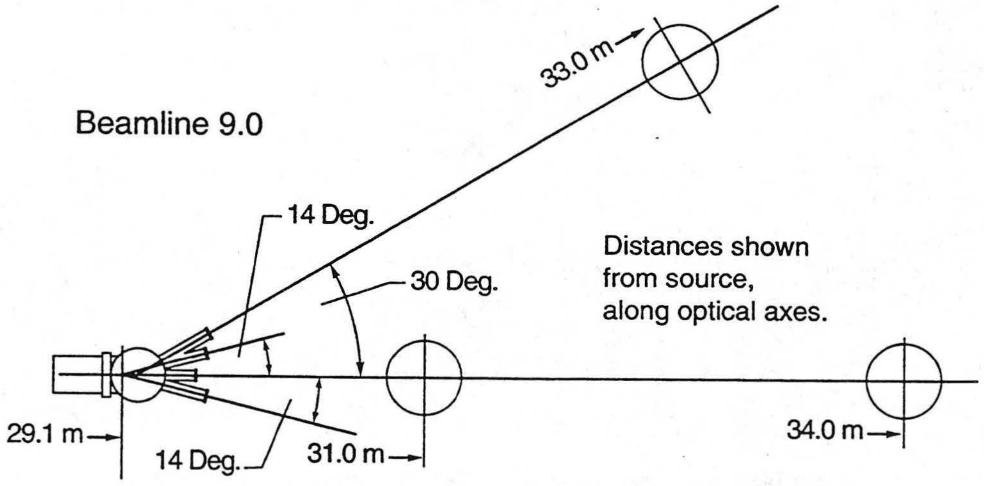


Figure 3. Floor layout of the experimental space at the end of Beamline 9.0.

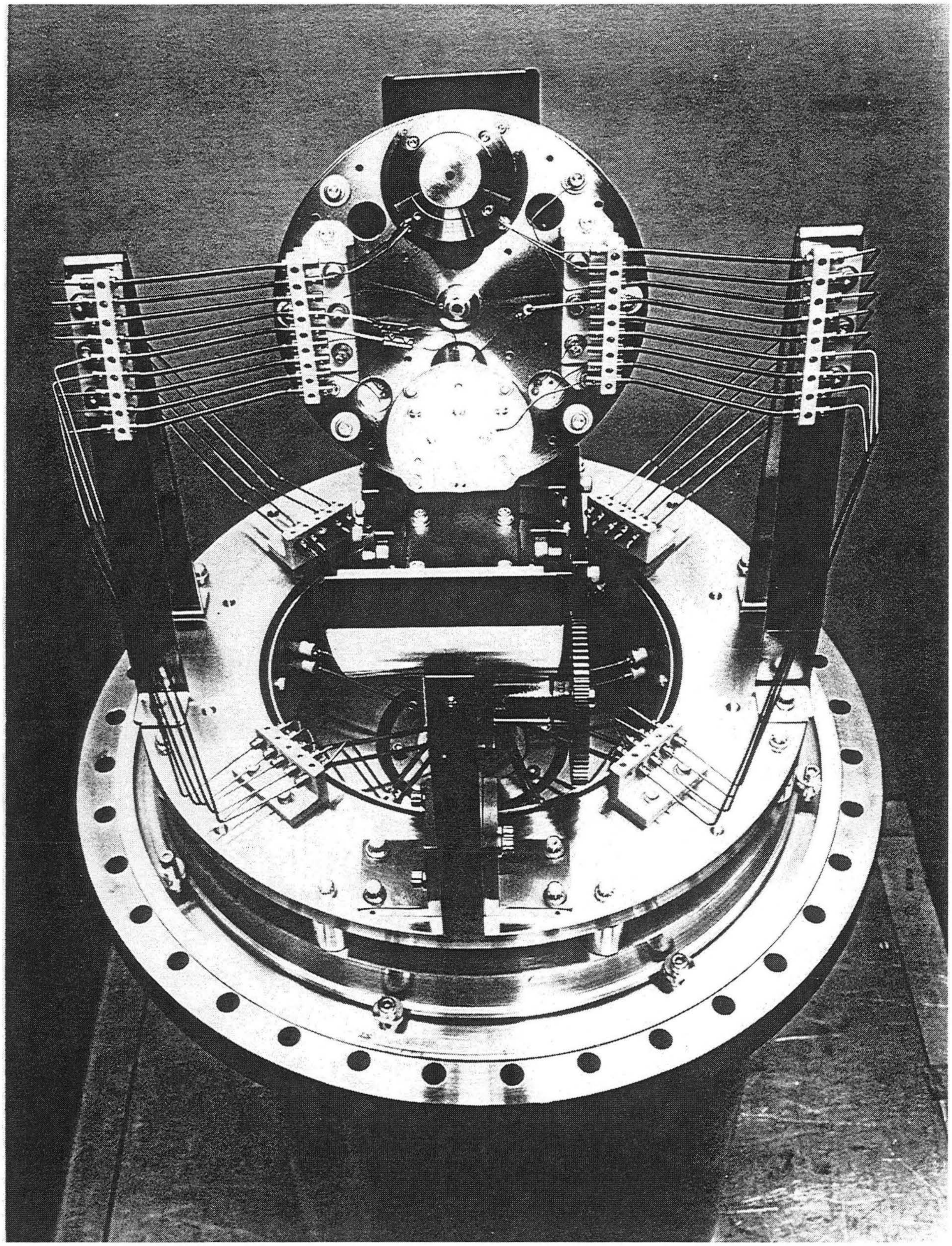


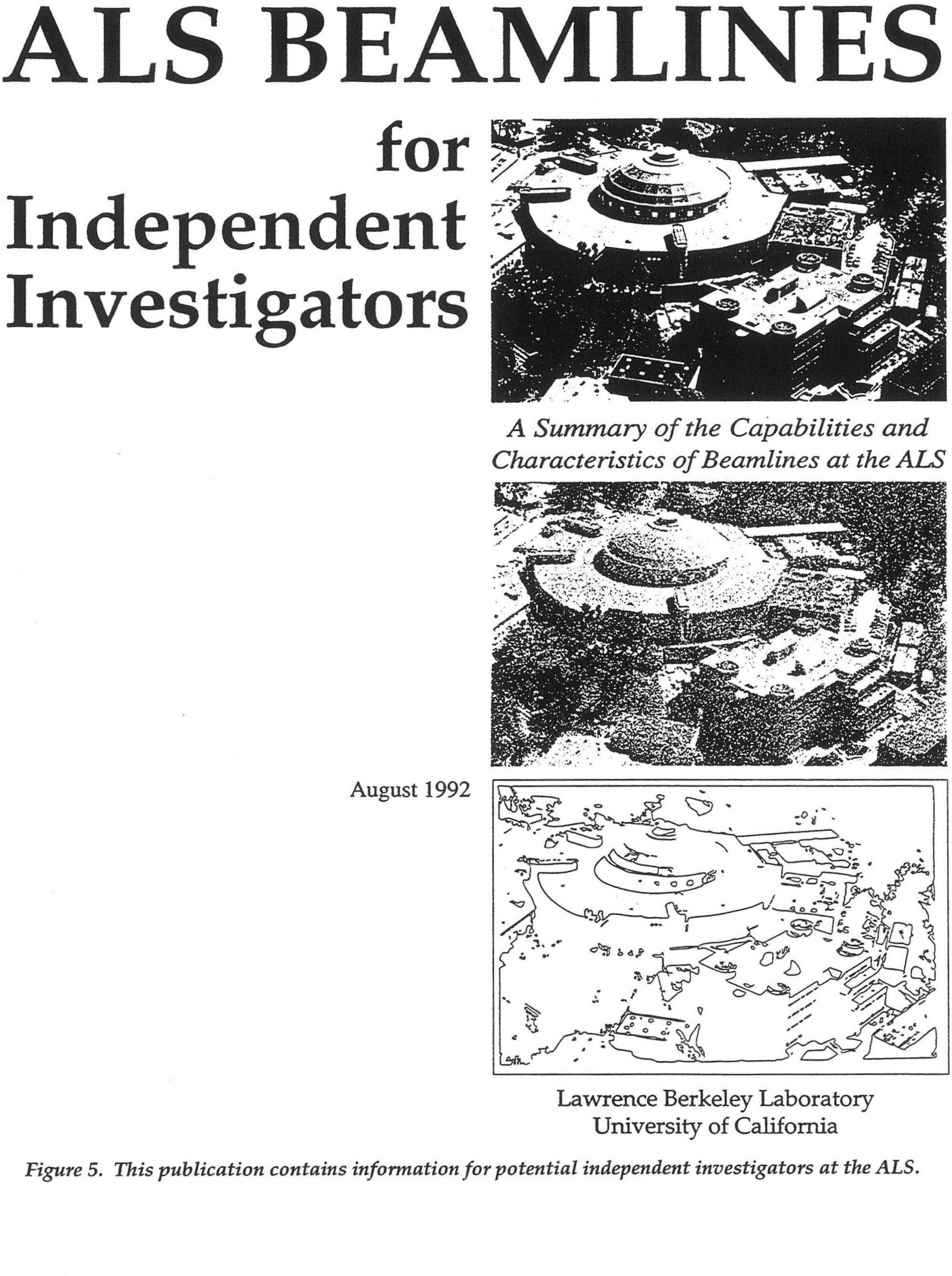
Figure 4. End station to be available to independent investigators for conducting condensed-matter, solid-state studies at the ALS.

insertion devices, three are under construction at the ALS: the two that I just mentioned to you (for Beamlines 7.0 and 9.0) and a second 5-cm-period undulator to be used by two PRTs composed chiefly of scientists from IBM, Tulane University, and the University of Tennessee. Construction will start on two new insertion devices next year: an undulator for biological x-ray microscopy with a period of perhaps 3.9 cm, and an undulator for x-ray lithography with a period of perhaps 5.5 cm. Both are still in the design stage, and the final decision on the period length is yet to be made.

That leaves five straight sections for other insertion devices. The previously mentioned Beamline Initiative submitted to the DOE calls for four insertion devices and beamlines. We do not know what the schedule of funding will be. As Bill Oosterhuis mentioned in his talk this morning, the DOE is certainly positive about funding that initiative, but on a still uncertain time scale. It is clear, however, that we will not have another insertion device besides these five before 1995. The challenge to those of us here at the ALS and to the community as a whole is to maximize the scientific output from these five insertion devices that we know we will have. What I have tried to do in this beamline handbook, and also by mailings that you will receive, is to interest the entire scientific community, not just the fraction of the community already in PRTs, in submitting proposals to conduct scientific research here. Fred Schlachter and I are committed to doing everything we can within the resources of LBL to get you here to do science at the ALS.

Figure 5 shows the cover of the handbook that is outside for you to take. Another document that we have produced is called *Advanced Light Source First Phase Scientific Program, 1993/1994* (Figure 6). I bring it to your attention because it describes the scientific programs of the PRTs and lists the team members for the first 10 beamlines, including those five insertion-device beamlines that I just mentioned. If you are interested in joining a PRT or want to know what the PRTs are doing, request a copy of this document from Fred Schlachter.

You will hear examples of the scientific opportunities that the ALS offers in the remainder of the talks today and tomorrow. I am particularly enthusiastic about the work that will be presented tomorrow by Harald Ade (SUNY, Stony Brook), by Yan Wu (IBM–Almaden), and by Jim Tobin (Lawrence Livermore National Laboratory). I think that these presentations will highlight the best kinds of scientific opportunities that the ALS offers. To quote one of Brian Kincaid's favorite sayings about the ALS: "These opportunities show why ALS stands for Advanced Light Source and not Another Light Source."



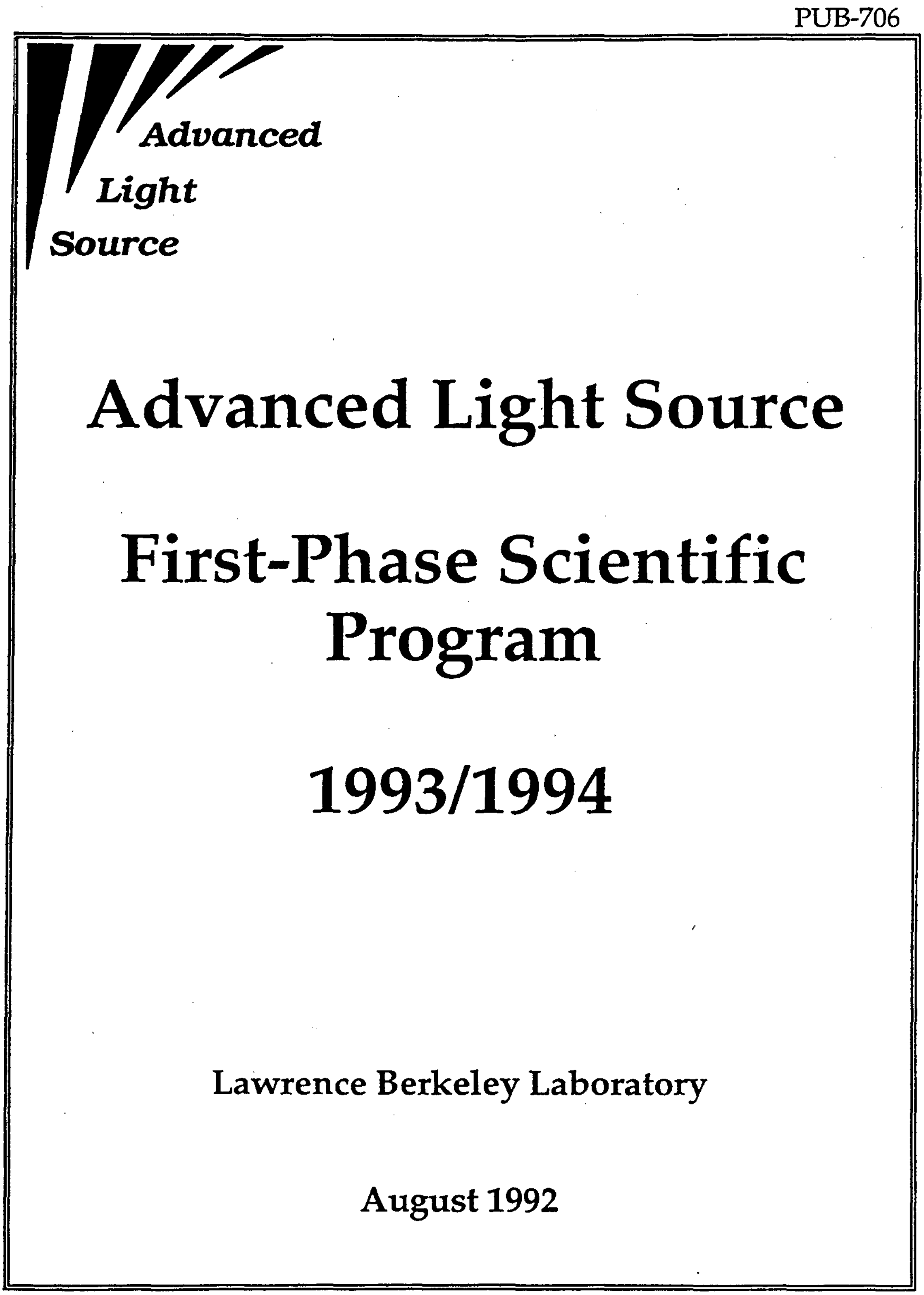
ALS BEAMLINES
for
Independent
Investigators

A Summary of the Capabilities and
Characteristics of Beamlines at the ALS

August 1992

Lawrence Berkeley Laboratory
University of California

Figure 5. This publication contains information for potential independent investigators at the ALS.



PUB-706

Advanced
Light
Source

Advanced Light Source

First-Phase Scientific Program

1993/1994

Lawrence Berkeley Laboratory

August 1992

Figure 6: This publication contains information about the scientific programs for each of the first 10 ALS beamlines. It also contains estimated beamline parameters and lists the members of the associated PRTs.

HIGH RESOLUTION CORE-LEVEL PHOTOEMISSION

I. Lindau

MAX-Lab, Lund University
and
SSRL, Stanford University

ABSTRACT

In 1964 electron spectroscopy of inner core levels had reached sufficiently high energy resolution that chemical shifts [1] were detected for the first time in some sodium compounds--the technique of electron spectroscopy for chemical analysis (ESCA) was born. About ten years ago, Gelius et al [2] published a paper where monochromatized Al Kα radiation made it possible to resolve vibrational levels in the carbon 1s level of CH_4. Since the mid-1970's, synchrotron radiation has played an increasingly important role in high resolution core-level spectroscopy. The instrumental resolution has been improved to well below 100 meV for core levels with binding energies below about 200 eV. In this talk, we will review some recent high resolution core level work at MAX-Lab, Lund University, Sweden, and we will then discuss future opportunities with the third generation of synchrotron radiation sources, of which the Advanced Light Source in Berkeley will be the first in operation.

It is argued that it is extremely important to have an optimal match between the synchrotron radiation source, the monochromator/optical system, the electron spectrometer and the detector. The system in its entirety will not perform better than its weakest component. The centerpiece of MAX-Lab is a 550 MeV storage ring, with fairly low emittance: 40 nm-rad horizontally. The beam current is typically 100-200 mA and the lifetime 3-4 hours. The work reported here was done on a bending magnet beam line, equipped with a modified SX-700 plane grating monochromator [3]. With a typical source size of 100 microns (vertical) x 400 microns (horizontal), the photon spot on the sample is about 0.5 mm x 3 mm. This spot size is well matched to the acceptance of the energy analyzer which is of the hemispherical type, developed and manufactured at the Institute of Physics at Uppsala University (under the leadership of Prof. N. Martensson) in close collaboration with Scienta [4,5].

The beam line covers the spectral region from 20 eV to 1000 eV. The resolving power of the monochromator at 240 eV is for instance 4000. For core levels with binding energies below 100 eV, extremely good resolution and intensity can be achieved, as demonstrated by the 2p core level spectra from a single crystal of Al (100). With a total instrumental resolution of 50 meV and a data accumulation time of less than 20 minutes, a surface core-level shifted peak can be determined with high accuracy, -96 ± meV [6]. On the (111) surface, no core-level shifted peak is observed to within 15 meV. These observations pose challenges for future theoretical calculations.

Measurements of surface core level shifts play an important role in the understanding of both the electronic and structural properties of surface layers. Furthermore, surface core level shifts can be correlated with thermodynamical properties of the surface, like solution, segregation, and adhesion energies. With the new experimental capabilities at MAX-Lab, it has been possible to study the 3d core levels of the 4d transition metals with high resolution: 0.2-0.3 eV total instrumental resolution for photon energies 380-450 eV [7]. For a Pd (100) single crystal, a surface core-level shift of 0.44 ± 0.03 eV towards lower energy has been determined for the Pd 3d core level (binding energy 335 eV). Adsorption of CO on the very same surface results in three different ordered structures dependent on the CO coverage. High resolution spectra of the Pd 3d and C 1s core levels (instrumental resolution of 270 meV and 220 meV, respectively) make it possible to establish a direct relation between the detailed geometry of the CO overlayer and differently shifted peaks in the Pd 3d spectra [8]. From the C 1s spectra, it is furthermore possible to establish that CO only occupies bridge sites on Pd (100).

As a final example of high resolution core-level spectra, we demonstrate intermixing in the Na/Al (111) system [9]. It has been commonly assumed that no intermixing occurs for alkali metal chemisorption onto free-electron like metals: in all models, the alkali atoms have been thought to reside on the surface. Recent work at MAX-Lab on the Al 2p [instrumental resolution, $\Delta E = 40$ meV] and Na 2p [$\Delta E = 60$ meV] core levels for different ordered structures of Na/Al (111) clearly demonstrates that intermixing does occur. All previous models must therefore be discarded, and a new picture is emerging of the surface structures for these prototypical systems.

Based on core-level spectroscopy with a total instrumental resolution of 40-50 meV, as illustrated above, it is argues that it makes sense to improve the resolution another order of magnitude for the instrumentation being planned for the third generation of synchrotron radiation sources. Even if the instrumental response function can be deconvoluted (if it is known accurately enough) from the recorded core-line, it is highly advantageous if it is sufficiently small, so that it can be neglected compared to other broadening mechanisms.

References

1. S. Hagström, et al, Phys. Lett. 9, 235 (1964).
2. U. Gelius, et al, Chem. Phys. Lett. 28, 1 (1974).
3. R. Nyholm, et al, Nucl. Instrum. and Meth. A 246, 267 (1986).
4. J. N. Andersen, et al, Synchrotron Radiation News 4, (4), 15 (1991).
5. U. Gelius, et al, J. Electron Spectrosc. and Relat. Phenom. 52, 747 (1990).
6. R. Nyholm, et al, Phys. Rev. B 44, 10987 (1991).
7. R. Nyholm, et al, J. Phys. C 4, 277 (1992).
8. J. N. Andersen, et al, Phys. Rev. Lett. 67, 2822 (1991).
9. J. N. Andersen, et al, Phys. Rev. Lett. 68, 94 (1992).

PHOTOELECTRON DIFFRACTION AND HOLOGRAPHY

Charles S. Fadley

Physics Department
University of California-Davis
and
Materials Science Division
Lawrence Berkeley Laboratory
University of California

In *photoelectron diffraction*, electrons are emitted from core levels of various atoms in a sample, and the variations of their intensities with emission direction and/or exciting photon energy are measured. These variations in intensity are in turn due to scattering of the outgoing "direct" photoelectron wave from atoms that are near-neighbors to the emitter, and they thus can be used to determine the short-range atomic structure around each type of emitter. There are by now several groups doing such diffraction measurements, and the resulting data have been shown to provide several useful types of surface structural information. In this talk, we review both the present status of such diffraction studies, and also consider the relatively new method of *photoelectron holography*. In the latter, the direct wave is identified with the "reference" wave and the scattered-wave components with the "subject" waves that are essential to the production of a hologram. With this interpretation, photoelectron diffraction patterns can be treated as holograms, and can in principle be inverted by mathematical means to directly yield three-dimensional images of short-range atomic structure, something that is not possible with any other current surface structure probe. However, such holographic images also contain several types of artifacts or distortions, and we review some of the methods that can be used to reduce or eliminate these. Finally, we consider some new possibilities in such studies that will be opened up by third-generation synchrotron sources such as the ALS. Literature citations can be found directly on the following figures and so will not be given here.

