CONF-830910--10

An Overview of United States Synchrotron
Radiation Facilities

BNL--33969

DE84 005095

R. E. Watson
Physics Dept.
Brookhaven National Laboratory
Upton, New York 11973

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

MASTER

The submitted manuscript has been authored under contract DE-AC02-76CH00016 with the Division of Basic Energy Sciences, U.S. Department of Energy. Accordingly, the U.S. Government retains a nonexclusive, royalty-free license to publish or reproduce the published form of this contribution, or allow others to do so, for U.S. Government purposes.

EJAB

1. INTRODUCTION

There has been considerable activity within the past year involving the creation of new and the improvement of existing capabilities for research with synchrotron light. The purpose of this review is to summarize what has happened within the United States. Being a status report, some of the information necessarily has a date attached to it--the date, in this case, being early September, 1983.

The existing U.S. facilities are listed in Table I along with facilities just funded or being proposed. The latter include a 1 GeV ring, just funded, on the Stanford University campus for the development of a free electron laser (FEL). This facility will have an undulator which will be available for other purposes when FEL investigations are not in progress. Sources which are proposed or under study include a 1.3 GeV Advanced Light Source at Berkeley and a pair of dedicated rings at ~ 2 and ~ 6 GeV as part of SSRL (the Stanford Synchrotron Radiation Laboratory). The institutions listed in Table I are represented in the census which appears as an appendix to these Proceedings. This census was taken by Herman Winick and the present author in an effort to measure world-wide synchrotron light usage and capability. The census questionnaire was imperfect but it is hoped that the answers provide information that is of use and of interest.

This review will concentrate on existing U.S. facilities. Two of these are currently preoccupied with the commissioning of new storage rings while the others have machine upgrading as a significant part of their activities. We will consider those facilities engrossed in commissioning first.

2. AN OVERVIEW BY INSTITUTION

University of Wisconsin: This laboratory has the 1/4 GeV ring, Tantalus, which has been in operation for some time and Aladdin, a 3/4 to 1 GeV ring, which is being commissioned.

Tantalus and the facility surrounding it have been extraordinary. In recent years Tantalus has operated at 95% of its scheduled time, which represents extreme machine reliability. The facility has been remarkably "user friendly" and serves as a model for other user facilities. Some of this success may be a matter of scale which will be hard to maintain at the larger facilities characteristic of the future.

Aladdin is currently being commissioned. Electrons have been injected, stacked and accelerated to 750 MeV and as many as 40 pulses of injected electrons have been stacked without encountering saturation effects. It has been demonstrated that the major storage ring systems work and no design flaws, that might impede the commissioning, have been encountered. The next major task is that of getting the high power rf system on line.

There are currently eight monochromators operating on Tantalus and most of these will be shifted over to Aladdin as part of the twenty-three devices which will be available in its early stages of operation. About half the monochromators belong to participating research teams (PRT's) while the other half are built and operated by the facility. A number of the new Aladdin monochromators will operate in the difficult several hundred to several thousand eV photon regime.

Aladdin has straight sections designed to accept wigglers or undulators but, as on the new storage rings at Brookhaven, the first

generation of experiments will take radiation from bending magnet ports. Among the special capabilities being developed for use on Aladdin will be the spectroscopy of gases at "high pressures."

NSLS, Brookhaven: Its $3/4$ GeV VUV storage ring is an operating bright light source. Currently it operates in single bunch mode with a 200 mA starting current at $3/4$ GeV with 1-1/2 to 2 hour lifetimes. The emittances are within better than a factor of two of the design values. Considerable loss in brightness occurs in multibunch operation due to the accumulation of positive ions in the orbit region. The stability in beam position has proven troublesome over the last year--of course a bright source with its small beam size has more stringent requirements on this than do less bright sources. This problem is now under control. Improvements in current and beam lifetime are needed and are being worked on: some experiments, such as microscopy and lithography, require higher average currents than are now available.

