A Model Synchrotron Light Source in Berlin

Users want photons on a reliable schedule; Berlin's electron storage ring (BESSY) provides 2400 hours of bright ultraviolet light yearly

Those used to a "small science" style of research now often have to travel to large centralized research facilities in order to do forefront experiments. This article is one of a series in which Science *looks at such centers in Europe.*

West Berlin. Though the advantages of its high brightness and continuous, broad spectrum were undoubted, synchrotron radiation in its early days often seemed better at delivering promises than real photons. No pioneer in the field is without numerous tales of anger and frustration traceable to a weak or undependable source, as often as not operated by high energy physicists with other things on their minds.

The present generation of electron storage rings dedicated only to the production of synchrotron light was built to change all this. One of the most successful of these is here in West Berlin. The 2½-year-old Berlin Electron Storage Ring for Synchrotron Radiation (BESSY), while by no means perfect, clearly shows off the best side of synchrotron radiation. With a combination of adequate funding, typically European conservative engineering, and a decided user service orientation, BESSY is a facility that delivers all the photons it promises.

Synchrotron radiation users concern themselves with two measures of source performance: the number of hours it is up without interruption and the quality of the light it delivers. Although BESSY shines in both categories, officials here are most obviously proud of the reliability of their light source.

During the first year of operation after the initial photons streamed down beamlines to waiting users in July 1982, the facility delivered 1076 of a scheduled 1200 hours, despite a breakdown in the radio-frequency system that powers the storage ring. The second year, performance improved to 1492 hours. Last July, BESSY managers went from one to two shifts per day and thereby doubled the scheduled output to 2400 hours of usable light annually. So far, beams Alexander Bradshaw, the director of BESSY's scientific program, the facility is right on its schedule of 40 weeks per year user operation with 60 hours of photons per week.

BESSY's light blankets the entire ultraviolet and extends into the soft x-ray region with useful intensities to a minimum wavelength of about 6 angstroms. Researchers gauge the synchrotron light quality by brightness (sometimes also called spectral brilliance), which is the number of photons per second per unit spectral bandwidth per square millimeter cross sectional area of the electron beam and per square milliradian solid angle into which the electrons emit radiation. BESSY and the vacuum ultraviolet storage ring of the National Synchrotron Light Source (NSLS) at the Brookhaven National Laboratory are the only two operating high-brightness machines specialized for this spectral range.

BESSY came along at just the right time to land in West Berlin.

By the mid-1970's, it was clear to investigators everywhere that synchrotron radiation was going to blossom into the research tool of choice for a wide spectrum of structural and spectroscopic studies of solids, liquids, and gases and might have industrial applications, as well. In West Germany, synchrotron radiation grew up mainly at the German Electron Synchrotron (DESY) laboratory in Hamburg as a parasitic activity on high energy physics machines there. In pondering where to go next with synchrotron radiation, three groups with distinctly different interests found a way to combine these, as well as take advantage of West Berlin's special position as a political island within East Germany, with preferential treatment from Bonn, and thereby create BESSY.

First, to look at the question of whether a storage ring dedicated to synchrotron radiation should be constructed in West Germany, a commission headed by Manuel Cardona of the Max Planck Institute for Solid State Research in Stüttgart was set up in 1977 under the auspices of the German Research Society, the granting agency for funding basic research in universities.