Photoelectron diffraction effects are large (up to about 70% as measured against the maximum peak intensity in a given scan over direction or energy) and, especially for kinetic energies of 1 keV or more, can also yield features that are as narrow as only a few degrees. Such diffraction patterns are thus straightforward to measure and rich in fine structure. At lower energies of the order of 100 eV, the electron-atom scattering has significant amplitude for all scattering angles from forward to backward, but at higher energies approaching 1000 eV, its form simplifies to a dominant forward scattering peak and a weak s-like tail going out to backscattering directions. Backscattering effects have been successfully used at lower energies to determine the positions of atoms "behind" a given emitter (e.g., Cl on Ni(111)), whereas forward scattering effects have directly provided information on the orientations of adsorbed molecules (e.g., CO on Fe(001)) and on low-index directions (e.g., in epitaxial growth). A further unique feature of photoelectron diffraction is in being able through chemical shifts or multiplet splittings in core-level spectra to carry out independent structural determinations for atoms in different chemical or magnetic states in a given sample (e.g., outer and inner N atoms in N_2 on Ni(001), different surface layers on W(001), and electrons of different spin in $KMnF_3$). Analyzing either scanned-angle or scanned-energy data by fitting them to diffraction calculations for various trial geometries has also shown that it is possible to derive not only adsorbate vertical positions relative to the first substrate layer, but also more subtle structural information concerning relaxations in the underlying substrate layers (e.g., S on Ni(001) and Cl on Ni(111)). It has recently also been suggested that scanned-energy data chosen to be either constructive or destructive in nearest-neighbor backscattering might be useful in a direct way to determine bond orientations (e.g., CO on Cu(110)); however, recent calculations indicate that this method might be complicated by the effects of large-angle scattering from other near neighbors away from the forward direction. Spin-resolved core spectra (e.g., those from multiplet-split levels) have also been shown to yield spin-polarized photoelectron diffraction effects that should permit determining short-range magnetic order around a given emitter. In summary, the range of structural and even magnetic information available from photoelectron diffraction is very broad, and it compares very favorably and in a complementary way with several other widely used structural probes (see table).

Photoelectron holography is a much newer development in the analysis of such data in which the presence of both a reference wave and well-defined subject waves permits avoiding the so-called "phase problem" that is inherent in the more common diffraction and scattering measurements using an externally-generated beam of electrons, x-rays, or neutrons. In the latter case, the reference wave does not contribute to the diffraction pattern, and a trial-and-error solution is in general needed to solve a structure, whereas in photoelectron holography, it should be possible to directly derive a three-dimensional image of the short-range structure. The generation of such holographic images can furthermore be reduced in its most simple form to a two-dimensional Fourier transform, although more complicated image-forming integrals may be needed to be able to correct for certain types of image artifacts and aberrations that have been predicted theoretically and/or observed experimentally. Although there are still relatively few atomic images from experimental data, it already seems clear that those obtained at higher energies from multilayer single-crystal substrates (e.g., Cu(001), Ni(001), Si(111), Ge(111)) exhibit significant elongation along forward scattering directions and/or the vertical direction above a surface; this may limit the amount of useful information that can be derived for such cases, and further suggests concentrating instead on adsorbate overlayers or thin epitaxial layers. The several effects leading to artifacts or aberrations in such images consist of one that is common with optical holography: the possible overlap of a real images at $+\underline{r}$ with a twin or conjugate image at $-\underline{r}$. Several other undesirable effects are associated with the photoelectron emission process and the strong nature of the electron-atom scattering involved: amplitude anisotropy in the outgoing reference wave; amplitude anisotropy (e.g., forward scattering) and phase shifts in the scattered waves; self-interference effects (analogous to the Patterson functions used in normal diffraction analyses) if the scattering is too strong to permit their neglect; and multiple scattering effects that may shift single-scattering peaks or introduce additional peaks in images. Model calculations on chains and simple clusters however indicate several procedures that are promising for the correction of these artifacts or aberrations: cutting the full hologram angle so as to eliminate undesirable forward scattering or multiple scattering effects from the portion analyzed; eliminating or reducing forward scattering peaks in the hologram before analysis, for example, by multiplying by a suitable gaussian function; correcting for scattered wave amplitude and phase effects by altering the image-formation integral so as to divide them out; analyzing only a part of the hologram to emphasize the interference effects associated with one nearest neighbor, thus reducing the effects of real/twin overlap in subsequent analyses of the data; and finally, doing a phased summation of about 10 or more images obtained at different photon energies (without or with a correction for scattered-wave effects at each step), a procedure which has been predicted to suppress both twin and multiple scattering effects. These methods have been applied to experimental data and theoretical simulations for high-energy emission from a simple adsorbate overlayer (S/Ni(001)) as a test case. The results are very encouraging in showing nearest-neighbor images that are well localized in all three dimensions (i.e., with no elongation). These images can furthermore be brought to within about 0.2-0.3 Å of the known positions by applying a scattered-wave correction to data over one half of the hologram, thus minimizing deleterious effects due to real/twin overlap. Finally, model calculations on spin-polarized diffraction measurements suggest that taking the difference of spin-up and spin-down images should permit directly deriving the local spin order around a given type of site. Thus, photoelectron holography is a very promising new type of analysis for certain types of problems, and the study of it should be much advanced by the availability of higher brightness synchrotron radiation sources.

At least three beamlines at the ALS will be significantly involved with photoelectron diffraction and holography (two U5 undulators on 7.0 and 8.0 and a bend magnet on 9.3.2). New end stations on these beamlines will be specifically geared toward very high accuracy diffraction/holography coupled in some cases with parallel angle-resolved valence photoemission studies. Improved energy resolutions of 50 meV or better for core level studies will also permit significantly expanding state-specific diffraction measurements. With undulator radiation, it should also be possible to accumulate spectra in as little as 1 msec, making diffraction and holography studies much more practical from a time perspective. Higher speed detectors will also be needed to take full advantage of the latter capability, and these are in development.

SOFT X-RAY EMISSION SPECTROSCOPY OF SOLIDS AT THE NSLS AND THE ALS

T.A. Callcott, University of Tennessee, Knoxville, TN 37996
D.L. Ederer, Tulane University, New Orleans, LA 70118

ABSTRACT

A description is presented of the collaborative research program in soft x-ray spectroscopy lead by the authors at the NSLS since 1986, and of the related research program planned for the ALS beginning in the summer of 1993. The PIs for the research at the NSLS have been T.A. Callcott, University of Tennessee, D.L. Ederer, Tulane University (formerly NIST), E.T. Arakawa, Oak Ridge National Laboratory, and D.R. Mueller, National Institute of Standards and Technology. At the ALS, R.C.C. Perera of Lawrence Berkeley Laboratory with join the colloboration, which will share a U5 undulator beamline with the IBM Laboratories at Almaden, CA and Yorktown Heights, NY.

A brief description of the facilities used and planned is given, with particular attention being given to the design features of the high efficiency spectrometer used for emission studies,[1] and of the variable line space beamline monochromator recently installed at the NSLS.[2]

A review of the principle features of photon excited soft x-ray emission (SXE) spectroscopy is presented. This spectroscopy, which measures radiation from filled valence states to shallow core levels, is particularly useful for light elements. Because radiative yields are often very low (< 1%), a very efficient spectrometer is required. The low penetrating power and low reflectivities of soft x-rays requires the use of windowless beamlines and grating monochromators used in extreme grazing incidence.

Within the one electron (band structure) approximation, SXE spectra are produced by dipole transitions to core states of well defined angular momentum, and thus provide a measure of the angular momentum selected partial density of states (PDOS) of the valence states of a solid. The spectra are local and chemically selective for particular elements in a complex solid. Finally SX spectroscopies are deep probes that can measure buried structures and interfaces, and can determine bulk electronic properties beneath protective or contaminating overlayers.[3]

The advantages of photon excitation of SXE spectra are described.[4] These include the reduction of damage to fragile materials, and the elimination of Bremstrahlung, which greatly improves detection of very weak spectra. It permits the selective excitation of particular core levels, which simplifies spectra by suppressing overlapping spectra and high energy satellites. Of particular importance, it permits the study of "threshold effects", which include a variety of processes that couple excitation and emission processes for excitation near an excitation threshold. TwO of these threshold studies are described briefly below.

The major disadvantage of the NSLS is that available photon fluxes provide core excitation rates that are about two orders of magnitude below those available with electron excitation, so that many studies are not practical. The 50X greater fluxes available from the ALS will make these studies accessible.

Several experimental studies are described which illustrate the value of SXE spectroscopy for the study of electronic structure and bonding in solids.
- The spectrum of silicon is discussed as the prototype of covalent bonding, with the K and L spectra providing the p-PDOS and s-PDOS respectively.
- The $L_{2,3}$-spectra of Al and P in AlP are discussed to illustrate the chemical selectivity of SXE spectroscopy. Dramatic differences in the Al and P spectra are associated with the ionic nature of the compound. This chemical selectivity is not available in other probes of electronic structure such as photoemission spectroscopy, which integrate signals from all elements in a complex material.
- The $L_{2,3}$-spectra of Si in the technologically important materials $NiSi_2$ and $CoSi_2$ demonstrate that sp^3 covalent bonding plays a significant role in the bonding, clarifies the role that p-d bonding, and clearly illustrates the filling of antibonding states that occurs when Ni replaces Co in these materials.[5] Further filling of these antibonding states with the substitution of Cu for Ni, prevents the formation of the same structure for $CuSi_2$.
- In Beryl, a complex mineral oxide containing Be, Si and Al, radiation damage is induced by both energetic electrons and x-rays. By studying the SXE spectra of Be, Si and Al in this compound, it is shown that the damage is a result of the breaking of the Si-O bond and that the Be-O and Al-O bonding is unchanged. Similar damage also occurs in SiO but not in the saturated oxide SiO_2.

In the light element oxides MgO, Al_2O_3, and SiO_2, the core hole created by the x-ray excitation process can bind an electron to create a "core exciton". Excitation to an exciton state lying within the band gap accounts for a large fraction of the transistion oscillator strength in the $L_{2,3}$ absorption process. Emission is observed not only from the exciton state within the gap, but from an "exciton resonance" state which overlaps the bottom of the conduction band.[6] Another study of these oxides is described which examines phonon coupling by measuring the thermal broadenings observed in core-core transistions, in valence band spectra from SXE measurement, and in exciton states and the conduction band spectra from absortion measurements.[7]

Dramatic changes in SXE spectra may be observed when spectra are excited by photons near an x-ray threshold. Structural features of the Si $L_{2,3}$ SXE spectra are strongly modulated in intensity, but not shifted in energy with near threshold excitation.[8] We believe that the explanation of these shifts has recently been given by Ma et al., who propose that the excitation/emission process may be described as an inelastic scattering scattering process in which crystal momentum is conserved between the excited electron and the valence hole left after the core hole is filled. We have recently demonstrated that the modulation effects are entirely absent in spectra from amorphous silicon, where long range order is absent and states of crystalline momentum are no longer well defined.[9]

In B_2O_3, large energy shifts (1.8 eV) are observed in spectral features when atoms are core excited into exciton states rather than into the conduction band.[10] When the exciton level is filled, the energy of the SXE spectra is reduced by the difference in the binding energy of the core exciton and the binding energy of the valence exciton which remains after recombination is complete. In BN, excitation near threshold results in both energy shifts in the SXE spectra, and the modulation of the intensity of spectral features, indication that both the effects of exciton screening and of crystal momentum conservation may be affecting the observed spectra.

The availability of a high flux, high resolution source of exciting electrons at the ALS will make the ALS an exceptionally valuable facility for the study of coupled excitation-deexcitation processes with near threshold excitation of SXE spectra.

References:

1. T.A. Callcott et al., "High efficiency soft x-ray emission spectrometer for use with synchrotron radiation instrumentation", Rev. Sci. Instrum. 57, 2680 (1986).

2. T.A. Callcott et al., "A simple variable line space grating monochromator for synchrotron light source beamlines", Nuc. Instrum. and Methods A319, 128 (1992).

3. R.C.C. Perera et al., "Electronic bonding of buried interfaces determined by soft-x-ray-emission spectroscopy", J. Appl. Phys. 66, 3676 (1989).

4. T.A. Callcott et al., "The photon excitation of soft x-ray emission spectra", Nuc. Instrum. and Methods A291, 13 (1990).

5. J. Jia et al., "Local partial densities of states in Ni and Co silicides studied by soft-x-ray emission spectroscopy," Phys. Rev. B43, 4863 (1991).

6. W.L. O'Brien et al., "Resonant absorption and emission from localized core hole states in Al_2O_3 and SiO_2", Nuc. Instrum. and Methods B56/57, 320 (1991).

7. W.L. O'Brien et al., "Temperature dependence of electronic transitions in MgO, Al_2O_3, and SiO_2: Final state effects on phonon coupling", Phys. Rev. B45, 3882 (1992).

8. J.E. Rubennson et al., "Excitation-energy dependence in the $L_{2,3}$ fluorescence spectrum of Si", Phys. Rev. Lett. 64, 1047 (1990).

9. Ken Miyano et al., "Localized versus band structure interpretations of threshold variation in Si $L_{2,3}$ X-ray fluorescence", to be published.

10. W.L. O'Brien et al., "Photon excitation energy dependence of B_2O_3 and h-BN soft x-ray emission: Spectator vs. normal emission", to be published.

GAS-PHASE SPECTROMETRY

James A. R. Samson
University of Nebraska, Lincoln, NE 68588-0111

The study of photon interactions with free atoms and molecules has given us much of our present general knowledge of atomic and molecular structure. However, the advent of intense sources of synchrotron radiation, continuous and highly polarized from the infrared to x-ray wavelengths, has opened up an almost unlimited area for research into photon/atom (or molecular) interactions. To name a few examples: measurements of the angular distribution of photoelectrons have been made within autoionizing structure, the angular distribution of fluorescent radiation has been measured from excited atomic states, photoionization studies of ions have started, and in the future photoionization studies will be conducted with state selected species prepared by laser excitation.

Our discussion of research in the gas phase will concentrate primarily on the excitation of two or more valence shell electrons by a single photon. This can lead to the production of doubly excited states, to single ionization plus excitation (that is, a satellite state), or to multiple ionization. This latter interaction is quite distinct from Auger processes and can occur only by electron correlations. The understanding of electron correlations has become a very important area of theoretical study. This choice for discussion will emphasize the need for experimental versatility by illustrating experiments that study photoelectrons, ions, and fluorescent radiation. Coincidence measurements between electron–ion, electron–photon, and ion–photon processes are very scarce and will require the enhanced radiation intensity from undulator beam lines. Preliminary studies indicate that satellite states are primarily populated via autoionization from high-lying doubly excited levels. These satellite states can be observed either by using photoelectron spectrometry and/or by studying the fluorescence emitted as the excited states relax. The advantage of one method over another can be seen from the following examples. When two satellite states have almost identical energies their photoelectron spectra are indistinguishable. However, if the states fluoresce the wavelengths emitted are generally quite different and easily identified. On the other hand some low-lying satellite states are metastable and no fluorescence is observed. Thus, photoelectron spectrometry techniques must be used. The energy of the autoionizing levels observed in satellite state production provides direct measurements of the energies of the doubly excited neutral states. This type of study has already identified many previously unknown energy levels.

When doubly excited states lie above the double ionization threshold, an interesting question arises. Namely, can autoionization occur directly into the double ionization continuum by ejecting two electrons simultaneously or will some relaxation occur to produce a satellite state and/or fluorescence. By observing the doubly ionized atoms with a mass spectrometer and varying the incident photon energy we do in fact see autoionizing structure. In one case we have observed fluorescence competing with autoionization from the same energy level.

High lying double excited states can be seen also in the dissociative ionization of molecules. Examples of N_2 will be given making use of fluorescence and photoelectron spectrometry techniques. However, the ultimate measurements, requiring coincidences between the fluorescent radiation and the ejected photoelectrons, awaits the high flux of the Advanced Light Source.

Spectromicroscopy

Harald Ade
Dept. of Physics, SUNY at Stony Brook, NY 11794

It has been recognized by many researchers that x-ray spectro-microscopy offers the promise to investigate surface and material science problems where electron probes such as SAM/SEM/TEM have failed, due mostly to their high damage and limited spectroscopic information. Even "ultimate" resolution imaging with scanning probe instruments suffers from a variety of short-comings depending on the application.

Several research groups have therefore in the recent past developed largely complimentary approaches to achieve high resolution XPS and XANES imaging. These include micro-focus devices based on zone plates, multilayer coated Schwarzschild objectives, grazing incidence ellipsoidal mirrors, and electrostatic, and magnetostatic imaging instruments [1]. The spectral range these instruments cover varies widely, and they each have distinct advantages and disadvantages (see copies of viewgraphs). The choice and preference for a particular instrument is therefore mostly governed by the anticipated applications and the particular emphasis on one of the parameters such as spatial resolution, tunability, working distance, ease of use, time resolution, etc.

At the present juncture much progress has been made with instruments at existing synchrotron radiation sources, and first crucial demonstrations of the applications of the technique have been demonstrated. These include for example C-XANES imaging of polymer blends [2], the recording of two kinetic regimes of the thermal desorption of SiO2 [3], and MCD-imaging of magnetic domains [4]. However, even with the present day high brightness synchrotron radiation storage rings most of these instruments will be limited in their capabilities, awaiting third generation x-ray sources. This is a direct consequence that for most instruments the signal intensity is proportional to the source brightness. It is anticipated that with the advent of third generation sources such as the ALS, Elettra, MAX-II, BESSYII, etc., the field of x-ray spectro-microscopy will grow rapidly.

For example, the spectro-microscopy IDT at the ALS, headed by B.Tonner, is in the process of designing two zone plate based instruments installed at a U5.0 undulator, scheduled to go into operation the summer of 1994. One instrument will be a UHV microscope with a hemispherical analyzer with multichannel detection, while the other instrument will operate in medium to low vacuum or even at atmospheric pressure with a fluorescence and transmitted flux detector. The goal is to achieve a few tens of nm spatial resolution with sub-100 meV energy resolution. The potential use of the third order focus of a zone plate might in fact improve the spatial resolution for thin samples or secondary yield detection to the 10-20 nm level.

The highest resolution spectro-microscopy images to date have been obtained with the Scanning Transmission X-ray Microscope (X1-STXM) at the NSLS. The X1-STXM has achieved a Rayleigh resolution of 55 nm, while features smaller than 35 nm have been observed in test patterns [5]. At this resolution, C-XANES imaging with the X1-STXM has been used, for example, to identify and map the phases in a polymer blend of polypropylene and a random co-polymer of acrylonitrile and styrene. Spectra from areas 0.1x0.1 micron in size of the two phases were also optained (see copies of viewgraphs).

With user beam at the ALS expected to start in 1993, and the completion of the two spectro-microscopes in the summer of 1994. an exciting time is awaiting those interested in x-ray spectromicroscopy.

[1] For a recent review see H.Ade, *Nucl. Instr. Meth. Phys. Res.* A **319**, 311-319 (1992) and references therein.

[2] H. Ade et al., Science (to be published).

[3] G.R. Harp, Z.L. Han and B.P. Tonner, *J. Vac. Sci. Technol.* A **8**, 2566 (1990), and B. Tonner, private communications

[4] Y. Wu, these proceedings

[5] C. Jacobsen et al., *Opt. Commun.* **86**, 351 (1991).

X-RAY DICHROISM EXPERIMENTS USING CIRCULAR POLARIZATION

**J.G. Tobin[A], G.D. Waddill[A], D.P. Pappas[B], P.A. Sterne[A], T. Gouder[A],
A. Jankowski[A], and D.J. Webb[C]**
A· Lawrence Livermore National Laboratory, Livermore, CA USA
B. Naval Research Laboratory, Washington, DC USA
C. University of California, Davis, CA USA

One of the basic thrusts of the investigation of nanoscale magnetic structures, whether it be ultrathin monolayer films, multilayers, or clusters, is the establishment of structure-property relationships. Ordinarily, efforts to measure nanoscale magnetic properties in conjunction with atomistic geometric and electronic structures runs headlong into the same problem: The magnetic perturbation tends to be a small component of the overall effect. In contrast to this, here we report giant circular dichroism in the near-edge core-level x-ray absorption of a near-monolayer metal film. The essential effect is the relative amplification of the $2p^{1/2}$ peak where the magnetization and helicity are parallel, regardless of whether the magnetization is into or out of the surface plane. (Because the magnetization and x-ray incidence are normal to the surface, we call it perpendicular dichroism.) This is a direct measurement of the spin polarization and the density of the unoccupied states near E_F in a ferromagnetic system.

The temperature dependence of the perpendicular magnetization can also be followed with this technique. Here, we are using branching ratio (BR) as a measure of the dichroism. BR is defined in Eq. (1). I is the integrated intensity of the white line peak at each edge jump.

$$BR = I(2p_{3/2}) / \left[I(2p_{3/2}) + I(2p_{1/2}) \right] \qquad (1)$$

We have developed a simple, one-electron picture to analyze our results, which can be summarized into the closed form analytic expression shown in Eq. (2).

$$BR = \frac{3 + 2(1-\alpha)\beta + 2(1-\beta)\alpha}{6} \qquad (2)$$

α is the spin down alignment of the unoccupied 3d states and β is the degree of right circular polarization. (β = 100% for right β = 0% for left, and β = 50% for linear.)

To use a one-electron picture, it is necessary to "normalize-out" the non-statistical many-body effects. To do this we multiply all BR values by $^2/_3/BR_{EXP}(\text{lin})$. This allows us to concentrate upon the effects of helicity variation. The results of our analysis, assuming $2\mu_B$/Fe atom (α = 25% and 75%) is shown in Table I, for Fe/Cu(001).

Table 1.

P vs M	BR_{EXP}	BR'_{EXP}	BR_{TH}
+	0.645	0.585	0.60
–	0.83	0.75	0.73
lin	0.74	0.67	0.67

P = polarization
M = magnetization direction
P vs M: relative directions of helicity and magnetization
\+ = parallel
– = anti-parallel
BR = branching ratio
BR_{EXP} = raw experimental results
BR'_{EXP} = experimental results, normalized to the linear statistical prediction
BR_{TH} = atomic theory prediction, 2mB/Fe atom, α = 25%, 75% and b = 10%, 90% pol.

Additionally, we have used MCD with core-level photoemission to measure the exchange splitting of the 2p3/2 and 2p1/2 peaks of 4ML of Fe/Cu(001)^2. The exchange splitting of 2p3/2 peak is 0.22 ± 0.10 eV. The apparent change in the spin-orbit splitting between the two peaks is 0.33 ± 0.14 eV. There are less than those observed in the bulk (see Ref. 2 and References therein). We have also observed an "exchange splitting" in the Fe3p spectra of Fe/Cu(001).

We have performed magnetic circular dichroism (MCD) experiments upon Fe/Cu(001), using both core-level photoemission and near-edge absorption fine structure, as well as photoemission of the exchange split 3s states. The coverage and temperature dependences have been investigated. A simple, one electron picture supported by supercell calculations, has worked well to explain normalized branching ratio measurements. Work has begun using FePt multilayers and uranium compounds. The insertion of x-ray quarter-wave plates (Kortright and Underwood) into the ALS spectromicroscopy facility beamline was also discussed. We plan to continue and expand this work.

Acknowledgments

Work performed under the auspices of the U.S. Department of Energy by the Lawrence Livermore National Laboratory under contract No. W-7405-ENG-48. D.P. Pappas was supported by IBM Almaden when this experimental work was done. These measurements were made on Beamline 8–2 at the Stanford Synchrotron Radiation Laboratory. Beamline 8–2 is part of the UC/National Laboratories Participating Research Team (PRT)3. The authors wish to thank Ms. Karen Clark for supporting this work.

