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# THE SUPERCONDUCTING WIGGLER BEAMPORT AT THE NATIONAL SYNCHROTRON LIGHT SOURCE

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W. Thomlinson, D. Chapman, N. Gmür, N. Lazarz
National Synchrotron Light Source, Brookhaven National Laboratory,
Upton, New York

## Abstract

A beamport is currently being instrumented to utilize high energy synchrotron radiation from the superconducting wiggler magnet on the x-ray ring at the National Synchrotron Light Source. Two independent programs are being developed to run in tandem, non-concurrently, on the central beamline: material sciences on X17B1 and medical research/angiography on X17B2. A high pressure research program will run independently on a side station, X17C. Considerations in the design of the beamline include handling severe power loading, radiation shielding protection and beam energy filtering.

*Contact author for proofs: Nancy Lazarz
National Synchrotron Light Source
Brookhaven National Laboratory
Upton, New York 11973

## DISCLAIMER

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MASTER

## 1.0 Introduction

The X17 beamport at the National Synchrotron Light Source is currently being instrumented to take advantage of the high energy synchrotron radiation from the superconducting wiggler (SUW) insertion device. The principle spokesperson for this project is Dr. William Thomlinson, NSLS. The original beamline layout and design parameters were specified in the *NSLS Superconducting Wiggler Beam Line (X17) Conceptual Design Report* , March, 1984 [1]. The experimental programs proposed by the X17 Insertion Device Team (IDT) will utilize the high energy and high flux from the SUW. The superconducting wiggler magnet can provide useful photon fluxes at energies up to 100 keV.

X17B1 and X17B2 experiments will run in tandem, non-concurrently, while the side station X17C will run independently. The X17B1 program is dedicated to material sciences research, utilizing white beam or monochromatic beam for crystallography, EXAFS and topography. The principle spokesperson for this project is Dr. Dean Chapman, NSLS. Downstream from X17B1, the X17B2 program is designed for medical research, principally angiography [2]. For this program, a medical suite has been built as part of the NSLS Phase II construction project to accommodate physicians, patients, scientists and computers. Dr. Edward Rubenstein, Stanford University Medical Department, is the angiography program's principle investigator [3][4]. The X17C IDT is currently designing a program which concentrates on high pressure research. Dr. Earl Skelton of the Naval Research Laboratory is the program's spokesperson.

## 2.0 Source Parameters

Commissioned in 1984, the NSLS X-ray Ring achieved 2.5 GeV in August, 1985. The ring operates at currents over 200 mA with lifetimes of 8 to 12 hours at 100 mA. By 1988, approximately 30 beamports will be utilized and 54 beamlines will be operating or under commissioning.

A total of five insertion devices are planned for installation into the NSLS X-ray ring, including the X17 SUW. Figure 1 shows a photograph of the SUW prior to installation. The operation of the SUW at 5 Tesla magnetic field, and its effective 6 poles, will result in a photon operation with higher critical photon energy (20.8 keV), higher photon flux, and higher available photon energy (up to 100 keV) than the arc sources. Figure 2 presents the calculated spectrum for the SUW beam line. Important SUW parameters are given in Table 1 [5]:

### DEVICE PARAMETERS

| | |
|---|---|
| **Poles - Full Field** | 5 |
| **- Half Field** | 2 |
| **Period Length** | 17.4 cm |
| **Gap** | 3.2 cm |
| **Magnetic Field** | 5 Tesla |

### OPERATIONAL PARAMETERS

| | | | | |
|---|---|---|---|---|
| **Maximum Wiggler Field, (T)** | 5 | 5 | 5.4 | 5.4 |
| **Ring Energy, (GeV)** | 2.5 | 2.8 | 2.5 | 2.8 |
| **Min. Bending Radius, (m)** | 1.67 | 1.87 | 1.54 | 1.73 |
| **Critical Energy, $E_c$ (keV)** | 20.8 | 26.1 | 22.4 | 28.2 |
| **Deflection Parameter,K** | 80.9 | 80.9 | 87.4 | 87.4 |
| **Horisontal Opening Angle, (mrad)** | 33.1 | 29.5 | 35.7 | 31.9 |
| **On Axis Vertically Integrated Power Density, (W/mrad-mA)** | 2.0 | 2.81 | 2.16 | 3.03 |
| **Total Power, (W/mA)** | 46.6 | 58.4 | 54.3 | 68.2 |

