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A status update on the Advanced Photon Source Project - summer 1993

by
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The Advanced Photon Source Project has passed the mid-point in its construction. The linac and synchrotron booster enclosures are complete. A portion of the experiment hall has been completed and put into use to support accelerator component assembly, test, and installation. Plans for the user lab/office modules and the central laboratory/office complex are well advanced. Installation of the linac injection system has been completed and commissioning is beginning. Installation and commissioning of the positron accumulator ring, the booster synchrotron, the storage ring, and the rf power systems will follow. Accelerator operations capable of supporting the commissioning of the experimental beamlines is planned for the summer of 1995. A strong research program is continuing to produce results supportive of both accelerator and beamline construction and operations. Collaborative Access Teams have been formed to conduct research with the initial set of 32 beamlines that will be available at the completion of the first phase of construction.

I. Technical description

The Advanced Photon Source (APS) at Argonne National Laboratory is scheduled to begin operations in 1995 as a national user facility for synchrotron radiation research across a wide range of scientific disciplines. The APS is specifically designed[1] to optimize the use of tunable insertion devices (IDs) and capitalize on their extremely high-brilliance radiation. The APS bending-magnet beamlines will have unique capabilities above ~20 keV. Every effort has been made to design and build a light source that will function with a high degree of reliability.

The APS acceleration system begins with a 200-MeV electron linac. A tungsten-film target is the source for positrons, which are then accelerated to 450-MeV in the positron linac. Positrons are collected in an accumulator ring and injected into a 450-MeV to 7-GeV, 1-Hz injector synchrotron via a low-energy transport line. When the positron energies have reached 7 GeV, they are injected into the storage ring. The early decision to implement full-energy injection[2] is proving to be a fortuitous design criterion. When all machine components run at fixed tuning conditions, beam characteristics will be stable. This will result in a sensitive, low-emittance machine with characteristics amenable to experimental use. A full-energy injector also permits consideration of using "top-up" mode to replenish a degraded beam after a certain running time, increasing beam stability and availability. The feasibility of top-up-mode operations at APS is being examined in depth.

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The APS storage ring has been designed with inherent flexibility in anticipation of any new scientific concepts and/or experimental devices that may appear during the lifetime of the facility. The 1104-m-circumference ring has a 40-sector Chasman-Green-type magnetic lattice. All 40 straight sections have zero dispersion in order to minimize the effects of individual insertion devices on the stored beam emittance. Of the 40 straight sections, five will be occupied by accelerator equipment servicing the storage ring, such as rf equipment. The remaining 35 straight sections will each accommodate as many as 3 IDs up to 5 m in length and their associated beamlines. In addition, 35 photon beams will originate at bending magnets. The parameters of the APS storage ring appear in Table I.

Table I. Storage ring parameters.

Beam Energy	7 GeV
Beam Current	≥100 mA
Beam Lifetime	10 h
Number of Bunches	1-60
Bunch Duration	73 ps
Horizontal Emittance	$< 10^{-9}$ m•rad
Circumference	1104 m
Number of Straight Sections to Extract Radiation Beams	40
Straight Section Length (standard)	5 m
Straight Section Vertical Aperture (Mature Operations)	8 mm
Number of Insertion Devices per Straight Section	1 to 2
Radiation Sources	Undulators, Wigglers, Bending Magnets
Fundamental Undulator Energy (10-mm ID gap)	20 keV (tunable)
Beam Particle	Positron
Injection Energy	7 GeV

The experiment hall floor can accommodate beamline lengths of up to 80 m. The experiment hall floor is isolated from all other parts of the facility so that the effects of mechanical vibrations on the storage ring and beamlines are minimized. Consideration in the design and orientation of the experiment hall leave open the possibility of constructing long beamlines that will extend from the storage ring through an external wall of the experiment hall.

II. Reliability

Accelerator system reliability is of critical importance to future experimenters at the APS. The APS Project has conducted a workshop on the subject of accelerator reliability,[3] including representatives of accelerator installations such as the Superconducting Super Collider, the Continuous Electron Beam Accelerator Facility, and the Cornell High Energy Synchrotron Source. The workshop focused on what steps can be taken to raise the level of accelerator reliability, which has led to a number of follow-on studies involving experts from local engineering schools. They are working with APS staff on applying systematic techniques of reliability engineering to improve the reliability of various accelerator subsystems.