References

1. J.G. Tobin, G.D. Waddill, and D.P. Pappas, Phys. Rev. Lett., 68, 3642 (1992) and references therein.

2. G.D. Waddill, J.G. Tobin, and D.P. Pappas, Phys. Rev. B 46, 552 (1992).

3. L.J. Terminello, G.D. Waddill, and J.G. Tobin, Nucl. Instrum. Meth. (1992), in press.

Magnetic Circular X-ray Dichroism and MCXD Microscopy

Yan Wu
IBM Research Division
Almaden Research Center

Magnetic circular x-ray dichroism (MCXD) is a newly developed technique which measures local magnetic properties with element specificity. The element specificity makes it possible to probe both the magnetic and the "non magnetic" elements in alloys and multilayers. When MCXD is combined with a suitable electron or x-ray microscopy technique, it can be used on multidomain samples without any external magnetic field and the samples can be studied with high spatial resolution. We present a series of MCXD studies on magnetic thin films and multilayers which clearly demonstrated all of these aspects.

Large MCXD signals have been observed near the Co L_3 and L_2 edges in pure Co thin film and Co/Pd multilayers. Application of a recently proposed sum rule to our data indicates that the orbital magnetic moments at the Co site in the multilayer samples are greatly enhanced compared to pure Co metal. This gives strong support to recent theoretical predictions and has implications for the strong perpendicular anisotropy observed in these samples. MCXD results near the Pd L_3 and L_2 edges on Co/Pd multilayers showed that Pd atoms near the interface have non-vanishing magnetic moments with its direction parallel to that of Co atom.

Using the large difference in x-ray absorption intensity as the relative orientation of the photon spin and the magnetization vector is varied, it is now possible to use x-rays to obtain magnetic contrast in an microscopy experiment. We have used this technique along with an electrostatic imaging lens system to examine a CoPtCr magnetic recording disk which had been patterned with a recording signal. We have obtained images with good contrast(up to 20% in the raw data) and a spatial resolution of 1μm. With improved electron optics and x-ray source, this new microscopy technique should provide a much higher spatial resolution. We have also used two different scanning method to study the oscillatory magnetic coupling across a non-magnetic layer in wedged samples where the thickness of the non-magnetic layer is varied continuously. It appears that this technique is particularly valuable for the investigation of magnetism at interfaces and in complex materials where the magnetic contribution from different elements needs to be distinguished. In addition, the relatively long penetration depth of the x-rays and the escape-length of the secondary electrons should extend this technique to technologically important applications.

This is joint work with J. Stöhr, M. Samant, D. Weller, S. Parkin, and G. Harp of IBM Almaden Research Center, B. Hermsmeier of IBM San Jose, and S. Koranda, D. Dunham, and B. P. Tonner at the University of Wisconsin-Milwaukee.

Applications of Soft X-ray Optics
to Sub-Micron Silicon Device Technology

Jeffrey Bokor
ULSI Technology Research Department
AT&T Bell Laboratories
Murray Hill, NJ 07974

As the semiconductor industry begins to consider the challenge of creating device technologies at minimum dimensions of 0.25 μm and below, it is becoming increasingly clear that we will need all the help we can get. The recent rapid advances in the field of soft X-ray sources and optics make it possible to consider both lithographic and analytical technology options that have previously been unthinkable. In particular, this talk will describe recent progress in the development of soft X-ray projection lithography, a technology which has been demonstrated to be capable of minimum feature sizes as small as 50 nm. Possibilities for the application of soft X-ray optics to microprobe analysis of semiconductor device structures will also be discussed.

Currently, integrated circuit manufacturing produces devices with minimum features slightly below 1 μm, and devices with 0.5-0.35 μm features are under development. As time passes, feature sizes become smaller while the patterned area gets larger. It is estimated that by the end of this decade, features will be approaching 0.1 μm and areas will be ≥ 5 cm^2. None of the current lithographic systems can be extended far enough to meet these requirements. Step-and-repeat cameras, even those using ultraviolet or deep-UV radiation and resolution enhancing phase-masks[1] will be limited by the physics of diffraction and will not be capable of producing features smaller than about 0.25 μm. Advanced e-beam direct-write tools can produce features below 0.1 μm, but are much to slow for mass production. X-ray proximity printing will require breakthroughs not yet on the horizon to accurately produce and place 0.1 μm features on a thin membrane mask.[2]

Soft X-ray projection lithography is a new technique that has 0.1 μm resolution and a depth of focus large enough to provide good process latitude. It also promisies to have the high throughput needed to justify its high cost. The technique is based on a reduction camera with reflective optics that uses X-rays in the 5 to 20 nm wavelength range to project an image of a mask onto a photoresist coated semiconductor wafer. Recent experiments using a simple, two-mirror Schwarzschild objective have demonstrated near diffraction limited imaging, and fabrication of 50 nm features.[3]

In the initial experiments,[3] the image field was quite small, of the order of only 50 μm. The mirrors were spherical and therefore relatively easy to make and test; additionally, only a small area of each mirror was used. A production camera will necessarily have a large image field and will use larger mirrors that have some degree of asphericity. To produce diffraction limited resolution, the overall shape of each mirror must conform to the design to about $\lambda/20$, or about 0.6 nm, over the entire surface. Furthermore, to be compatible with high reflectivity multilayer mirror coatings, the surface micro-roughness must be no more than a few Å. These requirements are currently beyond the state of the art of optical fabrication. To achive this precision, opticians will require higher precision metrology tools than are available today.

"At-wavelength" soft X-ray testing of the optics will play an important role in the development of the high precision metrology that is required. An experimental demonstration[4] of the Foucault knife-edge test at 14 nm has already shown the capability of $\lambda/16$ metrology. Plans are now being made for much more sophisticated soft X-ray phase-measuring interferometry at the ALS.

Another potential application of soft X-ray imaging techniques is the use of advanced spectromicroscopy in the analysis of fabricated device structures. The chemical sensitivity of spectromicroscopy offers significant advantages over traditional SEM or TEM analysis. This will be invaluable in both the process development phase as well as in failure analysis. The recent results obtained with a first generation scanning photoemission microscope at the NSLS[5] offer a glimpse of the potential of this technique. The dramatic improvements in signal/noise, energy resolution, and spatial resolution that will be possible at the ALS offer the device designer the promise of actually measuring 2-D profiles and materials structures in fabricated devices that hitherto could only have been guessed at.

REFERENCES

1. M. D. Levenson, N. S. Viswanathan, and R. A. Simpson, IEEE Trans. Electron Devices, **ED-29,** 1828 (1982).
2. J. Warlaumont, J. Vac. Sci. Technol. **B7,** 1634 (1989).
3. J. E. Bjorkholm, et al., J. Vac. Sci. Technol. **B7,** 1509 (1990).
4. E. L. Raab, D. M. Tennant, W. K. Waskiewicz, A. A. MacDowell, and R. R. Freeman, JOSA A **8,** 1614 (1991).
5. H. Ade, J. Kirz, S. Hulbert, E. Johnson, E. Anderson, and D. Kern, J. Vac. Sci. Technol. **A9,** 1902 (1991).

BEND MAGNET MICROPROBE

Gene E. Ice and Cullie J. Sparks
Metals and Ceramics Division, Oak Ridge National Laboratory
Oak Ridge, Tennessee 37831-6118

X rays have many advantages over electrons and other charged particles for elemental and structural microcharacterization. X rays are more efficient in photoejecting inner shell electrons, which results in characteristic x-ray fluorescence. X rays produce less Bremsstrahlung, which results in a far higher signal-to-background ratio than is obtained with electrons. Minimum detectable limits (MDL) for x-ray excited fluorescence can be a few parts per billion, 10^{-3} to 10^{-5} less than for electron excitation.[1] X-rays diffraction is also quite useful for determining lattice parameters and structure. A 1 μm diameter x-ray microprobe can be 2-3 orders of magnitude more sensitive to lattice spacing than an electron microprobe. An x-ray microprobe being built on an ALS bending magnet will be the first of a new generation of x-ray microprobes which combines synchrotron radiation with new advances in x-ray optics. The combination of the ALS source with advanced Kirkpatrick-Baez optics will make it possible to develop a submicron x-ray probe with unprecedented sensitivity in diffraction and with unprecedented MDL in fluorescent identification of sample chemistry.

Advantages of an X-ray Probe

The availability of vastly more brilliant x-ray sources and new developments in x-ray optics will lead to new capabilities in sample characterization for materials science, environmental science and biology (Fig. 1). A key element in the x-ray microprobe planned for the ALS is an advanced Kirkpatrick-Baez (KB) multilayers system.[2] This system is especially well suited for a fluorescent microprobe because it is achromatic, it allows a large bandpass, and it has a large aperture relative to alternative microprobe optics (Fig. 2). An x-ray probe will compliment charged particle probes. Although the spatial resolution will not approach that available with charged particle probes, the fluorescent signal-to-background and ultimate MDL are much better with x-ray excitation (Fig. 3-5). In addition, for thick samples the spatial resolution for an x-ray microprobe may actually exceed that of an electron microprobe due to scattering in the sample[3] (Fig. 6). An x-ray microprobe will also have unique advantages for nondestructive analysis (Fig. 7). It can operate in the presence of air, water and gases and does not require extensive sample preparation. Although these advantages have been known for many years, x-ray microprobes have been unable to compete with electron microprobes due to the low x-ray beam brilliance from conventional x-ray tubes(Fig. 8-10). Even with the most modern capillary optics[4], the beam brilliance from conventional sources limits the flux densities at the sample to ~10^4 c/s/μm^2. The ALS beamline should achieve flux densities 7-8 orders of magnitude greater. The x-ray microprobe optics to be used on the ALS line have already been extensively tested (Fig. 11-12). Elliptical mirror surfaces are presently being procured to eliminate spherical aberration and allow the realization of a 1 μm^2 x-ray probe (Fig 13). The beamline is presently being assembled on the ALS floor (Fig. 14).

Applications of an X-ray Microprobe

The ALS bend magnet microprobe will have many important applications to materials science, biology and environmental science. Microfluorescence analysis with μm resolution will advance our understanding of elemental distributions (Fig. 15). Elemental segregation and inhomogeneities are critical to the behavior of materials (Fig. 16). With an x-ray microprobe it will be possible to measure elemental segregation to interfaces and at surfaces with better elemental sensitivity than with other more invasive measurement techniques. Among the materials to be studied will be encapsulated toxic or radioactive materials, integrated circuits, and structural materials (Fig. 17). Spatial resolution adequate to study grain boundary diffusion will help elucidate diffusion mechanisms (Fig. 18). An important advantage of x-ray microanalysis is the ability to penetrate deep within a sample. This allows the study of chemical segregation below the surface in a dissolution reaction (Fig. 19). It is possible to map out the three dimension distribution of an element in a smooth and fairly homogeneous sample by varying the angle relative to the surface at which the fluorescence is observed (Fig 20). This technique may be important for studying elemental distributions in quasi two dimension samples like Si wafers. In biological materials x-ray analysis will have high sensitivity with minimum damage (Fig. 21). Elemental analysis of the chronological growth patterns in durable biological structures can help study the distribution and uptake of pollutants (Fig. 22).

Another important application of an x-ray microprobe will be for the measurement of diffraction with μm spatial resolution. X-rays are the premiere tool for measuring atomic structure (Fig. 23). Until recently microdiffraction experiments employed laboratory x-ray sources with necessarily poor spatial resolution to allow adequate counting rates (Fig. 24). With a white beam x-ray source and a perfect crystal monochromator, it is possible to study diffraction as a function of wavelength, while the volume of the sample illuminated by the x-ray beam remains fixed (Fig. 25). This will allow a rapid and accurate measurement of strain. Strain measurement and phase identification are already important diagnostic tools for understanding the properties of materials (Fig. 26-28). The few reported synchrotron measurements of microdiffraction show the promise of the technique. (Fig. 29-31). A measurement of the strain distribution near a notch of a single crystal demonstrates the remarkable sensitivity of x-ray diffraction to crystallographic strain.[5]

Acknowledgements

This research sponsored by the Division of Materials Sciences and Division of Chemical Sciences, U.S. Department of Energy, under Contract No. DE-AC05-84OR21400 with Martin Marietta Energy Systems Inc.

References

1. C. J. Sparks,"X-ray Fluorescence Microprobe for Chemical Analysis", Chapter 14 (459-509) in *Synchrotron Radiation Research* edited by H. Winick and S. Doniach, Plenum Press,New York (1980).

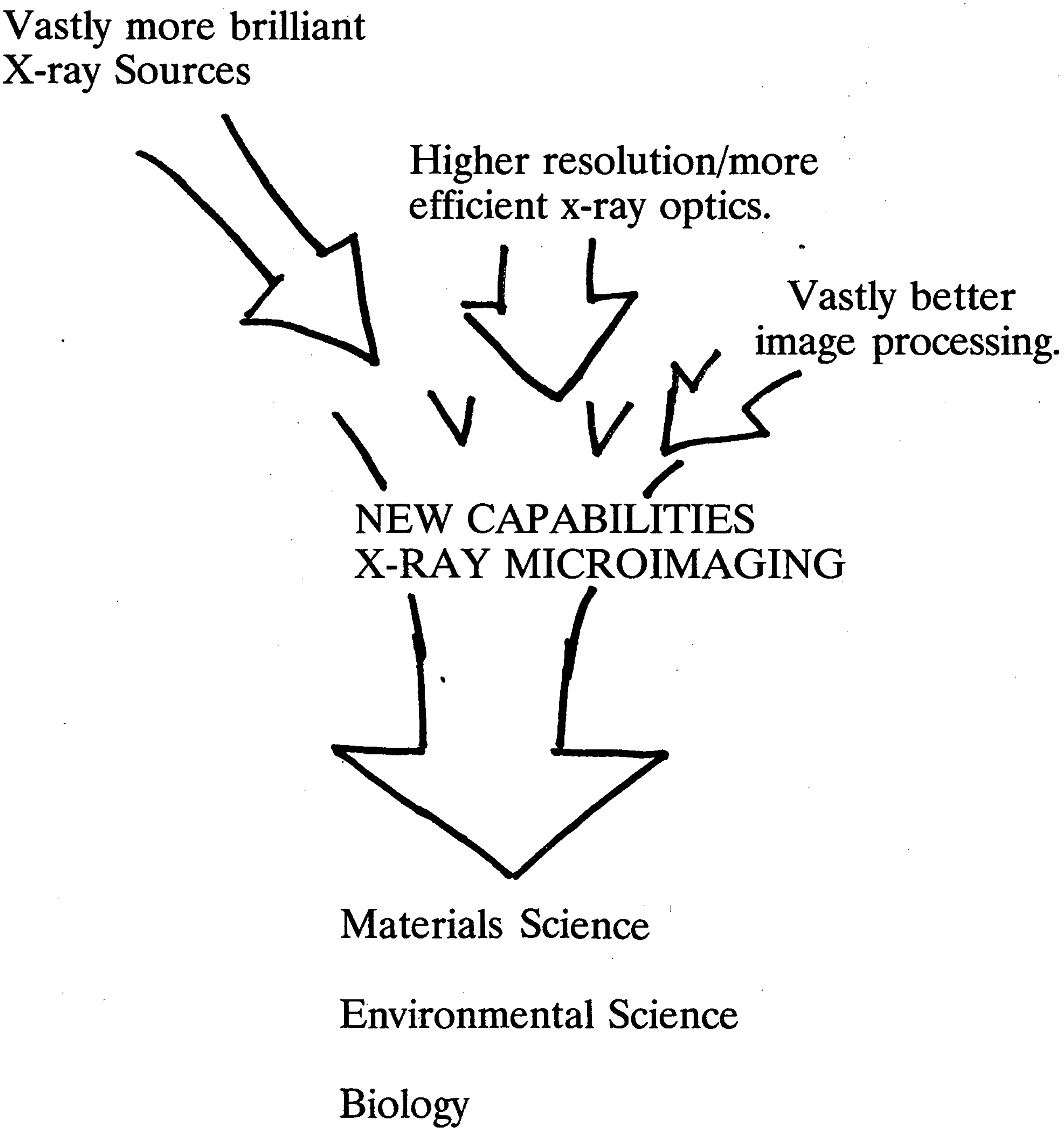
2. Y. Wu, A.C. Thompson, J.H. Underwood, R.D. Giague, K.L. Chapman, M.L. Rivers and K.W. Jones, *Nucl. Inst. and Meth.*, A291 146 (1990).

3. D. A. Carpenter, M. A. Taylor and C.E. Holcombe, "*Applications of a Laboratory X-ray Microprobe to Materials Analysis*",in *Advances in X-ray Analysis* 32, Edited by C. Barrett, J.V. Gilfrich, R. Jenkins, T.C. Huang, and P.K Predecki, Plenum Pub. Corp. (1989).

4. Curgenuer and Duncumb, *TIRL Report 303*, Essex England (1971).

5. R. Rebonato, G.E. Ice, A. Habenschuss and J.C. Bilello, *Phil. Mag. A*, 60 571-583 (1989).

WE ARE AT THE BEGINNING OF A REVOLUTION IN OUR ABILITY TO MICROIMAGE ELEMENTAL COMPOSITION AND STRUCTURE.



Vastly more brilliant X-ray Sources

Higher resolution/more efficient x-ray optics.

Vastly better image processing.

NEW CAPABILITIES
X-RAY MICROIMAGING

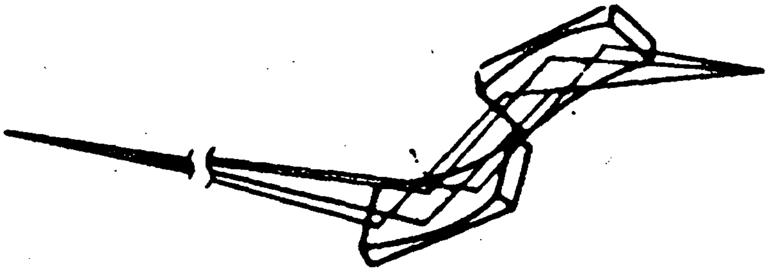
Materials Science

Environmental Science

Biology

Figure 1

Key element of ALS Microprobe beamline is an advanced KB multilayer focusing system to obtain an x-ray microprobe with ~1 μm^2 area.- Thompson,Underwood et al.



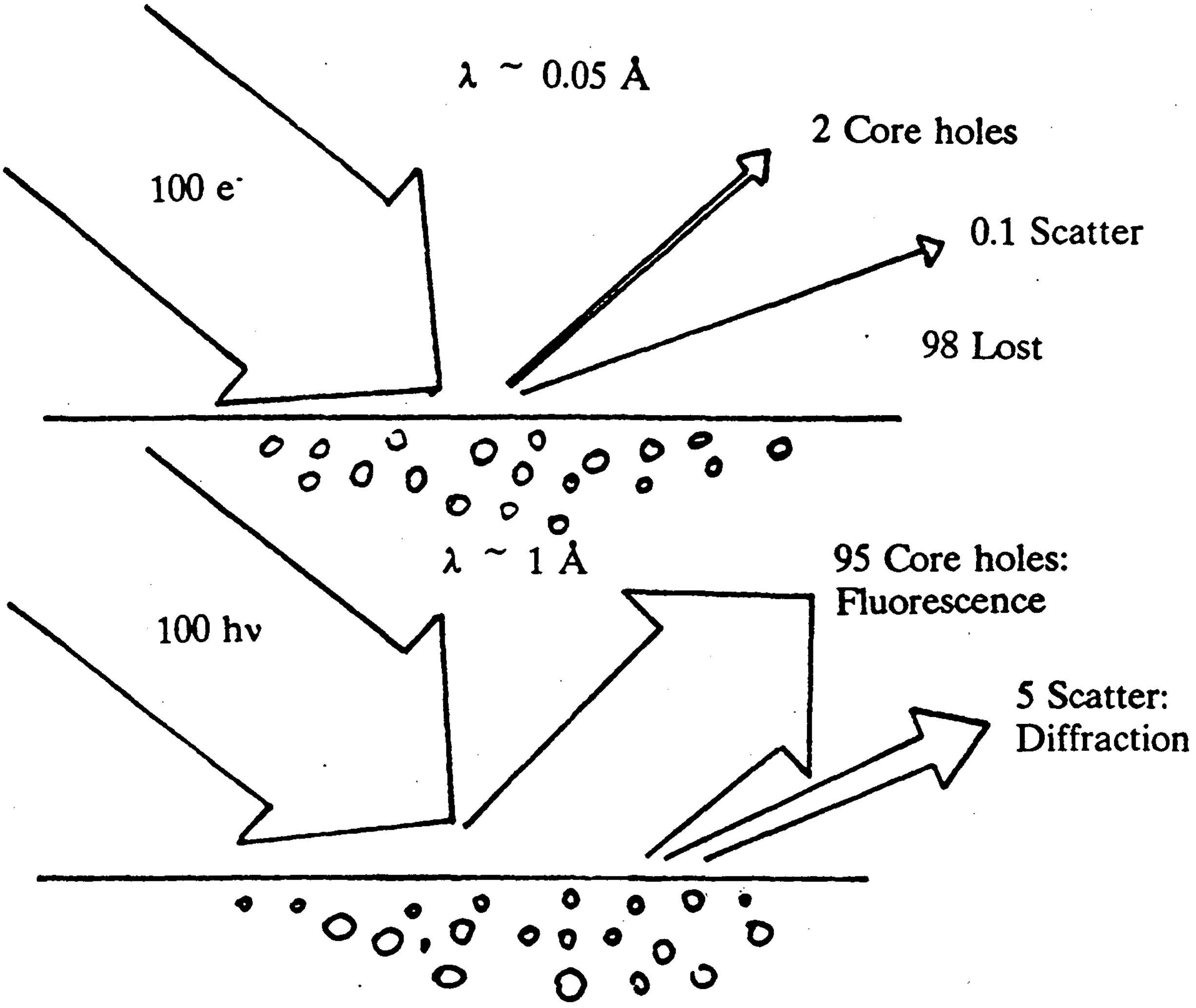
This system favored because-

Achromatic- 10% bandwidth (fluorescence)

Large aperture-

Figure 2

X RAYS COMPLEMENT CHARGED PARTICLE PROBES.