### TABLE 1: SUW PARAMETERS

The SUW maximizes current density by using two winding layers in the superconducting NbTi conductor coil package [6]. There are two coil assemblies per pole with the poles and outside structure made of iron. Original magnet testing in 1983 achieved 6 Tesla. Recent magnet tests, on and off the central axis, have been conducted by NSLS staff members. These tests were completed to ascertain the effects of the SUW on the electron beam and to investigate the field characteristics of the magnet. Results showed that a peak field of 5.2 Tesla at 215 amperes, could be achieved regularly without quenching. Reaching higher fields increases the probability of a quench as does using ramp rates greater than 0.2 amps per second [7].

A major concern is controlling the power load and thermal problems associated with the high energy SUW beam. Thermal analysis and stress calculations by NSLS engineers established the design criteria of the front end water cooled aperture/splitter assembly and the front end safety shutters. Analysis of beam motion during ramping and operations is currently being considered in the design of the exit chamber from the storage ring and the magnet bore tube.

A liquid helium cryogenic system will be used to refrigerate the SUW. A separate cryogenic building has been constructed to house the system with a direct connection to the SUW through the roof of the x-ray ring tunnel. Designed, built and tested in 1983/84, the system is currently being retested, mated with the SUW, and hardware/software integrated with two microprocessors. Continuous computer monitoring of the system will help ensure a steady- state operation and will keep the beam line and NSLS Control Room up-to-date on the status of the cryogenics and the magnet.

## 3.0 Beamline Components

The X17 beamport comes off the x-ray ring at zero degrees to the dipole magnet and has a maximum beamline length of 40 meters from the source, considered to be the last pole of the SUW magnet. Figures 3a,b and c show a schematic of the beamline. A water cooled crotch assembly separates X17 and X18 as well as protects downstream valves and flanges from dipole radiation. With the SUW operating at 5 tesla, a total radiation fan of 33.1 mrad exits from the magnet. The storage ring vacuum chamber walls are bathed in radiation and absorb about 18.1 mrad of the horizontal radiation fan. This leaves about 15 mrad of beam which enters the front end aperture/splitter assembly.

## 3.1 Beamline Mask and Valves

Located 8.04 meters from the source, a water-cooled mask protects the downstream flanges and valves from dipole radiation. The vacuum integrity of the system is protected by a UHV valve and a modified 30 mm vertically opening fast valve. The pneumatically operated UHV valve can close within 2 seconds of a vacuum failure and the fast valve within 8 milliseconds. Neither the mask nor the valves can withstand SUW radiation thereby necessitating a beam dump if they are in the closed position when the SUW is operating.

### 3.2 Beam Position Monitor

A beam position monitor, similar to a design developed by the Lawrence Berkeley Laboratory and used on Beamline VI at the Stanford Synchrotron Radiation Laboratory [8], is placed at 8.58 meters from the source. The NSLS monitor consists of two molybdenum blades, 38 x 32.5 x .25 mm, establishing the vertical beam position by measuring the difference current of photoemission electrons ejected from the blades. The blades are moved into position above and below the beam, where they remain during operations, by remotely controlled actuators. If the beam is too high or too low, a higher electrical current is read from the upper or lower blade and the beam position is modified accordingly. A heat pipe, cooled by a closed-loop water filled heat exchanger, conducts the heat away from the blades [9]. A beryllia sleeve surrounds the heat exchanger to electrically isolate the heat pipe from the cooling water [10].

### 3.3 Front End Aperture/Splitter Assembly

Approximately one year of engineering work and one year of designer effort went into the design of the front end apertures. They act not only as apertures for X17A,B and C, but also as the primary beam splitters between the branch lines and the primary synchrotron radiation photon shutters for all three lines. Figure 4 is a photograph of the aperture/splitter component in the assembly stage prior to being enclosed in its housing.

The aperture absorbers will be positioned at an angle in the beam in order to increase the exposed absorber surface area and to reduce the high power density per unit absorber length associated with the SUW beam. The absorbers are rectangular OFHC copper tubes, 5/8 inches thick x 1 inch wide with a 3/8 inch water channel, which sit in the beam at a 6 degree horizontal grazing angle. To control the 406 $W/cm^2$ power density in the absorbers at 10 meters from the source, the required water cooling would be 7 gpm with a maximum cooling wall channel temperature of 66.4° C [11].