The Project has applied the principle of redundancy to those systems deemed to be potentially disruptive to reliability. For instance, radio frequency (rf) systems are difficult to make reliable, and are critical to storage ring performance. The APS will have twice the number of storage ring rf cavities required for the minimum design goal of 100 mA at 7 GeV.

Not only are power supplies plentiful in a machine like the APS, they all must function in order for beam to continue circulating. When one multiplies the mean-time-to-failure for every chip by the number of chips by the number of power supplies in the APS, one gets a mean-time-to-failure for the entire system of approximately one week. Special temperature-controlled rooms are being used to heat power supplies to high temperatures in pursuit of a better understanding of operational reliability. In addition, high-power tests are being conducted in order to discover failure points in the power supplies before they are installed. The Project has improved the designs of the power supplies by minimizing the number of components and by using only those components with high reliability figures.

III. Facility construction

The Advanced Photon Source Project was approved by the U. S. Department of Energy in 1989. Construction of the facility began in June 1990. As of this writing, civil construction of the APS accelerator-housing structures and experiment hall is nearing completion. The linac enclosure, injection building, synchrotron tunnel, rf/extraction building, and storage ring enclosure are all complete (Fig. 1). Also complete and fully functional is the utility building, which distributes all utilities to the site. The experiment hall is being completed in sections or "zones," which correspond to storage ring installation sequencing. The early assembly area (EAA), the storage bays, and zones 1 and 2 of the experiment hall and storage ring enclosure have been occupied by the Project. The EAA is being utilized for measurement and test of accelerator magnets. Yet to be started are the user laboratory/office modules situated around the perimeter of the experiment hall, the central laboratory/office building, and a user residence facility to be funded by the State of Illinois.

IV. Technical components

IV.1 Vacuum chambers

A vacuum-chamber fabrication facility has been constructed and is operational. Each of the 40 sectors in the storage ring requires 6 vacuum chamber sections, for a total of 240 chambers. This number includes the straight chambers at the ID locations, which are of a somewhat different cross section. After extensive cooperation with industry to develop an extrusion quality-control process that would satisfy APS design requirements, storage ring vacuum chambers have been extruded and delivered. Chambers are being machined to accept magnet pole faces and various fittings. Two computer-numeric-controlled welding systems are performing a total of 2400 precision welds while attaching photon-absorber flanges and bellows connections to the chambers. Booster synchrotron vacuum chambers have been completed and are being installed. An 18-ft-long prototype extruded-aluminum insertion device vacuum chamber was evaluated at Argonne. The total out-of-flatness deviation along and across the entire vacuum chamber is smaller than .002 in. This measurement verifies the APS-devised method for maintaining stringent flatness tolerances while extruding a lengthy, uninterrupted section of aluminum. These tolerances were required in order to maximize the performance of APS Undulator Type A.

IV.2. Magnets

There will be ~1500 magnets in the APS accelerator. Prototypes of all magnets were constructed in order to isolate problems in magnet design well before production. Designs were altered as needed. For example, saturation in storage ring quadrupole magnets was eliminated. The design of storage ring sextupoles was changed to remove a combined function of steering and sextupole focusing and separate those between two different magnets.

IV.3. Rf cavities

The first of 16 storage ring rf has cavities arrived from the vendor. The cavity was assembled on its test stand for power testing. After conditioning, the cavity operated at full power for over a week at 100 kilowatts without mechanical interruption. The cavity is working extremely well and has met all design specifications. All four production rf cavities for the booster synchrotron are on hand and are being installed.

IV.4. Insertion devices

Prototype APS undulators have been constructed and tested at both the Cornell High Energy Synchrotron Source[4] and the National Synchrotron Light Source at Brookhaven National Laboratory[5]. Testing has confirmed the performance parameters of these devices, particularly errors and how they diminish the synchrotron radiation that is produced. Tests have also verified the ability of the external vendor community to provide insertion devices to specification. A contract has been awarded for procurement of the first set of Undulator Type A devices. Undulator Type A will be the primary source of radiation for most APS beamlines.

IV.5. High-heat-load optics

High heat loads pose a major challenge for the APS and other next-generation light sources due to the high brilliance and high power densities that are brought to bear on optical elements. An early R&D program explored the use of liquid gallium as a coolant for beamline optics. A high-pressure, moderate flow rate electromagnetic induction pump has been developed to deliver liquid gallium to monochromator crystals[6]. This technology has been successfully applied to the high-heat load problem. A small spin-off company, Qmax, is developing gallium-pump technology for cooling high-power electronics used in commercial applications. We expect this company to be in a position to provide gallium pumps to be used in conjunction with APS monochromators.

