SYNCHROTRON RADIATION INSTRUMENTATION COLLABORATIVE ACCESS TEAM
SRI-CAT
SECTOR 4

Outline

I. Executive Summary

I.1 Research Objectives

The research objective for this sector of the Advanced Photon Source (APS) is the development of sources and applications of polarized x-rays covering the energy range from 0.5 to 50 keV. Both linearly and circularly polarized x-rays have been very successfully applied to the study of magnetic properties of materials. However the applications have been limited due primarily to the lack of energy-tunable, high-brilliance x-ray beams with adjustable polarization properties. It is our intention that this sector will to some extent ameliorate that situation. Based on our experience on Sector 1, we are confident that optics can be fabricated to simultaneously provide a high-quality beam with adjustable polarization in the energy range above 5 keV using the standard undulator A as a source. That is not the case below 5 keV, and hence we are planning to develop and install a helical undulator that can generate beams of variable (linear or circular) polarization in this lower energy range. Magnetic circular dichroism, resonant and non-resonant magnetic x-ray scattering, and other polarization-dependent phenomena will be investigated using hard x-rays. Techniques similar to those described for the hard x-rays plus spatially resolved, spin-polarized photoemission studies will be developed and used with the intermediate energy x-rays.

Although the primary focus of this beamline will center around the use of polarized x-rays, we have incorporated some features not directly related to polarization studies, which were not available elsewhere on SRI-CAT beamlines. One of those features is a large vacuum tank immediately downstream of the ratchet wall into which high heat load beamline components can be installed and tested. A second feature is a mirror capable of focusing the white beam for high heat flux optical-component development and other uses. The insertion-device development, polarization programs, and beamline component testing all fall well within the existing scope of the SRI CAT programs.

I.2 Operation Plans

The experimental apparatus developed for this beamline will be designated "Strategic Instruments," as is the apparatus on the Sector 2 and 3 insertion-device lines, and will follow the operational guidelines we have previously laid out for strategic instrumentation programs. We have already begun to recruit Scientific Members to be associated with these instruments because it is important to get their input into the design of the beamline before component fabrication begins. The Scientific staff associated with Sector 4 will come from within the existing membership of the SRI-CAT, namely Kevin Randall and Joe Xu for the soft x-ray program and George Srajer and

Jonathan Lang for the hard x-ray program. The insertion-device group, lead by Efim Gluskin, will design and fabricate the helical undulator, the high heat load optics team will assist in thermal issues related to optical design. and Deming Shu and other members of the Beamline Engineering Group will participate in the design and fabrication of the beamline components.

Besides the unique capabilities described above, this beamline will be the first designed explicitly to operate with two different insertion devices (IDs) simultaneously. By inserting a weak horizontal steering magnet between the two tandem IDs, a deflection or "dogleg" can be produced in the particle beam orbit. This will cause the radiation from the two IDs to be horizontally separated on the experimental hall floor and allow the beams to be used simultaneously. We feel that this concept may have the potential to nearly double the availability of insertion-device radiation from a single straight section and will use this opportunity to explore this possibility.

I.3 Summary

The SRI-CAT was motivated to develop an additional sector (Sector 4) for several reasons. The experience gained on our existing beamlines clearly showed that, if the hard x-ray polarization program was to grow and flourish, it needed to be based on an undulator beamline. This, in combination with our desire to develop a variable polarization, soft x-ray undulator, led us to consider a consolidation of the those programs and expansion into an additional sector. Moving the hard x-ray polarization program from Sector 1 and the soft x-ray spectroscopy branchline from Sector 2 ID will relieve some of the pressure on these two beamlines, both of which are already in high demand, and will allow us to more readily provide beamline access to the scientists from Australia and the X-ray Physics Group, a collection of x-ray scientists from universities and national laboratories, who have recently joined the ranks of SRI-CAT membership.

Our current plan is to develop only the insertion-device line on Sector 4. This does not preclude the build-out of the Sector 4 bending magnet beamline in the future.

II. Experimental Program

As detailed in section I. the addition of an extra sector to SRI-CAT is extremely desirable because of the diverse experimental programs to be undertaken by SRI-CAT, especially with the recent addition of the Australian and X-ray Physics Group personnel. The volume of additional experiments and the capabilities of existing beamlines are such that these studies cannot be undertaken on the existing three sectors.

The program objectives for Sector 4 of the SRI-CAT are based on several fundamental initiatives. The principal objective is to merge the hard x-ray (1-BM) and soft x-ray (2-ID-C) polarization programs onto a single sector, with the addition of the high heat load component testing, which will take place in the first optics enclosure (FOE). In the time scale of Sector 4 construction, several instrumentation and techniques will become reasonably mature, as detailed in the following subsections. Therefore a greater emphasis will be devoted to applied research of novel materials, in a manner consistent with the instrumentation development, which was the *raison d'être* of SRI-CAT.

II.1 Hard X-Ray Polarization Program - *G. Srajer, Principal Investigator*

Recently, there has been a great interest in polarization-modulated x-ray diffraction and spectroscopy techniques.[1-3] In particular, the importance of photon helicity in spin-dependent magnetic interactions has expanded the need for high-quality circularly polarized x-ray sources with fast switching capabilities. Because circularly polarized photons couple differently with the magnetic moment of an atom than do neutrons, they are able to provide unique magnetic information not accessible by neutron techniques. The development of experiments utilizing circularly polarized x-rays, however, has been hampered by the lack of efficient sources.

There are two different approaches for the production of circularly polarized x-rays: i) employing specialized insertion devices, and ii) utilizing x-ray phase retarders based on perfect crystal optics. Both of these methods are under development for use at the Advanced Photon Source. For intermediate energy x-rays (1.0 - 3.0 keV), source development has centered primarily on insertion devices because there are currently no polarizing crystals or multilayer optics available at these energies. For harder x-rays (> 3.0 keV), phase-retarding optics have been demonstrated and have shown[4] that they provide a viable alternative to specialized insertion devices.

