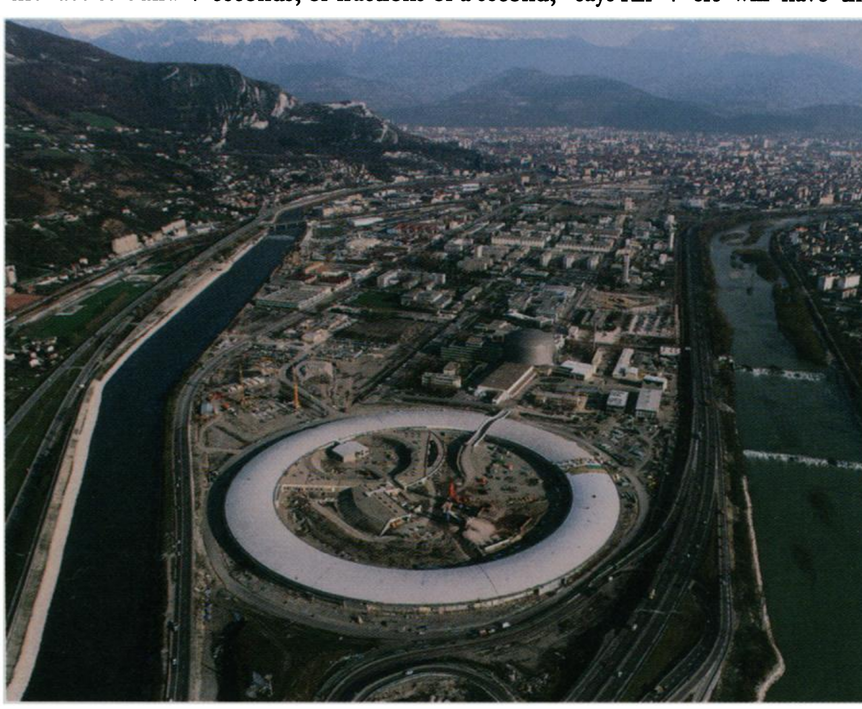
Synchrotron Light: The Third Generation

Europe enters the homestretch in the race with Japan and the United States for more powerful synchrotron light sources

Grenoble, France—RUPRECHT HAENSEL CAN look back to the start of his career as a physicist at the DESY laboratory in Hamburg and feel he has had the last laugh. In the 1960s, when he and his colleagues wanted to carry out experiments with powerful x-rays, the only source they could find was the unwanted radiation generated as a by-product when particle physicists ran big synchrotron accelerators like that at DESY. "We were just playing a marginal role," he says. "We were called 'the parasites.'" Now times have changed. Synchrotron radiation is big science in its own right, and Haensel is director-general of the $500-million European Synchrotron Radiation Facility (ESRF) taking shape here amid the Dauphiné Alps.

In September Haensel celebrated the completion of the huge, doughnut-shaped building that houses the 844-meter main particle storage ring, where electrons accelerated to 6 GeV will pass through a series of insertion devices—undulators and wigglers—designed to make them radiate intense x-rays. With that step, reached 6 months ahead of schedule, Europe opened up a 3-year lead over the United States and a 5-year lead over Japan in the race to build the first of the world's third-generation synchrotron light sources.

"We never dreamed that one day we would be the masters of such a machine," says Haensel. The third-generation machines differ from the preceding generation—the first purpose-built synchrotron sources—by their extreme luminosity. When ESRF runs its first experiments at the beginning of 1994, it will provide the brightest continuous x-rays in the world—two orders of magnitude more brilliant than anything available now. With that extra power, European researchers will be able to create more detailed pictures of the structures of atoms, surfaces, crystals, and biological macromolecules than ever before, and they will be able to do this at unprecedented speed—fast enough even to follow the changing structure of biological molecules during enzyme reactions and muscle contractions.