The front end aperture assembly consists of a set of vertical apertures, 2 beam splitters and 3 beam shutters. The vertical absorbers define the vertical source size up to 1.5 mrad (±0.75 mrad) for the full incident 15 mrad beam. Sitting at 6 degrees to the beam, the absorber length is 774.7 mm at 11 meters [12].

Two 2 mrad wide beam splitters permanently sit directly downstream of the horizontal apertures at a 2 degree angle to the beam. The splitters allow 5 mrad down the central B line, cut off 2 mrad on either side, and allow 2.3 mrad down the outside A and inside C beamlines. A non-uniform power distribution hits the splitters with a maximum power per unit length of 343 W/cm [11].

The individual absorbers are mounted to the frame, outside of the housing, while the stainless steel housing itself is 'free-floating' through an innovative bellows arrangement. This design was used to protect and preserve the aperture and splitter alignment from any structural motion of the housing associated with bakeout or vacuum changes.

Downstream from the splitters, there are three water cooled photon shutters, two horizontal and one vertical. These shutters are the primary beam stoppers and must be in the closed position when the front end safety shutters, beam line safety shutters, or any downstream valves are in the closed position or when entry into the radiation tunnel or hutches (white beam mode) is required. Currently the X17A line is shuttered closed, awaiting proposals for development. The photon shutters are pneumatically driven, as opposed to using stepper motors, a design based on safety and reliability considerations.

### 3.4 Filter Assemblies

A filter assembly, at 12.5 meters from the source, consists of 18 graphite foil filters, two beryllium windows and an experimental gas filter. This assembly is placed in the beamline to reduce beam power to acceptable levels for experimental programs and beamline optics. The graphite filters, with a total thickness of 0.391 mm, attenuate the soft x-ray flux so that beryllium windows may be inserted in the line. A similar filter assembly, designed by the Lawrence Berkely Laboratory Design Group, has been successfully used at the Stanford Synchrotron Radiation Laboratory on Beamline VI [13].

Just slightly downstream, two 0.254 mm thick beryllium windows enclose a 180 mm long gas chamber which can be maintained at 0 to 1 atmospheric pressure of an inert gas such as xenon or krypton. The beryllium and gas act as filters which attenuate the low energy photons and will decrease the total power on the first monochromator crystal by a factor of five.

### 3.5 Front End Safety Shutters

The front end safety shutters for the three beamlines can be operated independently. Located 13.3 meters from the source, the safety shutters are the last front end component before the beamline exits from the front end shield wall. Three heavymet (tungsten alloy) shutter blocks, six inches in length, sit in line with the A,B and C beams. The blocks move vertically in and out of the beam, one inch in 15 seconds. They are not water cooled and therefore can not be inserted into the direct SUW beam. To prevent this, the front end photon shutters must be in the closed position before the blocks are dropped into the beam. Additional tungsten inserts are positioned between the A,B and C beams, directly downstream of the shutter blocks to help in eliminating possible bremsstrahlung radiation crosstalk between the beamlines.

## 4.0 Beam Transport Components

### 4.1 Beamline Beam Position Monitor

The beamline exits the shield wall 14 meters from the source. At 20.15 meters, a beam position monitor will check the exact position of the beam and have the ability to close the photon shutters if the beam exceeds pre-set limits. The monitor will be remotely controlled and must be able to withstand the high power of the SUW beam.

### 4.2 Beamline Apertures

Downstream from the monitor at 21.27 meters from the source, beamline apertures further define and clean up the beam prior to entry into the B1, B2 and C experimental hutches. These copper absorbers set the height and width of the beam individually for the B and C beamlines. A set of two vertical absorbers, one above and one below the beam, will independently define the vertical height of the beam from 0 to 1.5 mrad for the B and C beamlines.

Directly downstream, a set of two 'flipper-like' absorbers will define the beam horizontally for B and C by swinging into the beam from either side. The B line can be adjusted from 0 to 5 mrad and the C line from 0 to 2.3 mrad.

### 4.3 Material Sciences Monochromator

A monochromator for use by the material sciences program is located at 22.8 meters from the source. Forecast to be installed in the beamline in 1988, the 'day-one' two crystal monochromator will be used to provide monochromatic beam to the B1 program, as well as for thermal analysis for the next generation focusing devices.