X RAY EXCITED MDL → 10^4 SMALLER

Figure 3

AN X RAY PRODUCES FROM 10 TO 100 TIMES THE FLUORESCENT SIGNAL PRODUCED BY AN ELECTRON

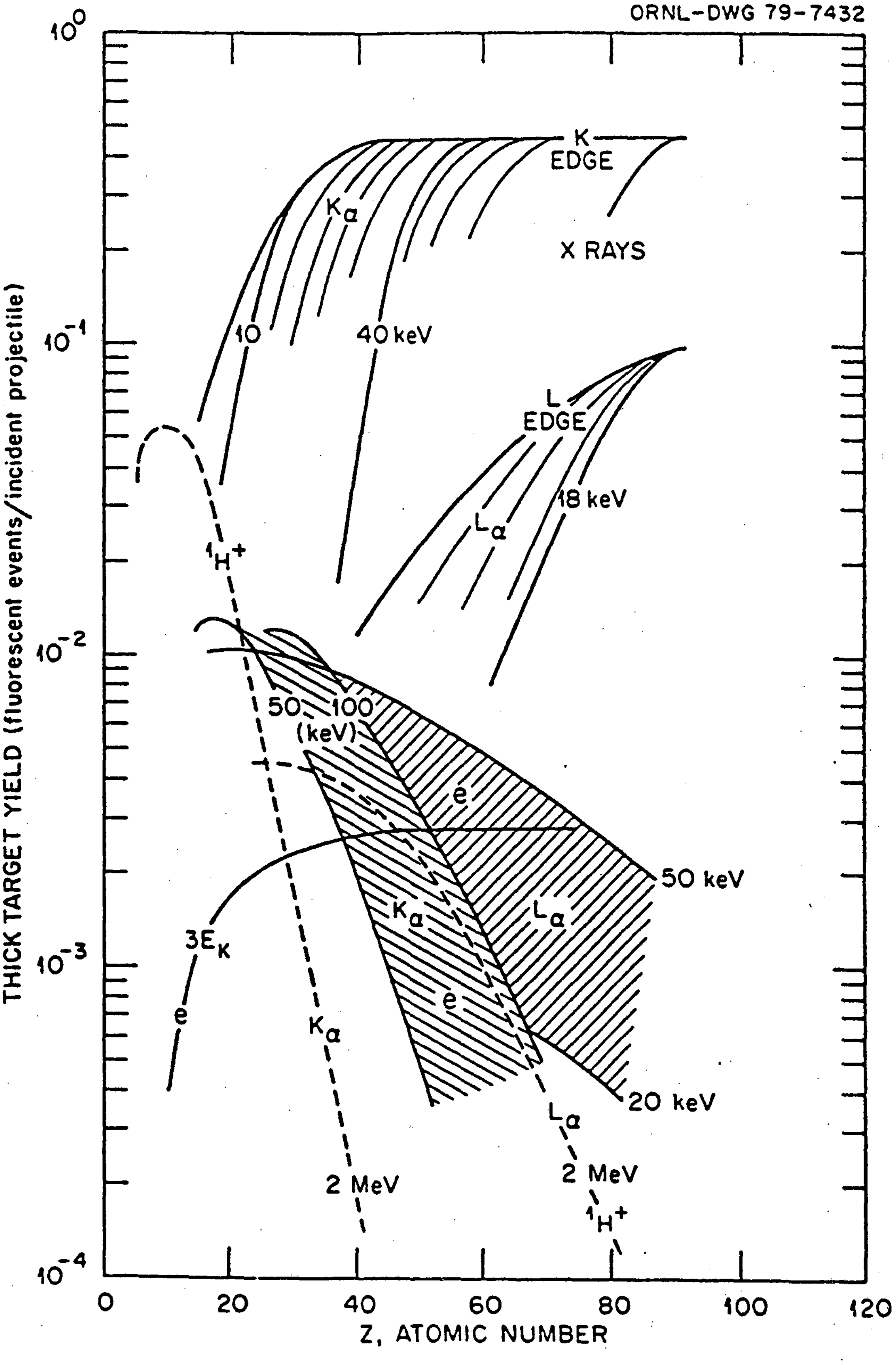


Figure 4

X-RAY PRODUCED FLUORESCENCE HAS 10^4 TO 10^5 GREATER SIGNAL TO BACKGROUND THAN FROM ELECTRONS

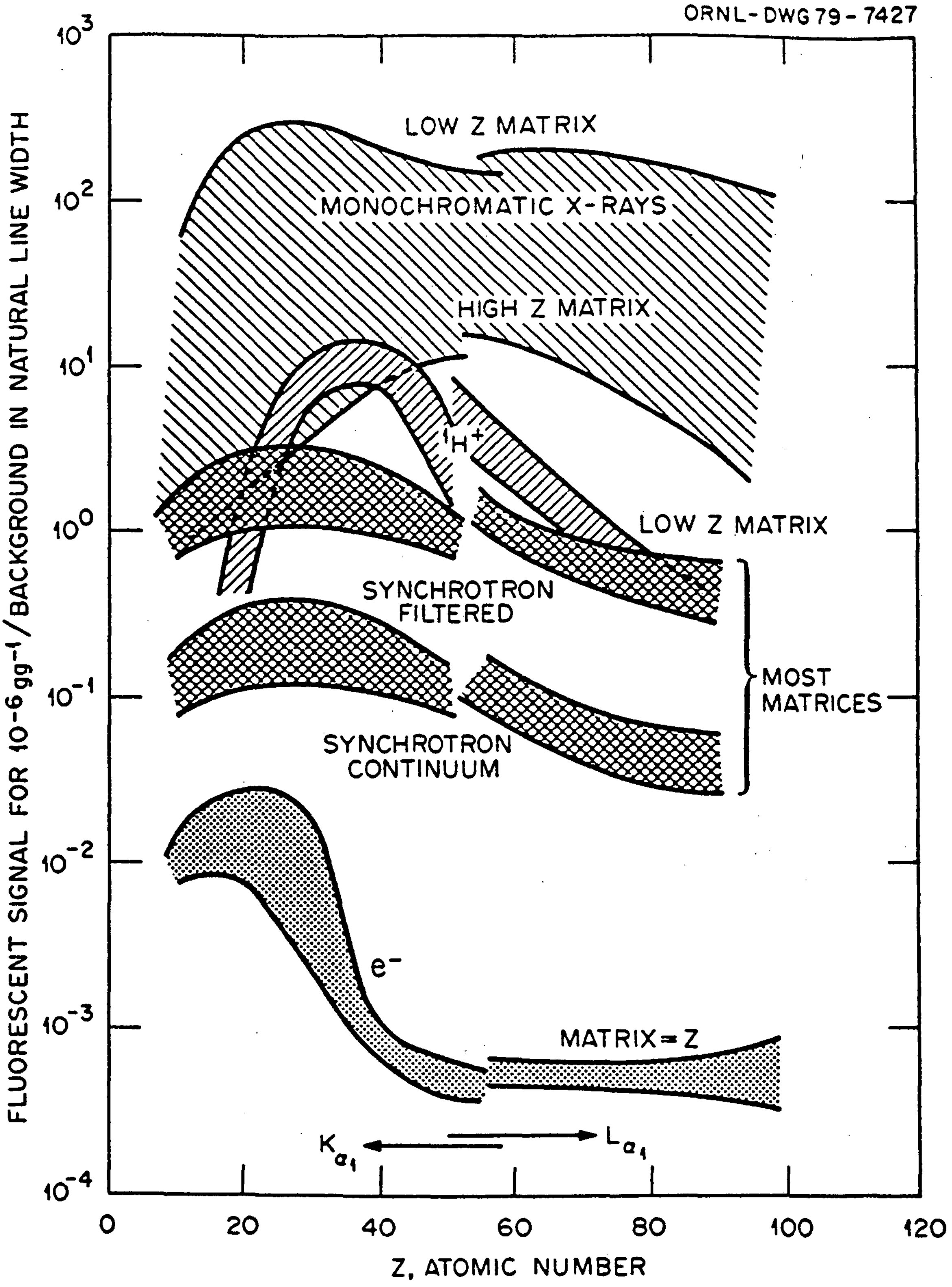
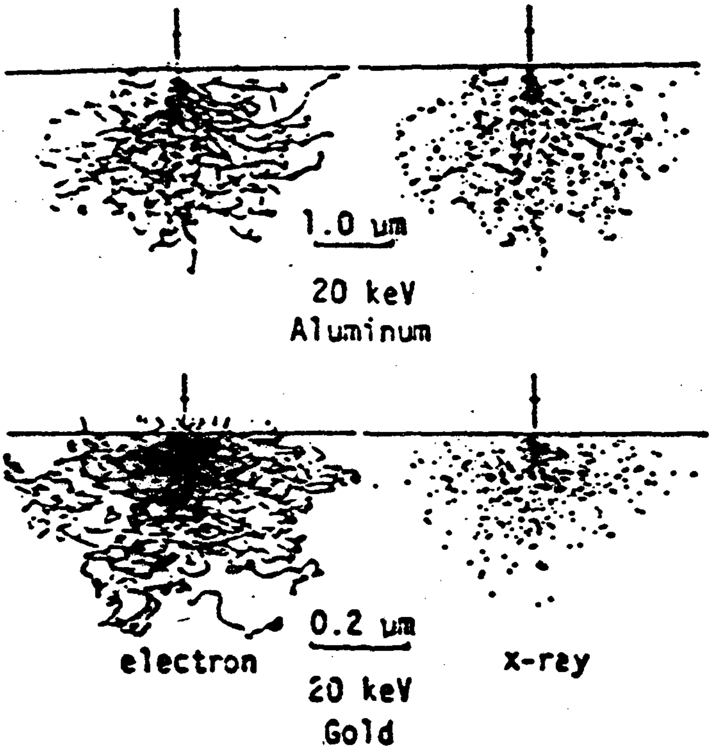


Figure 5

SUBMICRON X-RAY PROBE WILL SURPASS ELECTRON RESOLUTION FOR THICK SAMPLES-



FROM CURGENVER AND DUNCUMB
TIRL REPORT 303, ESSEX, ENGLAND, 1971

Figure 6

AN X-RAY MICROPROBE WILL BE UNIQUE

1. Nondestructive

   Reduced heat and radiation damage by 10^{-3} to 10^{-5}

   Intact samples

2. Minimum sample preparation/modification

   Bulk samples-no thinning

   Negligible charge collection-uncoated insulators

3. Advanced microanalysis

   Lower detection limits by 10^{-3} to 10^{-4}; PPB; Fast

   Strain resolution $\Delta d/d$ to 10^{-5}

   Penetrate below sample surface

   Improved spatial resolution in thick samples to 500 Å

   No vacuum required (in vivo, air, water,gases, encapsulated).

Figure 7

EARLY 1960 X-RAY MICROPROBE

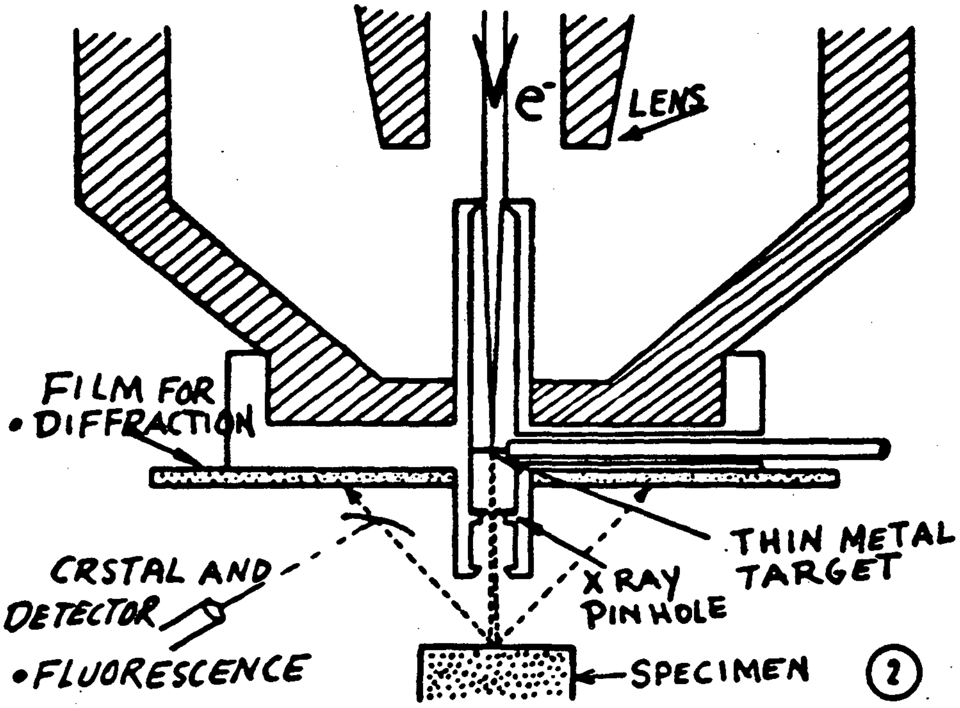


Figure 8

THE ADVENT OF HIGH BRILLIANCE ELECTRON MICROPROBES ENDED THE STRUGGLE TO USE WEAK X-RAY SOURCES

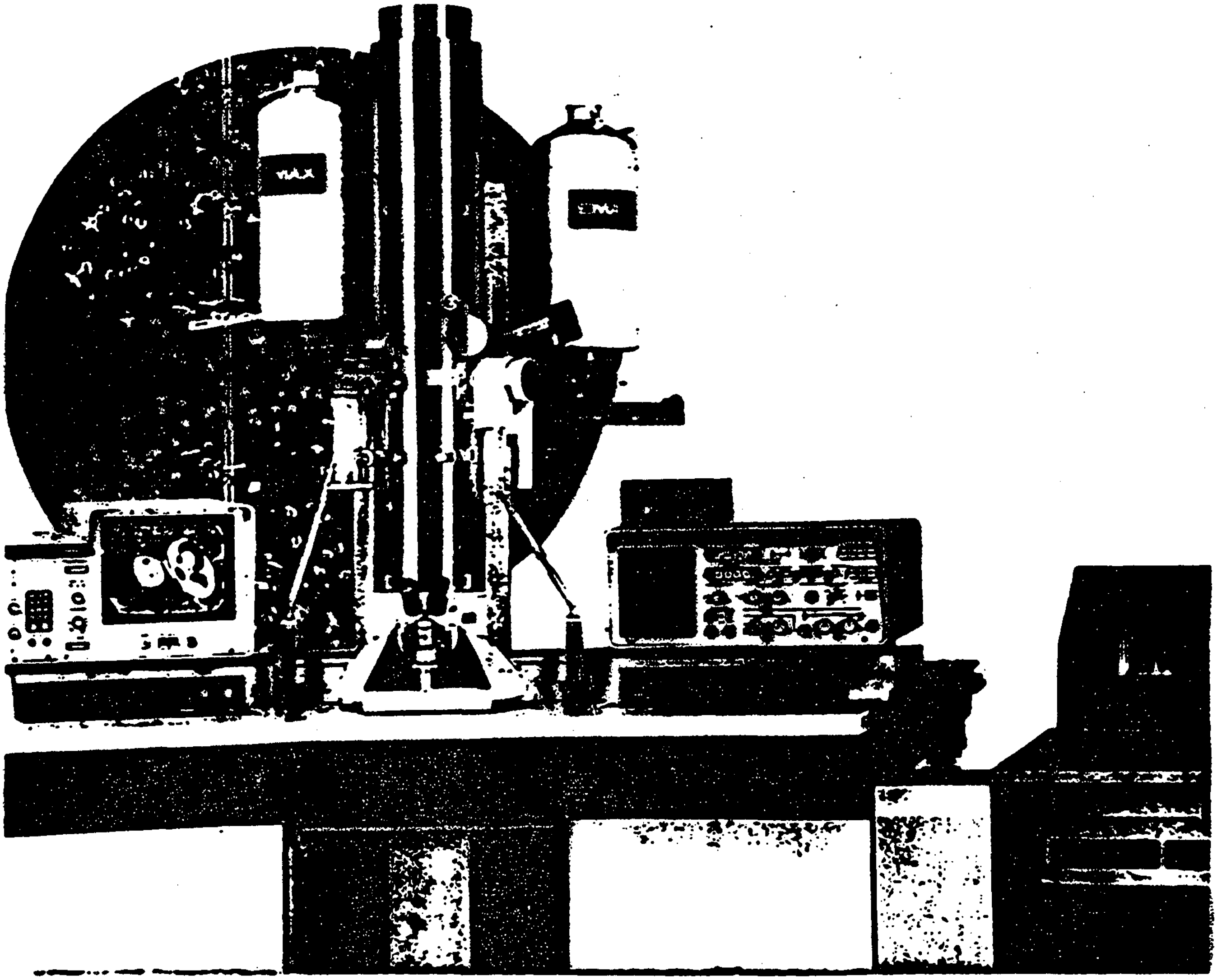
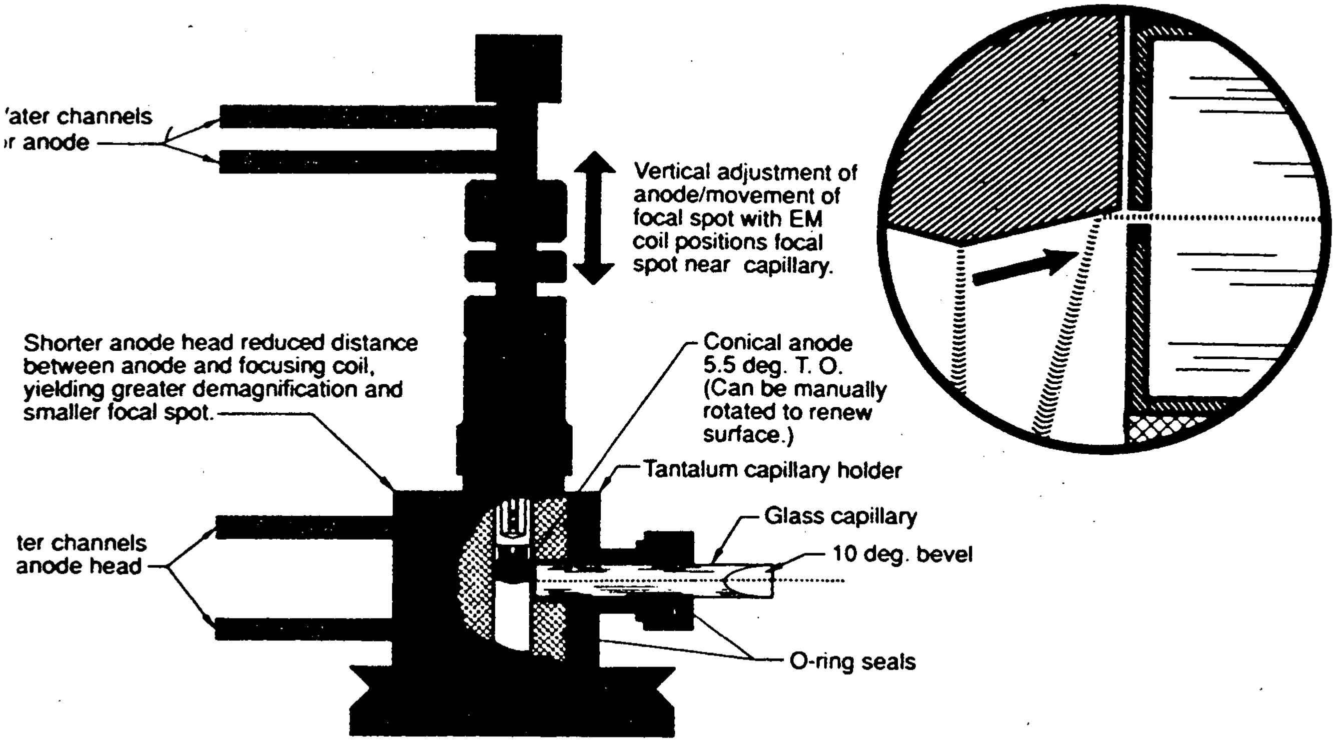


Figure 9

Recent x-ray microprobes using laboratory sources have used condensing capillary optics.



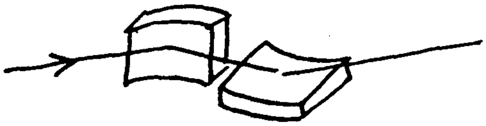
Beam Parameters of the Oak Ridge Microprobe

Capillary Size	Anode	Ni kα Fluorescence (c/s)	Beam Power (c/s)
10 μm	Mo	3300	8×10^5
10 μm	W	6865	7×10^5

Figure 10

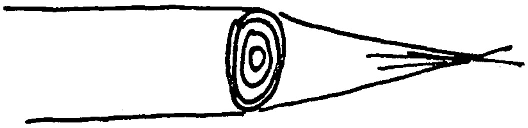
X-RAY OPTICS ARE EVOLVING TO ACHIEVE SMALL FOCAL SPOTS.

1. KIRKPATRIK-BAEZ CROSSED MULTILAYERS OR MIRRORS



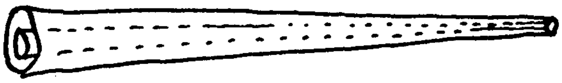
- Demonstrated 50· % efficient, 200:1, ~ 1 μm
- Wide bandpass.

2. X-RAY ZONE PLATES



- Demonstrated 33% efficient, 100:1, ~ μm
- Chromatic aberration limits bandpass/focal spot size

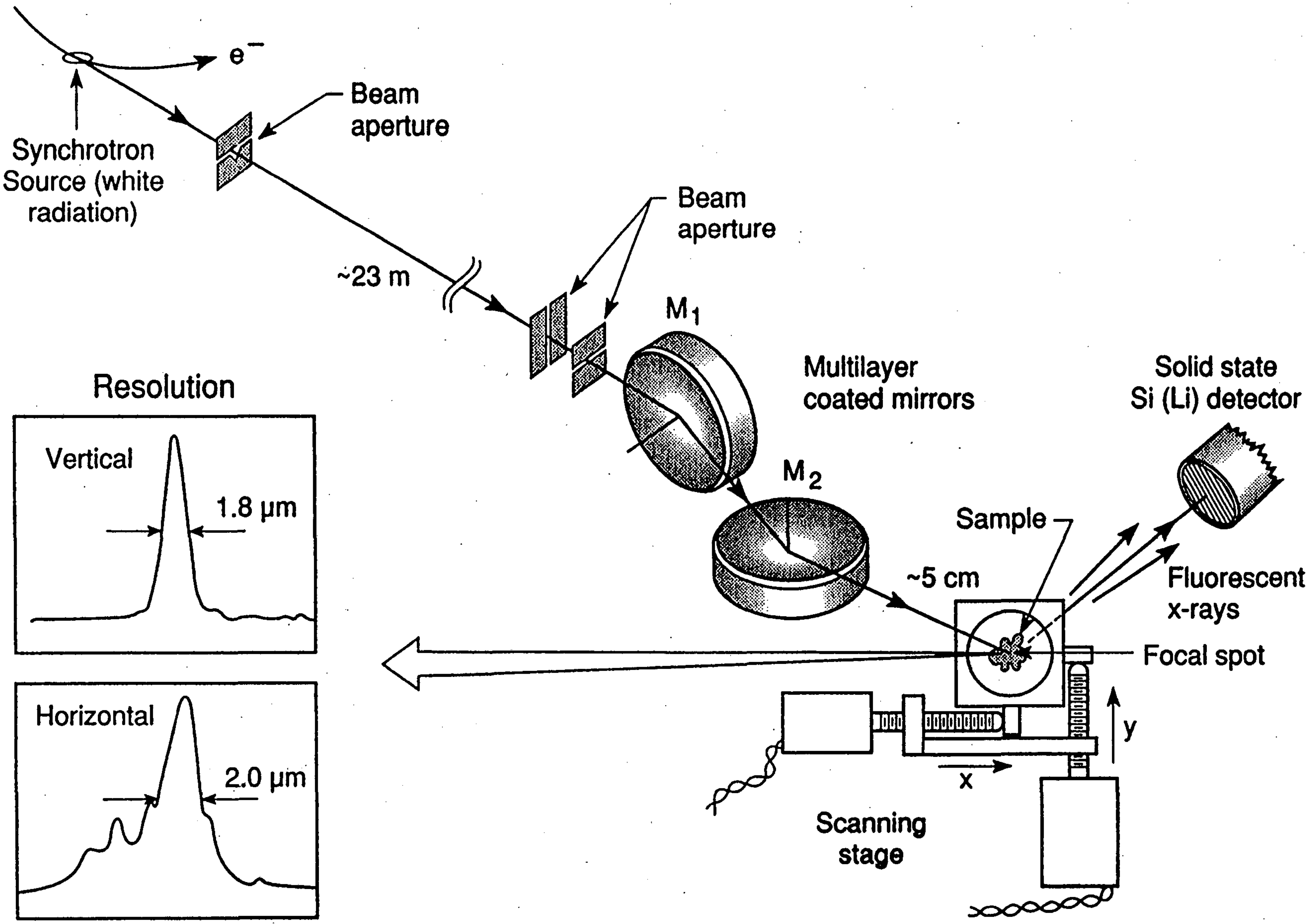
3. CONDENSING CAPILLARIES



- Demonstrated 50% efficiency 22μm → 2μm, submicron reported
- Must be near sample
- Used in existing lab microprobes.