A. CHILDERIC/A. M. FREUND

Leading the way. *ESRF's main ring.*

U.S. researchers will have to wait until 1996 for a machine of their own that matches ESRF's power. That's when the Argonne National Laboratory's 7-GeV Advanced Photon Source (APS) is scheduled to begin operating (although ESRF will allow them to join European collaborations at a price). And Japan's researchers will have to wait even longer, until 1998, when SPring-8 will leapfrog the competition and take them to the highest x-ray energies in the world (see box).

For scientists who use x-rays, whether they be biologists or physicists, the attraction of brighter x-rays is simple: more means better. The resolution of their techniques and the time in which they can see results depend in large measure on the brightness of the x-ray light that they can shine on their specimens.

"We'll be able to get a picture in minutes, seconds, or fractions of a second," says Andrew Miller, a biochemist who studies the structure of muscle at the University of Edinburgh and who until last month doubled as co-director of research at the ESRF. "We will get much less specimen damage if we can get our photons in and out in a millisecond," he says.

More powerful synchrotron radiation will also please Jens Als-Nielsen, a materials scientist at the Riso National Laboratory in Roskilde, Denmark. He is hoping to use ESRF to study the structure of monomolecular layers on water surfaces. "This is similar to what you see when you have a drop of light on a water puddle, and the interference of light waves scattered from the interface creates a rainbow," he says. "But if you do the same thing with x-rays and come in with your beam at a grazing angle, you can study as little as one single monolayer at atomic resolution."

Small wonder that U.S. researchers are also eager to get their hands on this technology. "We will be able to do experiments in structural biology that are qualitatively different than has been possible in the past," says Keith Moffat, a biophysicist at the University of Chicago who co-directs one user consortium for APS. For example, "In the case of many proteins and other biological molecules, it is very difficult to grow crystals that are large and well ordered," he says. "With such a brilliant radiation source, we will be able to look at microcrystals, crystals whose dimensions might be in the 10 to 20 micron range. This will open up a whole new class of molecules to study."

When APS comes on line, U.S. researchers will have the consolation of knowing that even though they are late they have something extra to offer. Thanks to its extra 1 GeV of power, APS will provide a more continuous range of x-rays than available in Europe, bridging several x-ray energies where the Europeans are likely to have gaps. But that is still in the future; right now, the subject that concerns U.S. scientists is the way the two machines will differ in their planning and finance.

Europeans will have it easy: the 12 countries that are paying for ESRF have agreed to pay for the entire outfitting of the insertion devices—the arrays of magnets that greatly intensify the radiation beams—and the beam lines and detectors where experiments are conducted. That means researchers who have their plans approved will be directed to an already existing experimental station (seven at first, 30 by 1998). At APS, however, the current budget covers the construction of only half of the insertion devices and their support instrumentation, but none of the actual experimental stations. Thus universities, national laboratories, and industry must go out and find funding to build optics and experimental stations of their own. Nineteen consortia have already been formed for this purpose.

David Moncton, the associate laboratory director at Argonne responsible for the APS project, argues for this system. He says that when scientists create their own beam lines, they "have a much more substantial stake in the facility, and they have a much easier mode of access to it. They are not writing elaborate proposals for each piece of beam time they get."

The Big Three

	ESRF	APS	SPRING-8
Energy	6 GeV	7 GeV	8 GeV
Main ring circumference	844m	1104m	1435m
First use	1993	1996	1998
Final no. of beam lines	30	70	80
Cost	**$500m**	**$456m[1]**	**$1000m[2]**

[1]Only half insertion devices and beam line front ends included.
[2]Current estimate.

But Moffat does not entirely agree. He is co-director for biological sciences of the Consortium for Advanced Radiation Sources (CARS), a group based at the University of Chicago and including scientists from about 30 institutions. "It's like going out and buying an automobile off the showroom floor, but without the steering wheel, the instruments, or the seats," he complains. "The plus side is that the beam lines will be custom tailored for the needs of a specific group of scientists. But uncertainty comes from not knowing whether we will be able to raise the money. If you can't afford the complete new car, you might have to stick with the old one."