We propose to use phase retarders to transform linear to circular polarization by inducing a $\pm \pi/2$ phase shift between equal amounts of incoming σ- and π-polarized beams. Being the final optical element before the experiment. phase retarders offer the greatest degree of circular polarization incident on the sample ($P_c \geq 0.9$). The type of phase retarder utilized depends on the energy range of interest. For low energies (3 - 30 keV), phase retarders that operate in a transmission [5-8] or Bragg reflection [9,10] geometry must be used, while high energies (> 30 keV) require phase retarders based on the Laue reflection geometry.[1,11,12]

In a transmission phase retarder. a thin crystal is deviated a fixed amount ($\Delta q \sim 10$ - 100 arcsec) from the exact Bragg condition and the transmitted beam is used as the circularly polarized x-ray source. The advantage of this approach is that the polarization properties change relatively slowly on the tails of the diffraction peak compared to the maxima. Thus the degree of collimation in the incoming beam and the degree of crystalline perfection of these phase retarders required to obtain a well-defined polarization state is greatly relaxed compared to phase retarders that require operation at the exact Bragg condition. Furthermore, helicity switching can be accomplished by switching from one side ($+ \Delta q$), to the other side ($- \Delta q$) of the Bragg condition. Because this requires a movement of only a few arcseconds, helicity switching can be done rapidly. Finally, a high degree of circular polarization is achieved with a minimal attenuation because $\pm\pi/2$ phase shifts require thickness of only 1-2 absorption lengths.

For energies greater than 30 keV, a phase retarder based on Laue reflection must be used. For this type of optic, a phase shift of $\pi/2$ is induced only at discrete energies determined by the thickness of the crystal traversed by the beam. Currently, a helicity-switching phase retarder designed to operate at 86 keV is being developed. Two simultaneously excited reflections, (220) and (2-20), are utilized to produce two beams of opposite helicity.

Several types of experiments are planned for the Sector 4 hard x-ray polarization beamline.

Circular Magnetic X-Ray Dichroism

Circular magnetic x-ray dichroism, defined as the difference between the absorption of left and right circularly polarized x-rays by a magnetized sample, is a powerful tool for studying magnetic properties of a variety of condensed matter systems. A particularly important development in the field has been the derivation of sum rules for the dichroic signal, which make it possible to separately determine the orbital[13] and spin[14] contribution to the magnetic moment for individual and constituent elements. Of great interest is the study of L_{II} and L_{III} edges of rare-earth compounds that are in the energy range between 6 - 10 keV, ideally suited for application of transmission phase retarders.

Magnetic Compton Scattering

By alternately measuring the standard Compton profile with opposite sample magnetization (or photon helicity), magnetic Compton scattering provides a measure of the momentum distribution of the difference between the spin-up and spin-down electrons. To be sensitive to the magnetic electrons, these experiments require circularly polarized photons that couple to the term in the incoherent scattering cross section arising from the interference between charge and magnetic scattering. Compared to the charge-scattering contribution, however, this term is down by a factor of $h\omega/m_0c^2$, where m_0c^2 is the rest mass energy of the electron, and $h\omega$ is the incident photon energy. Therefore, these experiments must be performed at relatively high photon energies (> 50 keV) in order to maximize the cross section for magnetic scattering. Our immediate plan is to use helicity-switching Laue reflection phase retarders as a source of high-energy circularly polarized photons for the study of magnetic Compton profiles in Fe_3Pt alloys and Fe_3Pt single crystals.

Thin Film Magnetism Studies

The high brilliance of undulator A in conjunction with phase-retarding optics provides a unique opportunity to study magnetism in thin films. Of particular interest is the study of thin (~ 200 Å), epitaxially grown film of chromium on single-crystal iron because the giant magnetoresistance effect was first observed in an Fe-Cr system. In addition, the study of a wide variety of spin structures in Gd/Fe multilayers, which depend on both temperature and magnetic field strength, offers the possibility of determining the magnetic roughness of these systems. Again, helicity-switching transmission phase retarders will be used as a source of circularly polarized x-rays.

II.2 Soft X-Ray Spectroscopy Polarization Program - *K. J. Randall, Principal Investigator*

The soft x-ray program at 4-ID-C will be an improvement of that developed at 2-ID-C. The branchline will be moved from Sector 2, largely intact, with few modifications necessary to fit within the layout of Sector 4. The photon energy range of 4-ID-C will be identical to 2-ID-C, namely 500 to 3000 eV. The major programatic change will be due to the availability of a variably polarized soft x-ray undulator source. This undulator will be a new type of fully electromagnetic device with the ability to choose either horizontal or vertical plane polarized, or elliptically polarized radiation. This source is described in more detail in section IV.1. During the transition from Sector 2 to Sector 4, the phase 2 addition of a refocusing mirror for 2-ID-C will be implemented as detailed in section IV.3.

The recent strong interest in thin film and multilayer magnetic and magneto-optical materials comes at an ideal time in the development of our soft x-ray program at the APS since the L and M edges of the transiton and rare-earth metals fall with in the 0.5 to 3 keV energy range. Other edges of spectroscopic interest include the Z=8-17 (O - Cl) K edges, which will be studied as surface, thin film, surface adsorbate and gas phase samples. Because a third-generation soft x-ray source, such as the Advanced Light Source, cannot access this energy range with undulator radiation as indicated in section IV.1 below, the APS has the unique oportunity to perform brilliance limited experiments over this important energy range.

Spectroscopy in this energy region can be broadly categorized according to the detection of products resulting from photoexcitation: i) x-ray electron (Auger and photoelectron) spectroscopy, which can have energy-, angle-, and spin-dependent resolution; ii) x-ray photon spectroscopy, subdivided into scattering and fluorescence subgroups, and; iii) x-ray photo-ion spectroscopy subdivided into energy-, mass-, and angle-dependent subgroups. Further one can add spatial resolution at the sample through the use of zone plates, capillary optics, or focusing mirrors. At 4-ID-C, we plan to capitalize on the effort put into the 2-ID-B and 2-ID-D/E beamlines and implement a spectromicroscopy program at 2-ID-C, which will be transferred to 4-ID-C. Another spectroscopic technique is made possible by using two or more detection schemes in a "coincidence" geometry to "tag" specific decay mechanisms. Coincidence techniques can also be used for temporal resolution of specific decay pathways. In addition to all of these spectroscopic tools, one can routinely use the polarization properties of the incoming radiation to define a geometry plane, in angle-resolved techniques for example, or impose excited state selectivity rules. A further, commonly used, technique is absorption spectroscopy, which measures the total excitation probability at a specific energy. Although experimentally the simplest of all spectroscopic techniques, one can learn a great deal by utilizing high spectral resolution with a polarized x-ray source.

High-resolution x-ray absorption spectroscopy

Photo-absorption provides information about unoccupied valence and conduction band states. The spectral width is limited in principle by the lifetime of the core levels, which range from ~0.01 eV to a few eV. Until recently[15,17], measurements have often been limited by the resolution of the monochromator. At 4-ID-C, we expect an energy resolution between 0.05 to 0.5 eV over the entire photon energy range. This will be useful for studying multiplet structures of biological, pharmaceutical, and organic chemical materials, as well as transition metal and rare-earth element compounds, high Tc superconductors, and heavy fermion system. Previously unresolved multiplets will make it possible to obtain detailed information on crystal field and hybridization effects.

