# SYNCHROTRON RADIATION RESEARCH

## A REVIEW OF PROGRESS AND PLANS AT THE STANFORD SYNCHROTRON RADIATION PROJECT (SSRP) AND AROUND THE WORLD

Contents



### A. A BRIEF SUMMARY

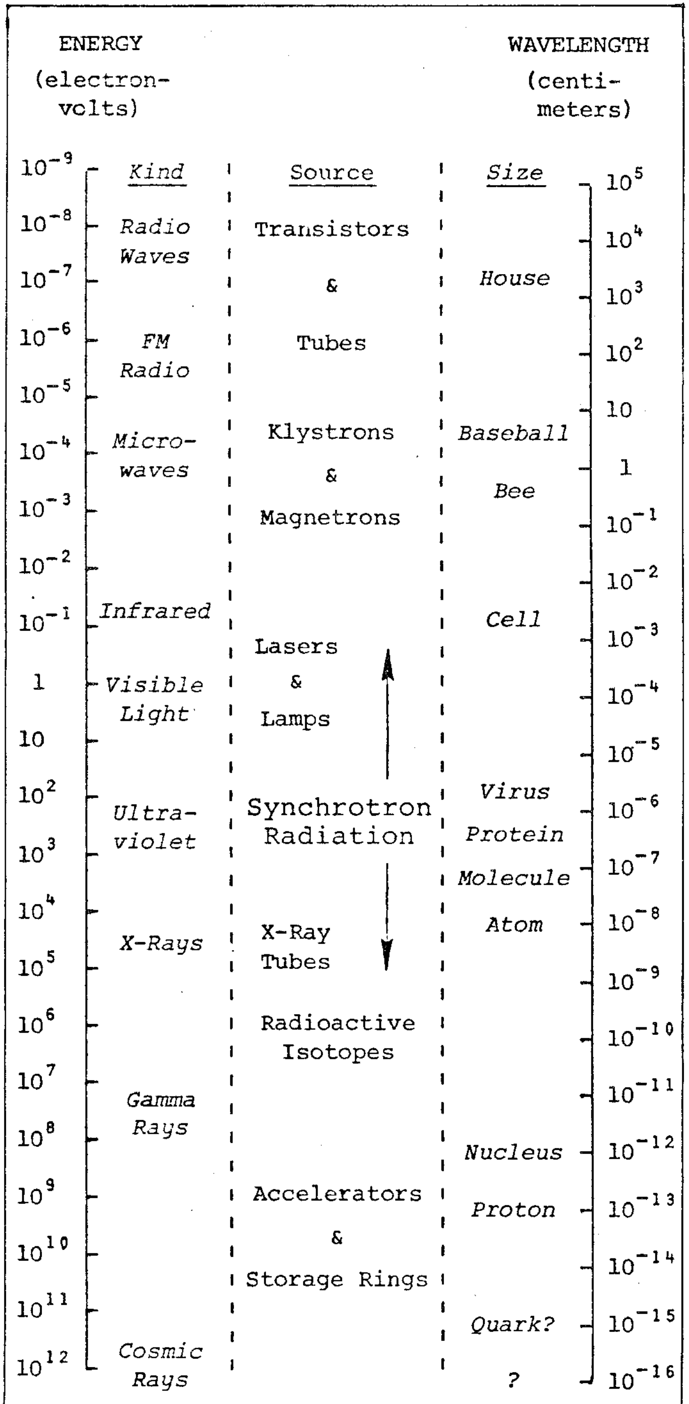
Storage rings such as the SPEAR machine at SLAC, although intended for high-energy physics colliding-beam experiments, turn out to be the world's most intense sources of ultraviolet radiation and X-rays. As the electrons and positrons travel around the ring in a circular path, they emit or "throw off" electromagnetic energy that is called synchrotron radiation. This radiation can be up to perhaps 100,000 times as intense as that available from conventional sources such as X-ray tubes. Programs for the use of this extraordinary radiation in physical, chemical and biological research have been developed at about 20 different laboratories around the world, in most cases as symbiotic, or secondary, programs on machines whose primary function is still high-energy physics research. This article describes the recent, very rapid development of synchrotron radiation research, the facilities that now exist, and the plans for proposed new facilities.

The January 1975 issue of the *Beam Line* contains an article describing synchrotron radiation and the SSRP facility in somewhat more detail than will be given here. This information was updated and expanded in a second article in the January 1976 issue.

### B. SOME BACKGROUND INFORMATION

During the last three years, and owing largely to the experimental results obtained at the Stanford Synchrotron Radiation Project, the utility of synchrotron radiation as a research tool in the far ultraviolet and X-ray regions of the electromagnetic spectrum has become firmly established. In fact, many of the chemists, physicists and biologists involved in this work are convinced that a quiet revolution is experimental capabilities is taking place. This is attributable to the remarkable properties of the synchrotron radiation obtained from a multi-GeV storage ring such as SPEAR: high and stable intensity over a broad energy range including the ultraviolet and X-ray regions of the spectrum, high polarization and extreme collimation of the radiation, pulsed time structure, small source size, and high-vacuum environment.

With the establishment of SSRP, SPEAR was the first multi-GeV storage ring to be equipped for synchrotron radiation research in a manner that facilitated its use by a large number of scientists from many different disciplines. This experience is now being repeated at other large storage rings in Hamburg, West Germany; Orsay, France; Frascati, Italy; and Novosibirsk, Soviet Union. However, the demand for synchrotron radiation research facilities continues to exceed the supply, and increasing pressure from interested experimentalists has led to the construction of new facilities and to proposals for even more extensive facilities both in this country and throughout the world. Many of the new proposals call for storage rings that will be dedicated solely to synchrotron radiation research, so that the design and operation of the machines can be optimized for the production of synchrotron radiation rather than for high-energy physics studies. These newer facilities should make possible a very significant increase in the number and kinds of experiments that can be carried out.




Part of the spectrum of electromagnetic radiation. Longer wavelengths, such as low-frequency radio waves, lie off the top of the scale. Very energetic gamma rays produced by cosmic radiation sometimes reach energies of $10^{20}$ electron volts--far off the bottom of the scale. Although a vast range is shown here, all electromagnetic radiation is basically the same. Baseballs and living cells can be seen with visible light, but smaller objects (proteins, atoms, protons) must be studied with "smaller" radiation--ultraviolet radiation, X-rays, gamma rays.

## C. RECENT RESEARCH ACCOMPLISHMENTS

As the first laboratory significantly to exploit the synchrotron radiation from a high-energy storage ring, SSRP has produced many scientific results and has pioneered in the development of instrumentation and techniques for exploiting this radiation. We give some brief examples of these results below.

### *1. "EXAFS" STUDIES*

A major success at SSRP has been the development (by a collaboration of scientists from Bell Labs, Stanford and the University of Washington) of a new tool of structural chemistry and biology called EXAFS, which is an acronym for Extended X-Ray Absorption Fine Structure. This is a very powerful tool which gives unique information about the atomic environment within a few angstroms (1 angstrom = $10^{-8}$ cm) of a specific elemental constituent in a complex material. It has been applied to the study of proteins (such as hemoglobin), catalysts (such as those used in petroleum refining), superconducting materials, environmental pollutants, and a wide variety of other materials. In this work the EXAFS technique has revealed structural information that is not obtainable by other methods.

Although EXAFS experiments were performed with conventional X-ray tubes before the availability of synchrotron radiation, these earlier experiments were tedious and time-consuming. For example, with conventional methods it often required a period of two weeks or more to obtain a single spectrum. Using the synchrotron radiation from SPEAR makes it possible to get considerably improved spectra (better signal-to-noise ratio) in a period of only a few minutes.

(For a detailed description of EXAFS experiments, see "The Analysis of Materials by X-ray Absorption," by Edward A. Stern, in the April 1976 *Scientific American*.)

