INVITED PAPERS

J. Synchrotron Rad. (1998). **5**, 155–157

The Advanced Photon Source: Performance and Results from Early Operation

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(*Received 4 August 1997; accepted 3 November 1997*)

The Advanced Photon Source at Argonne National Laboratory is now providing researchers with high-brilliance undulator radiation from below 1 keV to beyond 100 keV. All technical facilities and components are operational and have met design specifications. Fourteen research teams, with responsibility for 40 beamlines on the APS experiment hall floor, are currently installing beamline instrumentation or actively taking data. An overview is presented for the first operational year of the Advanced Photon Source. Emphasis is on the performance of accelerators and insertion devices, as well as early scientific results and future plans.

Keywords: Advanced Photon Source; storage rings; insertion devices; light sources.

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 (Argonne National Laboratory, 1987). The APS is situated on an 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 working at the APS.

2. Facility status

Construction of the APS facility began on 4 June 1990 and was completed ahead of schedule, within budget and with an excellent safety record. The construction cost for the originally planned scope was $449 million, compared with the total estimated capital cost of $467 million. Favorable economic circumstances allowed the difference of $18 million 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 much lower than both the US Department of Energy and US construction-industry averages for projects of commensurate size.

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

The APS has achieved design goals of 10–40 h lifetimes and emittance of 8.2×10^{-9} nm rad for a 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 $\sim$5000 h year^{-1} of high-brilliance X-ray beams to users. Data on storage ring stability to date are shown in Table 1.

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

At the time of writing, 20 IDs (18 undulators, one 33 keV critical-energy wiggler and one elliptical multipole wiggler) have been installed. 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 is in remarkably good agreement with calculations (Argonne National Laboratory, 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 the time of writing, these teams comprise 427 researchers from US universities, 210 from industry, 271 from federal laboratories and 59 from non-US 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.*, personal communication) 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, analysed 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 polyphosphates (Lima *et al.*, 1997).

The use of phase zone plates developed at the APS is resulting in 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.*, personal communication) at beamline 2-ID, 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 *et al.*, 1998).

Also at beamline 2-ID, a scanning X-ray microprobe (XMP) developed by a Bell Laboratories/APS team was used to image a Lucent Technologies InGaAsP-based

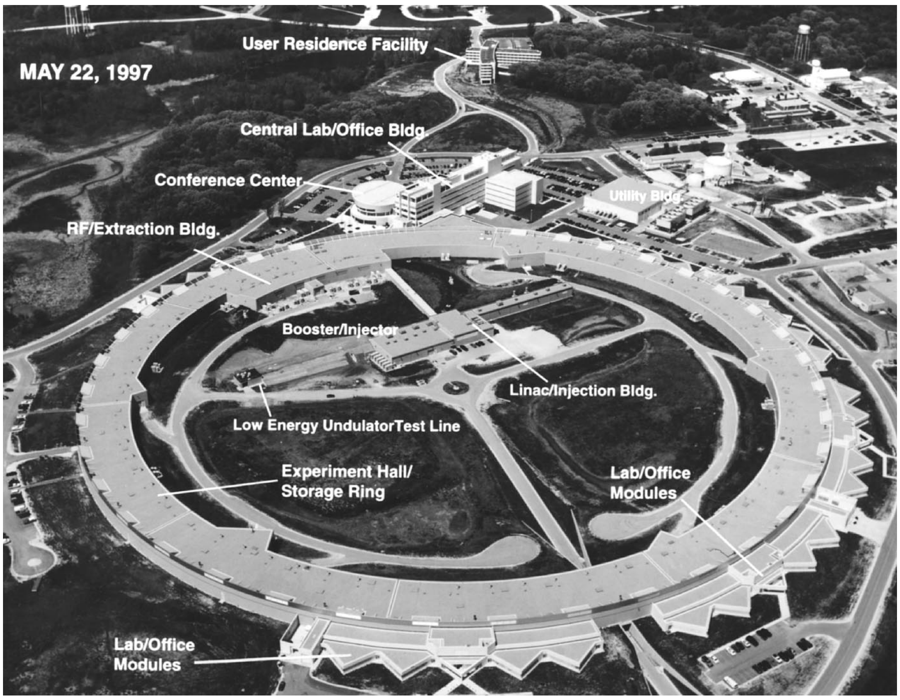

Figure 1
The Advanced Photon Source at Argonne National Laboratory, as of May 1997.

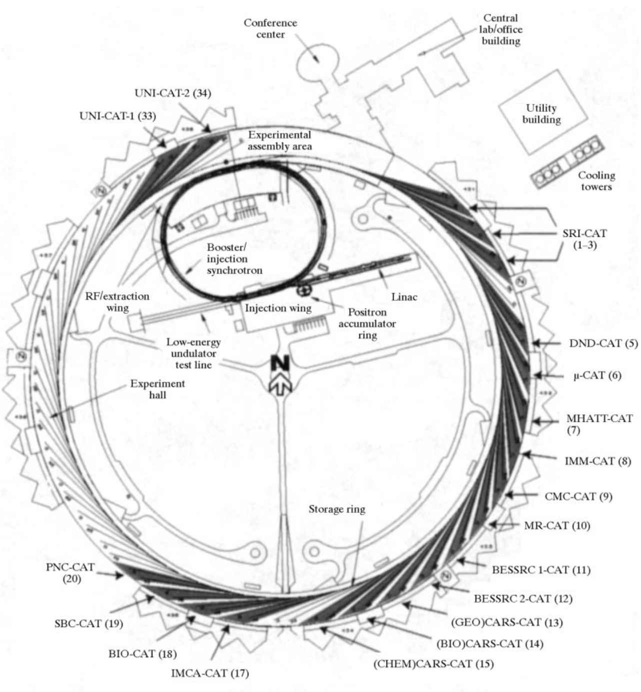

Figure 2
Plan view (not to scale; March 1997) of the Advanced Photon Source with Collaborative Access Team locations indicated. Sector numbers are in parentheses.

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 *et al.*, 1998).

4. Future development

There are 14 uninstrumented sectors remaining 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, another protein crystallography beamline for the study of structure–function relationships, a broad-based imaging beamline for applications in medicine, archeology and materials science, and a facility for high-pressure 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 research and development with a view toward producing a fourth-generation light source capable of generating ultrahigh-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 for APS use and to support the development of fourth-generation free-electron laser 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 1998.

This work is supported by the US Department of Energy under contract No. W-31-109-Eng-38.

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