Figure 11

X-Ray Microprobe Using Synchrotron Radiation



XBL 903-5796

Figure 12

Negligible aberrations with elliptical mirrors.

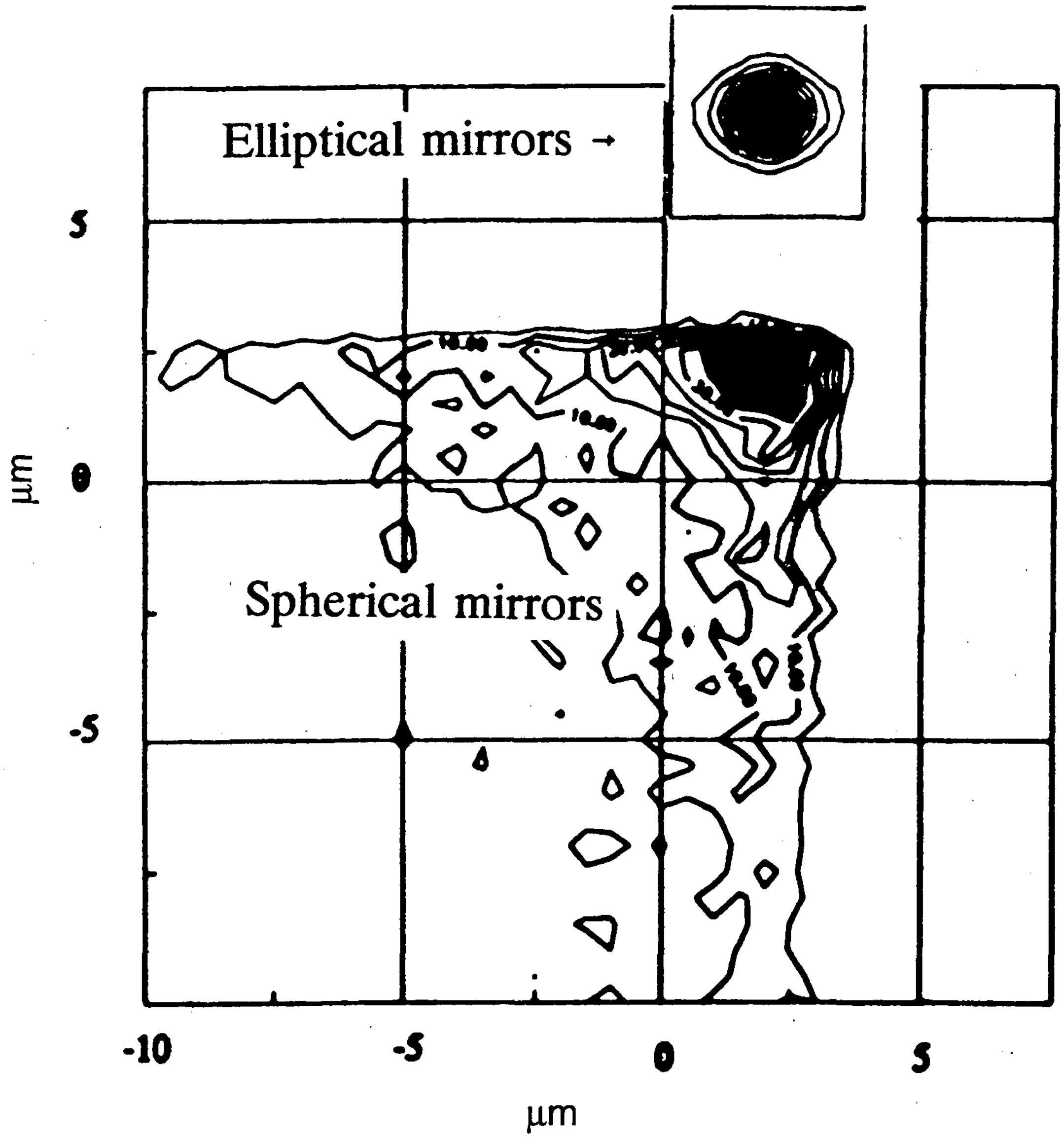


Figure 13

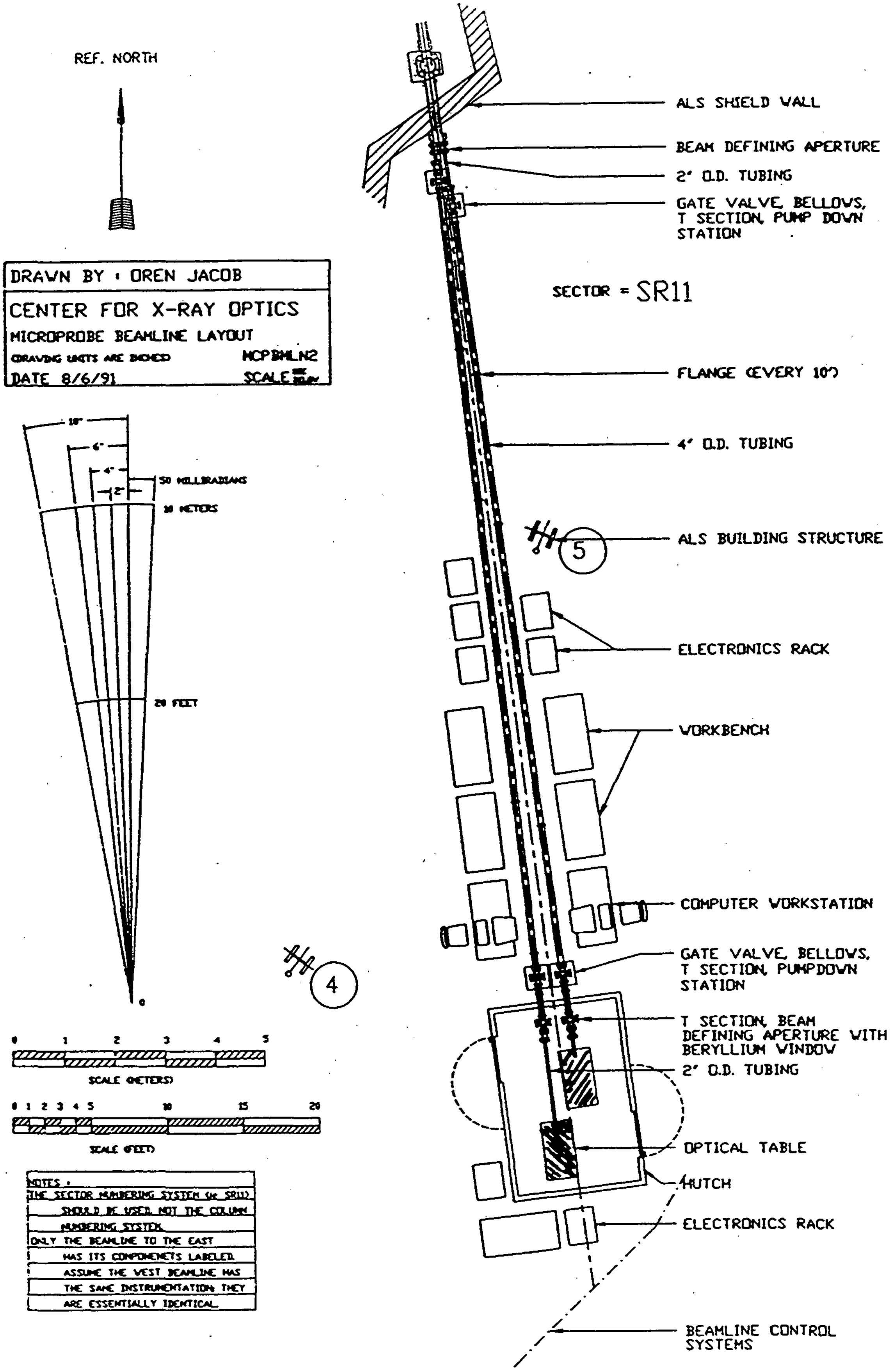

REF. NORTH
DRAWN BY : OREN JACOB
CENTER FOR X-RAY OPTICS
MICROPROBE BEAMLINE LAYOUT
DRAWING UNITS ARE INCHES
MCPBMLN2
DATE 8/6/91
SCALE
10"
6"
4"
2"
50 MILLIRADIANS
10 METERS
20 FEET
0
0 1 2 3 4 5
SCALE (METERS)
0 1 2 3 4 5 10 15 20
SCALE (FEET)
NOTES :
THE SECTOR NUMBERING SYSTEM (ie SR11)
SHOULD BE USED, NOT THE COLUMN
NUMBERING SYSTEM.
ONLY THE BEAMLINE TO THE EAST
HAS ITS CONPONENETS LABELED.
ASSUME THE WEST BEAMLINE HAS
THE SAME INSTRUMENTATION, THEY
ARE ESSENTIALLY IDENTICAL.
4
5
SECTOR = SR11
ALS SHIELD WALL
BEAM DEFINING APERTURE
2" O.D. TUBING
GATE VALVE, BELLOWS, T SECTION, PUMP DOWN STATION
FLANGE (EVERY 10')
4" O.D. TUBING
ALS BUILDING STRUCTURE
ELECTRONICS RACK
WORKBENCH
COMPUTER WORKSTATION
GATE VALVE, BELLOWS, T SECTION, PUMPDOWN STATION
T SECTION, BEAM DEFINING APERTURE WITH BERYLLIUM WINDOW
2" O.D. TUBING
OPTICAL TABLE
HUTCH
ELECTRONICS RACK
BEAMLINE CONTROL SYSTEMS

Figure 14

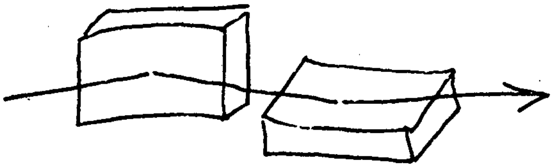
MICROFLUORESCENCE ANALYSIS WILL ADVANCE UNDERSTANDING OF ELEMENTAL DISTRIBUTIONS

Applications-materials, biological, environmental

Synchrotron radiation important-brilliance limited.

Emittance limited x-ray optics

S/N best for limited bandpass



MOSAIC CRYSTAL SPECTROMETERS

Resolution near perfect crystal

Int. reflectivity 10-1000 better

Avoids matrix from swamping detector

Achieves best MDL.

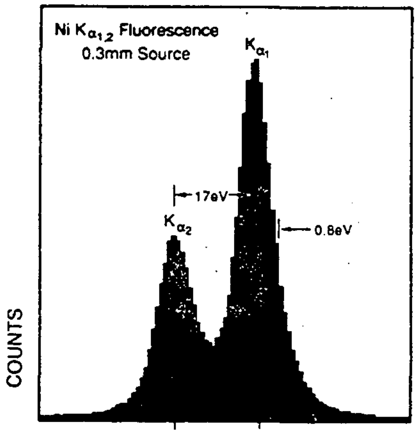
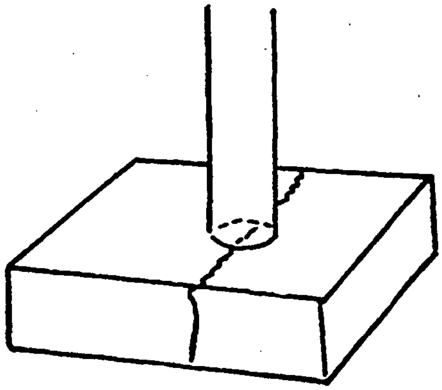


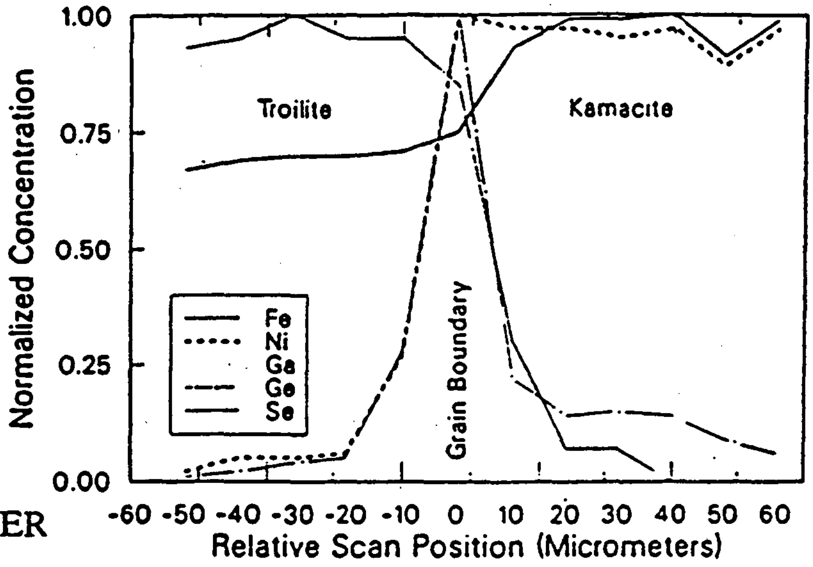
Figure 15

ELEMENTAL DISTRIBUTION CRUCIAL TO BEHAVIOUR OF MATERIALS

INTERFACES



X RAY MDL ~ 5 x 10^{-5} MONOLAYER
AES (CLEAVED) MDL ~ 10^{-2}.



Segregation at a grain boundary
M. Rivers, S. Sutton and B. Gordon
Mater. Res. Soc. Symp. Proc. 143
739 (1986).

SURFACE IMPURITIES/SECOND PHASES

MDL WITH μm^2 PROBE

- 2.7 x 10^{-4} Monolayer
- 5 x 10^3 Atoms
- 40 Å- diam Particle

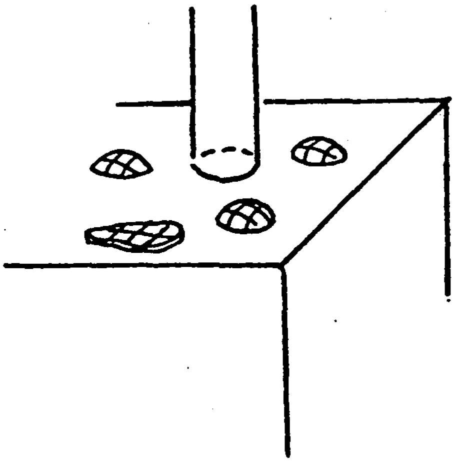
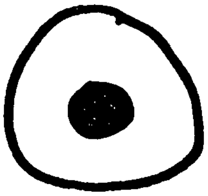


Figure 16

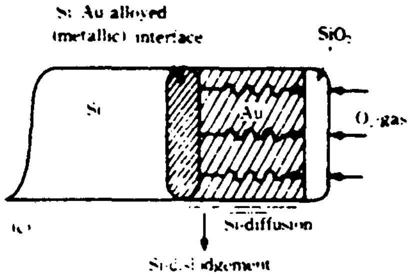
Toxic/radioactive waste encapsulation



Grain boundary diffusion

- Integrated circuits-


(a) (b)

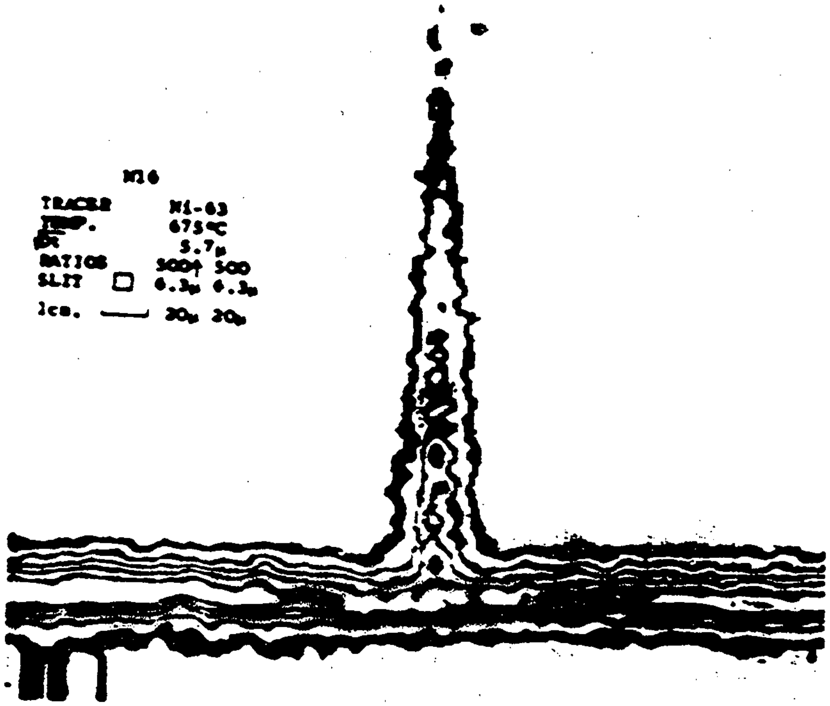


- **Structural materials - e.g. S in Ni**

Figure 17

DIFFUSION CAN BE MEASURED QUANTITATIVELY AND EXTRAPOLATED MORE RELIABLY

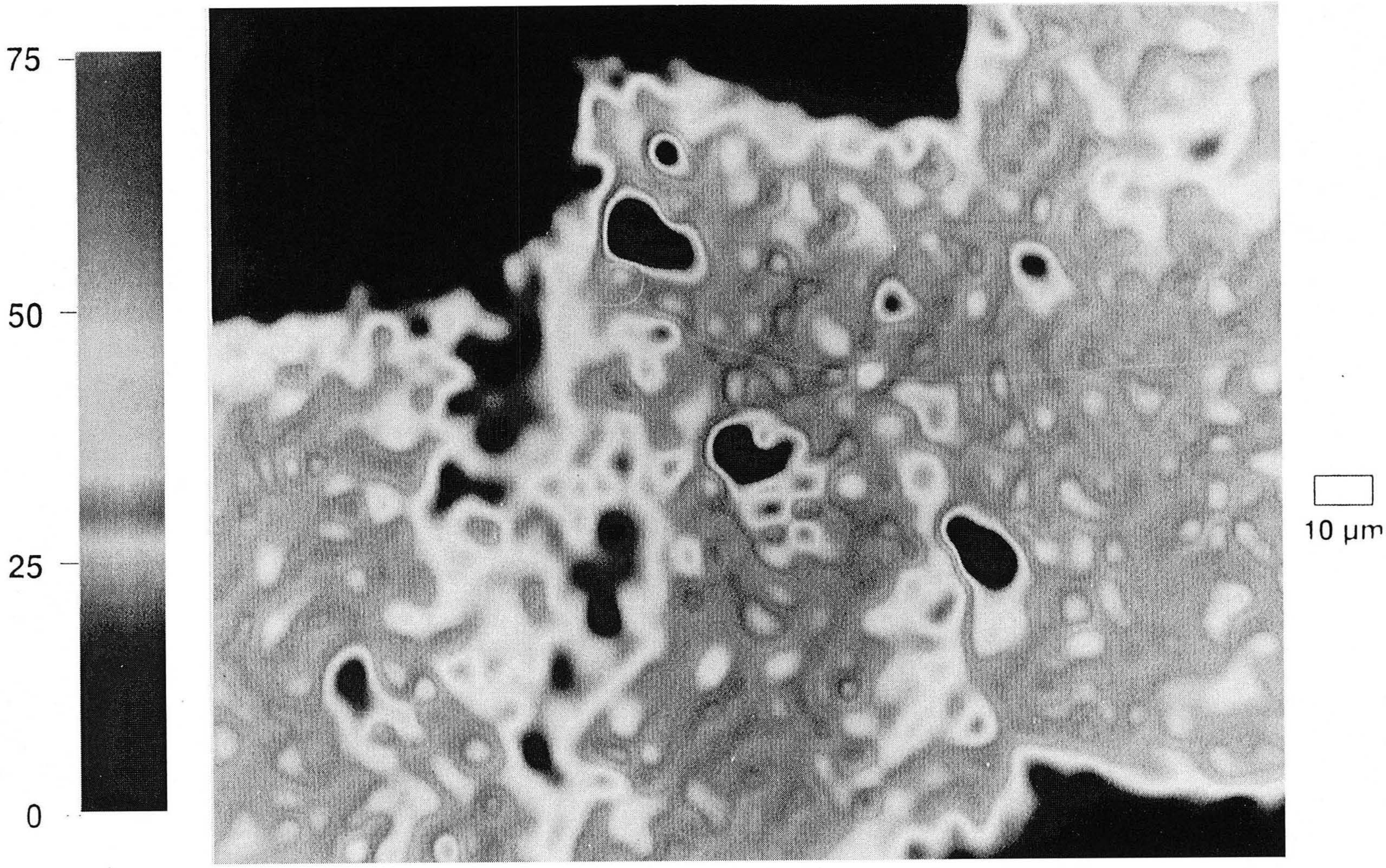
- Diffusion along grain boundries can be studied



- Greater sensitivity will speed measurement of diffusion; Sample can be tested later to verify extrapolated performance.

Figure 18

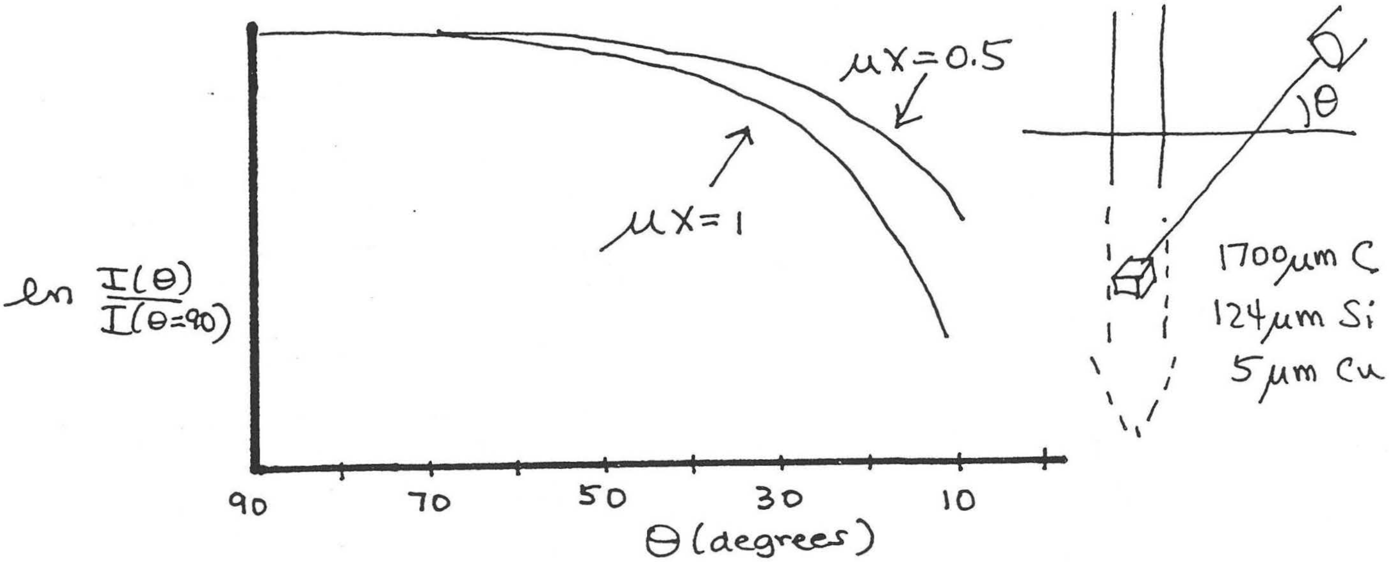
Surface Interaction of a Chromium Salt with Galena, PbS



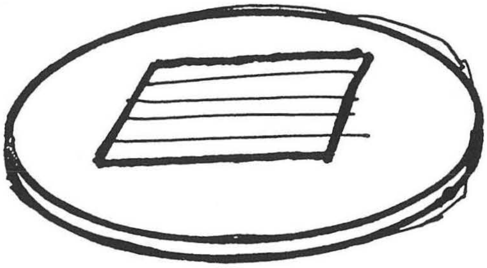
5 µm 2s 240 × 300 µm 10 keV 6 × 7 µm

Figure 19

Linear absorption can be used to measure near surface depth distributions.