### *2. OTHER EXPERIMENTS*

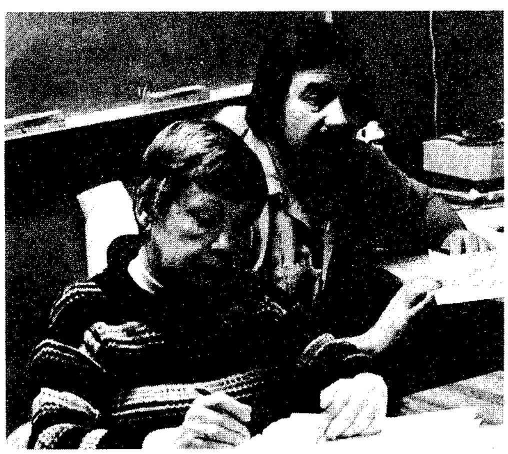
Important results have also been obtained at SSRP in studies of surface physics (which is relevant to catalysis and to oxidation and corrosion processes); the electronic structure of solids by ultraviolet and X-ray photoemission;* structural studies of biological materials such as muscle and nerve tissue by X-ray diffraction; trace-element determination by fluorescence analysis (including a search for super-heavy elements); measurements of relaxation-time con-

*The first use of synchrotron radiation at SPEAR was an X-ray photoemission experiment carried out by Lindau, Pianetta, Doniach and Spicer in July 1973 on a pilot-project beam line set up about a year before full SSRP operation began.

stants in atomic and molecular systems; and several other applications.

*3. BASIC AND APPLIED WORK*

Most of the studies with synchrotron radiation fall into the category of basic research in physics, chemistry, biology or other subfields of science. However, as can be seen from some of the preceding examples, a good fraction of the work has important implications for technology and for industrial processes. A particularly important example of applied work with synchrotron radiation was done recently at the DESY electron synchrotron in Hamburg, West Germany, by a group from IBM. These experiments demonstrated the feasibility of using synchrotron radiation to replicate microstructures such as integrated circuits on a scale of a few hundred angstroms, and also to produce micrographs of biological organisms. This work could lead to the further miniaturization of integrated circuits and to the development of higher resolution X-ray microscopes. Facilities to permit the study of these techniques (now called X-ray lithography) are now being planned for the next beam line at SSRP.



Shown here are two of SSRP's mainstays: Ray Dannemiller (left) and Ben Salsburg. Ray (everyone calls her "Priss") Dannemiller has been with SSRP from the beginning. She runs the SSRP office and, together with camera-shy Hallie Stephens, supplies much of the administrative and secretarial needs of the SSRP staff and users. One or her critical jobs is keeping track of the many accounts that SSRP and its users have with SLAC for engineering and technical services. She is shown here taking shorthand notes at the weekly SSRP staff meeting.

Ben Salsburg has recently been appointed Coordinator of Engineering Services for SSRP and has major responsibilities for facility operation, development and user support. His years of experience at SLAC help greatly in getting SSRP-related work done at SLAC.

*Note: All photographs in this article were taken by Joe Faust.*

Shown here is Arthur Bienenstock, who is Associate Director of SSRP, Vice-Provost for Faculty Affairs at Stanford, and also Professor of Applied Physics and of Materials Science and Engineering at Stanford. He was originally attracted to SSRP because of the exciting possibilities it offered in his particular field of interest--the structure of amorphous materials. He has continued these studies at SSRP and is also playing an increasing role in the development of the expanding facility as an Associate Director.

The examples given above are only a few of the many possible applications of intense electromagnetic radiation as a basic tool for both pure and applied research in a wide variety of different scientific fields. As more facilities become available, and as instrumental improvements are made, many important new results can be expected. Among the proposals already being made for new work are those concerned with X-ray holography, with the pumping of X-ray lasers, and with the use of synchrotron radiation for Mossbauer experiments.

## D. SOURCES OF SYNCHROTRON RADIATION

Synchrotron radiation research dates back more than twenty years. During the period from 1955 to 1968, the source of such radiation was the class of accelerators known as electron synchrotrons. In this section we briefly compare electron synchrotrons and storage rings as sources of synchrotron radiation.

*1. ELECTRON SYNCHROTRONS*

An electron synchrotron is a circular accelerator into which electrons are injected at a low energy (usually from a small linear accelerator) and are then accelerated to the maximum energy during a time of about 10 milliseconds. The accelerated beam is then directed against either an internal or external target in order to carry out high-energy physics experiments. The cycle of injection, acceleration and targeting is typically repeated 50-60 times per second. This method of operation has the following consequences:

(a) The electron energy increases rapidly during the acceleration cycle.

(b) The number of electrons accelerated varies from cycle to cycle.

(c) The position of the electron beam within the accelerator and the cross-sectional area of the beam changes during each cycle.

Each of these three effects is unfavorable for synchrotron radiation because they produce rapid variations in the intensity and spectral distribution of the radiation, and also in the position and size of the source from which the radiation emanates.

*2. STORAGE RINGS*

A storage ring for electrons or for electrons and positrons is in many ways similar to an electron synchrotron. However, the chief difference between the two is the fact that the electron beam in a storage ring remains circulating in a stable orbit, at a constant energy, for several hours, rather than for a small fraction of a second. This stability means that the resulting synchrotron radiation will be emitted with a constant spectrum, from a stable source within the machine, and with an intensity that decreases only very slowly as the stored beam gradually dwindles away. (A typical time for the stored current to decrease to half of its original intensity is some 2-6 hours or even more.) Furthermore, the possible radiation hazards associated with a stored beam are in general much less worrisome than is the case for a rapidly cycling synchrotron, and this results in closer access to experiments and simplified shielding requirements.

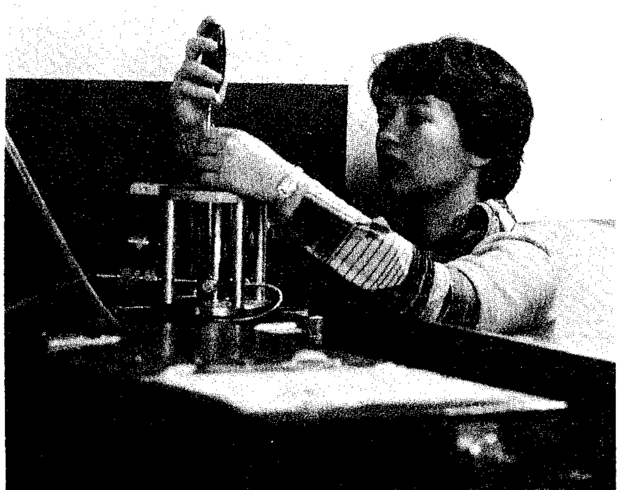
The excellent properties of a storage ring for synchrotron radiation were first demonstrated in the ultraviolet part of the spectrum by the 240 MeV ring at the University of Wisconsin in 1968. Higher photon energies became available in 1971 at the ACO 540 MeV ring in Orsay, France, and the X-ray part of the spectrum was first opened up in 1972 at the storage ring that had been built by modifying the Cambridge Electron Accelerator at Harvard University. All of the new proposals for synchrotron radiation research facilities are based either on the exploitation of existing storage rings or on the construction new storage rings.

## E. INSTRUMENTATION

Experiments with synchrotron radiation require specialized equipment that is analagous to the spectrometers, detectors, and beam-transport systems that are used in high-energy physics experiments. In this section we shall describe some of this specialized apparatus.

*1. MONOCHROMATORS*

The literal meaning of the word "monochrome" is "one color," and it is used rather loosely to indicate electromagnetic radiation that is all of the same energy or wavelength, even if it is not within the visible-light part of the spectrum. So a "monochromator" is a device that can be used to select only a narrow band of photon energies from the broad smear of synchrotron radiation that SPEAR spews out. Monochromators are perhaps the single most important elements in a synchrotron radiation experiment, and they are characterized by their bandpass (just how "mono" they are), their transmission efficiency, and their range of tunability. No one monochromator can cover the wide range of photon



Shown here is Stanford graduate student Sally Hunter. Sally's work is supervised by Professor Bienenstock. She grew up with the SSRP facility, learning the technique of Extended X-ray Absorption Fine Structure (EXAFS) experiments in the process. She is shown here working on a liquid-nitrogen dewar system used in low-temperature EXAFS studies. She expects to receive the Ph.D. in April of this year, after which she will join the SSRP staff.

energies that is used in the SSRP experimental program, so many different types are needed.