The monochromator carriage has a kinematic mount which can vertically move the crystals out of the beam with a 15mm offset. This allows the full 5 mrad white beam to pass directly through the monochromator and B1 hutch and into the B2 monochromator. As a result, the B1 material sciences program is able to run in either monochromatic or white beam mode. Two Si(111) crystals will be used with a 2° to 26° Bragg angle range and a 4.5 to 56.7 keV energy range. The first crystal can rotate while the second crystal can rotate and move horizontally. Beam acceptance of the monochromator will be 2 mrad horizontal.

Crystal cooling is a very important component of the monochromator design. The direct incident beam power density, after filters, with the storage ring running at 2.5 GeV, 500 mA and the SUW at 5 T, is calculated to be 750 watts/horizontal mrad. A finite-element, engineering software program is currently being used to calculate the thermal profiles. A temperature or pressure sensitive direct beam emergency monitor will be placed behind the first monochromator crystal. This monitor can activate safety procedures if the crystal fails, falls off the crystal mount or if the beam misses the crystal altogether.

### 4.4 Beamline Safety Shutters

The beamline safety shutters are directly downstream from the monochromator, 24.11 meters from the source. Operating independently, two heavymet blocks sit directly either in or out of the B or C beams. The main purpose of the shutters is bremsstrahlung radiation protection when entry into the B1, B2 or C hutch is required. These shutter blocks can not withstand the direct SUW beam, so either the front end photon shutters must be closed or the beamline must be in monochromatic mode, for the blocks to be in the down position. The shutters also protect against bremsstrahlung radiation crosstalk between the B and C beamlines when entry into the B or C hutch is required and the other beamline is operating.

### 4.5 Beamstop

A beamstop is currently in fabrication for the X17B1 hutch. The component consists of eight copper water cooled absorbers which sit at a 15 degree angle to the beam and which are enclosed in a 1/4 inch lead housing. The absorbers main purpose is to intercept the beam before entering the X17B2 area when the materials science program is operating. Eight inch lead bricks behind the copper absorbers give a 2 inch overlap on all four sides of the beam profile and provide for bremsstrahlung radiation shielding. The beamstop manually slides in and out of the beam path on a track. The entire assembly is interlocked into place before beam is allowed into the X17B1 hutch.

## 5.0 Shielding

### 5.1 Radiation Calculations

A computer program, FILTER, was originally developed by P. Suortti and W. Thomlinson in 1984, to calculate the resulting photon flux as a function of energy and vertical angle when filters or absorbers were placed in the beam path [14]. This program, renamed PHOTON, was modified by D. Chapman, et al in 1987 [15].

The main purpose of modifying the program was to ascertain the amount of shielding required on the X17 beamline as a result of the high energy spectrum associated with the SUW beam. Calculations were run to determine the required shielding in the front end, by using the copper absorbers in the aperture tank as a source of scatter and around the beam line itself, by using the Si crystals in the monochromator as the main scatter source.

Experiments were carried out to verify the radiation calculations. The set-ups involved measuring the actual dose readings with a dosimeter, from several scatter sources, through successively thicker sheets of lead. Photons with energies up to 10 keV were scattered off materials such as germanium, tungsten and silicon. The results showed that the calculated doses were consistently higher than the measured doses by a factor of between 2 and 8 but with a correct energy and geometrical dependence [16][17]. These discrepancies were probably a result of the linear polarization of the incident photon beam combined with the fact that the dose was measured in the the horizontal plane at 90 degrees to the scatter source. The program was modified to more accurately reflect true experimental data.

## 5.2 Radiation Shielding

Radiation dose calculations showed that the storage ring front end, beamline and hutches would have to be heavily shielded. For example, high potential radiation dose values were calculated within the unshielded x-ray ring tunnel at 1.5 meters from the source where it was found that 1.2 x $10^9$ millirads per hour could be expected. In the front end, 1/4 inch lead sheet will be wrapped as close to the beam pipe as possible and placed within the quadrupole and dipole magnets where accessible. This will help control the scatter within the X-ray tunnel itself as well as help control the high levels of ozone expected with the SUW beam.