Magnetic Circular Dichroism

Varying the source polarization allows one to study dichroic effects in a wide variety of samples. This technique will also be used extensively on the hard x-ray branchline 4-ID-B, making Sector 4 a world-class facility for the dichroic behaviour of a wide variety of materials and samples over the energy range from 0.5 to 50 keV. Magnetic circular dichroism (MCD) has been studied in the 4f rare-earth and 3d transition-metal compounds by means of core-level absorption spectroscopy[18,19], providing important information on hybridization and spin correlation. Temperature is clearly an important parameter in the study of magnetic materials. For this reason we have recently commissioned three temperature-controlled cryostats: two liquid helium, and one liquid nitrogen.

High-Resolution X-ray Photoelectron Spectroscopy

Photoemission spectroscopy directly probes occupied states. As with absorption spectroscopy, one of the limiting factors has been the monochromator resolution. Further, the photoelectron energy analyzer resolution is constrained by count-rate limitations. To date the energy resolution of x-ray photoemission spectroscopy has usually been in the range of ~0.5 to 1 eV. This resolution is not sufficient to reveal the electronic structures of solids, particularly those near the Fermi level that are most important in understanding the physical properties of solids. Recently, however the use of high resolution monochromators coupled to an undulator source has proven that high resolution XPS is possible20,. For this reason, we have commissioned a high-throughput (±20° acceptance with multichannel detection), high-resolution photoelectron analyzer. Further, with the use of refocusing mirrors, we will be able to illuminate the sample with the sub-millimeter x-rays required by this analyzer. By using high-resolution x-ray photoemission techniques, we expect a great deal of new information on the electronic states of semiconductors, high Tc superconductors, Kondo insulators, and heavy fermion systems.

Spin-Polarized Photoemission

The photoelectrons, Auger electrons, and secondary electrons of magnetized ferromagnetic materials can be spin polarized due to the spin-exchange interaction[21-23]. The high brilliance of the undulator radiation from the APS, together with a high-throughput electron energy analyzer, is necessary due to the inherent inefficiency ($\sim 10^{-4}$) of electron spin polarimeters. As in MCD, the detailed study of of spin polarization as a function of temperature will be measured in various magnetic materials.

Even for nonmagnetic materials, spin-polarized photoelectrons can be excited by use of circularly polarized light. This phenomenon is due to the selection rule of the electric dipole transition from (or to) a state with non-negligible spin-orbit splitting. The high polarization of the elliptically polarized undulator proposed for Sector 4 will make this kind of experiment feasible.

Photoelectron spin-polarization phenomena in magnetic materials has so far been observed for excitations in the low photon energy region. By adding angular resolution to these measurements one can, in principle, make use of diffraction or holographic techniques for (magnetic) surface symmetry reconstruction.

Because we will have plane-polarized radiation at 2-ID-C, one of our main instrumentation initiatives for the study of magnetic materials is the construction (in collaboration with Brookhaven National Laboratory) of an electron spin polarimeter. This will be commissioned shortly.

X-ray Reflectivity and Scattering

Angle and energy dependence of the reflected intensity from a thin film or multilayer can be used for optical constant or magnetic-moment determination. When the energy is tuned near the L or M edges of the transition and rare-earth magnetic materials, respectively, resonant scattering effects increase the detected signal significantly due to the electron inter-band transition[24]. In collaboration with the National Synchrtron Light Source (NSLS), we are currently modelling resonant magnetic scattering data from NSLS beamline U4B with the aim of using this technique, not only for sample analysis, but also for x-ray beam polarization analysis in the 500 to 3000 eV energy region. Conventional optical polarimetry techniques are not applicable over this energy region.

For these studies, we are currently commissioning a UHV reflectometer for optical and magneto-optical studies of thin films and multilayers using specular and diffuse reflection, resonant and non-resonant magnetic scattering, and ReflEXAFS. This reflectometer is equipped with a LHe cryostat. We plan to develop several techniques with this system on the plane-polarized Sector 2 source, which can be fully expanded with the variable polarization source at Sector 4.

In addition to the instrumentation and technique development initiatives undertaken internally within APS, and outlined above, external investigators will use their own fully developed experimental stations. These include, among others, i) an angle-resolving photoelectron analyzer system capable of surface structure determination by photoelectron holographic techniques, and; ii) a high-resolution soft x-ray fluorescence spectrometer. Both necessitate the use of a high-brilliance source of intermediate energy x-rays, initially at 2-ID-C, and both will benefit immensely from the use of a variably polarized source at 4-ID-C.

II.3 High Heat Load Testing of Phase II Standard Components - *T.M. Kuzay and D. Shu, Principal Investigators*

Although the APS currently runs with a 7 GeV, 100 mA stored beam, the accelerator was designed for future operation at 7 GeV, 300 mA, or 7.7 GeV, 200 mA. To meet this future goal, front-end and beamline optical component upgrades will be necessary. Building and extensive testing of new component designs will be necessary. For this reason, we propose to install a multipurpose UHV test tank in 4-ID-A, as close to the front-end shield wall penetration as possible. The beamline component test facility (BCTF) will comprise a 1.75-meter-long vacuum chamber equipped with large access flanges for insertion of a variety of test components, such as white-beam photon shutter blades, white-beam masks, or white-beam slits. Numerous smaller flanges will be used for thermocouple, electrical, and water cooling feedthroughs, infrared camera, and visible light viewports and actuator ports to vary the angle of incidence on the component under test.

Upstream of the BCTF chamber, there will be two L-shaped masks which can be manipulated into many aperture shapes, from a vertical slot to a horizontal slot or a square aperture down to 0.1 mm x 0.1 mm. By controlling the aperture size and shape together with incidence angle onto the sample, we will be able to simulate a wide range of total power and power density scenarios.

III. Key Personnel

The personnel presently involved in this CAT are listed below. Detailed vitae for these staff members can be found in Appendix A of this proposal. The staff and their current responsibilities are listed below. (See also the organizational chart in Section VI.1 for further information.)

