The Advanced Photon Source: Performance and Results from Early Operation

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The Advanced Photon Source at Argonne National Laboratory is now providing researchers with extreme-brilliance undulator radiation in the hard x-ray region of the spectrum. All technical facilities and components are operational and have met design specifications. Fourteen research teams, occupying 20 sectors on the APS experiment hall floor, are currently installing beamline instrumentation or actively taking data. An overview is presented for the first operational years of the Advanced Photon Source. Emphasis is on the performance of accelerators and insertion devices, as well as early scientific results and future plans.

1. Introduction

The Advanced Photon Source (APS) (Fig. 1) is a third-generation light source optimized for delivery of extremely brilliant undulator radiation in the hard x-ray region of the spectrum. The APS is situated on a 80-acre site at Argonne National Laboratory. The facility (Fig. 2) comprises a particle-beam injection and storage system (electron gun, electron linac, positron target, positron linac, positron accumulator ring (PAR), booster synchrotron, and storage ring); beamline front ends; insertion devices (IDs); a Low Energy Undulator Test Line (LEUTL); a circular experiment hall; user laboratory/office modules adjacent to the experiment hall; a central office and laboratory building for operations staff; support buildings providing utilities; and a residence facility for researchers staying at the APS on a short-term basis (7-GeV Advanced Photon Source Conceptual Design Report, 1987).

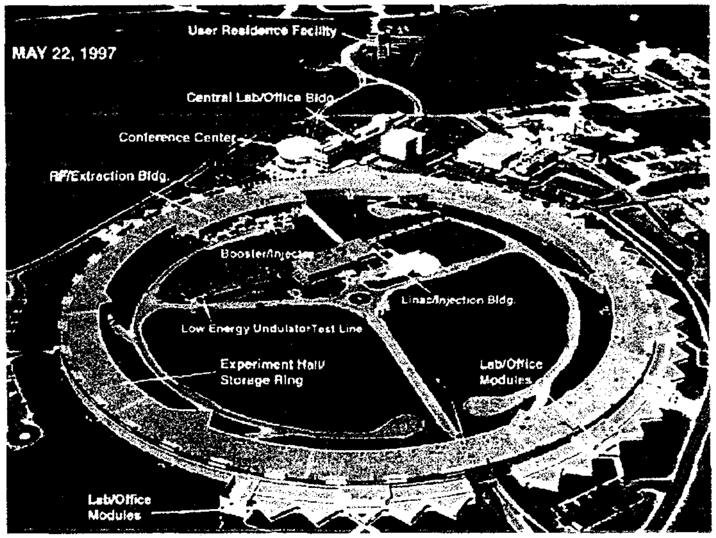

Figure 1
The Advanced Photon Source at Argonne National Laboratory, as of May 1997.

2. Facility Status

Construction of the APS facility began on June 4, 1990, and was completed ahead of schedule, within budget, and with an excellent safety record. The construction cost for the originally planned scope was $449M, compared to the total estimated capital cost of $467M. Favorable economic circumstances allowed the difference of $18M to be used in construction of more beamlines and laboratory/office modules, while remaining within the original cost estimate. No fatalities or major injuries were incurred during construction of the APS. The overall injury rate was lower than both the U.S. Department of Energy and U.S. construction-industry averages for projects of commensurate size.

Commissioning of the APS technical systems began on October 7, 1993, with 50-MeV electron beam in the linac. The first electron beam was stored in the PAR on April 17, 1994. On January 22, 1995, the first 7-GeV electron beam was attained in the booster synchrotron. Injection of 7-GeV electron beam from the booster synchrotron to the storage ring occurred on February 20, 1995, with the first turn of 7-GeV electron beam in storage ring coming on March 18, 1995. A 4.5-GeV electron beam was stored on March 25, 1995, and storage ring bending-magnet radiation was detected on March 26. An electron beam with the design energy of 7 GeV was stored on April 15, 1995. On August 9, 1995, undulator radiation was first observed at the Sector 1 (1-ID) beamline. The storage-ring commissioning milestone of 20-mA operation and minimum 10 hours of beam lifetime was achieved on October 11, 1995. First 100-mA operation of an APS undulator occurred on January 26, 1996. Operational readiness was achieved on June 4, 1996 (versus schedule requirement of first-quarter FY 1997). Positron operations began in earnest on July 30-31, 1996, with the first store of 7-GeV positrons and first stored positron beam at 100 mA current, respectively.

The APS has achieved design goals of 10-40-hr lifetimes and emittance of 8.2 x 10-9 nm-rad for stored positron beam at the full design energy of 7 GeV.

Operational priorities now center on providing optimal beam stability, achieving reliable operations, and delivering ~5000 hrs/yr of high-brilliance x-ray beams to users. Data on storage ring stability to date are shown in Table 1 below.

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Table 1
Storage ring stability

Average horizontal motion at ID sources	
Stability specification:	17 μm
No correction:	25-30 μm
Slow drift correction only:	20-25 μm
Fast orbit feedback plus slow drift correction:	9 μm
Average vertical motion at ID sources	
Stability specification:	4.4 μm
No correction:	8 μm
Slow drift correction only:	6 μm
Fast orbit feedback plus slow drift correction:	3 μm

Twenty IDs (18 undulators, 1 33-keV critical-energy wiggler, and 1 elliptical multipole wiggler) have been installed at the time of this writing. The APS undulator A is designed to provide high-brilliance x-ray radiation in the 3.2-45 keV spectral energy range. Measured spectral performance for the undulator A's are in remarkably good agreement with calculations (Experimental Facilities Division Progress Report 1996-97, 1997).