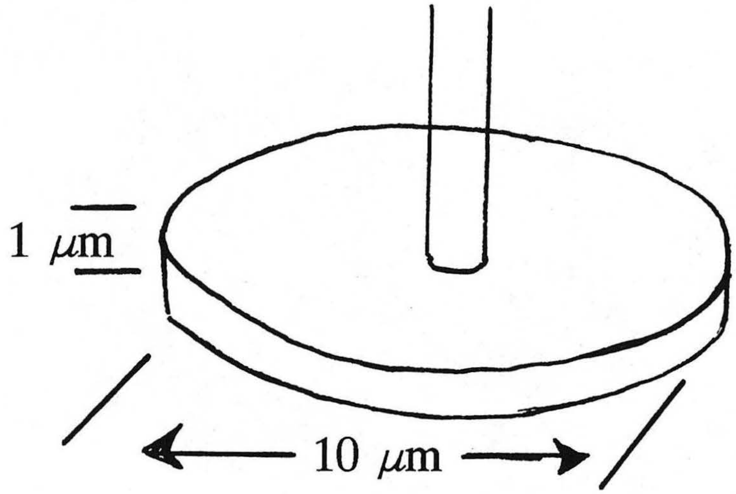
Important for samples not suitable for transmission tomography.



Requires smooth or well characterized surface

Figure 20

BIOLOGICAL SPECIMENS CAN BE EXAMINED WITH MINIMUM DAMAGE AND HIGH ELEMENTAL SENSITIVITY.



Single Red Blood Cell

50 PPB

10^{-4}-10^{-5} less energy deposited.

Quantitative analysis Al, Br, Ca, Cl, Co, Cu, I, K, Pb, Mn, and P.

Figure 21

ELEMENTAL ANALYSIS OF THE CHRONOLOGICAL GROWTH PATTERNS IN BIOLOGICAL STRUCTURES PORTRAY ENVIRONMENTAL EXPOSURE TO TOXIC ELEMENTS.

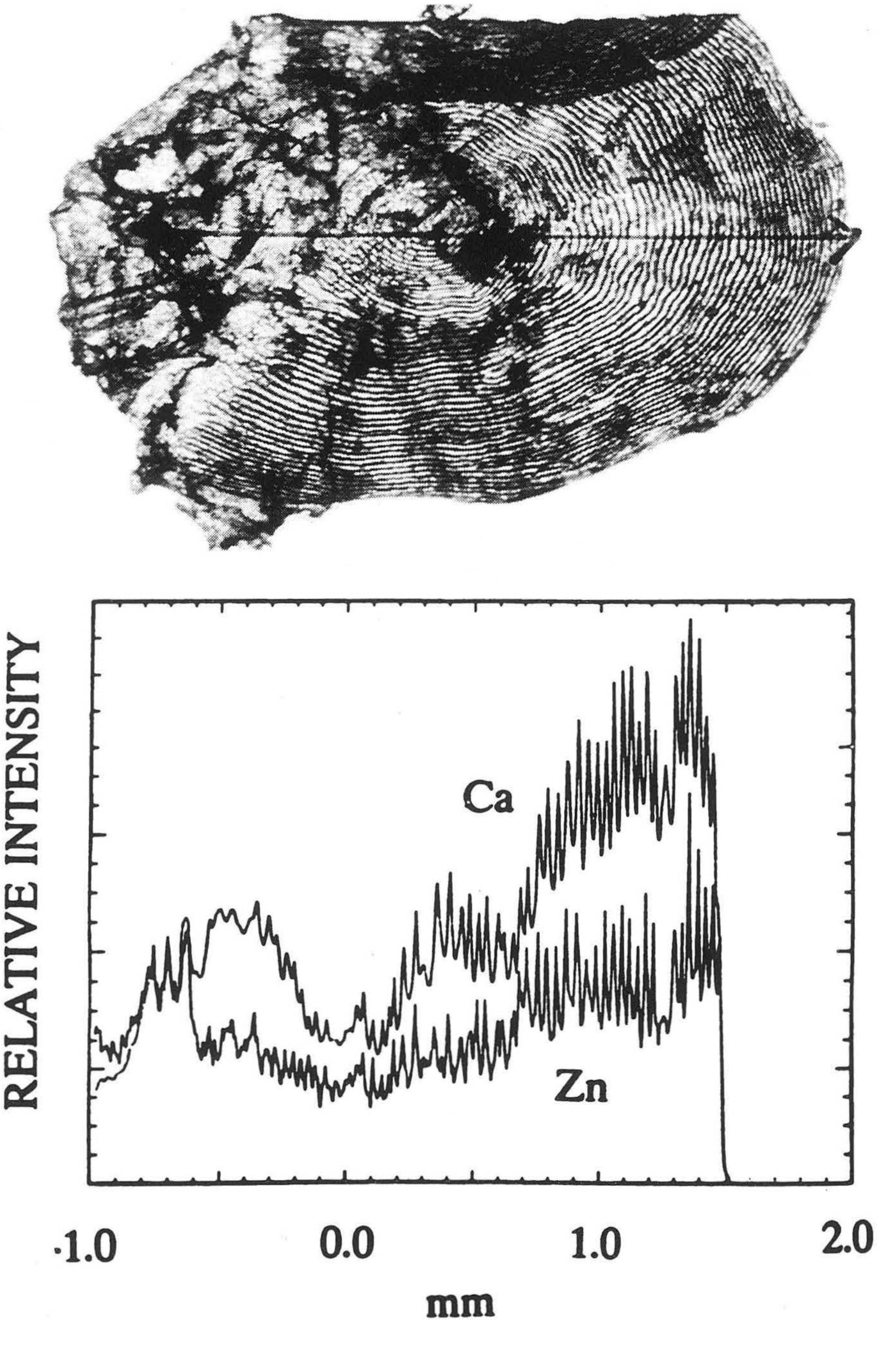
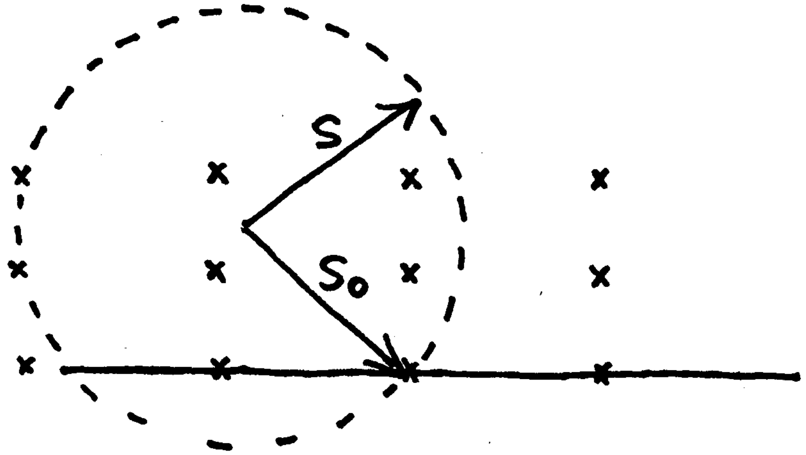


Figure 22

X-RAY DIFFRACTION IS THE PREMIER TOOL FOR MEASURING ATOMIC STRUCTURE.

Wavelength well matched to atomic spacing-distinct reflections.



Samples many planes

→ Phase identification

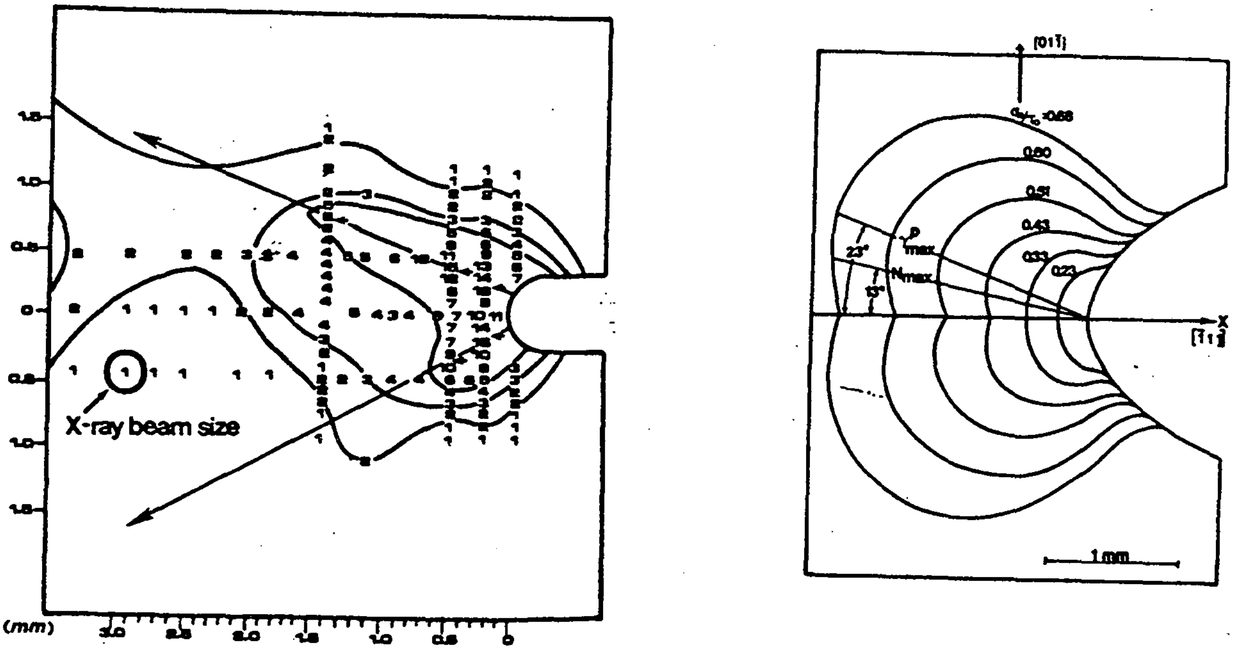
→ Strain mapping Δa/a ~ 10^{-7}-10^{-8}

Microdiffraction is brilliance limited-APS crucial to achieve submicron resolutions.

Figure 23

REPORTED MICRODIFFRACTION EXPERIMENTS PRIMARILY HAVE USED LABORATORY X-RAY SOURCES

Weissmann et. al. (1974-1982)- Combines rocking curves with electron imaging and topography to study crack tip strain.



Experiment

Theory

Microdiffraction allows quantitative comparison to theory.

Figure 24

TUNABLE RANGE OF 300-1000 eV WITH LINEAR OR AREA DETECTOR WILL ALLOW STRAIN DETERMINATION.

FIXED ENERGY

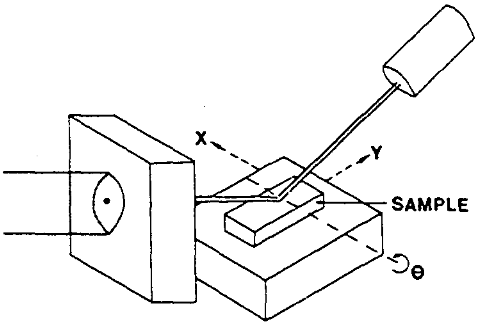


Fig. 1. Schematic drawing of the geometry used to measure strain fields with monochromatic radiation. The X-ray beam size at the pinhole was about 1.5×1.5 mm^2. Replacement of the detector with a position sensitive detector will allow simultaneous measurement of the crystallographic tilts and *d* space variation.

TUNABLE ENERGY

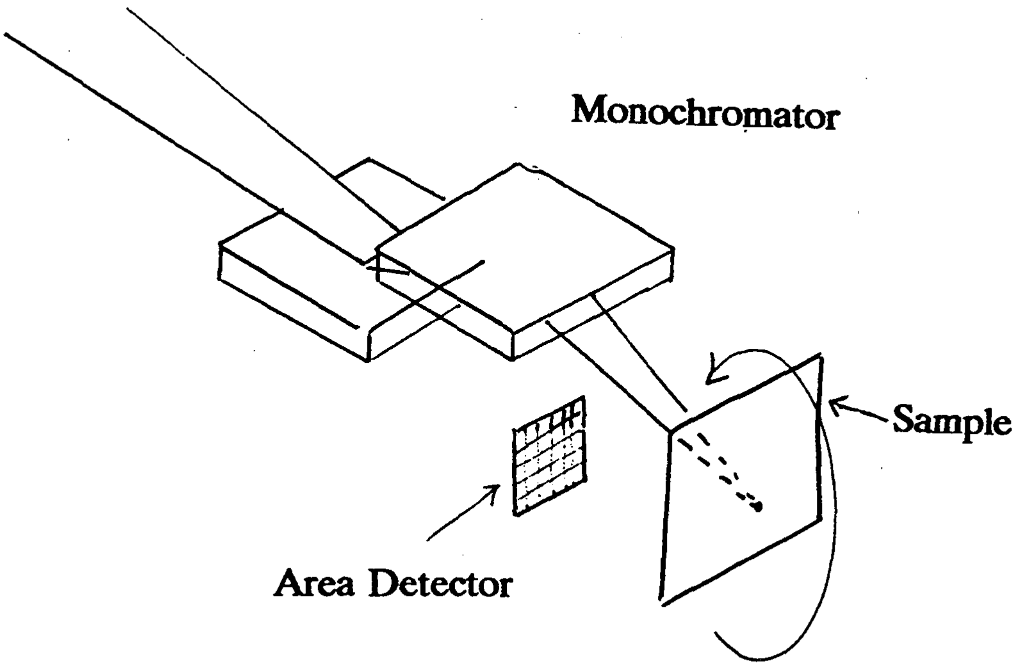


Figure 25

X-RAY MICRODIFFRACTION EXPERIMENT AT CRACK TIP IN MANGANESE AUSTENITIC STEEL IDENTIFIES "RESTORED" AND OR "POLYGONIZED" ZONE NEAR CRACK TIP.

Latiere and Picard (1982)- 100μm

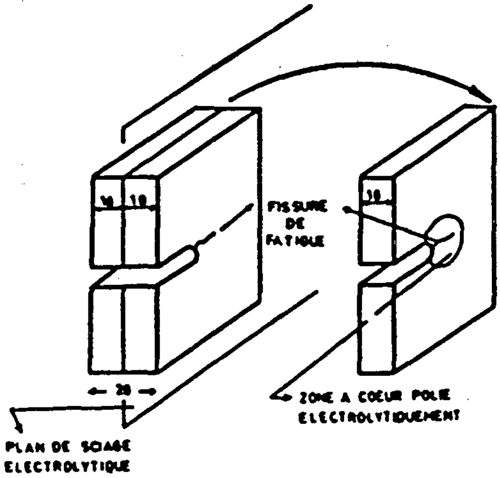


Fig. 1. – Schéma de préparation des éprouvettes.

Fig. 1. – Samples preparation plan.

Rappaz,Kaspar,Blank (1984-1987) measure strain and defects combining ω and 2θ micro-diffraction measurements with topograph.

- 100 μm resolution
- full 4-circle geometry

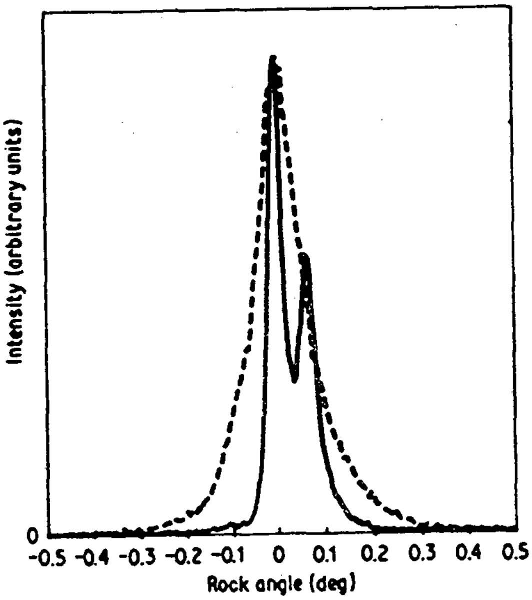
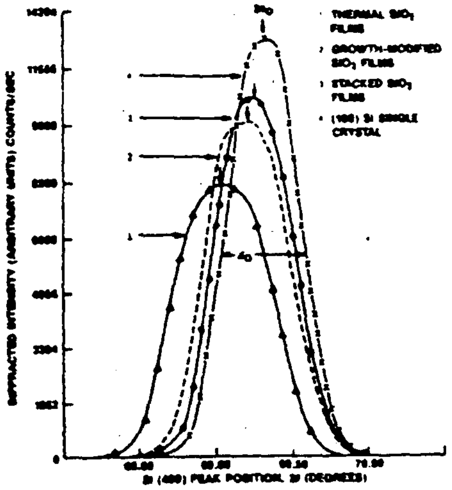


Figure 26

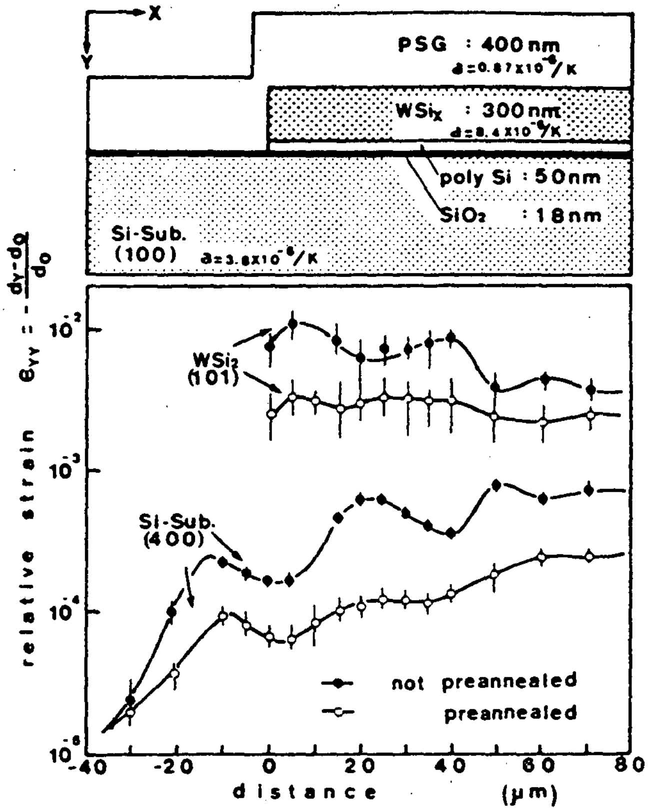
X-RAY MICRODIFFRACTION MEASUREMENTS OF STRESS AT INTERFACES DETECTS EFFECTS OF PROCESSING

- Roy nad Kannan Si/SiO$_2$ interface 1989- 30 μm



XRMD Si (400) PEAK POSITION PROFILE
IN (100) Si/SiO$_2$ STRUCTURE
FOR VARIOUS GATE OXIDE FILMS

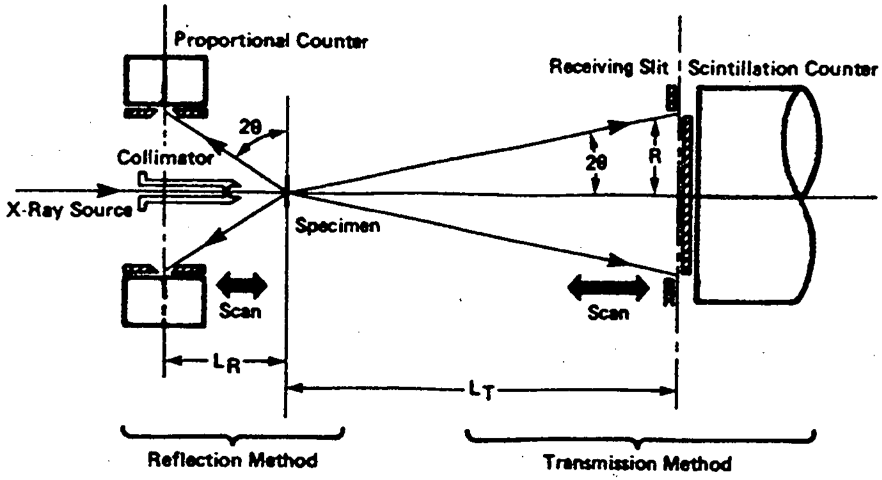
Yamamoto and Hosokawa- WSi$_x$/ Si 1988 6 μm beam with energy dispersive detector.