Most of the beamline, outside of the shield wall, will be enclosed in an 8 foot high radiation shielding tunnel. The tunnel will be made of sandwich panels composed of 1/8 inch steel - 1/4 inch lead - 1/8 inch steel. The panels will be removeable for ease in moving and accessing equipment. The B1 and C hutches and B2 monochromator room will also be constructed out of the same sandwich panels. Individual components such as the monochromator, may require additional shielding as indicated by real-time radiation measurements during beamline commissioning.

## 6.0 Experimental Programs

The X17B1 material sciences program will be used for experiments such as scattering, crystallography, EXAFS, topography and high pressure work. The large B1 experimental area and hutch provides for the easy exchange and access of apparatus. The experimental equipment, currently being assembled includes a six circle Huber diffractometer on a kinematic mount, a lift table and computer controlled CAMAC data acquisition system. This program is allocated 75% of the operational beam time with the other 25% reserved for the X17B2 program.

The medical research program on X17B2 will initially concentrate on digital subtraction angiography. This research is a collaborative effort between the NSLS and the Stanford University Angiography Project at SSRL [3] [4]. Taking advantage of a dedicated synchrotron source, the availability of a high energy photon flux from the SUW, and a commitment to build a medical research facility, the angiography program at SSRL is slated to move to the NSLS in late 1987 [2].

The angiography program is developing a diagnostic procedure using digital subtraction to image restricted or diseased coronary arteries. A dual energy monochromator will provide energies above and below the contrast agent (iodine) k-absorption edge. A 600 element detector will record images which, when digitally subtracted, provide a high resolution picture of the coronary circulation.

Currently under development, the X17C program is geared toward high pressure physics research. A white beam energy dispersive diffraction system will be used to investigate the structure/phase of small samples in a diamond anvil cell.

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# FIGURES

| | |
|---|---|
| **Figure 1** | Superconducting Wiggler Magnet (SUW) prior to installation into the magnet housing. |
| **Figure 2** | Calculated High Energy Spectrum for the Superconducting Wiggler Magnet, Beamline X17. |
| **Figure 3a** | Schematic - X17 Beamline - Front End<br>Distances of components are measured in millimeters from the last pole of the SUW. |
| **Figure 3b** | Schematic - X17 Beamline - Shield Wall to X17B1 Hutch<br>Distances of components are measured in millimeters from the last pole of the SUW. |
| **Figure 3c** | Schematic - X17 Beamline - X17B1 Hutch to X17B2 Experimental Area<br>Distances of components are measured in millimeters from the last pole of the SUW. |
| **Figure 4** | X17 Aperture/Splitter Assembly |