The NSLS 2 - $2-1/2$ GeV x-ray ring is being commissioned and has had as much as 14 mA in it and 9 mA has been accelerated to 1.8 GeV. Much work was done in recent months on the stability of the magnet power supplies with a measurable improvement in ring performance though there remain problems associated with the reproducibility and reliability at injection. As with Aladdin, the commissioning is a matter of completing systems, of diagnosing problems and of straightening out details.

There are currently 16 experimental stations operating on the VUV ring and another 18 are under construction with 11 more planned. There will be a similar investment on the x-ray floor. The facility's x-ray monochromators will be in vacuum with metal mirrors as first elements. A

second phase of construction, involving expanding the building and instrumenting beam lines, starts October 1983. With the exception of an infrared line, the new beam lines will take radiation from wigglers or undulators. It is anticipated that the x-ray wiggler lines will employ multilayer mirrors as their first elements in order to deal with the heat load (see Hastings and Thomlinson--this meeting).

SURF II, National Bureau of Standards: SURF is the longest operating synchrotron light facility in the country. The pioneering work on gas spectroscopy was done there. SURF II operates at 280 MeV with an initial current of 30-60 mA. Machine improvements over the last year in the rf, in power supply regulation and in the vacuum are responsible for an increase to the present current and an increase in beam lifetime. New monochromators, emphasizing resolution and throughput are coming on line as is a new high resolution angle resolved electron spectrometer, designed for gas spectroscopy. This spectrometer involves a twice standard size spherical analyser so as to improve throughput at high resolution and there are three layers of magnetic shielding. There are currently eight experimental stations with three more due on line next year.

Unlike the case of the other storage rings, SURF's electron orbit is circular because the entire orbit is between the pole faces of a single magnet. This makes SURF a particularly opportune absolute standard light source because, one must know how many electrons there are at what energy, position and bending radius if one is to estimate the intensity of synchrotron light being emitted at some given wave length. This is more readily done if one has circular orbits. The SURF staff estimates that using SURF as an absolute source can be done currently to ~ 2% accuracy

at 200 nm (and ~ 3% at 4 nm) [see Madden, these proceedings]. Such accuracy is better than what is required for the calibration of spectrographs employed in astronomical and other investigations.

CHESS, Cornell University: This facility operates parasitically on a high energy machine which runs 24 hours per day, seven days per week. There are six experimental stations each accepting 14 mrad of light. Operation at 5 to 5-1/2 GeV is typical, which makes this the source of hardest radiation in the United States. Starting currents of 15-20 mA were typical until recently, but last summer the ring was upgraded to multibunch operation and as much as 75 mA, in three bunches 870 nsec apart, is now anticipated.

Time dependent studies have been of particular concern at Cornell (Mills, this meeting). Studies of the time dependence of the laser annealing of Si, done in collaboration with Oak Ridge, were reported at last year's Hamburg meeting. More recently, Mills and coworkers have taken time dependent EXAFS snapshots of myoglobin and Kostroun and Hastings have done time of flight spectroscopy. A major effort has involved time dependent Bragg-Laue white light crystallography [Chess Tech Memo #60, 1983]. The problem in such schemes is that individual diffraction spots tend to involve more than one Bragg peak thus inhibiting any intensity analysis. The number of such spots has been brought to a small fraction of the total by employing a band of x-ray frequencies 2 to 5 keV in spread. This band is produced by cutting off the hard radiation by total external reflection from a mirror and by attenuating the soft radiation with several metal foils and a column of air. Recently 400 msec usable snapshots have been taken and significantly faster ones are anticipated.

A six pole, 18 kg wiggler station is currently being implemented at Chess. On it will be a carousel monochromator spanning 4 to 60 keV as well as a line for the Bragg-Laue crystallography. In addition, there will be a large 4 axis Huber instrument for accurate structure factor measurements and the electron density mapping of crystals. Hard radiation will be employed for this so as to reduce the importance of extinction corrections.