An innovative crystal geometry will further ameliorate the effects of high heat loads. A double crystal slanted at a very high angle distributes radiation over a much larger area. This geometry also has the effect of orienting the crystal in such a way that the inevitable thermal bump, even though it is of a reduced magnitude due to the spread of the beam, is perpendicular to the diffraction plane rather than being in the diffraction plane, further reducing distortion. A combination of the optimized cooling channel geometry, the liquid-gallium-pump technology, and inclination of the crystals has produced a monochromator with the inherent capability to withstand the power levels of about 150 w/mm^2 at the APS[7]. It also has a broader scanning range than a traditional asymmetric crystal, thereby preserving the full tunability of the monochromator.

V. System installation

Installation of the linac injection system has been completed and commissioning is beginning. All of the positron accumulator ring dipole magnets have been received from the fabricator, measured, and are being installed in the injection building. Magnetic measurements of all booster synchrotron dipole magnets are complete and they are being installed in the synchrotron tunnel along with rf power systems. Storage ring magnets are being mounted on girders and equipped with vacuum chambers before each girder is moved into the storage ring enclosure. Commissioning of each of these systems will follow in a phased manner. Storage ring commissioning is scheduled to begin in January 1995. Accelerator operations capable of supporting the commissioning of the experimental beamlines is planned for the summer of 1995.

VI. User issues

VI.1. Collaborative Access Teams

To date, research proposals have been approved for 15 Collaborative Access Teams (CATs) requesting 22 APS sectors. Current project funding levels will initially support the immediate construction of 16 sectors. As of this writing, these teams comprise 25 private companies, 18 national laboratories, and 78 universities and medical schools. They have been chosen via a process that requires (1) submission of a letter of intent, (2) submission of full proposals from teams whose letters of intent are approved, and (3) review by a Proposal Evaluation Board (PEB) established in consultation with the APS Users Organization Steering Committee[7]. Each proposal is reviewed by the PEB on the basis of scientific merit, management planning, and funding strategy. The PEB also receives input from scientific review panels with expertise in the relevant discipline(s). The PEB then makes recommendations to APS management, which has the final responsibility for CAT selection. Anticipated investigations by APS CATs will be conducted in materials science, biophysics, structural biology, geoscience, chemistry, soil and environmental science, tomography, topography, macromolecular crystallography, and physics.

VI.2. User Housing Facility

In 1986, the State of Illinois pledged financial support for a user residence facility to be constructed on the APS site. Plans have been drawn up for a 240-bed facility equipped with data links and various other amenities that will enable visitors to make maximum use of their time at Argonne. The Illinois legislature has included in its final FY1994 budget an appropriation for start-up on this residence, with the balance of the construction funding to follow in the next year or two. This will enable the Project to meet its goal of completing the residence in the FY1994-96 time frame so that it is ready for users.

VI.3. Collaborative Research Program

The Collaborative Research Program is an opportunity for cooperation between APS staff and users with a common interest in developing a particular instrumentation. Teams consisting of APS staff and outside users share resources while focusing on instrumentation objectives that are judged by APS staff and members from the users organization to have some application or utility beyond an individual experiment. The process is meeting with success, as measured by the number of proposals that have been accepted.

VII. APS Instrumentation Initiative

A proposal drafted for DOE specifies objectives and requirements for a second construction phase, known as the APS Instrumentation Initiative (APSII). The intent of APSII is to complete the APS by the year 2000. Meeting that goal will require construction of the remaining four laboratory/office modules not built under Phase 1, and the development of 8 additional sectors in the same style as the first 16, for a total of 24 CAT sectors. The remaining 10 unfinished sectors will be developed following consultation with the APS Users Organization. It is hoped that these final beamlines will possess very specialized capabilities that may be outside the scope of what any individual CAT can accomplish. These capabilities would then be available to all groups. The intent is to implement these beamlines at the rate of two per year over a 5-year period.