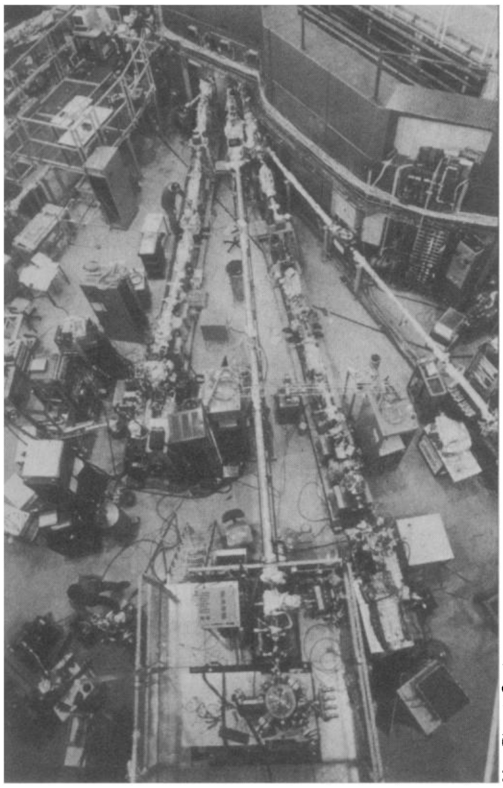
Cardona's commission came down in favor of a dedicated ultraviolet source plus x-ray facilities better than then available at DESY. The x-ray advice was implemented with the 1981 inauguration of the Hamburg Synchrotron Radiation Laboratory or HASYLAB on the DESY premises (*Science*, 21 August 1981, p. 854), where an electron storage ring is now shared by high energy and synchrotron light researchers. As for siting the new ultraviolet source, the commission recommended Bonn, where there is a synchrotron being used as a light source, and Hamburg for consideration.

Second, inspired by preliminary experiments at DESY by Eberhard Spiller and his co-workers from the IBM Yorktown Heights Laboratory on the use of x-rays for the photolithographic process by which integrated circuit patterns are transferred to silicon chips, a working group within the Federal Ministry for Research and Technology (BMFT in German) began studying the promise of so-called x-ray lithography as a way of economically making the ultrasmall transistors and other circuit elements needed if the march toward ever-decreasing circuit size is to continue.

After a year or so, the working group concluded that it would be advantageous to demonstrate the entire circuit fabrication process up to the pilot line scale of operation. For this an ultraviolet source that emitted into the soft x-ray region would be required. And industrial participation by German electronics companies would also be an ingredient. IBM, for its part, is continuing its own x-ray lithography efforts using the NSLS vacuum ultraviolet ring.

Third, the German equivalent of the National Bureau of Standards, the PTB, wanted a small synchrotron source for the calibration of light sources. The American NBS synchrotron source SURF in the Gaithersburg, Maryland, laboratory is presently the most accurately calibrated source in its spectral range. The PTB already had facilities in Berlin, so, together with the Free University and the Fritz Haber Institute, it composed a proposal for a small facility that would serve local university users as well.

Last was the question of financing. As



Experimental hall

Overhead view of part of the basic research area in BESSY's experimental hall. Ultraviolet light from the storage ring inside the shielding at the top streams down the beam lines to the experimental stations at the bottom.

it happened, the BMFT had funds earmarked for West Berlin that were as yet unspent, while there was no money immediately available elsewhere. Moreover, the electronics companies were anxious to proceed with the lithography project and were pressing for a source to be built as soon as possible. Given the choice between a facility now in West Berlin and an additional wait of 2 to 3 years for a possibly more desirable location, the interested parties settled on the former. In effect, the synchrotron light source came along at just the right time to land in West Berlin.

The BESSY that emerged from all this is as multifaceted as the considerations that went into its founding. However, as the major financial source behind the project, the BMFT had the largest say. The ministry's wish, for example, that the electronics companies be directly involved translated into the establishment in March 1979 of a limited liability company (a GmbH in German) with shareholders and a board of supervisory directors. Shareholders receive no dividends or related financial rewards, but they pay no taxes either. Surpluses can be accumulated, however, for special BESSY projects.

There are eight shareholders, four electronics companies and four balancing research-related institutions. The companies are Siemens, Telefunken, Eurosil, and Valvo. Apart from Siemens, these companies are not purely German. The United Technologies Corporation (American) owns 49 percent of Telefunken, and also a part of Eurosil, for example, while Valvo is associated with Philips in the Netherlands. The balancing institutions are the Max Planck Society, the Fraunhofer Society (a partly government-financed applied research organization that coordinates the x-ray lithography project at BESSY), and as basic research representatives DESY and the Hahn-Meitner Institute.

The board of supervisory directors comprises 14 persons, a member from each of the shareholders plus government ministry and university representatives. However, the daily operation of BESSY is overseen by three directors: Gottfried Mülhaupt, who is in his second 5-year term as director in charge of the accelerator complex; Bradshaw, who is also a professor at the Fritz Haber Institute and will be returning there full time when his term expires later this year; and the currently vacant post of administrative director. Ernst Koch from HASYLAB will be the new research director.

