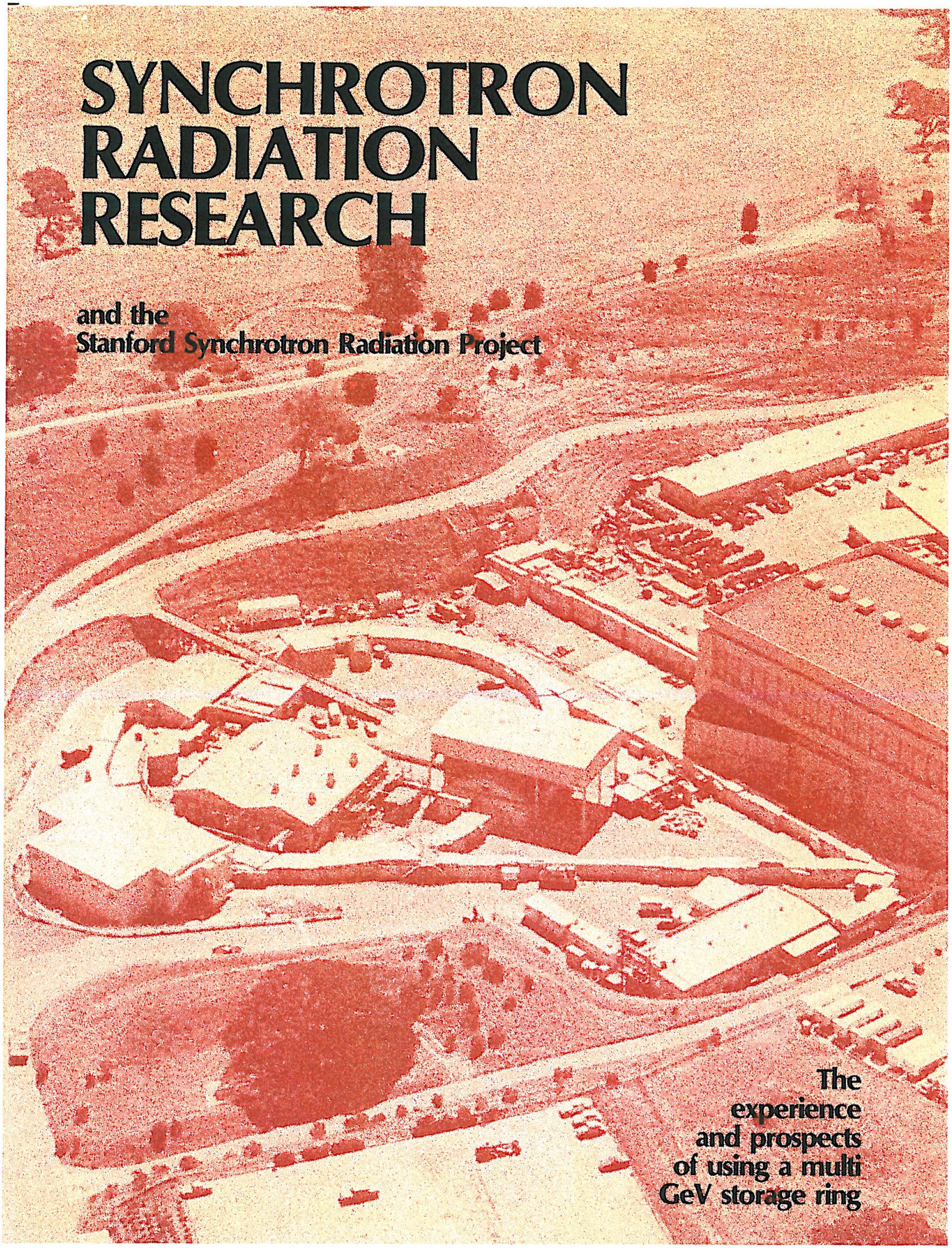
SYNCHROTRON RADIATION RESEARCH

and the Stanford Synchrotron Radiation Project



The experience and prospects of using a multi GeV storage ring

STANFORD SYNCHROTRON RADIATION PROJECT

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To: SLAC Faculty

From: S. Doniach and H. Winick

Dear Colleague:

We and many other people involved with SSRP have been thinking about the future possibilities at SPEAR. We enclose some of the results of this work.