Management:

Dennis M. Mills	SRI-CAT Executive Director
Efim Gluskin	SRI-CAT Director

Hard X-Ray Polarization Subgroup (4-ID-B):

George Srajer
Jonathan Lang

Soft X-Ray Spectroscopy Polarization Subgroup (4-ID-C):

Kevin J. Randall
Zhongde Xu

Heat Load/High Flux Testing of Phase II Standard Components Subgroup (4-ID-A)

Tuncer M. Kuzay
Deming Shu

In addition to this staff, technical support will be drawn from:

a) Insertion Device Group will be responsible for the elliptically polarized undulator (EPU) design and construction, and the engineering associated with both insertion devices, as well as construction activities for 4-ID-C;

b) Beamline Engineering Group will be responsible for front end and beamline transport standard components, shielding, and utilities design and construction ;

c) Beamline Operations Group will be responsible for the installation of front end, personnel protection systems, and utilities;

d) Optics Group will be responsible for the 4-ID-B end station, and;

e) Optics Fabrication and Metrology Group will be responsible for the specification and testing of optical components.

During operations, it is expected that the number of temporary staff (postdoctoral associates or students) will be approximately the same as the current number.

IV. Conceptual Design of the Beamlines

The experience gained from construction of Sectors 1,2, and 3, together with the availability of a large base of standard components means that our conceptual design for Sector 4 is already at an extremely advanced stage. One new concept that we propose to introduce at Sector 4 is the ability to use both x-ray beams from two insertion devices in the same straight section, as discussed below.

IV.1 Choice of Insertion Devices

In order to provide x-rays from 0.5-50 keV with high brilliance, two undulators will be installed in the Sector 4 straight section. Both devices will be 2.4 m long. The hard x-ray range will be covered using the APS standard undulator A. A custom 12.8-cm-period variably polarized undulator will be used for the soft-x-ray range. Fig. IV-1 shows the brilliance range of the two devices in linear polarization mode, together with a comparison with a 5.0-cm-period elliptical device planned for the Advanced Light Source.

The 12.8 cm device is based on a new design using both horizontal and vertical electromagnetic poles. The first harmonic of this device will cover the energy range from 0.4 keV to 3.5 keV. An important and unique feature of a fully electromagnetic device is that it will allow us to generate 100% horizontally (K_x=0) or vertically (K_y=0) plane-polarized radiation, which will enable many experiments otherwise not technically feasible to be performed. With symmetric deflection parameters (K_x=K_y), the on-axis radiation will be ~100% circularly polarized. The brilliance of the ALS and APS elliptical undulators operating in helical mode are shown in Fig. IV-2.

Important source parameters for the beamline design are summarized in the following two tables:

Table IV-1 Parameters of undulator A as a source*

Undulator A		
Period	3.3	cm
Number of periods	72	
Length	2.4	m
Minimum Gap	10.5	mm
Maximum K**	2.77	
Minimum First Harmonic**	2.92	keV
Maximum Field	0.899	Tesla
Total Power	6.0	kW
Peak Power Density	180	$kW/mrad^2$
Peak Flux @ 28 m	230	W/mm^2

* From ANL/APS/TB-17 "Undulator A Characteristics and Specifications: Enhanced Capabilities" R.Dejus, B. Lai, E. R. Moog and E. Gluskin.

** Updated values from subsequent measurements (R. Dejus, private communication).

Table IV-2 Parameters of the 12.8-cm soft x-ray EPU as a source

Elliptically Polarized Undulator		
Period	12.8	cm
Number of full vertical poles	35	
Number of full horizontal poles	36	
Overall length	2.4	m
Vertical pole gap	11	mm
Maximum magnetic field	0.24	Tesla
Energy Range	0.5-3.0	keV
Switching frequency	0 - 10	Hz
Switching rise time (including overshoot)	< 20	ms
Electromagnet dc stability	< 1	%
Maximum total power	800	W
Maximum power density	17	W/mm^2

IV.2 Simultaneous Operation of Two Insertion Devices

We plan to spatially separate the beams from the two undulators by introducing an angular deviation of the positron beam between the devices. An initial estimate requires an 8 mm beam separation in the FOE at approximately 30 meters from the center of the straight section. This will require a dipole electromagnet sufficient to steer the beam through 267 microradians. Since the standard APS correction dipoles have an angular range of 1 milliradian we believe that this is not a technical challenge. Design of the front end and the masking required by downstream optical components will require a significant amount of effort. However, because the soft x-ray EPU is significantly lower powered than undulator A, this should not prove to be an insurmountable problem.

IV.3 Hard X-Ray Branchline

The hard x-ray branchline is designed for polarization manipulation in the 3-100 keV x-ray energy range. The primary goal of this beamline is to convert the linearly polarized beam from undulator A to a circularly polarized beam by using phase-retarding crystal optics.

The major optical components of the beamline are a double-crystal monochromator (DCM) and a vertically focusing mirror. The mirror is installed downstream of the DCM. For producing circularly polarized photons in the energy range between 3- 30 keV, the beamline is configured so the DCM is in a diffracting position. The monochromatic radiation then impinges on a transmission Bragg phase retarder. However, for energies above 30 keV, white-beam radiation is delivered directly onto a Bragg-Laue type phase retarder. Because a phase retarder is typically mounted in the experimental station close to a sample, the consequence of this mode of operation is that both the beam transport and the experimental station have to be compatible with white-beam shielding requirements.

The DCM is the first optical component that is exposed to high heatload conditions. Liquid nitrogen cooling of crystals will be implemented, similarly to that at the 1-ID beamline. Major design specifications are given below. The main difference between the DCM proposed for Sector 4 and other conventional DCMs is that, in the Sector 4 DCM, both crystals can be rotated by 45 degrees around the axis defined by the beam direction. This feature will eliminate dispersion mismatch between the DCM and a transmission phase retarder.

Table IV-3. Double crystal monochromator specifications:

Horizontal Beam Acceptance	2.4 mm
Vertical Beam Acceptance	0.5 mm
Vertical Beam Displacement	35 mm (fixed exit)
Bragg Angle Rotation Range	0 - 45°
Bragg Angle Resolution	0.0001°
Bragg Accuracy	0.0004° (RMS) over 360°
Crystal Orientation	Si(111)
Energy Range	3 keV - 24 keV
Cooling	Liquid Nitrogen
Vacuum Specification	10^{-7} to 10^{-8} Torr

Downstream of the DCM, a mirror is installed. The function of this mirror is to vertically focus radiation into the end station. Because the mirror is placed after the monochromator, substrate cooling is not needed. The shape of the mirror is cylindrical, with a radius that can be varied in order to achieve maximum flexibility in focusing.

Mirror specifications are shown in the following table:

Table IV-4. Focusing mirror specifications:

Surface roughness	< 4Å
Slope error parallel to the mirror length	< 1 microradian
Slope error parallel to the mirror width	< 10 microradians
Mirror radius	4.1 km
Mirror length	1000 mm
Mirror width	35 mm
Substrate	Si
Surface coating	Si, Pt
Incident angle	0.18 degree

The optimum length of the mirror and the useful range of radii are currently being determined via ray-tracing.