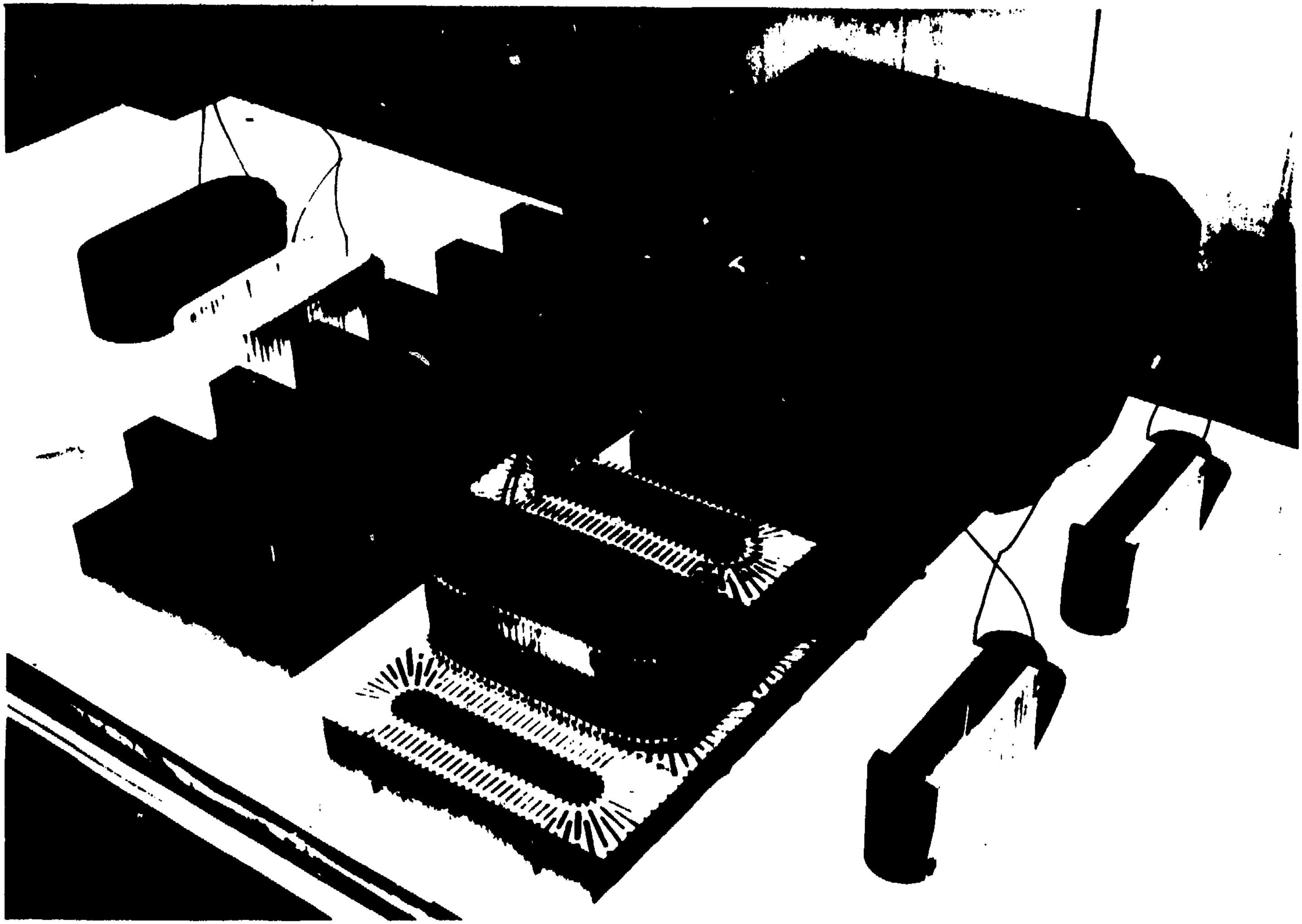

Figure 1 - Photograph - Superconducting Wiggler Magnet prior to installation

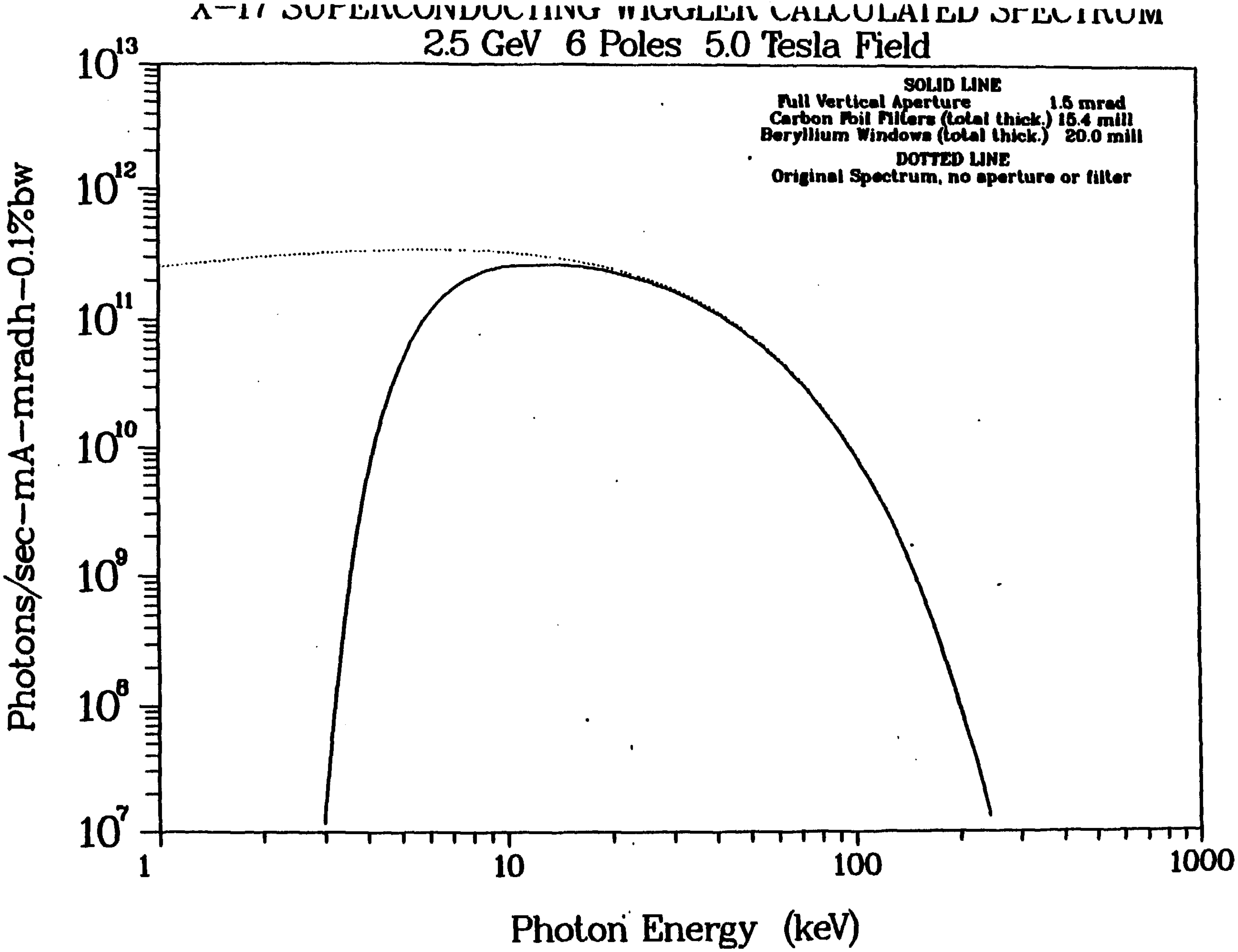

**Figure 2 Plot - Superconducting Wiggler