We are optimistic that it should be possible to work out ways to share both the costs and the benefits of running SPEAR in the 1980's between the high energy physics and synchrotron radiation communities.

We would welcome discussion of this anytime.

Sincerely,

Seb Doniach

Seb Doniach
Director

Herman Winick

Herman Winick
Deputy Director

SD:HW:hs
Enclosed

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August 9, 1976

TO: Members of the Synchrotron Radiation Research Community

In response to the national scientific need for additional synchrotron radiation research facilities, the Stanford Synchrotron Radiation Project is proposing an expansion of research capability based on seven additional beam lines, 14 monochromator systems, a new building and additional equipment including two wiggler magnets. Requests for funding of this expansion have been submitted to both the National Science Foundation and the U. S. Energy Research and Development Administration.

To assist in evaluating these proposals, a technical study has been made, a copy of which is enclosed for your interest. This study has the following goals:

1) To summarize the scientific and technical results that have been achieved to date in the first significant use of a multi GeV electron storage ring, SPEAR, as a synchrotron radiation source;

2) To consider future prospects for research using synchrotron radiation;

3) To document the potential of the SPEAR storage ring for expanded use as a radiation source over the next few years leading to the period (around 1980) when it will become available on a 50% time basis as a dedicated source.

This multidisciplinary study was made possible through the generous contributions of many individuals whose names are cited throughout the study and in the acknowledgements (Appendix A). Where possible, contributors to individual sections are identified with their section. The SSRP research facilities and program that are described in the study were supported by the National Science Foundation and made possible by the broad technical support provided by the SSRP staff and many at SLAC. The study itself was edited by Keith Hodgson, Herman Winick, and Gil Chu.

We hope that you will find this study useful and that it will help to further the application of synchrotron radiation to research in the fundamental and applied sciences.

Seb Doniach   Herman Winick   Keith Hodgson

Seb Doniach   Herman Winick   Keith Hodgson

Enclosure: Book

SYNCHROTRON RADIATION RESEARCH

and the Stanford Synchrotron Radiation Project

The experience and prospects of using a multi GeV storage ring

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and
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August, 1976

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I. INTRODUCTION

Research with synchrotron radiation has come of age! The emission of light by electrons in circular orbits was predicted before 1945 and was first observed on the General Electric 70-MeV synchrotron in 1947. Research with synchrotron radiation began in 1955 at the 300-MeV Cornell synchrotron. The constant spectral distribution and stable intensity characteristic of storage rings was first provided by the 240-MeV storage ring at the University of Wisconsin, which began producing vacuum ultraviolet radiation in 1968 as a dedicated synchrotron radiation source. These desirable characteristics were extended into the x-ray part of the spectrum in 1972 at the Cambridge Electron Accelerator operating as a storage ring at 3 GeV.

In 1973, a panel was convened by the National Science Foundation to study proposals for new synchrotron radiation research facilities. The panel concluded that synchrotron radiation from a high-energy storage ring offered interesting research prospects for radiation extending all the way into the short wavelength x-ray region. It recommended that the Stanford Synchrotron Radiation Project be funded as the least costly way to evaluate these prospects.

RESEARCH AT THE STANFORD SYNCHROTRON RADIATION PROJECT. Since the start of operation in May of 1974, many significant scientific advances have been achieved at SSRP. These results, along with accomplishments at smaller storage rings and high-energy electron synchrotrons throughout the world, have clearly established the power of synchrotron radiation as a research tool.

At SSRP, radiation above about 150 eV has been made available to a large community of users for the first time. Among the many significant results (described in more detail in Section III), are the studies of Extended X-ray Absorption Fine Structure (EXAFS) that have developed the method from a technique that was previously very tedious and limited into a powerful structural tool. EXAFS studies have led to new detailed information on the structural and electronic environment of metal ions in diverse systems, such as metalloproteins in solution, dispersed catalysts, and amorphous materials.