3. Research

Fourteen research teams, occupying 20 sectors on the APS experiment hall floor, are currently installing beamline instrumentation or actively taking data. At this writing, these teams comprise 427 researchers from U.S. universities, 210 from industry, 271 from federal laboratories, and 59 from non-U.S. institutions. The locations of these teams in the experiment hall are shown in Fig. 2. Early data from investigations include several noteworthy accomplishments.

The three-dimensional crystal structure of the putative tumor suppressive fragile histidine triad (FHIT) protein was determined to 1.9-Å resolution by a group (C. D. Lima et al.) using multiwavelength anomalous diffraction data of the selenomethionyl protein measured with undulator radiation at APS beamline 19-ID. This beamline is operated by the Structural Biology Center Collaborative Access Team. These new data show that FHIT has similarity to another HIT family member, solved previously by the same group, which is highly conserved throughout evolution. The data also show that, contrary to previous studies, FHIT catalysis is not metal dependent. The data led to a detailed analysis of the critical residues involving binding and catalysis of nucleotide polyphosphate (Lima, D'Amico, Naday, Rosenbaum, Westbrook, & Hendrickson, 1997).

The use of phase zone plates developed at the APS is resulting beam-spot sizes well below 1 μm. The spatial distributions of many trace elements, including Cu, K, Ca, Cr, Mn, Ni, Fe, and Zn, in a Plantago lanceolat root infected with Glomus mosseae fungi have been imaged by researchers (Z. Cai et al.) at beamline 2ID, operated by the Synchrotron Radiation Instrumentation Collaborative Access Team. This "map" was achieved through the use of an undulator x-ray beam focused to 0.33 μm spatial resolution and a few parts per billion elemental detection sensitivity (Yun, Pratt, Miller, Cai, Hunter, Jarstfer, Kemner, Lai, Lee, Legnini, Rodrigues, & Smith, 1997).

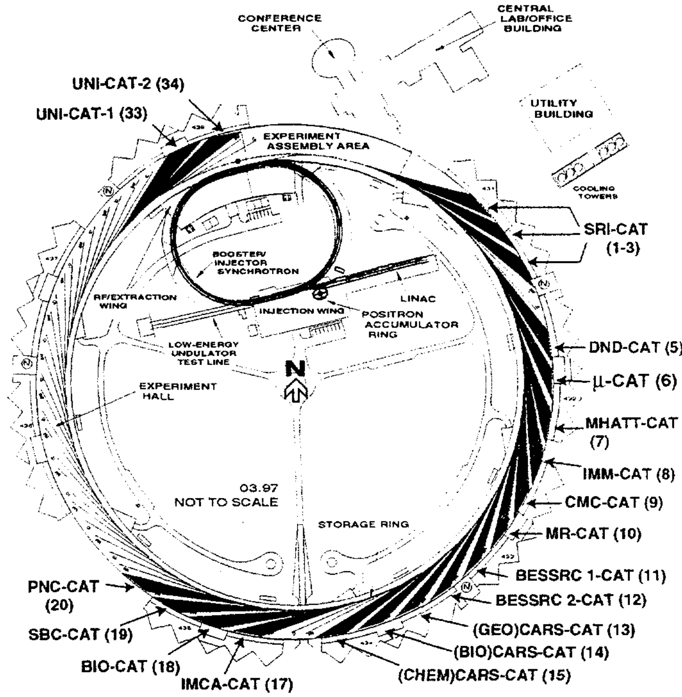

Figure 2
Plan view of the Advanced Photon Source with Collaborative Access Team locations indicated. Sector numbers are in parentheses.

Also at beamline 2ID, a scanning x-ray microprobe (XMP) developed by a Bell Laboratories/APS team was used to image a Lucent Technologies InGaAsP-based monolithically integrated quantum-well laser/modulator, a key component in long-haul lightwave communications systems. Because the laser/modulator has an active region ~1 μm wide, this XMP, with its 0.33 μm spot size at 10 keV, has provided strain measurements for the device material, which have important consequences for improving laser/modulator performance (Isaacs, Evans-Lutterodt, Marcus, MacDowell, Lehnert, Vandenberg, Sputz, Johnson, Grenko, Ketelsen, Pinzone, Glew, Yun, Cai, Rodrigues, Lee, & Lai, 1997).

4. Goals

Fourteen uninstrumented sectors remain at the APS. Plans call for developing those 28 beamlines to serve new and growing research communities. These plans include a sector dedicated to x-ray polarization studies; a commercial beamline to provide x-ray analytic services to industry; a protein crystallography beamline for the study of the structure-function relationship; and a broad-based imaging beamline for applications in medicine, archeology, and materials science.

New instrumentation in development is aimed at coherent imaging, time-resolved methods, inelastic scattering, and high-energy x-ray techniques.

In order to attain these objectives, the APS will identify priorities, establish strong user community interest, coordinate with prospective funders, and aim for construction of one or two new sectors per year.

Argonne is one of several national laboratories carrying out R&D with a view toward producing a fourth-generation light source capable of generating ultra-high-brilliance synchrotron radiation. The APS is constructing a low-energy undulator test line, which is an extension of the 450-MeV linac. This line will be used for testing new undulator designs to support the development of fourth-generation linac-based light sources. The LEUTL will be operated for undulator testing in the fall of 1997, and APS intends to set up a gain measurement experiment by the end of CY 1998

5. References

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