The rapid progress in the early SSRP research program was largely a result of the development of 5 monochromator systems that were ready for use soon after SSRP operations began. This work was carried out, and funded, by several collaborative activities between SSRP and other institutions, including the Xerox Corporation, the U.S. Navy's Michelson Laboratory at China Lake, the California Institute of Technology, the University of Washington, Stanford University and Bell Labs.

Much has been learned about the design of monochromators during the past several years of experience on the first SSRP beam line, and this has resulted in the improved devices now in use on the second beam line. One of these newer monochromators, for example, can provide a photon flux 50 times greater, and a flux density 250 times greater, than the earlier comparable systems. This device made use of a double-focusing toroidal mirror, designed by Paul Horowitz of Harvard, and a two-crystal monochromator. The basic design concepts for this new system were developed and implemented by Jerry Hastings of SSRP (now at Brookhaven to help get their synchrotron radiation program started), and also by Peter Eisenberger and Brian Kincaid (first Ph.D. from the SSRP program) of Bell Labs.

This is an example of the improved instrumentation that should continue to become available. At present, for example, there is no monochromator in hand that can function in the photon energy range from about 700 to 2000 eV. But designs to cover this region are now in progress at SSRP and elsewhere so that the high flux available in this spectral region can be exploited in experiments.

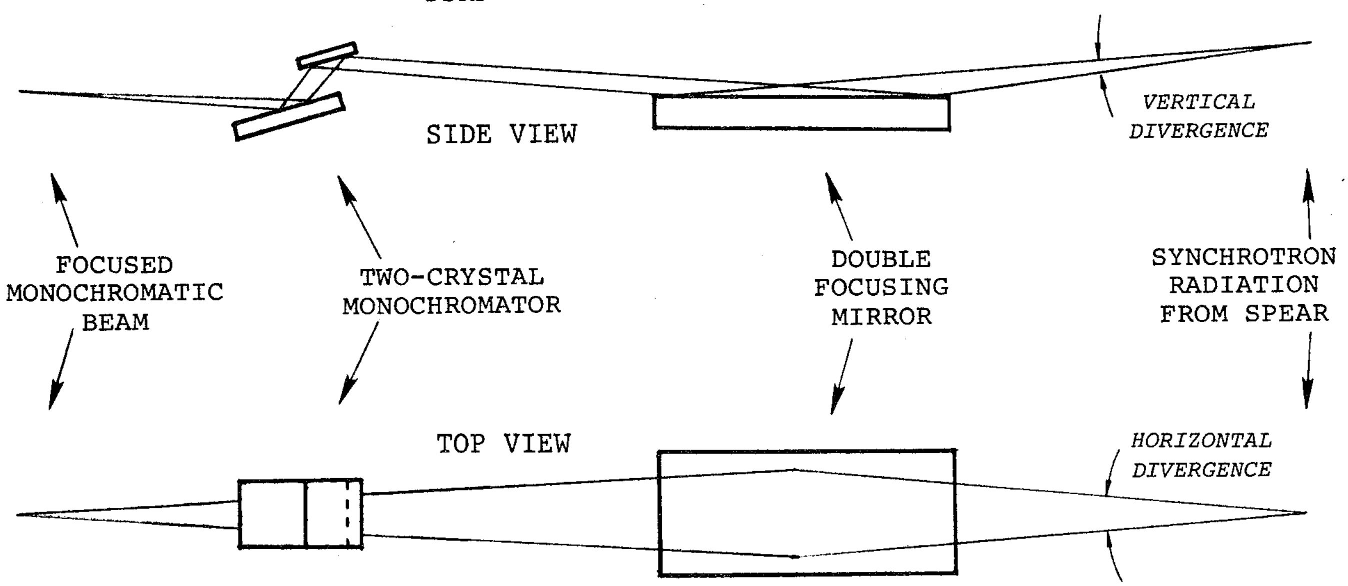
*2. DETECTORS*

The detectors presently in use for synchrotron radiation research include film, ionization chambers, scintillation counters, proportional counters, solid-state detectors, photomultipliers, and others. Development work is now being done at SSRP and at other places on fast gated detectors and on two-dimensional multi-wire proportional counters. The gated detector would permit accurate, low-level counting after an intense, prompt pulse. Successful development of such devices may make it possible to carry out Mossbauer-effect experiments. Specially designed multi-wire proportional chambers should permit counting of individual photons at rates up to about 1 MHz (one million counts per second). Such a device would allow the recording of diffraction patterns on a millisecond time scale. This detector would be used, for example, to follow structural changes in live biological systems such as a muscle during contraction, or a nerve propagating a stimulus.

*3. GAS CELLS*

Also under development at SSRP are thin windowed gas cell target systems to permit photoabsorption and photoemission studies on gas

SSRP FOCUSING MONOCHROMATOR SYSTEM

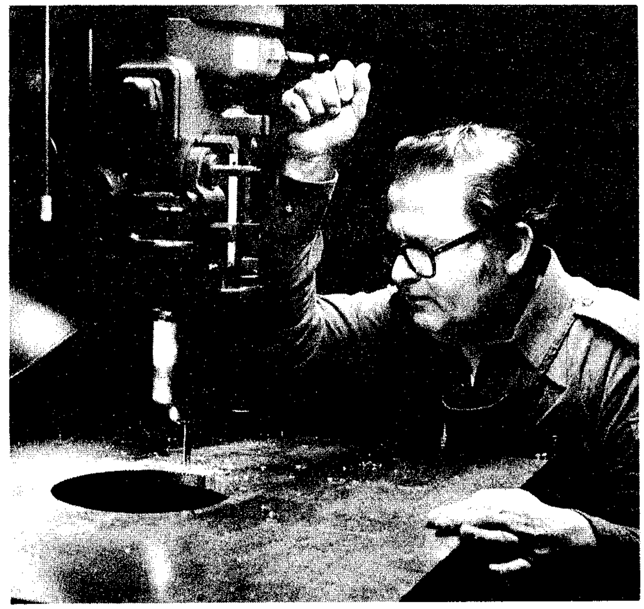



A schematic representation of the focusing monochromator system recently developed for use at SSRP. This system is rapidly tunable by a single adjustment, and it can provide an X-ray flux about 50 times higher, and a flux density about 250 times higher, than previous SSRP beams. The system is about 20 meters long from the source to the target.

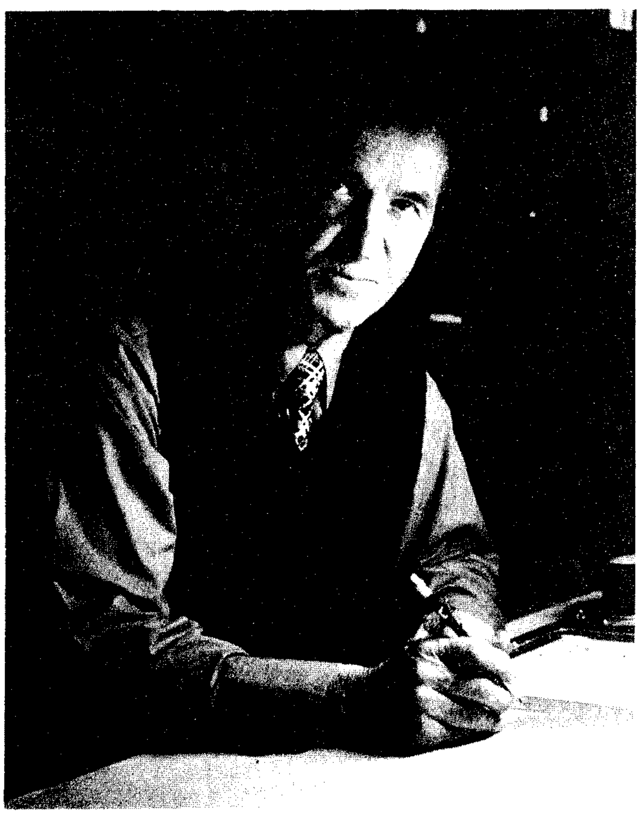
phase samples to be made in the high vacuum beam lines. Such systems could also be used for X-ray microscopy studies of biological specimens "in vivo". This development work, as well as all vacuum related work at SSRP, is done in close collaboration with Ralph Gaxiola, Earl Hoyt, Joe Jurow and Chuck Wilson of the SPEAR vacuum group to insure that provision is made for a high level of protection against contamination of the SPEAR vacuum.