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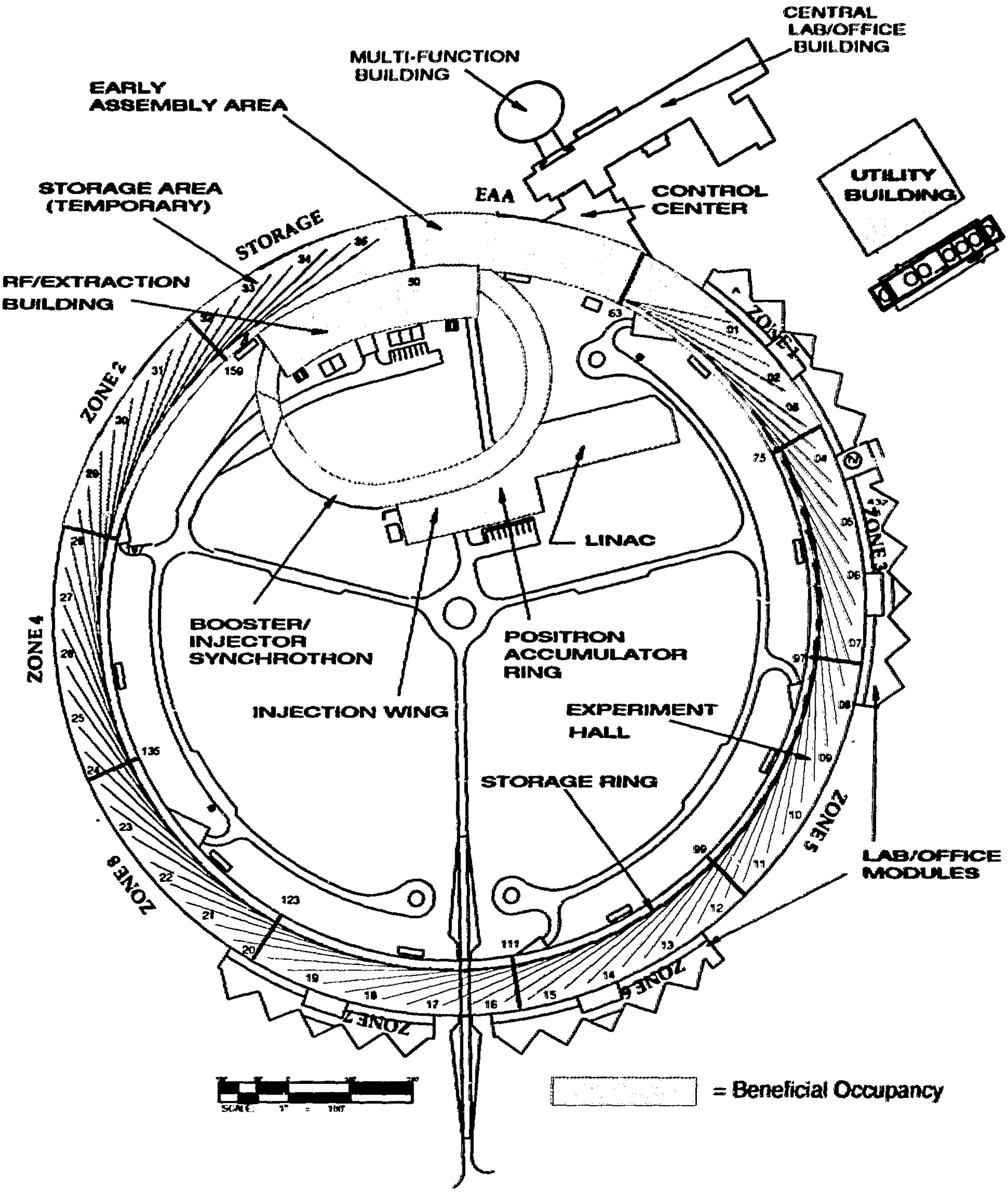
Fig. 1. Plan view of the Advanced Photon Source facility. Shaded areas denote buildings that have been completed and occupied by the Project as of 8/93.



CENTRAL LAB/OFFICE BUILDING
MULTI-FUNCTION BUILDING
EARLY ASSEMBLY AREA
UTILITY BUILDING
STORAGE AREA (TEMPORARY)
EAA
CONTROL CENTER
STORAGE
RF/EXTRACTION BUILDING
ZONE 1
ZONE 2
ZONE 3
ZONE 4
ZONE 5
ZONE 6
ZONE 7
ZONE 8
LINAC
BOOSTER/ INJECTOR SYNCHROTRON
POSITRON ACCUMULATOR RING
INJECTION WING
EXPERIMENT HALL
STORAGE RING
LAB/OFFICE MODULES
= Beneficial Occupancy