There is still more. The Fraunhofer Society's x-ray lithography area and the PTB's radiometry area are physically separated by walls from the basic research area in the large octagonal experimental hall that surrounds the storage ring. The walls do not reflect hostility but special environmental needs of these two kinds of research. However, the walls are matched by an administrative separation. Bradshaw has no say over the lithography or radiometry research, for example. Anton Heuberger is director of the Fraunhofer Institute for Microstructure Technology, the organization formally in charge of the lithography project. And Burghard Wende oversees the PTB area.

Although BESSY's construction budget of 74 million deutsche marks, which also included instrumentation, was relatively straightforwardly financed—90 percent from the BMFT and 10 percent from the city of West Berlin—its operating costs are paid for in a more unusual way. As befits a private company, BESSY charges by the hour for its photons and receives no direct subsidy from the federal government in Bonn.

According to Mülhaupt, about 20 percent of the expected 1985 operating budget of 9.5 million deutsche marks will come from industry, 10 percent from the PTB, and 70 percent for basic research from the universities and the Max Planck Society. These percentages also roughly reflect the floor space and beam time used by the respective groups of users. There are five beamlines in the lithography area, three for radiometry, and 13 that service 20 experimental stations devoted to basic research. The lithography and radiometry experiments sometimes require special storage ring operating conditions that are not advantageous for the basic researchers. The financial contributions also determine how many hours or "main-user shifts" with these special conditions can be requested.

In the case of basic research, paying for photons by the hour is more of a philosophical concept than a matter of money changing hands. German universities do not have money to spend in this way. Instead, in research proposals to the BMFT (rather than the German Research Society, which by agreement is not funding synchrotron radiation research at BESSY), the universities ask for a certain number of hours of photons and the type of instrument needed. If the proposal is approved by the BMFT, the ministry pays BESSY. However, if the universities do not ask for beam time, BESSY in principle gets no money, thereby applying some pressure to be a reliable performer. Typical blocks of beam time to one experiment are 2 to 5 weeks, although some projects are given special status. A group from the University of Göttingen has long-term use of one beamline for installation and testing of a scanning x-ray microscope, for example (*Science*, 8 January 1982, p. 150).

Overall, according to Bradshaw, the division of research breaks down roughly into three categories: 40 percent of the time goes to solid-state physics and surface science, 40 percent to gas phase spectroscopy, and the rest to a mixed bag of others, which includes the x-ray microscope. While judgment of scientific productivity is obviously a long-term affair, BESSY is doing well in one measure—publications in *Physical Review Letters*.

Among those that have appeared recently, the measurement of the spin polarization of photoelectrons ejected during photoemission spectroscopy illustrate the virtues of high brightness. Detectors of spin polarization are notoriously inefficient. Moreover, when the photoelectrons must be further analyzed according to their energies and angles of emission, there are not enough electrons to get a measurable signal at each setting without an intense source of polarized radiation.

The motivation for spin polarization

measurements is to resolve the details of the quantum states in systems in which the interaction between electron spin and orbital angular momenta are important. For example, in solids the quantum states are arrayed in bands, which may be split by the so-called spin-orbit interaction into multiple bands. In one experiment published last April, a group headed by Ulrich Heinzmann of the Fritz Haber Institute characterized the surface quantum states of platinum by this means.

BESSY was built and commissioned remarkably quickly. Following formation of the company, groundbreaking took place in September 1979, with construction finished in 2 years. The first stored beam was achieved immediately, and after a 6-month commissioning process, the facility was opened to its first users.

The combination of adequate funding and Mülhaupt's conservative approach to the accelerator complex no doubt go a long way toward accounting for the success. Comparison of total costs of American and European projects is always a contentious undertaking, partly because of shifting currency exchange rates, different accounting practices, and variations in funding mechanisms. But no one would argue against the proposition that, as compared to the NSLS, for example, BESSY has been well supported.