SSRL, Stanford University: This is the largest of U.S. synchrotron light facilities and until the advent of Chess was the sole source of x-rays. As at other institutions, much of the concern in facility development has involved wigglers, undulators and machine upgrading and this is due to the priority which has been placed on improving the central brightness available to experimenters.

Two eight pole 18 kG wigglers are operational at SSRL as is a 60 pole variable gap undulator which was constructed in collaboration with the Lawrence Berkeley Laboratory (see Halbach in these proceedings). This undulator's fundamental spans photons from $3/4$ to $1-1/4$ keV when SPEAR operates at 3 GeV. Currently this undulator and one of the wigglers share the same insertion region and one or the other may operate at some given time. A 54 pole, variable field gap wiggler, which may operate up to 12 kG, is under construction. A ~ 25 pole undulator for use on SPEAR, as well as a hard x-ray undulator for parasitic use on the PEP (15 GeV) storage ring are being planned. Now, the sharply peaked spectra of the current generation of undulators is associated with much longer wavelengths than that of normal synchrotron radiation. Substantially harder undulator radiation can be obtained by going to magnetic devices

with substantially shorter periods than those currently built or by going to higher storage ring energies. Since the first option is hard to implement, there is great interest in having an undulator on PEP.

Machine improvements are also of importance to SSRL and these are being implemented as finances allow. These include improving SPEAR's brightness as well as the stability and control of the electron orbits. In addition, there is a scheme to use a segment of the SLAC linear accelerator for injection into SPEAR. This is needed because other California power requirements make it impossible to operate the full linear accelerator during the summer.

As for beam line development, several matters require mention. First, JUMBO, an ultra high vacuum monochromator, has been standardly providing 800 to 4500 eV photons, thus relieving the drought in this difficult wavelength regime. JUMBO utilizes four pairs of crystals to span this wavelength range and these may be interchanged in situ. Secondly, there has been a gaseous wire area detector in operation on the protein crystallography line and, finally, an x-ray rotation camera is being installed on one of the wiggler lines. The latter will allow the rapid collection of high resolution crystallographic data as well as the study of very small crystals. The camera will be able to utilize 0.7 to 1.9Å light so as to exploit anomalous scattering.

3. SUMMARY

The discussion above suggests areas of rather similar activity and concern at the various U.S. facilities. These areas include:

UV and Soft X-rays - While there have been significant advances in UV and soft x-ray instrumentation (look elsewhere in these proceedings) the notable change is the great increase of experimental stations available, or about to become available, in the U.S. For soft x-ray usage, there is JUMBO operating at SSRL and crystal and other [e.g. see Himpsel et al., this meeting] monochromators coming on line at NSLS and Wisconsin. (The NSLS UHV crystal monochromator is the same as will be used on x-ray beamlines.) Lithography studies are underway at NSLS (Haelbich and Silverman, this meeting) and will be shortly at Wisconsin and SSRL. Soft x-ray microscopy (Kirz, this meeting) and holography investigations are also being done.

X-rays - Perhaps the most notable activity is the investment in crystallographic capability on wiggler beam lines at both CHESS and SSRL.

Wigglers and Undulators - The development and usage of such insertion devices is growing at a rapid rate. Some of these are devised as wavelength shifters, providing harder radiation than is obtainable from a ring's bending magnets. Others are being developed so as to provide greater flux and brightness than is otherwise available. This is essential to some experiments but there are significant numbers of experiments which do not gain qualitatively from such devices. This does not take away from the importance of insertion devices for those experiments for which they are essential. Of particular interest is SSRL's proposal for an undulator on PEP which would provide undulator light at hard x-ray wavelengths (also of interest would be an undulator at CHESS if that were feasible).