Magnet High Energy Spectrum for the X17 Beamline**

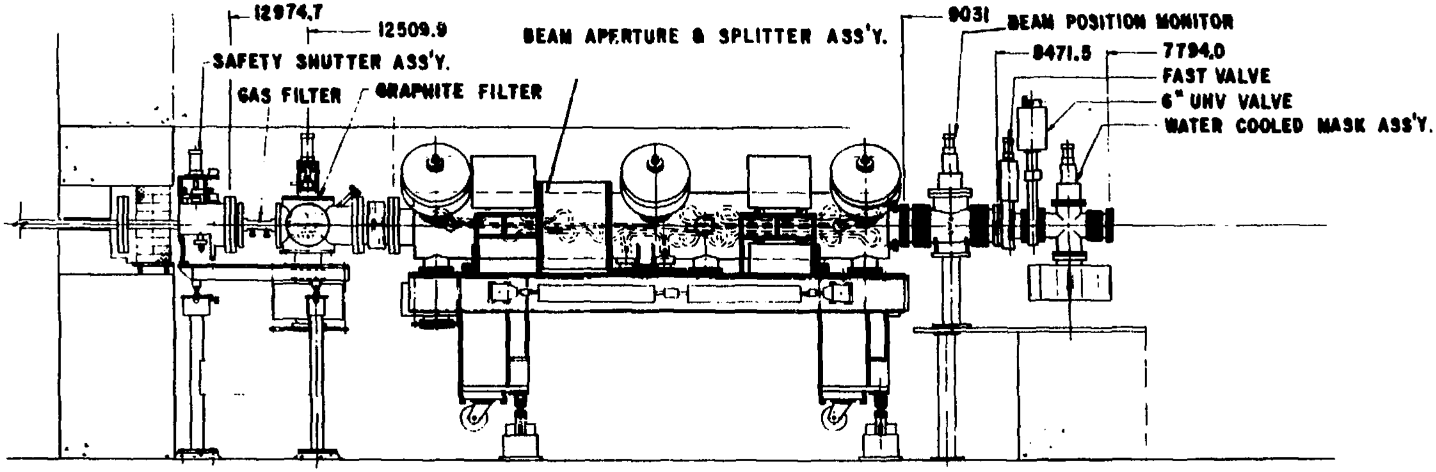

Figure 3a Schematic - X17 Beamline - Front End

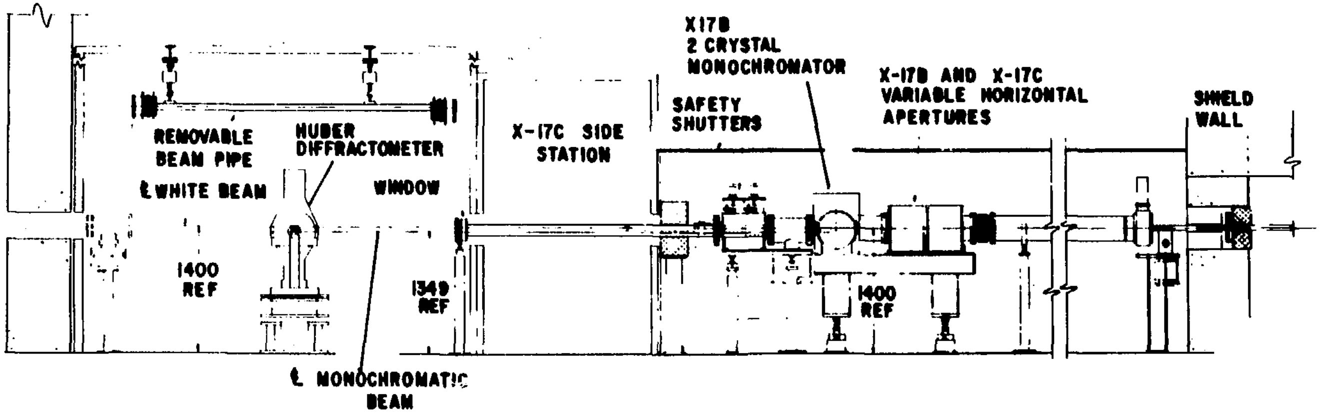