Notable achievements have also been made in the study of surfaces by the use of photoemission spectroscopy. These studies take advantage of the tunable intense UV and soft x-ray photons. The high surface sensitivity of photoemission in the range of 100 to 300 eV, which is due to small electron escape depths, makes this technique ideal for the study of surface phenomena, such as oxidation, corrosion, and catalysis. Angular-resolved photoemission experiments also have promising potential to provide information on surface states, geometry of substrate binding, and details of dangling bonds through analysis of the photon energy and polarization dependence of the angular-dependent electron emission.

Important preliminary results obtained at SSRP suggest that the solution of crystal structures from x-ray diffraction data may be facilitated by being able to tune routinely above and below the absorption edge of almost any element and thereby use anomalous dispersion to help solve the phase problem. In addition, the intense synchrotron radiation, when highly monochromated, allows diffraction patterns to be recorded with shorter exposure times and less radiation damage than would be possible with conventional sources. Promising initial results have also been obtained using position sensitive x-ray detectors for low-angle diffraction studies of structural changes in biological systems (such as muscle and nerve) by time dependent x-ray diffraction (similar work is being done at the synchrotron radiation facilities in Hamburg).

The unique time-structure of the SPEAR source has recently been used to measure fluorescence lifetimes of molecules such as NO_2, tetracene, Ar, and Kr. There are no limitations, as there are with lasers, that require experiments be carried out in the visible or near-ultraviolet region.

There are a number of intriguing and more speculative proposals for the use of synchrotron radiation from SPEAR. Studies of the Mössbauer effect, holography, high-speed Laue diffraction and time-resolved EXAFS are several areas under consideration. One recent speculative proposal serves, perhaps, to illustrate the potential for future research at a high-energy storage ring. A question frequently asked is, "Why is nature left-handed?" Naturally occurring amino acids are almost exclusively of the L form. It has been proposed that this phenomenon is an indirect consequence of parity nonconservation in beta decay. The circularly polarized x-rays produced by bremsstrahlung from the longitudinally polarized electrons could cause selective decomposition of right handed or D forms of the amino acid. This mechanism has been difficult to test because of the lack of a suitable circularly polarized source. A helical wiggler on a storage ring would provide highly circularly polarized radiation that could be used for photochemical studies to test these ideas of the primordial origin of optical activity.

SSRP–THE CURRENT RESOURCES. The research achievements at SSRP have been made using one beam line divided so that five or six users can simultaneously share the radiation. This initial line and its associated monochromators are described in detail in Section 4, Part 4.2 of this study. These facilities permitted the first significant exploitation of the extraordinary properties of synchrotron radiation from a multi-GeV storage ring: high intensity over a broad spectral range extending from the visible to 50 KeV, constant spectrum, stable source size and position, exceedingly sharp forward collimation, high-vacuum environment, high plane polarization, and pulsed time structure. A second beam line was installed in May of 1976 and is now being equipped with three x-ray monochromators. With full exploitation of these facilities ten or more simultaneous experiments will be possible.

Even with this expansion, the exploration of new ideas and the full exploitation of already proven techniques will be severely limited by the minimal research facilities at SSRP, which, at present, is the only storage ring source of synchrotron radiation above 150 eV in this country. There is an urgent, clear need for extending the present research capability.

As one particular example, the available time on the one monochromator at SSRP that provides tunable radiation in the region 100 to 600 eV is far less than that needed to meet the demands of an increasing number of experimentalists eager to exploit these new capabilities in a wide variety of spectroscopic studies. In another instance, the demand on the EXAFS monochromator would have required two years of running to satisfy. Thus the decision was made to implement two new EXAFS monochromators on beam line II.

The demands on SSRP facilities are mirrored worldwide. Considerable progress is being made abroad in establishing synchrotron radiation research facilities. A number of countries, aware of the experience with synchrotron radiation from the SPEAR multi-GeV storage ring, are studying, designing, and constructing new research facilities. A summary of worldwide activity is given in Table I.