IV.4 Soft X-Ray Branchline

Our approach to continuous coverage of the 0.5 to 3 keV energy range was driven by the desire to maintain high resolution and simultaneously conserve source polarization. For this reason an extended-range grazing-incidence grating monochromator was designed and is being commissioned at 2-ID-C. The concept of installing a variably polarized soft x-ray source has been part of the SRI-CAT strategic program initiative since the title I review. The development of Sector 4 will not only bring this into reality but will also optimize the utility of all four SRI-CAT sectors. In particular, the ability to operate two IDs simultaneously at Sector 4, as detailed in section IV.2, will have a huge impact on the prospective program for Sector 4.

The soft x-ray branchline, 4-ID-C, will cover the photon energy region from 500 eV to 3000 eV. This branchline is currently being commissioned at 2-ID-C with a 5.5-cm-period plane-polarized soft x-ray undulator. This branchline will be transposed from Sector 2 to Sector 4 with few modifications. The design of that branchline (REF), based on the high-resolution "Dragon" spherical grating monochromator developed at NSLS (REF). During commissioning of 2-ID-C we hope to verify the calculated performance specifications of the monochromator as detailed in table

IV.3. In the original pre- SRI-CAT Synchrotron Sources and Techniques (SSAT-CAT) proposal for the soft x-ray branchline, a high order rejector and refocusing mirror was placed between the exit slit and the experimental end station. This was subsequently modified by introducing a "two phase" approach to bringing the beamline into operation. In phase 1, an end station directly adjacent to the exit slit can take advantage of the relatively small beam size of approximately 1 x 1 mm^2, which is adequate for some experimental configurations. Also, according to calculations, high order rejection is performed by a suitable combination of mirror-coating materials on the upstream optics. Addition of the phase 2 refocusing system can take place in parallel with commissioning and initial operation activities. The refocusing system delayed as a phase 2 development is neccessary for many of the high-numerical aperture analyzers currently available in high throughput detection systems. For example, to conserve the Hemholz product of our Phi "Omega" photoelectron analyzer (acceptance angle = ± 20°), the accepted detection area is 1 x 0.25 mm^2, meaning that we only use approximately 1/6th of the phase 1 beam flux. As another example, outside users have expressed an interest in using fluorescence analyzers with accepted profiles of 50 μm x 100 μm. Optimal use of the high-brilliance APS undulator beam can therefore only take place with the refocussing system, which is currently being designed.

Another driving force behind the concept of having a two-station system is that many surface-science-based experiments require lengthy sample-preparation procedures. In this case, one or other of the end stations can remain operational.

Table IV.5 2-ID-C High-Resolution Monochromator Specifications

Total Power	20	W
Maximum resolving power (RP)	7,000-14,000	
Flux at sample with max. RP	10^{11} - 10^{12}	Ph/s
Maximum Flux	10^{13}	Ph/s
Focussing:		
Horizontal Demagnification	1:1	
Vertical Demagnification	9:1	
High Order Rejection (2nd/3rd Order)	>50:1 / 100:1	
Beam Size at Sample:		
"Phase 1"	1 x 1	mm^2
"Phase 2"	50 x 50	μm^2

IV.5 Beamline Engineering Test Facility

The Beamline Engineering Test Facility (BETF) provides a multi-purpose test tank in UHV for standard beamline component development and testing under full source power/flux conditions. It will be most needed for development of ID front-end/beamline components capable of functioning at 300 mA beam current. Such research cannot be conducted in a front end for a variety of practical reasons. Front end has strict access controls in operations, and the available space is very restricted for component placement and instrumentation. Furthermore, it is not at all desirable to break the front end vacuum transport for new component testing.

The BETF receives an unaltered white beam to impose high heat load and/or high heat flux on the test piece for general purpose engineering research. The BETF is being designed to be a unique, universal test bed with the requisite instrumentation for temperature, flow, pressure, vibration, strain, etc. It will have viewing ports for remote sensing and recording. It will also allow for orientation and motion of the component under test. A fast shutter upstream allows for transient studies. It will allow engineering studies of component and materials for design; destructive or non-destructive testing, performance limit investigations; filter, window and bonding interface life-time studies under steady state or cyclic high power/ high flux condition with the real beam. When the BETF is not in use, the white beam can pass through the tank unhindered without disturbing the beamline configuration for other development work. Hence it provides critical flexibility in beamline operation. With this in mind, a large area for the white-beam has been planned. We have configured BETF to be located immediately downstream of the first optics enclosure, as shown in Figure IV-3. This white-beam station will be used for testing high heat load optics, other novel optics, and for the develoment of the high energy x-ray program.

IV.6 Data Acquisition and Control

Data acquisition electronics and software supporting this sector will be at an extremely advanced stage prior to Sector 4 is commissioning. Software will be supported by the Beamline Controls and Data Acquisition Group using EPICS software in a VME/Sun workstation environment.

IV.7 Cost Estimates and Procurement Plan

IV.7.1 Cost Estimates

Since most of sector 4 will be fabricated from existing standard components we can give accurate budgetary estimates for may of the beamline components. Some items such as the EPU, and the the DCM which needs to be rotated from 0 -45° about the beam axis may not be as accurate. Hower to the best of our present knowledge this table provides an extremely good budgetary estimate. The cost estimates are summarized in the following table.

Sector 4 WBS	K$	
Insertion Devices		**1180**
Elliptically Polarized Undulator	500	
Undulator A	600	
Beam Steering Magnet	30	
ID Vacuum Chamber	50	
Front End		**400**
Front End Shutters etc.	300	
Front End Utilities (PSS/EPS)	100	
4ID-A FOE		**1234.5**
FOE Hutch	170	
"Utilities for hutch, incl. PSS/EPS"	120	
V2 Differential Pump with Fixed Aperture	40	
Table for V2	8.5	
BETF	170	
White beam movable aperture	80	
Table for BCTF/ movable aperture	30	
K1 Collimator	10	
F2 Filter Assembly	50	
Table for K1/F2	8.5	
Y4-1 Mirror Tank (incl. mirror)	220	
Y4-2 Mirror and transition tank (incl. mirror)	220	
P9 Shutter	32	
Table for P9	8.5	
P4 Shutter	67	
Table for P4	8.5	
4ID-B HXR Polarization		**1650.5**
Beamline transport (White Beam)	100	
Pump w/ enclosure	60	
Optics Enclosure	125	
4ID-X4 DCM	500	
4ID-Y7 Vertical Mirror	500	
4ID-L5 Adjustable apertures	100	
Table for L5	30	
P4 Stop	67	
Table for P4	8.5	
4ID-B Enclosure	160	
Utilities for Enclosure (incl. PSS/EPS)	150	
"Electronics (Workstation, VME, motor support)"	125	
4ID-C SXR Polarization		**420**

Misc Modifications to beam transport	30
Vertical Focussing mirror	20
Y5-30 Refocusing mirror tank w/ optics	250
4ID-C Enclosure	40
Utilities for enclosure (incl. PSS/EPS)	80
Electronics	30
Total	**5198.5**

IV.7.2 Procurement and Fabrication of Major Components

SRI-CAT intends to use the procurement services of the APS Procurement Cell, which has considerable experience in this area and is fully responsible for the procurement activities of this CAT. This organization is handling all the technical procurements for APS R&D and construction. The group consists of procurement specialists with considerable Argonne and DOE experience. The procedures developed by this group for the APS are in strict compliance with the DOE requirements, which if efficiently implemented lead to successful results.