*4. WIGGLERS*

An exciting new development that is likely to have a dramatic effect on synchrotron radiation research is the device called the "Wiggler" magnet. In one form this magnet consists of short sections (10-15 cm) of high transverse field magnets (16-50 KG) alternating in polarity. Because the magnetic field is higher than that in the storage ring bending magnets (typically the bending magnets operate at 5-12 KG) the electron bends more sharply in the Wiggler and hence produces more synchrotron radiation. By alternating the polarity of each section, many sections (perhaps 10) can be placed adjacent to one another, further increasing the total radiation produced but with no net bending of the electron. Thus such a transverse Wiggler could be installed in a straight section of a storage ring such as SPEAR.



Shown here is Bob Filippi, whose skill in constructing and repairing mechanical components for experiments has drawn universal praise from SSRP users. In his small but well-equipped machine shop, Bob also fabricates general equipment for the facility and trains many experimenters in the use of power tools.



Shown here is Walt Basinger, who passed up a well-deserved retirement date to do most of the design drawings for the second beam line at SSRP and is now working on beam line III. Walt thus follows in the tradition of Fred Johnson, who carried out the same work for beam line I after his temporary retirement from SLAC.

In another form of the Wiggler a magnetic field with a large number of periods (perhaps 100) would be used to produce interference effects which could result in a large increase in synchrotron radiation intensity at certain photon energies. One such geometry involves a double helical superconducting winding. The device is called a helical wiggler.

Preliminary designs of both transverse and helical wigglers for SPEAR have been made by Steve St. Lorant of SLAC.

Interest in wiggler structures has increased rapidly in the past few years. In addition to enhancing the spontaneous emission of synchrotron radiation the wiggler structure may also be used for stimulated emission, in a device called the free electron laser. Very promising results in this development in the infra-red region of the spectrum have recently been obtained by Madey and collaborators at the Hansen Labs on the Stanford campus using the superconducting linear accelerator as the electron source. The next step in the development would be to incorporate the device in a small storage ring.

Wigglers are also planned as part of the magnet lattice of PEP. An analysis by Paterson, Rees and Wiedemann shows that the synchrotron radiation produced by the wiggler may be used to control damping rates and beam size, resulting in improved performance of PEP (higher luminosity) at energies below 15 GeV.

Although ideas about using wiggler structures abound, to date there has been only one experience where a wiggler was successfully used in a storage ring. This was at the CEA storage ring where a five pole transverse wiggler was used to redistribute damping rates so that all three modes of oscillation were damped, thus permitting beam storage in the alternating gradient structure of the machine.

The various applications of wigglers will be the subject of a Wiggler Workshop organized by Herman Winick to be conducted at Stanford on March 21-23, 1977. Representatives of several laboratories in this country and abroad (including Brookhaven, Wisconsin, CERN, DESY, Frascati, Daresbury) are expected to attend.

## F. PRESENT U. S. FACILITIES

At present synchrotron radiation programs are underway at the following four U.S. laboratories:

*1. UNIVERSITY OF WISCONSIN*

The synchrotron radiation source is a 240 MeV storage ring called Tantalus I, which has been in operation under the directorship of Ed Rowe as a dedicated source since 1968. A vigorous program is in progress with up to 11 simultaneous users on 8 tangential beam ports. Stored currents in excess of 100 mA are regularly achieved, providing high flux up to about 150 eV photon energy.

*2. SSRP - STANFORD*

Two beam ports serving up to 9 simultaneous users are installed on the SPEAR 4 GeV storage ring. Many programs are underway over the full spectral range from the visible through the ultraviolet and into the X-ray region up to about 50 keV. Stored currents are limited to 5-40 mA (depending on the energy) during colliding-beam runs. In single-beam, multi-bunch mode, currents of 225 mA have been stored, and even higher currents should be possible. SSRP is directed by Seb Doniach.

*3. NATIONAL BUREAU OF STANDARDS*

The original 180 MeV synchrotron at NBS, Washington, used for synchrotron radiation research since 1961, has recently been converted to a 250 MeV storage ring called SURF II. This is now operated as a dedicated synchrotron radiation facility, directed by Bob Madden, in the spectral range up to about 150 eV. Three beam lines are installed, and up to 8 more could be added. Currents of 10-15 mA are now achieved, and higher stored currents are anticipated.

*4. CORNELL UNIVERSITY*

The 12 GeV electron synchrotron at Cornell is equipped with one synchrotron radiation beam port, with two simultaneous users. This facility serves a small number of local users with hard X-rays up to 150 keV during high-energy physics runs. Bob Batterman is in charge of the program.

Stanford graduate student Jim Phillips is shown here checking out a newly acquired "four-circle goniometer"--a complex, computer controlled device that is used for precise alignment of crystals. An X-ray beam striking the crystal at a well-defined angle produces diffraction spots that are recorded by a scintillation detector, and large arrays of such diffraction spots can be analyzed to determine the crystal structure. At SSRP, the wavelength of the incident X-ray beam can be selected to enhance the diffraction due to certain heavy atoms that may be present in the crystal. This particular technique, known as "anomalous dispersion," has a great advantage in trying to determine protein crystal structures that are inaccessible with a conventional, fixed-wavelength source such as an X-ray tube. Keith Hodgson, Assistant Professor of Chemistry at Stanford and Jim's Thesis supervisor, works closely with SSRP in developing instrumentation for diffraction experiments.

*5. A LOOK TOWARD PEP*

When the PEP colliding beam storage ring now under construction at SLAC becomes operational (expected in 1980), yet another, and by far the most powerful, synchrotron radiation source will become available. The PEP ring will produce several megawatts (compared to about several hundred kilowatts for SPEAR) of synchrotron radiation, with photon energies extending to several hundred kilovolts. Synchrotron radiation beam runs could be installed, and possible locations of a laboratory building have been identified. However, no firm plans or requests for funding have yet been made for such a PEP synchrotron radiation facility. At present only a few experiments (e.g.: the search for superheavy elements) would require very high X-ray energies, and some of these could be served as well by a wiggler magnet at SPEAR. Still, PEP has unique characteristics, such as an interval between pulses that is almost three times longer than in SPEAR. Also, if a wiggler with a large number of periods were installed on PEP, interference effects would produce quasi-monochromatic peaks of X-rays in the energy range of 5-30 keV with much higher intensity than could be produced at SPEAR. Because the vast potential of SPEAR for synchrotron radiation research is still only barely exploited, most of the action and plans are centered on using SPEAR at present. However, more compelling reasons for using synchrotron radiation from PEP may develop in the future.

## G. FUTURE U.S. FACILITIES

*1. THE NAS-NRC PANEL*

Recently an assessment of the national need for facilities dedicated to the production of synchrotron radiation was made by a scientific panel under the auspices of the National Research Council of the National Academy of Sciences. In some ways this panel performed the same function for synchrotron radiation research that ERDA's High Energy Physics Advisory Panel (HEPAP) does for high-energy physics research; that is, it reviewed the national needs, the ongoing and proposed programs, and it made recommendations for future funding. An important difference is that HEPAP is a continuing body whereas the synchrotron radiation panel is not.

The chairman of the Panel, Robert Morse, a physicist and oceanographer, from Woods Hole, Massachusetts, was selected to assure neutrality since proposals for new facilities had already been made. In his preface to the report Dr. Morse says, "Although I have remained neutral, I hope the reader of this report does sense genuine enthusiasm in it for the future promise of synchrotron radiation. Certainly this enthusiasm is one that I now share even though my professional interests are now far afield."

### NAS-NRC PANEL REPORT

*The Report of the Panel established by the National Research Council of the National Academy of Sciences to consider national needs in synchrotron radiation research reads in part as follows:*

The Panel finds that there exists outstanding scientific and technological justification for a greatly expanded synchrotron radiation capability. Both construction of new dedicated facilities and expansion and dedication of existing facilities are required to meet national needs over the next ten years. Because new facilities require five years to plan and construct, the projected need requires the expansion of existing facilities during the next five years. Needs for synchrotron radiation beyond the next five years can be satisfied only if a commitment to the construction of new dedicated facilities is made now, because full expansion and dedication of existing facilities would satisfy less than one half of the national need projected for 1986. Even with an immediate commitment to the expansion of existing facilities and the construction of new facilities, there will be a chronic undercapacity that will become most acute five years from now.