The experience gained at SSRP using SPEAR has been a significant factor in the British decision to construct a new dedicated synchrotron radiation source, in the Italian decision to equip the storage ring ADONE with synchrotron radiation beam lines, and in the decision in several other countries (USSR, Netherlands, Japan, and India) to conduct preliminary studies or to make detailed designs for such facilities.

Thus, there is a perceived immediate need for expanded synchrotron radiation research capabilities. SPEAR can fill an important role in meeting these needs during the coming decade and it is to these capabilities that a substantial part of this study is addressed.

TABLE I
SYNCHROTRON RADIATION RESEARCH FACILITIES–1976

STORAGE RINGS *LABORATORY*	*ENERGY (GeV)*	*CURRENT (mA)*	*BENDING RADIUS (m)*	*CRITICAL ENERGY (KeV)*	*REMARKS*
DORIS, Hamburg, Germany	1.5-4.0	~ 250	12.2	11.6	
SPEAR, Stanford, USA	1.5-4.0	5-35	12.7	11.1	> 300 mA available in multi-bunch mode
VEPP-3, Novosibirsk, USSR	2.25	200	6.0	4.2	
VEPP-2M, Novosibirsk, USSR	.67	100	1.22	.54	
ACO, Orsay, France	.54	100	1.1	.32	Dedicated to Synchrotron Radiation
INS-SOR, Tokyo, Japan	.30	100	1.0	.059	Dedicated to Synchrotron Radiation
TANTALUS I, Wisconsin, USA	.24	100	.64	.048	Dedicated to Synchrotron Radiation
SURF II, NBS, Washington DC, USA	.24	~ 50	.84	.036	Dedicated to Synchrotron Radiation
DCI, Orsay, France	1.8	500	3.8	3.4	
PACHRA, Moscow, USSR	1.3	10-300	4.0	1.1	
IPP, Moscow, USSR	1.35	100	2.5	2.2	In Design–Dedicated
Daresbury, UK	2.0	500-1000	5.55	3.2	In Construction–Operational 1980–Dedicated
Brookhaven, USA	2.0	500-1000	8.1	2.2	Proposed–Dedicated
Wisconsin, USA	2-2.5	500-1000			Design Study–Dedicated
Photon Factory, Japan	2.5				Design Study–Dedicated
ADONE, Frascati, Italy	1.5	60	5.0	1.5	Synchrotron Radiation Beam Lines in Construction
Amsterdam, Netherlands	1-2				Design Study–Dedicated
ALADDIN, Wisconsin, USA	.75	500	2.0	.46	Design Study–Dedicated
SYNCHROTRONS					
Cornell, USA	12	2	100	38	
DESY, Hamburg, Germany	7.5	10-30	31.7	29.5	
ARUS, Yerevan, USSR	6.0	20	24.6	19.5	
NINA, Daresbury, UK	5.0	40	20.8	13.3	Terminates Operation in 1977
BONN I, Germany	2.5	30	7.6	4.6	
INS-SOR, Tokyo, Japan	1.3	30	4.0	1.22	
Frascati, Italy	1.1	10	3.6	.82	
C-60, Moscow, USSR	.68	10	1.6	.44	
BONN II, Germany	.5	30	1.7	.16	

THE CAPABILITIES OF SPEAR AS A SYNCHROTRON RADIATION SOURCE. Along with the DORIS storage ring in Hamburg, Germany, SPEAR is one of the two most powerful electron storage rings now operational. It provides intense synchrotron radiation from the visible and UV to the x-ray parts of the spectrum. The basic characteristics of SPEAR as a synchrotron radiation source are the following:

- Demonstrated capability to store beams up to 4 GeV.
- 500 kW of installed rf power.
- High injection energy (2.25 GeV), which permits rapid filling of the ring and should facilitate reaching high stored-current in multi bunch mode. A current of 225 mA has already been achieved.
- Capability of operating in one bunch mode with a pulse duration of 60 to 400 psec and pulse repetition rate of 1.28 MHz.
- Ample space for the eventual installation of a large number of beam runs (nine tangential runs from bending magnets, eight from wiggler magnets in straight sections, including the low beta interaction region where the beam transverse dimensions are exceedingly small, and ten large-angle UV ports).