It has been customary in the early phase of the procurement to establish the requirement, specification, and QA/QC steps for any of the procurements or services. The members of the technical staff responsible for a WBS element will take an active part in the process by obtaining manufacturer literature, through discussions with the vendor representatives on specifications and constructability of the component, and on the delivery schedule. During the pre-award phase, the Procurement Coordinator prepares the request, obtains solicitations, evaluates the responses with the help of the technical staff, and, if required, carries out negotiations with the vendor. In the final phase, the contract is awarded, administered, and closed by the Contract Administrator/Buyer in the APS Procurement Cell. The Project Engineer in the division office will keep track of all the procurements at every stage so that the delays can be avoided through proactive communication.

Most of the major fabrications will be carried out at the Argonne Central Shops, which provides excellent shop facilities and experienced staff to work on many large components of the beamline, such as the chambers for the monochromator and other optics. The Central Shop also has the capability to handle jobs requiring superior tolerances, such as mirror benders and linear translation stages. Some of the optics needs will be met by the Optics Shop, which has served this group very well during the R&D phase of the APS.

IV.8 Construction Time Line for Sector 4

The projected time line for construction and comissioning activities is presented in figure IV-4.

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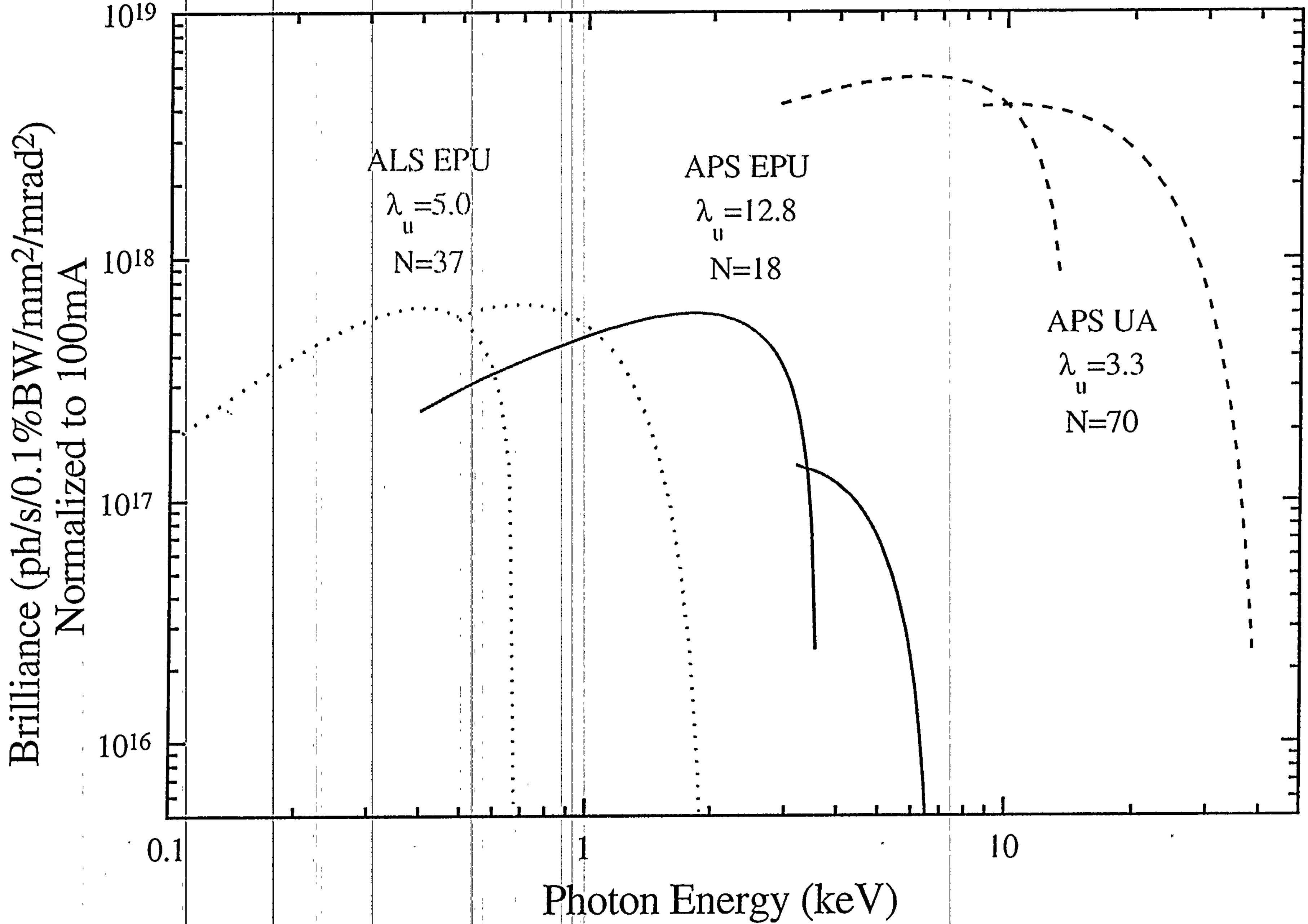