The old car is, in any case, what most Americans will have to stick with until the opening of APS. ESRF officials say that foreigners will be welcome—but beam time will be allocated to scientists roughly in proportion to how much cash their respective countries donated to construction costs. That means, in most cases, that researchers from outside nations who want a piece of the new synchrotron action will have to form collaborations with eligible users. The other route, Haensel says, is by an arrangement in which an institution in another country makes a "contribution against a certain share of beam time." That would close the circle—three decades after being labeled a parasite on other people's machines, Haensel now finds himself contemplating charging researchers to use Europe's world-leading facility. ■ MICHAEL BALTER

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The Biggest and the Brightest

Tokyo—Japan's SPring-8 (Super Photon Ring-8 GeV) will be the last of the big three synchrotrons to be completed, but by 1998 it will be the most brilliant x-ray source in the world. "That is what makes it exciting for me," says Hiromichi Kamitsubo, a nuclear physicist who heads the project.

Construction is set to begin next week at Harima Science Garden City, a new town about 60 miles west of Osaka. Original plans were for a 6-GeV machine similar to that at European Synchrotron Radiation Facility (ESRF), but the demands of Japanese atomic spectroscopists forced planners to head for the world's most powerful machine, says Kamitsubo. Researchers wanted 20-25 keV x-rays capable of reaching the binding energies of inner-shell electrons of heavy elements, he says, giving them the unique capacity to study the electronic structure of atoms, all the way up to uranium. To generate x-rays that powerful, the storage ring energy had to be boosted to 8 GeV.

With its higher energy and brilliance, SPring-8 will push the frontiers back even further than ESRF and the Advanced Photon Source in terms of the speed and resolution with which it will be able to gather data. Thanks to its added power, SPring-8 will also have a big advantage in the international race to realize the x-ray crystallographer's dream—x-ray holography.

If high-resolution x-ray holography can be made to work, it would be possible "to directly visualize—not just see complex x-ray diffraction patterns of—the structure of materials, as if we are looking at them with a microscope," says Kamitsubo. The principle is just like conventional holography in which a beam of coherent laser light is scattered from an object, recombined with a reference beam, and a three-dimensional hologram created in a photosensitive material. The problem is that there is no easy way to produce high-powered coherent x-rays.

One possibility is to use the Mossbauer effect, in which gamma rays (high-powered x-rays) emitted from a nucleus keep their natural very narrow energy line width. To stimulate gamma ray production—in, for example, the 14.4 keV transition of the Fe57 nucleus—an extremely powerful source of synchrotron radiation is needed. At 8 GeV, SPring-8 may have what it takes to steal a march over its competitors.

X-ray holography is just one possible application for SPring-8, however. Like the other big two synchrotrons, SPring-8 will provide for an extraordinarily diverse set of research areas: everything from nuclear excitation and atomic physics through nuclear resonance scattering and photoacoustic spectroscopy to studies of biological macromolecules in solution.

But even in more conventional areas some Japanese researchers are clearly worried about their ability to take a world lead. Japan may not have enough engineering manpower for such a difficult project, says Seiji Iwata, head of the physics department at Japan's High-Energy Physics Research Institute (KEK), even though the project is backed by two of Japan's biggest research institutes—the Institute of Physical and Chemical Research (RIKEN) and the Japan Atomic Energy Research Institute (JAERI).

Kamitsubo admits the challenge is great but says that Japan has succeeded in the past. "When we made our cyclotron, we used a staff one-tenth of that at a similar project in France," he says. Once the project is under way, he believes he will be able to borrow many talented engineers from industry. And until then he is using scientists from around the world to obtain feedback on SPring-8's design. Final details, he says, will be worked out in the light of their comments. ■ FRED S. MYERS

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