Some of these characteristics are uniquely available at SPEAR and will very likely not be provided by a new source. It is unlikely, for example, that an injection system comparable in capability to that provided by SLAC would ever be built for a new stand-alone storage ring. Economic factors also tend to limit the photon energy that would be available from bending magnets of a new machine. Thus, these new machines could require special insertions (wigglers) to reach the x-ray energies available from SPEAR bending magnets.

PROPOSED EXPANSION OF RESEARCH CAPABILITY–NEAR FUTURE. A gradual expansion of SSRP capabilities in the near future is proposed, to be centered around additional beam lines and monochromators in a new experimental hall. Seven additional lines equipped with 14 monochromators are planned, which would utilize radiation from SPEAR bending magnets and from wiggler magnets. Installation of all of these is compatible with high-energy colliding beam operation of SPEAR and could be provided in a shorter time scale than necessary to construct new sources.

A commitment has been made by the Stanford Linear Accelerator Center (SLAC) that at least 50% of SPEAR operations time will be available for synchrotron radiation research when the LBL/SLAC 18 GeV colliding beam storage ring, PEP, is performing high energy physics experiments for 50% of its operations time. According to the PEP construction schedule, this should occur during 1980. Thus, at that time, it is estimated that at least 350 shifts per year of SPEAR time will be available for dedicated synchrotron radiation research operation. During the remaining 350 shifts, synchrotron radiation research can still continue symbiotically as is now done. By the time that substantial dedicated operation begins, the expanded research capability described in this report could be installed and in operation.

A further commitment has been made by SLAC that a fraction (5%) of SPEAR operations time will be made available now for dedicated synchrotron radiation research with SPEAR. Because data-taking rates for most synchrotron radiation experiments are about a factor of 10 higher on these runs compared to symbiotic operation, even this small amount of the time (about 35 shifts per year) significantly extends research capabilities. Furthermore, these shifts provide an invaluable opportunity to test and use wiggler magnets in a real storage ring very soon and to develop the techniques of operating SPEAR at high currents.

This early experience with wigglers will be of great benefit to the development of these promising devices, for use in SPEAR and also in lower energy machines where they are essential to reach the higher photon energies.

PROSPECTS FOR SYNCHROTRON RADIATION RESEARCH AT STANFORD-LONG RANGE. In the long-range future, additional opportunities for synchrotron radiation research at Stanford will become available with further exploitation of SPEAR as a dedicated source for more than 50% of its operation time and eventual complete dedication to synchrotron radiation research as the high energy program on SPEAR terminates. This could occur at any time subsequent to PEP operation for Physics at the 50% level. This is the primary direction that is now foreseen for continued development of synchrotron radiation research at Stanford.

The total high-energy capabilities of SLAC provide further synchrotron radiation research opportunities. The PEP storage ring, which will be in operation in the early 1980's, will provide radiation from the bending magnets with a critical energy of 45 KeV (useful flux is provided to four or five times that energy) when PEP operates at 15 GeV. Provisions have been made in the design of the PEP ring housing so that a synchrotron radiation research facility could be added in the future. High field wiggler magnets, which are an integral part of the PEP lattice, will produce even higher energy synchrotron radiation (critical energy of 85 KeV) during lower energy operation of PEP.

In addition, an interesting possibility would be the use of PEP's high electron energy to enable operation of a helical wiggler to produce tunable, quasi-monochromatic, circularly polarized x-rays to the 0.5 Å region. In later sections, we discuss the construction of a helical wiggler in SPEAR. Because of SPEAR's energy range and beam characteristics, this type of wiggler is most effective in the 5 Å wavelength range. With the developed experience, however, we could seriously approach the design and construction of the 0.5 Å wiggler for PEP should such a wiggler be compatible with PEP high-energy operations. Successful utilization of the synchrotron radiation from PEP would require the solution of several new engineering problems due to the higher electron and photon energies (presenting increased radiation hazards) and the large radius (resulting in longer beam runs). No real study of these problems has yet been made.