Figure IV-1. Comparison of linear polarized undulator brilliance

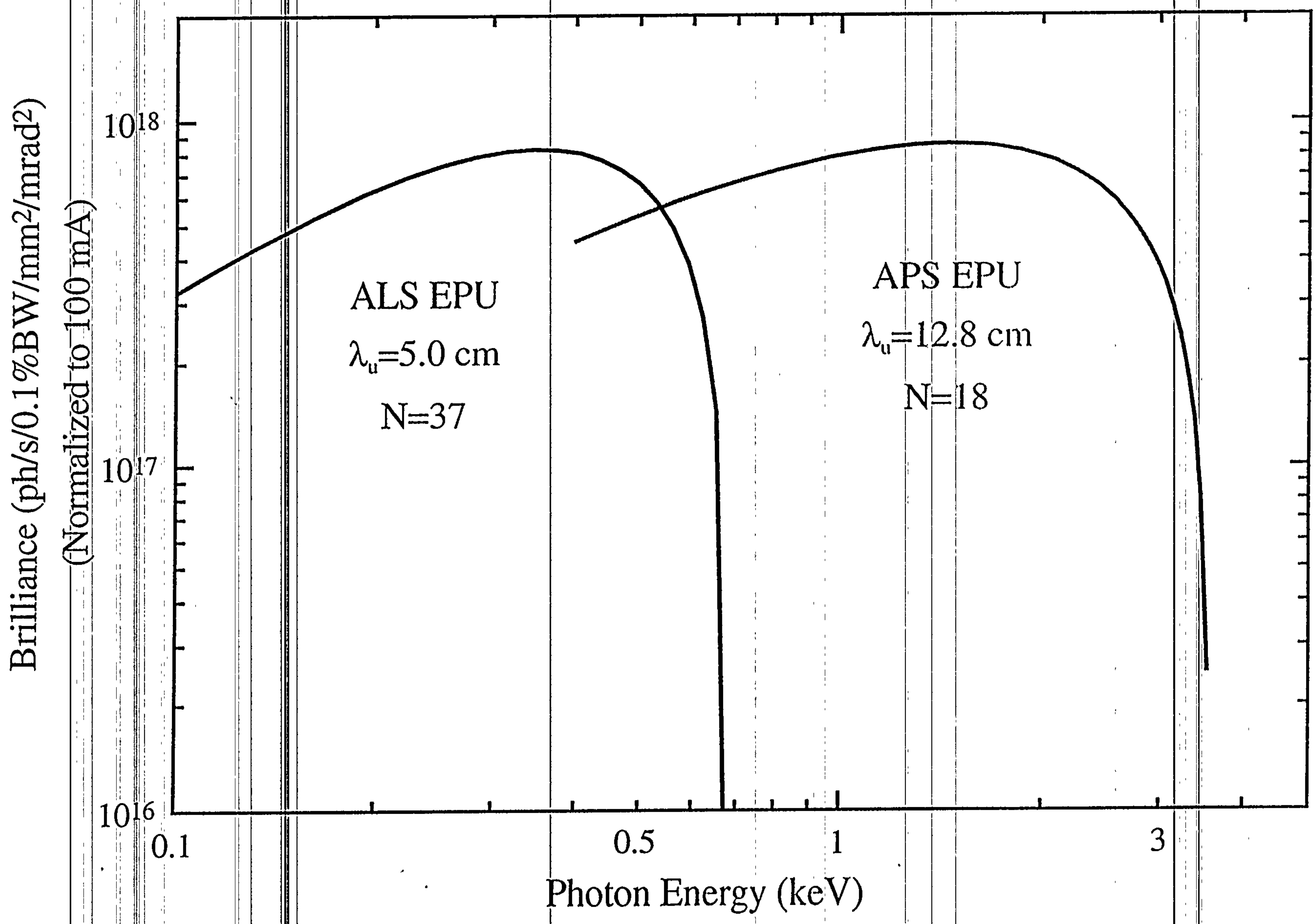

Figure IV-2. Comparison of Helical Undulator Brilliance

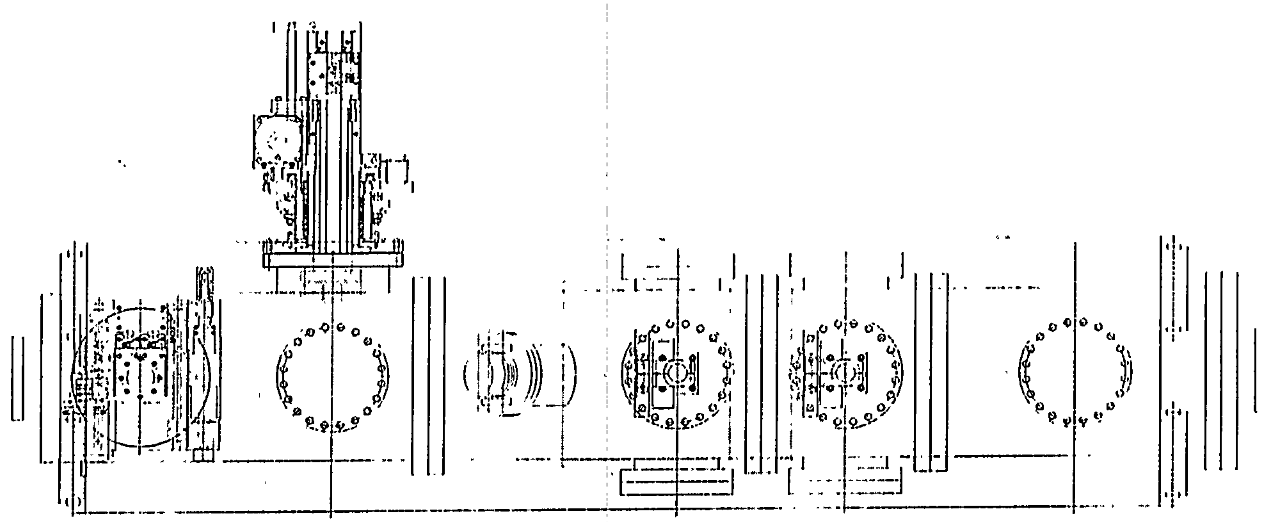

Figure IV-3. Beamline Engineering Test Facility UHV Test Chamber

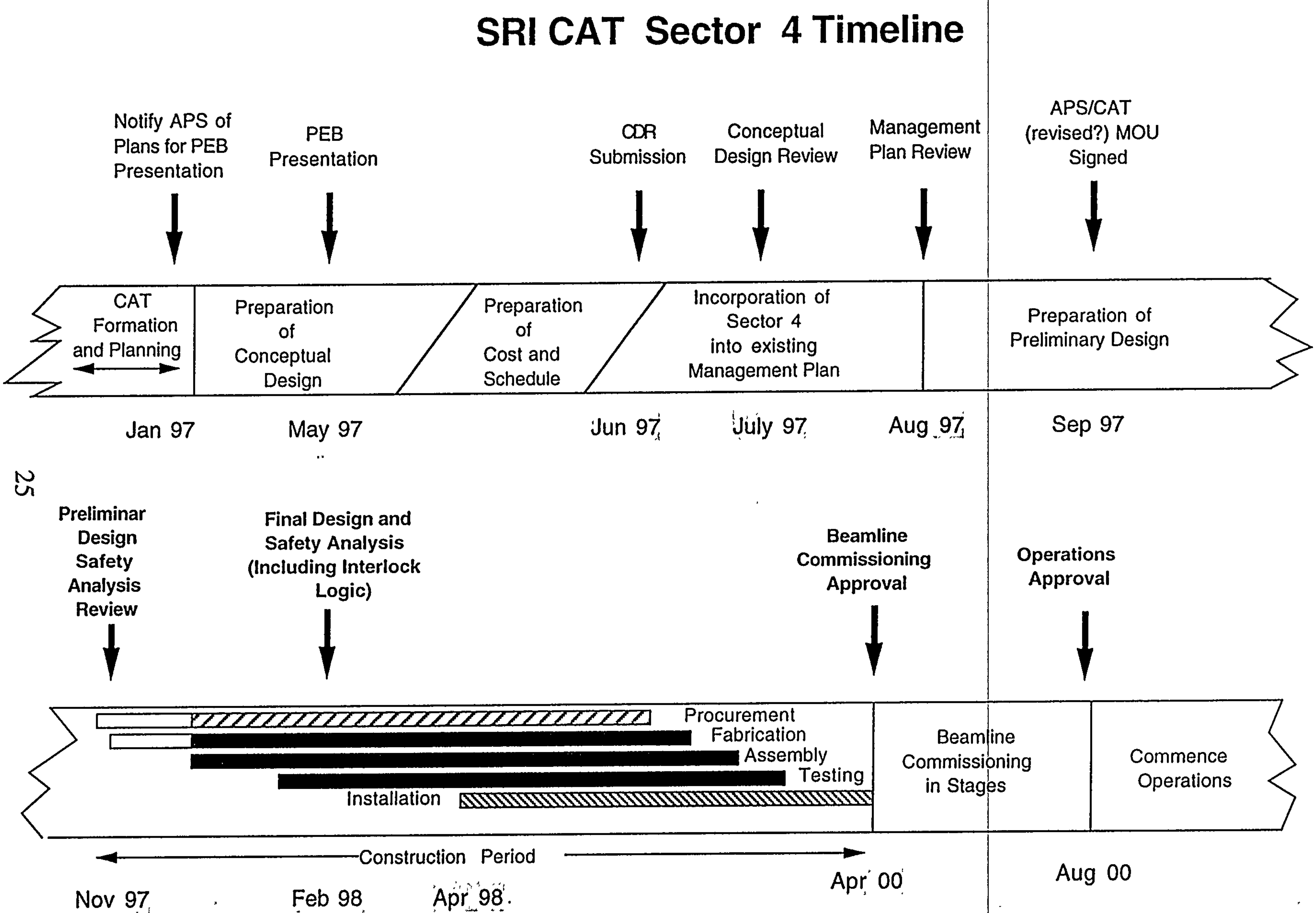

Figure IV-4. Construction Time Line for Sector 4

April 29, 1997

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Brandeis University
- Teaching Assistant, 1982-1984

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AT&T Bell Laboratories
- Postdoctoral Member of Technical Staff, 1988-1991

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- Assistant Physicist, 1991-1995
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RESEARCH INTERESTS:

Development of synchrotron radiation instrumentation; magnetic x-ray scattering techniques; circular magnetic dichroism; quasi-elastic light scattering techniques; phase transitions: non-linear phenomena

PROFESSIONAL SOCIETIES:

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Professional Experience

August 1992-Present: Physicist
Advanced Photon Source, Argonne National Laboratory, Argonne, IL 60439

January 1987-March 1992: Post-Doctoral Research Fellow
Fritz-Haber-Institut der Max-Planck-Gesellschaft,W. Berlin, FRG
January 1987 - February 1989: BESSY, Berlin
February 1989 - March 1992: NSLS, Brookhaven, NY 11973

January 1985-September 1986: Post-Doctoral Research Fellow
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Education

Ph.D.: December 1986
Reading University, England

- Thesis Advisor: Prof. Keith Codling.
- Thesis Title: "Photoelectron-photoion coincidences in molecular oxygen and xenon in the photon energy range from 10 to 45eV".

B.Sc.: July 1981
Reading University, England

- B.Sc. (Hons) II(i) Physics with Maths.

Research Experience

APS, Experimental Facilities Division (August 1992 - present)

- Lead scientist for soft x-ray spectroscopy beamline and experimental program.
- Responsible for detailed specification, statement of work drafting, and procurement of all beamline and end station components.