Although not so widely appreciated then as now, accelerator specialists have always understood that it is much better to inject the large electron currents needed for a powerful synchrotron radiation source into the storage ring at the energy at which the beam will circulate. The synchrotron radiation acts immediately to calm down the beam, which is always jittery immediately after injection, whereas there is not much radiation emitted for this purpose when the beam energy is low.

A so-called full energy injector (which usually means a synchrotron of energy equal to the storage ring energy) is expensive. But BESSY has one, and this has enabled operators there to bypass some of the problems encountered in the NSLS x-ray ring and at the University of Wisconsin Synchrotron Radiation Center, where accelerator operators are still trying to commission a storage ring similar to BESSY (*Science*, 11 January, p. 154).

Another BESSY feature is the ability to vary the magnetic optics of the storage ring. The optics determine how tightly focused the electron beam is, as measured by the parameter called the emittance. A low emittance translates into a small beam and hence a bright source. BESSY has both high- and low-emittance optics. Since it is easier to operate with a high emittance, this was the mode chosen until accelerator engineers learned how to accumulate and store large currents (several hundred milliamperes) reliably. In recent months, only the low-emittance optics have been used with beam currents of more than 600 milliamperes and beam lifetimes of 3 hours.

As successful as BESSY is, between runs the eyes of synchrotron light researchers around the world are increasingly turning to third generation or ultrahigh-brightness sources, such as the x-ray generating machines being planned in the United States (*Science*, 25 January, p. 396) and Europe (*Science*, 27 July 1984, p. 391 and 14 December 1984, p. 1294). So plans are already forming for a BESSY II, which would again concentrate on serving ultraviolet users. Mülhaupt says he does not expect a formal proposal to be made until about 1988 and, assuming approval, construction to begin before the next decade. But one can already assume that, when BESSY II does arrive, it will be a beauty.

—ARTHUR L. ROBINSON

Paleoclimates in Southern Africa

The Antarctic ice sheet has probably been an important driving force of African climate and biotic evolution; this idea begins to be tested

The slightly bizarre, Las Vegas–like setting of Sun City, Bophuthatswana, southern Africa, was the venue of a recent workshop* on paleoclimates and evolution, the second in a series of five or six such gatherings contemplated over the next 5 years. The overall aim of the workshops is to see what—if any—patterns of speciation and extinction are to be discerned in the fossil record during the past 25 million years; to discover how—if at all—these patterns relate temporally to global and local climate change; and, if there is a relationship, to decide if it is causal.

The first workshop, held last fall at the Lamont-Doherty Geological Observatory, New York, reviewed glacial information relating to the Antarctic, climatic and microfossil evidence from deep-sea cores from around the globe, and terrestrial faunal evidence, principally from East Africa and Eurasia (*1*). The Sun City gathering concentrated, appropriately enough, on southern African.

The conclusion from Lamont, as expected, had been that the deep-sea record is far superior in quality and continuity to the continental data. The same can be said of the second workshop, only more so. For instance, John Harris, of the Los Angeles County Museum, pointed out that barely 40 percent of the Miocene (25 to 5 million years before present) is at all well represented faunally in the southern African sites. And Elizabeth Vrba of the Transvaal Museum, Pretoria, remarked that, for a variety of reasons, accurate dating of material continues to be a severe problem.

"Nevertheless, it was extremely valuable to obtain an overview of what is currently available," said C. K. Brain, also of the Transvaal Museum, "even if it turned out to be rather less rosey than one had anticipated." As a result of the meeting, the South African Society for Quaternary Research has asked Tim Partridge of the University of the Witwatersrand to convene a group whose responsibility is systematically to develop sites that will begin to fill in some of the temporal gaps

The notion that the environment—specifically environmental change—is important in evolutionary change has long been part of biological theory. As a result there is a diversity of hypotheses about how this might occur and how it might manifest itself. Vrba has been developing an additional hypothesis, called the turnover-pulse hypothesis, which draws variously on the ideas of punctuated equilibrium and vicariance (the fragmentation and coalescence of species' geographic ranges).

*Workshop on Neocene Paleoclimates and Evolution in Southern Africa, Sun City, Bophuthatswana, 6 and 7 February 1985.