Machines - A major effort has been put into the commissioning of new and the upgrading of existing storage rings. The very scale and nature of this effort will have a qualitative impact on the science which will be done. There is a program of machine upgrading planned for NSLS which is relevant to any high energy, high brightness synchrotron light facility. This involves being able to inject the rings in a topping off mode at full operating energy (which can be done at NSLS with the existing machines for the VUV ring but requires the construction of a new booster synchrotron for the x-ray ring). There are four reasons for doing this.

- Injection at full energy increases the initial current which may be injected into a ring.
- Injection at full energy avoids ramping down to lower energies with the possible change in magnet behavior which can then occur when the ring is brought back to full energy. Such changes have deleterious effects on beam position and stability and this is critical in high brightness machines.
- Frequent topping off allows one to maintain the current in the ring so that the average current and the current at injection are nearly the same. This could be equivalent to something like a five-fold increase in current.
- Running a ring at constant current means that the optical and other machine components are subjected to constant power densities, thus reducing thermal cycling.

There are also areas which are but slightly represented in last year's activities, one being the development of detectors. This may be

because detectors are at the very end of experimental beamlines. Whatever the reason, there appears to be no concerted effort in detector R & D.

4. GENERAL ISSUES

Traditionally, beamline instrumentation has started at the safety shutter and vacuum valve which separate the beamline from the machine vacuum. However, as D.J. Thompson noted in his discussion of a European facility at last year's Hamburg meeting, it is appropriate to consider a wiggler or undulator (or, for that matter, a bending magnet) as the first element of the beam line because of how these sources interact with elements further down the line. This view is reflected in the program of the present meeting and one might go one step further and argue that certain aspects of storage ring design and operation should be considered to be part of the same system.

The activities of the past year indicate that participating research teams (PRT's) are playing an increasing role in the instrumentation effort in the United States. This is, in part, a practical matter of economics but more importantly one might expect some excellent imaginative instrumentation, when done by scientists driven by their own research interests. Such instrumentation tends to be more "refined" and more "fragile" than that which, of necessity, is developed by the facilities themselves. One matter which is sometime a complication, is that PRT's are often organized by individual institutions and compromises may be necessitated by the various research needs of the institution in question. Such difficulties seem slight compared with the gains in having different groups taking diverse approaches to what are often common instrumentation problems.

Finally, there is an issue which has been raised by Artie Bienenstock several times this past year. Should the priorities be put on having beam line and other ancillary facilities which are "best" or which are "user friendly"? One, of course, wants to do the best possible science but user friendly facilities are essential if synchrotron light sources are to have impact on the large number of investigators who regularly use photons in their laboratories and who would benefit from occasional use of synchrotron light. Sometimes it takes little or no compromising to meet the two priorities. However, there are times when this can't be done. Clearly some facilities must be made "user-friendly" while others must be "best" if synchrotron radiation based research is to reach its full potential.

This work was supported by The Division of Materials Sciences U.S Department of Energy under contract DE-AC02-76CH00016.

Table I United States Synchrotron Light Facilities

Operating or being commissioned:

National Bureau of Standards	0.28 GeV	SURF II
Univ. of Wisconsin, SRC	0.25 GeV	Tantalus
Univ. of Wisconsin, SRC	0.75 - 1 GeV	Aladdin
Stanford Univ., SSRL	3 - 3.5 GeV	SPEAR
Cornell Univ., CHESS	5 - 5.5 GeV	ring
Brookhaven Natl. Lab., NSLS	0.75 GeV	VUV ring
Brookhaven Natl. Lab., NSLS	2 - 3 GeV	x-ray ring

Funded:

Stanford Univ., Appl. Physics Dept.	1 GeV ring for FEL investigations
-------------------------------------	-----------------------------------

Proposed or under study:

Lawrence Berkeley Lab, NCAM	1.3 GeV ALS
Stanford Univ., SSRL	undulator on 8-15 GeV PEP
Stanford Univ., SSRL	Dual - 2 and - 6 GeV dedicated rings