The Panel recommends that, in response to synchrotron radiation needs, an immediate commitment be made to construct new dedicated facilities and to expand existing facilities so that optimized VUV and X-ray capabilities are provided . . . .

Dr. Morse expressed this enthusiasm in another way at one of the working meetings of the group when, during a discussion among partisans for various sites for a dedicated storage ring, he said essentially, "You are all going to be surprised when the machine gets built in Woods Hole."

The main conclusion in the report of the panel was that there is a large need for additional synchrotron radiation research facilities in this country, and that this need would not be met over the next 10 years even if a single storage ring, such as SPEAR were to be fully dedicated to synchrotron radiation research. The panel therefore recommended that new storage rings be authorized and that existing facilities be more fully exploited.

*2. SSRP EXPERIENCE*

Much of the background for these conclusions and recommendations came from the experience at SSRP, where there has been a rapid growth in the number of scientists eager to use synchrotron radiation in their research.

Starting from about 15-20 researchers in May 1974, SSRP now has about 100 active research proposals representing the interests of about 200 scientists from about 40 institutions including universities, government laboratories and private industry. These scientists are from many parts of this country, and also from Canada, France, Italy and Japan.

Within the first six months of operation of the first beam line at SSRP (which was divided to enable operation of five simultaneous experiments), it became clear that additional research facilities, particularly in the X-ray region, were urgently needed to meet the growing demand and to exploit new scientific opportunities. A second beam line, designed for X-rays only, was funded by the NSF in June 1975 and became operational one year later. SSRP now has the capability of operating 8-9 simultaneous experiments (two using ultraviolet radiation and 6-7 using X-rays), but still the demand exceeds the supply.

In particular there is now an acute shortage of experimental facilities serving users with radiation in the photon energy range from 25 eV to 2 keV (called the vacuum ultraviolet or VUV). At present, SPEAR is the only storage ring facility in this country capable of serving this energy range as well as the more energetic X-ray region up to 50 keV, since the Wisconsin and NBS storage rings provide high flux only up to about a photon energy of 150 eV. A study has been made for a third beam line at SSRP that will provide new capabilities in the ultraviolet and soft X-ray portions of the spectrum, and that will also better accomodate the overall present need for VUV facilities.

Shown here is Ron Gould, who is Assistant Director of the Hansen Labs on the Stanford campus. Administratively, SSRP is a part of the Hansen Labs, and Ron is responsible for most of the complex coordination that is needed among SSRP, Stanford, SLAC and the National Science Foundation. This includes the handling of such intricate matters as the patent rights of industrial users of the SSRP facilities.

SSRP's Director is Sebastian (Seb) Doniach, Professor of Applied Physics at Stanford. Doniach has been the Director of SSRP since its inception. He and Bill Spicer made the original proposal to the National Science Foundation that led to the creation of SSRP. Doniach's interests range broadly over the field of solid-state physics and more recently biophysics. Although primarily a theoretician, he has participated in SSRP experiments (and is credited with one dump of the SPEAR beam while attempting to open a locked experimental enclosure).

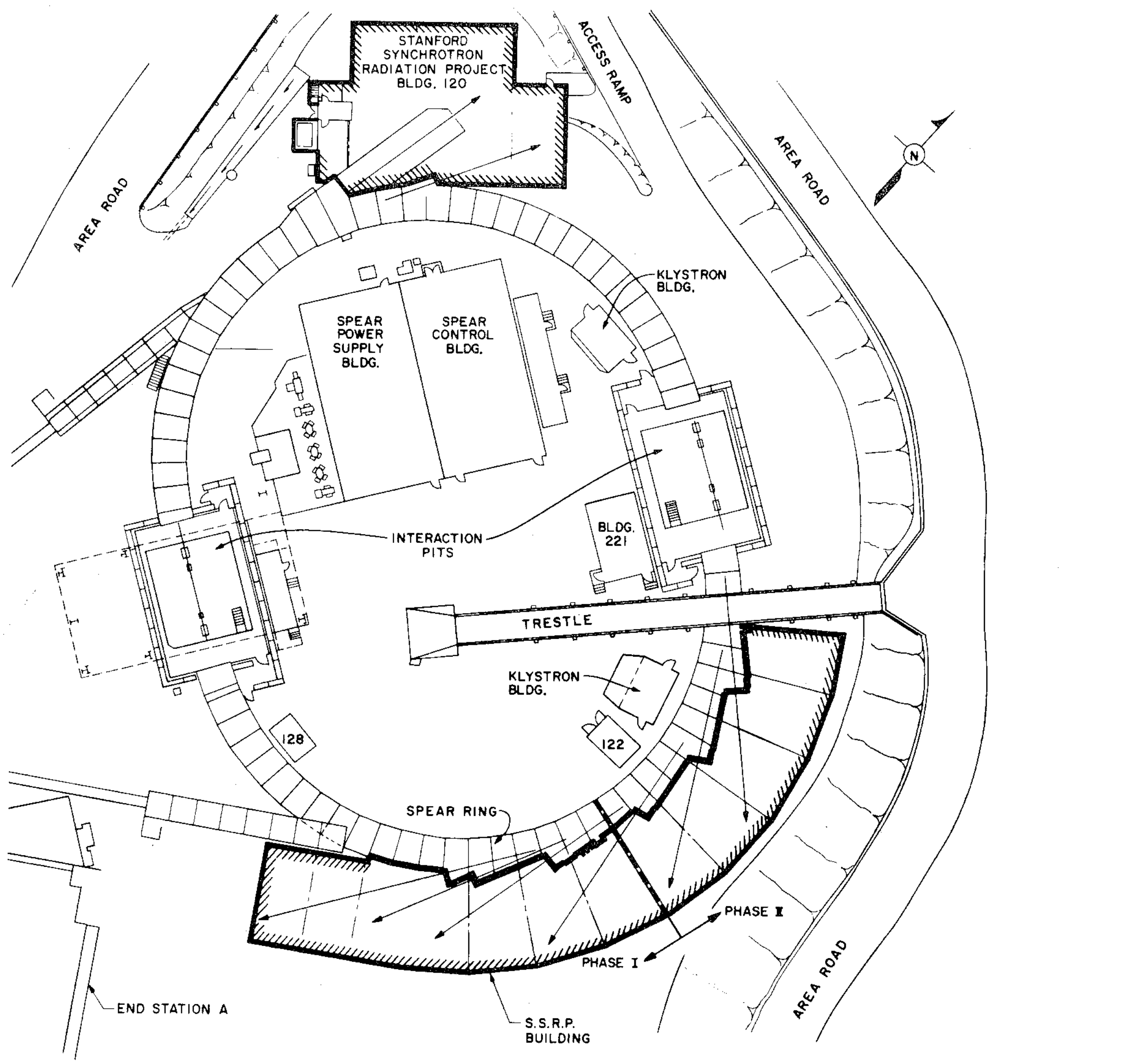
### 3. *PROPOSALS FOR NEW FACILITIES*

As a result of the national needs as expressed in the panel report, three major proposals for synchrotron radiation research facilities have been submitted to government funding agencies. In addition, there is a proposal to construct an 8 GeV colliding-beam storage ring at Cornell which would also be used for synchrotron radiation research. The details are as follows:

(a) SSRP. A proposal has been submitted to NSF and ERDA to construct seven new beam ports on SPEAR, initially serving 14 experimental stations each equipped with a monochromator system. In addition, two wiggler magnets and a new building on the South arc of SPEAR would be constructed. These facilities would require three years to complete at an estimated cost of $6.7 million and would be constructed in a manner compatible with colliding-beam operation. If funded in FY 1978, as requested, additional research facilities would start to be available during 1978. The complete package would be operational in about 1980. This coincides well with the schedule for startup of research operation for PEP, and it is expected that SPEAR will become increasingly available for dedicated synchrotron radiation research (high currents, high energy, electrons only) at that time. In particular, there is a tentative understanding that, at the time PEP is scheduled for 50% of its operation time for high energy physics experiments, SPEAR will be available for dedicated synchrotron radiation research for 50% of its operations time. In single-beam mode, considerably more synchrotron radiation is produced because stored current levels are not limited by beam-beam collison effects. Furthermore, the size of the electron beam is smaller in the absence of collisions, resulting in increased source brightness. This increases the useful flux per milliampere of stored beam by as much as a factor of four for some experiments. Further improvements in source brightness are believed possible by changing quadrupole magnet currents on single beam runs.