Figure 3b Schematic - X17 Beamline - Sawtooth to X17B1 Hutch

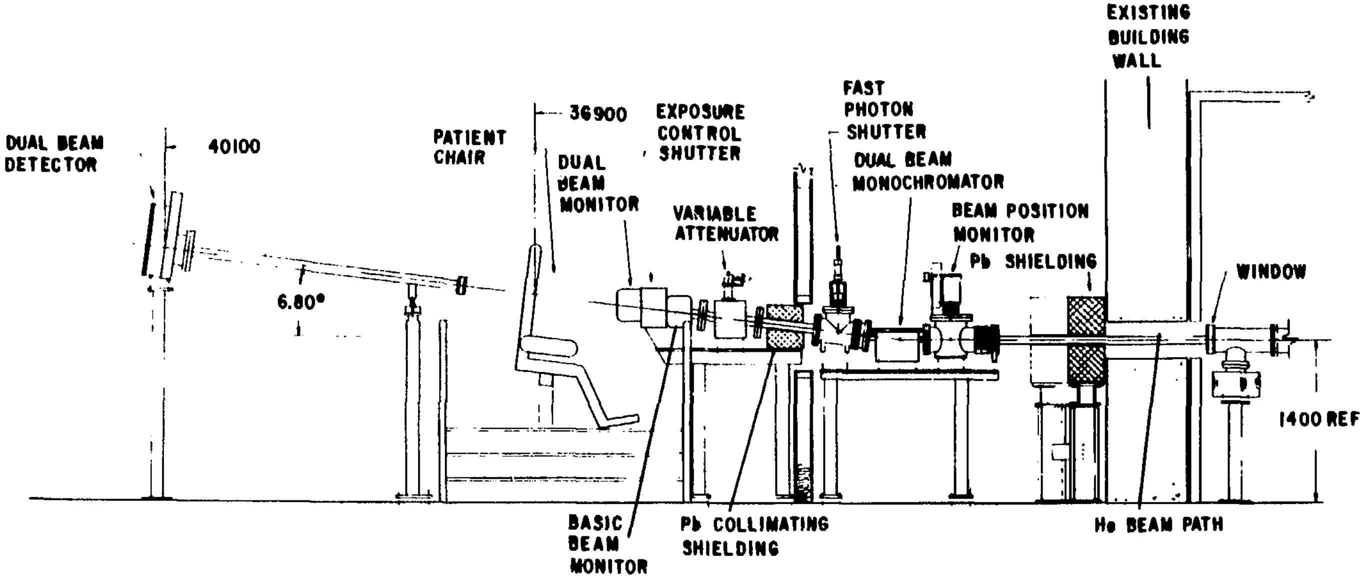

Figure 3c Schematic - X17 Beamline - X17B1 Hutch to X17B2 Experimental Area

Figure 4 Photograph - X17 Aperture/Splitter Assembly