Strain Distribution in WSi$_x$/poly Si MOS capacitor. The "a"

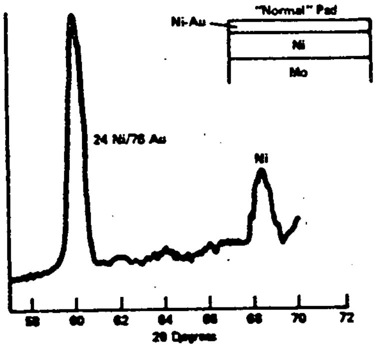
Figure 27

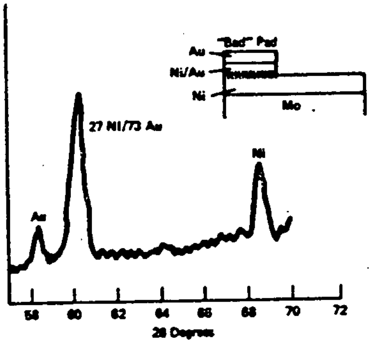
Goldsmith and Walker (1984)- Rigaku Micro-diffractometer 30-100μm→



Geometrical Arrangement

- phase identification of "stain"





- Measurement of strain in palladium plated pin heads (0.7 mm)

- Measurement of strain in alumina between engineering-change pads

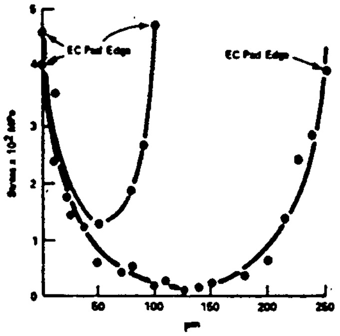


Figure 28

ROCKING CURVES NEAR PRECIPITATE USING 25μ PINHOLE SHOW LARGE LATTICE ROTATIONS

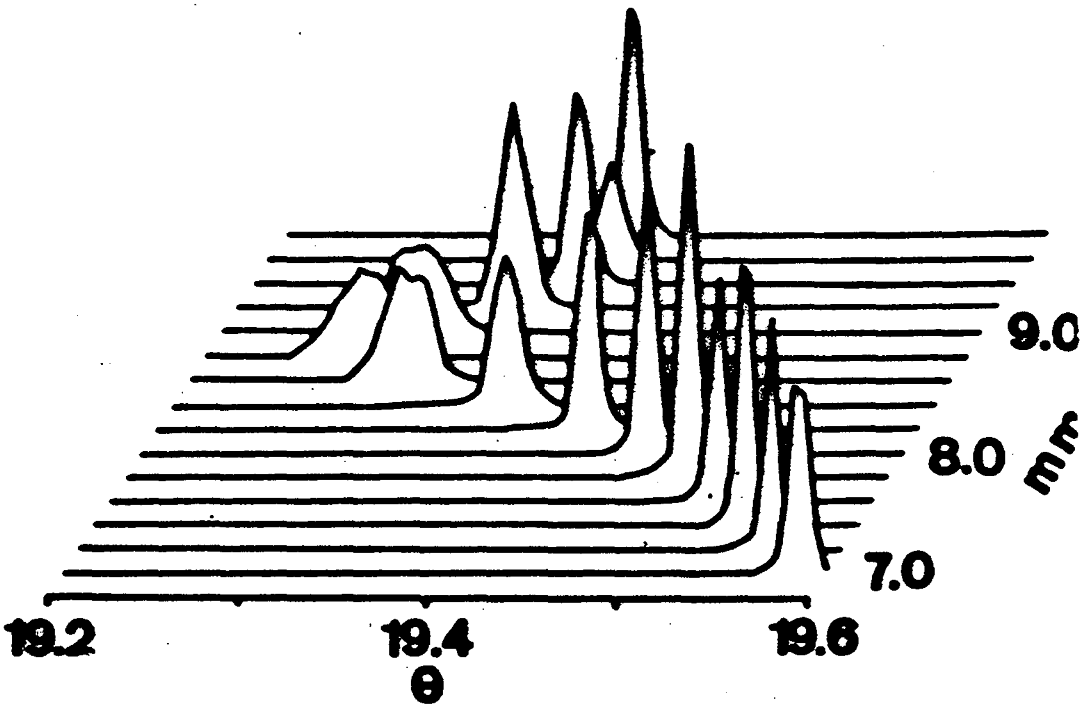
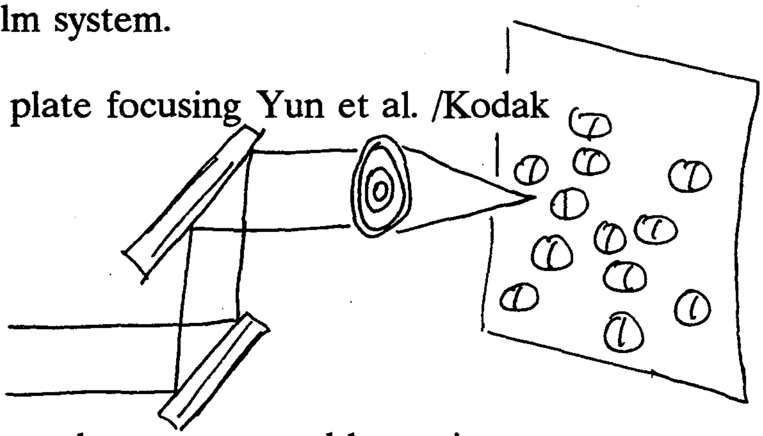


Figure 29

Zone plate focusing allows measurement of crystallite orientation in a two phase film system.

- Zone plate focusing Yun et al. /Kodak



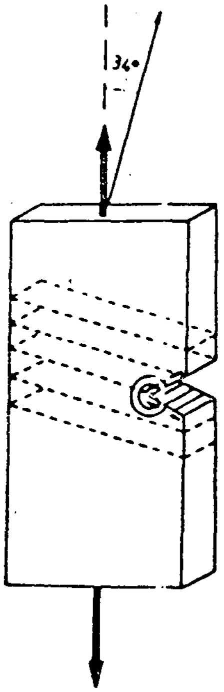
- Reciprocal space scanned by tuning x-ray energy

- Two phase particles ~ 0.5 μm^3 and 0.3 μm^3

- Associated phase orientation with partner phase and with substrate.

Figure 30

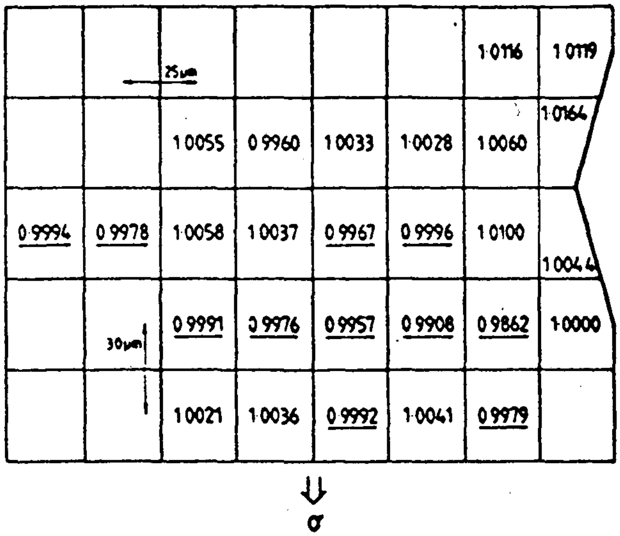
Synchrotron Microprobe allows study of strain in imperfect crystals.



Extends topography to crystals with too many dislocations

Separates lattice rotations from dilations.

Study purely local effects of free surfaces etc.



						1·0116	1·0119
		1·0055	0·9960	1·0033	1·0028	1·0060	1·0164
0·9994	0·9978	1·0058	1·0037	0·9967	0·9996	1·0100	1·0044
		0·9991	0·9976	0·9957	0·9908	0·9862	1·0000
		1·0021	1·0036	0·9992	1·0041	0·9979	

Thick samples

Highly sensitive
$\Delta d/d$ 10^{-5} X rays
$\Delta d/d$ 10^{-2} 100 keV e^-

Quantitative

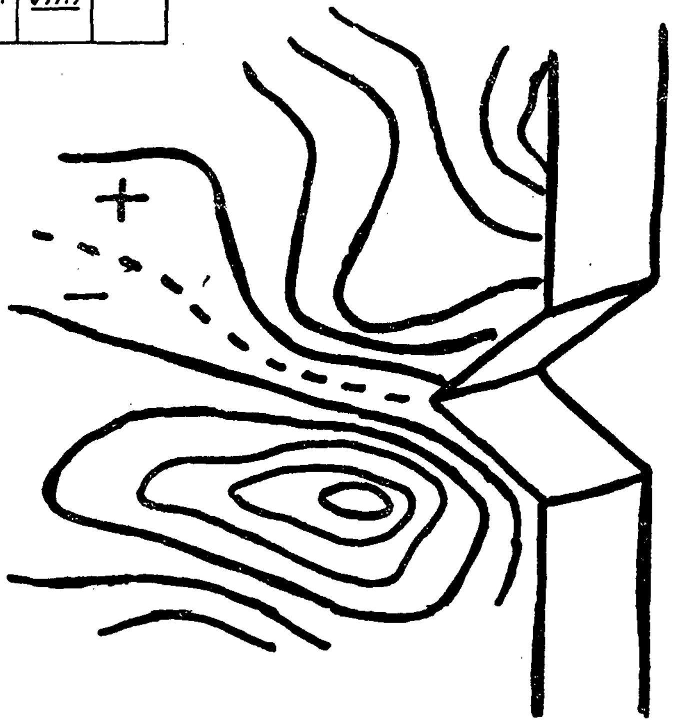
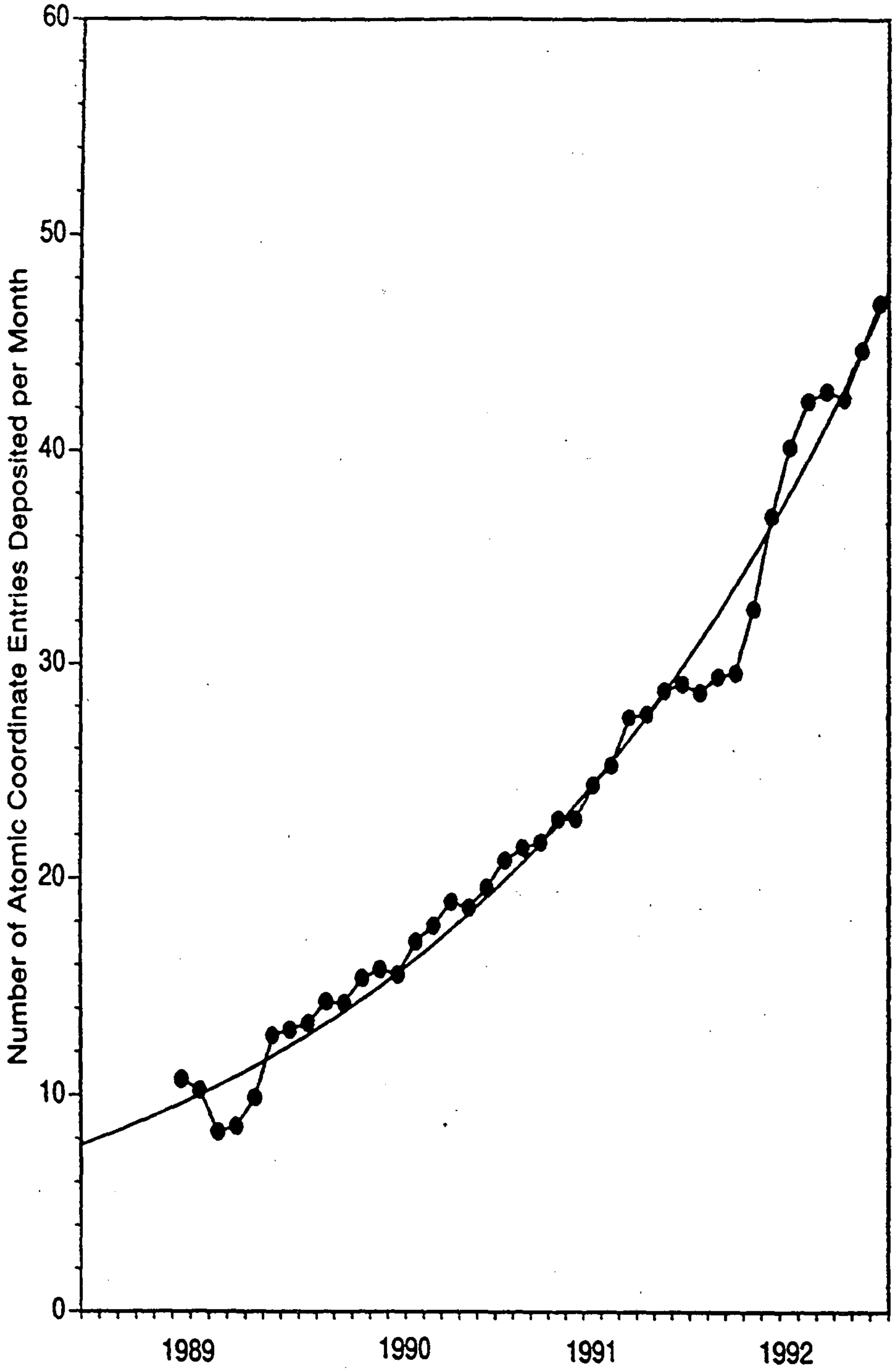


Figure 31

Proton Crystallography: Recent Developments and Plans for the ALS

S.-H. Kim

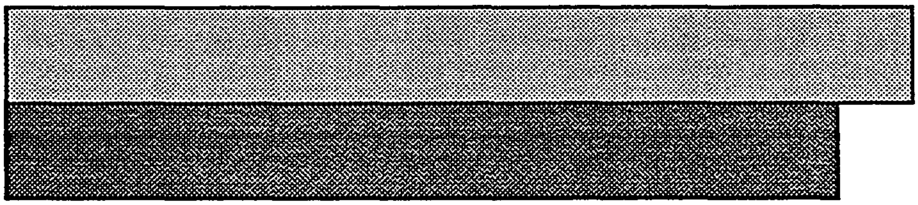
Structural Biology Division
Lawrence Berkeley Laboratory
University of California
Berkeley, CA 94720



Running 12-month average number of atomic coordinate entries deposited per month since 1989. The curve shows an exponential fit to the experimental data points. PDB

Normal

Monochromatic Beam



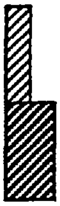
0.9 - 1.5 Å

MAD

Tunable Monocheromatic Beam

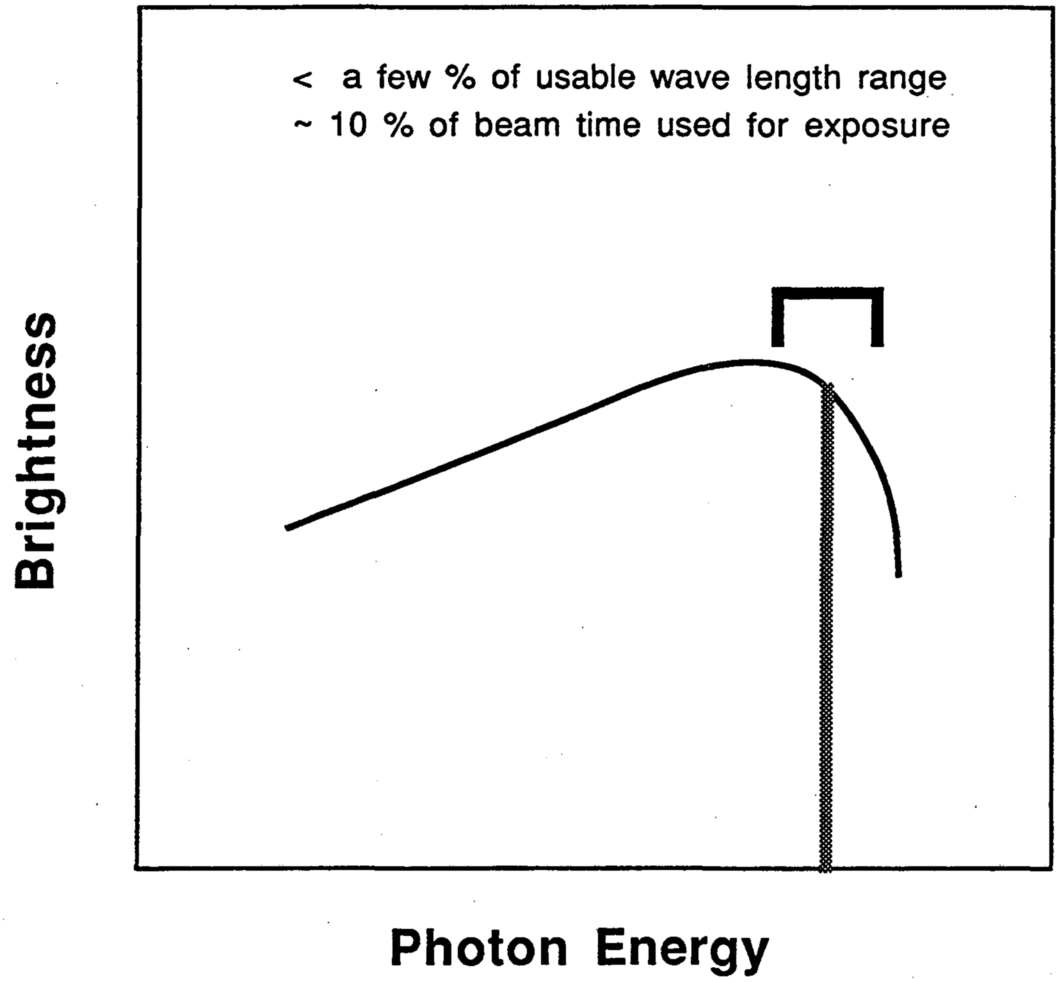
0.9 - 1.5 Å

Laue



General Beam

0.6 - 2.2 Å


< a few % of usable wave length range
~ 10 % of beam time used for exposure
Brightness
Photon Energy

Practical Limitations in Crystallographic Data Collection

Under optimal operating conditions (based on Photon factory runs)

4 data sets per 24 hr day (usually 3 data sets)

For each data set · 1 to 1.5 hr of data collection (17 to 25 %)
4.5 to 5 hrs of crystal screening and alignment (75 to 83 %)

- Data collection time can be shortened by using better detectors, but crystal screening and alignment time can not be shortened.
- Practical limit may still be about 4 data set per day per detector.

Factors to be considered for.........

- For most users any wavelengths between 0.9 to 1.5 Å are usable.
  e.g. 0.9, 0.95, 1.0, 1.05, 1.1 Å ..... etc.
- For most users very high brilliance is not essential.
  e.g. 60 sec. exposure per data frame
- For very small crystals (5 - 50 u) high brilliance is essential.
- For MAD users accurately tunable wavelength between 0.9 - 1.5 Å.
- For Laue users entire spectra between 0.6 - 2.2 Å are usable.
- User friendliness is of the utmost importance to the majority of users.
- Remember the ratio of state-of-art feature users to routine monochrom users is less than 1 to 10, and any facility supported by public funds should benifit the majority of user community while supporting frontier research requiring special features.

Applications of High-Brightness Synchrotron Radiation to Protein Crystallography

E. Westbrook
Argonne National Laboratory

Explosive growth of information in molecular and cellular biology during the past decade has contributed to, and been aided by, a simultaneous growth in our ability to solve protein crystal structures rapidly. Synchrotron x-ray sources have enormous potential to contribute to this expansion in structural biology, but much of that potential has not been realized in the past.

The Structural Biology Center of Argonne National Laboratory is developing a systematic program to design, build, and operate synchrotron-based data-collection facilities for protein crystallography. At present, we operate two beamlines at the NSLS in Brookhaven National Laboratory, and we are now developing designs for two additional beamlines to be built on the APS in Argonne National Laboratory.

It is not sufficient to develop excellent x-ray optics on high-brightness synchrotron sources. Detectors that match the technical power and capability of bright synchrotron beamlines must also be designed, built, and operated. Furthermore, technical instrumentation along will not make a data-collection facility function optimally; the entire operation must be properly organized, staffed, funded, and run. We are now testing a number of ideas about facilities management at the NSLS, and we expect to improve the data-collection performance of our beamlines as we go.

We are developing new detectors for synchrotron x-ray beamlines that are optimized for macromolecular crystallography. These detectors are based upon charged-coupled devices (CCD) technology. X-rays are imaged with a thin phosphor film, and the image is projected quantitatively onto CCD chips. Our current detectors make use of image intensifiers; the next generation will not. Big active surfaces are necessary for good detectors, so we are using fiber-optic tapers to photoreduce images onto the small CCD chips. Without image intensifiers, each taper's reduction ratio must remain limited or too much light will be lost and the detector will be inefficient. Therefore, we now make detectors from arrays (or mosaics) of smaller modules.

One module has been built, tested, and is now operational at beamline X14 of the NSLS. Its detective quantum efficiency is 89%, its dynamic range is about 10,000:1, its point-spread function is 150 μm FWHM, and its readout requires 0.8 seconds.

The detector prototype we are now building contains nine such modules, arranged in a 3 × 3 array. Its total front surface will be a square 153 mm on a side. It will be read out into 3,072 × 3,072 pixels and multiplexed in 36 readout channels. The 3 × 3 array detector is expected to exhibit characteristics similar to those of the X14 single module when it is installed at beamline X8C of the NSLS in May 1993.

Larger, faster detectors are now on the drawing boards. Our goal is to create a detector capable of handling the immense x-ray fluxes we will generate on APS wigglers and undulators in 1997. Users of APS beamlines must be able to record, back up, process, and reduce a complete 3D diffraction dataset from a protein crystal within 30 minutes. Therefore, we are also developing crystal-handling equipment, software, computer networking and interfacing, graphical user interfaces, and other methods to optimize utilization of each beamline. We believe these activities will permit synchrotron sources to fulfill their full promise as valuable resources for structural biology.