(b) Brookhaven National Laboratory and University of Wisconsin. Proposals that are independent but quite similar to each other have been submitted by each of the above laboratories. In both cases, two storage rings are proposed; one at 700-750 MeV to independently serve users in the vacuum ultraviolet and soft X-ray part of the spectrum (up to 1-2 keV), the other at 2-2.5 GeV to serve X-ray users. All four storage rings are designed with "C" magnets to facilitate extraction of synchrotron radiation into many different beam lines, and emphasis is placed on achieving high source brightness by keeping the electron beam emittance as small as possible. High currents (up to 1A) are planned, and provision is made to incorporate wigglers.

Different injection schemes are proposed. The Wisconsin proposal uses a 100 MeV microtron to inject into the small storage ring. The beam is then slowly accelerated to 750 MeV and transferred to the larger storage ring,

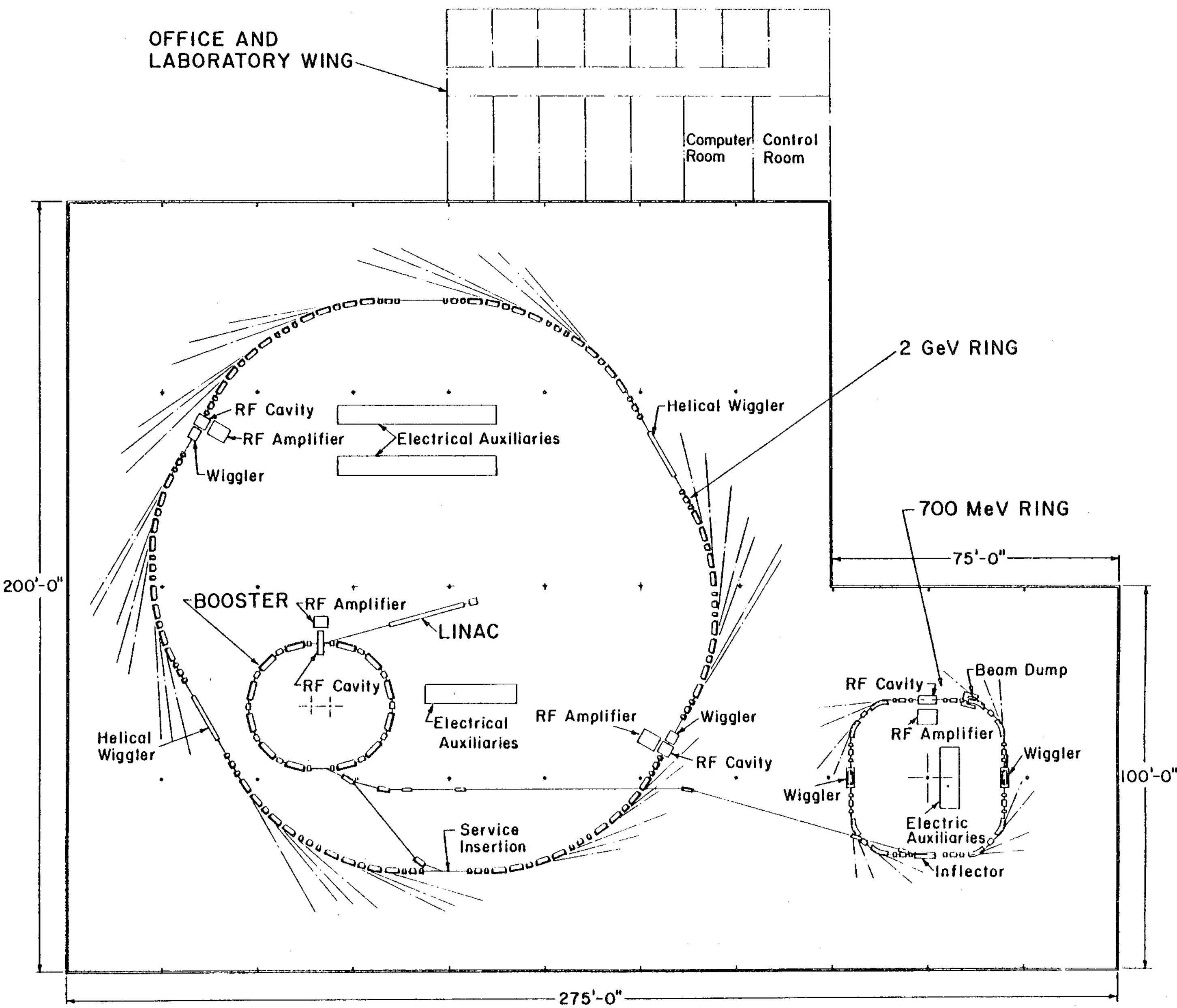



This drawing shows the location of the present SSRP facility (upper building) at the SPEAR storage ring, and also that of the proposed new SSRP facilities (lower building) that are planned for future construction. Gary Warren is presently studying possible shielding needs to isolate the new facility radiologically from End Station A.

where it may be ramped up to 2.5 GeV. In the Brookhaven proposal the injector consists of a 50 MeV linac and a 700 MeV booster synchrotron. Both the 700 MeV storage ring and the 2 GeV storage ring are served by the same injector. Both laboratories estimate a cost of about $22 million, including some experimental apparatus, and about a 3½ year construction period.

(c) Cornell University. The proposed 8 GeV colliding-beam storage ring includes three beam ports for synchrotron radiation and an isolated working area for experiments. Much advance planning has been done on this machine and, if authorization to proceed is received soon, the Wilson 12 GeV synchrotron will be shut down in October 1977 to begin construction of the storage ring, with stored beams expected in 1980.

Based on the budget submitted to Congress by outgoing President Ford, there is a high level of confidence in the synchrotron radiation research community that many of these proposed facilities will be funded starting in FY 1978. In particular, it seems likely that the SSRP expansion, the 750 MeV storage




General layout of the synchrotron radiation research facility that has been proposed for construction at Brookhaven National Laboratory. Both this proposal and a similar proposal from the University of Wisconsin include two separate storage rings (700 MeV and 2 GeV) as sources of synchrotron radiation.

ring at Wisconsin, and the 700 MeV and 2 GeV rings at Brookhaven will be funded in FY 1978. Furthermore, the proposed Cornell 8 GeV storage ring is also likely to be funded.

*4. THE SITUATION FIVE YEARS AGO*

It is interesting to note that a similar situation existed in 1972, a time when the following three proposals for synchrotron radiation research facilities had been presented to the NSF:

(a) A proposal by E. Rowe and R. Borchers for the construction of a new 1.76 GeV electron storage ring at the University of Wisconsin to be dedicated to synchrotron radiation research.

(b) A proposal by W. Paul, K. Strauch and H. Winick for the dedication of the CEA 3 GeV storage ring in Cambridge, Massachusetts to synchrotron radiation research (it had already been decided to terminate the high-energy physics program).

(c) A proposal by S. Doniach and W. Spicer (assisted by G. Fischer at SLAC) for the construction of the Stanford Synchrotron Radiation Project utilizing synchrotron radiation produced during colliding-beam operation of SPEAR.

The NSF assembled an advisory group to assist in deciding among these proposals. The general feeling was that synchrotron radiation as produced by storage rings was a tool whose utility had been demonstrated in the ultraviolet part of the spectrum by four years of experience at the 240 MeV storage ring in Wisconsin. Indications of even greater research potential from a more powerful storage ring was present, based on the brief experience (less than one year) of a few scientists using the CEA 3 GeV storage ring. The NSF authorized construction of SSRP in June 1973 as the least costly way to evaluate the scientific prospects of synchrotron radiation from a high-energy storage ring. The SSRP experience has provided a clear affirmation of these prospects.