SCIENTIFIC BASE. A broad spectrum of scientific participation is as important to the scientific productivity as the physical capabilities of the resource. SSRP was particularly fortunate to have had the active collaboration of 12 scientists in developing five monochromator systems within the ten-month facility construction period. The early start of the scientific program at SSRP is due in large measure to the contributions of these scientists and their respective institutions (Bell Laboratories, California Institute of Technology, Stanford University, University of Washington, U.S. Navy Michelson Laboratory at China Lake, and Xerox Corporation).

More recently there has been increased participation at SSRP (in both research and instrumentation development) by additional groups from Stanford University and from the University of California at Berkeley (including the Lawrence Berkeley Laboratory).

The very considerable scientific talent at all of the above institutions could form part of the broad scientific and technical base of a much expanded facility, supplementing a core of in-house SSRP research workers.

The total number of researchers served by SSRP has grown to about 150 from all parts of the United States, from Canada, and from Europe in such fields as surface physics, structural biology, catalysis, x-ray physics, and chemistry. In addition to many Stanford scientists, a large number of other distinguished senior scientists from outside have been using the facility in their research programs, and have stated their intentions to continue and expand their activities at SSRP. Of note is the participation of Fred Brown, Stig Hagström, Ricardo Lopez-Delgado, Victor Rehn, and David Shirley, among others, who are doing research in the vacuum-ultraviolet and soft x-ray regions. Biologists and biophysical chemists, including

John Baldeschwieler, William Blumberg, Carolyn Cohen, Lyle Jensen, Melvin Klein, Manuel Morales, Richard Podolsky, Robert Shulman, and Robert Stroud, are studying various aspects of life processes. Physicists and physical chemists, including Bernd Crasemann, Richard Deslattes, Peter Eisenberger, Farell Lytle, Herbert Schnopper, John Sinfelt, Cully Sparks, and Edward Stern are using or planning to use SSRP as a valuable resource in their research programs to investigate fundamental processes ranging from mechanisms of catalysis to x-ray Raman scattering and the Mössbauer effect.

Synchrotron radiation research draws upon an unusual breadth of scientific resources. It is in this context that the establishment of national user's facilities is necessary. Such facilities allow specialized workers to define proposals in the context of their own laboratories and research programs, performing those parts at a facility that use to advantage the special properties of synchrotron radiation. Given the very broad usage of ultraviolet and x-ray radiations within the country (there is probably at least one x-ray diffraction generator in almost every laboratory dealing with materials in the United States), and the variety of materials whose understanding can be enhanced through studies by these radiations, it is most advantageous to have facilities that are not centered around the specific research interests of a small number of investigators.

Stanford University has supported the creation and growth of SSRP in a variety of direct ways, such as appointing new adjunct and consulting professorships, providing surplus equipment, and providing substantial funds for initial synchrotron radiation activities and for this study. A more recent example relates to the critical need for sophisticated laboratory facilities to be available to visiting scientists in the area of biochemical and structural studies. Within the auspices of a new biological structure unit being formed in the medical school, these facilities and transient research space will now be made available along with the possibility for interaction with strong groups headed by Professors Stryer and Hodgson in the area of molecular structure.

The major focus of this study is centered around the capabilities of SPEAR and within this study it is made apparent that further expansion of synchrotron radiation capabilities utilizing SPEAR is readily obtainable at relatively low cost.

It is already clear that new sources will be needed to satisfy the national needs projected for the next ten years. However, due to the time scale for construction of new sources, SSRP will be the only major national resource for the next four to five years producing high energy photons.

Because of the demonstrated capabilities of present SSRP facilities, the ability to economically expand these facilities to support a larger research program, the presence of a large resource of scientific and technological talent in the area, and the long-range opportunities that will be available at Stanford, we urge that plans be made now to establish a major national synchrotron radiation center at SSRP that will provide for a large fraction of the continuing national need over the next five years and beyond.