- APS lead scientist in a collaborative project with Peter Takacs (Brookhaven) and Werner Jark (Trieste) on *in-situ* high heat load optics diagnostics.
- Played a major role in defining the conceptual design of APS sector 2 beamlines.
- Communication of ideas with engineers and technicians.
- Guidance of post-Docs and staff.

NSLS Beamline X1B (February 1989-March 1992)

- Lead scientist constructing a high resolution undulator based beamline at NSLS, Brookhaven National Laboratory.
- In charge of day-to-day construction activities and problem solving for beamline and beamline diagnostic set-up.
- Supervised Ph.D. student, technicians and provided outside user support for the beamline
- Wrote data acquisition software in Turbo-C using CAMAC, GPIB and RS232 instrumentation.

NSLS Beamline U4B (February 1989-March 1992)

- Made several series of photoabsorption measurements at the AT&T high resolution soft X-ray beamline, U4B.
- Collaborated with AT&T and NSLS staff to set up experiments and take measurements.
- Collaborated with theoreticians at Heidelberg University, Germany in data fitting and modeling.

BESSY, W. Berlin (January 1989-February 1989)

- Performed high resolution near edge soft X-ray photoemission experiments at BESSY.
- Performed high resolution VUV measurements at the BESSY undulator beamline.
- Design and modified electron/ion optical systems.
- Wrote FORTRAN code to control a photoelectron analyzer.
- Supervised a diploma student and technician.

SRS, Daresbury (September 1981-September 1986)

- Participated in the construction and operation of a UHV threshold electron ion coincidence experiment used at the SRS, Daresbury.
- Designed electron/ion optical systems for electron/ion time-of-flight measurements.
- Participated in beamline alignment and diagnostics

ACO, Paris (November 1982)

- Lead scientist in a series of atomic metal ion yield measurements using a time of flight analyzer for multiple ionization studies at ACO, Paris.

Summary of Research Interests

- High resolution spectroscopy of simple molecules related to vibrational/electronic structures and molecular symmetry.
- Development and construction of synchrotron radiation based experiments.
- Photoemission and coincidence spectroscopy of gas phase molecules.