Appendix A: Program

ALS Users' Association Annual Meeting

Building 50 Auditorium
August 27–28, 1992

Wednesday Evening, August 26:

6:00 – 8:00 p.m.	Registration and Reception	Shattuck Hotel

Thursday, August 27:

7:30 – 8:30 a.m.	Special Shuttle Bus Service (Approximately every 20 minutes)	Shattuck Hotel to LBL Building 50 Auditorium
8:00 – 8:30	Registration and Coffee	Building 50, Auditorium Lobby Area

Introduction to the ALS

(Chair: Dennis Lindle, University of Nevada, Las Vegas)

8:30 – 8:45	Welcome	C.V. Shank, Director, LBL
8:45 – 9:15	Report from DOE	W. Oosterhuis, DOE, Basic Energy Sciences
9:15 – 10:00	ALS Project Status	J.N. Marx, Director, ALS
10:00 – 10:30	**BREAK**	
10:30 – 11:00	Accelerator Commissioning	A. Jackson, Deputy Director for Accelerator Systems, ALS
11:00 – 11:30	Experimental Facilities	B.M. Kincaid, Deputy Director for Experimental Systems, ALS
11:30 – 12:00 p.m.	ALS User Program	A.S. Schlachter, Scientific Program Coordinator, ALS
12:00 – 1:45	Box Lunch, PRT Posters, and Tour of the ALS	Building 6

Electron and X-Ray Emission

(Chair: Brian Tonner, University of Wisconsin–Milwaukee)

1:45 – 2:15	Scientific Program	P. Ross, Acting Scientific Director, ALS
2:15 – 3:00	High-resolution Photoemission	I. Lindau, MaxLab
3:00 – 3:30	**BREAK**	
3:30 – 4:15	Photoelectron Diffraction/Holography	C. Fadley, UCD/LBL
4:15 – 5:00	X-ray Emission	T. Callcott, University of Tennessee
5:00 – 5:30	User Meeting	P. Pianetta, Chair, ALS Users' Association
5:30	**ADJOURN**	Special Shuttle Bus Service to Shattuck Hotel
6:45	Special Shuttle Bus Service	Shattuck Hotel to Hong Kong East Ocean Seafood Restaurant
7:00	Reception	Hong Kong East Ocean Seafood Restaurant

Thursday, August 27 (Con't):

7:30	Conference Banquet	Speaker: Pat Williams, Earth Sciences Division, LBL Subject: Earthquakes, Basins, and Mountains: New Understanding of California's Plate Boundary
10:00	Special Shuttle Bus Service	Restaurant to Shattuck Hotel

Friday, August 28:

7:45 – 8:30 a.m.	Special Shuttle Bus Service (Approximately every 20 minutes)	Shattuck Hotel to LBL Building 50 Auditorium
8:00 – 8:30	Coffee	Auditorium Lobby Area

Spectroscopy and Microscopy

(Chair: Christof Kunz, University of Hamburg, Germany)

8:30 – 9:15	Gas-phase Spectroscopy	J. Samson, University of Nebraska
9:15 – 10:00	Spectromicroscopy	H. Ade, SUNY Stony Brook
10:00 – 10:30	**BREAK**	
10:30 – 11:15	X-ray Dichroism Experiments Using Circular Polarization	J. Tobin, Lawrence Livermore National Laboratory
11:15 – 11:45	Microscopy of Magnetic Materials	Y. Wu, IBM Almaden Research Center
11:45 – 1:45 p.m.	BOX LUNCH and Industrial Exhibit	Building 70A

Applications

(Chair: Stephen Cramer, UCD/LBL)

1:45 – 2:30	Projection Lithography	J. Bokor, AT& T Bell Laboratories
2:30 – 3:15	Bend-magnet Microprobe	G. Ice, Oak Ridge National Laboratory
3:15 – 3:45	**BREAK**	
3:45 – 4:30	Protein Crystallography: Recent Developments and Plans for the ALS	S.-H. Kim, LBL
4:30 – 5:00	Structural Biology with High-Flux Insertion Devices	E. Westbrook, Argonne National Laboratory
5:00 – 5:15	Conclusion	P. Pianetta, Chair, ALS Users' Association
5:15	**ADJOURN**	Special Shuttle Bus Service to Shattuck Hotel

APPENDIX B: LIST OF PARTICIPANTS

ADVANCED LIGHT SOURCE USERS' ASSOCIATION ANNUAL MEETING

August 27-28, 1992

Harald W. Ade
Suny @ Stony Brook
Stony Brook, NY 11794

Linda D. Anderson
U.S. Geological Survey/WRD
345 Middlefield Rd., MS 465
Menlo Park, CA 94025

David Attwood
Ctr. for X-Ray Optics
Lawrence Berkeley Laboratory
1 Cyclotron Road
Berkeley, CA 94720

Paul S. Bagus
IBM Almaden Research Ctr.
650 Harry Road
San Jose, CA 95120

Susan H. Barr
Argonne National Laboratory
XFD/APS Bldg. 362
9700 S. Cass Avenue
Argonne, IL 60439

Robert N. Beck
ANL
University of Chicago
5841 S. Maryland Ave.
Chicago, IL 60637

Raul Beguiristain
Lawrence Berkeley Laboratory
1 Cyclotron Road
Berkeley, CA 94720

John W. Bender
Rockwell Power Systems
2511C Broadbent Parkway NE
Albuquerque, NM 87107

Richard S. Benson
LeCroy Corporation
5912 Stoneridge Mall Rd #150
Pleasanton, CA 94588

Richard J. Blattner
Charles Evans & Associates
301 Chesapeake Drive
Redwood City, CA 94063

Jeffrey Bokor
AT&T Bell Laboratories
600 Mountain Avenue
Murray Hill, NJ 07733

Chris E. Brion
Department of Chemistry
University of British Columbia
2036 Main Mall
Vancouver, B.C. Can V6T 1Z1

Reinhard F. Bruch
Department of Physics
University of Nevada, Reno
Reno, NV 89557

C. R. Brundle
IBM Almaden Research Ctr.
650 Harry Road
San Jose, CA 95120

Howard C. Bryant
Physics & Astronomy
University of New Mexico
Albuquerque, NM 87131

Thomas Callcott
Physics Department
University of Tennessee
401 Nielsen Physics Bldg.
Knoxville, TN 37996

Katherine Cantwell
Stanford Synchrotron Rad. Lab.
P. O. Box 4349
Bin 69
Stanford, CA 94309

Renyu Cao
Stanford Synchrotron Rad. Lab.
P. O. Box 4349
Stanford, CA 94309

John Carusiello
Meyer Tool & Mfg., Inc.
9221 S. Kilpatrick Ave.
Oaklawn, IL 60453

Robert L. Chaney
Seiko Instruments, Inc.
1150 Ringwood Court
San Jose, CA 95131

Karen L. Chapman
Ctr. for X-Ray Optics
Lawrence Berkeley Laboratory
1 Cyclotron Road, Bldg. 2-400
Berkeley, CA 94720

Krishna M. Choudhary
Dept. of Electrical Eng.
University of Notre Dame
275 Fitzpatrick Hall
Notre Dame, IN 46556

Dennis Clark
Fisons Instruments
Cherry Hill Drive
32 Commerce Center
Danvers, MA 01923

Carl Cork
Lawrence Berkeley Laboratory
1 Cyclotron Road
Berkeley, CA 94720

Stephen P. Cramer
E & E Division
Lawrence Berkeley Laboratory
1 Cyclotron Road, 2-400
Berkeley, CA 94720

Paul W. Davies
Intel Corporation
3065 Bowers Avenue
Santa Clara, CA 95051

Peter Dusza
Process Physics, Inc.
385 Reed Street
Santa Clara, CA 95050

Norman M. Edelstein
Lawrence Berkeley Laboratory
1 Cyclotron Road, 70A-1150
Berkeley, CA 94720

Arthur W. Ellis
IBM Almaden Research Ctr.
P. O. Box 218
Route 134
Yorktown Heights, NY 10598

Walton P. Ellis
Los Alamos National Laboratory
CLS-2/MS-J565
Los Alamos, NM 87544

Charles S. Fadley
Lawrence Berkeley Laboratory
1 Cyclotron Road
Berkeley, CA 94720

Bob Feichlmeir
Fisons Instruments
Cherry Hill Drive
32 Commerce Center
Danvers, MA 01923

John R. Frank
Sematech
2706 Montopolis Drive
Austin, TX 78741

David P. Gaines
Advanced X-Ray Optics Prog.
Lawrence Livermore Natl. Lab.
P. O. Box 808
L-395
Livermore, CA 94550

Bob Garcia
MKS Instruments
3350 Scott Blvd., Bldg. 4
Santa Clara, CA 95054

David C. Gibson
MKS Instruments, Inc.
3350 Scott Blvd., Bldg. 4
Santa Clara, CA 95054

Stanley R. Goldfarb
Exxus
3031 Tisch Way, Ste. 605
San Jose, CA 95128

Gary Goudzwaard
Leybold Vacuum Products, Inc.
5700 Mellon Road
Export, PA 15632

Edward Graper
Lebow Corporation
5960 Mandarin Avenue
Goleta, CA 93117

David Paul Gregg
Eclectic Associates
3650 Helms Avenue
Culver City, CA 90232-24

Gisela Grindel
Continental Optical Corp.
15 Power Drive
Hauppauge, NY 11788

Manfred W. Grindel
Continental Optical Corp.
15 Power Drive
Hauppauge, NY 11788

Eric Gullikson
Lawrence Berkeley Laboratory
1 Cyclotron Road, 2-400
Berkeley, CA 94720

William Hammer
Grumman Aerospace Corporation
So. Oyster Bay Road
Bethpage, NY 11714

Cheryl Hauck
Lawrence Berkeley Laboratory
1 Cyclotron Road, 80-101
Berkeley, CA 94720

Phil Heimann
Lawrence Berkeley Laboratory
1 Cyclotron Road
Berkeley, CA 94720

Franz J. Himpsel
Thomas J. Watson Res. Ctr.
IBM
P. O. Box 218
Yorktown Heights, NY 10598

Philip Hopstone
Lawrence Berkeley Laboratory
1 Cyclotron Road
Berkeley, CA 94720

Eric Hudson
Lawrence Berkeley Laboratory
1 Cyclotron Road, 2-300
Berkeley, CA 94720

Zahid Hussain
Lawrence Berkeley Laboratory
1 Cyclotron Road, Bldg. 2-300
Berkeley, CA 94720

Gene E. Ice
Oak Ridge National Laboratory
Room B254 4500S
MS-6118
Oak Ridge, TN 37831-61

Yasuo Iguchi
Faculty of Engineering
University of East Asia
2-1, Ichinomiya-gakuen-cho
Shimonoseki,
Yamaguchi, Jap 751

Steve Irick
Lawrence Berkeley Laboratory
1 Cyclotron Road
Berkeley, CA 94720

Alan Jackson
Lawrence Berkeley Laboratory
1 Cyclotron Road, Bldg. 80-101
Berkeley, CA 94720

Keith H. Jackson
Ctr. for X-Ray Optics
Lawrence Berkeley Laboratory
1 Cyclotron Road, Bldg. 2-400
Berkeley, CA 94720

Paul Johnson
Lawrence Berkeley Laboratory
1 Cyclotron Road
Berkeley, CA 94720

Robert J. Johnson
Tinsley Laboratories, Inc.
3900 Ladeside Drive
Richmond, CA 94806

Roderich Keller
Lawrence Berkeley Laboratory
1 Cyclotron Road
Berkeley, CA 94720

Stephen D. Kevan
Physics Department
University of Oregon
Eugene, OR 97403

Charles H. Kim
Lawrence Berkeley Laboratory
1 Cyclotron Road, Bldg. 80-101
Berkeley, CA 94720

Sung-Hou Kim
Lawrence Berkeley Laboratory
1 Cyclotron Road
Berkeley, CA 94720

Brian M. Kincaid
Lawrence Berkeley Laboratory
1 Cyclotron Road
Berkeley, CA 94720

Paul L. King
Stanford Synchrotron Rad. Lab.
P. O. Box 4349
Mail Stop 99
Stanford, CA 94309

Larry V. Knight
Department of Physics
Brigham Young University
Provo, UT 84602

Jude Koenig
Perkin-Elmer
6509 Flying Cloud Dr.
Eden Prairie, MN 55344

Masato Koike
Lawrence Berkeley Laboratory
1 Cyclotron Road
Berkeley, CA 94720

Jeffrey B. Kortright
Ctr. for X-Ray Optics
Lawrence Berkeley Laboratory
1 Cyclotron Road
Berkeley, CA 94720

Gary F. Krebs
Lawrence Berkeley Laboratory
1 Cyclotron Road
Berkeley, CA 94720

Christof F. Kunz
University of Hamburg
I. Inst. Exp. Physik
Kuruper CM 149
Hamburg 50, Ger D-2000

Peter W. Langhoff
Department of Chemistry
Indiana University
Bloomington, IN 47405

Gloria Lawler
Lawrence Berkeley Laboratory
1 Cyclotron Road, 46-161
Berkeley, CA 94720

Jackson Leung
Osaka Vacuum, Ltd.
911 Bern Ct., Ste. 140
San Jose, CA 95112

Kevin Liddane
Instruments S.A., Inc.
6 Olsen Avenue
Edison, NJ 08820

Ingolf Lindau
Lund University
Max Laboratory
Box 118
Lund, SweS-22110

Dennis W. Lindle
Department of Chemistry
Univ. of Nevada, Las Vegas
Las Vegas, NM 89154

Richard A. London
Lawrence Livermore Natl. Lab.
7000 East Avenue, L-477
Livermore, CA 94550

Fred H.G. Lothrop
Lawrence Berkeley Laboratory
1 Cyclotron Road, 51-208
Berkeley, CA 94720

David Lunt
Photon Sciences Intl. Inc.
202 S. Plumer Ave.
Tucson, AZ 85719

Yanjun Ma
University of Washington
Bldg. 535B
Brookhaven Laboratory
Upton, NY 11973

Larry Madison
Lawrence Livermore Natl. Lab.
P. O. Box 808
MS L-379
Livermore, CA 94550

Mark D. Maldman
Exxus
3031 Tisch Way, Ste. 605
San Jose, CA 95128

Giorgio Margaritondo
Lawrence Berkeley Laboratory
1 Cyclotron Road
Berkeley, CA 94720

Steve Marks
Lawrence Berkeley Laboratory
1 Cyclotron Road
Berkeley, CA 94720

Jay Marx
Lawrence Berkeley Laboratory
1 Cyclotron Road
Berkeley, CA 94720

Dexter J. Massoletti
Lawrence Berkeley Laboratory
1 Cyclotron Road, 80-101
Berkeley, CA 94720

Pat McKean
Lawrence Berkeley Laboratory
1 Cyclotron Road
Berkeley, CA 94720

Wayne McKinney
Lawrence Berkeley Laboratory
1 Cyclotron Road
Berkeley, CA 94720

Ed Melczer
Lawrence Berkeley Laboratory
1 Cyclotron Road
Berkeley, CA 94720

Frank Meyer

Marek Miclak
Varian
P. O. Box 10022
3100 Hansen Way
Palo Alto, CA 94304

Mike Miller
Perkin-Elmer
6509 Flying Cloud Dr.
Eden Prairie, MN 55344

Tom Morgan
Wesleyan University
Berkeley

Marion Murphy
Varian
P. O. Box 10022
3100 Hansen Way
Palo Alto, CA 94304

Ronald E. Negri
Perkin Elmer
Physical Electronics Division
6509 Flying Cloud Drive
Eden Prairie, MN 55344

Art J. Nelson
National Renewable Energy Lab.
1617 Cole Blvd.
Golden, CO 80401

Khanh Nguyen
Lawrence Berkeley Laboratory
1 Cyclotron Road
Berkeley, CA 94720

Heino Nitsche
Lawrence Berkeley Laboratory
1 Cyclotron Road, 70A-1150
Berkeley, CA 94720

Marjorie A. Olmstead
Dept. of Physics, FM-15
University of Washington
Seattle, WA 98195

William Oosterhuis
U.S. Department of Energy
Basic Energy Sciences
ER 132
Washington, DC 90545

Stephen Palermo
MKS Instruments, Inc.
3350 Scott Blvd., Bldg. 4
Santa Clara, CA 95054

Eric Palmer
Photon Sciences Intl. Inc.
202 S. Plumer Ave.
Tucson, AZ 85719

W. Jorge Pearce
Maxwell Laboratories
Brobeck Division
4905 Central Avenue
Richmond, CA 94804

Georgeana Perdue
Lawrence Berkeley Laboratory
1 Cyclotron Road, 80-101
Berkeley, CA 94720

Rupert Perera
Lawrence Berkeley Laboratory
1 Cyclotron Road
Berkeley, CA 94720

Yvette M. Perez
Gordon & Breach Publishers
5301 Tacony Street
Philadelphia, PA 19137

Piero A. Pianetta
Stanford Linear Accelerator Ctr.
P. O. Box 4349
Mail Stop 69
Stanford, CA 94309

Alan A. Pitas
Pitas Instruments, Ltd.
120 W. Church Street
Evansville, WI 53536

Charles K. Pooley
Eclectic Associates
3650 Helms Avenue
Culver City, CA 90232-24

Mike Preuss
Fisons Instruments
Cherry Hill Drive
32 Commerce Center
Danvers, MA 01923

Arthur L. Robinson
Lawrence Berkeley Laboratory
1 Cyclotron Road, 80-101
Berkeley, CA 94720

Philip N. Ross
Lawrence Berkeley Laboratory
1 Cyclotron Road
Berkeley, CA 94720

Carolyn S. Rossington
Lawrence Berkeley Laboratory
1 Cyclotron Road, Bldg. 70A-3363
Berkeley, CA 94720

Thomas W. Rusch
Perkin-Elmer Corporation
6509 Flying Cloud Drive
Eden Prairie, MN 55344

Mahesh G. Samant
IBM Almaden Research Ctr.
650 Harry Road
San Jose, CA 95120

James A.R. Samson
University of Nebraska
Behlen Laboratory of Physics
Lincoln, NE 68588

Fred Schlachter
Lawrence Berkeley Laboratory
1 Cyclotron Road
Berkeley, CA 94720

Ross Schlueter
Lawrence Berkeley Laboratory
1 Cyclotron Road
Berkeley, CA 94720

Dietmar M. Schoeffel
McPherson
Division of S.I. Corp.
530 Main Street
Acton, MA 01720

Martin Semmler
MDC Vacuum Products Corp.
23842 Cabot Blvd.
Hayward, CA 94545

Charles V. Shank
Lawrence Berkeley Laboratory
1 Cyclotron Road
Berkeley, CA 94720

Christopher Sheppard
Kaman Aerospace
5055 E. Broadway
Tucson, AZ 85711

Meir Shiezinger
Lawrence Berkeley Laboratory
1 Cyclotron Road
Berkeley, CA 94720

David K. Shuh
Lawrence Berkeley Laboratory
1 Cyclotron Road, 70A-1150
Berkeley, CA 94720

Ken Skulina
Lawrence Livermore Natl. Lab.
P. O. Box 808, L-278
Livermore, CA 94550

Neville Smith
AT&T Bell Laboratories

Gary Sommargren
Lawrence Livermore Natl. Lab.
P. O. Box 808
Livermore, CA 94550

Joachim Stohr
IBM Almaden Research Ctr.
K32/802
650 Harry Road
San Jose, CA 95120

Rai-ko Sun
Lawrence Berkeley Laboratory
1 Cyclotron Rd., Bldg. 90-2148
Berkeley, CA 94720

Louis Terminello
Lawrence Livermore Natl. Lab.
P. O. Box 808, M/S 357
Livermore, CA 94550

Jeff Terry
Stanford Synchrotron Rad. Lab.
P. O. Box 4349
Mail Stop 99
Stanford, CA 94309

James G. Tobin
Lawrence Livermore Natl. Laboratory
P. O. Box 808, L-357
Livermore, CA 94550

Larry H. Toburen
Pacific Northwest Laboratory
P. O. Box 999
P8-47
Richland, WA 99352

Shigeo Tohyama
Hitachi Instruments, Inc.
3100 North First Street
San Jose, CA 95134

Tetsu Keith Tokunaga
Lawrence Berkeley Laboratory
1 Cyclotron Road, 50E
Berkeley, CA 94720

Harry W. Tom
AT&T Bell Laboratories
Room 48429
101 Crawfords Corner Rd.
Holmdel, NJ 07733

Brian P. Tonner
Department of Physics
University of Wisconsin
Milwaukee, WI 53211

John Troy
Fisons Instruments
Cherry Hill Drive
32 Commerce Center
Danvers, MA 01923

Jan van Elp
Energy and Environment Div.
Lawrence Berkeley Laboratory
1 Cyclotron Road
Berkeley, CA 94720

Michel A. Van Hove
Lawrence Berkeley Laboratory
1 Cyclotron Road, Bldg. 66
Berkeley, CA 94720

Alexander von Brenndorff
Ctr. for X-Ray Optics
Lawrence Berkeley Laboratory
1 Cyclotron Road
Berkeley, CA 94720

Karl Wada
Osaka Vacuum, Ltd.
911 Bern Ct., Ste. 140
San Jose, CA 95112

Chunxi Wang
Lawrence Berkeley Laboratory
1 Cyclotron Road, 2-400
Berkeley, CA 94720

Xin Wang
Dept. of Applied Science
Univ. of California, Davis
228 Walker Hall
Davis, CA 95616

Tony Warwick
Lawrence Berkeley Laboratory
1 Cyclotron Road
Berkeley, CA 94720

Bob Wayrynen
Fisons Instruments
Cherry Hill Drive
32 Commerce Center
Danvers, MA 01923

Marvin J. Weber
Lawrence Livermore Natl. Lab.
P. O. Box 808, L-326
Livermore, CA 94550

Max Wei
Lawrence Berkeley Laboratory
1 Cyclotron Road
Berkeley, CA 94720

Edwin Westbrook
Argonne National Laboratory
9700 So. Cass Avenue
Argonne, IL 60439

Robert L. Whetten
Department of Chemistry
Univ. of California, Los Angeles
405 Hilgard Avenue
Los Angeles, CA 90024-15

Mike White
Lawrence Berkeley Laboratory
1 Cyclotron Road
Berkeley, CA 94720

Gwyn Williams
Brookhaven National Laboratory

Pat Williams
Earth Sciences
Lawrence Berkeley Laboratory
1 Cyclotron Road
Berkeley, CA 94720

Bob Willis
Granville-Phillips Company
5675 East Arapachoe Ave.
Boulder, CO 80303

Roy F. Willis
Department of Physics
Pennsylvania State University
University Park, PA 16802

Herman Winick
Stanford Linear Accelerator Ctr.
P. O. Box 4349
Mail Stop 69
Stanford, CA 94309

Mervyn Wong
Lawrence Berkeley Laboratory
1 Cyclotron Road, 50A-2129
Berkeley, CA 94720

Jin Wu
Stanford Linear Accelerator Lab.
P. O. Box 4349
Bin 69
Stanford, CA 94309

Robert C.Y. Wu
Univ. of Southern California
Space Sciences Center
University Park
Los Angeles, CA 90089-13

Yan Wu
IBM Almaden Research Ctr.
650 Harry Road
San Jose, CA 95120

Francois Wuilleumier
Univ. Paris Sud, Orsay

Jory A. Yarmoff
Department of Physics
Univ. of California, Riverside
Riverside, CA 92521

Joyce Young
Lawrence Berkeley Laboratory
1 Cyclotron Road
Berkeley, CA 94720

Ron Yourd
AFRD
Lawrence Berkeley Laboratory
1 Cyclotron Road
Berkeley, CA 94720

Kin Man Yu
Lawrence Berkeley Laboratory
1 Cyclotron Road, 2-200
Berkeley, CA 94720

Andrew Zege
Ctr. for X-Ray Optics
Lawrence Berkeley Laboratory
1 Cyclotron Road
Berkeley, CA 94720

Tom Ziemba
Huntington Mech. Lab., Inc.
1040 L'Avenida
Mountain View, CA 94043

APPENDIX C: EXHIBITORS

Continental Optical Corp.
15 Power Drive
Hauppauge, NY 11788
(516) 582-3388

Granville-Phillips Company
5675 East Arapachoe Avenue
Boulder, CO 80303
(303) 443-7660

Leybold Vacuum Products Inc.
5700 Mellon Road
Export, PA 15632
(412) 327-5700

Meyer Tool & Mfg., Inc.
9221 S. Kilpatrick Avenue
Oaklawn, IL 60453
(708) 425-9080

Perkin-Elmer
6509 Flying Cloud Drive
Eden Prairie, MN 55344
(408) 473-9070

Seiko Instruments, Inc.
1150 Ringwood Court
San Jose, CA 95131
(408) 922-5829

Exxus
3031 Tisch Way, Ste 605
San Jose, CA 95128
(408) 993-9987

Huntington Mech. Lab., Inc.
1040 L'Avenida
Mountain View, CA 94043
(415) 964-3323

McPherson
530 Main Street
Division of S.I. Corp.
Acton, MA 01720
(508) 263-7733

MKS Instruments, Inc.
3350 Scott Blvd., Bldg. 4
Santa Clara, CA 95054
(408) 988-4020

Photon Sciences Intl. Inc.
202 S. Plumer Avenue
Tucson, AZ 85719
(602) 882-0954

Varian
3100 Hansen Way
P. O. Box 10022
Palo Alto, CA 94304
(415) 829-1558

Fisons Instruments
Cherry Hill Drive
32 Commerce Center
Danvers, MA 01923
(508) 524-1271

Lebow Corporation
5960 Mandarin Avenue
Goleta, CA 93117
(805) 964-7717

MDC Vacuum Products Corp.
23842 Cabot Blvd.
Hayward, CA 94545
(510) 887-6100

Osaka Vacuum, Ltd.
911 Bern Court, Suite 140
San Jose, CA 95112
(408) 441-7658

Process Physics Inc.
385 Reed Street
Santa Clara, CA 95050
(408) 988-8161

LAWRENCE BERKELEY LABORATORY
UNIVERSITY OF CALIFORNIA
TECHNICAL INFORMATION DEPARTMENT
BERKELEY, CALIFORNIA 94720