## H. THE INTERNATIONAL SCENE

There is considerable activity abroad in this field at present, with 15 sources being used in seven countries. Furthermore, a major dedicated storage ring (2 GeV) is under construction in England. Designs and proposals for dedicated storage rings have also been made in Japan, The Netherlands and the Soviet Union. The details are as follows:

*1. ENGLAND*

Two beam lines for synchrotron radiation have been in use at the Nina 5 GeV synchrotron at Daresbury since 1971. However, this accelerator is to be closed down by early 1977. Authorization was given in 1975 to construct a high current (1 A) 2 GeV storage ring at Dares-

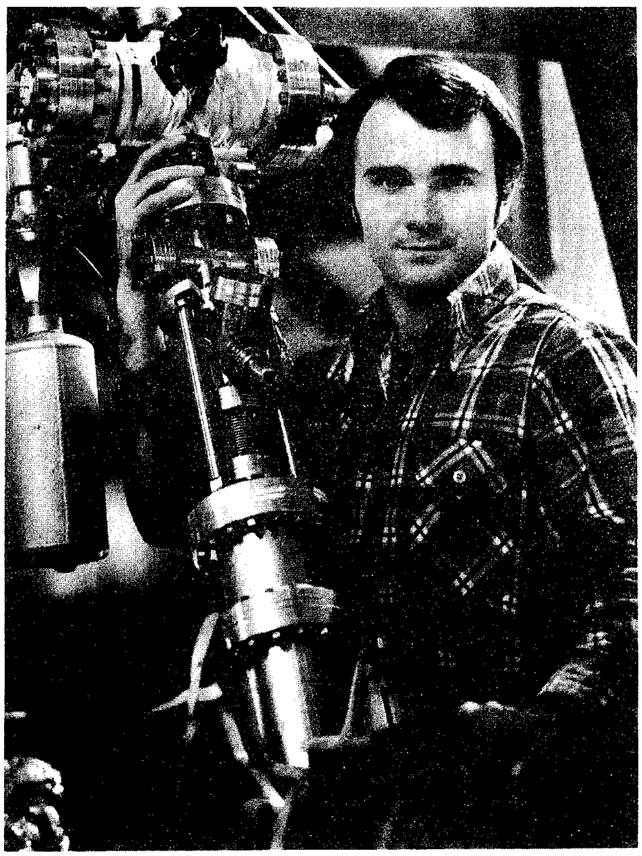
William Spicer (left) and Ingolf Lindau are shown outside the SSRP Building at SPEAR. Spicer is Consulting Director of SSRP and Professor of Electrical Engineering and of Materials Science and Engineering at Stanford. As a pioneer in the field of ultraviolet photo-emission spectroscopy, Spicer readily appreciated the potential of SPEAR as a source of synchrotron radiation, and he initiated discussions about its possible use with SLAC's Director, W. K. H. Panofsky, in 1968. As Deputy Director of SSRP, he played a major role in developing the original facility, and he presently maintains his interest and involvement as Consulting Director, advising on the development of new experimental capabilities in the ultraviolet and soft X-ray part of the spectrum.

Lindau is Adjunct Professor at the Hansen Labs and in the Department of Electrical Engineering at Stanford. He used synchrotron radiation from SPEAR for photo-emission experiments even before SSRP was built. Together with graduate student Piero Pianetta (who recently obtained his Ph.D. and now works at SSRP), Lindau mounted an experiment outside the SPEAR shielding in 1973 with no protection from the weather (remember how it rained back in 1973?). He continues an active research program at SSRP using ultraviolet photo-emission techniques and has major responsibilities for the experimental program on the SSRP vacuum beam lines. When SSRP is not in operation, he can often be found making measurments with more conventional light sources in Spicer's lab on the Stanford campus.

bury called the SRS, a dedicated Synchrotron Radiation Source. This project is now underway. The scheduled completion date of 1979 may slip due to Britain's severe economic problems which have resulted in cutbacks in the rate of funding of this project.

*2. FRANCE*

Two storage rings are used for synchrotron radiation research at Orsay. The synchrotron radiation project there is called "LURE", an acronym for Laboratoire pour l'Utilisation du Rayonnement Electromagnetique. The 540 MeV ring, ACO, originally a colliding-beam machine, has been used since 1971 and is now a dedicated synchrotron radiation source--proof that parasites can consume the host. The colliding-beam storage ring DCI, now operating at 1.6 GeV but expected to reach 1.8 GeV, is used as an X-ray source. ACO was the first machine in which the pulsed time structure was used to measure fluorescense lifetimes in atomic and molecular systems. In fact the scientist primarily responsible for this work, Ricardo Lopez-Delgado, has been attracted by the much superior time structure of SPEAR. He has done two experiments at SSRP while on brief visits during the past 14 months and is planning to spend one year at SSRP.



Shown here is Kevin Monahan, who received a Resident Research Associate award from the National Science Council after obtaining his Ph.D. from UC-Santa Barbara. He is using this support to carry out a research program at SSRP in close collaboration with Vic Rehn's group from the U.S. Navy's Michelson Laboratory at China Lake, California. Kevin is shown here with the monochromator system developed by Rehn's group. He is particularly interested in exploiting the sharply pulsed time structure of the SPEAR radiation in studies of flourescence lifetime.

Ernie Moss, shown here, *is* the SSRP electrical shop. Ernie looks after a large array of electrical and electronic equipment for the facility and its users, including four PDP-11 computers.

*3. GERMANY*

Three synchrotrons and one storage ring are used for synchrotron radiation research in Germany. The DORIS storage ring at Hamburg is equipped with two beam lines. DORIS has operated primarily at energies below 2.2 GeV, and most of the work now being done is in the vacuum ultraviolet part of the spectrum. Higher energy operation (4 GeV) is planned, at which time a more intense X-ray flux will be available.

The DESY synchrotron (originally 6 GeV) now operates up to 7.5 GeV and has supported a major program over the entire spectral range starting in 1966. Also, considerable work is done on two synchrotrons in Bonn; one operates at 0.5 GeV, the other at 2.5 GeV.

The large colliding-beam storage ring PETRA at DESY, which will store beams up to about 18 GeV, is scheduled to begin operation in 1979. Similar to PEP, this machine will produce several megawatts of synchrotron radiation extending to photon energies of hundreds of kilovolts. As yet, however, no definite plans exist to utilize this radiation experimentally.

*4. ITALY*

Since the early 1960's a synchrotron radiation research program has been underway at the Frascati 1.1 GeV synchrotron. However, this machine is scheduled to be closed down in early 1977. In October of 1976 the first part of a beam line was installed on the 1.6 GeV storage ring ADONE, also at Frascati. An experimental program is scheduled to begin on this source by mid-1977. A wiggler magnet is now being designed for ADONE to provide flux to higher X-ray energies. Two scientists from the Frascati facility, Antonio Bianconi and Rino Natoli, are presently spending a year at SSRP before returning to the "PULSA" synchrotron radiation project at Frascati.

*5. JAPAN*

A 300 MeV storage ring has recently been completed at the Institute of Nuclear Studies in Tokyo. This machine is noteworthy in that it is the first machine to be conceived, designed and built as a dedicated source of synchrotron radiation. Since about 1965 work has been done on the 750 MeV (now upgraded to 1.3 GeV) synchrotron at the same institute. This synchrotron serves as the injector for the 300 MeV storage ring--a very favorable situation since injection takes place at the operating energy of the storage ring. This avoids the need for time-consuming (and sometimes tricky) ramping of the beam energy after injection.

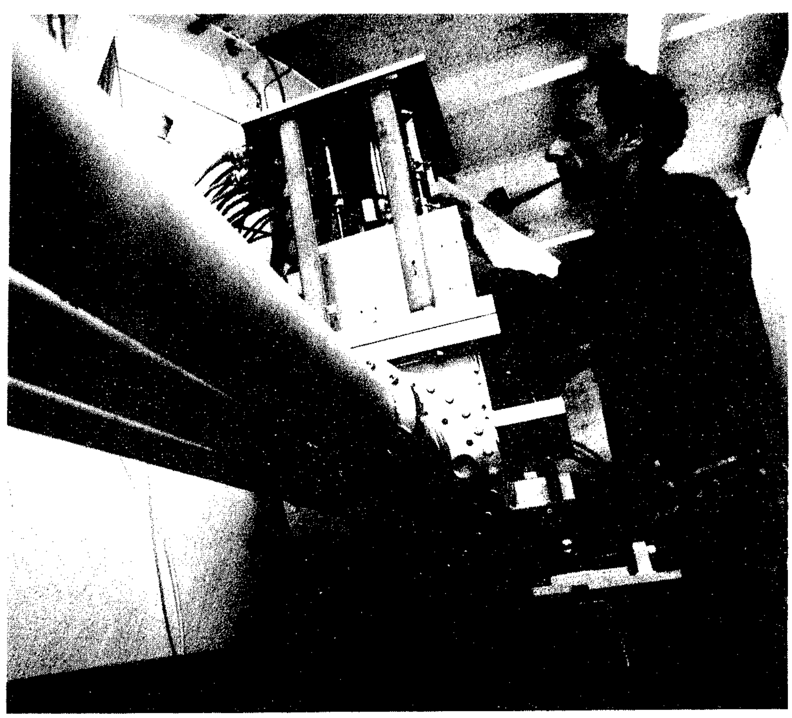
An ambitious proposal has been made to construct a 2.5 GeV storage ring called the "Photon Factory" as a dedicated source of synchrotron radiation at Tsukuba. Authorization for this machine is expected within about two years. The injector for this machine would be a 2.5 GeV electron linac, so that injection would be at the operating energy. The X-ray lithographic techniques for fabricating higher density integrated circuits are of particular interest to the Japanese, and their storage rings will probably be used in this program.

Shown here is Axel Golde, who played a major role in developing the mechanical facilities for SSRP, and who is now kept very busy with the care and feeding of an expanding user group. Out of action for a time following an illness, Axel is now back in harness, applying his many talents to the solution of the manifold problems of a growing laboratory.

SSRP's Deputy Director is Herman Winick, who is also Adjunct Professor at the Hansen Labs. As Deputy Director, Winick coordinates the activities of the SSRP engineering and technical staff, works closely with the users of the facility, and plans for new experimental facilities and for improved utilization of SPEAR. He first came to Stanford in 1973 to work with Doniach, Spicer, Lindau and others in designing the initial SSRP facility and in getting it into rapid operation. Before that time, he had spent 14 years at the Cambridge Electron Accelerator at Harvard University working on the design and operation of the original 6 GeV electron synchrotron and its later conversion to an electron-positron colliding-beam storage ring. He was also instrumental in getting a small synchrotron radiation research program underway at CEA before that facility closed in 1973.

Above is a scene from the weekly SSRP staff meeting.


At the left are Seb Doniach (left), SSRP's Director; Associate Director Art Bienenstock; and Deputy Director Herm Winick.



At the right is SSRP's newest technical staff member, John Cerino, who arrived in January 1976 to help get beam line II under way. John's long experience at the Cambridge Electron Accelerator at Harvard makes him well-qualified to provide support to users of the SSRP facility, and to tackle a variety of new equipment design problems. In this photo he is shown adjusting electrical limit switches on a multiple-shutter unit for beam line number II.

*6. THE NETHERLANDS*

A proposal has been submitted for the construction of a 1.5-2 GeV dedicated storage ring called PAMPUS, an acronym for Photons for Atomic and Molecular Processes and Universal Studies (and also the name of an island off the Dutch coast). There is optimism that this machine will be authorized, partly because a major component, the 500 MeV electron linear accelerator at the Institute for Nuclear Physics (IKO) in Amsterdam, is nearing completion. This machine, for which S-band waveguides and other components were made at SLAC, would be the injector.

*7. THE SOVIET UNION*

Several powerful sources of synchrotron radiation are now in operation in Russia including the Novosibirsk storage rings VEPP-2M (0.67 GeV) and VEPP-3 (2.25 GeV), the Yerevan synchrotron ARUS (6 GeV), the Moscow C-60 synchrotron (0.68 GeV), and possibly also the Pachra synchrotron/storage ring (1.3 GeV) near Moscow. Some synchrotron radiation research is done at these laboratories, but little is known of the magnitude of the programs.

In construction is the VEPP-4 (7 GeV) storage ring in Novosibirsk, scheduled for completion in 1977, to be primarily used for colliding beams. A dedicated storage ring at about 1.5 GeV has been proposed by Sergei Kapitza at the Institute for Physical Problems near Moscow.

*8. SWEDEN*

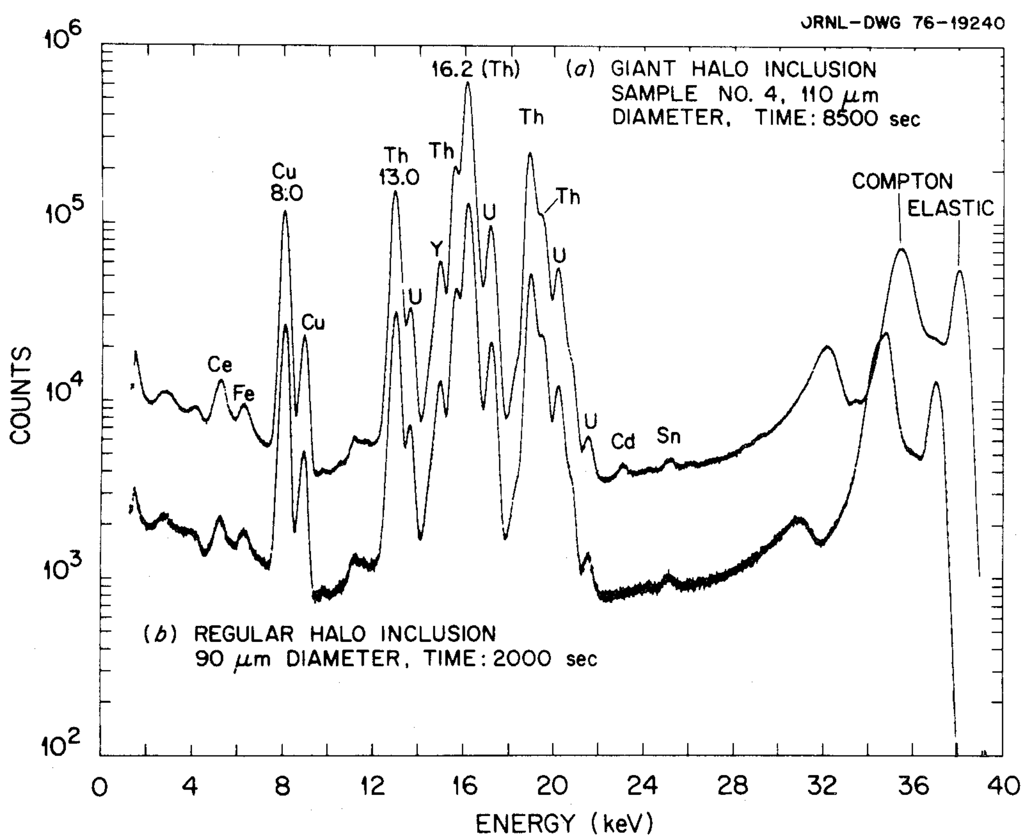
A 1.2 GeV synchrotron in Lund has been used for synchrotron radiation research and is still operational.

*9. OTHER STUDIES*

Preliminary studies for synchrotron radiation sources have been made in Canada and India, and there are also reports from the People's Republic of China that a storage ring of about 3 GeV is being considered there for both colliding beams and synchrotron radiation research. Chinese scientific delegations visiting Stanford have shown great interest in SSRP.

An effort is being made by the European Science Federation to coordinate the existing and proposed programs of synchrotron radiation research in Europe. One possibility for the future that is being considered is a central synchrotron radiation research facility for Europe where a large storage ring would be built for use by all--somewhat like the CERN model in high-energy physics.

--Herman Winick




An example of results obtained by a group from Oak Ridge National Laboratory (C. Sparks *et al.*) in their search for superheavy elements. Although no evidence for these elements was found, the results demonstrate the capabilities of synchrotron radiation for trace element detection. For example, the small peak labeled Cd in the upper curve is due to the presence of about $5 \times 10^9$ atoms of cadmium in the ≃100-micron-diameter sample. The investigators conclude that they could see a signal from $10^8$ atoms or even less.